The Hong Kong Polytechnic University

Institute of Textiles and Clothing

Reinventing Jacquard Textile Design via the Deployment of Digitisation Technology towards Innovative Ends

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A thesis submitted in partial fulfillment of the requirements for the

Degree of Doctor of Philosophy

February 2008

CERTIFICATE OF ORIGINALITY

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it reproduces no material previously published or written, nor material that has been accepted for the award of any other degree or diploma, except where due acknowledgement has been made in the text.

Zhou Jiu

ABSTRACT

Among the many types of textile fabrics, jacquard fabric is one of the high graded fabrics due to its higher technological requirements in design and production and its often intrigued figured and coloured textures. For thousands of years, jacquard fabric design has very much been a mechanical reproduction of hand-paintings under a conventional single plane design mode that is often laborious and time-consuming. Moreover, owing to the restriction of handcraft, jacquard fabric is restricted in its scope and effect in colour expression. Today, with the rapid development of digitisation technology, this study was made possible via the deployment of digitisation in jacquard design and production and the expansion of past and present jacquard fabric design theories and methods; and in turn enabled new ways of jacquard textile design and development toward various "novel effects" of jacquard fabrics that were otherwise not possible to realise before. Traditionally, structure of jacquard fabrics has been designed based on single plane design mode and one-to-one corresponding structural design principle with reference to the colour effect of hand drawing pattern. The innovative design mode invented in this study, i.e., layered-combination mode, was inspired originally from the design principle and method of digital image instead. By combining several single layers of fabrics, jacquard fabrics created in this study enabled colour expression at mega-level.

This design research is practice-led in nature. A novel design concept for jacquard fabric design was proposed and developed. The study is presented in three parts: the first part is establishment of a theoretical framework. Based on the design characteristics of digital image, the design principles and methods for digital jacquard fabric were developed under layered-combination mode during which the design method of digital image was analysed from colourless design mode to colourful design mode. The second part is the practical research during which the key technical issues and related optimal solutions of the process of layered-combination design were suggested. Particular focus was given to the principle and method of fabric structure design and corresponding colour mixing theory. Subsequently, a design method of full-colour compound structure was invented for creation of digital jacquard fabrics. The third and last part is the design creation. It follows the innovative design principles and methods of digital jacquard fabric so derived under the aforementioned layered-combination mode. By applying full-

colour compound structure design, not only were the designs created able to simulate black-and-white and multicoloured digital images, but also were they able to innovate new visual effects, e.g., figured shot-effect and figured double-face fabrics, by which the merits of layered-combination design mode were highlighted.

The thrust of this research lies in the establishment of new design concept, principles and methods of jacquard fabric, by which the technical and creative scope of jacquard textile creation are expanded with the possibility of creating a range of novel jacquard effects that are otherwise not possible to be realised before.

ACKNOWLEDGEMENTS

I am greatly indebted to the many people who have generously assisted in the completion of this project, and offered stimulating insights into the possibilities of digital jacquard creation.

First of all, my heartfelt gratitude goes to my supervisor, Dr. Frankie Ng, Associate Professor of Institute of Textiles and Clothing of The Hong Kong Polytechnic University, who has guided my research from start to finish. Moreover, my thanks go to my Co-supervisors, Mr. Y.C. Szeto and Dr. C.L. Hui, Institute of Textiles and Clothing of The Hong Kong Polytechnic University, for their suggestions and assistance in various aspects of my study.

In addition, I am very grateful to Mr. Wong Wang-wah, the technician of Weaving Laboratory of Institute of Textiles and Clothing, and Mr. Tu Yongjian, the director of design department in Zhejiang Babei Garment & Ornaments Co., Ltd, for their support on assisting me in the experimental works that contributed significantly to the this research.

I would like to express my appreciation to the members of The Institute of Textiles and Clothing of The Hong Kong Polytechnic University for their support for my study and research work.

My deep thanks go to my family, especially to my wife Gong Suli and my daughter Zhou Kewen. Without their encouragement and support, this research would not have been completed with so many happy moments.

Last but not the least, I would like to acknowledge the financial support provided by The Hong Kong Polytechnic University in the form of a postgraduate scholarship.

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LIST OF NEW TERMS AND DESCRIPTIONS

1. Single Plane Design Mode (單一平面設計模式)

A method of designing jacquard fabric based on one-to-one corresponding principle of which one specific woven structure is used to realise one corresponding colour in a 2D pattern. The limited number of colour expression on the face of jacquard fabric produced by this method makes the jacquard fabric design easy to be copied.

2. Layered-Combination Design Mode (分層組合設計模式)

A method of designing jacquard fabric by combining several single-layer fabric structures that enabled the jacquard fabric to express rich mixed colours up to mega level. The random and exclusive combined structural effects of jacquard fabric produced by this mode make it difficult to be copied without the original design data. Moreover, even when the same weaves are being used to design individual single-layer fabric structures, the different motifs of image being employed will make the colour number on the face of fabric varied after structural combination.

3. Colourless Design Mode (無彩設計模式)

A method of designing single-layer fabric structure under the layer-combination design mode that is based on the brightness of grey scales in digital image, it is compatible with computer-programmed processing. The digital image applied for design should be in grey scale mode without any colour information. Taking brightness as standard, the grey scale of an image can be replaced by corresponding gamut weaves.

4. Colourful Design Mode (多彩設計模式)

A method of designing compound fabric structure under the layer-combination design mode, by combining and arranging several single-layer fabric structures in a prescribed manner, a multicoloured effect of jacquard fabric will be obtained.

5. Gamut Weaves (全息組織)

A series of weaves devised from a primary weave through an increase or decrease of their interlacing points. The interlacing points can be changed in various manners (number and/or position). When the changing number of interlacing points is 1 between the two adjacent weaves, maximum weave number of gamut weaves results whereas when the changing number of interlacing points equals to the value of weave repeat between the two adjacent weaves, minimum weave number of gamut weaves results.

6. Full-colour Compound Structure (全顯色組合結構)

A kind of compound structure created by layered-combination design mode that features unique full-colour structural effect. Since the juxtaposed threads employed in such compound fabric structure are not covered by other threads, the jacquard fabric produced with this compound structure with different floating thread lengths exhibits a kind of full-colour effect.

7. Colour Shading Effect (彩色影光效果)

A kind of colour changing effect derived from the effect of printed textiles. It exhibits smooth gradation of two or more colours. In case where that the shading is produced by primary colours, e.g., the cyan, magenta or yellow, with black, a spectrum colour shading effect will be achieved.

8. Simulative Effect (仿真效果)

A kind of jacquard fabric effect that aims to imitate an existing image. The simulated effect of traditional jacquard fabric achieved by the single plane design mode has always been regarded as the highest technique-based design creation in jacquard fabric design. In this thesis, "black-and-white simulative fabric" refers to the fabric constructed with black and white threads to imitate an achromatic image, and "colour simulative fabric" refers to the fabric constructed with multicoloured threads to imitate an polychromatic image.

9. Innovative Effect (創新效果)

A kind of jacquard fabric effect that aims to innovate (new woven art form) rather than to simulate. The colour and pattern of innovated effect are different from that of the jacquard fabric designed under the traditional single plane design mode.

10. True-colour Effect (真彩效果)

A term borrowed from computer terminology. It is used in this study to refer to a multicoloured effect of jacquard fabric in which the number of mixed colours on the face of fabric can be as high as at a mega level in theory.

11. Figured Shot-effect (花紋閃色效果)

A kind of iridescent effect of jacquard fabric design created by the layered-combination design mode in which both the shot-effect and the figured effect are being exhibited at the same time.

12. Figured Double-face Effect (雙面花紋效果)

A kind of innovation effect of jacquard fabric created by layered-combination design mode in which both the face and the reversed sides of a jacquard fabric are capable of expressing independent figured effect/image.

CHAPTER 1
INTRODUCTION

1.1 Research Background

Jacquard textile weaving is an ancient craft with centuries-old history. Jacquard textile design and production have always been regarded as a tedious and time-consuming endeavour in which considerable skill and experience were required in producing hand-drawn pattern to form figured woven fabric (Cheng, 1992; Kadolph, 2007). In addition, due to its intricacy and uniqueness of woven colours and patterns, jacquard textiles and their related jacquard products have extended their applications to a wide range of fashion materials, home furnishings and decorations. Nowadays, with the increase of demands for sophisticated and high-quality jacquard textiles, the jacquard products made by the conventional method are often of a relatively crude quality that no longer satisfies consumers' aspiration. It is imperative for us to design and produce jacquard textiles that are more sophisticated and more intricate with added commercial and artistic values. To these ends, digitisation technology and the proposed digital design concept in this study have proven to be effective and powerful tools to achieve the said goals.

Theoretically, there exists a basic difference in the effect of colour and pattern between jacquard woven fabrics and printed fabrics. For printed fabrics, the printed pattern is a result of superimposing several transparent colour inks. Such superimposition of transparent inks enables a pattern to be reproduced on fabric with over a million shades. Hence, the reproduced pattern is very close to its original. For jacquard fabric as well as woven fabric, however, pattern is reproduced through a kind of woven figuration, where the colour and pattern effect are dependent on the woven structure of interlacing warp ends and weft picks. Due to the different colour theories and restrictions of woven structures, the pattern of jacquard fabric ought to be designed with reference to the weaving and figuring technical conditions such as fabric density, materials, the hook number, and the manner of mounting of the jacquard machine (Li, 1987; Weng, 2001; Tao, 2004). In addition, since the structure design of jacquard fabric is approached in a traditional single plane design mode and one-to-one corresponding principle, i.e., designing weave one by one according to the effect of each colour drawn on a certain pattern, the colour expression of present jacquard fabric is limited to not more than 100 colours in each pattern design (Zhou, 2006g). Even by employing CAD system today, the design principles and processes are still subjected to a plane design mode. Thus, the colour and pattern effect of jacquard fabric remain very much the same in terms of expression. To date, it is still a major challenge and aspiration for jacquard textile designers to be able to design a method that enables the creation of print-like pattern on figured woven fabric that can be processed and produced conveniently at an industrial scale (Gray, 1998; Daly 2005).

Today, digital image design is one of the popular design tools that merged technology and design. It represents an important design movement in the history of modern design. Capitalizing on digitisation technology, digital image design features higher efficiency in design processing and greater compatibility in design applications. The effects produced by digital image are more picturesque and imaginative than that expressed by freehand. Thus, digital images fulfill well the increased demands for innovation and novelty in the fast-moving commercial design industry. Due to its popularity, substantial investment and resources have been put into digital imaging technology, notable, for example, in the movie making industry. The basic principle of computer technology, i.e., binary system, was originally transformed from the controlling principle of the jacquard machine (James, 2006). It was only a matter of time that the design and production of jacquard textiles would be innovated through digital design technology. Over the past ten years, for example, prior research had been carried out to study computer-aided design via digitisation technology with a purpose of enhancing the design efficiency of jacquard fabric. However, because of the unresolved constraints of plane design mode, design method of jacquard textile was remained unchanged, digital image design was employed only to replace hand-drawn pattern and point paper in the course of CAD design. It did not go as far as to apply digitalization technology directly to design creation of jacquard textile *per se*. Since structural design of fabric plays the most important role in the creation of jacquard textiles, attempt has been made to innovate the traditional principle and method of structural design through the deployment of digitalization technology.

In addition to structure design, colour theory of woven fabric is another important factor in the innovation of jacquard fabric. In colour science, colours are a result of colour mixing of the three primary colours. For colour mixing, three theories prevail: additive colour mixture of light, subtractive colour mixture of pigment, and optical colour mixture (Robyn, 1989; Zelanski, 1999). For jacquard fabric as well as woven fabric constructed with opaque colour threads, the resultant colour effect exhibited on the face of fabric is subject to optical colour mixing. By tradition, jacquard fabric design is a mechanical reproduction under the single plane design mode that aims to imitate the colour and pattern effects of hand paintings. The potential aesthetic innovation of colour and figuration of woven structure of fabric had largely been overlooked and under explored. Having said that, the potential artistic and commercial values of innovative design and production of jacquard textiles have not been explored. This area remains a fertile field of research.

1.2 Research Aim and Objectives

Digital textile is one of the most important research directions in advanced textile technology and science. Development of innovative textile products is of both artistic and commercial values. At present, research of digital printed textiles attracted global interests and have yielded fruitful results in commercial applications. By contrast, research in digital jacquard textile is still in its developing stage, due partly to the complication of digitisation processing for woven structure. Since jacquard fabric is interwoven with warp and weft threads, the colour and pattern effect of jacquard fabric can only be realised through its woven structure. Innovation in fabric structure is thus crucial to future design innovation of jacquard fabric. To these ends, this project aimed to invent new design concept, principles and related design methods in jacquard textile design and production via the deployment of digitisation technology. The specific objectives of this study are:

(1) To (re-) invent the concept, methods and procedures of jacquard textile design via the deployment of digitisation technology in replacement of the traditional single plane design mode

(2) To explore and expand the creative dimension of woven textile structures and their colour expression based on digital design principles and methods

(3) To investigate the optimal structural design method in accordance with the layered-combination design mode

(4) To construct a theoretical framework for design creations of digital jacquard fabric in which a series of weave-databases will be established with which design

and production of digital jacquard fabric under varied processing conditions and fabric technical parameters are made possible

(5) To create sample jacquards to illustrate and elucidate the simulative and innovative effects of digital jacquard textile design

(6) To analyse and appraise the results against a set of aesthetic and commercial criteria toward optimal values; and

(7) To publicize and promote the findings in various form of deliveries

1.3 Research Methodology

The design concept of this study was originally borrowed from the "layered–combination" design method of digital image. In theory, colour digital image is displayed in the form of colour mixture effect of primary colours, each with its individual colour path/channel. Since digital image can be separated into several colourless layers through colour separation, attempts had been made in this study to translate the design concept and principle of digital image into the digitisation processing of jacquard fabric design. The result was an innovative design method by the name of "layered-combination" design mode proposed in this study that enables innovative jacquard textile design and production. In general, the layered-combination design mode consists two parts: colourless mode and colourful mode. The design of colourless digital jacquard is based on the grey scale mode of digital colour and single-layer woven structure. By using layered combination design method, several colourless single-layer structures can be combined to form a compound structure that enables the production of true-colour effect jacquard fabric with millions of colour shades. By employing an innovative design method of full-colour compound structure invented specially for layered-combination mode, jacquard fabrics created are capable of expressing picturesque and print-like effects with smoother colour gradation.

This project was practice-led research in nature. The practice-led research was suggested originally for art research in 1993, which produced knowledge through creative practice with novel concept (Biggs, 2002; Lyons, 2006; Macleod, 2000). Differing from the practice-led research of fine art, research on textile design should be a combination of art and technology. In this project, with the new design concept both in layered-combination design mode for digital jacquard fabric design as well as related full-colour structure design method, several designed images were specially created to illustrate the thrust of the proposed design concept and principles. Two directions were proposed for design creation: simulative effect and innovative effect. The former enabled simulation of both black-and-white and colourful effects whereas the latter enabled creation of various original effects that included figured shot-effect and figured double-faced effect.

The stepwise procedure of the study is summarised in Figure 1-1. It consists five stages: 1) research background, 2) theoretical research, 3) practical research, 4) design creation, and 5) results analysis. Theoretical research and practical research are two crucial stages in this study. During which theoretical design of new jacquard structures and practical realisation were carried out vis-à-vis.

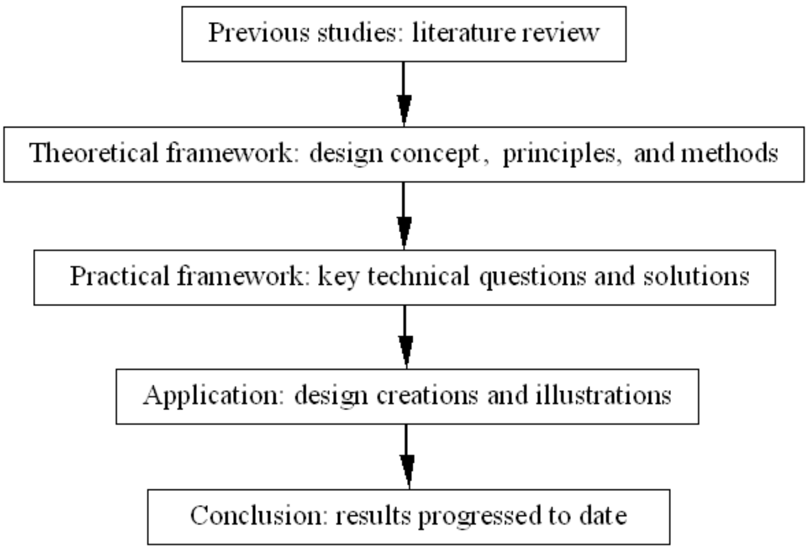


Figure 1-1. Stepwise procedure of the study.

In the initial stage, literature review was conducted. Comparison in design concept, principles and methods between traditional jacquard fabric and digital jacquard fabric were made. In the second and third stages, based on the principles of digital image design and digital colour theory, the “layered-combination design mode” was theorized and proposed for digital jacquard fabric creation. The design mode was further evaluated from theory to practice. The practical research was divided into colourless and colourful streams in which key technical problems and related optimal solutions were introduced. The “colourless” and “colourful” referred not only to the subsequent colour effect of fabrics, but also the design mode by which digital jacquard was designed and created. The fourth stage of study targeted the creation of specimens that testify to the validity of the proposed concept, principles and methods under the layered-combination design mode. The design specimen created in this stage illustrated both the simulative effect and innovative effect produced under lower warp density (see Appendix B.1) as well as higher warp density (see Appendix B.2) (Zhou, 2001a). In the final stage, conclusion was drawn, limitations were identified and further work in this area was recommended.

1.4 Project Significance and Values

The contributions of this study is that not only the proposed design concept, principles and methods are particularly suitable for digitisation processing of sophisticated structural design of jacquard textiles, but also the provision of detailed design illustrations and technical parameters of digital jacquard created for ease of reproduction. For thousands of years, jacquard textiles has very much been designed and produced by a single plane design mode of mechanical reproduction of the colour and pattern effects of hand paintings. However, the new theoretical concept of digital jacquard proposed in this study merged digital design technology into jacquard textile design, and has made it possible to design and produce jacquard textile directly from digital image. The digital jacquard textiles produced thus are capable of exhibiting fabric effects far beyond what traditional jacquard fabric could express. During the study, a layered-combination design mode of digital jacquard textile was proposed. With reference to the design principle of digital image, in particular digital colour theory, the number of colour expressed on the face of fabric can now be at mega level. The study so far has succeeded in inventing a new concept and method of digital jacquard textile design that gave rise to a number of original effects. The originality of the present research lay in the establishment of an original concept, principles and methods of digital jacquard textile design and production toward innovative ends. It involved an innovative layered-combination design mode and related unique structural design method by which innovative jacquard textiles were created. In short, the results of this research provides a brand new concept for innovation of colour design and structure design of jacquard fabrics that should have a significant influence on the future development of creation of jacquard textile.

Individual significance and values of this study include:

(1) Proposing the layered-combination design mode

(2) Digitizing jacquard fabric structure and fabric creation

(3) Industrializing jacquard textiles with extremely competitive costs and production led-time

(4) Expanding the creative and aesthetic dimensions of jacquard textiles

(5) Laying a foundation for future digital jacquard textiles, and

(6) Serving as a fine reference of practice-led research in design

1.5 Organisation of Thesis

Chapter one, "Introduction", the first chapter of this thesis, introduced the broad outlines of the project, such as general research background, objectives, corresponding research methodology, significances and values of the project, as well as a detailed writing organisation of thesis structure.

Chapter two, "Literature Review", the second chapter of this thesis, introduced the background relevant to this research project, involving the features of jacquard textile and the evolution of jacquard fabric designing. In order to understand clearly the difference in design principles and methods between the design of traditional jacquard fabric and digital jacquard fabric, two representative design methods for figured colourful woven fabrics i.e. Chinese brocade and western tapestry, were introduced and analysed deeply before the introduction to development and application of digitisation technology in the field of jacquard textile design.

Chapter three, "Theoretical research", the third chapter of this thesis laid the theoretical foundation for design research of this project, presented clearly the design innovation in theoretical aspect, i.e. design concept, principles and methods of digital jacquard textile design. The innovative design mode originally proposed in this project especially for digital jacquard fabric designing was named as layered-combination design mode, which may be approached from colourless design mode to colourful design mode of digital jacquard fabric.

Chapter four, “Practical research”, the fourth chapter of this thesis focused on the practical research, in which key technical issues both in mixed colour theory and relevant fabric structure design under layered-combination design mode, and efficient solutions were introduced correspondingly after proper design practice and experiment.

Chapter five, “Design creations on simulative effect”, the fifth chapter of this thesis introduced the design creations on simulative digital jacquard fabric under layered-combination design mode, and proper design illustrations on both black-and-white simulative digital jacquard fabric and colourful simulative digital jacquard fabric were introduced.

Chapter six, “Design creations on innovative effects”, the sixth chapter of this thesis introduced the design creations on innovative digital jacquard fabric under layered-combination design mode, and proper design illustrations on both figured shot-effect digital jacquard fabric and figured double-face digital jacquard fabric were introduced.

Chapter seven, “Conclusion and recommendations”, the seventh chapter of this thesis summarised the investigative work involved in the project. Based on design creations, an overall conclusion and the major findings obtained in this study were summarised. In addition, the remaining problems and the recommendations of further research work were suggested as well.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

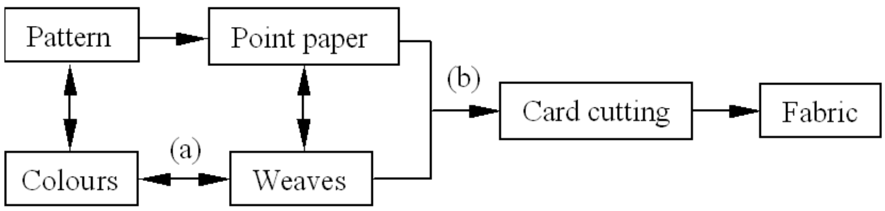
This research was carried out to innovate the design of multicoloured jacquard fabric with complex fabric structure via the application of digital design technologies. Multicoloured jacquard fabric with splendid coloured and figured effect is a unique variety of woven fabrics. Sophisticated design skill and production technologies are required in fabric processing. In this chapter, the development of jacquard technology as well as the evolution of jacquard fabric design was introduced. These include 1) the background in relation to jacquard textiles and corresponding design technologies, 2) introduction to the design methods for traditional multicoloured jacquard fabric design and creation, and 3) the development of digitisation technologies applicable to jacquard textile design. The design methods of both traditional Chinese brocade and Western tapestry were put up for comparison, through which the limitations of single plane design mode for traditional jacquard fabric design were explained. It is precisely that this deficiency laid the foundation for the design innovation of digital jacquard fabric in this research.

2.2 Background

Jacquard textile was often referred to as figured woven fabric (Denton, 2002). However, jacquard textile did not enjoy such definition until the broad application of the "jacquard machine"- an automatic figuring machine invented by Joseph Jacquard in 1804 (Jean, 2003). Given this disparity of definition, it should be clarified here that jacquard fabric was named as figured woven fabric before the application of the aforementioned jacquard machine.

2.2.1 Jacquard Textiles and Jacquard Textile Design

For thousands of years, jacquard textile has been designed in very much the same way under the so-called single plane design mode. Most of these designs were produced by conventional concept and methods that required a great deal of handiwork and time (Cheng, 1992). The traditional design and production process of jacquard textile involve three major phases: pattern and colour design, weave and structure design, and craft design of point paper drawing and card-cutting planning. All of them demand dexterous skills and a good understanding of woven fabric structures. Figure 2-1 summaries the design process of jacquard fabric design by traditional plane design mode (Johnk, 1979; Kienbaum, 1994). Being restricted by the one-to-one corresponding principle for fabric structural design, colour expression of jacquard design can only be achieved through an even more laborious and intricate process, and the number of colour expression is nevertheless limited. In addition, due to the great variety of weaves, e.g., simple weaves, variant weaves and compound weaves, when jacquard fabric was designed to try to simulate the colour effect of an given objective image, the task would be excessively complicated and time-consuming due to the variety and complication of weaves involved. Repetitious trials were often required before an optimal weaving structure that could barely imitate the colour effect drawn on a certain pattern was identified.



(a) One-to-one corresponding principle between colours and weaves
(b) Card cutting plan

Figure 2-1. Design processes of jacquard fabric in a single plane design mode.

2.2.2 Evolution of Artistic Jacquard Textile Design and Applications

Traditional jacquard textile design was an applied art work that combined aesthetic judgment and technology-based handicraft. In 1887, the first art textile exhibition "Arts and Crafts Exhibition Society" was held in London. It gave the textile artistically sympathetic surroundings for the first time. More than three decades later, in 1923, the Bauhaus exhibition "Art and Technology - A New Unity" was held in Weimar. Weavers showed a wide range of textile work, from excellent textile art works to forefront of design in art and technology for industry. These work established the concept of contemporary textile "design" whose influence has lasted until today (Cumming, 1991; Braddock, 1998). Today, jacquard textiles are playing an increasingly important role in commercial industry due to their artistic merit and commercial potential. They serve as one of the most resourceful inspirations for fashion and interior designers. Jacquard Textiles are being showcased in major international textile shows and exhibitions in Paris and New York, for instance, to attract buyers and designers from around the world for their latest textile trends (Yates, 1995; Yeager, 2000). However, along with the rapid development and creation of textiles through novel knitting and innovative printing, jacquard textiles that are designed under the traditional design concept and methods, often with rather tedious design processes and complicated technical production, can no longer satisfy the needs of discerning customers. Having said that, it is imperative for this category of textiles with a long history to revive their ancient glory with new artistic forms and advanced techniques. To this end, the rapid development of digital technologies in both design and production provide a powerful tool.

2.2.3 Digital Technologies in Jacquard Textile Design

The digital jacquard technology includes aided-design technologies, represented by the jacquard textile CAD system, and digital production technology, represented by electronic jacquard machine and new-generation weaving looms (Dimitrovski, 1998; Li, 2000; Chu, 2000). Both the design and production processes are subject to total digital control, of which the data of the jacquard fabric from design to weaving are all processed, controlled, and transmitted in the computer system. It provides a technological base for innovative digital jacquard design. Design and production procedures of jacquard textiles under the application of digital technologies are shown in Figure 2-2.

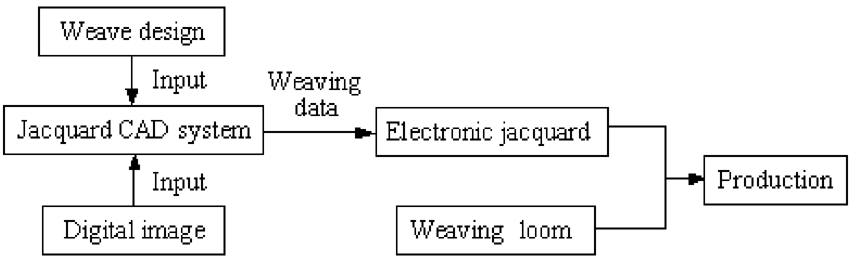


Figure 2-2. Workflow of digital jacquard design and production.

2.2.3.1 Development of jacquard technology

Jacquard was a traditional technology with a long history, and the production of jacquard textile by hand has lasted for more than thousands of years. At the beginning, the original loom was named “treadle loom”. It was later renamed as “pattern loom” or “draw loom” (Zhou, 1988). In the early Nineteenth century, Joseph J. M. Jacquard of Lyon, France, invented a loom which is now named after him. The woven pattern on his machine was indicated by a set of punched cards and were mechanically controlled (Penava, 2005). This allowed elaborate and intricate patterns to be woven with much less manpower (Melling, 1975). Today, the new generation electronic jacquard machine such as Unival 100 - the product of Staubli Company of

Switzerland - has stretched the technical limit of the jacquard machine to the extent of enabling installation of 6,144 to 20,480 individual needles/yarns (Jean, 2003). Individual hooks of electronic jacquard machine today have been increased to more than 20,000. Such technical advancement has made possible the creation of jacquard that were otherwise not possible to be designed and produced before.

2.2.3.2 Development of jacquard textile CAD system

The application of jacquard textile CAD system began in 1979 (Li, 2000; James 2006). Meanwhile, jacquard textile CAD system developed drastically along with the rapid advancement of computer technology. In less than 30 years, jacquard textile CAD system has developed from one with small RAM (random access memory) and of low speed to one with large RAM and of high speed. There is no doubt that not far from now, artificial intelligent CAD system will be developed to replace humans to perform most of the design works of jacquard. In such a way, the development of jacquard textile CAD is anticipated to play an increasingly important role for guiding new design concept of jacquard textiles. In addition, nowadays, digitisation technology has become one of the cutting-edge technologies in the CAD system (Aldrich, 1994; Gao, 2004). It gave rise to a new range of visual sensations that have not been experienced before, notable for its wide range of applications across creative fields, e.g., advertising, fashion, graphics, illustrations, and textiles. Taking advantage of the rapid development of computing science and technology, design and production of jacquard textile deploying digital technologies are being created. It is envisaged that the deployment of digitisation technology and digital design concept will establish a new set of design principles and methods for reinventing unconventional digital jacquard textiles of significant aesthetic and commercial values.

2.3 Development of Research on Digital Jacquard Textile Design

The concept of digital textile was derived from printed textile. In the International Textile Machinery Association (ITMA) exhibition held in 1999 in Paris, digital textile was proposed for the first time due to the wider applications of digital printing technology (Hilden, 2004; Weinsdorfer, 2004) at a time when printed fabrics designed and produced in a digital manner already brought new height and excitement in printed textiles. Following the design trends of digital textiles, the research on digitalizing woven textile design was carried out with the aim to revolutionise the traditional design method. In 2004, a digital textile forum was held in Hangzhou, China. "The development of digital woven technology and its design creations" was the one of forum topics (Zhou, 2007d). The design of digital jacquard fabric has attracted considerable interests in the research of digital textiles.

Over the past 30 years, research on jacquard textile design via computer-assisted method has been developing rapidly along with the advancement of digital technologies. Since the research foci differed from one researcher to another, research methodology employed for digital jacquard textile design differed too. However, all efforts shared a common research objective to try to revitalize the traditional jacquard design method through deployment of digitisation technologies. The research foundation of digital jacquard laid essentially in two traditional structural design methods, i.e., Chinese brocade structure and Western tapestry structure. The following summarises the major prior research in digital jacquard textile design:

(1) Before 1979 when the CAD system had not yet been employed for jacquard design, jacquard fabric was designed by handiwork. Since then, the application of the jacquard CAD system enabled traditional jacquard to increase in design efficiency (Zhou, 2003). However, computer used then were of lower capability and design was still conceived very much under the traditional design concept and methods.

(2) In 1996, the German Company, Kaiser Lutz, presented a process for jacquard to be woven into a coloured fabric by splitting the original colour pattern through a scanning process into three primary colours as well as black and white. Each element had at least the size of a weaving point. Different colours of the pattern to be woven were achieved through the combination of different adjacent weaving points consisting of three primary colours as well as black and white (Kaiser, 1996). This method initiated increased research of designing colourful jacquard fabric by primary colour yarns with the assistance of a computer system. Nevertheless, the design concept remained the traditional plane design mode, and whose structural design method was borrowed directly from Western tapestry with no change. The proposed design method then merely raised the design efficiency via the application of CAD system with its design effect and creative scope remaining as the same as that of tradition jacquard tapestry.

(3) In 2001 and 2002, Li proposed a design method based on Chinese brocade structure via the application of jacquard CAD system. Jacquard fabric was designed to imitate art works by selecting five or eight threads of primary colours. This

method suggested a new design concept and method for colourful jacquard fabric design that made possible the design of richly coloured (up to thousands of mixed colours) jacquard fabric via deployment of designated regular shaded weaves (Li, 2001 and 2002). The design method separated scanned pattern into 5 or 8 threads of basic colours. Twenty-two shaded weaves for each colour were further fixed to form a compound fabric construction by computer for mixed colour expression on the face of fabric. If colour threads were employed with the same colours selected for colour separation previously, colourful brocade could be produced to imitate the colour effect of the original pattern in theory. However, due to the restriction of traditional plane design mode, the research then did not present a more appropriate design method for compound structure design. Thus, the compound structure created was unsteady and mutual covering effect among threads was difficult to control, and the colour deviation of the final fabric could be serious at times. In order to remedy this deficiency and so that a true-to-original colour effect of the original pattern could be reproduced by jacquard fabric, the colour table with fabric colour samples became indispensable. It was built up by a combination of 32 shaded weaves before the fabric design and served as a kind of design assistance (Li, 2004a). Figure 2-3 shows the partial fabric samples of the colour table, whose design process consists of selection of primary colour threads, production of colour swatch with different compound weaves, measurement of the data of colours by computer system. Although the colour table built by computer system could be used for colour matching between the original pattern and the final fabric for colour reproduction and such method was suitable for computer-programmed processing, yet, its disadvantage was the amount of preparation work required before the jacquard fabric design. In addition, if the specification of fabric were revised, the colour table established previously would need to be rebuilt. Therefore, this colour table approach for jacquard fabric design is time-consuming and laborious. Moreover, it was only useful for colour reproduction of a given image under the same specification of fabric. It did not provide assistance to innovate digital jacquard textile design. Currently, the Zhejiang Sci-Tech University (Li, 2004b) and North Carolina University (Mathar, 2005) are conducting research on the colour table approach on both traditional Chinese brocade structure and Western tapestry structure. It should be noted that although benefiting little innovative jacquard textile design, the colour table approach is nevertheless a very important access to realise computer-programmed design for jacquard fabric under the traditional plane design mode.

Figure 2-3. Partial fabric samples of colour table.

(4) In 2001, Zhou presented a design method for colourful jacquard fabric based on the mergence of Chinese brocade structure and Western tapestry structure and four basic colours (red, yellow, green, blue). With the addition of black and white, two special colour systems can be set up for colour reproduction of jacquard fabric of unrestricted structure. The research also suggested two structural design methods with the proposed colour systems. However, being restricted by the traditional plane design mode, the fabric structure produced was not satisfactory, nor was it able to meet the theoretical requirement of the colour systems. (Zhou, 2001b).

(5) In 2002, Speich (CH) presented a method of manufacturing coloured, patterned textile structures of which at least four weft threads of different basic colours were inserted in a specific constant sequence, and a constant cell was formed together with at least one thread (Speich, 2002). This method based mostly on the structure design method of Western tapestry while the design mode remained as the traditional plane design mode. The thrust of this research was that it offered a solution for Western tapestry design via jacquard CAD system. Jacquard textile could then be approached with a higher efficiency. However, the shortcomings of Western tapestry structural design remained. As a result, although the design efficiency increased, the fabric structure and colour expression were still limited.

(6) In 2002 and 2004, inspired by digital image design, a layered combination design method for jacquard fabric design using digital image and CMYK colour mode directly from colour separation to structure combination was proposed by Zhou and Ng. This research attempted to reinvent traditional plane design mode as a new phase of jacquard fabric design under a layered combination method, i.e., individual fabric structure was first designed and then combined to form a compound fabric structure. It was hypothesized that in theory, using compound fabric structure without producing any added colour table, jacquard fabric that enabled expression of mega-level mixed colours on fabric surface could be produced. It sufficed for creation of jacquard fabric with true-colour effect (Zhou, 2002c; 2004). Although this

research presented a new design concept of layered combination design method for jacquard fabric design, little had been done to the study of an optimal structural design method due to the varied and complex structural problems when different regular shaded weaves were deployed to design compound structure. Attempts failed so far to control the structural colour stability on the face of fabric produced under this concept.

(7) In 2004, Speich (CH) further presented a design method relating to patterned fabric of an image. The method has the advantage of exact reproduction of a model image of which a cell was formed by at least two warp threads and 2 weft threads. The cell has a defined colour impression characterized by having it consist of weaves formed irregularly in the warp direction and weft direction without repetition (Speich, 2004). This research presented an interesting design approach suitable for computer-programmed design. It targeted at patterned fabric with a mixing colour effect similar to that of bitmap digital image displayed on the computer screen. By doing so, the method freed the restriction of traditional plane design mode and benefited well the simulative effect design of jacquard fabric directly from digital image. However, the employment of digitisation of irregular weaves led to the mutual covering structure with over long floats on the reversed side. Although the simulative effect achieved by this method was more satisfactory than before, new technical problem resulted. It was thus difficult for this compound fabric structure to meet the technical requirement of mass production of jacquard fabric due to the unbalanced interlacement of colour threads. In addition, with random digitisation weaving points, the produced fabric effect was stipple-like; i.e., the print-like colour shading effect could not be reproduced by such design method. Figure 2-4 shows the fabric effect designed by such method.

Figure 2-4. Stipple-like effect of digital jacquard fabric.

Literature review of research on digital jacquard textile design concluded that the prior research on digital textile design had been carried out largely based on the traditional Chinese brocade structure and Western tapestry structure toward the aim of improving the traditional design method and procedure via the deployment of computer aided-design technology. The initial research intent focused on increasing design efficiency of jacquard design and production in simulative design, i.e., imitation of artistic hand paintings, through the deployment of primary colour yarns in jacquard CAD system. However, due to unpredictable mixed colour expression and complicated compound fabric structures, simulative designs of jacquard fabric produced were unsatisfactory so far. Although several colour tables of 3 to 8 basic colour threads were suggested for jacquard fabric design, the traditional plane design mode and one-to-one corresponding design principle for fabric structural design are still being employed for creating jacquard textiles. Colour deviation on final fabric remains to be solved.

2.4 Design Methods for Traditional Multicoloured Jacquard Fabric

Literature review of the evolution of jacquard textile and related design technologies has inspired the re-invention of the traditional plane design mode of jacquard fabric design through the deployment of digitisation design concept and technology. The research in the field of digital jacquard is believed to be of great value and prospect in design applications. Higher technical requirements are needed for designing and producing multicoloured jacquard fabric, and breakthrough in the research on figured colourful jacquard fabric would need to be achieved through the innovative design of fabric structure. Literature review suggested two types of structural design methods in traditional jacquard textiles. They are the brocade structure, a kind of weft figuring fabric structure that was the representative of ancient Chinese figurative colourful fabric (Huang, 2002) and the tapestry structure, a kind of warp figuring fabric structure that was abundant among Western figurative colourful fabrics (Jenkins, 2003). These two structure design methods under the single plane design mode have lasted for thousands years. It provides essential technical reference for the innovative design of fabric structure of multicoloured jacquard through digitisation technology.

2.4.1 Design Principles and Methods of Chinese Brocade

Chinese brocade is a kind of figured silk fabrics originated from ancient China, in which multiple wefts are employed in conjunction with one series of warp threads. All the wefts are floating on the surface as required in producing the figured effect and to assist in providing the ground structure. Therefore, brocade fabric is a kind of weft figuring fabric with intricate weft-backed or multi-layer structure. It was the highest achievement of silk fabrication in ancient China and is still being well received in the world market today. Among the many variations of brocade fabrics, the typical varieties are brocades with two wefts, three wefts or four wefts, all featuring complex weft backed fabric structure (Anquetil, 1995; Baricco, 1997). In this study, three wefts brocade of weft-backed structure was selected as an example to illustrate the design principles and methods of traditional Chinese brocade fabric.

2.4.1.1 Design principles and methods of colour

Chinese brocade is an exquisite fabric produced with coloured silk threads, showing colourful and magnificent woven effect. It was originally a weft figuring fabric. Since the Sui and Tang Dynasties, weft-face brocade had attained a dominating position in textiles due to the advancement of figuring technology and the inherited convenience of colour changing of weft threads (Cheng, 1992; Agrawal, 2003). Since weft figuring fabrics need the deployment of backed structure, the design of Chinese brocade often rejected sharp contrasts of colours to avoid the colour affect of backing threads. More often than not, colour gradients were made up of similar shades and were superimposed on one another. Thus, the artistic effect of traditional Chinese silk brocade was achieved with patterning of beautiful yet subdued colours, complicated yet non-chaotic. In addition, Chinese brocade was also characterized by the use of the so-called live-colour method, by changing colour wefts in rotation, the repeated pattern could exhibit more colour effects than what three basic weft colours could realised (Zhejiang Institute of Silk and Textiles, 2002).

Taking three wefts and one warp brocade structure as an example, the pattern effect is mainly determined by the employment of weft colours fabricated in a weft-backed structure. Hence, theoretically, the pattern and colour design principle of Chinese brocade is that, before pattern design, the available colour palette should be confirmed first. The number of colour of the palette is mainly limited by the application of weft threads. Normally, only 7 colours can be used to design a brocade fabric pattern. This included 1 warp grounding colour and 6 basic patterning colours of wefts arranged in single/couple colour threads. Even when the length of weft floats in weave structure is changed, restriction of handcraft only allows the maximum available for pattern designing to be less than $1+7\times4 = 29$ colours under the assumption that each basic weave has three variants. As a result, chintzing technique was frequently used in the design of multicoloured Chinese brocade to increase the colour expression of fabric. Figure 2-5 presents a brocade fabric designed with the renowned *"Tuan Hua"* image. The figure was produced in three colours of wefts with a pick inserted into each weft in succession. Two of the wefts were inserted continuously and the third was chintzing (colour changing with four colours in each pattern repeat) for added variation of design. In this colour example one weft is floating with its colour shown on the surface while the second one weaved plain underneath and thus is invisible from both face and reversed side, and the third one floats on the reversed side where it is loosely stitched. The ground colour effect is usually a result of a warp-faced satin whose formation is contributed by each of the three wefts (Zhejiang Institute of Silk and Textiles, 1987).

Face side Reversed side

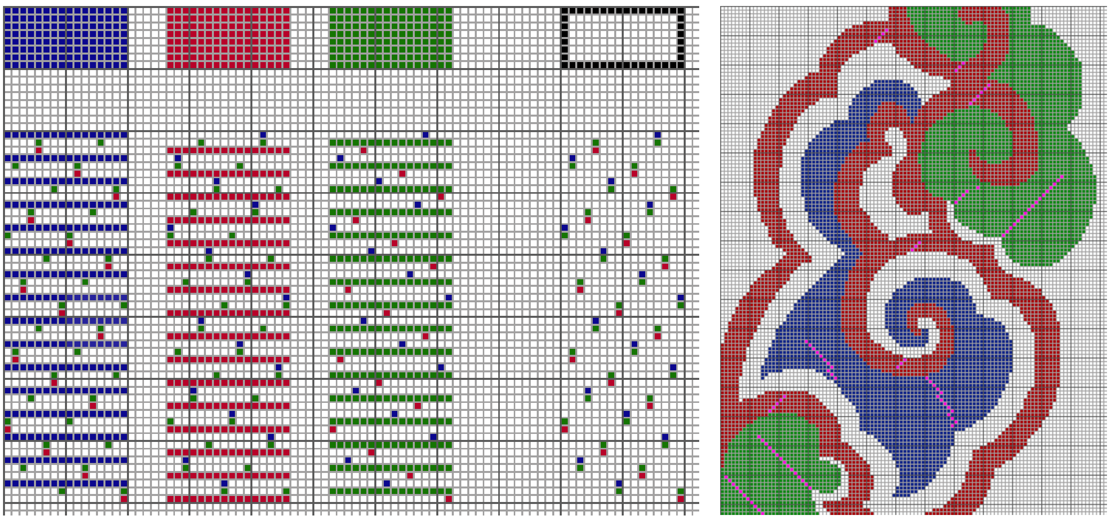
Figure 2-5. Effect of Chinese brocade with chintzing craft.

2.4.1.2 Design principles and methods of structure

Structure design played the most important role in Chinese brocade design. The colour expression and principle aforementioned could only be realised by appropriate structure design method. Literatures revealed two parts in the structure of Chinese brocade: patterning weave and ground weave.

The ground area of Chinese brocade fabric are normally formed by colour warp woven in regular satin weave. Chinese brocade features higher warp density, of which one needle is connected to one harness including two warps. A kind of special shedding device called "lifting rods" is installed for raising the single warp, forming the shed and weaving the fabric. The shed of ground weave is only controlled by "lifting rods" (Huang, 2002). In the design of patterning weave, the long floats serve as the basic element for colour and pattern on the face of fabric. Since there are multi-wefts being deployed in Chinese brocade, it is apparent that the arrangement of wefts laid the foundation for the structure design of fabric. Since the patterning weaves should be produced through the cooperation of hooks and "lifting rods", it is a daunting task to match the weaves of hooks and "lifting rods" during structure design process.

Figure 2-6 shows a simplified weave design for brocade structure that has been condensed by three wefts. A different colour is used to indicate the float of each of the three wefts on the surface and the ground is left blank. The detailed weaves for each of the colours (at the top of the weaves) in the painted area of the point paper drawing are shown in Figure 2-6 in the corresponding columns. The pink colour points drawn in the point paper serves as cutting points that shorten the overlong floats of each weft. Since the cutting point is a sign where all the warps do not rise in the weaving process of face-reversed in order to avoid conflict between weaves of hooks and "lifting rods", the cutting points on the patterning weft must locate in the position of even number grids in the point paper.



Patterning Ground Point paper drawing

Figure 2-6. Structure design for Chinese brocade with three wefts.

It will be seen in Figure 2.6 that that in each patterning weave, one out of three wefts forms continuous figuring floats without any cutting points on the face of the fabric when another two colour wefts exhibit colour floats in 1 and 15 order and 1 and 7 order respectively on the underside. In the ground weave, 8-satin compound weave is designed by using three wefts in succession. Since the structure of Chinese brocade is designed as a kind of backed structure, in which the first and third colour wefts are stitched on alternate binding points in the same shed as that of the second colour weft, this tends to throw the first or third colour wefts, especially when they are in strong contrasting colours with that of the warp, to the back to prevent the solid colour ground effect achieved by the warp-face satin weave from being spoiled. This structure allows the warp-face 8-satin upon second colour weft shown on the face of fabric while the compound weft-face 16-sateen with combination of first and third colour weft is formed at reversed side. In addition, both the first and the third colour wefts may utilize chintzing technique to enrich the colour effect of the fabric.

2.4.2 Design Principles and Methods of Western Woven Tapestry

The original tapestry was referred to as a kind of decorative fabric constructed through warp and swivel wefts. It can be produced only in a manner of handcraft (this kind of technique was named as *Ke Si* in ancient China) (Zhao, 1992). When weaving and patterning machines were widely used for mass production of tapestry, the woven construction of using through warp and through weft became popular in Europe. The fabric woven featured colourful effect similar to that of hand-made tapestry. This kind of structure was given the name of “woven tapestry structure”. Since then, woven tapestry thus become a typical multicoloured woven fabric in the West (Jenkins, 2003) and still enjoys broad utilization today. In general, woven tapestry is a yarn-dyed product made of cotton, linen and/or woollen materials (Walker, 1995; Tinham, 2000). It is being used widely in upholstery and clothing textiles. The group of colour yarns in warp-wise is between 4 and 6 and the coloured yarns employed in weft direction are within 2-4 groups. Therefore, the colour expression on the face of woven tapestry fabric is rather rich.

2.4.2.1 Design principles and methods of colour

The colour effect of woven tapestry was a kind of colour mixture formed by interlacing points of warp and weft that is dependent on fabric structure and the colours of warp and weft threads. Coloured warp yarns are figured and forms the colour on the face of fabric whereas the colours of weft threads are usually employed to adjust the colour brightness. Therefore, the arrangement of warp and weft colours of the woven tapestry is quite important before fabric design. The typical colour arrangement for woven tapestry of 4-6 warps and 3 wefts are as the following:

(1) Warp colours of four-warp fabric are red, yellow, blue and green while the weft colours are black, white and silver grey (silver grey is for stitching weft).

(2) Warp colours of five-warp fabric are red, yellow, blue, green, black or white while weft colours are black, white and silver grey (silver grey is for stitching weft).

(3) Warp colours of six-warp fabric are red, yellow, blue, green, black and white while weft colours are black, white and silver grey (silver grey is for stitching weft).

Red, yellow, blue and green are the fundamental colours of multicoloured woven tapestry fabric in the colour arrangement of warps and wefts aforementioned. The fundamental colours and the mixed colours are the colours and figured effect on the face of fabric whereas black and/or white are used to adjust the brightness and saturation of the mixed woven colours. When fundamental colours, e.g., red, yellow, blue and green, are extended to the serial colours in which each fundamental colour is taken as the centre, the colour mixture palettes for selecting warp colours of fabric is set up. It enables the textile designer to handle thousands of colour mixture effects conveniently. In the design of weft colour group, black and white are the basic colours, and it can be extended to dark colours and light colours. If there are stitching wefts in the weft group, the neutral colours are the best choice for stitching wefts due to its minimal influence on face colour effect.

In colour arrangement of woven tapestry fabric, when the warp group are between 4 to 6 colours, three colouring methods including single warp colouring, double-warp mixed colouring and three-warp mixed colouring can be applied for designing mixed woven colours of fabrics. Under the same weave structure, e.g., the tabby weave, the feasible warp colour principle and the colour number of multicoloured warp jacquard fabric are specified as follows, where N represents the number of warp groups (Zhou, 2006c):

Colouring method of single colour: $C_N^1 = N$ (a)

Colouring method of double-colour: $C_N^2 = N(N-1)/(1\times 2)$ (b)

Colour development method of three-colour: $C_N^3 = N(N-1)(N-2)/(1\times 2\times 3)$ (c)

When the tapestry structure in weft direction employs three wefts, the additional warp may interlace with stitching weft. In case the warp colour on stitching weft is set as two colours at the most, the calculation of formula (a) should be multiplied with $C_{N-1}^{1}+C_{N-1}^{2}$; the result of formula (b) needs to be multiplied with $C_{N-2}^{1}+C_{N-2}^{2}$; and the result in formula (c) should be further multiplied by $C_{N-3}^{1}+C_{N-3}^{2}$ or C_{N-3}^{1} (N=4). In consideration of the application of warp colour principle and the colour number on two weft colours of black and white respectively, the colouring number on fabric surface calculated above is re-duplicated. Taking the variety of four-colour warps and three-group wefts as an example, the mixed colour number on fabric surface under the same weave structure will be as below:

$$\left[C_{N}^{1}\times\left(C_{N-1}^{1}+C_{N-1}^{2}\right)+C_{N}^{2}\times\left(C_{N-2}^{1}+C_{N-2}^{2}\right)+C_{N}^{3}\times C_{N-3}^{1}\right]\times 2=[4\times(3+3)+6\times(2+1)+4\times 1]\times 2=(24+18+4)\times 2$$
$$= 92 \text{ (colours)}$$

As a result, the tapestry with four-colour warps and three-group wefts has 92 varieties of mixed colours formed by changing the combination of warp colours under the same weave structure. When the fabric construction is changed to five-colour warps or six-colour warps, the corresponding calculated results would be 280 colours and 720 colours respectively. However, due to the limitation of handcraft and the complexity of structural design, the available number of colour expression of woven tapestry by far barely exceeds one hundred. Even with CAD system, if the restriction of plane design mode for structure design would need to remain unchanged, the colour expression of Western tapestry, both in theory and in practice, still has a big gap for realizing a picturesque effect (Zhou, 2006c).

2.4.2.2 Design principles and methods of structure

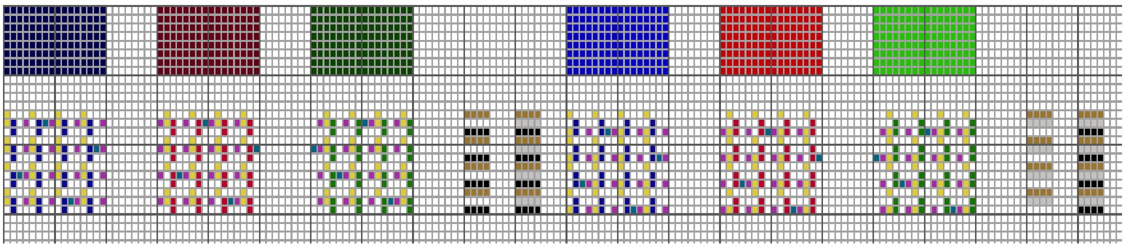
The original tapestry made by handcraft was simple in structure. Only tabby and simple twill were employed in conjunction with several swivel wefts to produce multicolour fabrics (Cheng, 1992). Woven tapestry constructed by through warp and through weft continued to use simple weaves but adding more groups of threads in warp and weft directions. Through the combination of certain basic weaves, woven tapestry was enabled to exhibit richer colour effect by the colour mixture of warp ends and weft picks. Woven tapestry features complex fabric structure combined with multi-warp and multi-weft. Figure 2-7 illustrates a woven tapestry constructed with six warps and three wefts. It was figured by colour warps and wefts for realising a greater diversity of patterns. The warps are comparatively fine. Therefore, when they operate on the face, they will not cover the picks completely and thus make it possible for the weft to be visible. The figuring wefts are quite coarse and are usually in two stark contrasting colours - one very dark (normally black) and another very light (normally white). Being visible, each weft is capable of influencing the colour of a given warp that rests upon it. This will result in having the same warp colour area being different in colours due to different coloured wefts running underneath it.

Face side Reversed side

Figure 2-7. Effect of Western woven tapestry with chintzing warp.

The example of a four-colour warp structure in Figure 2-8 shows that when a blue warp operates on the background of a black weft [see (a)], the hue of this portion of the design differs considerably from that of another area with the same blue warp being backed by a white weft [see (d)]. Thus, using the above method in which both wefts form an effect in conjunction with any one warp, it wound be possible to produce 8 distinct colour areas with four figuring warps and two contrasting wefts. In addition, it is possible to produce other areas in which each weft figures on the face independently, as is shown in Figure 2-8. Being much coarser than the warp, weft will cover the surface completely with no noticeable colour difference. Furthermore, the figuring threads are closely bound by the warp and weft stitching elements that help to achieve a distinctive ribbed, hard weaving surface.

In each weave from (a) to (f) in Figure 2-8, the colouring warp required on the surface floats over both colouring picks and under the stitching pick, thus making a continuous 2 up and 1 down interlacing. One of the remaining colour warps acts as wadding, and separates the wefts into a face and a back layer being operated in a continuous 1 up and 2 down order. The third colour warp floats on the back and is loosely stitched into the body of the fabric in a satinette order. The stitcher is also invariably raised on each stitching picks, being responsible for the characteristically ribbed appearance of this class of structures. The manipulations of weft inserting order are shown in Figure 2-8 (g) that corresponds with the face colour wefts respectively. It is noteworthy that all the weaves (a) to (f) are structurally similar, and the differences between them are entirely due to change of colours (Watson, 1977). Since the basic weaves used in Figure 2-8 are the same, it means that by changing the position of the basic weave, a complex structure can also be produced for an enhanced colour expression. Such flexible structure design method could be regarded as the key thrust in woven tapestry design. It enables woven tapestry to show multicoloured effect with limited warps and wefts interwoven by simple basic weave.



(a) (b) (c) (g) (d) (e) (f) (g)

(a) Dark blue; (b) Dark red; (c) Dark green; (g) Face wefts and insert order; (d) Light blue; (e) Light red; (f) Light green.

Figure 2-8. Weave design illustration for woven tapestry (outspread effect).

The two traditional structure design methods introduced above indicate that in principal, the colour effect of jacquard fabric is determined by fabric construction. Any design innovation obtained from jacquard textile is likely to be achieved through the innovation of fabric structure. Based on stable and accurate fabric construction, any type of colour threads can be used for jacquard fabric design. On the contrary, unsteady fabric construction will cause difficulty in foreseeing the final colour effect of the fabric. For this reason, to reinvent jacquard fabric design via the deployment of digitisation technology requires a paradigm shift in the design method of fabric structure. Moreover, the proposed compound fabric structure meets the required technical requirement of balanced interlacement to enable jacquard fabrics to be manufactured in an industrial scale.

2.5 Summary

High quality textiles like jacquard textile have good value in commercial applications. However, the design of jacquard fabric under traditional plane design mode using a one-to-one corresponding structural design method as the basic design principle would not produce full-colour jacquard textiles to meet the discerning taste of customers today. Chinese brocade and the Western woven tapestry are the forerunners of jacquard fabric with complicated and multicoloured patterns. They are a perfect marriage of structure design and technology on which all design innovations of multicoloured jacquard fabric are based.

Although digital technologies for jacquard textile design and production have been developed rapidly and of wide applications today, e.g., the broad employment of electronic jacquard machine, the advanced weaving loom and the jacquard CAD system, the traditional plane design mode for jacquard fabric remained relatively unchanged. So far, while applications of jacquard CAD system as well as other digital production devices have been to increase design efficiency, they have not been able to contribute to the innovative design of jacquard textiles. The thrust of the study by the author on digital jacquard textile lays in the design innovation of fabric structure. To this end, the layered-combination design mode proposed in this study rides on digital design concept and principles. With layered-combination design mode, fabric structure of traditional jacquard textiles can be produced through digitisation processing, and is anticipated to be of important value and implications to the design and production of innovative digital jacquard textiles.

CHAPTER 3
THEORETICAL RESEARCH

3.1 Introduction

This chapter laid the theoretical foundation for design research in the field of digital jacquard textile. New design concept, principles and methods relevant to the digitisation structure of jacquard textile were introduced. The theoretical foundation served as the basic guideline to future practical design research and design creations of the digital jacquard textiles.

Inspired by the design principles and methods of digital image, the design mode of digital jacquard textile innovated in this study was named layered-combination design mode. The new design mode was divided into two parts in terms of the applied digital colour theory: the colourless design and the colourful design. Here, colourless and colourful referred to not only the colour effect of jacquard fabrics, but also the design processes for digital jacquard textile design that was originally introduced from the design principles and methods of digital image. By using layered combination design method, several colourless single-layer structures designed by gamut weaves were combined to form a digitisation compound structure. As a result, the jacquard fabrics constructed with such compound structure were capable of expressing picturesque and print-like effect with rich mixed colours on the face of fabric up to mega level.

This chapter introduced the innovative design principles and design methods of the layered-combination design mode in both colourless design mode and colourful design mode.

3.2 Basic Design Concept of Digital Jacquard Textile

3.2.1 Natures of Traditional Jacquard Textile

Rich in variety, jacquard fabric can be divided into four categories in terms of weaving structures: single-layer, backed structure (weft-backed, warp-backed), double-layer and multi-layer (Watson, 1975). The process of traditional jacquard textile design begins with freehand design of pattern and colour. Structural design of jacquard fabric is a technical means to imitate the effect of patterns and colours of the original drawing (Figure 3-1) (Zhejiang Institute of Silk and Textiles, 1987). Limited by the craftsmanship of manual labour, the role of traditional jacquard textile design has been a passive process of mechanical imitation and recreation of given hand-drawn image.

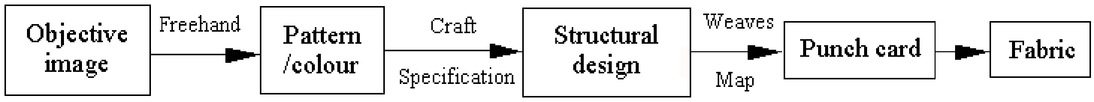


Figure 3-1. Design processes of traditional jacquard.

Although jacquard CAD system today can improve the efficiency of structural design, the jacquard CAD system *per se* was but to assist the structural design of jacquard (Li, 2000). The design of jacquard textiles still relies on free handiwork that enjoyed no further innovation in its design concept. Thus, this improved approach has not been able to bring about the advantage of innovative digital technology. Figure 3-2 summarises the design principles and methods of traditional jacquard textile design. The design of complex weave, fabric structure and final fabric effect are illustrated below. The nature of traditional plane design mode can be summarised as follow:

(1) The pattern of a given image is designed in a manner of hand drawing with 16 colours only.

(2) Based on one-to-one corresponding design principle and 16 available colours, 16 complex weaves are designed by combination of simple weaves under single weave design mode.

(3) Through the replacement of 16 colours by corresponding 16 complex weaves, the fabric structure of jacquard fabric takes shape. The fabric exhibits only the mixed effect among the 16 colours and complex weaves.

(4) The jacquard fabric produced expresses the pattern and colour effects that imitate the effect of hand painting to the extent allowed by these colours and weaves.

Figure 3.2 illustrates the effect of jacquard textile designed by traditional plane design mode. Since free-hand design is necessary in both the pattern design and the weave design of the traditional plane design mode of jacquard textile, the process is time-consuming and complicated. It requires the weaver to be experienced in designing woven structure, drawing free-hand patterns and weaving jacquard textiles. Besides, due to the limited colour expression, traditional jacquard fabrics are designed only to imitate the effect of hand painting mechanically, featuring little innovation during the design process.

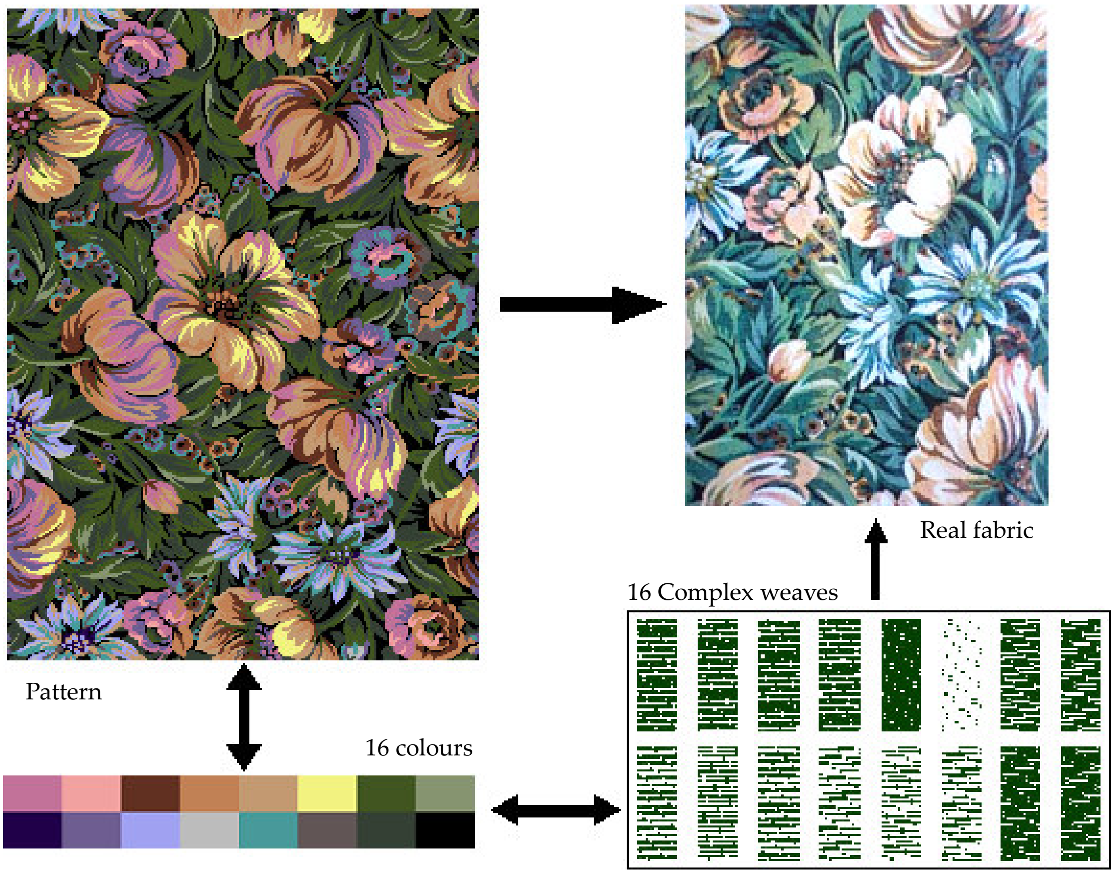


Figure 3-2. Single plane design mode of traditional jacquard textile.

3.2.2 Innovation of Digital Jacquard Textile Design

Digitisation technology has provided a technological basis for the innovative design of digital jacquard. If the constraints of handiwork are removed and be replaced by computer technology that link the design and production of jacquard textiles, genuine innovation in designing jacquard can be realised. Since the theory of computer technology originated from the principles of figured information control over jacquard (James, 2006), based on the digital weave design method for woven structure, it is possible for digitized images to be translated directly into woven structure by the layered-combination design mode proposed in this study. This design concept and methods have removed the need of hand drawing along with its constraints, allowing for a larger scope of innovativeness of jacquard design. Figure 3-3 summarises the innovative design processes.

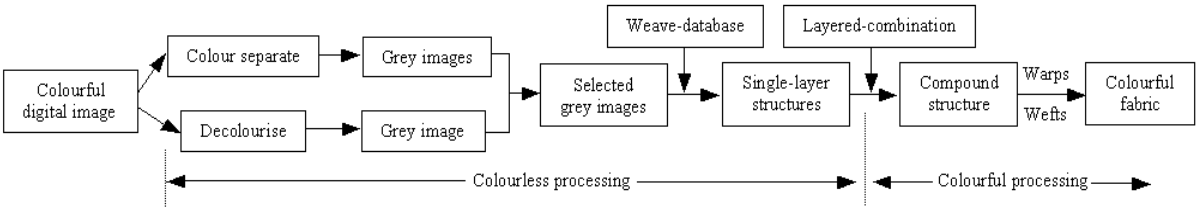


Figure 3-3. Innovative layered-combination design processes for digital jacquard.

In terms of the colour mode of digital image and corresponding design methods, the study of digital jacquard design can be divided into two design parts: colourless and colourful. The "colourless" and "colourful" referred not only to the subsequent colour effect of fabrics, but also the design mode by which digital jacquard is designed and created. The design of colourless digital jacquard is based on the digital colourless mode (achromatic theory) and single-layer woven structure. By using layered combination design method and shaded gamut weaves, several colourless single-layer structures can be combined to form a compound colourful structure, which enables the mixed colour number on the fabric surface to be expressed at mega level. Subsequently, digital jacquard fabric with novel digital colour effect can be created. The core technologies of digital jacquard fabric design lay in two aspects: colour design and structural design. By this design approach, the computer image serves as the template for the structural design of jacquard fabric. It does not represent the final colour effect of jacquard fabric. The final colour effect of fabric should depend upon the employment of colour warps and wefts.

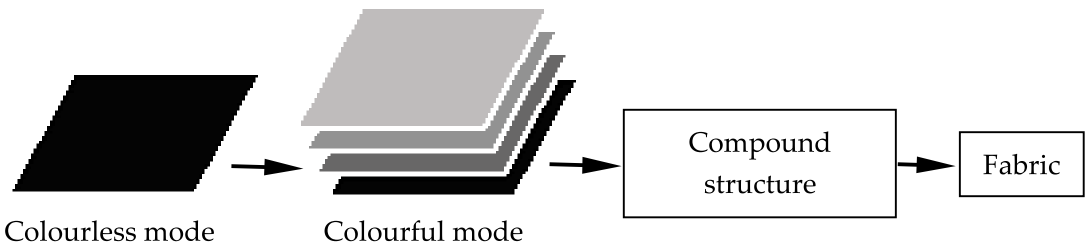


Figure 3-4. Layered-combination design mode of digital jacquard textile.

Figure 3-4 shows the basic design concept of the layered-combination design mode of digital jacquard textiles proposed in this study. In brief, colourless digital jacquard textile design is processed based on the mergence of digital colourless mode (achromatic colour) and single-layer structure. Employing digital colour theory and layered-combination design method, the colourful digital jacquard textile design can be realised. Fabrics produced by this means are constructed with compound structure formed by the combination of several colourless single-layer structures. In effect, each single-layer structure in the compound structure serves as indivudal colour channel/path of different basic colours that contribute to the subsequent colour mixing. With the change of floating length of threads in compound structure, the mixed colours produced on the face of fabric is capable of showing multicoloured pattern effect.

3.2.3 Research Framework of Digital Jacquard Textile Design

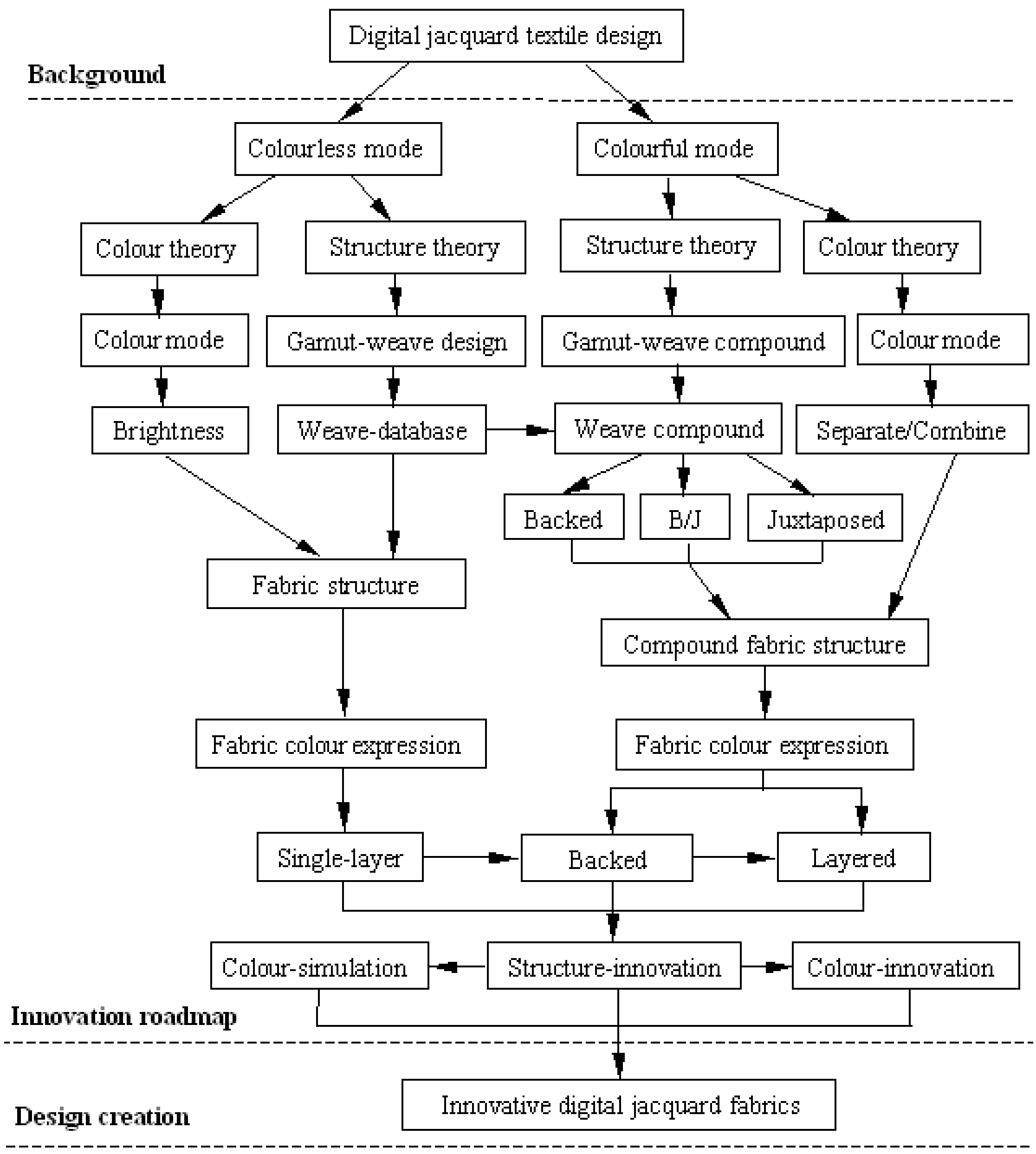


Figure 3-5. Detailed research framework of digital jacquard textile design.

Figure 3-5 maps the research route and relevant key technical points of design innovation by which research progress in both theoretical research and practical research are guided. The theoretical research includes design concept, principles and methods of digital jacquard textiles. It focused on structure design and colour expression in colourless and colourful design mode of digital jacquard textile design. A detailed working route as well as a research plan is presented for design creations of digital jacquard fabrics.

The key technical point of layered-combination design mode that merged colourless digital jacquard design and colourful digital jacquard design lies in the design and combination of gamut weaves. Fabric structure designed by layered-combination mode can be divided into three categories, i.e., single-layer structure, backed structure and layered structure. Single-layer structure takes one warp and one weft interlacement as a foundation. Any gamut weaves may be applied directly to design colourless digital jacquard fabric following the design approach of colourless digital image. Although the structure is simple, the relations between the fabric structure/texture and the fabric effect vary greatly. By changing the design method of gamut weaves, single-layer colourless digital jacquard fabric can be produced showing novel grey shading effect. Therefore, the design of colourless digital jacquard fabric can be regarded as a design innovation of digitisation of woven construction based on digital grey images directly. Indeed, any grey mode digital image can be transformed into jacquard fabric.

The backed structure is a compound structure produced through the combination of single-layer structures designed by gamut weaves. It can be divided into three types: full backed, partial backed and non-backed. Full backed is a kind of compound structure that after combination, its backing threads are fully covered by face threads. The non-backed structure is one that the colours of all the threads interwoven in fabric construction can be seen on the face of the fabric. On the other hand, partial backed structure shows incomplete backed effect due to the different status of thread floats. Certain backing threads may still be seen on the face side. Non-backed structure is one that the colours of all the threads interwoven in fabric construction are seen on the face of the fabric. Non-backed structure could be applied to simulative design for digital jacquard whereas full-backed and partial backed structural design method is more suitable for innovative design.

Layered structure is a kind of innovative structure that can only be generated under layered-combination design mode. Both single-layer and compound structure are individual fabric structures. Combining two fabric structures with the aid of stitching weave will result in a compound layered structure bearing respective fabric effects, Stitching method of layered fabric structures can either be from upper layer to lower layer or vice versa. By using layered structure, it is convenient to design various patterns on both the face and the reversed side of a double-face effect digital jacquard.

3.2.4 Design Creations of Innovative Digital Jacquard Fabric

Innovation in jacquard textiles is achieved based on the application of textile materials and corresponding finishing techniques and/or fabric structure. With the application of digitized technology, the innovation of digital jacquard fabric obviously lays in the innovative design of fabric structure, by which the innovative colour and pattern effects on fabric surface are achieved. It is also a crucial factor in distinguishing jacquard fabric from the fabrics produced by other means, e.g., dyeing, printing, knitting, embroidering, etc.

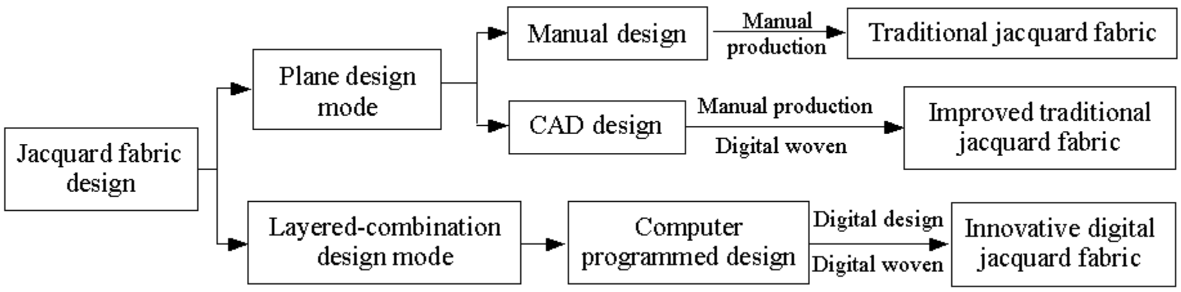


Figure 3-6. Relationships between design modes and design creations.

The plane design mode has been the fundamental design method for traditional jacquard fabric design. The application of jacquard CAD system only played the role of improving design efficiency due to the limitation of the plane design mode, making little or no progress in design creation of jacquard fabric towards innovative effects. Differing from traditional plane design mode, digital layered-combination design mode was conceived based on the application of digitized technology through a mergence of digital image design method and digital colour theory. So long as the principle and method of fabric structure design under layered-combination mode are abided to, computer programmed design for digital jacquard fabric can be realised.

By then, the computer no longer serves as a simple aid in the course of design. It is used to replace part of manual design work by what can be called intelligent design of jacquard fabric. Figure 3-6 summarises the relationships between design modes and design creations are shown in, by which the values and significance of the layered-combination design mode of digital jacquard textile design proposed in this study are also suggested.

The change of design mode as well as the design innovation of fabric structure and colour mixture theory laid the foundation for design creations of digital jacquard fabrics. These propositions acted as a crucial technical bridge between the theoretical research, practical research and the design creations. Any design creations of innovative jacquard fabrics requires application of digitisation technology through the new fabric structure and the mixed colour effect based on the proposed design mode. Given the new relationship between fabric structure and colour innovation, various effects in design creation of digital jacquard fabric are invented and summarised in Figure 3-7. Innovative designs of digital jacquard fabric can be broadly divided into two types of effect: simulative effect and innovative effect. However, due to the difference in colour mixture theories, the simulative digital jacquard fabric created was but a relatively crude simulation of the original digital image. The innovative design of digital jacquard fabric capitalized on the structure of woven fabric as the foundation. It could be realised by either innovating the structural design or variant design upon the effect of simulative design.

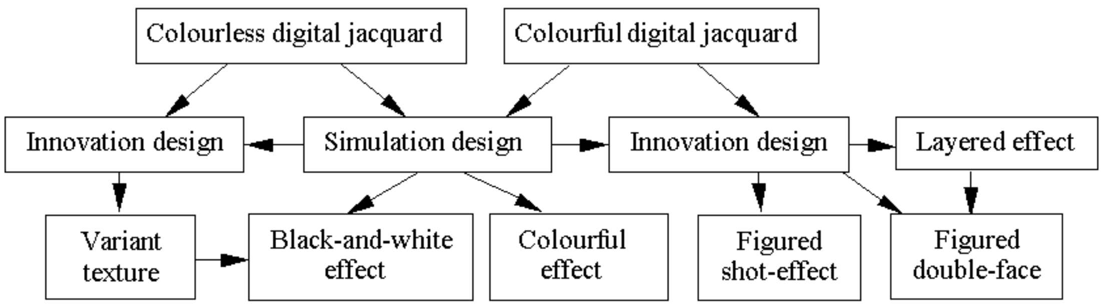


Figure 3-7. System of innovative digital jacquard fabric design.

3.3 Design Principles and Methods of Digital Jacquard Textile Design

Directly borrowed from layered design method of digital image and corresponding colour theory, the innovative design method of digital jacquard fabric can be divided into two design processes: the colourless design and the colourful design.

Theoretically, the design of colourless digital jacquard is based on the grayscale mode of digital colour and single-layer woven structure. By using layer combination design method, several colourless single-layer structures are combined to form a compound structure. It enables jacquard fabric to express a multicoloured effect with millions of mixed colours to achieve a picturesque and print-like effect with smooth colour shading. The core technologies of digital jacquard fabric design lay in colour design and structural design. The study of design principles and methods of digital jacquard textiles started from colourless design mode to colourful design mode.

3.3.1 Design Principles and Methods of Colourless Digital Jacquard

3.3.1.1 Principles of colourless digital jacquard fabric design

According to the colour principles in design, achromatic colour consists of black, white, and a series of neutral greys. Similarly, in digital colour principle, any colourless image could be rendered in and processed with corresponding greys without colour information, e.g., hue, saturation, etc. with certain brightness displaying white colour under maximum brightness value or black colour under minimum value. In addition, any colour image can be converted to its "achromatic" version whose greys are controlled by bit lengths (Green, 1999; Fraser, 2004). Table 3-1 shows the relationship between bit lengths of grey image and grey scales. In fact, an 8-bit length and 256-scale grayness will be enough to satisfy expression of any image, whose grey scales of various brightness values are denoted with values 0 to 255.

Table 3-1 Conversion between bit lengths and grey scales of a grey image.

Bit lengths	Grey scales
1-bit	2
2-bit	4
4-bit	16
6-bit	64
8-bit	256

Fabric construction of a single-layer structure bears certain commonalities with a grey image in terms of processing approach, i.e., a single-layer structure designed by a shaded weave can express jacquard fabric in a way similar to the grey scale of a grey image. For example, a five-thread satin is generally applied with five-thread weft faced sateen and five-thread warp faced satin in fabric designing respectively. Thus, if the five-thread satin are designed in a whole series of weaves, the nature of its structural variation will be those shown in Figure 3-8. This method could be defined as digital gamut weaves design.

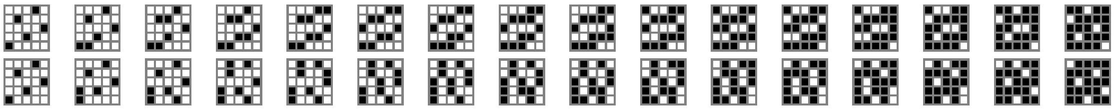


Figure 3-8. Digital gamut weaves of five-thread satin.

The gamut weaves of five-thread satin designed by two design approaches illustrated in Figure 3-8 have the same results in the processing method of computer grey image. In effect, the design approaches for gamut weaves might vary, but the number of weaves remains unchanged. This provides the reference for building a weave-database for colourless digital jacquard design, and at the same time, fulfils the requirement of intelligent match between grey scales of digital image and weaves in the weave-database. According to the technical characteristics of single-layer jacquard fabric, the applicable weave repeats should range between 5 and 40. However, in practice, weaves require the number to be a sub-multiple of hooks for weave repeat (Zhou, 2002b). Having said that, the effective weave repeats between 5 and 40 are: 5, 8, 10, 12, 16, 20, 24, 32 and 40.

Table 3-2 Data of grey scales under different weave repeats.

Weave repeat	Grey scales (M=R)	Grey scales M=(1/2) R	Grey scales M=(1/4) R	Grey scales (M=1)
5×5	4	-	-	16
8×8	7	13	25	49
10×10	9	17	-	81
12×12	11	21	41	121
16×16	15	29	57	225
20×20	19	37	73	361
24×24	23	45	89	529
32×32	31	61	121	961
40×40	39	77	153	1521

*M represents added/reduced value of weaving points, R represents weave repeat.

Table 3-2 shows the data of gamut weaves that can be established under various weave repeats. When processing below scale-256 greyness, the number of gamut weaves can be determined under each weave repeat. This is helpful to support structural design. The data is underlined in Table 3-2, where R represents the number of weave repeat; *M* represents increased value of weaving point among the weaves. The method of calculating grey scale is: when *M*=*R*, the formula is (*R*-1); when *M*=(1/2)*R*, the formula is 2 (*R*-1)-1; when *M*=(1/4)*R*, the formula is 2[2(*R*-1)-1]-1; and when *M*=1, the formula is *R*(*R*-2)+1. This method applies to any digital weave-database established with all regular primary satins and twills. When *M*=1, the digital weave-database will involve whole gamut weaves with all variations of a primary weave.

3.3.1.2 Design methods of colourless digital jacquard fabric

All images can be digitized into a computer image. Under the principle and method of computer grey image processing, the digital image can be converted to grey image in a computer. As shown in Figure 3-3, colourful digital images may be acquired through camera recording, scanning, format converting, or other digital means. They can be processed under various colour modes. Through image processing, modification and adjustment, the 256-scale grey images will be taken shape. As there is no colour expression, the level of contrast in the grey scale must be enhanced to ensure that the brightest in the grey scale has the brightness value 255 while the darkest 0 for better fabric effect. The brightness of level-256 grey scale is at grade 1, and that of level-128 is at grade 2, and that of level-64 is at grade 4, so on and so forth. Different from traditional computer-aided designs for jacquard fabric, the grey scale image needs no modification on its margins whereas they should be edited freehand in traditional means. On the contrary, the frequent intersection of details of grey scale in the digital image allows the design of digitized structure to be unaffected. As opposed to the traditional structural design where weave design imitated the colour effect of hand painting passively, the method of structural design for colourless digital jacquard is to establish a digital weave-database so that the constant weave-database can meet any requirements of structural designs for digital images with different grey scales.

(1) Method to Establish a Digital Weave-database

The weave-database of the colourless digital jacquard is realised through the design principle of shaded weaves. Any primary weave with different weave repeats may have its own weave-database with whole gamut weaves. If the weave repeat of primary weaves is same, the number of gamut weaves in weave-databases is identical. Under the design principle of shaded weaves, the gradual transition of warp/weft faced weave to a weft/warp faced weave for serial weaves proceeds primarily in three directions based on primary satin or twill: diagonal transition, lateral transition and longitudinal transition (see Figure 3-9). Owing to the lack of balanced interlacement in its weaving structure, the diagonal transition enjoys little applications. The lateral transition applies to expression in products whose warp density of fabric is less than its weft density. The longitudinal transition applies to designs whose warp density of fabric is greater than its weft density.

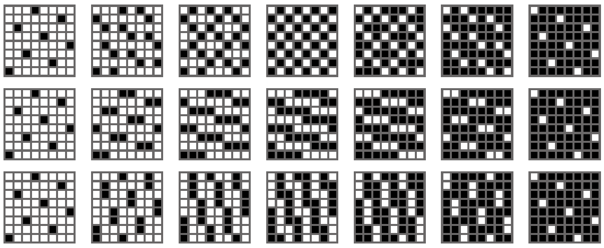


Figure 3-9. Three directions in the transition of shaded weaves.

Besides the directions of transition, the increase of interlacing points for the transition of shaded weave also plays an important role and has influence on the number of weaves in the weave-database. The routine procedures for increasing the interlacing points include: M=R, M=(1/2)R, M=(1/4)R, and M=1. Figure 3-10 shows that the 8-thread satin establishes its weave-databases by increasing the interlacing points under M=8, M=4 and M=2 respectively (from top to below). Therefore, the weave-database of colourless digital jacquard is defined by M, adding value to interlacing points for the shaded weave. When M is defined as the weave repeat, the number of weaves in the weave-database established will be at the minimum value. When M is 1, the number of weaves is at the maximum value, indicating gamut weaves of the primary weave. The greater the repeat of weave, the more weaves could be devised in a weave-database.

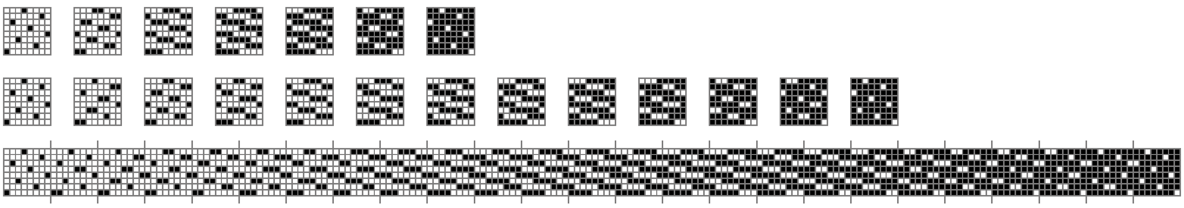


Figure 3-10. Methods to increase interlacing points in the transition of shaded weaves.

(2) Application of a Digital Weave-database

Giving the principle and method for the design of gamut weaves, it is apparent that a digital weave-database contains all the variations of a certain primary weave. Coupled with the weaves of a weave-database, structural design is available to colourless digital images, of which the brightness of grey scale serves as the basic parameters for correspondence of weaves. According to different colours of warps and wefts, the maximum and minimum values of brightness could be distributed to weft/warp faced weaves or warp/weft faced weaves at the two extremes in a weave-database. The medium grey scales can also find their corresponding weaves in the weave-database according to the grading of their brightness. In addition, for the same weave repeat, and similar structural tension, weaves in a digital weave-database could automatically meet the requirement of structural balance. The weave-database of different weave repeats selected for structural design only affects the warp and weft densities of the target fabric. Therefore, the design of colourless digital jacquard is based on a well-organized digital weave-database without referring to the subject matter of a digital grey image. In other words, innovative design of the digital image is free from limitation. Moreover, the larger the size of the digital grey scale image, the higher is the warp and weft densities of the fabric. It also enables more elaborated effects to be achieved.

3.3.2 Principles and Methods of Colourful Digital Jacquard

3.3.2.1 Principles of colourful digital jacquard fabric design

In colour science, primary colours are the basis to express an object's colour. All colours are the result of mixing primary colours under various proportions. Computer processed colours of colourful images work on similar principles of mixing and separation of primary colours. The colour effect of jacquard fabric is expressed through the combination of warps and wefts, of which the colour yarns serve as the primary colours in the fabric. Though differences exist between the two, they share the greatest common ground for colour mixing. It is this foundation on which innovative colour design of colourful digital jacquard is based (Green, 1999).

The primary colours differ between light, pigment and computer in the following four ways: the three primary colours of light are red, green and blue, and the colour mode corresponding to a computer is RGB. The three primary colours of pigment are red, yellow and blue, and there is no corresponding colour mode in a computer. The physiological four primary colours are red, yellow, blue and green, and there is also no corresponding computer colour mode. The four basic colours in printing are cyan, magenta, yellow and black, and the colour mode of CMYK corresponds to a computer printer. Among them, the modes RGB and CMYK in computer applications are fine references for the colour design for colourful digital jacquard where image colours may be reproduced rationally through fabric construction according to the inherent characteristics of the structural design of jacquard fabric. Besides, the reproduction process not only enables simulation of colours of any image, but can also create a new colour effect through woven construction. Therefore, the colour design of colourful digital jacquard is built upon the combination of digital colour theory and colour expression of fabric construction that is far beyond what the colour expression of freehand can achieve. The colour theory of layered combination design method can be briefly defined as follows: the colours in any digital image may be separated into monochromatic layers and decolourised into several grey scale images, or directly decolourised without colour separation. Any colourless grey scale images could be subject purposefully to structural design according to various degrees of brightness. The structures designed from grey images can be combined to form an integral compound structure in layers proportionally, by which the effect of colour mixture can be extended to fabric.

The structural design for colourful digital jacquard is based upon layer combinations, and its principle can be construed as the combination of colourless digital jacquard fabrics (Zhou, 2006b). This innovative structural design of colourful digital jacquard is removed from the restrictions of traditional planed design mode. To meet the technical requirements of structural balance and structural stability combinations, the structural design of colourful jacquard requires combination of weaves with identical weave types in different weave-databases. The principles of the structural design are to first determine the primary weaves with which the weave-database can be established respectively. Then, weaves are applied in the same weave-database to grey scale layers alternately allocated. Thus, the subsequent combined structures may provide a satisfactory surface effect. Figure 3-11 shows the fundamental principle of two-layer combined structural design with 12-thread sateen as the primary weave of the weave-database. Effect drawings for the derivative weaves of the primary weaves and compound weaves are listed from top to bottom respectively. Based on the characteristics of the 12-thread sateen, the primary weaves have been confirmed as the 12/5 weft-faced sateen, of which 11 variations of weave are provided through displacements of the starting point of the primary weaves. Except for the first weave that shows the juxtaposed effect upon combination, there are 10 variant weaves. It shows that 11 digital weave-databases (including weave-database of primary weave) can be set up, i.e., *R*-1 kinds of derivation, where *R* refers to the number of weave repeat. In this way the 10 derivative weaves of Figure 3-11 can generate 10 effect drawings of compound weaves upon combination with the primary weave according to the combination method of 1-and-1 across weft. Such 10 combination effects feature either the different weave structures or the same weave structure but in different order of wefts. It provides 10 patterns available for further adding/reducing of interlacing points. This arrangement method also applies to the requirements of 1:1:1, 1:1:1:1, and so on. However, weaves in identical weave-databases should not be arranged adjacently. According to the result of the combination effect of primary weave shown in Figure 3-11, it could be inferred that the same result can also be achieved with the combination of gamut weaves designed on the basis of those primary weaves in the weave-database. Moreover, in fabric design process, the combination method of primary weave can serve as a model for combining single-layer fabric structures to form a compound fabric structure.

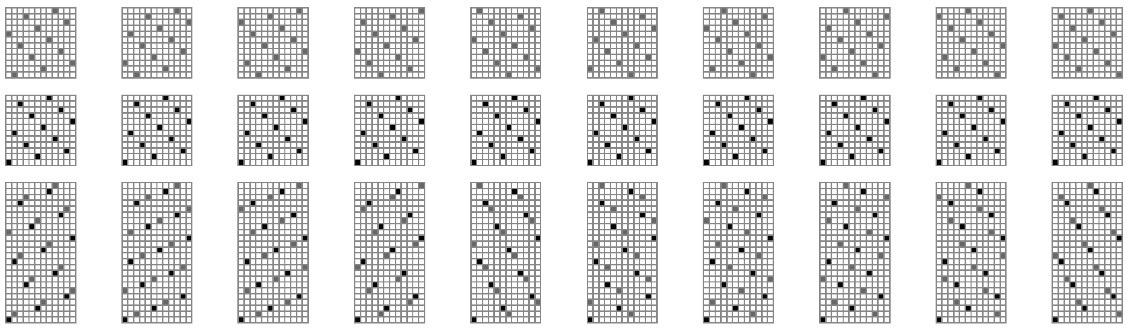


Figure 3-11. Principle of structural design for 12-thread sateen of colourful digital jacquard.

The method for structural design of colourful digital jacquard built upon that of colourless digital jacquard could extend the range of combined colourful jacquard fabrics with the ability to express a variety of rich colours because of the availability for design with gamut weaves. In Table 3-3, typical grey scales (underlined) have been selected from different repeats of weaves, and a combination datum of colour development has been calculated for the grey images upon the two-layer, three-layer and four-layer, of which *G* represents the grey scale, *R* represents the number of weave repeats and *M* represents the added value of weaving point. If all layers apply the same grey scale, the multi-layer colour mixture is calculated according to G^L, of which *L* represents the number of layers. If the grey scales vary in any layer, the multi-layer colour mixture is calculated under the product of multiplying the scales of all the grey scale layers. Table 3-3 utilizes a same grey scale. It is obvious that, notwithstanding the partial backed structure in the process of colour reproduction, the data for colour mixing of the four layers of grey images all exceed mega-level where colour expression is beyond what the human eye can detect (Zhou, 2006a) and which process is unequaled by traditional hand drawing. In addition, different from the traditional plane design mode, the number of mixed colours on the face of digital jacquard fabric is not a constant due to the random combination effect caused among gamut weaves. Certain mixed colours may be lost in the course of structure design. For example, when designing fabric with 8-thread weave, 49 grey scales and two-layer combination, after combination of two single-layer fabric structure, the mixed colour number of fabric will be varied due to the change of employed image. The maximum number of mixed colours will remain 2401, which is shown in Table 3-3.

Table 3-3 Relationship between colour numbers and grey scales after combination.

Weave repeat	Grey scale *M*=(1/4) *R*	Grey scale (*M*=1)	Mixed colour 2-layer (G^2)	Mixed colour 3-layer (G^3)	Mixed colour 4-layer (G^4)
8×8	25	<u>49</u>	2401	117,649	5,764,801
12×12	41	<u>121</u>	14,641	1,771,562	214,358,881
16×16	<u>57</u>	225	3,249	185,139	10,556,001
20×20	<u>73</u>	361	5,329	389,017	28,398,241
24×24	<u>89</u>	529	7,921	704,969	62,742,241
32×32	<u>121</u>	961	14,641	1,771,562	214,358,881
40×40	<u>153</u>	1,521	23,409	3,581,577	547,981,281

**M* represents added/reduced value of weaving points, *R* represents weave repeat.

3.3.2.2 Design methods of colourful digital jacquard fabric

The innovative principle for colourful digital jacquard fabric design implies perfectly integrated structure and colour through colour separation, layered design and recombination. According to the design processes shown in Figure 3-3, digital colourless image could be obtained under four methods. RGB and CMYK colour separation are the two most fundamental methods, which could be applied to simulative effect design of digital jacquard fabric. The third method is to separate colourful image by representative colour to form grey scale layers of designated colours. Yet, the grey image requires essential modification because of the lost of information of primary colours during the separation of compound colours. The fourth method is that the grey image could be obtained directly from a desaturated colourful image that is provided with integral modeling information, so its application will result in unimaginable, innovative design effects. When the grey images are formed, they can be selected for structural design and combination according to specific design requirements and characteristics of individual grey scales.

The colour design of colourful digital jacquard provides high flexibility and openness in the design process, allowing free choice of layered grey images for combination. The weaves in a weave-database in structural design of colourful digital jacquard always remain unchanged. No matter how complex the colour design is, or how varied the layers of grey images are, the structural design does not become any more complex than it already is. Similarly, given no change to the colour of weft, jacquard fabrics of various colour inclinations could also be devised by structural design through modification of the levels of grey scale on the grey images (no similar values). Take the theory of establishing a digital weave-database with the 12-thread sateen as an example, eleven digital weave-databases could be established that can meet any requirement on combined design of layers of various grey scales. Figure 3-12 shows two of them (*M*=*R*), by which alternative employment can meet the combined design of two or four grey scale layers, i.e., the identical digital weave-databases applied to the first and the third, or the second and the fourth layers.

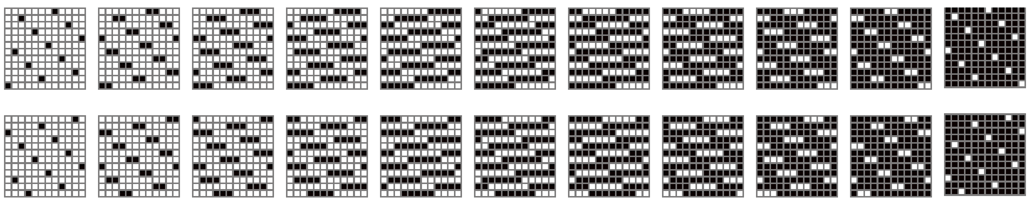


Figure 3-12. Digital weave-database of 12-thread sateen for colourful digital jacquard.

As a fixed factor, the structural design of colourful digital jacquard has no connection with the subject matter of digital images. Thus, any digital weave-database of any type of weave could be established independently. Under the principle of correspondence between predetermined, fixed grey scales and weaves in a weave-database, the intelligent design of colourful digital jacquard fabric could easily be realised. Designed effect varies with the change of grey scale layers in the digital image, from simulative design to innovative design. Since the colour design and structural design for colourful digital jacquard are comparatively independent, when the structural design is finished, innovative colour design may result due to different structural characteristics. This process resembles modeling before colouring in artistic design, adding not only the sheer pleasure of innovative design, but also the creativity and personality of the creator.

3.4 Summary

The design concept, design principles and design methods aforementioned conclude that the design research merging digitisation technology with jacquard textile innovation under a layered-combination mode integrated the basic principles of woven fabric structure, colour science and computer science in one. It was invented to replace the traditional plane design mode. Since digital jacquard fabric designed with digitisation compound structure has the capability of raising the valid mixed colour number on fabric surface up to mega level without any restriction regardless of the subject matter of digital images, digital jacquard textiles with simulative effect design and innovative effect design can both be processed as conveniently as that of digital image printing. The results of this study suggested a new direction for design research of jacquard fabric in the future. However, for a relatively new field of textile research, the key technical problems of digital jacquard textile design should be studied further through elaborative practical research and experiments.

CHAPTER 4
PRACTICAL RESEARCH

4.1 Introduction

The design research of digital jacquard textile was conducted with a new design concept. Little prior knowledge and experience are considered relevant to support such conceptual originality. Thus, following the theoretical research of the design concept, principles and methods of digital jacquard textile design stated in Chapter 3, this chapter sets out to identify the key technical problems and the solutions in the course of digital jacquard textile design under layered-combination design mode.

As mentioned in Chapter 3, the key points of digital jacquard textile design laid in colour design and structural design. Therefore, the relationship of structural design and its colour expression obviously played an important role for the design creation of digital jacquard textile that must be understood thoroughly. For this reason, this chapter reported the study of structural design methods available and their related colour expression, as well as the way technical requirements of mass production of digital jacquard fabrics were met by the proposed methods. In addition, the practical work of a practice-led research as this study served to validate the theoretical design concept, principles and methods put forth in the previous chapter. Meanwhile, any hidden problems in the course of design were identified and tackled for optimal results.

The chapter is divided into four major parts. The first part presents the practical design of fabric structure that involves the design method of gamut weaves and weave-database, the design method of compound structure as well as the design method of full-colour compound structure. The second part is the practical research in colour design and in particular, colour mixture theory and the phenomenon of woven structure. The third and fourth parts are two integrative design practices in both the colourless design mode and the colourful design mode. Detailed key technical points of digital jacquard textile design are shown in Figure 4-1 in accordance with the progress of this research.

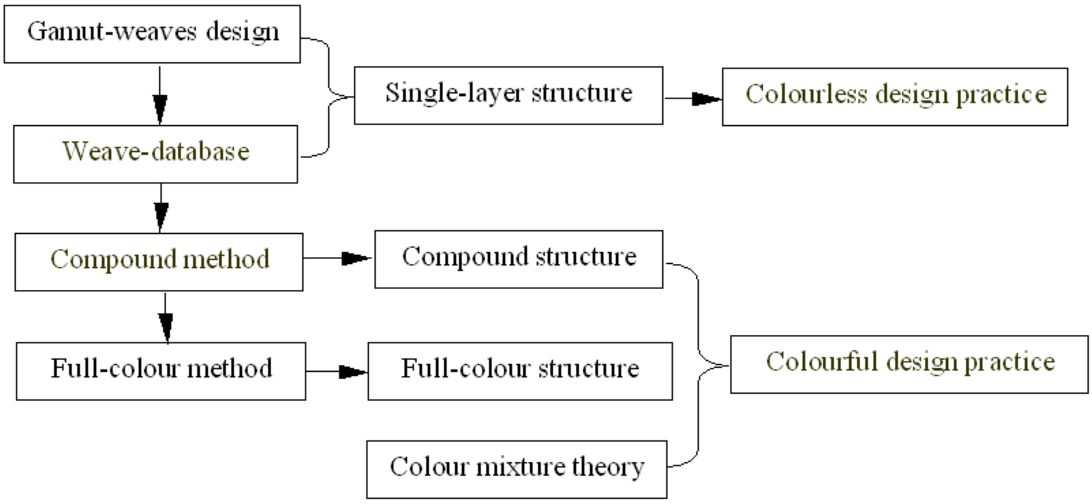


Figure 4-1. Key technical points of digital jacquard textile design.

4.2 Research on Structure Design of Digital Jacquard Textile

The results of theoretical research proposed in Chapter 3 indicated that layered-combination design mode enables digital jacquard fabric to express a mega level mixed colour effect. Thus, the appropriate method of weave and structure design should be put forward to address such a design concept. Since traditional structural design method with the plane design mode was unsuitable for designing digital jacquard textile, it was essential to explore the optimal structural design method for the creations of digital jacquard fabrics in line with mass production.

4.2.1 Gamut Weaves and Weave-database Design

Jacquard fabric is one kind of woven fabrics with warp and weft threads interwoven with each other. This rule of interlacement is called weave (Watson, 1975). Any weave is composed of alternative warp and weft interlacing points. The number of threads required for arrangement of the warp and weft interlacing points repeats for one time is called a weave repeat, say R, and the number of threads of warp and weft in the weave repeat are represented by R_j and R_w respectively. In general, the weaves could be divided into three categories: 1) the simple weave, which includes elementary weaves, variations of elementary weaves, and combinations of elementary weaves; 2) the complex weave (compound weave), which includes multi-weft, multi-warp, double-layer and multi-layer weaves, and 3) the special weave such as leno, pile, terry, etc. (Zhejiang Institute of Silk and Textiles, 1987). Figure 4-2 shows the traditional design approach from weave to fabric. R (weave repeat), S (step number) and other necessary parameters of the elementary weave must be confirmed firstly; elementary weave could then be devised according to the principles of the weave construction. When the design is completed, design of variation and combination weaves is conducted based on elementary weaves. In the design of complex weaves, specific simple weave must first be devised prior to the compound design, i.e., arrangement and combination of simple weaves under certain prescribed proportion. Therefore, the traditional method for structural design of woven fabric always commenced with a design mode of single weave due to the restrictions imposed by hand drawing (Watson, 1977).

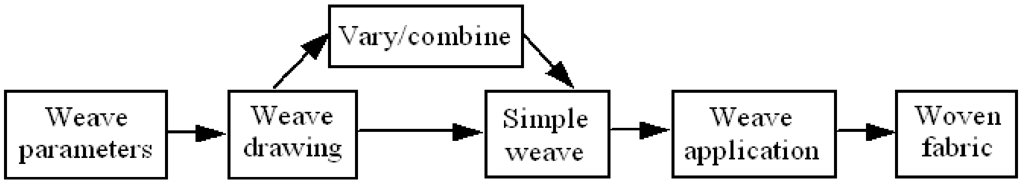


Figure 4-2. Traditional design processes from weave to woven fabric.

The digital approach to structural design of woven fabric has caused single weave design being replaced by the design of gamut weaves, i.e., a series of derivative weaves based on elementary weave featuring very similar texture characteristics. Gamut weaves are deployed to establish independent weave-databases (Figure 4-3). In this way the structural design of woven fabric has transformed the single weave design mode to an integrated digital design one.

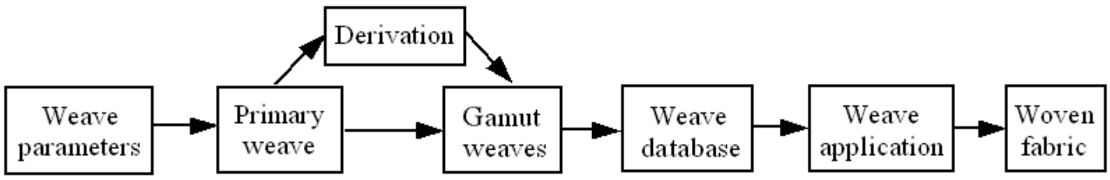


Figure 4-3. Digital design processes from weave to woven fabric.

4.2.1.1 Design principles

The application of digital technology facilitates the upgrade of traditional principle and method for the structural design of woven fabric. The design of woven fabric by hand-drawn pattern is being gradually replaced by computer-aided design. The design mode of woven fabric construction is also changing from single weave to gamut weaves with associated characteristics. To this end, based on the intrinsic features of weave structure, it is of great practical importance to research and establish a principle for the design of gamut weaves as well as for method of application.

(1) Nature of Weave and Structure Digitisation Design

The elementary weave is the foundation for structural design of woven fabric. Elementary weave is defined as follows: in each weave repeat every warp or weft has but one warp interlacing point or weft interlacing point. Notwithstanding the step number of the interlacing points, the kinds of weave that could meet the requirement for the construction of elementary weave are $2\times\left(C_{R}^{1}\times C_{R-1}^{1}\times C_{R-2}^{1}\times\cdots\times C_{1}^{1}\right)$, including both warp-face and weft-face weaves. If the step number of the interlacing points is defined as a constant in the elementary weave, three types of elementary weave can be formed: plain weave, twill weave, and satin weave. Any weave with practical value can be generated by the variations of these three types of elementary weaves. This method is also applicable to digital structural design. Based on the structural characteristics and technical requirement of woven fabric, weaves sharing common grounds and suitable for joint application could be analysed and categorized, and be further transformed into individual gamut weave-database that meets the demand for the design and production of digital woven fabrics. However, research on the principle of digital structural design must take into account the intrinsic principles of structural design and technical requirement governing the production of woven fabric.

(2) Balanced Interlacement for Woven Structure

For woven fabric under warp and weft interweaving, in addition to the principle of structural design, another key factor lies in balanced interlacement because each weave is a result of interlacement of warps and wefts, and the interlacing of straight warps and wefts, up and down, inevitably results in shrinkage of the threads. If every warp or weft features the same shrinkage after interlacement, this situation can be called balanced interlacement of warp and weft. If only the warps feature the same shrinkage after interlacement, the situation is called the balanced interlacement of warp, whereas if only every weft features the same shrinkage after interlacement, the situation is called the balanced interlacement of weft. In traditional structural design of woven fabric, the balanced interlacement of warp and weft can be regulated at any moment during drawing point paper design. However, in digital design, the hand drawing is replaced by computer-aided design. Thus, control over the balanced interlacement of warp and weft will need to be solved in a uniform way in the process of programmed structural design. Given the expectation of high efficiency of digitized production, improper control over the balanced interlacement of warp and weft during structural design may lead to failure of operation. In fact, regardless of the quality of fabric effect, it is not acceptable if the structural design fails to meet the technical requirement of balanced interlacement of warp and weft (Shen, 1991).

Study on the structure of woven fabric revealed that the balanced interlacing of warp and weft is based on certain rules in terms of construction. In Figure 4-4, in order to meet the requirement of balancing the black warps in the left section, the times of interlacing with the wefts in the structure must be the same. As the times of interlacing are independent of the length of interlacing points, every change to the properties of the interlacing points is called one time interlacing. Since continuous interlacing points share the same times of interlacing, the shrinkages are identical after interlacement, and the warps are of balanced structure. This principle also applies to weft, as shown in the right section of Figure 4-4. In practice, since the weaving has strict requirement on the take-up of warp, the mode of weaving is optional, warp-wise or weft-wise, for the weave is balanced in both warp and weft. According to design requirement, before looming and weaving, any structural design with the balanced interlacement of warp can be put into production warp-wise, whereas the weft direction must be turned into a warp one for the structural design of balanced interlacement that only satisfies the weft.

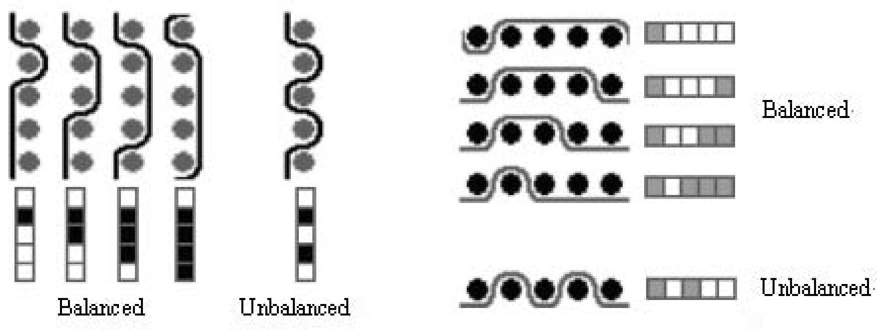


Figure 4-4. Balanced and unbalanced interlacement of warp and weft.

(3) Design Principles of Gamut Weaves and Weave-database

In terms of design principle of woven construction, any structural design is built upon the three elementary weaves, on which new weaves can be formed through derivation and combination. The gamut weaves now proposed also consist of a series of derivative weaves based on the three elementary weaves. The gamut weaves contain all the variable information that are suitable for the design of digital woven fabric, and feature the same characteristics of the weaves as well as method of application.

The three elementary weaves, the simplest of all weaves, have the basic construction characteristics of having the same warp and weft weave repeat, i.e., $R=R_j=R_w$ with only one interlacing by a warp or a weft as well as constant S for the step number of interlacing points in a weave (Adanur, 2001). Giving these characteristics, a series of derivative weaves can be devised by changing the number of interlacements, step number, and starting point of the three elementary weaves. The plain weave has but one variation parameter at the starting point of weave, whereas the twill weave has two, i.e., the number of interlacements and starting point. Its step number is fixed at 1 or R-1. Satin weave has all the three parameters. Taking a 5-thread satin shown in Figure 4-5 as an example, from top to bottom are the series of weaves generated by varying the step number of 5-thread weft sateen, a series of weaves are generated by varying the starting point and another series of weaves are generated through the increase of interlacing points. The number of weaves generated by varying step number is defined as M_s, and M_s could also be construed as the amount of step numbers that can form satin weave. In this case, two kinds of step number, namely step 2 and step 3, meet the requirement for the 5-thread satin. Taking one of the weaves as the foundation, a series of weaves can be formed through changing the starting points of weaves. If M_w represents the number of weaves and it is equal to weave repeat R, the number of weaves will be equal to 5. Taking another weave among these five weaves as the basic weave, another series of weaves can be formed through increasing the interlacing points. The number of weaves is represented by M_p, thus $M_p=R\times(R-2)+1=16$ weaves (Zhou, 2002b). When increasing the interlacing points, only two methods can be adopted under the principle of balanced interlacement of interlacing points: warp-wise or weft-wise (Zhou, 2006b). As the positions of increasing interlacing points vary, given the requirement for continuous increase and balanced increase of the interlacing points, there are $C_R^1 \times C_{R-1}^1 \times C_{R-2}^1 \times \cdots \times C_1^1$, namely $R!$ (factorial) kinds of possibilities on the variation for each direction. Thus, in total, there would be $4\times R!$ kinds of method to increase the interlacing points of every foundation weave, with the top/bottom of the warp-wise and left/right of the weft-wise inclusive. In this case, the number of approaches for increasing the interlacing points in the 5-thread satin is $4\times R! = 4\times 5! = 480$.

To conclude, theoretically, an elementary weave can entertain $4\times R!\times M_s\times M_w\times M_p$ gamut weaves and $4\times R!\times M_s\times M_w$ weave-databases, each of which has $R\times(R-2)+1$ weaves.

Therefore, the 5-thread satin is provided with 76800 gamut weaves (M_a=4×$R!$×M_s×M_w×M_p=76800) and the total number of weave-databases that could be established is 4800 (Z=4×$R!$×M_s×M_w=4800), each of which contains 16 gamut weaves [M_p=R(R-2)+1=16].

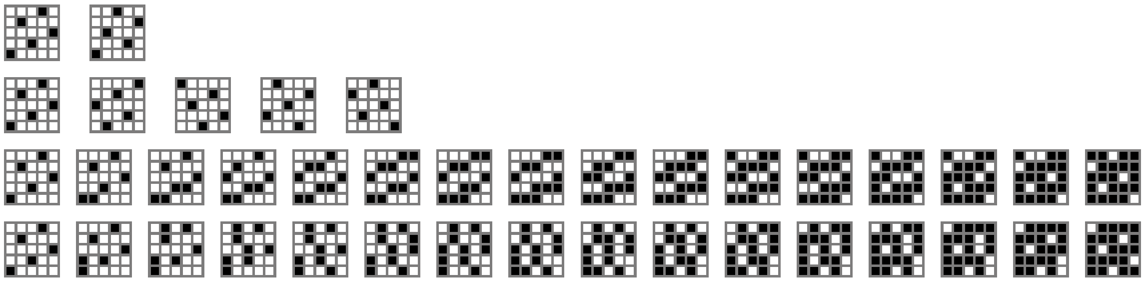


Figure 4-5. Design principles of gamut weaves on 5-thread satin.

According to the characteristics of the three elementary weaves and the principle for the design of gamut weaves, it is apparent that plain weave features only one weave-database with both odd and even starting points inclusive. Table 4-1 shows data for the gamut weaves design of the three elementary weaves where R is weave repeat; M_s is the number of elementary satins that feature identical weave repeat of different step numbers (see Table 4-2 for details), and M_w is the number of weaves at the derivation of weave starting point, i.e., M_w=R.

Table 4-1 Data for gamut weaves design of three elementary weaves.

Elementary weaves	**Number of weaves/per weave-database M_p**	**Number of weave-databases Z**	**Number of whole weaves M_a**
Plain	2	1	2
Twill	M_p=R×(R-2)+1	Z=2×4×$R!$×M_w	M_a=2×4×$R!$×M_w×M_p
Satin	M_p=R×(R-2)+1	Z=4×$R!$×M_s×M_w	M_a=4×$R!$×M_s×M_w×M_p

Table 4-2 The number of satins under different weave repeats (with different step numbers).

Weave repeat	**M_s**	**Weave repeat**	**M_s**	**Weave repeat**	**M_s**	**Weave repeat**	**M_s**	**Weave repeat**	**M_s**	**Weave repeat**	**M_s**
5	2	14	4	21	10	28	10	35	22	42	12
7	4	15	6	22	8	29	26	36	10	43	40
9	4	16	6	23	20	30	6	37	34	44	18
10	2	17	14	24	6	31	28	38	16	45	22
11	8	18	4	25	18	32	14	39	22	46	20
12	2	19	16	26	10	33	18	40	14	47	44
13	10	20	6	27	16	34	12	41	38	48	14

4.2.1.2 Design methods

The method for the structural design of digital woven fabric differs fundamentally from the single weave design mode - the principle and method for the traditional structural design. The digital structural design that targets at creating weave-databases takes all weaves in a weave-database as a joint unit of application whereby any individual weave in the weave-database can be easily replaced by any other weave in the same weave-database with no interference on the balanced interlacement of the fabric structure. According to the principle of designing gamut weaves, the key lies in the establishment and optimization of a weave-database. A weave-database could be set up in various ways. However, only one way is optimal for a specific kind of application with regard to fabric design. As shown in Figure 4-6, the design approach for 5-thread weft sateen realises a balanced interlacement for both warp and weft and is provided with five different displacements. It means that five sorts of weave-database can be established with each of them containing four weaves. Owing to the characteristics of the balanced interlacement of warp and weft, the weaves in each weave-database can be replaced by each other (Zhou, 2007g).

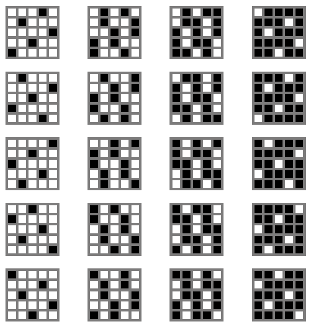


Figure 4-6. Weave-database of 5-thread satin designed under the balanced interlacement of warp and weft.

Figure 4-7 shows the design of gamut weaves for the five weave-databases of the 5-thread weft sateen. They are added based on the weaves in the weave-database as shown in Figure 4-6. The weave-databases meet the requirement of warp-wise balance of interlacing with an increase of balanced interlacing points, i.e., balanced interlacement of warp albeit unbalanced interlacement of weft. Thus, the application of this gamut weave-database for fabric design can choose any weave in the same weave-database for replacement. The completed design can be immediately put into production warp-wise. This weave-database can also be applied to the design of fabric with a compound structure arranged in proportion to the warp direction, without affecting the performance of balanced interlacement.

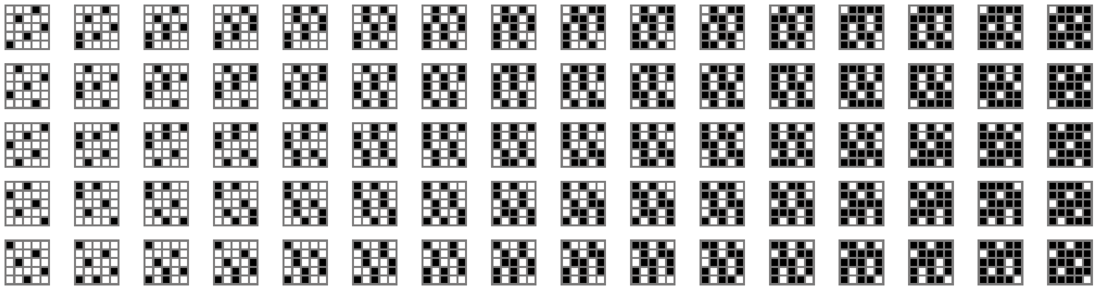


Figure 4-7. Weave-database of 5-thread satin designed under balanced interlacement of warp.

Figure 4-8 shows the structural designs of the five gamut weave-databases being produced under the method of weft-wise reinforcement of interlacing point of 5-thread weft sateen. Although the warp direction does not meet overall balanced interlacement in the weave-database, the weft direction is able to satisfy the requirement of balanced interlacement. Since the interlacing points are added under balanced increase, this weave-database is more suitable for design of weft-wise multiple combination. There are three available approaches to using weave-database directly for the design of single-layer woven fabric. First, take the weft direction of a fabric as the warp direction in looming and weaving, i.e., design the pattern laterally and weave the pattern longitudinally. Second, choose only weaves to meet the balanced interlacement of warp and weft in the weave-database for design. Third, adopt only the patterns with colours in balanced arrangement for the fabric design.

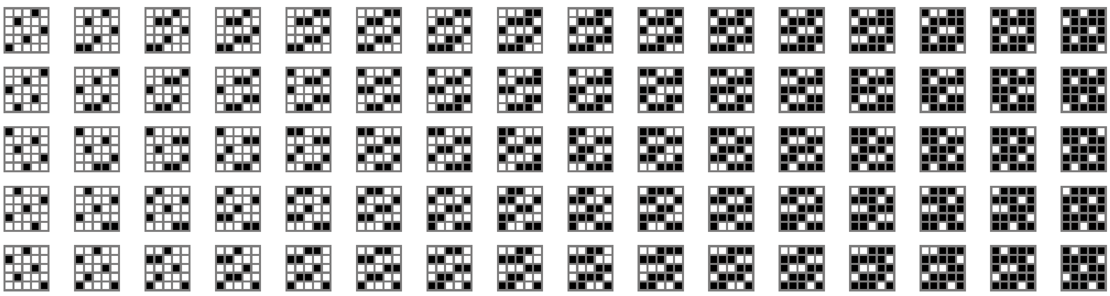


Figure 4-8. Weave-database of 5-thread satin designed under the balanced interlacement of weft.

In short, the design of gamut weaves and weave database is distinctive in innovation. Primarily, the design concept and principle have changed from the traditional single weave design to the design of gamut weaves. Besides, given the requirement for high efficiency in production, the design that adheres to balanced interlacement of warp and weft gives rise to free replacement between weaves in a weave-database already established. Finally, and more importantly, a weave-database of digital woven fabric is free from the restrictions on patterns and allows any pattern with different layout to be employed for designing woven fabric. The research on design practice of gamut weaves and weave-database based on the natures of digital woven fabric have laid the foundation for further research on digitizing fabric structure of digital jacquard fabric.

4.2.2 Compound Structure Design

The construction of woven fabric can be broadly classified into two parts: simple structure and complex structure. Complex structure is difficult to approach because of its complicated design processes and design variations. Thus, it is always designed by a combination method. With the layered combination design method proposed in this study, the structure design of woven fabric can be approached in a digital mode replacing the traditional single weave design (Zhou, 2007f). Thus, it is essential for continual research on combination methods of gamut weaves among different weave-databases.

4.2.2.1 Nature of complex weave and digitisation compound structure

Complicated structure of woven fabric is constructed with multi-series of warps/wefts and complex weaves such as weft-backed weave, warp-backed weave and double-layer weave. Traditionally, complex weave as well as complicated fabric structure were based on simple weaves. The basic design process starts with selection of an appropriate simple weave, followed by the design of compound weave at a specific inserting ratio of warp and weft threads. This design method is a kind of single weave design mode. The usage of compound weave in fabric design is the same as that of simple weave. In addition, compound weave design is an experience-based process featuring complicated woven construction. Before weaving, the woven effect cannot be predicted. Therefore, the nature of simple weaves needs to be grasped thoroughly before the design of compound weave. Although the application of CAD system has enhanced the design efficiency of complex weave, yet, the single weave design mode, i.e., designing single complex weave via the combination of selected simple weaves, remains unchanged. Computer-assisted weave design still has some restriction on the innovation of fabric structure. The traditional design processes of complex compound weave and its application are shown in Figure 4-9.

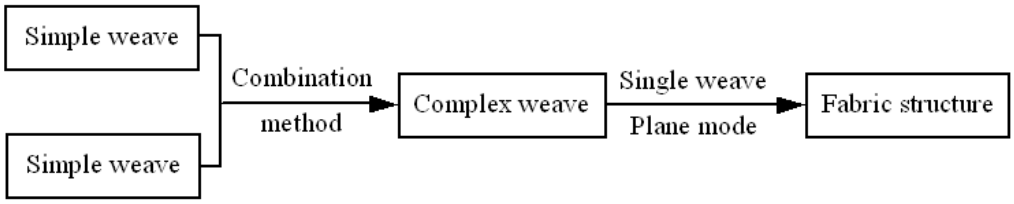


Figure 4-9. Traditional design processes of complex compound weave and application.

With the proposed layered-combination design mode for digital jacquard textile, opportunity has arisen to innovate the traditional single weave design mode. According to the design concept of digital jacquard textile, fabric structure can be produced through the combination of several single layer structures. The design of gamut weaves and weave-database has replaced the design of single simple weave. Thus, in the course of designing gamut weaves, fabric effect both of single-layer fabric structure and compound fabric structure should be taken into account. Besides, the balanced interlacement of threads in compound fabric structure needs to be considered for mass production. Based on simple weave design, the design processes of digitisation compound structure are shown in Figure 4-10. It should be noted that unlike the traditional complex compound weave design, the design of complex compound weave is removed. What is required is the design of a series of simple weaves, i.e., gamut weaves, and establishment of corresponding weave database. Therefore, when designing single-layer fabric structure, the gamut weaves serve as the smallest application unit. Since gamut weaves have the same weave repeat and closer characters of weave variant, so long as the unified starting point is being set up for gamut weaves, the single-layer structural design of digital jacquard fabric can be approached conveniently in the form of computer-programmed processing.

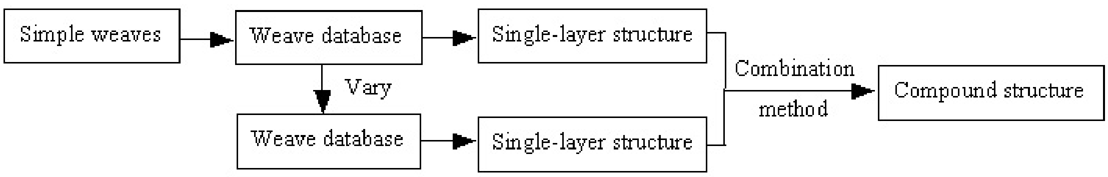


Figure 4-10. Design processes of digitisation compound structure.

4.2.2.2 Design principles of digitisation compound structure

Traditional complex weave design has been approached through the combination of simple weaves under the single weave design mode. However, in structure design of digital jacquard fabric, the design of single complex weave has been replaced by combination of single-layer structure. Thus, when designing gamut weaves, the combination effect among gamut weaves in different weave databases should be considered thoroughly. According to the combination principle of fabric structure, the neighbouring threads constructed in woven structure can produce two basic effects only, i.e., juxtaposition effect (non-backed structure effect) and mutual covering effect (backed structure effect). Therefore, the rule of non-backed and backed effect after weave combination is obviously the key technical problem in gamut weaves design and structure combination of digital jacquard textile. In addition, since gamut weaves are designed upon certain primary weaves which are a kind of simple weaves, e.g., regular satin weave, twill weave, etc., the weave characteristics of primary weave also represents that of all gamut weaves in the same weave-database. For this reason, based on the combination characteristics of primary weave, the combination characteristics of gamut weaves in different weave-databases and the combination effect of fabric structure design by the same gamut weaves could be deduced.

Figure 4-11 shows the fundamental design practice of two-layer combination of fabric structure, in which the whole of the effects are illustrated with 12-thread sateen as primary weave of each weave-database. Effect drawings for the derivative weaves of the primary weaves, primary weaves, and compound weaves are listed from top to bottom respectively. The primary weave is 12/5 weft-face sateen, which provides 11 variations of weave through displacing the starting point of the primary weave. It means that a total of 12 digital weave-databases are applicable to be set up (including weave-database of primary weave) as *R* kinds where *R* refers to the number of weave repeat. In this way the 12 derivative weaves of Figure 4-11 can generate 12 effect drawings of compound weaves upon combination with the primary weave in accordance with the combination method of 1-and-1 across weft. Two of them have full backed effect, featuring superimposition of interlacing points and ten produce non-backed effect (*R-2* kinds). According to the result of the combined application with primary weave, it could be inferred that the same result can also be achieved with the combination of whole gamut weaves in the same weave-database. Therefore, during the actual design process, the combination effect of primary weave may provide available reference for designing gamut weaves and combination of fabric structure.

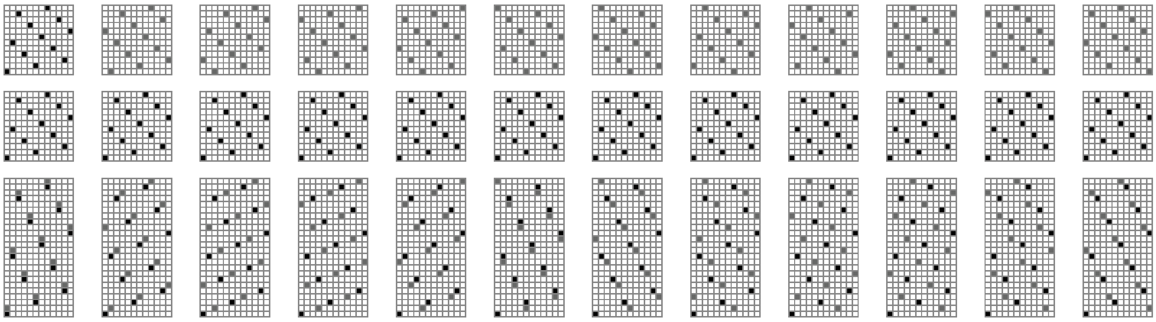


Figure 4-11. Combination effects of 12-thread satin in 1:1 order weft-wise.

When combining fabric structures in 1:1:1 order across three wefts, there will be three types of compounded effects of three wefts: backed effect, backed effect of any two wefts and non-backed effect. Among them, backed effect of three wefts is produced on the basis of backed effect of two wefts, and backed effect of any two wefts has the same combination principle as that of juxtaposed two wefts. Taking 12-threads sateen as an example, when adding one weft to a combination structure of two wefts, a total of 144 kinds of compound effects can be produced, i.e., $R\times R$=12×12=144, of which there are 33 kinds of backed effect, i.e., 2(R-2)+R+1=33. They include 2(R-2) kinds of backed effects being produced on the basis of previous non-backed effect of two wefts, R-2 kinds of backed effects being produced on the basis of previous backed effect of two wefts, and 3 kinds of backed effect of three wefts. In short, there are 30 kinds of backed effect of any combined two wefts, i.e., 2(R-2)+R-2=20+12-2=30. As for non-backed effect (juxtaposition), there are 111 kinds, i.e., (R-2)(R-2)+(R-1)=111. These include (R-2)(R-2) kinds of non-backed effect being produced on the basis of previous non-backed effect of two wefts and R-1 kinds of non-backed effect being produced on the basis of previous backed effect of two wefts. The principle of backed effect produced in three wefts combination is that the added weft has the same interlacing points as either upper weft or lower weft. Figure 4-12 shows the design practice and effects. In addition, an extra compound effect featuring the same compound interlacing points combined with both upper weft and lower weft with flamed weave effect will be produced when combining three wefts. (see Figure 4-12).

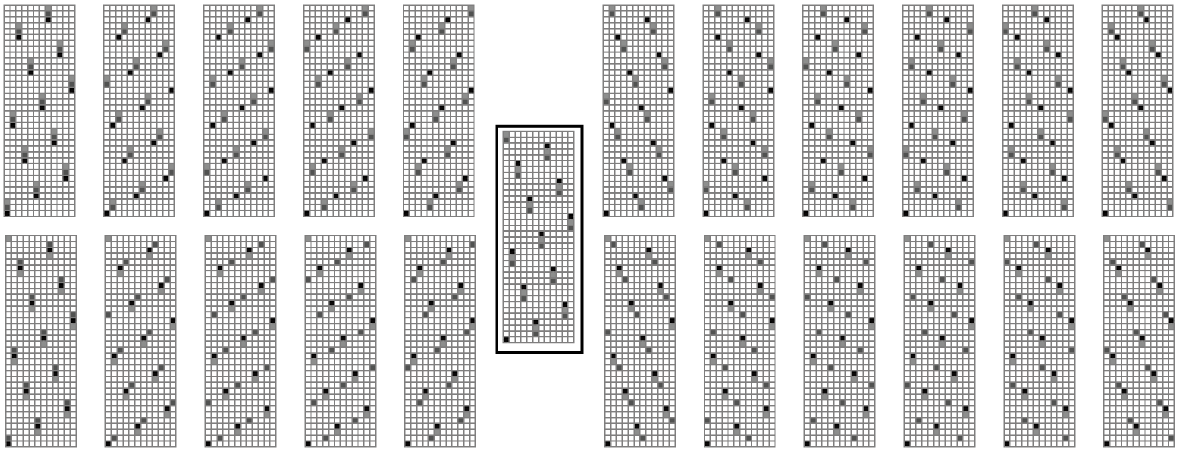


Figure 4-12. Backed effect of 12-thread satin combined in 1:1:1 order weft-wise (extra weave is framed).

Following the same method aforementioned, when combining fabric structures in 1:1:1:1 order across four wefts, there will be a total of 1728 kinds compound effects, i.e., $R \times R \times R$=1728. On the basis of the compound effects of three wefts, there will be (R-2)×1110 kinds non-backed effects produced based on previous non-backed effect of three wefts, i.e., (R-2)×[(R-2)×(R-2)+(R-1)]=1110, while 618 kinds of compound effects of four wefts will be produced, i.e., R^3-(R-2)×[(R-2)×(R-2)+(R-1)]=618. These will include backed effects of any two wefts, backed effects of any three wefts and backed effects of four wefts. Among the compound backed effects, only 4 kinds of backed effects of four wefts features the same interlacing points, and up to R kinds of extra weaves that have the same compound interlacing points combined with both upper weft and lower weft. It should be mentioned that due to the existence of extra weaves in weave combination, the number of compound effects of two wefts or three wefts in a four wefts combination is difficult to ascertain.

Based on the design experiment in weave combination, it was found that with the increase of wefts for weave combination of more than four wefts, it is difficult to anticipate the kind of compound effects that will be produced among partial backed compound effects due to the random effects generated. Therefore, in the course of digital jacquard textile design, the specified effects of partial backed compound effects should be ignored when compounding wefts for more than four groups. The data for 2-4 layers combination by different weave-databases are listed in Table 4-3. With the proper combination method, the data can be applied to the design of digital jacquard textile with any grouping of wefts. In addition, in order to control the floating length of warp threads, the separation-combination method of weave-database is also available for designing compound structure of digital jacquard textile, i.e., gamut weaves separated with the appropriate ratio to form several sub-weave-databases. It can be applied to designing single-layer fabric structures respectively; and then single-layer fabric structures are recombined with the same ratio of separation to form compound structure. By this method, for example, former 1:1 combination design of two wefts would be transferred to 1:1:1:1 combination design of four wefts, but the maximum float length of warps in the two design cases are the same.

Table 4-3 Data of layered combination with different weave-databases.

Layers	**Combination Methods**	**Non-backed Combination**	**Partial-backed Combination**	**Backed Combination**
2	R	R-2	0	2
3	R^2	(R-2)×(R-2)+(R-1)	R^2-[(R-2)×(R-2)+(R-1)]	3
4	R^3	(R-2)×[(R-2)×(R-2)+(R-1)]	R^3-(R-2)×[(R-2)×(R-2)+(R-1)]	4

* R represents weave repeat

4.2.2.3 Combination methods of digitisation compound structure

Two design methods can be deployed to design digital gamut weaves, i.e., regular weave design method and irregular weave design method. However, only the regular weave design method can be processed with CAD system. In the course of regular weave design for gamut weaves, there are three methods available for adding/reducing weaving points, i.e., horizontal transition, vertical transition and diagonal transition, and only horizontal transition and vertical transition can be used for designing compound structure of digital jacquard textile with the result of balanced interlacement. Taking 8-threads weft-faced sateen as an example, Figure 4-13 shows gamut weaves that are constructed by horizontal transition and vertical transition respectively. The result shows that only the upper series of gamut weaves in Figure 4-13 meet the requirement of balanced interlacement weft-wise while the lower series of gamut weaves meet the requirement of balanced interlacement weft-wise. Further employment of the two series of gamut weaves to design compound structure of fabric produced compound structure of different results.

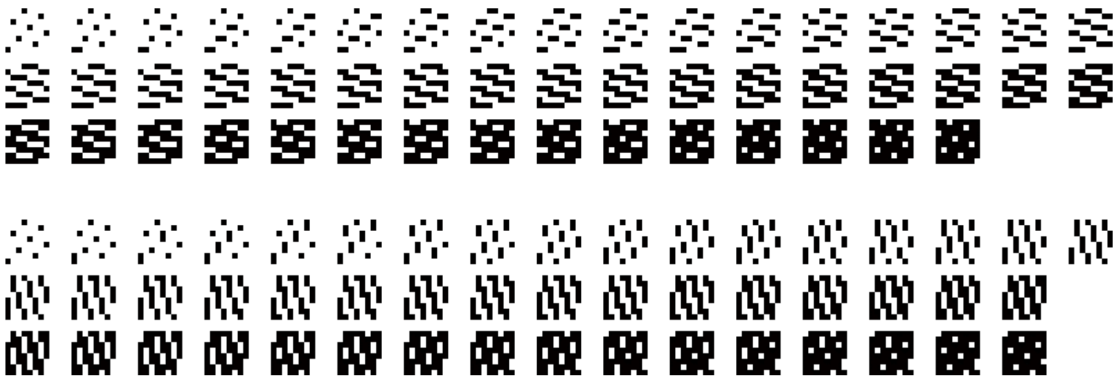


Figure 4-13. Gamut weaves design of 8-thread satin.

Figure 4-14 illustrates two compound structure effects combined with the gamut weaves of Figure 4-13 and a primary weave of another weave database respectively in the ratio of 1-and-1 across weft. The fixed primary weave employed for the compound structure is designed by changing the starting point of the primary weave of gamut weaves of Figure 4-13. Conclusion can be drawn that in Figure 4-14, the upper series of compound weaves exhibited better balance of interlacement than that of the lower series of which fabric structure featured balanced interlacement of both warp and weft. Yet, the upper series of compound weaves failed to maintain the balance of interlacement warp-wise and weft-wise. Therefore, it cannot meet the technical requirement for mass production. In other words, the lower series of gamut weaves in Figure 4-14 cannot be used to design digital jacquard fabric since the weaving loom cannot run smoothly in mass production. Having said that, the gamut weaves of weave database designed through vertical transition could only be applied to structure combination warp-wise for digital jacquard fabric while the gamut weaves of weave database designed through horizontal transition could be applied to structure combination both warp-wise and weft-wise due to better balance of structure interlacement.

The results of research indicated that with the appropriate combination method, the compound structure is capable of expressing various woven effects on the face of fabric. It benefits well the design creation of digital jacquard textile. In addition, since the structure design of digital jacquard textile is determined by gamut weaves design and combination method, any digital image can be used to design digital jacquard fabric.

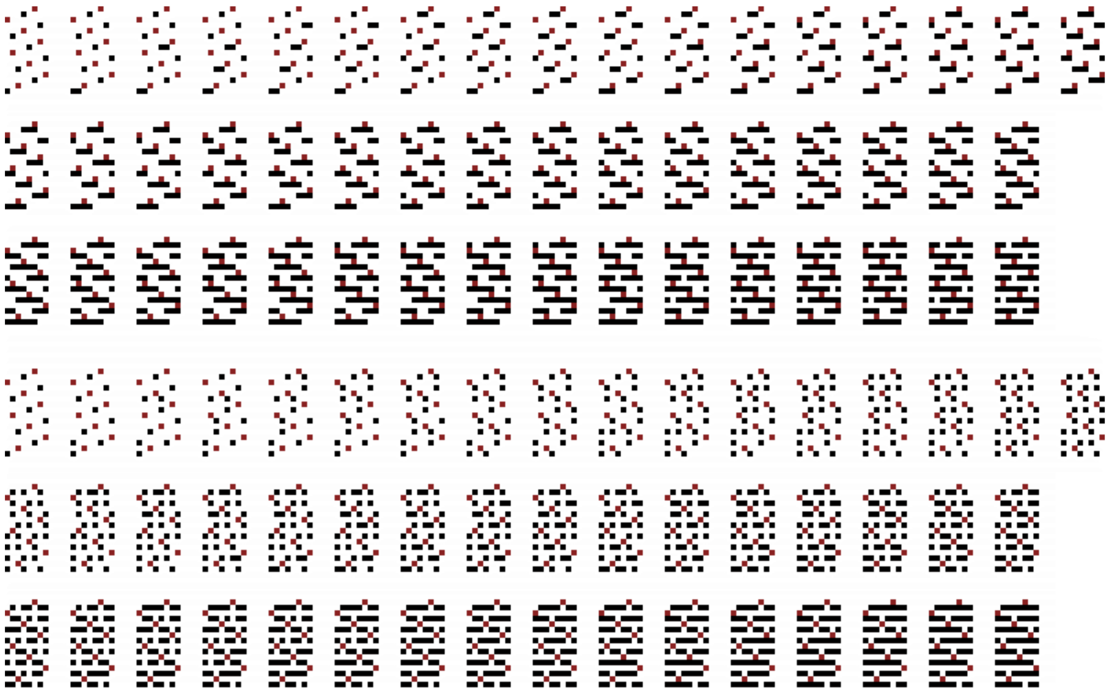


Figure 4-14. Combined effects of gamut weaves of 8-thread satin and primary weave.

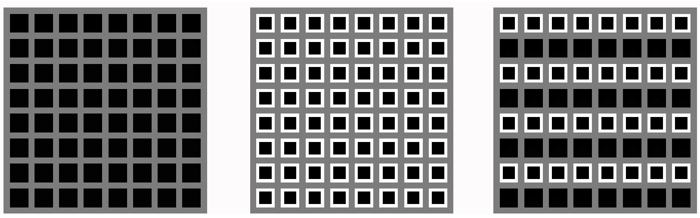
4.2.3 Full-colour Compound Structure Design

In terms of design principle and method of gamut weaves and compound fabric structure, it is necessary to investigate further the relationship between design method of gamut weaves and combination method of compound fabric structure so as to establish the optimal structural design method under layered design mode for design and creation of digital jacquard fabric.

4.2.3.1 Nature of full-colour compound structure

Jacquard fabric belongs to woven fabrics. The colour principle of woven fabric is a kind of colour-mixing of non-transparent colours (Wilson, 2001). This principle is in nature different from that of printing colour and computer colour. However, they also have some points in common. They all use limited primary colours or basic colours and realise rich colour expression by way of mixing colours. The warp and weft of woven fabric reflect the mixed colours by changing their structure and arrangement. When the inter-covering effect produced between warp and weft cannot be controlled, mixed colours of them cannot be predetermined because of resulting erratic colour deviation. In imitation design, colour deviation is more obvious between the final fabric and original artwork. According to the colour-mixing principles of non-transparent yarns, when paired colour threads are viewed at a distance, only the mixed colours that vary with the floats of colour threads can be seen. Thus, the jacquard fabric will exhibit a rich mixed colour effect. By such principle, full-colour structure necessitates involvement of all the threads used for colour mixing in the colouring. The merit of this kind of structure is that the changes of the colour ratio of each yarn produced no inter-covering among juxtaposed colour threads in the construction.

Figure 4-15 shows the colour effect of two wefts ranged in juxtaposition. (a) and (b) are lined in 1-and-1 that formed (c), showing a kind of mixed colour effect. At a distance, only the mixed colour effect can be seen instead of the original individual colours of (a) and (b). It is apparent that the mixed colour effect of (c) will vary along with the changing of colour ratio of (a) and (b). According to this method, manipulating the colour change of (a) and (b) can realise a range of colour (c). The full colour effect of such colour-mixing relates to compound “full-colour” structure. It should be noted that before defining the design effect of fabric, any colour can be selected for (a) and (b). The maximum number of mixed colours of (c) remains constant, irrespective of the colour change of (a) and (b). This result laid the foundation for structural innovation of digital jacquard fabric.



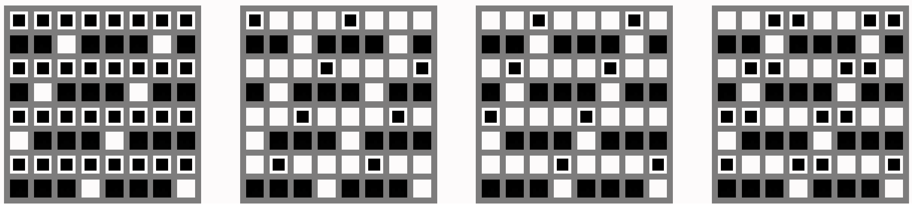
(a) (b) (c)

Figure 4-15. Colour expressions of two juxtaposed wefts.

When the juxtaposed threads are combined with no-covering effect in the woven structure, such colour-mixing can be considered as a kind of combined threads with full colour effect. By changing the colouring ratio between the two threads, various colour effects can be obtained. This fabric construction is being named “full-colour structure”. By this structure, digital jacquard fabric of print-like colour shading effect can be realised with limited colour threads. Various innovative designs can also be produced. This innovative structural design method is thus suitable for both colour simulative design and colour innovative design of digital jacquard fabric that enables woven fabric to be designed and produced as conveniently as printing.

4.2.3.2 Design principles of full-colour compound structure

The next step is to determine which kind of fabric structure can satisfy the full colour effect of threads. The analysis conducted suggested fabric construction with non-backed effect and gamut shaded effect. In principle, such effects can only be found in fabrics that are processed by the layered-combination design mode. In compound fabric construction, there is at least one interlacing point in opposite configuration on both sides of a line ranged in an alternate order, e.g., one warp interlacing point in horizontal line is correspondent to the lines above and below with at least one weft interlacing point respectively, and vice versa. In Figure 4-16, the structure of odd numbered horizontal lines is fixed. (a) is in the state prior to the design; (b) is designed for the all-backed structure effect; (c) is for partial-backed effect in which only the interlacing points on one side is in opposite configuration; and (d) is for non-backed effect that, to odd number structural lines, the interlacing points above and under are both in opposite configuration status. Thus, only (d) that represents no-covering structure of paired parallel wefts that can satisfy the requirement of full colour effect.



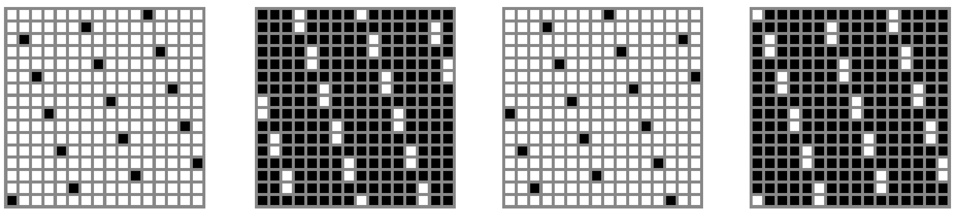
(a) (b) (c) (d)

(a) Original weave effect; (b) Backed effect; (c) Partial backed effect; (d) Non-backed effect.

Figure 4-16. Structure design for fabric with two colour wefts.

Given the aforementioned principle and the interlacing points between the two lines being alternately arranged, the weaves which are to be used for combination can be designed respectively. These are named "primary weaves". In the design process, it is necessary to set up a kind of technical full-colour points for primary weave in the course of designing gamut weaves in line with the requirement of having at least one interlacing point in contrasting configuration after combination. If no full-colour points are to be destroyed, any compound weave designed from primary weaves will exhibit the non-backed structure and full-colour effect. Similarly, shaded gamut weaves devised from primary weave and its weave-database can be built so long as the full-colour points exist by the same combination method as that of the compound single weave. The weaves in different weave-databases can be combined freely and compound weaves can all exhibit the non-backed effect. By further fixing starting points, the gamut weaves in different weave databases can be deployed directly to design single-layer fabric structure. After combination of single-layer fabric structures in the same way as that of compound weave, the compound structure of digital jacquard fabric is capable of exhibiting non-backed and full-colour effect.

Sixteen-thread satin is taken as an example to further explain the design method for full-colour points setting (Zhou, 2005). As shown in Figure 4-17, there are two primary weaves with their full-colour points set respectively. First of all, select two primary weaves having the same weave but with different starting points as I and II. Primary weave can be selected from twill or satin, which belong to the three elementary weaves with the same weave repeat of warp and weft. In order to control the length of floats on fabric surface, the best repeat range of primary weave should be between 5×5 to 48×48. For weave repeat that is over 48×48, the floats will be too long to construct the structure of fabric and are of little application value. Next, set the full-colour points (similar to a kind of weave) for primary weave I in line with the feature of primary weave II. This method is to reverse the interlacing points in primary weave II and to enhance it upward along warp direction [see (b) in Figure 4-17]. Similarly, set the full-colour point for primary weave II in line with the feature of primary weave I. This method is to reverse the interlacing points in I and to enhance it downward along warp direction [see (d) in Figure 4-17].



(a) (b) (c) (c)

(a) Primary weave I; (b) Full-colour points of primary weave I; (c) Primary weave II; (d) Full-colour points of primary weave II.

Figure 4-17. Primary weaves and their full-colour points.

The design of compound full-colour structure is inspired by the no-covering structure of woven fabric. After setting the technical full-colour points, the respective gamut weaves and its weave-databases can be designed on the basis of the two primary weaves; and the weaves in different weave-databases can be combined freely to create non-backed and full-colour structure that satisfy the full colour effect of digital jacquard fabric. Besides, full-colour structure remains albeit the images have been changed. In other words, full-colour structure design is determined by weave design and combination rather than the motif.

4.2.3.3 Design methods of full-colour compound structure

After confirming two primary weaves and their respective full-colour points, the gamut weaves for structure design can be carried out. In this study, the gamut weaves in the two weave databases are named basic weaves and joint weaves respectively.

(1) Design approach for basic and joint weaves

Based on primary weave I shown in Figure 4-17, a series of shaded weaves are designed without destroying the full-colour points. Such weaves are named "basic weaves" (see Figure 4-18). The enhancement direction originated from the right to the left in order to make the interlacing points continuous for the best interlaced balance. Where M=R, the number of basic weaves is the minimum R-2, whereas where M=1, the number of basic weaves is the maximum (R-2)+(R-3)(R-1). Here R and M represent weave repeat and the enhancement number of shaded interlacing points respectively.

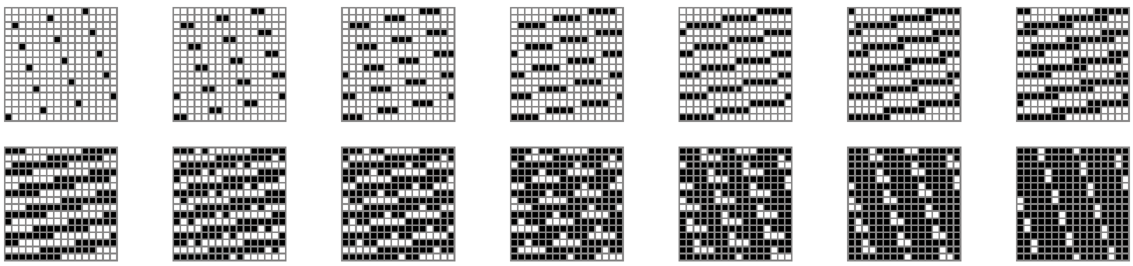


Figure 4-18. Design of basic weaves based on primary weave I.

Based on the basic weave II in Figure 4-17, a group of shaded weaves originating from the left to the right is designed without destroying the full-colour points. Such weaves are called "joint weaves" (see Figure 4-19). The enhancement direction is opposite to the basic weaves to optimize the colour effect of fabric after combination. Where M=R, the number of joint weaves is the minimum R-2, whereas where M=1, the number of joint weaves is the maximum (R-2)+(R-3)×(R-1).

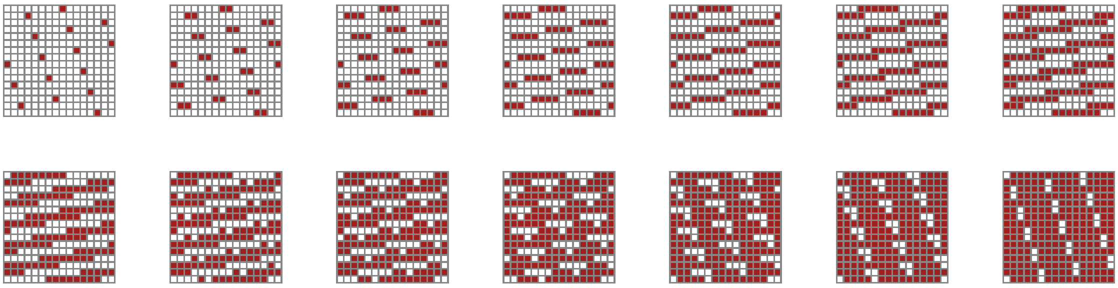
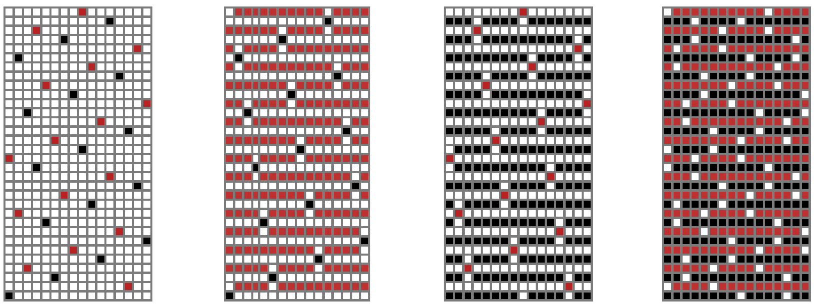


Figure 4-19. Design of joint weaves based on primary weave II.

(2) Application of basic and joint weaves

After having designed the basic weaves and joint weaves and before the application, a simple verification of the compound full-colour structure can be made. Since both basic weaves and joint weaves have their own specific full-colour points, so long as the starting point is the same during the combination, the validity of the full-colour points in designing fabric structure can be verified by the combination of single weaves. The verification methods are to use the first and last weave of the basic weaves to combine with the first and last weave of joint weaves respectively. Figure 4-10 shows the four kinds of effect created. When the requirement of non-backed effect for interlacing points in compound weave is met, all the basic weaves and joint weaves are in line with the methods aforementioned and that they can fully satisfy the full-colour effect with unrestricted combination.



(a) (b) (c) (d)

(a) Effect of combination of first basic weave and first joint weave; (b) Effect of combination of first basic weave and last joint weave; (c) Effect of combination of last basic weave and first joint weave; (d) Effect of combination of last basic weave and first joint weave

Figure 4-20. Non-backed effects of combination of basic and joint weaves.

Two points can be concluded for full-colour compound structure. First, where the verified 1:1 combination of basic weaves and joint weaves is valid, the alternately ranged basic weaves and joint weaves in 1:1 pairing order like 1:1:1:1 and 1:1:1:1:1:1 are also valid. Second, with the same full-colour points, so long as the combination effect of basic weaves and joint weaves in minimum number are valid, the combination effect of basic weaves and joint weaves in maximum number is also valid. Following these considerations, several experiments of weave combination were conducted to validate the result inferred in theory. The combination effects are shown from Figure 4-21 to Figure 4-24.

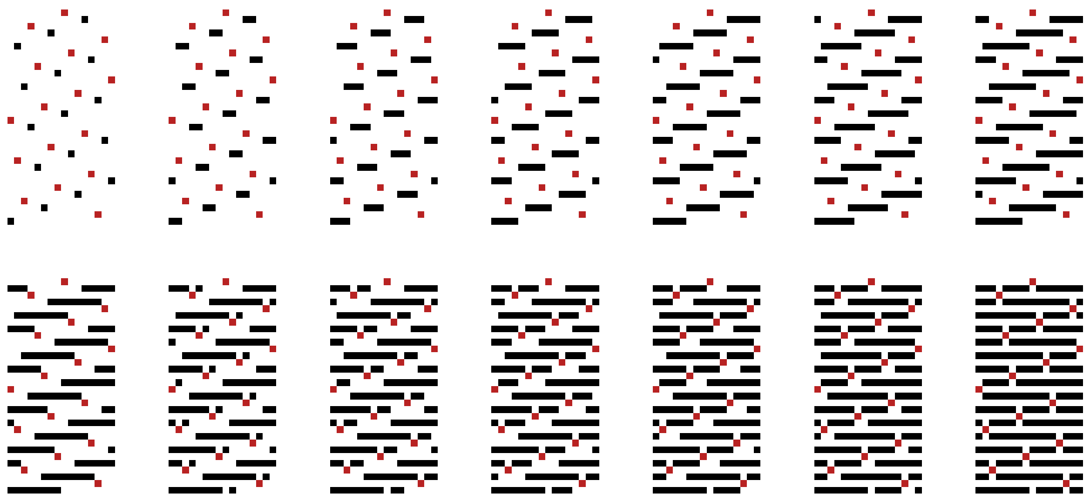


Figure 4-21. Non-backed effects of combination of basic weaves and first joint weave.

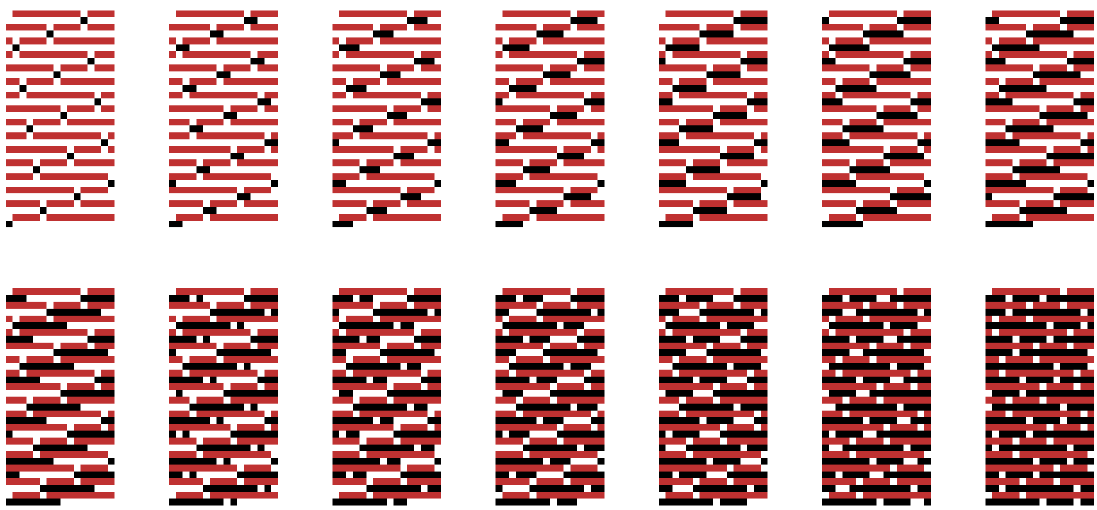


Figure 4-22. Non-backed effects of combination of basic weaves and last joint weave.

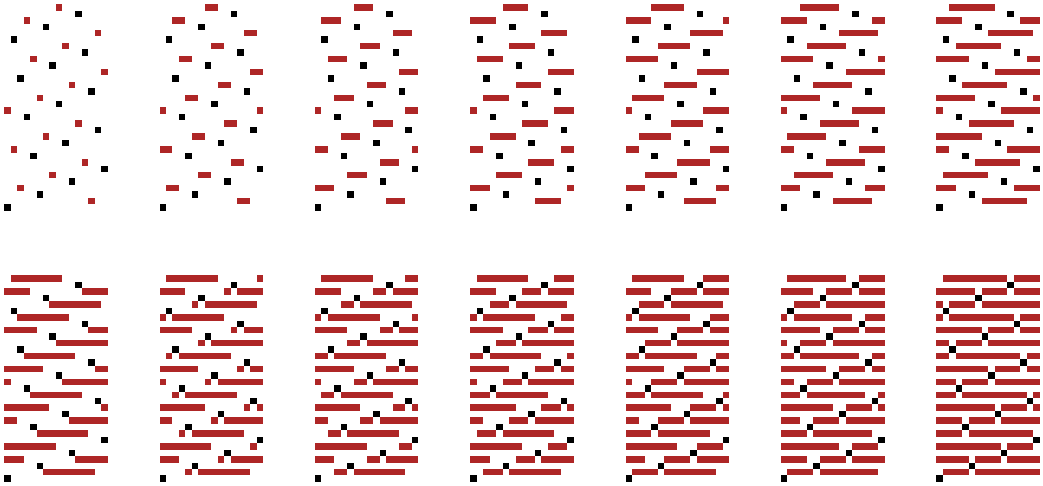


Figure 4-23. Non-backed effects of combination of first basic weave and joint weaves.

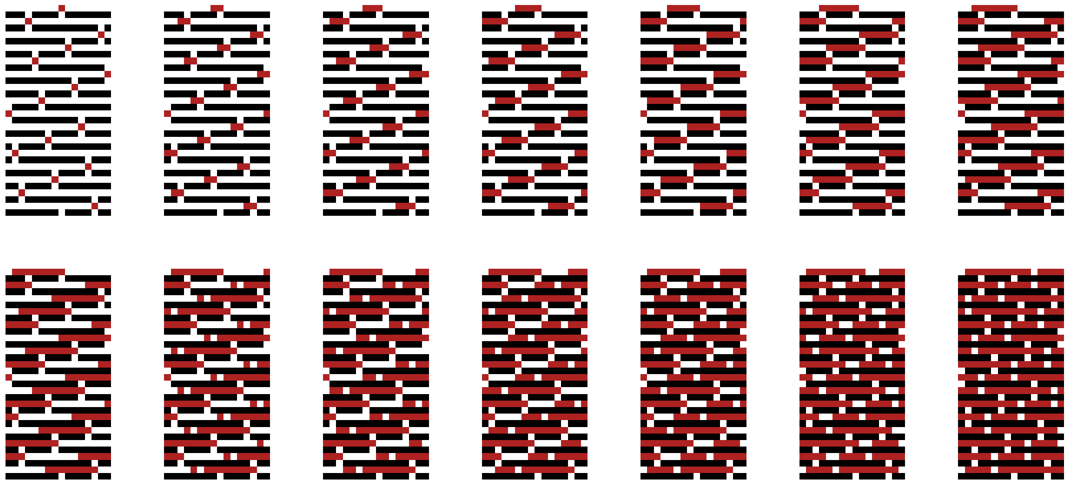


Figure 4-24. Non-backed effects of combination of last basic weave and joint weaves.

The verification shows that since full-colour points exist in basic weaves and joint weaves, non-backed effect can be satisfied after combination, and such a feature can be applied in fabric structure design. So long as the same starting points of the weaves are confirmed, the basic weaves and joint weaves can be used for designing single-layer structures of fabric. To further combine the designed single-layer fabric structures in specific arrangement, i.e., the combination ratio in weft direction as 1:1 or 1:1 pairing (1:1:1:1 or 1:1:1:1:1:1) while the designed fabric structure of basic weaves and joint weaves are alternately arranged, non-backed effect of interlacing points will be produced in the fabric construction after combination of single-layer structures. Such effect is not dependent on motifs of pattern. Moreover, in accordance with the feature of full-colour structure, the maximum number of mixed colour on the face of digital jacquard fabric with different repeat weaves can be accurately calculated by the formula $[(R-2)+(R-3)(R-1)]^L$, where L stands for the number of fabric structures used for combination. It is preferred as even numbers like 2, 4, 6, 8 and so on. With regard to design application, the full-colour compound structure together with the information of weft selection can be directly applied to producing multi-weft jacquard fabrics with full colour effect. When the full-colour compound structure is rotated by 90 degrees, together with information of weft selection, the multi-warp jacquard fabrics with full colour effect are produced.

The success of full-colour compound structure can be regarded as a major breakthrough in the field of innovative design research of digital jacquard fabrics. When designed in a layered combination design method and with full-colour compound structure, digital jacquard fabrics are capable of producing millions of mixed colours on the surface of a jacquard fabric for various pattern motifs. Thus, digital jacquard fabric can now be designed and created as conveniently as that of digital printing.

4.3. Research on Colour Mixture Theory of Digital Jacquard Textile

In the design of digital jacquard textile, the nature and principle of colour mixture appropriate for digital jacquard textile cannot be neglected. Not only do these principles govern the colour expression on the face of fabric, they also advance the innovation of structural design method for jacquard fabric. The expression of woven pattern and colour of jacquard fabric interlacing through warp and weft threads must be realised based on the woven construction and the deployment of colour threads both warp-wise and weft-wise. Generally, in traditional plane design mode, the number of mixed colours on the face of jacquard fabric is less than 100 due to mutual covering effect caused in fabric construction. Thus, the colour design of jacquard fabric was an experience-based work and the research of colour mixture theory is irrelevant for jacquard fabric design. However, with the proposed layered-combination design mode, especially with design method of full-colour compound structure, digital jacquard created is able to express true-colour effect with millions of mixed colours. The colour performance of digital jacquard textile has exceeded the scope that the eye can distinguish, and surpassed the design competence of manual skill. Mastering the nature of colour mixing has become one of most important factors for the design creation of digital jacquard textile.

4.3.1 Background

Research on colour mixture of jacquard fabric has two major directions: The first is colour simulation through the computer system based on fixed fabric structure, whereas the other is simulation design of jacquard fabric based on limited primary colour threads. These two research directions aim at increasing the design efficiency of jacquard fabric, yet very much based on the traditional plane design mode of jacquard fabric. The former direction addressed the design problem of colour matching of jacquard fabric - based on a fixed fabric structure, a computer system can be used to simulate changing colour effect through the variation of warp and weft threads, which replaced that of actual production. Although the design efficiency of colour simulation of jacquard fabric increased, yet, due to the lack of innovation of fabric structure, the colour mixture theory is the same as that of traditional design method of jacquard fabric. The latter research direction focuses on the establishment of an ideal colour model with limited primary colours that targets the design of jacquard fabric to imitate given images via the disposition of limited primary threads. At present, the proposed colour model has two types, i.e., primary colour model and designated colour model. The primary colour model involves part or all fixed primary colours of red, magenta, yellow, cyan, blue and green with the support of black and white. On the other hand, the designated colour model consists of changeable colours being selected on the basis of the colour effect of an objective image with normally 4-8 designated colours in a colour model. Due to the lack of design innovation for fabric structure, even when the colour model is optimal in theory, the available structure design method fails to address such idealization colour model. In order to avoid the insufficiency in design application, the use of colour table/chart way for jacquard fabric design was proposed, i.e., designing and weaving fabric colour samples to form a fixed colour table/chart prior to the design of fabric. However, such a method was only useful for designing jacquard fabric with the same fabric technical specification only.

In terms of colour design theory, the simulative effect of jacquard fabric can be better realised with the use of more threads of primary colours. However, when more colours are used as warp and weft threads, the compound fabric structure will be so complex that it will be difficult to approach. Therefore, the balance point between the number of primary colours and the design of the fabric structure should be considered for colour mixing on jacquard fabric. Such a balance point can only be realised through the innovative design of fabric structure. Thanks to the proposed layered-combination design mode, the restriction in structural design of jacquard fabric has been freed. Now, jacquard fabric is able to express millions of mixed colour effect accurately. Based on such an innovative structure design method, the research of colour mixture theory of jacquard fabric has good application value and design compatibility.

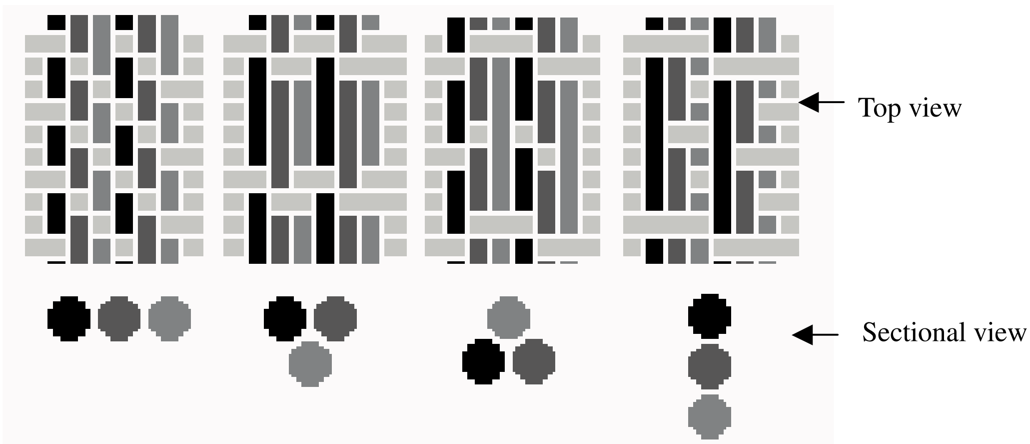
4.3.2 Colour Mixture Theory of Digital Jacquard Textile

4.3.2.1 Colour mixture theory of jacquard fabric

The colour mixing of jacquard fabric is different from that of artworks of other colouring means such as painting, printing, and screen display on a computer. In terms of colour science, there are three typical colour mixture theories: The additive colour mixture of light - the corresponding computer colour mode is RGB digital colour mode; the subtractive colour mixture of pigment - the corresponding computer colour mode is CMYK digital colour mode; and optical (medial) colour mixture - no corresponding digital colour modes (Zelanski, 1999; Green, 1999). Essentially, additive and subtractive colour mixtures are physical phenomena. However, optical colour mixture is a kind of the physiological phenomenon, i.e., colour illusion caused by the visual deficiency of the human eye. In terms of colour characteristics of jacquard fabric, the colour mixture is optical colour mixture. Optical colour mixture can be divided into two types in terms of application: juxtaposition mixture and rotatory mixture. The former is a kind of static spatial colour mixture while the latter is dynamic. Since the colour mixture of jacquard fabric is a phenomenon of static mode, it has to do with the theory of static colour mixture. Therefore, the colour mixing of jacquard fabric can be seen as a kind of juxtaposition mixture of optical colour mixture. The physical colour mixing principle is inadequate for explaining the changes of colour on jacquard fabric. In order to investigate the changing rule of mixed colour and colour mode during the design process of jacquard fabric, the influences pertinent to the colouring effect of jacquard fabric such as the design of the fabric structure, the disposition of the colour threads, and even the fabric technical specification should be taken into account.

4.3.2.2 Structural nature of digital jacquard fabric

Naturally, the woven structure of jacquard fabric is the foundation for colour mixture theory since the colour mixing of jacquard fabric is based on woven structure interlaced with warp and weft threads. For jacquard fabric, there are three types of compound structures: the juxtaposition and non-backed effect [Figure 4-25 (a)], juxtaposition and partial backed effect [Figure 4-25 (b) and (c)], and juxtaposition and backed effect [Figure 4-25 (d)]. In general, the fabric structure of jacquard fabric designed by traditional plane design mode is of either backed or partial backed effect. The entire compound structure such as weft-backed, warp-backed and double-layer structure should be produced on the basis of backed or partial backed structure. When designing fabric structure with non-backed effect under traditional plane design mode, the change rule of woven threads in compound structure will be beyond control. Such compound fabric structure cannot be drawn on point paper by manual means. However, when designing fabric structure under digital layered-combination design mode, with the application of full-colour compound structure, the resulting compound fabric structure shows non-backed effect, enabling jacquard fabric to express full-colour effect with the change of floating length of juxtaposed threads.



(a) (b) (c) (d)

(a) Non-backed; (b) Partial-backed; (c) Partial-backed; (d) Backed.

Figure 4-25. Colour effects of compound structures of jacquard fabric.

By nature, the design concept of layered-combination design mode for digital jacquard fabric is devised from juxtaposition of coloured threads. The colour mixing of digital jacquard fabric is based on full-colour compound structure in which the floats of colour threads arranged in juxtaposition can vary freely with the non-backed structure effect remaining unchanged. Figure 4-26 shows the basic principle of colour mixing and colour changing in full-colour compound structure. The colouring model consists of four wefts and one warp that meet the technical requirement of structure digitisation for jacquard fabric design. The gamut weaves used for each thread in the compound structure can be established conveniently. Taking the brightness of digital grey image as the standard, the replacement between the greyscales of the digital image and gamut weaves can be processed efficiently. Combining several monochromatic single-layer structures can produce a colourful fabric with a compound structure. Since the colour mixing of digital jacquard fabric features full-colour effect regularly, it can be interpreted as an artwork of which the artifact is made through the digitisation woven structure. The mixed colour effect of digital jacquard fabric interlacing with warp and weft threads cannot be substituted by other means of art making.

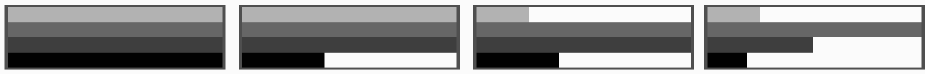


Figure 4-26. Colour mixture principles of full-colour compound structure.

4.3.2.3 Colour mode changes in design processes

In addition to colour mixture, the colour mode change in the design process of layered-combination design mode of digital jacquard is of considerable interest. Figure 4-27 shows that the colour mode change can be identified as first, any true-colour digital image can either be separated into several achromatic paths to form colourless grey mode digital images or be decolourised directly to produce a grey digital image without colour separation. Second, based on the brightness of grey scales, a colourless grey image can be designed into single-layer fabric structure via structure digitizing. Third, combining several single-layer fabric structures to create a compound structure in an appropriate proportion. Finally, colourful digital jacquard fabric can be produced by the deployment of coloured warp and weft threads. The structure is capable of showing rich mixed colours with its colour number reaching mega level. In the whole design process of layered-combination design mode, the colour mode change starts from true-colour effect digital image, to grey effect digital image, and finally to black and white (in both single-layer and compound structure) reflecting a state of *"no colour in the eyes, but in the depth of the heart"*. By then, the compound structure is able to express millions of mixed colours similar to the "true colour" effect of the digital image.

Moreover, it should be noted that in the course of layered-combination design mode, the shape and colour of the digital image are separated; the key being the digitized structure. When processing the structure design, only the shape of the digital image is used. The colour effect of the digital image and the final colour effect of the digital jacquard fabric may either be the same or different, depending solely on the purpose of the design. Both colour simulative design and colour innovative design of digital jacquard fabric share the same colour mixture theory and colour mode changing performance.

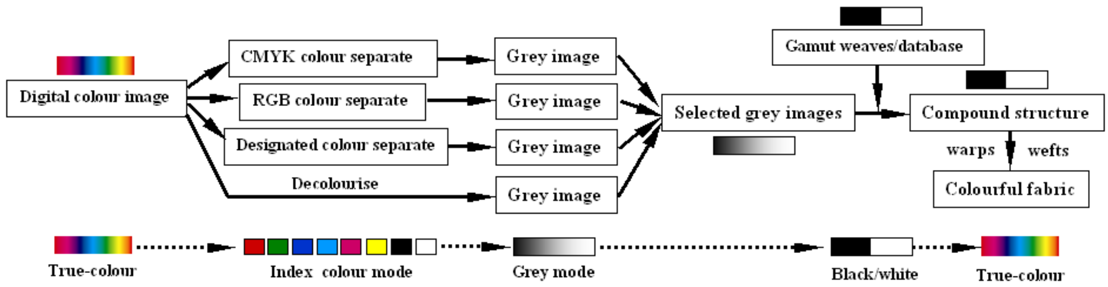
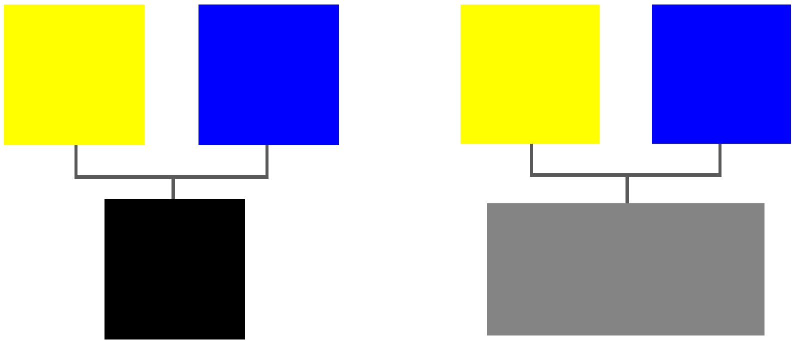


Figure 4-27. Colour mode change in the course of digital jacquard fabric design.

4.3.2.4 Colour mixing of digital jacquard fabric

Colour mixture theory of woven fabric has to be established based on the employment of limited colours of warp and weft threads. Among the primary colour theories, the digital primary colour modes, both RGB and CMYK, can provide available references to the colour design for digital Jacquard fabric because there is no existing colour mixture theory available for designing digital jacquard fabric under layer-combination design mode. When designing simulative fabric, the CMYK digital colour mode that is based on subtractive colour mixture theory and is used for output of digital image seems the optimal choice. Since the colour mixing of woven fabric is subject to the optical colour mixture theory, research on the differences between subtractive colour mixture and optical colour mixture is thus the key for digital jacquard fabric colour to reproduce accurate colour effects of digital images. Figure 4-28 shows the mixed colour effect of two contrasting colours with the same acreage and lightness. The resultant mixed colour under subtractive colour mixture results in black with the same acreage in theory. Under optical colour mixture theory however, the mixed colour effect is dark grey and the mixed area is the sum of the two original acreages. For this reason, the colour mixing of digital jacquard fabric interlaced with warp and weft threads is a spatial colour mixture in a non-superimposition manner. The main characteristic of this kind of colour mixture is that after colour mixing, the luminosity is invariable but with the mixed area increased. Therefore, the colour saturation is reduced when mixing colour with warp and weft threads. The available changing range of colour saturation and the brightness scope of mixed colours are reduced.



(a) Subtractive mixture (b) Optical mixture

Figure 4-28. Colour effects of subtractive mixture and optical mixture.

With reference to the colour mixture theory stated above, when designing digital jacquard fabric in layered-combination design mode, the resulting compound structure of jacquard fabric is capable of expressing millions of mixed colours based on the compound structure. If applying non-backed compound structure, fine colour shading effect can be produced. However, the colour mixing of digital jacquard fabric formed by the deployment of warp and weft threads are different from that of RGB additive colour mixture or CMYK subtractive colour mixture. It is based on a 3-D woven structure that brings about a distinctive quality for digital jacquard fabrics. Therefore, the colour mixing of digital jacquard fabrics features perfect integration of textile materials and fabric woven structure that cannot be imitated by other means of artwork. Similarly, as in the different colour mixture theories existing among the visual arts, the simulation design of digital jacquard fabric can only be made to produce a similar, but not exactly the same colour effect, of the original digital images.

4.4 Design Practice on Colourless Digital Jacquard Fabric

Practical research on colourless digital jacquard fabric design was carried out to investigate the relationship of structural design and fabric effect toward creating an appealing colourless digital jacquard fabric. To this end, two requirements were addressed: expression of woven image and capability of mass production.

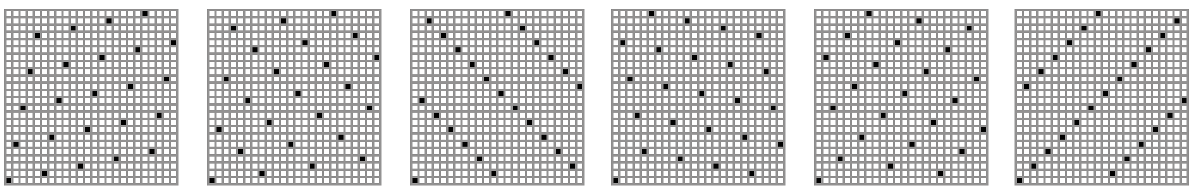
4.4.1 Choice of Digital Images

The images used for colourless digital jacquard fabric design do not impose any restrictions. Abstract or objective images of any sort such as portraits, landscapes, flowers, manuscripts, etc., can all be selected for fabric design. However, considering the expression of black-and-white shading effect and further technical analysis of structure, a portrait image is the optimal choice. So long as the simulative design with a portrait motif can be produced satisfactorily, its structural design method will satisfy design of any other images. Conversely, even if the structural design method satisfies other images such as landscapes or calligraphy, it does not necessarily mean that it will be suitable for simulating portrait images (Zhou, 2007e).

4.4.2 Selection of Structure Design Methods

Gamut weaves design comes first in the course of structure design. Gamut weaves contain a series of derivative weaves based on primary weaves that feature similar weave characteristics. Thus not only can it be applied to set up the corresponding weave-databases, but also can they can also employed to design single-layer fabric structure. Theoretically, a certain primary weave of simple satin weave entertains $4 \times R! \times M_s \times M_w$ weave-databases; of which each of them has a maximum of $R \times (R\text{-}2)+1$ weaves (here R refers to weave repeat. M_s refers to the number of elementary satins that features identical weave repeat but different step number; and M_w refers to the number of weaves via the changing of weave starting point, $M_w=R$). Thus, in design practice, it is important to optimize the design method of the weave-database instead of establishing all the weave-databases.

Taking 24-thread satin as an example, thus, six kinds of satin weaves can be drawn as primary weave under different step numbers (Figure 4-29). In terms of weave effect, six kinds of 24-thread satin weaves can form three pairs: (a) and (d); (b) and (e); and (c) and (f). Each pair of weaves shares the same weave effect but different slanting directions of interlacing points. For balanced distribution of interlacing points, the weave effect of (a), (b), (d) and (e) are preferred to (c) and (f) in Figure 4-29. Thus, according to the technical specification of fabric in design practice, the weave of Figure 4-29 (a) is selected as the primary weave for designing gamut weave and establishing a corresponding weave-database.



(a) (b) (c) (d) (e) (f)

Figure 4-29. Six kinds 24-thread satins with different step numbers.

Apart from the irregular design method in which weaving points vary without rules, three design methods can be used for designing gamut weaves, i.e., three regular transition directions of adding/reducing interlacing points: vertical, horizontal and diagonal transitions. Each of them can be used to build corresponding weave-databases based on the same primary weaves. Based on the primary weave of Figure 4-29 (a), three series of gamut weaves can be established. Figure 4-30 (from top to bottom) shows the gamut weaves designed through vertical transition, horizontal transition and diagonal transition. The value of adding/reducing interlacing points in each of these gamut weaves is the same, i.e., M=R=24. Thus, the black-and-white gradation effects of the three series of gamut weaves are the same. When applying these three series of gamut weaves to the design of colourless digital jacquard fabric respectively, the produced fabric effects should be same in theory when the digital images are the same. When there is a difference among the effects of the three digital jacquard fabrics produced, it can be concluded that the design method of gamut weaves affects fabric effect.

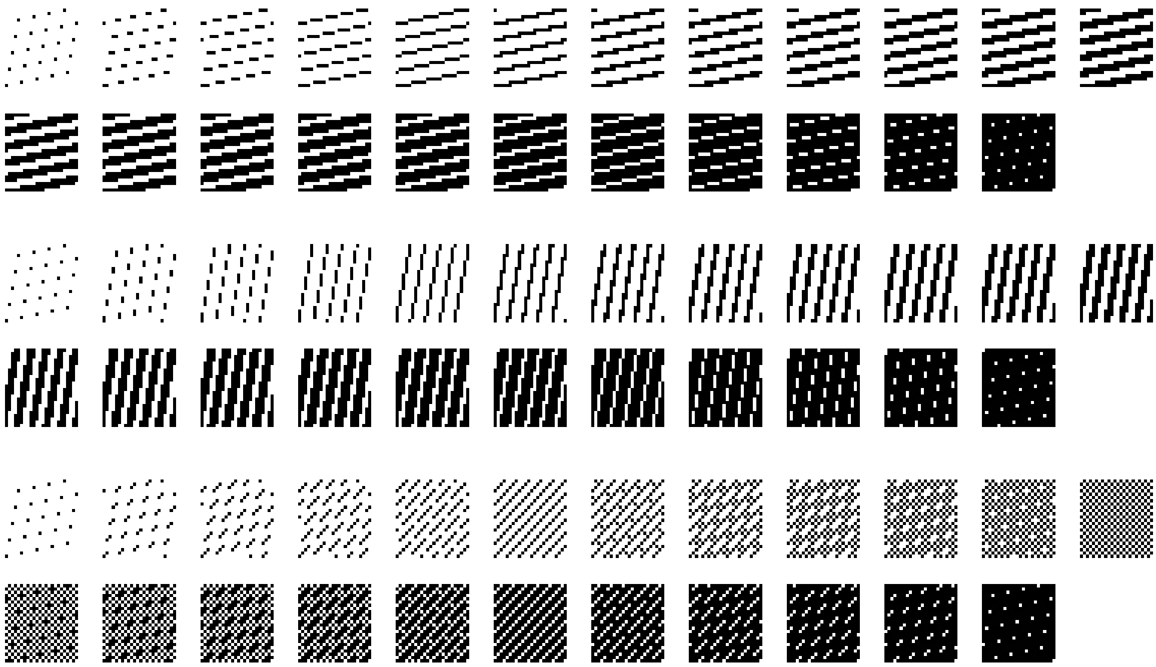
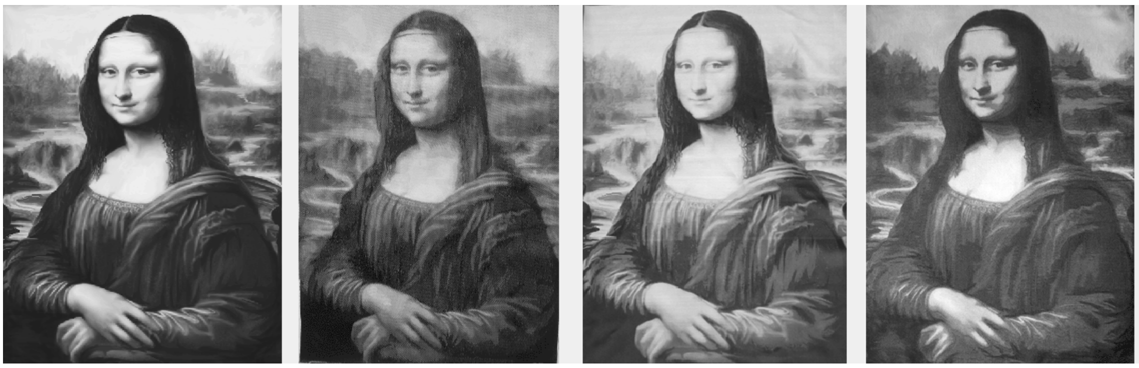


Figure 4-30. Three series of gamut weaves designed by three transition directions.

4.4.3 Comparison of Produced Fabric Effects

In addition, balanced interlacement is one of the key technical points for the production of jacquard fabric. It must be fulfilled satisfactorily in fabric structure design. Under the digital design approach, computer-aided design has replaced structure drawing on point paper; and thus the balanced interlacement of warp and weft is essentially dealt with in the course of gamut weaves design. Figure 4-30 illustrates three series of gamut weaves designed from primary weaves of 24-thread sateen. The number of gamut weaves is 23 for each series. Reducing the value of interlacing points can enlarge the number of gamut weaves. When M=1, the number of gamut weaves change to 529, i.e., $R(R$-2)+1=529; when M=12, the number of gamut weaves change to 45, i.e., 2(R-1)-1=45; when M=6, the number of gamut weaves change to 89, i.e., 2[2(R-1)-1]-1=89. The number of gamut weaves is 23 in each weave-database used to design colourless digital jacquard fabric respectively with the same portrait and the same fabric technical specification. The thread density is 115 threads/cm in both warp and weft directions. The warp threads are black and weft threads are white. The fabric effects produced are shown in Figure 4-31. Here (a) is the original digital image in grey colour mode; (b) is the fabric effect designed by using gamut weaves of diagonal transition; (c) is the fabric effect designed by using gamut weaves of horizontal transition; and (d) is the fabric effect designed by using gamut weaves of vertical transition. Taking simulated effect as the criterion to evaluate the overall effect, (d) is considered having the best-simulated effect; (c) has the worst simulated effect; and the simulated effect of (b) is barely satisfactory with the interlacement of warp and weft threads unbalanced which may well affected the efficiency of fabric production.



(a) (b) (c) (d)

(a) Original digital image; (b) Diagonal transition; (c) Horizontal transition; (d) Vertical transition.

Figure 4-31. Fabric effects designed by different gamut weaves.

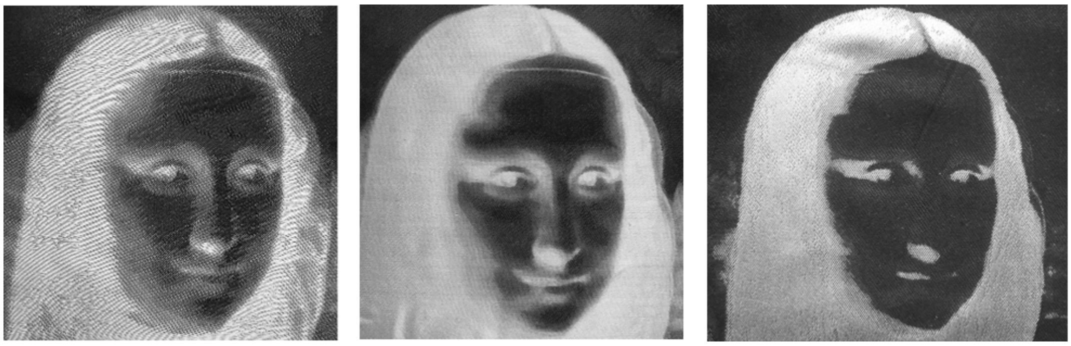
Further, to investigate the difference that is observed in overall fabric effects, it was found that the simulated effect of colourless digital jacquard fabric is determined by the expression of black-and-white shading effect reproduced on the face of fabric; and it is indeed manifested on the detailed fabric structure. Figure 4-32 shows detailed face effects of fabrics, in which (a) is the detailed face effect designed by diagonal transition; (b) is the detailed face effect designed by horizontal transition; and (c) is the detailed face effect designed by vertical transition. Taking the reproduced black-and-white shading effect as standard, (a) is satisfactory; (b) has the worse simulated effect in light areas but better in dark areas; and (c) has the reciprocal effect of having the worse simulated effect in dark areas but better in the light areas. Since the three series of gamut weaves designed had the same black-and-white shading effect, however different they will be after fabric production, it is apparent that the black-and-white shading effects of fabric could be affected by three-dimensional woven structure.

(a) Diagonal transition (b) Horizontal transition (c) Vertical transition

Figure 4-32. Details of face side of fabric.

In addition, since the design of colourless digital jacquard textile was based on single-layer fabric structure, the face and back effects of fabric were reversed showing a negative effect. Figure 4-33 shows the details of the reversed sides of fabrics, of which (a) is the detailed back effect designed by diagonal transition; (b) is the detailed back effect designed by horizontal transition; and (c) is the detailed back effect designed by vertical transition. Compared with the black-and-white shading effect on face side, (a) results with little difference; (b) results with opposite effect to face side, i.e., the worse simulated effect in dark areas but better in light areas; and (c) also results with opposite effect to face side, i.e., the worse simulated effect in light areas but better in dark areas.

The difference in black-and-white shading effect observed on the face and reversed sides of fabric suggested that the design method of gamut weaves has an impact on black-and-white shading effect on jacquard fabric. Conclusion can be drawn from the experience that in the course of black-and-white simulative design of colourless digital jacquard fabric, the black-and-white shading effect of gamut weaves cannot simply represent that of final fabric because there is a gap between paper drawing and woven structure.

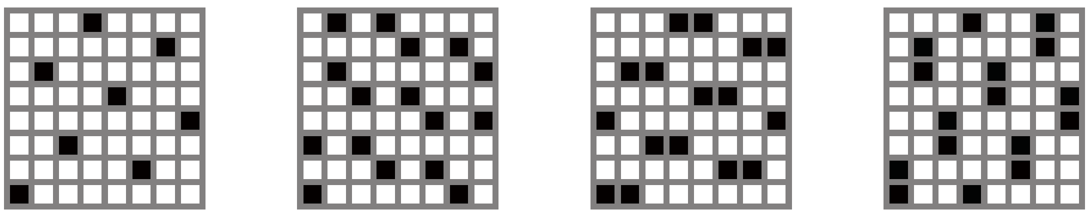


(a) Diagonal transition (b) Horizontal transition (c) Vertical transition.

Figure 4-33. Details of reversed side of fabric.

4.4.4 Technical Evaluation

Three series of gamut weaves share the same black-and-white effect, Yet, the black-and-white shading effects of the fabrics produced are different. It is evident that mutual covering happened among neighboring threads that has led to the inaccuracy of black-and-white shading effect. There could be two reasons for mutual covering: one is caused by common weaving points existing in the weave structure and the other is caused by juxtaposed threads due to overlong floats. Since common weaving points have been avoided in the course of gamut weaves design, the sole reason for mutual covering is caused by juxtaposed threads due to overlong floats. Thus, the longer the float, the better the covering effect. Figure 4-34 shows three methods of increasing weaving points. When using weft-face gamut weaves to design woven structure, the mutual covering of threads was caused mostly in the weft direction, i.e., mutual covering between weft threads. As a result, the covering effects of (b) and (d) in Figure 4-34 are worse than that of (c).



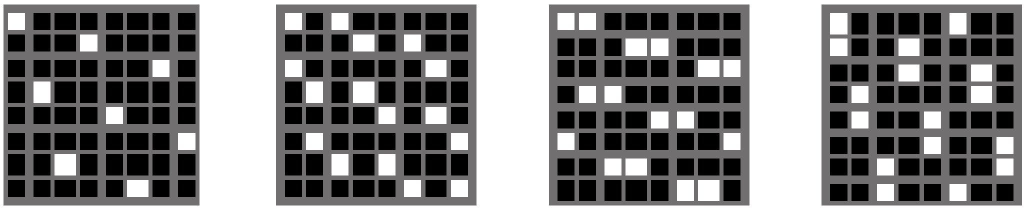
(a) (b) (c) (d)

(a) Original weave; (b) Diagonal transition; (c) Horizontal transition; (d) Vertical transition.

Figure 4-34. Effects of adding interlacement points on weft-face weaves.

Similarly, Figure 4-35 illustrates another three methods of adding weaving points.

When using warp-face gamut weaves (reversed effect of Figure 4-34) to design woven structure, the mutual covering of threads was caused mostly in the warp direction, i.e. mutual covering between warp threads. In this case, the covering effects of (b) and (c) in Figure 4-35 are worse than that of (d).



(a) (b) (c) (d)

(a) Original weave; (b) Diagonal transition;(c) Horizontal transition; (d) Vertical transition.

Figure 4-35. Effects of reducing interlacement points on warp-face weaves.

In brief, the lesser the mutual covering caused among threads in fabric structure, the better the effect of black-and-white shading being reproduced on the fabric. Table 4-4 shows the relationships between weave structures and black-and-white shading effects of designed fabric that coincide with the results of actual design theory in practice. If the arrangement of threads is revised to the warps being white and the wefts being black, the relationship between weave structures and black-and-white shading effect of designed fabric needs to be reversed too. Moreover, since the change of warp and weft density may also affect the covering effect of fabric, the design of gamut weaves needs to be considered for the distribution of grey scales in the digital image when processing a simulation design of colourless digital jacquard fabric.

Table 4-4. Relationship between weave structures and black-and-white shadings.

Character of gamut weaves	**Black-and-white shading effect**	
	Light areas	**Dark areas**
Diagonal transition	Satisfactory	Satisfactory
Horizontal transition	Worse	Best
Vertical transition	Best	Worse

*Black warp and white weft.

4.5 Design Practice on Colourful Digital Jacquard Fabric

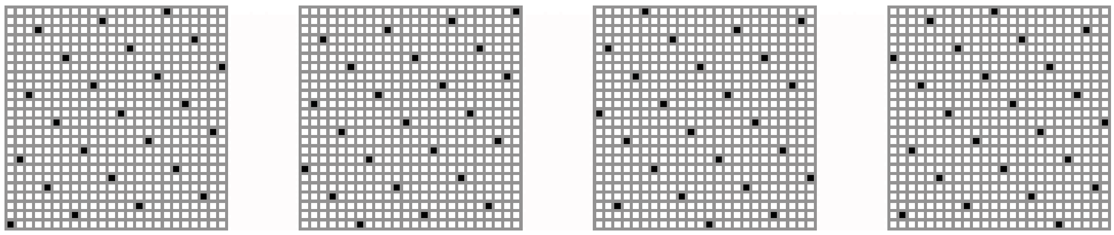
With the suggestion of layered-combination design mode for digital jacquard fabric, it is possible to produce jacquard fabric featuring a rich mixed colour effect via the combination of several single-layer structures. The colour expression of colourful digital jacquard fabric distinguishes itself from that of traditional jacquard fabric in two aspects. One is the increased colour number at mega level and the other is the capability of expressing multicoloured shading effect. As mentioned previously, this study was carried out to explore the relevant relationships between the structure design/combination methods and the final fabric effects. In addition, taking smooth colour shading effect of digital jacquard fabric as the objective, an optimal structure design/combination method has been proposed. Thus, the study has provided the essential technical references for the design creation of colourful digital jacquard fabric.

4.5.1 Choice of Digital Images

There is no particular limitation on the selection of image for colourful digital jacquard fabric design. The portrait image was selected as the optimal expression of colourful shading effect and structural characters due to its fine and smooth colour shading effect. So long as the simulative design of portrait is satisfactory in both aspects of colour and pattern, the structural design method can be applied to other digital images.

4.5.2 Selection of Structure Design Methods

The multicoloured jacquard fabric must be designed upon complex compound weave structure. Traditional complex compound weave design was approached by the combination of simple weaves in a single weave design mode. However, in digital jacquard textile design, the combination of single-layer structures has replaced the design process of single complex weave design. According to the combination principle of fabric structure, neighboring threads constructed in the woven structure only produced two basic effects, i.e., juxtaposition effect (non-backed structure effect) and mutual covering effect (backed structure effect). Therefore, the generation of the non-backed or backed effect after the weave combination needs to be thoroughly understood for designing gamut weaves and combination of single-layer fabric structures. In addition, since the combined effect of primary weaves may represent the combination of gamut weaves in the same weave-database, it can be concluded that when combining two single layer structures designed by backed effect weaves, the compound fabric structure will exhibit backed fabric effect. On the other hand, when two single-layer structures designed with non-backed effect weaves are combined, the compound fabric structure may show partial backed fabric effect, i.e., both backed effect and non-backed effect appear on the face of fabric at the same time. Figure 4-35 shows four primary weaves of 24-thread sateen designed by displacing the starting point of the original primary weave. It can be used to establish four weave databases respectively for further design practice.



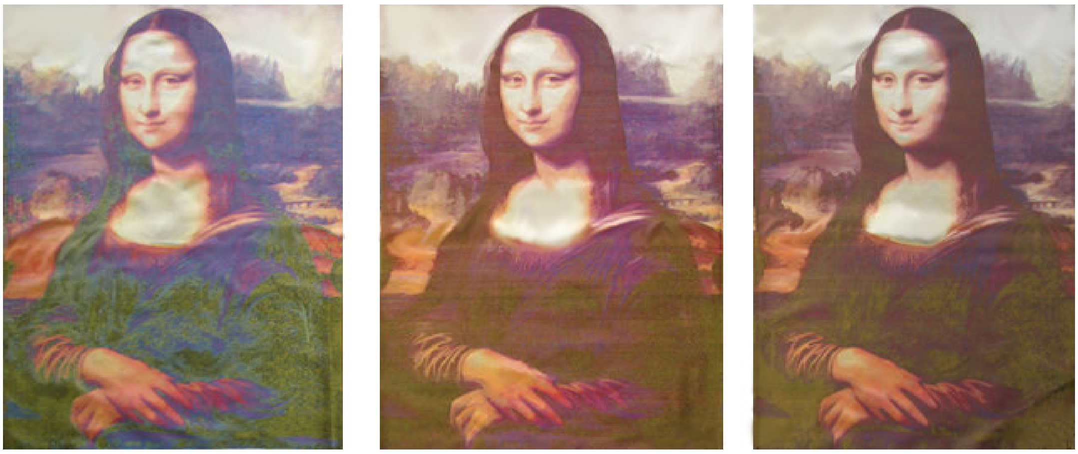
(a) (b) (c) (d)

(a) Original primary weave; (b) 6 points moved; (c) 12 points moved; (d) 18 points moved.

Figure 4-36. Four primary weaves of 24-thread satin.

4.5.3 Comparison of Produced Fabric Effects

In terms of the design principle of layered-combination design mode for digital jacquard textile, any colourful digital image can be separated into four grey layers of C, M, Y and K respectively. If four series of gamut weaves that are designed on the basis of four primary weaves in Figure 3-36 are applied to such four grey layers to design single-layer structures, three combination methods are available to combine these four single-layer structures to form compound ones. The first is the combination of four single-layer structures designed with the same gamut weaves which are used repeatedly four times. The resultant fabric effect is shown in Figure 3-37 (a). The mutual covering effect among juxtaposed weft threads dominate the face effect of the fabric in which the weft threads with shorter float are covered by that with longer float. The second is the combination of four single-layer structures designed with two series of gamut weaves (pairing) which are used twice. The two series of gamut weaves in different weave-databases have the same original primary weave but different weave starting points, i.e., the original primary weave and its starting point being shifted 12 points/threads. The fabric effect produced is shown in Figure 3-37 (b) in which the mutual covering effect and no-covering effect are both shown on the face of fabric at the same time. Compared with the original digital image, the colour reproduction in the area of no-covering structure effect is better than that in the area of mutual covering structure effect. The last effect is the combination of single-layer structure designed with the four series of gamut weaves which have the same original primary weave but different starting points, i.e., original primary weave, 6 points/threads shifted, 12 points/threads shifted, and 18 points/threads shifted. The resultant fabric effect is shown in Figure 3-37 (c) in which the mutual covering effect and no-covering effect are shown on the face of fabric at the same time. Compared with the original digital image, the area of no-covering structure effect seems to feature better colour reproduction than that in the area of mutual covering structure effect. Besides, during fabric production, a serious problem was generated, i.e., regular slanting effect of weft threads. This phenomenon seriously affected production efficiency.



(a) Same gamut weaves (b) Pairing gamut weaves (c) Four gamut weaves

Figure 4-37. Fabric effects designed by different compound structures.

4.5.4 Design Experiments and Technical Evaluation

In order to identify the reasons behind colour deviation caused in simulative design of colourful digital jacquard fabric, further design practices are being approached below targeting to reproduce the ideal effect of smooth colour shading of digital image. The design methods of gamut weaves and the combination methods of single-layer fabric structures applied are the same as the foregoing methods presented in Figure 4-37 (b), i.e., the method consists of pairing gamut weaves and pairing weave databases. In order to inspect the fabric effects generated from compound fabric structures, the image selected for design practice is of smooth colour gradation. As a result, the fabric produced exhibits the defect of broken streaks (Figure 4-38). Thus, it can be concluded that the shortcoming of structure design is the major reason leading to the generation of the broken streaks that has caused colour deviation in simulative design of digital jacquard textile.

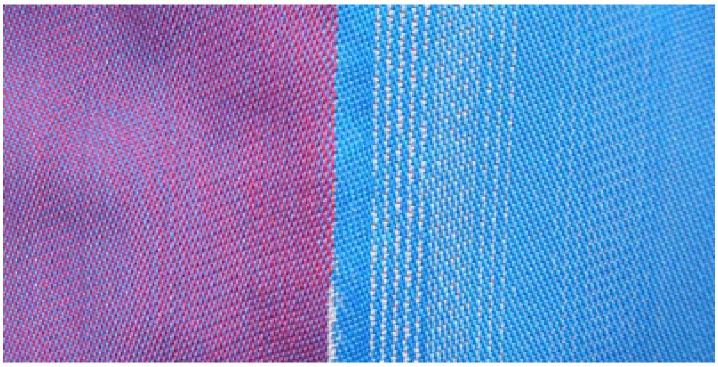


Figure 4-38. Broken streaks generated in colour shading effect.

To identify the main reason for the broken streaks, experimental research was carried out to inspect the combination effect between two series of gamut weaves. Figure 4-39 shows the basic gamut weaves and Figure 4-40 shows the joint gamut weaves designed by shifting 6 points of the original starting point. When using these two series of gamut weaves to design four single layer fabric structures, the basic gamut weaves were applied twice to design two single-layer structures arranged in odd layers while the joint gamut weaves were applied to two even layers.

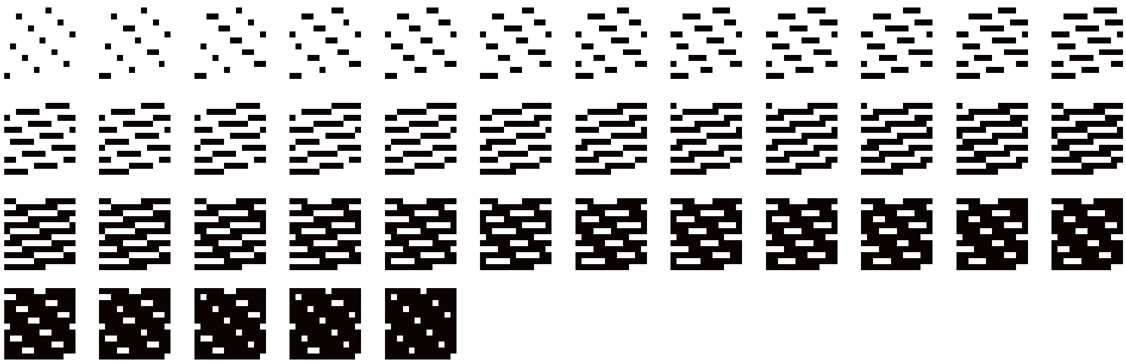


Figure 4-39. Effects of basic gamut weaves.

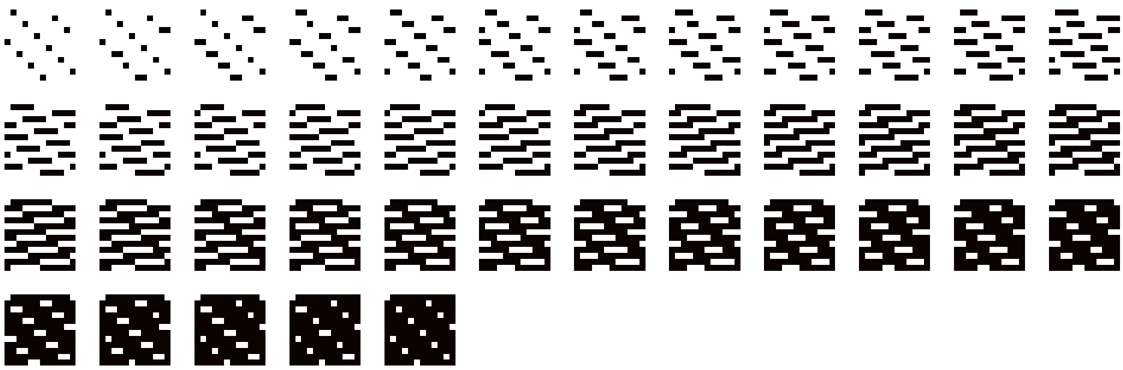


Figure 4-40. Effects of joint gamut weaves designed by shifting starting points.

After the combination of four single-layer fabric structures, a compound fabric structure was formed in which two single-layer structures designed from basic gamut weaves are located in odd layers, i.e., the first layer and the third layer, while another two single-layer structures designed from joint gamut weaves are located in even layers, i.e., the second layer and the fourth layer. In order to inspect the combination effect of the fabric produced, an experiment was carried out to ascertain the detailed effect of compound weaves combined from basic and joint gamut weaves. Figure 4-41 shows the combination effect of the first weave of basic gamut weaves and joint gamut weaves in two-layer combination. Due to the use of the same combination method, i.e., same starting point and same gamut weaves, the compound structure effect of two-layer combination is similar to that of the four-layer combination. Careful examination discovered that mutual covering effect and no-covering effect exist at the same time in compound weave effects. As shown in Figure 4-41, the compound weaves before the mark (vertical line) show non-backed compound effect while the compound weaves after the mark (vertical line) indicate partial backed compound effect.

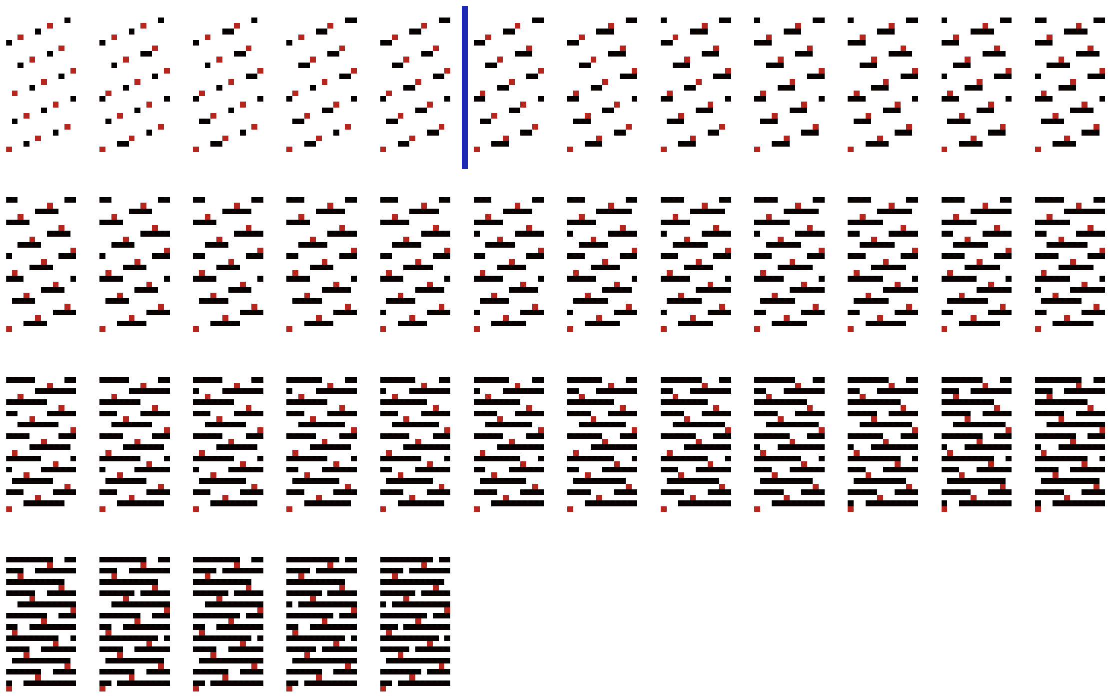


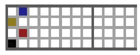
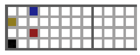
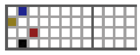
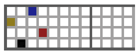
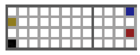
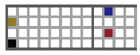
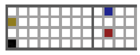
Figure 4-41. Combined effects of first basic gamut weave and joint gamut weaves.

The results obtained from practical research on the combination of gamut weaves indicated the fact that when two series of gamut weaves are being combined in which one series of gamut weaves are designed by shifting the staring point of another, the compound fabric structure will show both mutual covering effect and no-covering effect on the face of fabric at the same time.

In order to reduce and eliminate the broken streaks caused in compound fabric structure, further design experiments were conducted to investigate the main reasons that led to the generation of these broken streaks. Taking 12-thread satin as an example, twelve kinds of gamut weaves and weave-databases via the change of starting point and different methods of adding interlacing points were created. The effects of gamut weaves are shown in A.1 of Appendix A, of which 6 kinds of gamut weaves/weave-databases from N12-3w41-1 to N12-3w41-6 were designed by changing the starting points of primary weaves on the basis of gamut weaves N12-3w41. Two kinds of gamut weaves/weave-databases, N12-3w-z41 and N12-3w-z41-11, were designed by changing both the starting points of primary weaves and the insert directions of interlacing points, i.e., the insert direction of interlacing points of N12-3w-z41 is left while that of N12-3w-z41-11 is right. Two kinds of gamut weaves/weave-databases, N12-3w-z41-9 and C12-3w-z-y41-9, are paired. N12-3w-z41-9 was designed by changing the starting point of primary weave and the insert direction of interlacing points similar to the design method of N12-3w-z41-11 stated above. C12-3w-z-y41-9 was designed by changing the starting points of primary weaves and the insert direction of interlacing points, of which the insert direction of interlacing points was right-left-right in order to reduce the covering effect caused in fabric structure.

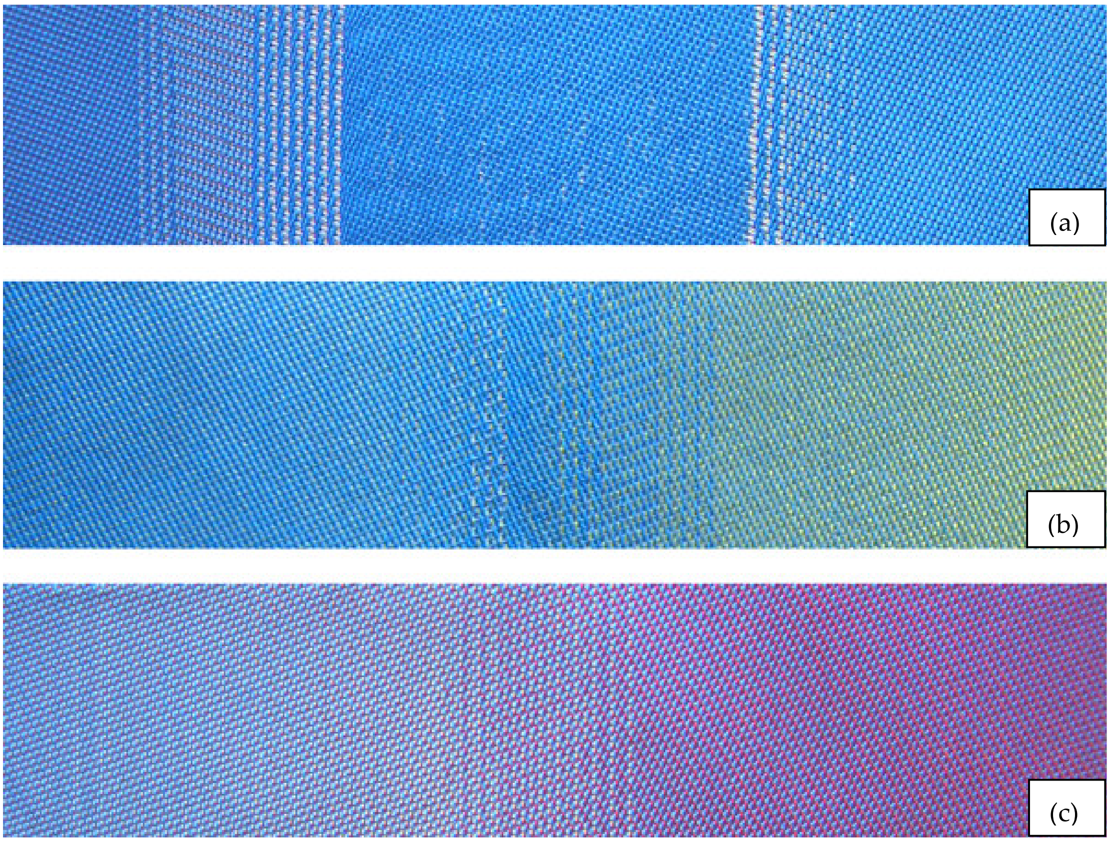
As shown in Table 4-5, with the aim of reducing broken streaks, seven design experiments were conducted with the same fabric technical specification of four-layers combination, but by different methods for gamut weaves design and single-layer fabric structure combination. In the experiments A to D, the design methods of gamut weaves were similar, i.e., same inset direction of interlacing points but different starting points. As a result, the combination effects of single-layer fabric structure of the experiments were different. After weaving the sample, the broken streaks generated on face of fabric of the four swatches were more pronounced and the fabric effect was seriously affected. Besides, the position of broken streaks on the fabric was random.

Table 4-5 Results of design experiments on reducing broken streaks.

Experiments	Gamut weaves and weave-databases	Insert direction of interlacing points (odd/even layers)	Diagram of combination method	Broken streaks/ colour influence
A	N12-3w41-1/N12-3w41/ N12-3w41-1/N12-3w41	Right		More/ Serious
B	N12-3w41-3/N12-3w41/ N12-3w41-3/N12-3w41	Right		More/ Serious
C	N12-3w41-2/N12-3w41/ N12-3w41-3/N12-3w41-1	Right		More/ Serious
D	N12-3w41-3/N12-3w41/ N12-3w41-5/N12-3w41-2	Right		More/ Serious
E	N12-3w-z41-11/N12-3w-z41/ N12-3w-z41-11/N12-3w-z41	Left/Right		Few/ Light
F	N12-3w-z41-9/N12-3w-z41/ N12-3w-z41-9/N12-3w-z41	Left/Right		Some/ Medium
G	C12-3w-z-y41-9/N12-3w-z41/ C12-3w-z-y41-9/N12-3w-z41	Left/Right-left		Few/ Light

*Gamut weaves and weave-databases see AA.1 in Appendix A

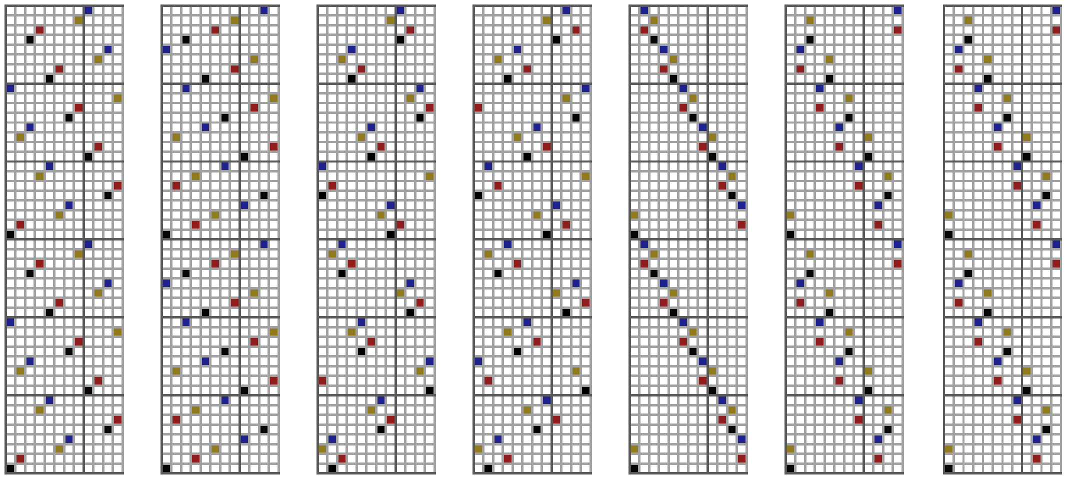
In experiment E, the insert direction of interlacing points of gamut weaves was changed to right and left respectively, whereby the broken streaks caused on the face of fabric were reduced visibly. In experiment F, the starting point was changed further, and the swatch produced had fewer broken streaks compared with the experimental swatches A to D, but more than that of experiment E. In experiment G, based on the design method of gamut weaves of experiment F, the insert direction of interlacing points of gamut weaves was changed into right-left. The fabric effect produced thus resulted in few broken streaks same as that of experiments E. Figure 4-42 shows the partial fabric effects of more/serious, some/less serious and few/light broken streaks produced in the design experiments. Figure 4-42 (a) indicates the fabric effect with more broken streaks. It was found that the broken streaks in the partial area on the face of fabric are connected. Thus, they have formed a backed structure that led to a serious covering effect in the compound structure. Subsequently, the colouring effect of the jacquard fabric has deviated more from the original image. Figure 4-42 (b) presents the fabric effect with some broken streaks. These broken streaks exhibited clearly on the face of fabric and have a mild influence on the fabric structure, but a more pronounced colour effect. Figure 4-42 (c) shows the fabric effect with few broken streaks, and the fabric structure is less affected when it is compared to the colour effect of fabric. Yet, the colour shading effect between the two colours is unsatisfactory.



(a) More/Serious (b) Some/Middle (c) Few/Light

Figure 4-42. Fabric effects of broken streaks generated in design experiments.

In addition, it is found that the broken streaks generated on the face of fabrics were distributed randomly and the position of broken streaks varied with the change of design methods of gamut weaves and combination methods of single-layer fabric structure. As shown in Figure 4-42, the broken streaks of the three fabric swatches designed by three methods are distributed differently on the face of fabric. In order to identify the major reason for the broken streaks, the combination effects of four primary weaves of four series of gamut weaves in seven design experiments from A to G are presented in Figure 4-43. Obviously, the combination effect of primary weaves can affect the woven texture of jacquard fabric. However, through the change of combination method of single-layer fabric structure, the generation of broken streaks can be reduced, but not to be removed completely.



(a) A (b) B (c) C (d) D (e) E (f) F (g) G

Figure 4-43. Combined effects of four primary weaves of four series of gamut weaves.

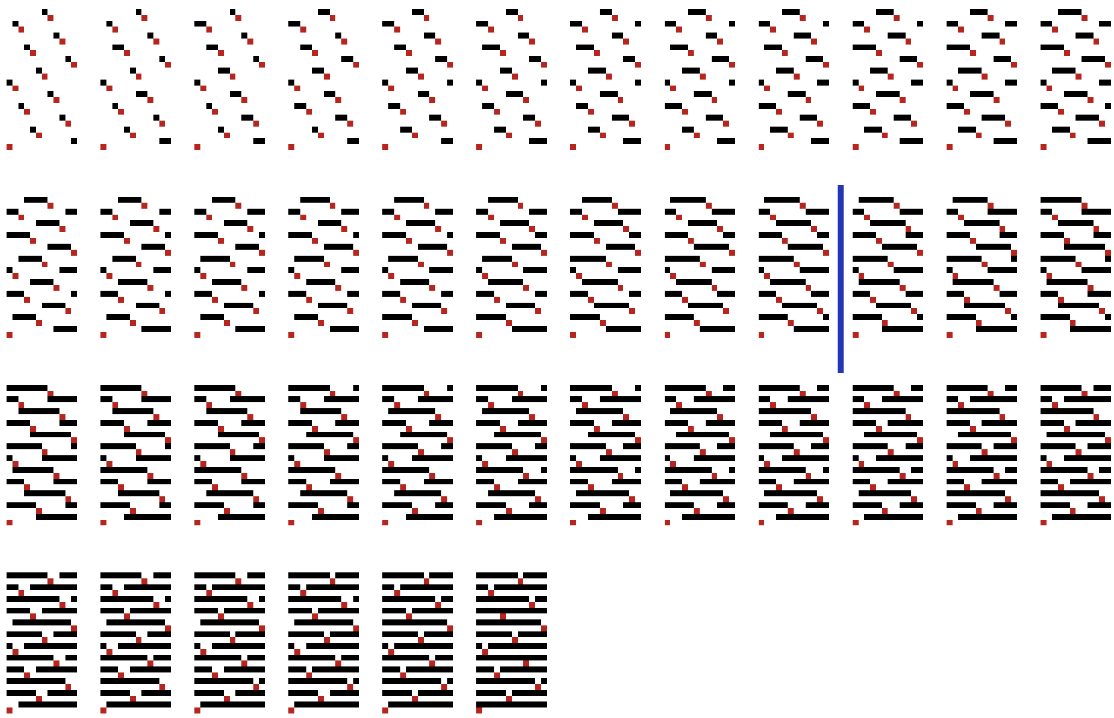


Figure 4-44. Combined effects of first basic gamut weaves and joint gamut weaves.

Since all the broken streaks were located at the junction area between covering and no-covering effect of compound weave structures, it implies that the proportion of backed structure and non-backed structure would vary when the single-layer structures designed by different gamut weaves and different combination methods were combined. Figure 4-44 shows the combination effect of the first weave of basic gamut weaves and the entire joint gamut weaves in design experiment E. In comparison with the result in Figure 4-41 that was combined by the first weave of basic gamut weave and all the joint gamut weaves in design experiment B, the non-backed compound weaves before the vertical mark in Figure 4-44 are more than that in Figure 4-41. In addition, the backed effect of the compound structure in Figure 4-44 is more of a half-backed effect, i.e., neighboring threads covering only one side while another side exhibits non-backed effect. As a result, the compound structure shown in Figure 4-44 is steadier than that of Figure 4-41.

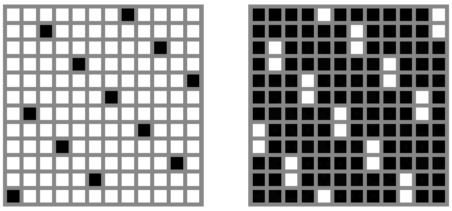
Based on the results of design experiments stated in Table 4-5 and the related technical analysis, conclusion can be drawn that the broken streaks exhibited on the face of fabric in digital colourful jacquard fabric design has to do with the design method of gamut weaves. When applying gamut weaves created by normal design method to design single-layer fabric structure, the broken streaks cannot be eliminated on the face of fabric after combination. Through changing insert direction of interlacing points during gamut weave design, the generation of broken streaks could be reduced, but they cannot be avoided completely. It can be argued that the design experiments were only conducted with simple colour shading effect as the sole and optimal method for verifying the broken streaks caused in digital colourful jacquard fabric design under layered-combination design mode. When designing fabric with complex images, because of a richer and more staggered mixed colours on the face of fabric, broken streaks may be avoided.

4.5.5 Design Practice with Full-colour Compound Structure

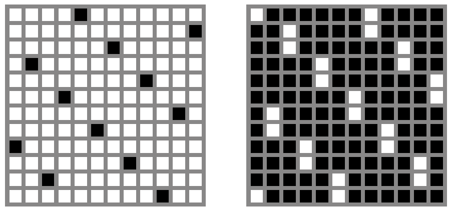
Compared with the original digital image, the colour effect of the jacquard fabric produced will deviate due to the existence of broken streaks caused by mutual covering effects in compound fabric structure. However, since more colour deviation was produced in the backed structure dominated area and less so in the non-backed structure dominated area, when the mutual covering effects among juxtaposed threads could be avoided during the design process of compound fabric structure, the simulative design of colourful digital jacquard fabric should be realised. In fact, the design method of full-colour compound structure has offers the capability of designing non-backed and full-colour compound structure. In theory, it meets the requirement of simulation design of colourful digital jacquard fabric. Having said that, design experiment was carried out using full-colour compound structure to avoid the influence of broken streaks and to reduce colour deviation.

4.5.5.1 Design of full-colour weaves

Taking 12-thread satin as an example, based on experiment G in Table 4-5, full-colour technical points were setup for basic primary weave and joint primary weave respectively in accordance with the design principles and methods of full-colour compound structure. The position of technical points is shown in Figure 4-45. The basic gamut weaves produced were Ac12-3w-z-y41 while joint gamut weaves were Ac12-3w-z-y41-9 (see AA.1 of Appendix A). Two series of gamut weaves have the same technical parameters, i.e., adding points once is 3, insert direction is right-left or left-right in weft-wise, and the number of gamut weaves for each is 37.



(a) Basic primary weave



(b) Joint primary weave

Figure 4-45. Primary weaves and their full-colour points.

4.5.5.2 Design practice of full-colour shading

The differences in fabric effects between digital jacquard fabric and traditional jacquard fabric relate to the substantial increase of mixed colour numbers and the capability of expressing print-like colour shading effect. Therefore, the major challenge is to design and produce a kind of colour palette with full-colour changing effect similar to that of spectrum colour effect. The superior design effect of digital jacquard fabric *per se* is a fine illustration of the superiority of digital jacquard fabric over those designed and produced by the traditional plane design method.

By using basic and joint gamut weaves alternately to design single-layer fabric structure, the completed compound fabric structure in which the odd number layers were designed by basic gamut weaves while even number layers were designed by joint gamut weaves after combination has made possible smooth colour shading effect on the face of jacquard fabric without broken streaks. Figure 4-46 shows the fabric effect of full-colour shading palette designed with four primary colours, i.e., three basic coloured threads (cyan, magenta and yellow), and one black thread. Following the design method of four-layer full-colour compound structure, the full-colour shading palette with three primary colours was realised, of which black could be applied to adjusting colour brightness. The structure design method started with designating two primary weaves. The full-colour points were designed first, then, basic and joint gamut weaves were designed respectively on the basis of the two primary weaves. Finally, basic and joint gamut weaves were applied alternately to design four single-layer fabric structures. Basic gamut weaves were used for odd number fabric structural design while joint gamut weaves were used for designing even number fabric structures. After combining the four single-layer fabric structures in an order of 1:1:1:1, the compound fabric structure obtained was capable of expressing full colour shading effect. Even if the colours of the threads were changed, the colour shading effect remained unchanged in the compound fabric structure. Therefore, designing full-colour compound structure under layered-combination design mode met the technical requirement of designing digital jacquard fabric with full-colour shading effect. Indeed this design mode enabled digital jacquard fabric to be produced with print-like colour effect that was impossible to attain under the traditional plane design mode. Colour plate C.1 of Appendix C shows more creations with full-colour shading effect.

Figure 4-46. Effect of smooth colour shading with full-colour effect.

4.5.6 Conclusion

Through design experiments on colourful digital jacquard fabric, especially those on fabric structure, the major reason for generating broken streaks was identified and the optimal solution was found. The results suggest that the design methods of gamut weaves and combination methods of single-layer fabric structure have laid the foundation for colourful digital jacquard fabric design and production. The compound structure of jacquard fabric combined with gamut weaves designed by normal method has the capability of expressing mega level mixed colours on the face of fabric. Yet, broken streaks cannot be avoided during the design process. When the design method of full-colour compound structure is used, through the setting of full-colour technical points upon gamut weaves, the digital jacquard fabrics produced were capable of expressing fine colour shading effect and accurate colouring effect. For these reasons, when approaching a design creation with the aim of attaining true-to-original effect of digital image, the full-colour compound structure is the optimal choice. When designing digital jacquard fabric to show innovative effects, both half non-backed and non-backed compound structure are capable of expressing unique woven effect of jacquard fabric that cannot be imitated by other means of artwork. Gamut weaves designed by normal method are regarded as unsuitable for design creations with either simulative or innovative effect due to the generation of too many broken streaks in the compound fabric structure.

Table 4-6 Findings of design practices for colourful digital jacquard textile.

Broken streaks/ Colour influence	Effect of compound structure	Corresponding experiments	Recommended design application
More/Serious	Forming backed area	A-D	Unfavourable
Some/Medium	Individual broken streaks	F	Unfavourable
Few/Light	Half-backed structure	E & G	Innovative effect
None/None	Non-backed	Full-colour shading	Simulative or innovative effect

4.6 Summary

This chapter has presented the most important part of the research on digital jacquard textile design. Since the layered-combination design mode is an original contribution to the design of digital jacquard textile, the technical problems discovered in the design experiments are unprecedented. These problems relate to colourless and colourful digital jacquard textile design such as the balanced interlacement required in fabric production and the broken streaks caused in compound structure. Through a series of experimental research and analysis of the results, the key innovation points of digital jacquard textile design pertaining to the design of colour and structure as well as the relationship of fabric structure design and its colour expression have been identified. In addition, the design concept, design principles and design methods proposed in the theoretical research have proved to be of tremendous benefit to the innovation of jacquard textile design. The results obtained from both experimental research in this chapter and the theoretical research in Chapter 3 have laid a solid foundation for the design creations of creative digital jacquard fabrics under the layered-combination design mode.

CHAPTER 5
DESIGN CREATIONS WITH SIMULATIVE EFFECTS

5.1 Introduction

Simulative jacquard fabric is one of the important varieties of jacquard textiles with its purpose of imitating the effects of given images. The design of true-to-original simulative jacquard fabric under the traditional plane design mode required the highest skill and technique due to the complex design processes and complicated fabric construction involved. The digital layer-combination design mode, especially the invention of the design method of full-colour compound structure proposed in this study, has overcome the restriction of the traditional single plane design mode. Thus, the simulative design of digital jacquard fabric can now be approached in an efficient and convenient manner.

The simulative design of jacquard fabric can be broadly divided into two types in terms of colour effect: black-and-white simulative effect and colourful simulative effect. In this chapter, based on the application of layered-combination design mode, the innovative design methods on true-to-original simulative jacquard fabrics with both the black-and-white simulative effect and the colourful simulative effect were introduced from basic design method to variant design method. As a result, the merits of designing digital jacquard textile in layered combination design mode have been reinforced.

5.2 Simulative Design on Black-and-white Effect Fabric

Simulative fabric refers to fabric whose visual effects such as pattern and colour are capable of imitating that of given images. In this study, the innovative design methods on black-and-white simulative fabric under layered-combination design mode were proposed. The main design problems during structural design were identified and solved effectively.

5.2.1 Background

Black-and-white simulative fabric that imitates achromatic artworks, such as paintings, portraits and landscape photographs must be produced on a jacquard machine (Zhejiang Institute of Silk and Textiles, 1987). Ancient China and Europe were two major regions where advanced jacquard techniques and jacquard fabric products developed quickly. A wealth of literature documenting black-and-white simulative fabric and related design methods could be found. In ancient Europe, black-and-white simulative fabric was produced with single-layer fabric structure in cotton or linen, often of rather coarse fabric effect. However, in ancient China, black-and-white simulative fabric was a normally silk product featuring elaborate pattern and colour effects. It was constructed with two-weft backed structure and threads of pure silk, and was given the name *Xiangjin* (Wang, 2002a; 2002b) - fabric with portrait and landscape simulated motifs.

The structural design of traditional black-and-white simulative fabrics was approached in a manual manner in both China and Europe. The fabric structure was drawn on point paper in detail. No doubt, it was a time-consuming task. For example, at least six months were needed to draw the fabric structure of an achromatic portrait or landscape painting on point paper. Although disadvantage exists in the traditional manual design method of jacquard fabric, its convenience in changing fabric structure when designing the structure of shading pays off. The designer may reduce or freely add interlacing points in any spot on point paper to meet the technical requirement of balanced interlacement. As a result, jacquard fabric created exhibits fine black-and-white shading effect with satisfactory grey scales albeit the manual process was time-consuming and often laborious.

With the rapid development of digital design and production technologies, new opportunities arose to improve simulative fabric. Computer-aided design (CAD) of black-and-white simulative fabric became popular and design efficiency was enhanced. Single-layer structure was used as the foundation; hand drawing on point paper was replaced by computer-assisted design processing (Neudeck, 2006). Yet, since the structural design principle remained unchanged, the computer-assisted method was not able to adjust the interlacing points of shaded structure as freely as that of the manual process (Zhou, 2001c). The inter-covering effect caused by mutual slippage among the juxtaposed threads could not be controlled efficiently. As a result, the middle gradations of the grey scales on the fabric were affected greatly. If the digital image presents rich gradations, great disparity exists between the actual fabric effect and the original digital image.

5.2.2 Basic Design Concept

Structural design is the key in black-and-white simulative fabric design. To produce black-and-white simulative fabric, the design of shaded weaves is indispensable. Among the various shaded weaves, single-layer shaded weaves are the simplest. They are designed on the basis of satin or twill weave and feature weaves transition effect gradually from the warp face to the weft face, or vice versa. The transition directions of shaded weaves mainly have three types: vertical transition, horizontal transition and diagonal transition. When designing simulative jacquard fabric manually, it is easy to adjust the interlacing points on point paper by the integration of the three transition directions of shaded weaves so that the inter-covering among juxtaposed threads could be avoided. When designed with the aid of a computer, however, the weaving points of fabric structure cannot be modified. The replacement between pattern colours and weaves is processed automatically with the fixed starting point by computer, i.e., the black-and-white shading effect cannot be adjusted by arbitrary addition or reduction of weaving points. As a result, even if the objective pattern and gradation of grey scales are the same, the final fabric effect with single-layer structure differs from the original image due to mutual extrusion and covering among juxtaposed threads.

Traditional Chinese black-and-white simulative fabric, *Xiangjin*, was a kind of jacquard fabric constructed with weft-backed structure. It consisted of one white warp thread and two weft threads (black and white). The white warp thread and the white weft thread construct with plain weave while the white warp thread and the black weft thread interweave to form a shaded weave structure. The black-and-white shading effect was designed through reducing the weave repeat and changing weaving points on the basis of satin primary weave, i.e., using plain weave as balance point to design warp-face and weft-face shaded weaves respectively. In order to meet the technical requirement of balanced interlacement of fabric construction, the *Bangdao* device (Zhou, 1988), a kind of warp lifting device whose working principle is the same as that of a heddle frame in a dobby machine) and *Bangdao* weave (Zhejiang Institute of Silk and Textiles, 1987; 2002) were employed when black weft was woven into plain weave. As a result, plain weave could be replaced by *Bangdao* weave. Weave repeat was enlarged. By such a method, it was convenient to adjust the interlacement balance at any point of the fabric structure through hand drawing of shading. Thus, any pattern could be applied to the design of black-and-white simulative jacquard fabric. Yet, such a design method was time-consuming, and available only under manual design mode. It cannot be approached by computer programmed processing. Moreover, at present, the digital jacquard machine is no longer installed with the bounding format of having "one harness corresponding to two ends". The *Bangdao* device thus cannot be employed in digital production processing. For this reason, the design method of traditional Chinese black-and-white simulative jacquard fabric has lost its popularity over time. It is imperative for a new design principle and method that can revitalize this traditional effect of jacquard fabric with more efficient and effective results.

5.2.2 Design Principles and Methods

In this study, the design innovation of black-and-white simulative jacquard fabric via the application of digital design and production technology has two directions: design with single-layer structure and design with compound structure. The former one is to design black-and-white fabric by tailor-made gamut weaves based on a colourless design mode and single-layer structure. The fabric structure is designed according to the varied brightness of grey scales of the digital grey image. The latter method is to produce the uncovered fabric structure with the support of proper accessorial threads based on the colourful design mode and compound fabric structure.

5.2.2.1 Design principles and methods with single-layer structure

The colourless design mode of layer-combination design mode can be applied directly to develop black-and-white simulative fabric with single-layer structure. It shares common design principles and methods as that described in the theoretical and practical research in this study.

(1) Colour Design Principles

The pattern design of black-and-white simulative fabric can now be achieved by using the CAD system. By such means, the pattern resolution is finer than that of traditional hand-drawn fabric design. In addition, the number of greys applied to the pattern design can be as high as 256. Given the fact that the human eye can only distinguish a maximum of 64 grades of grey in a monochromatic scale (Zhou, 2002b), the grey scale of the digital image should be either equal or more than this number if the design wants to imitate a true-to-original effect of colourless jacquard fabric. Any 8-bit digital grey image that shows a maximum of 256 grades of grey can fulfill the design requirement of black-and-white simulative fabric.

(2) Structural Design Principles

Structural design is one of the most important steps during design processes for black-and-white simulative fabric. It consists of weave design and fabric structure design. The weave design should be approached with an image of less than a range 256 greys to form shaded gamut weaves based on detailed technical specification of desired fabric. In general, there are three methods of adding interlacing points that are utilized to design shaded gamut weaves upon selected primary weaves: vertical (warp-wise), horizontal (weft-wise) and diagonal transitions. However, due to the restriction of balanced interlacement and mutual covering effect after production, the design of shaded gamut weave cannot be approached mechanically (Zhou, 2006d), as it needs to be varied frequently along with the change of technical parameter of the desired fabric and the nature of the applied image.

(3) Design Methods and Processes

The design and production of black-and-white simulative fabric in the colourless mode is based on the application of jacquard CAD system and electronic jacquard machine. The working route is described in Figure 2-2 in chapter 2. During fabric production, an advanced weaving loom is used together with an electronic jacquard machine. Black-and-white simulative fabric designed with single layer structure is interlaced by one series of warp and one series of weft threads so that the design of the fabric structure is correspondingly regular. The major design input during this process is the image and weave design in the jacquard textile CAD system. The series of tasks carried out are specified in Figure 5-1 (Ng, 2006).

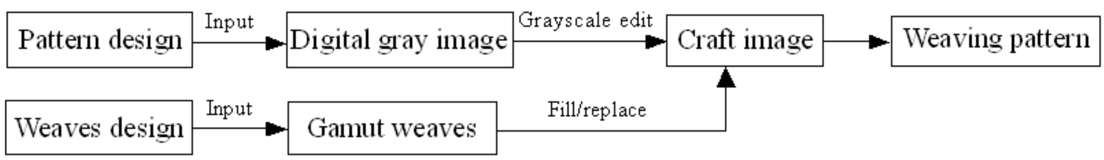


Figure 5-1. Design processes for black-and-white simulative fabric.

In fabric design, the first step is pattern design. The pattern could be a hand-drawn artwork and/or a photographic one. The pattern is scanned and saved in digital bitmap format. According to the weaving parameters of the fabric, the digital grey image is then revised by using the editing tools offered in the jacquard textile CAD system, forming a craft image with the required range of greys and proper technical parameter. At the same time, the weave design is tackled with the aid of the computer to form a series of gamut weaves that meet the requirements of production of the fabric. They are further applied to replace each of the corresponding greys in the colourless image under a fixed starting point. As a result, the output is a weaving pattern that consists of weaving data (see Figure 5-2), i.e., only either raiser points or sinker points in a thread. It provides the foundation for further production of black-and-white simulative fabric. In addition, since the colours of black-and-white simulative fabric are translated by changing either the warp or the weft thread, the black-and-white simulative fabric designed by the digital jacquard technique can therefore be used to develop a series of products with the same weaving pattern but with different monochromatic effects.

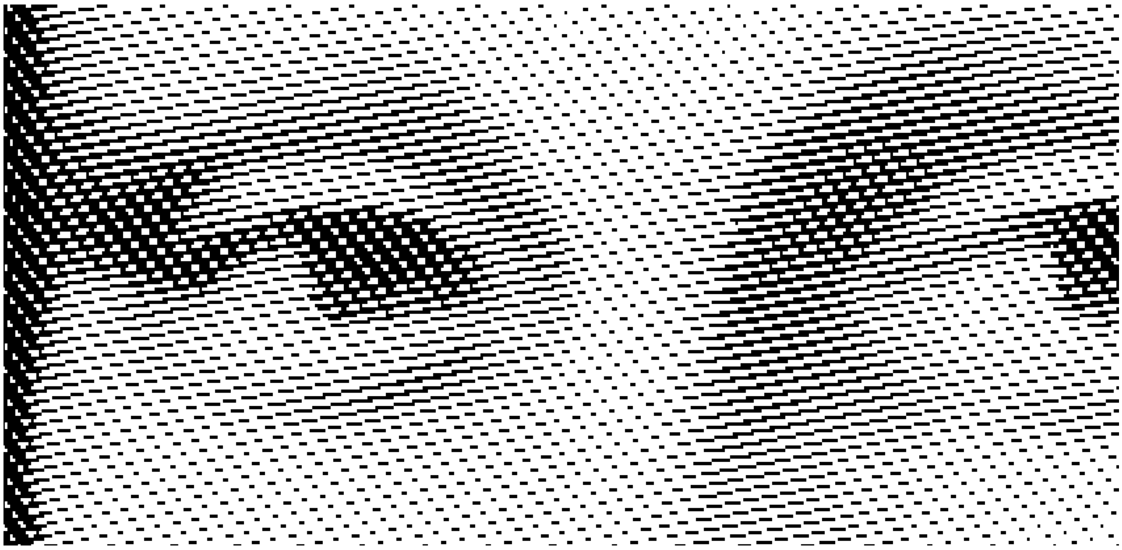


Figure 5-2. Weaving pattern of black-and-white simulative fabric.

5.2.2.2 Design principles and methods with compound structure

Different from the design method of single-layer structure, the design principles and methods of black-and-white simulative fabric with compound structure are based on a new design concept devised from layered-combination design mode.

(1) Design Principles

Since the design method of traditional Chinese black-and-white simulative fabric, i.e., *Xiangjin,* cannot be approached in a digital design manner, the design methods for black-and-white simulative jacquard fabric are mostly devised from the single-layer structural design method. Although design efficiency has been improved, the outstanding issue of mutual covering among juxtaposed threads has not been overcome yet. When designing digital jacquard fabric toward black-and-white simulation using a digital image directly, the final fabric effect is unsatisfactory because the black-and-white shading effect cannot be reproduced accurately. For this reason, this study introduced an innovative design method integrating single-layer structure and backed structure to address such structure-based technical problem. The basic design principle is to add a supplementary thread between the two adjacent threads of single-layer structure. By doing so, the mutual covering among colouring/floating threads arranged in juxtaposition can be avoided. Details are as follows:

1) The fabric is constructed by two series of threads arranged in juxtaposition and one series of thread in another direction. One group of juxtaposed threads is used as colouring/figuring threads, whereas the other group of juxtaposed threads is applied to forming a compound fabric structure as joint threads. The latter serves as a supplementary thread and functions to prevent the colouring thread from slipping and covering one another. The joint threads are not visible from the face side. Theoretically, colouring thread can be deployed in both warp-wise and weft-wise, however, weft-wise is preferred for better balanced interlacement of fabric structure.

2) Colouring threads are capable of expressing figured effect with smooth black-and-white shading through the deployment of shaded gamut weaves similar to that of single-layer fabric structure. The weave structure of supplementary threads is designed following the design principle of full-colour compound structure. Due to the existence of supplementary threads, the colouring threads will not move and be covered by each other.

3) For colour consideration, the colouring threads should employ black or dark colour while the supplementary threads should be of the same colour as that of the threads interwoven in the other direction (white or light colours). In addition, in order to reduce the colour influence on figuring effect, the supplementary threads are preferred to be finer than the colouring threads.

(2) Design Methods

The structure design of black-and-white simulative fabric with compound structure involves three parts: primary weave design, gamut weaves design of figuring threads and weave design of supplementary threads. The primary weave design is the same as that of full-colour compound structure design. It involves the selection of primary weave and the design of full-colour technical points upon primary weaves. Taking 16-threads satin as an example (see Figure 5-3), the primary weave is designed with

16-threads 5 step weft-face sateen, whose valid full-colour technical points is 16-threads 13 step warp-face satin.

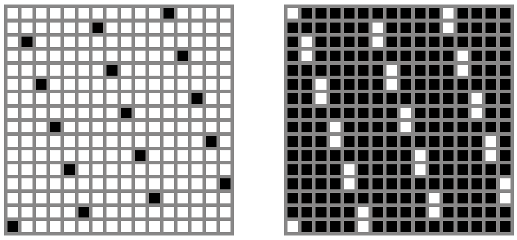


Figure 5-3. Primary weave and its full-colour points.

Based on the primary weave and its full-colour technical points, the design of gamut shaded weaves named as basic weaves for figuring threads can be approached, as shown in Figure 5-4. Enhancement method of weaving point is adding gradually along weft wise. In case when M=R, the number of basic weaves is the minimum as R-1; whereas when M=1, the number of basic weaves is the maximum as R (R-2)+1. Here R represents weave repeat and M stands for the enhancement number of shaded interlacing points.

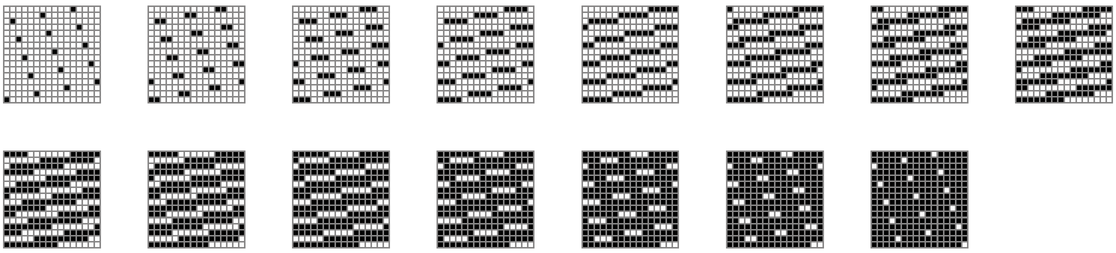


Figure 5-4. Basic gamut weaves design based on primary weave.

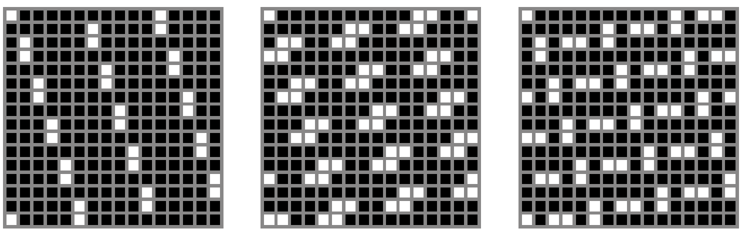


Figure 5-5. Three types of joint non-backed weaves.

The approach to the joint weave design for supplementary thread is based on full-colour technical points. Without destroying the full-colour points, the joint weave is designed by regular variation. Full-colour points can also be applied as joint weave directly. Figure 5-5 illustrates three basic design methods. Weave A is designed by directly transferring from full-colour points; weave B is designed through adding weaving points continuously on the basis of full-colour points; and weave C is designed by adding weaving points discontinuously on the basis of full-colour points. In fact, with different joint weaves, the tightness of woven fabric can be adjusted by compound structure. For combination method of fabric structure, the combination proportion is 1:1 across weft between colouring thread and supplementary thread. Figure 5-6 shows the combined structure effect between basic gamut weaves of Figure 5-4 and joint non-backed weave A in Figure 5-5. Due to the application of supplementary threads and corresponding full-colour structure, the adjacent figuring threads arranged in juxtaposition cannot be covered by each other and the entire weave variations are coloured on the face of fabric. It enables jacquard fabric to express the black-and-white shading of grey scales accurately, and thus the true-to-original simulated effect of black-and-white fabric can be achieved.

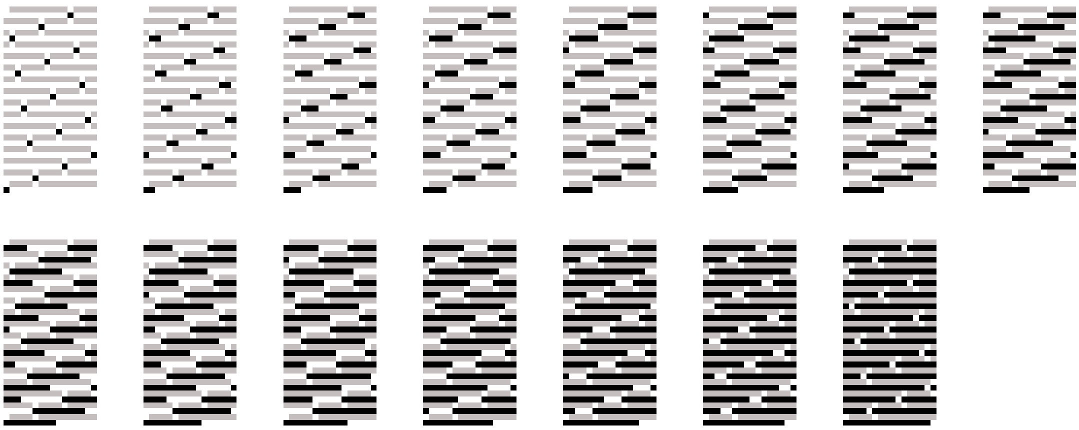


Figure 5-6. Combined effects of basic gamut weaves and joint non-backed weaves.

The key to black-and-white simulative design with compound structure laid in the innovation of fabric structure design. By merging the characteristics of traditional manual design method and the application of digital design technology, the innovated structural design method introduced in this study is capable of producing black-and-white simulative fabric accurately. It is envisaged that such technical advancement will have a tremendous potential in commercial applications.

5.2.4 Design Illustrations

The design illustrations of black-and-white simulative fabrics with both single-layer fabric structure and compound fabric structure were introduced to expound the design principles and design methods stated above.

5.2.4.1 Design illustration with single-layer structure

The design of simulative effect of black-and-white jacquard fabric with single-layer fabric structure is the basic design method of digital jacquard fabric design. Based on the design method introduced above, the design creation of simulated effect fabric was approached efficiently by using only one series of warp thread and one series of weft thread with tailor-made digital gamut weaves. Its simulated effects adequately achieved with the reproduction of a given image.

(1) Technical Specification

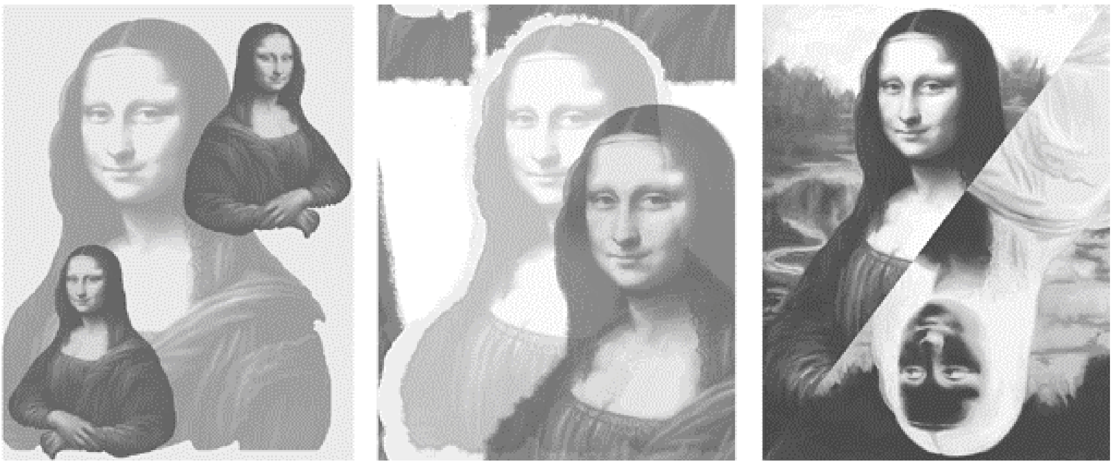
The key technical parameters of fabric are detailed in the technical specification table (Table 5-1). Due to the restriction of technical condition in fabric making, the parameters of the black-and-white simulative fabric based on the production devices cannot be modified during the design process. According to the key technical parameters shown in Table 5-1, the final fabrics were designed by using 12-thread gamut weaves with lower fabric density. Polyester threads were employed in both warp and weft direction to facilitate ease of production. In addition, since the design of jacquard fabric with the portrait image always has the highest technical requirement for simulative effect, the portrait image was selected for the design creation of black-and-white simulative fabric.

Table 5-1 Technical specification of black-and-white simulative fabric with single-layer fabric structure.

	Parameters	
	Warp	**Weft**
Materials	1/166.7 dtex polyester (white)	1/166.7 dtex polyester (dark/dark/light/light)
Density	45 threads/cm	60 threads/cm
Composition	Polyester 100 %	
Weave structure	12-thread gamut weaves, 41 grey grades	
Design repeat	1248 needles × 1680 fillings	
Pattern repeat	22.01 cm (width) × 28.07 cm (length)	
Weight	238 g/m^2	

(2) Design Processes

The design of black-and-white simulative fabric was approached on the basis of fabric specification and the aid of the computer system. The design processes mainly consisted of image design and structure design. In accordance with the fabric parameters and the design principles and methods of colourless digital fabric, the digital images were designed with less than 41 grey scales. Grey images with the same size are shown in Figure 5-7. Grey image (a) composes of two figures with contrast in both brightness and size; grey image (b) composes of a figure in repetition and contrast in brightness; and grey image (c) composes of a figure in its positive and negative effect.



(a) (b) (c)

Figure 5-7. Digital grey images for simulative design with single-layer structure.

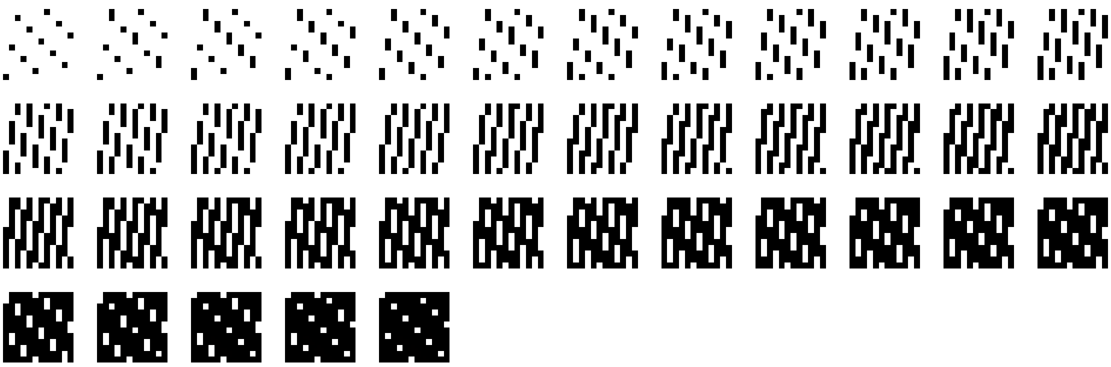


Figure 5-8. Gamut weaves for simulative design with single-layer structure.

Giving the fact that the same gamut weaves can be used for any digital image of the same fabric technical parameters, only one series of gamut weaves needed to be created in line with the basic technical requirement of having primary weave being 12-thread satin and the grey grades of gamut weaves being 41. In addition, since the fabric employed white warp threads and black weft threads, in order to obtain fine black-and-white shading effect in the dark areas of the portrait image, vertical transition was applied for gamut weaves design. The gamut weaves designed are shown in Figure 5-8.

(3) Fabric Effect

The black-and-white simulative fabrics produced are shown in Figure 5-9. In comparison with the original grey image, the simulated effect of the final fabrics is considered satisfactory though the colourful shading effect in light area is still defective. Given the design illustrations above, there is no doubt that the single-layer structure designed according to the design method of digital colourless mode benefits well the design creation of black-and-white simulative fabric. Moreover, if the major fabric technical parameters remain unchanged, the same gamut weaves can be used for designing black-and-white simulative fabrics with different grey images. The major properties of the fabrics such as the handle and thickness will remain unchanged too.

(a) (b) (c)

Figure 5-9. Fabric effects of simulative design with single-layer structure.

Simulative design of black-and-white fabric also suffered from the disadvantages of serious covering problem among threads due to the restriction of single-layer fabric structure when gamut weaves with larger weave repeat and higher thread density are being deployed. Thus, the design method with single-layer fabric structure is preferred to be applied for designing simulative effect fabric with lower thread density and smaller weave repeat gamut weaves.

5.2.4.2 Design illustration with compound structure

The simulative design of black-and-white jacquard fabric with compound fabric structure serves as a variant design. The compound fabric structure, originally based on single-layer fabric structure, could be produced through adding supplementary threads between two adjacent colouring threads. The figuring threads on the face of fabric feature non-covering (full-colour) effect. With such a compound structure, smooth black-and-white shading for simulative design can be achieved.

(1) Technical Specification

The key technical parameters of fabric are shown in Table 5-2. Similar to the design with single-layer fabric structure, based on valid technical parameters, there is no restriction for image used for simulative design of black-and-white fabric. Table 5-2 reveals higher thread density in the final fabric than that designed with single-layer fabric structure. Two silk threads were employed in weft direction. One weft served as figuring thread that had a contrasting colour to the warp thread while the other served as supplementary thread that had a similar colour to those of the warp thread. In order to reduce the colour influence by the supplementary threads, the figuring thread is 2.5 times thicker than the supplementary thread. Moreover, in order to achieve higher thread density, larger repeat gamut weaves, i.e., 24-thread weaves were applied which doubled those used for the design with single-layer structure.

Table 5-2 Technical specification of black-and-white simulative fabric with compound fabric structure.

	Parameters	
	Warp	**Weft**
Materials	22.2/24.4dtex×2 silk (white)	22.2/24.4dtex×5 silk (black) 22.2/24.4dtex×2 silk (white)
Density	115 threads/cm	(45+45) threads/cm
Composition	Pure silk 100 %	
Weave structure	24-thread gamut weaves, 45 grey grades	
Design repeat	12000 needles×3744 fillings	
Pattern repeat	104.3 cm (width)×41.6 cm (length)	
Weight	139.9 g/m^2	

(2) Design Processes

Since there is no restriction in the selection of digital image for simulative design of black-and-white effect fabric with compound structure, the key to design lies in structure design. A landscape image of 12000 pixels×3744 pixels and 45 grey scales with black and white inclusive was selected (Figure 5-10).

Figure 5-10. Digital grey image for simulative design with compound structure.

A series of gamut weaves of 24-thread weave and 45 grade shaded weaves was designed (Figure 5-11). The enhancement number of interlacing points was 12 between two gamut weaves and the transition direction used for gamut weaves design was horizontal.

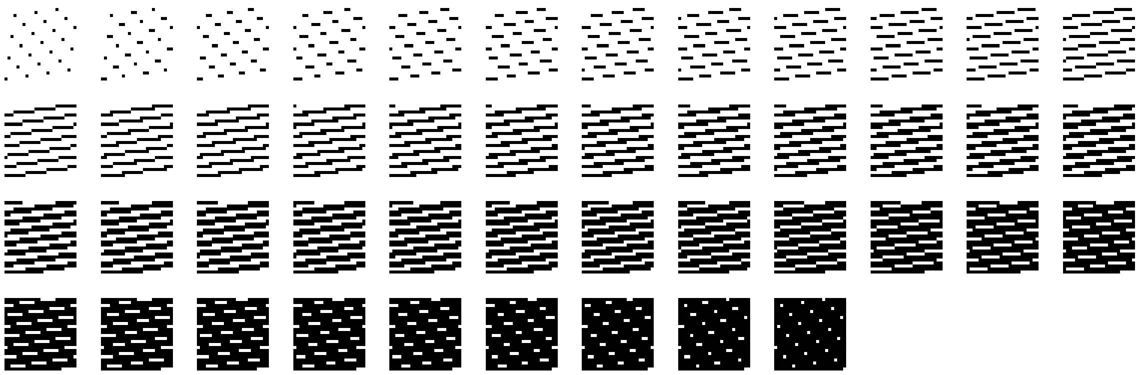
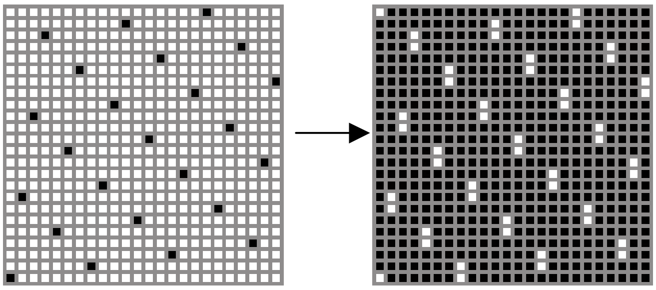


Figure 5-11. Gamut weaves designed for figuring thread.

The structure design of non-backed weaves for supplementary threads was approached with the design method of full-colour compound structure. In this case, the full-colour technical points were applied for joint weave directly, as shown in Figure 5-12.



Primary weave Joint weave

Figure 5-12. Design of joint non-backed weaves.

(3) Fabric Effect

Based on the application of basic gamut weaves and joint non-backed weave designed above, through appropriate combination method, i.e., combination proportion being 1:1 cross weft between colouring thread and supplementary thread, the black-and-white simulative fabric was produced. Figure 5-13 shows the real fabric created by the compound structure in which two threads were employed, i.e., black figuring weft and white supplementary weft. Due to the application of supplementary threads and corresponding full-colour structure, adjacent figuring threads arranged in juxtaposition are not being covered by each other. All the weave variations of figuring weft are displayed on the face of fabric. Moreover, since the supplementary thread is finer than the figuring thread, it can hardly be seen from the face side of fabric and thus does not affect the face effect of the fabric much.

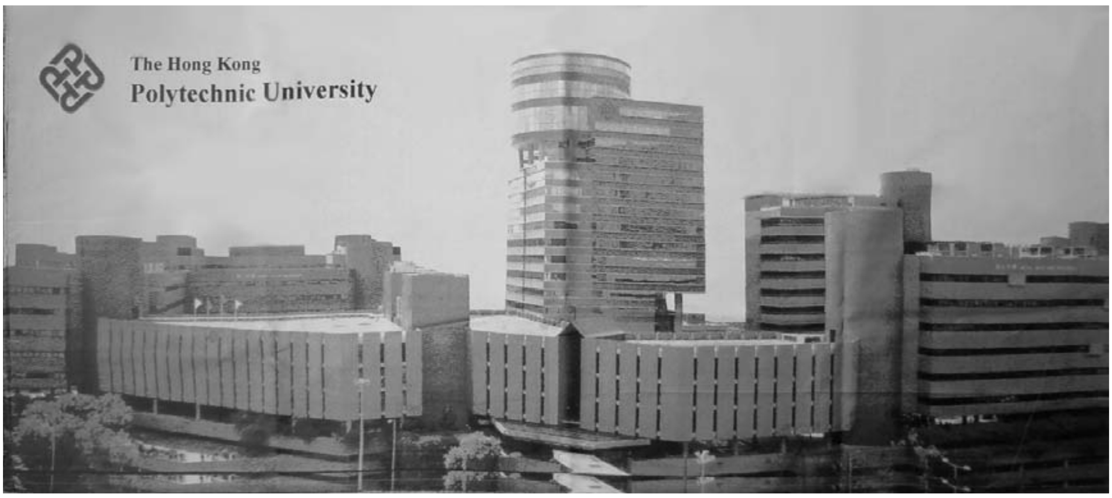
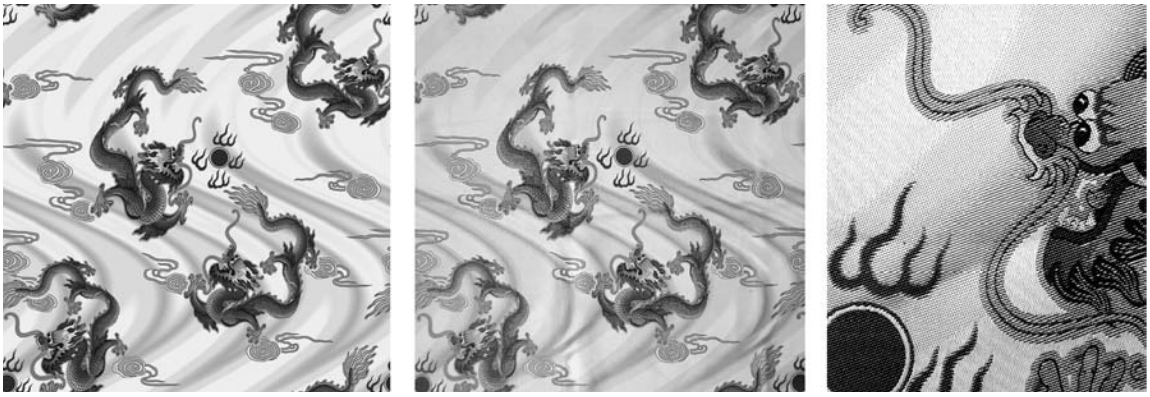


Figure 5-13. Fabric effect of simulative design with compound structure.

Given the aforesaid structure design principle, if the key fabric parameters remains unchanged, the designed gamut weaves and corresponding joint weave can be used for designing simulative effect fabric with any digital grey images. Figure 5-14 shows a design creation with decorative dragon motif. The image/fabric size is 6000 pixels/needles × 4704 pixels/fillings. Figure 5-15 shows another design creation with a portrait motif of an image/fabric size of 4000 pixels/needles × 2496 pixels/fillings.



(a) Original image (b) Fabric (c) Detail

Figure 5-14. Simulative design with dragon motif and compound structure.

(a) Original image (b) Fabric (c) Details

Figure 5-15. Simulative design with portrait motif and compound structure.

From the design creations of black-and-white simulative fabric designed with compound structure, it can be concluded that following the layered-combination design mode and design method of full-colour compound structure, the black-and-white simulative effect of jacquard fabric can be realised, and the fabric effect produced will be close to the true-to-original effect. On the other hand, given the application of two wefts of which one of them served as supplementary thread and the consideration of the covering effect between figuring and supplementary threads, the design method of simulative fabric with compound structure should be better applied to design creation with higher thread density and larger weave repeat of gamut weaves.

5.3 Design of Colourful Simulative Effect Fabric

In this study, the innovative design principles and methods of colourful simulative fabric was presented with the application of layered-combination design mode and full-colour compound structure.

5.3.1 Background

The colourful true-to-original fabric has been difficult to design manually due to the complex fabric structure. Thus, design creation of colourful simulative fabric has lagged behind in terms of advanced woven technology. With the application of computer aided design (CAD) system, the colourful jacquard fabric can be designed by mixing basic colours that enabled the number of mixed colours on the face of fabric to exceed hundreds. It opened a new chapter in the design of simulative effect fabric with the purpose of reproducing colour and pattern of the 2-D artwork. However, the simulative effect reproduced on jacquard fabric by CAD system was still unsatisfactory due to different theories of colour mixing and colour expression between 3-D woven fabric structure and 2-D artwork. In addition, the traditional plane design mode was employed as the basic design principle for jacquard fabric CAD system. Jacquard fabric was designed through designating basic colours of scanned digital image, and fabric structure was designed following a one-to-one corresponding principle (Zhou, 2006f). Yet, shortcomings are evident. Since secondary colours cannot mix to form a primary colour, the designated colours will lose some available colour information. Besides, when designing the structure upon designated colours with shaded weaves, it poses no problem in single-layer structure fabric. However, when designing compound structure by the combination of several single layer structures, the application of shaded weaves will lead to having some of the threads covered by one another. In order to reduce/remove the colour aberration, tailor-made pattern and weave structures are necessary for the design of colourful simulative fabric. Yet, the layout of the image and the number of colours will be restricted.

At present, there exists another design method available for designing colourful simulative fabric, i.e., using computer colour matching system (colour table way)(Li, 2004a; Osaki, 2001; 2003). The colourful simulative fabric can be approached more efficiently based on a fixed colour table. The design process start with the design of coloured fabric samples under designated fabric structure; and then, data of colour parameters are tested and collected for each sample by using the computer system to establish a corresponding colour table; finally, simulative fabric is designed through matching colours between colour table and colour image with the aid of the computer system. By doing so, it is possible to translate the colours of a given image into fabric structures accurately. Colour matching in a computer system is suitable especially for the computer programmed processing of true-to-original simulative effect fabric. However, due to the restriction of the colour space of colour table, such method is only used for designing fabrics with the same fabric specification. In case the technical parameters in the fabric specification varies, new colour samples and corresponding colour tables need to be reestablished, which is time-consuming indeed.

From the analysis stated above, it is evident that the key problem of colourful simulative fabric design lies in the structure design. Without an appropriate structure design method, compound structure of jacquard fabric that eliminates slippage and mutual covering between colour threads cannot be produced. The layered-combination design mode proposed for digital jacquard fabric design in this study proved to be a good solution for the innovation of structure design method of colourful simulative fabric. The application of layered-combination design method has enabled jacquard fabric to express mixed colours at mega level on the fabric surface. Moreover, compound full-colour structure with the colour threads arranged in juxtaposition displayed fully without slipping and covering (Zhou, 2007a). Such a design method governs the change of colour mixing of threads based on the variation of compound structures efficiently. Therefore, it is apparent that the innovative design of colourful simulative fabric can be realised so long as the problem of colour deviation caused by the difference in colour mixing principles between fabric structure and objective image could be solved. This will enable jacquard fabrics to imitate a digital image in its exactitude.

5.3.2 Design Principles and Methods

The colour threads of compound full-colour structure arranged in juxtaposition with even number groups are capable of expressing smooth colourful shading effect.

Accordingly, a kind of colour mixing theory suitable for the colour mixture of non-transparent threads of jacquard fabric has been established. With the change of floating length of threads, the juxtaposed colour threads can show multicoloured colour mixing effect. So long as the appropriate colour separation and colour combination methods for colourful digital image under the layered-combination design mode can be invented and optimized, the colourful simulative jacquard fabric created will be able to imitate the colour and image effect of digital image accurately.

5.3.2.1 Principles and methods of colour design

The colour principle of jacquard fabric based on colour mixing of non-transparent colour threads is different from the subtractive colour principle of transparent printing and the additive colour principle of computer screen display. Yet, they are common in showing mixed colours through limited primary colours.

Since mixing primary colours can produce secondary colours and tertiary colours but not vice versa, primary colours are the best selection for colour separation of digital image. For this reason, one of the main reasons for colour deviation caused in colourful simulative design is the use of non-primary colours. Since colour mixture of colour threads belongs to non-transparent colour mixture, whose colour mixing principle is different from that of RGB additive colour mode of chromatic light that consists of primary colours: red, green, and blue, CMYK subtractive colour mode for digital printing is the optimal selection for colour separation of digital image. In addition to primary colours for colour separation, another important result in this study is to have identified the optimal method that helped to eliminate the colour deviation caused in fabric design. In theory, M+Y=R，C+Y=G，C+M=B，C+M+Y=K. Yet, in practice, colour threads are arranged side by side instead of transparent overlapping. The frequent colour deviation of colour mixture in the simulative effect fabric design is a result of colour influence by surrounding colour threads and the difference in saturation of the primary colours of the material(s) used, notably between the dyed and mixed black. For this reason, resolving the problem of colour deviation during colour and structure design processes is the key in colourful simulative fabric design (Zhou, 2006f; 2007c).

The reason for colour deviation in black is that black thread cannot cover other colourful threads when mixing colour with juxtaposed threads. It results in the reduction of black ratio. Through design experiment, it was found that such a problem could be solved by grey component replacement technique. Grey component replacement, abbreviated as GCR, is a technique in digital printing processing for replacing grey tones made by mixing magenta, cyan and yellow by black ink (Hu, 1993; He, 2004). By using black to replace grey component formed by colours, the consumption of colour printing ink could be reduced. Since grey component replacement cannot affect the colour components of the original image, the colour effect of the printed image remains unchanged when applying the grey component replacement technique. The theory of grey component replacement for mixed colour is shown in Figure 5-16.

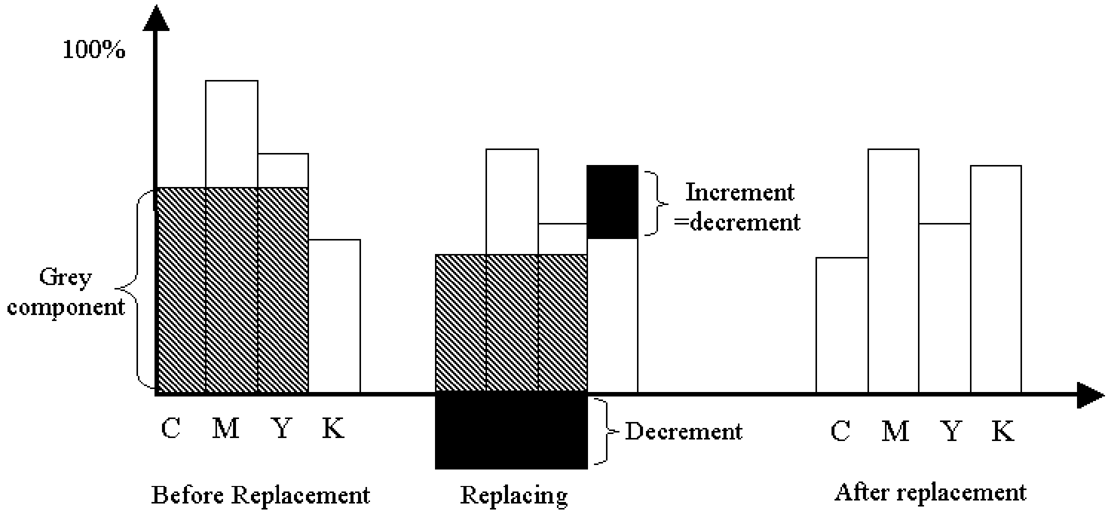


Figure5-16. Theory of grey component replacement.

When the grey component replacement is applied, the grey component formed by colours can be set apart from the colourful component. It is possible to increase the grey component of mixed colour that has no effect on the colour component of the original image. To this end, the innovated design method for colourful simulative fabric design is to separate the CMYK colours of digital images with different value of grey component replacement twice. The colour layers and the black layer are formed. After combining the CMYK layers that are designed by double separation, the compounded fabric structure will feature a unique colour character of grey component compensation. By adjusting the ratio of grey component replacement, the degree of grey compensation can be changed accordingly. Subsequently, the optimal grey effect of each layer is obtained (see Figure 5-17). In addition, as far as the problem of insufficient saturation of the primary colours found in mixed colours is concerned, the proper solution is to set three adjustable colour palettes of primary colours for selection of colour threads. The first colour palette ranges from magenta to red; second one from yellow to green; and the third one from cyan to blue. Moreover, in each colour palette, the grade of hue between two primary colours can be established based on practical design application. In some cases, the three adjustable colour palettes could have contained all the hues necessary for design creation of colourful digital fabric. However, in most design cases with a normal image, insufficient saturation found in mixed colour has little effect on the fabric. Thus, the application of CMY primary colours meets the requirements of most simulative effect design of colourful jacquard fabric. Only when special colour preference on red, green or blue primary colour, i.e., red, green or blue colour effect dominates in the digital image, would other colours in three colour palettes be selected for colour consideration and adjustment.

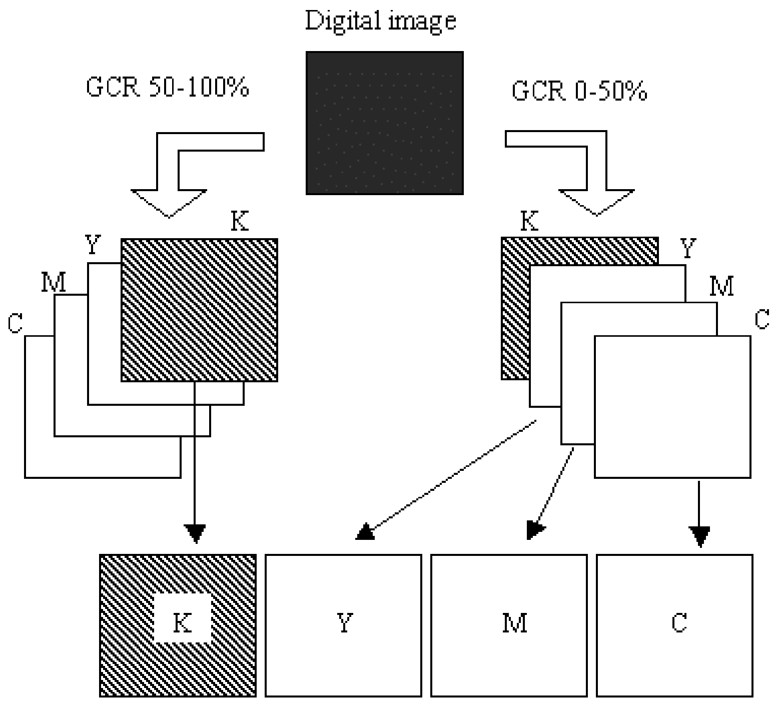


Figure 5-17. Method of grey component replacement via double CMKY separation.

5.3.2.2 Principles and methods of structural design

The colour effects of digital jacquard fabric are mixed by juxtaposing colour threads on woven structure, it is thus imperative to devise a reliable method of structure design that enables juxtaposed colour threads not to be covered by each other as a result of slippage of threads. The design method of compound full-colour structure proved to be a viable means to meet such technical requirement for expression of colourful effect with threads arranged in juxtaposition. Experiments confirmed that interlacing one group of white thread and four threads of CMYK primary colours in juxtaposition could produce a compound structure that was able to achieve colourful shading effect with full-colour presentation. It is similar to drawing a colourful image on white paper with only four colour threads, i.e., CKMY on woven structure. In addition, since the full-colour compound structure is stable and regular, the mixed colour on the face of fabric in each individual colour layer can be adjusted freely in pursuit of various design creations with any digital image.

In addition to the full-colour compound structure, another thrust arises from this study is to realise the accurate transformation between colour and fabric structure. Below are the detailed design methods of this transformation:

(1) Following the layer-combination design of digital jacquard fabric design from “colourless” mode to “colourful” one, the four images of CMYK generated through colour separation is transformed into grey images respectively in order to realise precise replacement between colour and fabric structure.

(2) The first step of structural design is to conceive and design primary weave and corresponding full-colour technical points based on the fabric specification. Then, the design of shaded weaves and establishment of full-colour basic weave-database and joint weave-database follow. When the weave number in each of the two weave-databases is N, value N represents the maximum number of grades of grey of digital grey images with brightness values ranging from 255 to 0, the maximum grey grades for each digital image is N.

(3) When N as the maximum value to merge with the grey scales of four grey images, the grey grades of each grey image could be different, yet, the maximum number of grey grades is N lest there will not be enough gamut weaves for replacement.

(4) When brightness value is taken as standard of replacement between greys and weaves, with the starting point being fixed, the grey scales in C and Y grey image could be replaced by basic weaves while the greys in M and K grey image could be replace by joint weaves. As a result, four colourless images with single-layer structure would be formed. They look like four irregular weaves with large weave repeat.

(5) When four single-layer structures designed from CMYK colourless images in

proportion of 1:1:1:1 cross weft is combined, a compound structure that exhibits full-colour effect would form, of which the precise true-to-original information of image and colour remain unchanged.

Together with weft selection, the compound structure produced can be used for producing four-weft true-colour simulative fabric directly. Normally, the colours of the wefts are CMYK while the colour of the warp is white. If colour effect needs to be adjusted, cyan or blue should be selected for the first weft thread; magenta or red for the second weft thread; yellow or green for the third weft thread; and black for the fourth weft thread. The warp thread colour remains white. In addition, if the compound structure simulative effect fabric is rotated by 90 degree, together with weft selection information, simulative fabric with four-group warps will be produced. However, the colour arrangement of threads should be transformed accordingly too, in which the warp thread colours are juxtaposed CMYK and the weft colour is white.

From the design principles and methods discussed above, it can be concluded that design of colourful simulative fabric by CMYK colours separated twice, colour threads employs CMY primary colours directly. If the applied digital images have special colour preference to red, green or blue colour, three adjustable colour palettes, i.e., magenta-red, yellow-green, and cyan-blue colour palettes are required to be set up for colour consideration and adjustment. In fact, the method of using adjustable colour palette benefits not only the design creation of simulative fabric, but also the design creation of innovative effect fabric based on simulative effect of digital jacquard fabric.

5.3.3 Design Illustrations

In order to explain clearly the design principles and methods introduced above, particular designs of colourful simulative fabric in both basic design and variant design with detailed technical fabric parameters and design processes are used for explanation. The merits of design creation with layered-combination design mode are highlighted.

5.3.3.1 Basic design of colourful simulative effect fabric

(1) Technical Specification

The key technical parameters of fabric are specified with the technical specification shown in Table 5-3. In this design case, the colourful simulative fabric was made by polyester materials and constructed with one white warp thread and four weft threads of CMYK primary colours; weft density was larger than warp density. It means that four weft threads dominate the figuring and colouring effect on the face of fabric. Since warp thread density is lower, the weave repeat of gamut weaves applied in fabric structural design was 16, and 53 gamut weaves were designed in each weave-database in terms of the design method of full-colour compound structure. In addition, the portrait motif was selected for the design creation of colourful simulative fabric.

Table 5-3 Technical specification of colourful simulative fabric.

	Parameters	
	Warp	**Weft**
Materials	1/166.7dtex polyester (white)	1/166.7dtex polyester (C/M/Y/K)
Density	45 threads/cm	90 threads/cm
Composition	Polyester 100 %	
Weave structure	16-thread gamut weaves, 53 grey grades	
Design repeat	1248 needles×2496 fillings	
Pattern repeat	22.01cm (width)×44.02cm (length)	
Weight	247.5 g/m^2	

(2) Design Processes

The design of colourful simulative fabric should be approached following the layered-combination design mode and the design method of full-colour compound structure. Based on the fabric technical specification, the design processes mainly consist of pattern design and structure design. In this case, in order to manifest clearly the application value of layered-combination design mode, a portrait motif together with a colourful shading effect background was applied to colourful simulative fabric design. The digital image is shown in Figure 5-18. The colour processing is shown in Figure5-19, in which CMYK digital colour mode was applied to colour separation and reproduction. The colour design method involved separating the digital image into the four layers CMYK twice with different percentage of grey component replacement, the corresponding CMYK can be obtained. In the first colour separation, the GCR was 0% and the three layers of CMY were selected; in the second colour separation, the GCR changed to 50%, and the black layer was selected. With the application of the technique of grey component replacement in colour separation, the saturation of achromatic colours was enhanced apparently while the colour component of CMY colours remained unchanged. Therefore, the achromatic colour effect reproduced on the face of fabric could be improved as well.

Figure 5-18. Digital image for basic design of true-colour simulation.

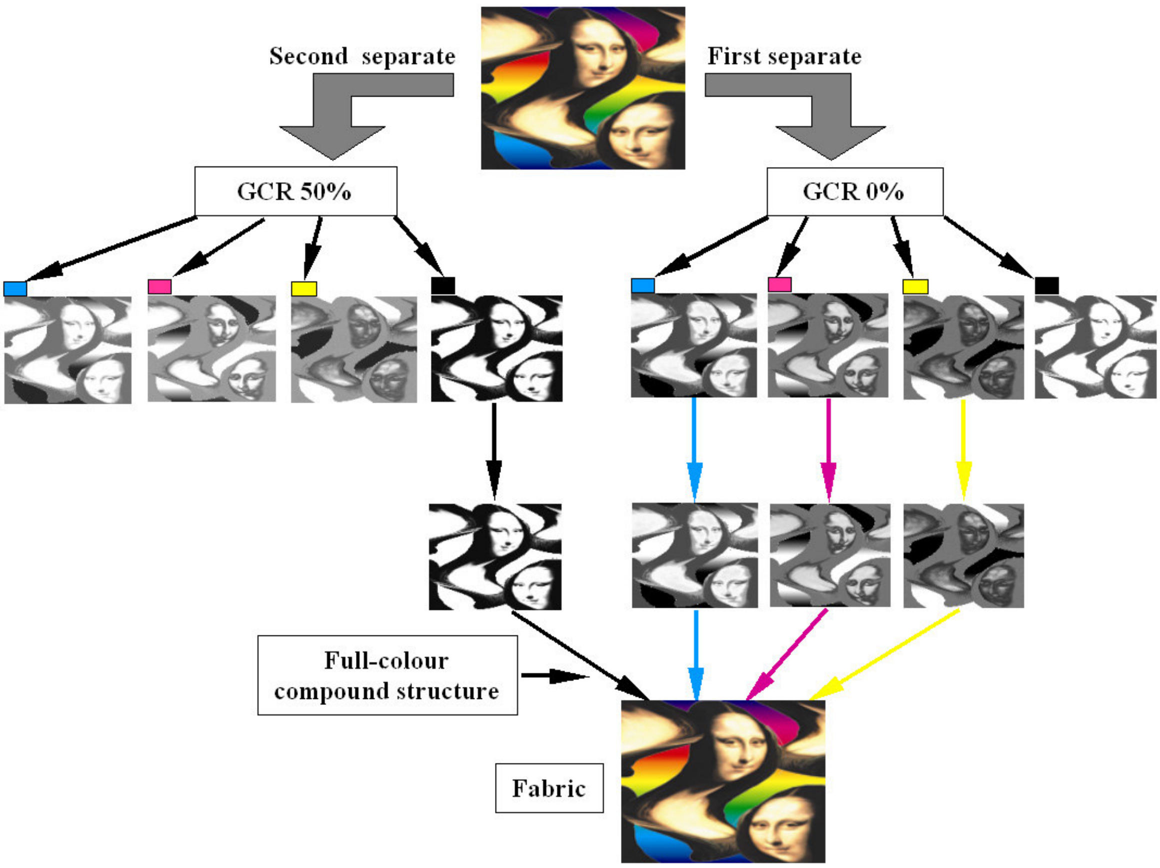


Figure 5-19. Colour processing for separation and reproduction.

The colour theory and method of colour separation mentioned above is suitable for producing true-colour simulative digital jacquard fabric. However without certain method of structural design, any simulative effect design of jacquard fabric cannot be kept away from colour aberration; therefore, the appropriate structure design method lays the most important foundation for the design creation of true-colour simulative fabric. Thanks to the innovative design method of full-colour compound structure that made it possible to design non-backed compound fabric structure constructed with 4 juxtaposition threads arranged in the proportion of 1:1:1:1. If a group of threads with four primary colours were interlaced with one white thread, such a compound full-colour structure would be capable of expressing true-colour simulative effect of digital colour image. According to the fabric parameters specified in Table 5-3, in this design case, 16-thread satin has been applied to design gamut weaves and full-colour compound structure, basic gamut weaves were shown in C16-4w-j53 of Appendix A.2, and corresponding joint gamut weaves were shown in C16-4w-j-z53 of Appendix A.2. The basic gamut weaves were used to design single-layer structures of the C and Y layers, and joint gamut weaves were applied to the M and K layers; after the combination of the four CMYK single-layer structures, a compound fabric structure took shape. Figure 5-20 shows detailed partial effect of compound structure.

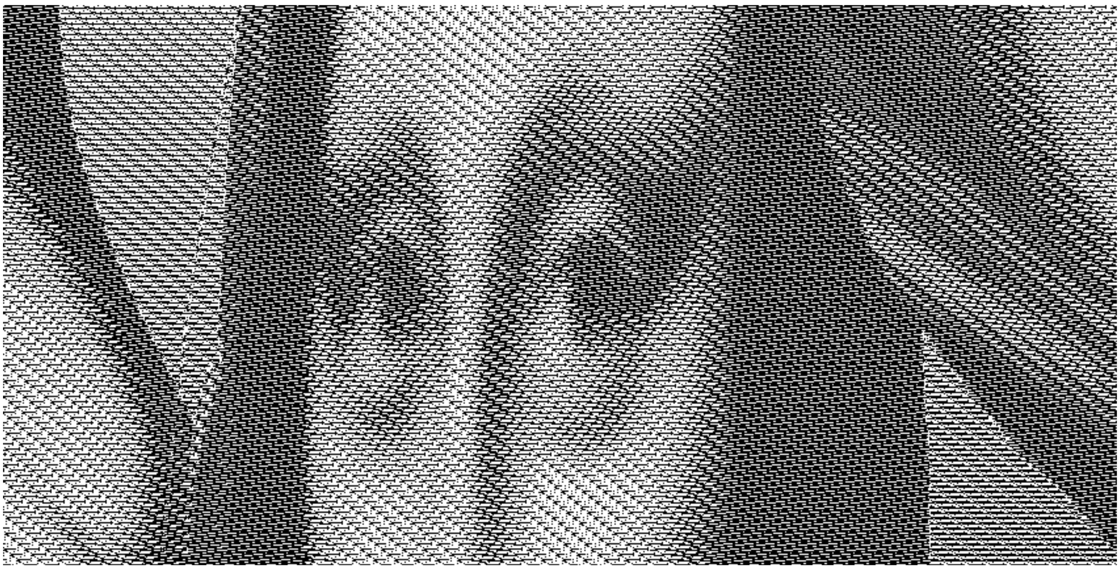


Figure 5-20. Detailed partial effect of compound fabric structure.

(3) Fabric Effect

The colourful simulative fabric was produced by using one white warp thread and four weft threads of CMYK primary colours. The fabric effect is shown in Figure 5-21 (colour plate C.2 in Appendix C). In comparison with the original digital image, the simulated effects of the final fabrics are satisfactory, though colour saturation is still defective, especially for the black. From the design illustration introduced, the conclusion can be drawn safely that full-colour compound structure designed according to the digital colourful mode benefited well the design of true-colour simulative fabric. Moreover, it proved that if the major fabric technical parameters remain unchanged, the designed basic and joint gamut weaves could be used to create colourful simulative fabric with any digital image. It is of great benefit in reviving the potential of the textile designer and in broadening the design space of fabric creation.

It also should be noted that due to the difference of colour mixtures between jacquard fabric with full-colour compound structure and art objects such as paintings, prints and photographs, the mixed colour effect of jacquard fabric cannot fully reach the same colour saturation as that of the original digital image. Therefore, the nature of the reproduced fabric is a kind of relative imitative effect embodied by the unique feature that belongs to woven structure only. In other words, the owning nature cannot be ignored in the design creation of simulative jacquard fabric; it may highlight the fascination of digital jacquard textile design under layered-combination design mode.

Figure 5-21. Fabric effect of colourful simulative design.

5.3.3.2 Design variation of colourful simulative fabric

In addition to the basic design illustrated above, interesting design variations based on the simulated effect produced by the basic design are introduced, which highlight the superiority of digital jacquard textile design under layered-combination mode.

(1) Technical Specification

The design variations of colourful simulative fabric were approached with the higher fabric density and silk threads in both warp and weft directions. The key technical parameters of fabric are listed in Table 5-4. The digital image selected for design creation is the same as that of the basic design.

Table 5-4 Technical specification of design variation of colourful simulative fabric.

	Parameters	
	Warp	**Weft**
Materials	22.2/24.4dtex×2 silk	22.2/24.4dtex×5 silk (C/M/Y/K)
Density	115 threads/cm	90 threads/cm
Composition	Pure silk 100 %	
Weave structure	24-thread gamut weaves, 85 grey grades	
Design repeat	12000 needles×9600 fillings	
Pattern repeat	104.3 cm (width)×106.6 cm (length)	
Weight	175 g/m^2	

(2) Design Processes

Given the basic design of colourful simulative fabric, the variant design could be made through the change of layered-combination fabric structure. It embodies the merits of the layered-combination design mode and the capability for the designer to produce digital jacquard fabrics with picturesque effects that is otherwise impossible to be achieved by the traditional plane design mode. Since the layer-combination fabric structure is a kind of compound structure featuring full-colour effect, changing the disposition of fabric structure in each layer will generate a series of creative effects that exhibit various unique woven effects. Figure 5-22 shows the real fabric effect based on the colourful simulative effect design. It was approached through the employment of weft threads of CMYK colours. The design method was to reduce the colour layer gradually from four layers of CMYK (true colour effect) to none (no colour layer). As a result, a total of 16 colour effects were created within one motif. Similarly, Figure 5-23 shows another creative fabric effect based on the same basic simulation design. In this example, the design method changed to one with the four colour layers of CMYK being gradually reversed from one layer to four layers (reversed effect). By doing so, 16 colour effects within one layout were created.

MYK	MY	Y	YK
MK	M	None	K
CMK	CM	C	CK
CMYK	CMY	CY	CYK

Figure 5-22. Variant design by reducing colour layers.

CMYK	CMYK	CMYK	CMYK
CMYK	CMYK	Reversed	CMYK
CMYK	CMYK	CMYK	CMYK
CMYK	CMYK	CMYK	CMYK

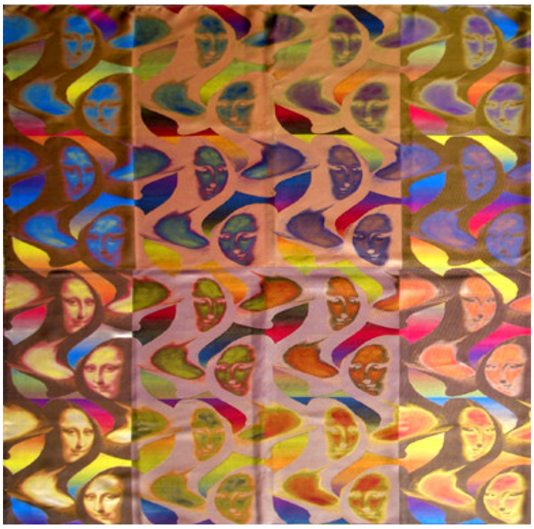


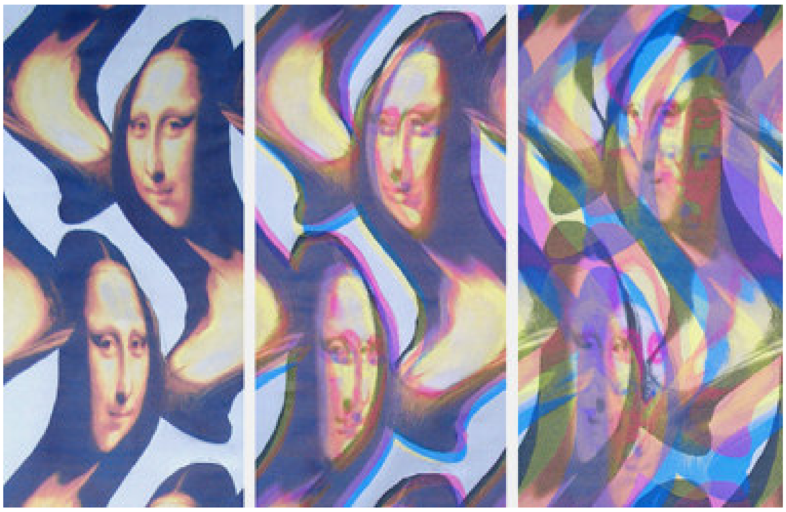
Figure 5-23. Variant design by reversing colour layers.

In addition, based on the design results of the two creations shown in Figure 5-22 and Figure 5-23, it is possible to create a design by means of integrating the 32 fabric effects. Relatively sophisticated integrative fabric effects can be further realised by manipulating these 32 effects. The interesting fabric effect created by such a method is shown in colour plate C.3 of Appendix C. These effects expanded the creative scope of novel art style for jacquard fabric through woven structure.

Figure 5-24. Variant design by integrative method of changing layer.

Since the full-colour effect of compound structure is determined by the design methods of gamut weaves and the combination methods of single-layer fabric structure, the change of applied image has no affect on the structure of full-colour non-backed compound fabric. In addition to the variant design realised by changing the deployment of layered compound structure in a manner of fixed position, the fabric effect produced by the basic design method of true-colour simulative effect can also be altered through shifting individual layers of a compound structure. By doing so, the subsequent fabric created can exhibit various combined fabric effects. Figure 5-25 (colour plate C.4 in Appendix C) shows the fabric effect of the variant design by shifting the layers of compound structure. In Figure 5-25, (a) is the original fabric effect designed by the basic method of true-colour simulative fabric; (b) is the fabric effect designed by slightly shifting individual layers of the compound structure; and (c) is the fabric effect designed by considerably shifting individual layers of the compound structure.

From the design variations of colourful simulative fabric presented above, it is not difficult to realise the potential applications of the layered-combination design mode proposed in this study. For example, it can be applied not only to the colourful simulative design targeting true-to-original simulation, but also to the realization of the many variant designs of innovative jacquard fabric. By such a structure, the fabric effect of jacquard fabric has achieved a much wider scope of simulation and innovation than what traditional jacquard fabric could conceive and realise. Last but not the least, the fabric effects obtained from variant designs of simulative fabric cannot be copied by other means of artwork due to the inimitable digital fabric structure and random colour expression.



(a) (b) (c)

Figure 5-25. Variant design by shifting the layers of compound structure.

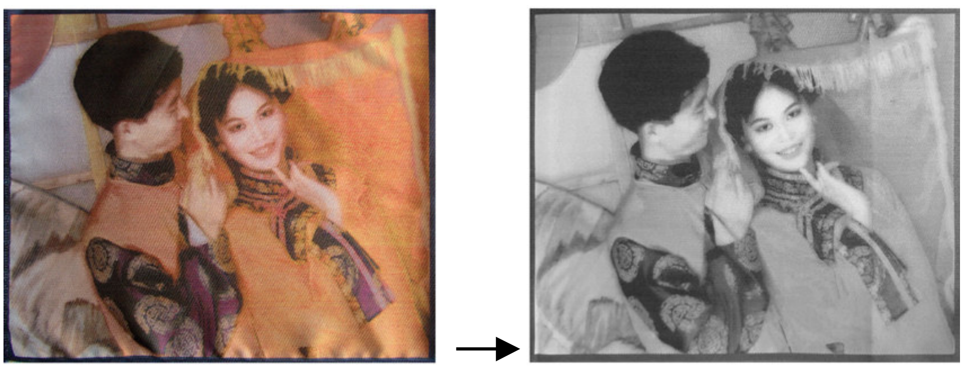
5.4 Simulation Design from Colourful Effect to Black-and-white Effect

In addition to the two design methods of black-and-white simulative fabric introduced above, following the design method of colourful simulative fabric, it is possible to design black-and-white simulative fabric based on designed compound fabric structure of colourful simulative fabric directly. As to the design of the digital image, decolourising a colourful digital image can produce a grey digital image. Similarly, when weft colours of colourful simulative fabric are transferred into grey scales with the same levels of brightness and under the same fabric structure, black-and-white simulative fabric would be produced from a colourful simulative fabric without any additional structural design procedure. Following this idea, the appropriate design illustration was approached to produce the black-and-white simulative fabric directly from the structure of colourful simulative fabric. Table 5-5 shows the technical specification of fabrics with both true-colour effect and black-and-white effect.

Table 5-5 Technical specification of fabric from colourful to black-and-white.

	Parameters	
	Warp	**Weft**
Materials	22.2/24.4 dtex×2 silk	22.2/24.4×2 dtex silk (CMYK-greys)
Density	115 threads/cm	160 threads/cm
Composition	Pure Silk 100 %	
Weave structure	24-thread gamut weaves, 85 grey grades	
Design repeat	4000 needles×4416 fillings	
Pattern repeat	34.8 cm (width)×27.6 cm (length)	
Weight	141.5 g/m^2	

The fabric was made by pure silk threads and has higher thread density in both warp and weft directions. The design processes are the same as that of colourful simulative fabric, accomplished by colour separation and combination of CMYK primary colours; however, in the course of fabric production, four grey colours were employed to replace the CMYK primary colours respectively with the same levels of brightness, and applied to fabric production. That is to say, four grey colours instead of CMYK primary colours produced the fabric notwithstanding the fact that the fabric structure was designed in CMYK true-colour mode. Figure 5-26 (colour plate C.5 in Appendix C) shows the fabric effect of both true-colour and black-and-white simulative fabric.



True-colour effect　　Black-and-white effect

Figure 5-26. Simulative fabric effects from true-colour to black-and-white.

5.5 Summary

In this chapter, based on the application of layered-combination design mode, the innovative design methods on true-to-original effect jacquard fabric, both of black-and-white simulative effect and colourful simulative effect, are introduced with illustrations. Several valuable results have been obtained based on the practice-led design research of simulative effect design of jacquard fabric, inspiring further attempts at design creation of digital jacquard textile under layered-combination design mode. For black-and-white simulative effect, three available design methods were introduced: design with single-layer fabric structure, design with compound fabric structure, and design by decolourising colourful simulative design. Based on the results of research on the design of black-and-white simulative fabric, it is concluded that for lower density fabric design, the design method of single-layer fabric structure is the optimal selection, whereas for design of black-and-white simulative fabric with higher thread density, the design method with compound fabric structure of both two threads and four threads proven to be the most ideal. As for colourful simulative effect, in order to resolve the problem of colour deviation generated during true-to-original colourful simulation, the present research proposed a series of resolutions that include grey scale compensation via double colour separation, precise transformation between colours and structure, and setting adjustable colour palettes for basic colour selection.

In addition, since both black-and-white and colourful simulative design are required to be processed on structure design method, it has been proved that the mixed colour effects constructed with warp and weft threads are firm and stable on the face of fabric, thus allowing such fabric structure for industrial manufacturing. So long as the fabric specification is planned thoroughly before design and production, and corresponding weave-databases of gamut weaves are built, there is literally no restriction in the selection of digital images. Therefore, the results achieved from this study hold promising prospects for wide creative and commercial applications. In short, from the research on the design of simulative effect of digital jacquard fabric presented in this chapter, the application value and technological advancement of the proposed layered-combination design mode for simulative jacquard fabric of both black-and-white and colourful effects has proved to be a powerful creative and productive tool of high commercial values, and has inspired future research in this direction.

CHAPTER 6
DESIGN CREATIONS WITH INNOVATIVE EFFECTS

6.1 Introduction

Traditional jacquard fabric design has been designed and produced only mechanically to imitate the colour and pattern effects of freehand paintings due to the complicated design process and the complex fabric construction. The proposed layered-combination design mode for digital jacquard fabric has made possible the design and production of jacquard fabric digitally. As a result, the complex fabric construction was regulated systematically and the respective complicated design process became much more fluent and efficient, and in turn contributed significantly to the innovative design and production of digital jacquard fabric.

Shot-effect fabric and double-faced fabric are unique varieties of traditional jacquard fabrics. The artistic effects cannot be imitated by any other means of artwork. In this chapter, with the application of layered-combination design mode and full-colour compound structure, the innovative design methods for novel figured shot-effect and figured double-face effect digital jacquard fabrics were deliberated with detailed design illustrations and valuable fabric technical specifications. In addition, in the course of this practice-led design research, the digitisation-based design procedure of innovative digital jacquard fabric was introduced from basic design to variant design. The creative values and commercial viability of the proposed digital design methods in comparison with the traditional one were confirmed.

6.2 Innovative Design on Figured Shot-effect Fabric

Shot-effect fabric is woven with a warp of one colour and a weft of a contrasting colour by using dyed yarns. Shot-effect is usually associated with the fabrics of plain or 2/2 twill weave, e.g., chameleon taffeta (Denton, 2002). Due to the simple fabric construction, it is impossible to produce a figured shot-effect fabric under the traditional plane design mode. Based on the layer-combination design mode and the application of full-colour compound structure, this study researches on the design creation of digital jacquard fabric that features novel figured shot-effect by using layered-combination design method and full-colour compound structure. With the two digital images that feature relationship of reversed negative, the fabric construction of figured shot-effect is realised.

6.2.1 Background

Literature defines shot-effects as a variety showing special effect among woven fabrics. The warp and weft of such fabric are interlaced with contrasting colour threads. In three-dimensional woven structure, the colour ratio of warp and weft constructed in fabric could be changed under different angles of view, and in turn led to the change of colour effect of the fabric, i.e., the fabric appears to be of one colour from one point of view and of another colour from another point of view. Moreover, from a structural design point of view, traditional shot-effect fabric is constructed with single layer structure in plain weaves by the employment of luster threads with contrasting colour effect in a group of warp and weft, e.g., plain weave or variations of plain weave. The colour threads of warp and weft are arranged in different directions and are not covered by each other, and when they are viewed from different angles, the colour ratio of the warp and weft threads changes accordingly. In the case when contrasting colours are employed, the changing effect of mixed colours is exhibited on the face of the fabric. This effect is named as "shot-effect" of woven fabric. For simple weaves and single-layer fabric structure, only plane shot-effect without any pattern effect is exhibited. Experiments revealed that "figured" shot-effect on fabric could be achieved with complex jacquard weaving. Under the traditional plane design mode, the objective of jacquard fabric design was only to imitate the colour effect of freehand patterns by appropriate woven structure. Even when complex backed weaves and double-layer weaves were used for designing fabric structure, and since such complex weaves were constructed by the combination of primary weaves in a single manner, the compound fabric structure created in this manner showed but singular mixed colour effect in which the interlacing points were covered by each other. Thus, it is not yet possible to realise figured shot-effect fabric design that shows complicated patterns and shot-effect.

6.2.2 Basic Design Concept

With the proposed layered-combination design mode for digital jacquard fabric, and in particular, the invention of the design method for full-colour compound structure, the technical deficiency aforementioned might be overcome. The basic design concept is that, following the design method of full-colour compound structure, two single-layer fabric structures are designed separately based on a digital grey image and its negative grey image. By combining the two single structures, the compound structure of the fabric created would result in full-colour effect in which the colour ratio of the threads arranged in juxtaposition can be changed freely. By employing threads with contrasting colours, multicoloured shot-effect jacquard fabric could be realised. Differing from the traditional short-effect fabric with contrasting colours arranged in different directions, the new jacquard fabric has pairing threads with contrasting colours arranged in the same direction. In addition, the application of full-colour compound structure enables colour threads interlaced in fabric construction to exhibit smooth colour shading. Fabric produced by such structure is capable of expressing a figured shot-effect with both contrasting figures and contrasting colours when fine luster colour threads are being used.

6.2.3 Design Principles and Methods

6.2.3.1 Principles and methods of colour design

The colour mixing of jacquard woven fabric is a non-transparent colour mixture. It differs from that of transparent printing colours or computer colours. The mixed colours on the face of fabric will change when they are viewed from different angles since woven structure is formed by solid interlacement, i.e., up & down construction of warp and weft threads. Therefore, when designing traditional shot-effect fabric, plain weave or variant plain weave was usually employed to produce such changing colour effect, in which the warp thread and weft thread featured contrasting colours with fixed colour ratio in fabric construction. Although two contrasting colours are arranged in different directions, the amount of colour (the sum of floating length with contrasting colours) on the fabric surface is a constant. Viewed from different angles, due to the solid interlacing structure, the colour ratio of contrasting colours is varied while the amount of colour remained nearly unchanged. When certain contrasting colours of warp and weft threads with luster are arranged, shot-effect would result. Given the design principles and methods of layered-combination design mode, under the colourless design mode, the digital jacquard fabric with smooth black-and-white shading effect could be realised. Mega level mixed colours on the face of fabric could be produced when several single-layer digital jacquard structures are combined. If particular negative effect were handled on pairing digital images, superimposition of original grey digital image and its negative image would create a combined colour image of which the colour value is a constant. Since the combination of several images consisting of original grey images and its negatives in pairs, the mixed colour effect is thus equal to the single colour effect. In other words, the mixed colour effect of an original grey image and its reverse is like to be separated from a single colour one (Figure 6-1). In fact, the combination of figured shot-effect is a kind of structural combination, of which the weaving pattern of each image remains self-juxtaposing without any overlapping with each other.

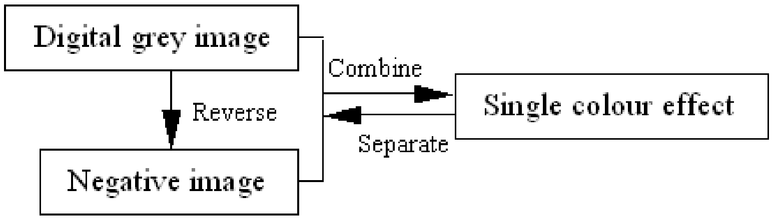


Figure 6-1. Colour design principles and methods of figured shot-effect.

Based on the colour design principles and methods stated above, attempt was made to resolve the key technical problem of colouring principle to show shot-effect and figure effect. It was found that so long as the appropriate structure design methods were introduced to arrange the contrasting colour threads in juxtaposition with equal colouring sum and that the threads are not covered, shot-effect would be produced. Meanwhile, the figured effect could be realised through the change of colour ratio of contrasting colours. As a result, the duo effects of colour contrast and figured contrast are present simultaneously in the compound fabric structure. Digital jacquard fabric produced by such construction exhibits novel and interesting figured shot-effect.

6.2.3.2 Principles and methods of structure design

Research on colour design principles of shot-effect fabric indicates that the colouring sum of threads with contrasting colours being a constant laid the foundation for producing shot effect. The selection and application of threads with different contrasting colours and luster only changed the degree of shot-effect. The key aspect for innovating shot-effect fabrics lies in the structure design. In order to produce fabric with figured shot-effect, it is essential for the design method of jacquard fabric to be used instead. Since the jacquard fabric with single-layer structure is figured by single warp and single weft, the figured shot-effect will be produced when weaves of shading effect are employed, Yet, only one pattern will be shown. In order to produce more figures with contrasting colour effects, the compounded complex weave must be employed in the structural design. Since the traditional jacquard fabric was designed by plane design mode, with complex structures such as backed structure and double-layer structure being designed with mutual covering effect, the basic technical requirement for figured shot-effect could not be satisfied and figured shot-effect design could not be produced. The design of figured shot-effect fabric can only be made possible by the layered-combination design mode and with the design method of full-colour compound structure. Since the full-colour compound structure requires the grouping threads to be arranged in the same direction and in even number, the fabric structure of juxtaposed colour threads of the figured shot-effect jacquard fabric must be arranged in the proportion of 1:1 pairing (Zhou, 2007b).

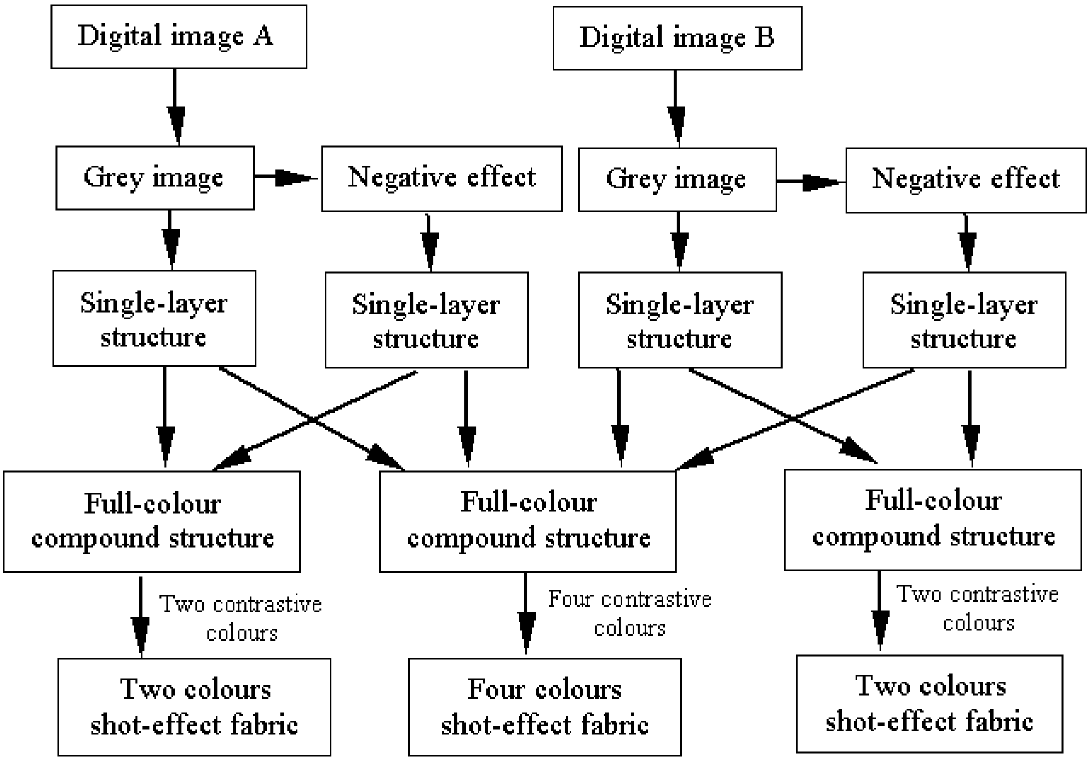


Figure 6-2. Structure design processes of figured shot-effect digital jacquard fabric.

As shown in Figure 6-2, the digital image A and B can be separated into two images with reciprocal relation, i.e., original grey image and its reversed image. Thus, there will be two pairs of grey images. With the fixed replacement between grey scales and weave structures, the structural design for the two pairs of grey images forms four single-layer structures. Combining these four single-layer structures produced a four-layer compound structure, in which the effect of mutual moving and covering of the juxtaposed threads could be avoided. The sum of floating length of each pair of threads in the compound structure remains constant. By doing so, the basic requirement of shot-effect fabric design can be met. In addition, since the colour ratio of the juxtaposed threads in full-colour structure can be changed, the figured effect in such compound fabric structure can be realised. As a result, the figured shot-effect jacquard fabric with two-colour effect can be designed upon either digital image A or B, in which the threads with contrasting colours should be arranged in juxtaposition alternately. When shot-effects of image A and B are merged in one full-colour compound structure, the figured shot-effect jacquard fabric with four colours featuring both the contrasting figure effects and the shot-effects can be produced.

6.2.4 Design Illustrations

Giving the design principles and methods of figured shot-effect digital jacquard fabric, appropriate illustrations were introduced. It helped to describe clearly the design methods and at the same time highlighted the advantages of digital jacquard textile design in a layered-combination mode.

6.2.4.1 Design creation with objective motif

The image motif for figured shot-effect digital jacquard fabric can be divided into two types: objective motif or abstract motif. In this design, objective motif was used.

Table 6-1 Technical specification of figured shot-effect fabric with objective design.

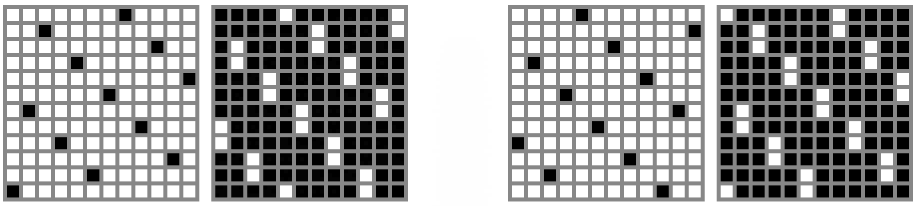
	Parameters	
	Warp	**Weft**
Materials	1/166.7 dtex polyester (white)	1/166.7 dtex polyester (dark/dark/light/light)
Density	45 threads/cm	90 threads/cm
Composition	Polyester 100 %	
Weave structure	12-thread gamut weaves, 37 grey grades	
Design repeat	1248 needles × 4096 fillings	
Pattern repeat	22.01 cm (width) × 45.5 cm (length)	
Weight	247.5 g/m^2	

(1) Technical Specification

Based on the production condition and the design motif, details of the major technical parameters of fabric and technical specifications are shown in Table 6-1. According to the major technical parameters, the final fabric was constructed by 12-thread gamut weaves with lower thread density warp-wise and higher thread density weft-wise. This fabric employed polyester threads both in warp and weft direction.

(2) Design Processes

In this case, 12-thread weave was used to design a full-colour structure and weave-database. In line with the design requirements of full-colour structure, weft-face sateen of 12-thread and 5 step was selected for primary weave, and the starting point of primary weave I was (warp, weft)=(1,1) in lower left while the starting point of primary weave II was (warp, weft)=(10,1) moved from the lower left. Firstly of all, according to the character of primary weave II, the full-colour technical points for primary weave I were set up while the full-colour technical points for primary weave II were set up in terms of the woven character of primary weave I (see Figure 6-3). A group of shaded gamut weaves based on primary weave I was then designed. The enhanced weave points once was 3; in order to make weaving points continue, the enhancement direction should be right first and then left, skipped when the full-colour technical points was encountered. In doing so, a group of basic gamut weaves that had 37 shaded effects was formed and a weave-database was established (see Ac12-3w-z-y41 of Appendix A.1). Similarly, a group of shaded weaves based on primary weave II was designed with its enhancement direction being left first and then right, skipped when the full-colour technical points were encountered. A group of joint gamut weaves that had 37 shaded effects was formed, and corresponding weave-database was established (see Ac12-3w-z-y41-9 of Appendix A.1).

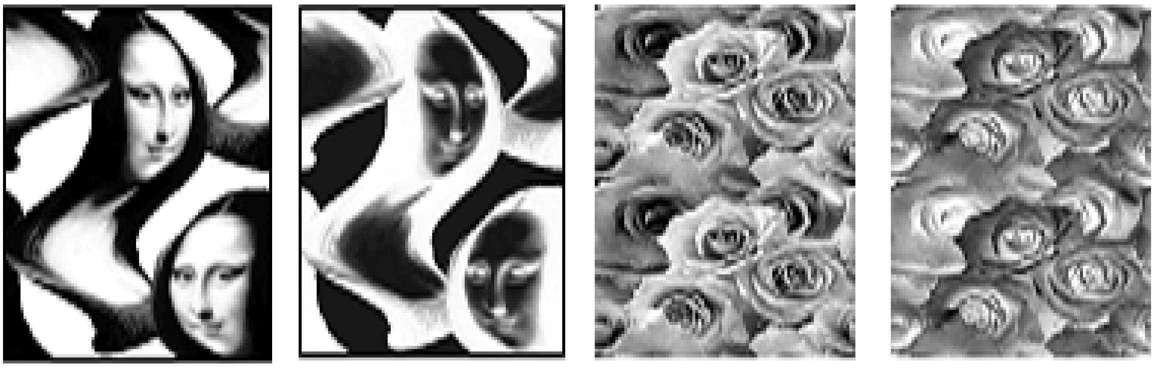


(a) (b)

(a) Primary weave I and full-colour points.
(b) Primary weave II and full-colour points.

Figure 6-3. Design of primary weaves and their full-colour points.

Below are digital grey images A and B in bitmap format (Figure 6-4). The corresponding digital grey images A1 and B1 were generated by reversing the grey scales of Image A & B respectively. In order to accord with the character of the weave-database, the grey scale of each grey scale image should be adjusted to less than 37 grades lest there would be a lack of available weaves for the structure design.



(a) Image A (b) Image A1 (c) Image B (d) Image B1

Figure 6-4. Digital images of design with objective design.

(3) Structure Combination and Fabric Effect

Fixing the replacement relationship between the grey scale in the digital grey images and gamut weaves, i.e., black colour corresponding to the maximum warp-face weave and white colour corresponding to the maximum weft-face weave in weave-database, requires that the corresponding grey scales of grey images A and B to be replaced by the basic gamut weaves under the same starting point. When the corresponding grey scales of A1 and B1 were replaced by the joint gamut weaves under the same starting point, four single-layer fabric structures were formed. These four single-layer structures were then combined in the proportion of 1:1:1:1 weft-wise. So long as the single-layer structures designed from basic gamut weaves or joint gamut weaves were lined alternately, the interlacing points in the compound structure of the fabric would not be covered by each other, and the full-colour compound structure embracing two figured information took shape. Applying two groups of contrasting colours, the figured shot-effect fabric with four colours and two individual images was produced (see Figure 6-5, also colour plate C.6 in Appendix C).

Since the compound full-colour structure features balanced interlacement, compound structure designed can be applied directly to the production of multi-weft figured shot-effect fabric. It can also be rotated 90 degree for production of multi-warp figured shot-effect fabric. In addition, the structure design of figured shot-effect jacquard fabric and the selection of colour threads are independent regardless of the design of the digital image. It means that digital images of any image design could be employed for creation of digital jacquard fabric with figured shot-effect.

Figure 6-5. Effect of figured shot-effect digital jacquard fabric with objective design.

6.2.4.2 Design creation with abstract motif

The said design processes excel itself in creation with abstract image since the shot-effect of the fabric created will be better than that of design creation with objective image due to the random disposition and combination of the threads with contrasting colours.

Table 6-2 Technical specification of figured shot-effect fabric with abstract design.

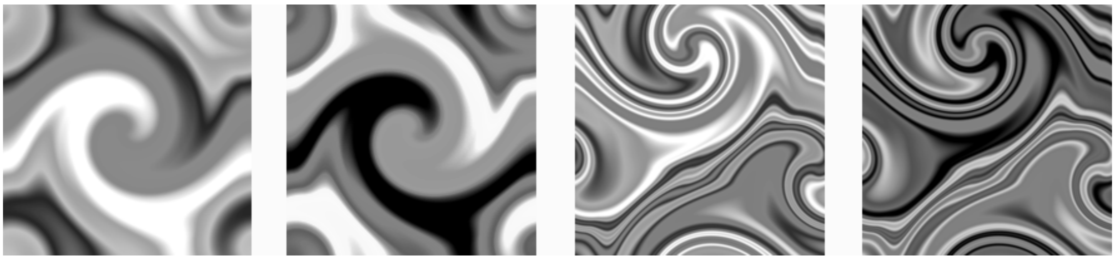
	Parameters	
	Warp	**Weft**
Materials	22.2/24.4dtex×2 silk (white)	22.2/24.4 dtex×5 silk (red/yellow/green/blue)
Density	115 threads/cm	90 threads/cm
Composition	Pure silk 100 %	
Weave structure	24-thread gamut weaves, 85 grey grades	
Design repeat	6000 needles × 4800 fillings	
Pattern repeat	52.2 cm (width) × 53.3 cm (length)	
Weight	175 g/m²	

(1) Technical Specification

The major technical parameters of fabric in this case are listed in technical specification in Table 6-2. The final fabric was constructed with pure silk threads. It features higher thread density than that of polyester fabric previously introduced. Moreover, 24-thread gamut weaves were employed for fabric structural design to be in line with the technical parameters of fabric.

(2) Design Processes

In structure design, 24-thread weft-face sateen with 7 step was applied to designing a full-colour structure and weave-database. The starting point of weave was determined as the lower left (warp, weft)=(1,1) and (warp, weft)=(20,1) respectively to form two primary weaves. According to the character of the two primary weaves, full-colour technical points could be set up for gamut weaves designing. With same 85 grades of gamut weaves, the basic gamut weaves and joint gamut weaves are designed and shown in C24-7w-j89-y-z and C24-7w-j-z89-z-y of Appendix A.3 respectively. Similar to the design processes of designing with an objective image, full-colour compound fabric structure can be designed further. According to the requirements of designing four-colour shot-effect fabric, digital grey images A and B and their reversed negative grey images were created and are shown in Figure 6-6.



(a) Image A (b) Image A1 (c) Image B (d) Image B1

Figure 6-6. Digital images of design with abstract design.

(3) Structure Combination and Fabric Effect

Fixing the replacement relationship between the 85 grey scales in the digital grey images and 85 gamut weaves, i.e., the black colour corresponding to the maximum warp-face weave and the white colour corresponding to the maximum weft-face weave in weave-database, the grey scales of grey images A and B were replaced by the basic gamut weaves under same starting point while the grey scales of A1 and B1 were replaced by the joint gamut weaves. Therefore, four single-layer fabric structures were formed. These four single-layer structures were then combined in the order of 1:1:1:1 weft-wise. So long as the single-layer structures designed from basic gamut weaves or joint gamut weaves were lined alternately, the interlacing points in the compound structure of fabric would not be covered by each other. The full-colour compound structure embracing two figured information took shape. With two groups of contrasting colours applied, the figured shot-effect fabric with four colours and two individual images were produced (Figure 6-7, also colour plate C.6 in Appendix C). Since the full-colour structure applied in figured shot-effect fabric featured non-backed and full-colour effects, the colour effect on the face of fabric was reversed to that of the reversed side. Both sides of the fabric exhibit figured shot-effect, yet with the colour configuration reversed.

Figure 6-7. Effect of figured shot-effect digital jacquard fabric with abstract design.

The figured shot-effect jacquard is one of the important creations designed in a layered-combination mode. Such digital fabric exhibits both contrasting colour and figure effects. Moreover, the smooth colour shading effect produced on the face of fabric is similar to that of printing textiles. The novel figured shot-effect is far beyond what flat printed textile can express. It optimizes the artistic quality of woven fabrics that cannot be replaced and reproduced by any other means of artworks.

6.3 Innovative Design on Figured Double-face Effect Fabric

6.3.1 Background

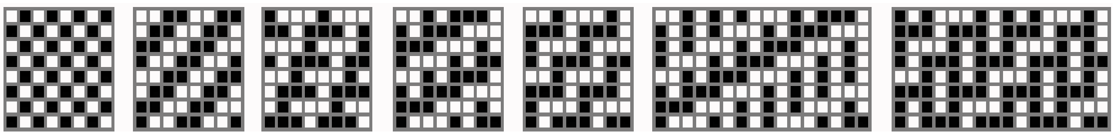
Double-face effect fabric is a special variety of woven jacquard fabrics produced by a unique structural design method. Both face and reversed sides of the fabric are designed with their own colours and patterns (Denton, 2002). Traditional double-face fabric can be divided into two types in terms of fabric effect: plain effect fabric and figured effect fabric. Plain effect double-face fabric can only be produced by two main design methods. The first design method is to employ double-face effect weaves directly to form double-face fabric. Designed double-face fabric will be a kind of single-layer fabric. The second design method is to design double-face fabric with compound weaves, such as warp-backed or weft-backed weaves where the face weave and backing weave of the double-face fabric may be designed of the same effect or otherwise. Since figured double-face fabric features complex colour and pattern effect on both face and reversed sides, it needs to be produced on a weaving loom with the support of a jacquard machine. When designing fabric structure, the alterable double-layer structure is indispensable. The patterns on the face and reversed sides of the fabric are interwoven by grouping warp and weft threads respectively, i.e., grouping threads on the face side of the fabric are interwoven to form pattern on the face side whereas pattern on the reversed side of the fabric is constructed by grouping threads on the reversed side. For this reason, double-face fabric produced by an alterable double-layer structure is capable of expressing individual figured effect on both face and reversed sides. Such double-face fabric can be named figured double-face jacquard fabric. Since design of alterable double-layer structure cannot be done with a plane design mode in a manual fashion, it has not been possible for jacquard fabric to be realised with figured double-face effect. The innovation of layered-combination design mode of digital jacquard has overcome the limitation of hand painting. The key problem for structure design of the figured double-face jacquard fabric could be solved. This enabled figured double-faced jacquard fabric to be developed efficiently. The basic design concept is that the face and backing structures are designed separately at first, and then such two fabric structures can be combined through proper stitch weaves under the layered-combination mode to produce compound structure which is capable of maintaining stability even when the figured effects change in both sides of a fabric.

6.3.2 Design Principles

In order to understand thoroughly the key points of innovative design on figured double-face jacquard fabric, the study on design principles of both double-face fabric and figured double-face was conducted with in-depth technical analysis.

6.3.2.1 Design principles of double-face woven fabric

The fabric effects on face and reversed sides of woven fabric interwoven by warp and weft threads are different. Take woven fabric with single-layer structure as an example. The face effect and backing effect form a kind of reversed negative effect, i.e., the area of woven fabric showing weft-faced structure effect on face side exhibits warp-faced structure in its reversed side. However, for woven fabric designed with complex weave structure, e.g., backed or double-layer structure fabric, the relationship between face effect and backing effect is extremely complicated. In general, face effect plays the role of colouring and figuring effects while backing effect is used as an assisting effect on the reversed side only. In other words, when certain grouping threads of warps and wefts are colouring and figuring on the face of fabric, the remaining threads form backing effect on the reversed side. Thus, it is apparent that the key point for designing woven fabric with double-face effect lies in fabric structure design. In general, the simplest effect of a double-face fabric is a plain fabric designed with plain weave, 2/2 twill weave, and other simple backed weaves (Gu, 1987). Figure 6-8 shows the design methods for plain effect double-face fabrics with same or different effects between face side and reversed side of fabric. Among them, (a) and (b) show the single-layer structure with same effect on both sides; (c) and (d) present the simple backed structure with same effect on both sides; (e) is double-layer structure with same effect on both sides. As for the design of double-face fabric with different effects on both sides of fabric, the alterable backed structure and double-layer structure are optimal selection. For example, in Figure 6-8, (f) was changed from (d) whereas (g) was changed from (e).



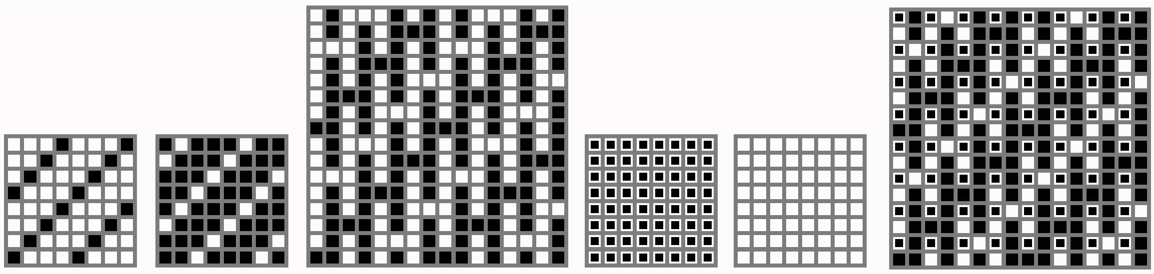
(a) (b) (c) (d) (e) (f) (g)

(a) Single plain; (b) 2/2 twill; (c) Backed 1/3 twill; (d) Backed 3/1 twill; (e) Double plain; (f) Face 3/1 twill, back 7/1 twill; (g) Face 3/1twill, back plain.

Figure 6-8. Principles of structure design for double-face fabric.

6.3.2.2 Design principles of figured double-face jacquard fabric

Double-layer weave structure should be used for designing figured double-face fabric (Zhou, 2002b). The design processes can be divided into three parts, i.e., face weaves design, backing weaves design and stitch weaves design. The design principles of double-layer weave are shown in Figure 6-9. (a) and (b) show face weave and backing weave respectively; (c) is the combined effect of (a) and (b); (d) and (e) are the intersection effect of face warp thread to backing weft thread and the intersection effect of backing warp thread to face weft thread respectively; and (f) is the compound weave structure without stitch weave.

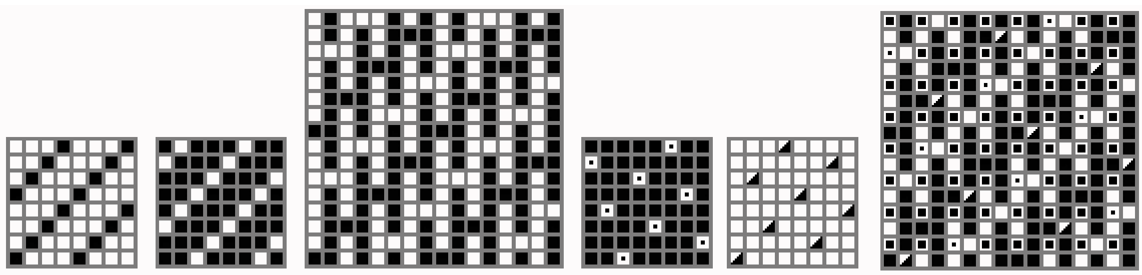


(a) (b) (c) (d) (e) (f)

(a) Face weave; (b) Backing weave; (c) Combination effect; (d) Interlacing effect; (e) Interlacing effect; (f) Compound weave structure.

Figure 6-9. Principles of structure designs for double-layer weaves.

Stitch weaves were further added to the weaves shown in Figure 6-9. Double-layer weaves with stitching effect produced are shown in Figure 6-10. Results show that the stitch weaves should be designed based on face weaves or backing weaves in order to achieve better covering effect. Moreover, stitch weaves should be designed to meet the technical requirement of having the number of interwoven of each warp thread and each weft thread the same for good balanced interlacement. Following this design rule, Figure 6-10 (d) shows the design for stitch weave based on backing weave through reducing weft interlacing points; (e) shows another design for stitch weave designed based on face weave through reducing warp interlacing points; and (f) shows the compound double-layer structure with dual stitch weaves.



(a) (b) (c) (d) (e) (f)

(a) Face weave; (b) Backing weave; (c) Combination effect; (d) Stitch weave; (e) Stitch weave; (f) Compound weave structure.

Figure6-10. Principles of structure design for double-layer weaves with stitch weaves.

With the assistant of CAD system, constant stitch weave can be simulated based on face and backing weaves before production. If stitching effect and covering effect can remain unchanged when the face and backing weaves vary, figured effect on both face side and reversed side of double-face fabric can be changed respectively. The design principles can be summarised as that when face and backing weave of double-face fabric are designed, stitch weaves are then designed on the basis of face weave and backing weave respectively. Taking face and backing weave as primary weave respectively, two series of gamut weaves can be designed to apply to the design of face and backing structures of the fabric. After combining face and backing structures with stitch weaves, the compound structure created is capable of expressing figured double-face fabric effect, of which fabric effect on each side can vary independently.

6.3.3 Design Methods

From the basic design principle aforementioned, available design methods under layered-combination design mode can be specified (see Figure 6-11). It provides a valuable reference for the design creation of figured double-face jacquard fabric. In fact, the design of face or backing effect of figured double-face jacquard fabric is independent, which is similar to designing two single-layer structure fabrics separately. Yet, the fabric specification (key technical parameters) should be the same or at least close, lest the structural combination cannot be approached. After the structure design for face and reversed sides of fabric, two independent fabric structures will have taken shape. Each of them will consist of black and white only, of which black colour represents the lift information of warp threads whereas white colour represents where the warp threads should be kept lower. Note that when designing backing structure, the digital image should be flipped and be transferred from positive to negative. These will result in having all the interlacing points in the fabric structure reversed (face down). Hence, through the combination of face and backing structure, the double-face fabric with independent colours and pattern effects on each side of fabric can be realised.

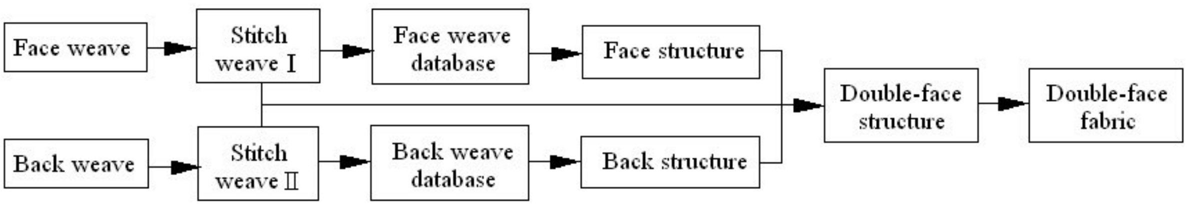


Figure 6-11. Design processes of figured double-face jacquard fabric.

6.3.3.1 Gamut weaves design

Taking stitch weaves (d) and (e) in Figure 6-10 as the foundation, the gamut weaves used for structure design on both sides could be established. Design method details that taking face weave and backing weave as starting weave and ending weave, a series of weaves can be designed by increasing or reducing the interlacing points, and a corresponding weave-database can be established. The weave variation is ranged between face weave and backing weave. Figure 6-12 shows the design method with regular weave variations. Such a design method is similar to the design of shaded gamut weaves. Established weave database can be used for fabric structure design on both face and reversed sides. In fact, when designing shaded gamut weaves by increasing interlacing points one by one, the number of gamut weaves in the weave database is the maximum. Moreover, when weave repeat of face or backing weave is enlarged, the number of weaves in weave-database will be increased too. Considering the ease of structure combination, it is thus better for the face weave and backing weave to share the same gamut weaves and weave-database.

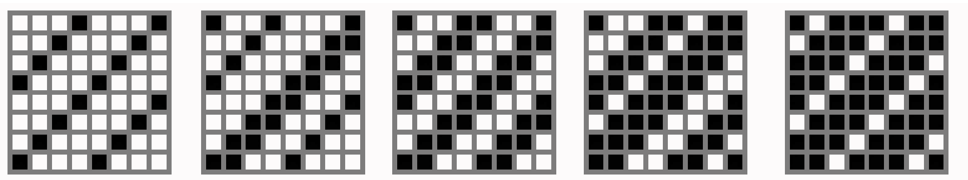


Figure 6-12. Gamut weaves design with regular variations.

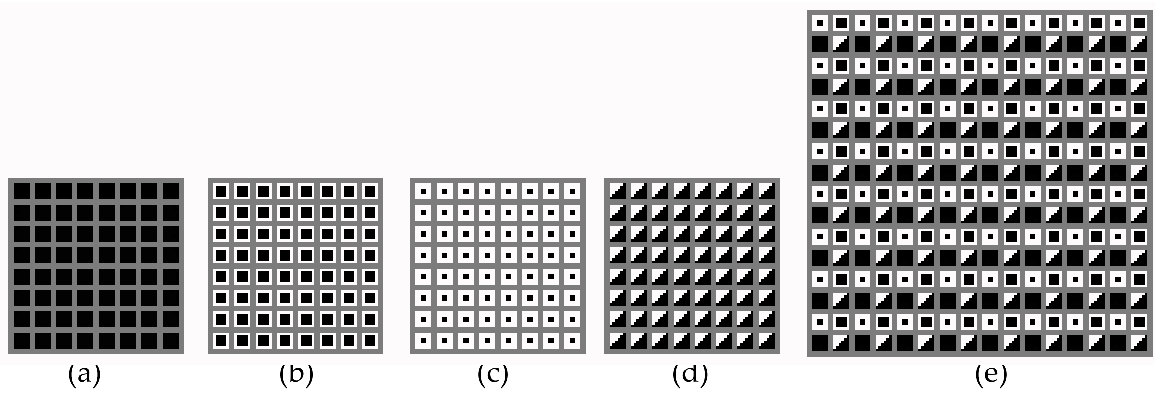
6.3.3.2 Combination methods of face and backing fabric structure

The combination method of face and backing effects of figured double-face jacquard fabric is the most important design process proposed for innovative digital jacquard textile design. The basic design method is to arrange warp and weft threads into two groups with 1:1 order. One group of warps and wefts are interwoven to form face fabric effect as face warp and face weft; another group of warps and wefts are interwoven to form backing effect of double-face fabric as backing warp and backing weft. In this way, four relationships of interwoven threads are generated, i.e., face warp and face weft, backing warp and backing weft, face warp and backing weft, and backing warp and face weft. Their corresponding structures are face fabric structure, backing fabric structure, stitch weave of face warp and backing weft, and stitch weave of backing warp and face weft. The relationship is shown in Table 6-3, in which stitch weave I is formed from face warp and backing weft, and stitch weave II is designed from backing warp and face weft.

Table 6-3 Relationship of warp/weft threads and fabric structures.

Wefts	Face warp	Backing warp
Face weft	Face structure	Stitch weave II
Backing weft	Stitch weave I	Backing structure

Based on the relationship of warp/weft threads and fabric structures, fixing the starting point to combine the face and backing structure into 1:1 arrangement, the weave repeat of resultant compound structure are double of that of the original face or backing weave in both warp and weft. Figure 6-13 shows that when the lower left corner is being taken as the starting point to combine the face structure, backing structure, stitch weave of face warp and backing weft, and the stitch weave of backing warp and face weft, compound fabric structure will be created. Together with production technical parameters and weft selection information, digital jacquard fabric with figure double-face effect can be produced.



(a) Face structure; (b) Backing structure; (c) Stitch weave I; (d) Stitch weave II; (e) Compound structure.

Figure 6-13. Combination of weaves and structures.

From the design principles and methods of figured double-face jacquard fabric introduced above, it can be concluded that the key technical problem of structure design for figured double-face fabric has been solved by the layer-combination design method. So long as the technical requirement of designing regular variant weaves and building corresponding weave-database can be fulfilled, the face side and reversed side of double-face fabric are capable of expressing independent colour and pattern effects in both black-and-white and full-colour.

6.3.4 Design Illustrations

In terms of the design principles and methods of figured double-face digital jacquard fabric aforementioned, two typical design illustrations are put forward with detailed design processes. It helps to describe clearly the design method and to highlight the advantages of digital jacquard textile designed in layered-combination design mode.

6.3.4.1 Design of full-colour figured double-face effect fabric

The key design technique of figured double-face jacquard fabric lies in structural design. The application of digital design technology has laid the foundation for the design of figured double-face jacquard fabric with full-colour effect on both sides of the fabric. The design illustration is approached by the layered-combination design mode. After designing the fabric structures on both sides of figured double-face fabric by the application of full-colour compound structure and with the design of the stitch weaves based on primary weave and its full-colour technical points respectively, the completed compound structure created is capable of showing colourful pattern individually on both face and reversed sides of the fabric. At the same time, it enables all the threads interwoven in fabric construction to express a full-colour effect.

Table 6-4 Technical specification of full-colour figured double-face fabric.

	Parameters	
	Warp	**Weft**
Materials	1/166.7 dtex polyester (white)	1/166.7 dtex polyester (dark/dark/light/light)
Density	45 threads/cm	100 threads/cm
Composition	Polyester 100 %	
Weave structure	12-thread gamut weaves, 37 grey grades	
Design repeat	1248 needles × 4608 fillings	
Pattern repeat	22.01cm (width) × 46.08cm (length)	
Weight	265.8 g/m^2	

(1) Technical Specification

The major technical parameters of full-colour figured double-face fabric are shown in Table 6-4. The fabric material was polyester in both warp and weft. It was constructed by 12-thread gamut weaves with lower thread density warp-wise and higher thread density weft-wise. Since a two-layer structure is indispensable for double-face fabric, four weft threads had been used for fabric construction. The colours of which are dark, dark, light and light arranged in the proportion of 1:1:1:1.

(2) Design Processes

When designing fabric that exhibits full-colour effect, the compound fabric structure is required on both sides of the fabric. Therefore, the key technical point lies in the design of stitch weave. The stitch weave design should meet two basic technical requirements: first, the stitch weave must be a kind of regular weave addressing the requirement of balanced interlacement for mass production; second, when applying stitch weave, the full-colour non-backed effect on both sides of the fabric should always be kept unchanged. These two requirements can be addressed fully by the design method of full-colour compound fabric structure with appropriate design skill. The design concept and principles require that the primary weave and its full-colour technical points be confirmed first and based on which stitch weaves on the basis of primary weave and full-colour points will be designed respectively. Since the primary weave and its full-colour technical points stay unchanged in compound structure design, the design of the stitch weaves based on primary weave and its full-colour points should be regular weave. Thus, the full-colour effect on both the face and reversed sides of the fabric can be realised. The design processes are specified in Figure 6-14.

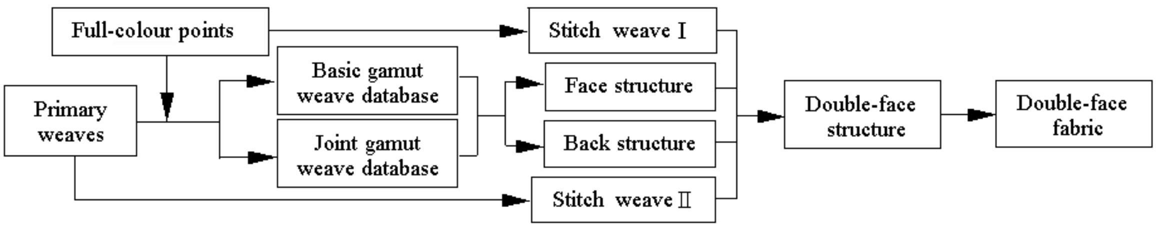


Figure 6-14. Design processes of full-colour figured double-face jacquard fabric.

The face and backing structure of full-colour figured double-face fabric are compound structures. Design processes are detailed in Figure 6-15. Note that both face structure design and backing structure design is independent. Yet, in view of further structure combination, the technical fabric parameters and weave-database applied for design of face and backing structure should be similar or the same. In addition, in the course of structural design, the image applied to both face and reversed sides should be transferred into grey mode through colour separation or decolourising, and the image used on the reversed side should be flipped from right to left before structure design so that after structure combination, the face of image will not be altered. In this particular specimen, the face image is a portrait while the back image is a rose pattern.

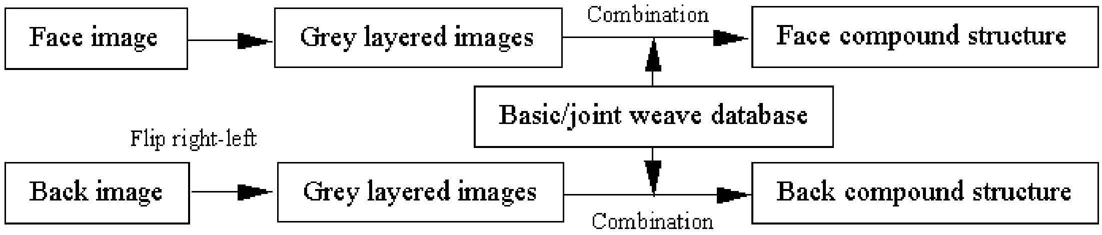
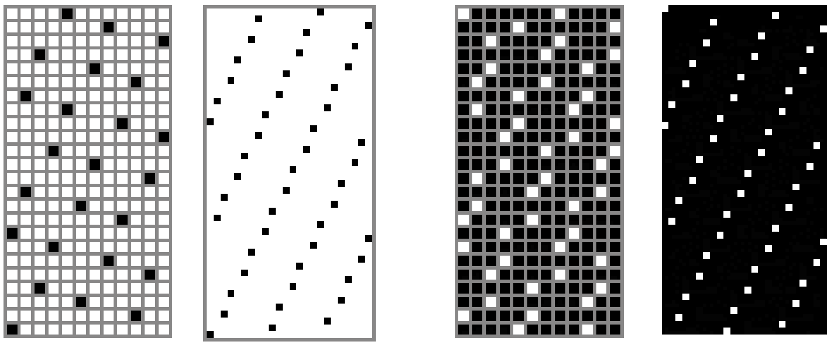


Figure 6-15. Structural design of full-colour figured double-face fabric.

In terms of technical specification of the fabric, the 12-thread weave was used to design full-colour structure and weave-database. Primary weave I was designed as 12-thread weft-face sateen with 5 step, with the starting point of weave determined as the lower left (warp, weft)=(1,1) while primary weave II was designed as 12-thread weft-face sateen with 5 step with the starting point of weave determined as the lower left (warp, weft)=(10,1). According to the character of primary weave I and primary weave II, corresponding full-colour technical points could be set. Two primary weaves and its full-colour technical points were the same as that shown in Figure 6-3 above. In addition, based on primary weave I, the basic gamut weaves could be designed and applied to building relative weave-database. Similarly, based on primary weave II, the joint gamut weaves and relative weave-database could be designed.

In order to obtain a good effect for structure combination, the same gamut weaves were applied to designing both face and backing fabric structure in this case. Thus, the double-face fabric created had the same structural property of balanced interlacement on both sides. Yet, the images on the face and reversed sides varied. As mentioned previously, the key technical point for full-colour figured double-face fabric designing lies in stitch weave design. Since primary weave and its full-colour points should not change in the course of fabric structure design, the combination effect of two primary weaves and the combination effect of two full-colour points should be constant in the compound fabric structure even when the images varied on both sides of the fabric. Therefore, the design of regular stitch weaves can be based on the combined primary weave and full-colour points respectively. Figure 6-16 shows the design diagram, where (a) is the combination effect of primary weave I and primary weave II, on which stitch weave I was designed by reducing the warp interlacing points; and (b) is the combination effect of full-colour points devised from primary weave I and primary weave II respectively, on which stitch weave II was designed by reducing the weft interlacing points. Note that stitch weave I is a kind of weave constructed by backing warp and face weft, whereas stitch weave II is constructed by face warp and backing weft.



(a) (b)

(a) compound primary weave and stitch weave I;
(b) compound full-colour points and stitch weave II.

Figure 6-16. Design of stitch weaves.

(3) Structure Combination and Fabric Effect

After the design of face and backing structures and relative stitch weaves, design of structure combination of full-colour figured double-face fabric follows. The combination method of full-colour figured double-face fabric was having white warp and four weft threads classified into two groups with 1:1 order, i.e., face group threads and backing group threads. Face group threads consist of one group of white warp and two groups of weft with dark and light colours interweaving to form the fabric effect on the face, whereas backing group threads are composed of one group white warp and two groups weft with a colour similar to that of the face group threads. The relationship of deployment of warps/wefts and fabric structures can be referred to Table 6-3, in which stitch weave I is produced from face warp and backing weft, and stitch weave II is generated from backing warp and face weft. In this design, both stitch weave I and stitch weave II are employed in a compound fabric structure. In addition, the weft selection is face weft and backing weft alternatively. The corresponding colour effect is dark, dark, light and light.

Based on the combination relationship shown in Table 6-3, the compound fabric structure was produced by fixing the starting point to combine the face and backing structure with two stitching weaves, and whose size is twice of that of the face/backing fabric structure. Such a compound structure is capable of expressing double-face effect with different images on the face and reversed sides of fabric, of which the grouping threads both face and reversed sides can vary independently. The produced fabric is shown in Figure 6-17 (colour plate C.8 in Appendix C). Since full-colour compound structure could meet the technical requirement of balanced interlacement, figured double-face jacquard fabric produced by said method poses no problem in mass production and thus has tremendous commercial values.

Figure 6-17. Figured double-face digital jacquard fabric.

6.3.4.2 Design of layer-figured double-face effect fabric

In addition to the design of full-colour figured double-face fabric, the design variation of layer-figured double-face effect can be realised by removing stitch weaves under layered-combination design mode. The fabric produced thus has two layered fabric structures of which the face effect of fabric in each layer can be arranged up or down freely.

(1) Technical Specification

Taking silk fabric as an example, the major technical parameters are detailed in Table 6-5. The final fabric was constructed with higher thread density both warp-wise and weft-wise by using 24-thread gamut weaves. Pure silk threads were employed in both warp and weft directions. Similar to the design of full-colour figured double-face fabric, four weft threads were used for fabric design, they are dark, dark, light and light colours in the proportion of 1:1:1:1.

Table 6-5 Technical specification of layer-figured double-face fabric.

	Parameters	
	Warp	**Weft**
Materials	22.2/24.4dtex×2 silk (white)	22.2/24.4dtex×5 silk (dark/dark/light/light)
Density	115 threads/cm	92 threads/cm
Composition	Pure silk 100 %	
Weave structure	16-thread gamut weaves, 53 grey grades	
Design repeat	6000 needles × 4800 fillings	
Pattern repeat	52.2cm (width) × 52.2cm (length)	
Weight	126.6 g/m^2	

(2) Design Processes

The key technical point of this design case lies in pattern design/layout and related fabric structure design. Since stitch weaves were removed from the compound fabric structure of layer-figured double-face fabric, the interchanging double-layer structure should be employed in the course of fabric structural design. Figure 6-18 shows the pattern layout of layer-figured double-face fabric, of which a repeatable image was designed with four branch patterns, i.e., pattern 1, pattern2, pattern 3 and pattern 4. According to the design requirement, four branch patterns with a two-layer structure were arranged into different relationships between face and back effects. In theory, there are four relationships between the face layer and backing layer, i.e., face up and face down, face up and face up, face down and face down, and face down and face up (see Figure 6-18).

Pattern 4 **Face down** Backing	Pattern 1 **Face up** Face
Pattern 2 **Face up** Face	Pattern 3 **Face down** Backing

Pattern layout of face layer

Pattern 2 **Face up** Face	Pattern 3 **Face down** Backing
Pattern 1 **Face up** Backing	Pattern 4 **Face down** Face

Pattern layout of backing layer

Figure 6-18. Pattern layout of layer-figured double-face fabric.

In addition, due to the deployment of interchanging double-layer structure, the face layer and backing layer were exchanged alternately in the pattern layout. It served as the function of stitch weave in the compound fabric structure. In the design of fabric structure, with the exception of stitch weaves, the gamut weaves and weave databases used for designing full-colour figured double-face fabric could also be applied to the design of layer-figured double-face fabric. The face pattern effect was designed with the aforementioned pattern arrangement (see Figure 6-19). Four branch patterns were integrated to form a repeated image, and the maximum grey scales in each branch pattern was 53 grades.

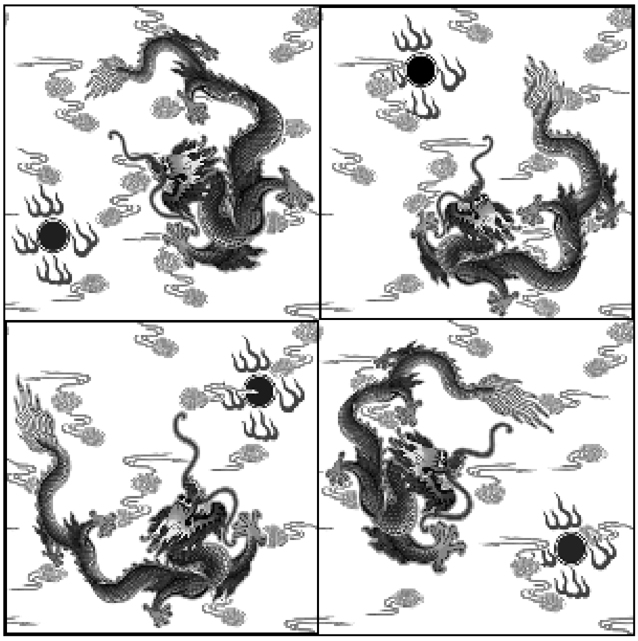


Figure 6-19. Pattern design of face side of layer-figured double-face fabric.

(3) Fabric Effect

Based on the combination relationship shown in Table 6-3, four individual compound fabric structures with four branch patterns respectively were generated by fixing the starting point to combine four times the face and backing structure. After combination, the final compound fabric structure was formed, the size of which was four times of each of the branch patterns. By using proper weft selection specified in technical specification, the layer-figured double-face fabric was produced (see Figure 6-20, also colour plate C.9 in Appendix C). The face and backing layer of this fabric was exchanged, with each layer having its individual pattern effect. In fact, the colour and pattern effect on each layer of the layer-figured double-face fabric could be altered freely through the change of pattern design and coloured threads.

Face side   Reversed side

Figure 6-20. Effects of layer-figured double-face digital jacquard fabric.

6.4 Summary

Based on the design specimens introduced above, major findings on both figured shot-effect fabric design and figured double-face fabric design can be summarised as follows:

Figured shot-effect fabric, an innovation in jacquard textiles, was successfully created with luster threads of contrasting colour effect deployed in juxtaposition in full-colour compound structure through the combination of digital grey image and its negative image. It well fulfilled the technical requirements of mass production of jacquard textiles. When the paired juxtaposed threads had the same floating length, the fabric effect in such area would look like that of traditional shot-effect fabric constructed with plain weave. When, however, the paired juxtaposed threads had different floating lengths of colour contrasting threads, figured effect was produced. When paired luster contrasting colour threads arranged in juxtaposition were applied for making of the fabric, the fabric produced was thus able to express interesting figured shot-effect, i.e., both contrasting figure effect and contrasting colour effect were exhibited at the same time. Since full-colour compound fabric structure was applied, the figured shot-effect fabric created could express the colour shading effect similar to that of printed textile. In addition, because digital image could now be employed directly to design shot-effect fabric, the complicated procedures for image modification were removed and the design efficiency increased greatly.

Different from simulative fabrics and figured shot-effect fabric, the design of figured double-face fabric was approached by using a double-layered fabric structure under the layered-combination design mode. When two groups of threads on the face and reversed sides were employed together with full-colour compound structure and proper stitch weaves, figured double-face fabric could be produced. Such fabric was fulfilled the technical requirements of mass production of jacquard textiles. In order to obtain a good covering effect between face and backing layers, while at the same time maintaining a the balanced interlacement, designed stitch weave had to be a regular one. By using full-colour compound structure, the major technical problem of stitch weave design was overcome. Since the fabric designed with full-colour compound structure under layer-combination design mode is capable of expressing a rich colour mixture effect, figured double-face fabric can exhibit full-colour effect on both sides of the fabric. In addition, since the woven patterns on the face and reversed sides of the fabric were individually constructed with no influence on each other, the pattern and colour effect on both sides of the figured double-face fabric can be varied separately with independent colour threads. Moreover, interesting layer-figured double-face fabric could be produced by removing the stitch weaves, with their patterns in the face layer and backing layer altered freely.

From the design specimens of innovative fabric presented above, conclusion can be drawn that the design creations of innovative effects of both figured shot-effect fabric and figured double-face fabric offer technical, aesthetic and commercial values well beyond what printed fabric can offer. Meanwhile, it has been proven that the layered-combination design mode benefited well the design creations through its ability not only to simulate, but also to innovate new images that are otherwise not possible before. Undoubtedly, the results of this study have broadened the creative scope of jacquard fabric design through the original design concept, principles and methods of innovative digital jacquard fabric proposed in this chapter. The versatile commercial applications from this invention remain a fertile field of future research.

CHAPTER 7
CONCLUSION AND RECOMMENDATIONS

7.1 Introduction

This chapter summarised the research work done, the results and insights yielded in this study, the reflections, limitations and implications for future research. The present study proposed an innovative design concept named "layered-combination design mode" with the aid of digitisation technology that is particularly suitable for the creation of digital jacquard. The study set out to explore major technical issues concerning the design principles and methods of jacquard textiles under the proposed "layered-combination" design mode. By merging design theory with practice, the design innovations that involve design concept, design principles and design methods proposed in this thesis have been validated and shown to have very positive creative and commercial values. Results of this study laid a solid foundation for further research of digital jacquard textile design. In this chapter, the key technical points that are crucial to the design research of digital jacquard textile were summarised. The major characteristics of design innovation in both theoretical aspect and practical aspects were identified. The values and significance of the results obtained in this study were highlighted. Limitations and recommendations were reported.

7.2 Contributions

Research in the design of digital jacquard textile integrated the basic principles of fabric science, colour science, and computer science. It departed from the traditional concept and means of jacquard fabric design that has lasted for thousands of years in which colour expression was rather limited. The present study merged digital design concept with jacquard textile design and has made some valuable theoretical and practical contributions to jacquard textile design and production. The table below summarises the major distinctions of traditional jacquard textile and the digital jacquard textile proposed in this study (Table 7-1).

7.2.1 Contributions in Theoretical Research

The established theoretical research laid the foundation that guides the following design practice and design creations in the study. It helped to identify the innovation factors in design concept, design principles and design methods differing from the traditional ones. In order to explain explicitly the originalities and the contributions of the proposed theories in the present research as opposed to the design theories of traditional jacquard textile, the theoretical innovation of digital jacquard textile design are summarised below.

Table7-1. Distinctions between traditional jacquard textile design and digital jacquard textile design.

	Identities / Characteristics	
	Traditional jacquard textile	**Digital jacquard textile**
Design concept	Single plane design mode	Layered-combination design mode
Design principles & methods	One-to-one corresponding	From colourless mode to colourful mode
Weave design	Simple weave & complex weave designed by single weave design mode	Gamut weaves & weave database
Fabric structure	Simple weave and/or complex weave	Single-layer fabric structure & compound fabric structure
Colour mixture theory	Experience-based colour consideration & colour table	Juxtaposition colour mixture
Colour number	Less than one hundred	Up to mega level
Colour effect	Individual colour with distinctive colour borders	Colour shading effect without obvious colour borders
Fabric effect	Mechanical effect imitating objective pattern	Variable digital effect with digitisation structure

7.2.1.1 Design concept

Traditional design concept of jacquard fabric has been based on single plane design mode that allowed limited scope of design innovation. Before the advent of CAD system, little progress has been made in reforming traditional single plane design mode due to its complex design method and fabric construction. Although there have been some advanced devices in fabric making, e.g., jacquard machine and powered weaving loom, only the design and production efficiency of jacquard textiles were enhanced. There has not been any significant breakthrough in the creative side of fabric effect. Inspired by digital image design, the present research proposed a brand new design concept by the name of “layered-combination” as a substitution for the traditional single plane design mode of jacquard textile design. The design of digital jacquard textile lies in the invented “layered-combination design mode” that cannot otherwise be realised by any manual attempts. As a result, the fabric effects of digital jacquard textile through digitisation of fabric construction cannot be imitated by any other means of design and production. It is apparent that with the advent of a genuine digital era of jacquard textile design, the creative scope of textile design has been significantly expanded.

7.2.1.2 Design principles and methods

Like the design concept of digital jacquard textile, the design principles and methods of digital jacquard textile differed from that of traditional jacquard textile too. There is no denying the fact that fabric structural design serves as the most important role in the course of jacquard textile design. The structural design of traditional jacquard fabric was done by a "one-to-one corresponding" principle. Both simple weaves and complex weaves of fabric structure must be designed one by one to imitate the corresponding colour effects of pattern, and through replacing individual colours by certain weaves to form fabric structure in a rather complicated and inefficient manner. Moreover, the woven structure of jacquard fabric produced by this method can only express colour effect in less than one hundred colours.

This study innovated the traditional design concept through a layer-combination design mode. The alternative design principles and methods proposed in this study consist of colourless design mode and a colourful design mode. The design of colourless digital jacquard is devised on the basis of the colourless mode (digital grey colour theory) and traditional single-layer woven structure, in which the "one-to-one corresponding" principle, is still being referred to in the design of single-layer fabric structure. Yet, the design of single simple weave or complex weave has been replaced by the design of gamut weaves. In the course of colourful digital jacquard textile design, the combination design of selected single-layer structures is being employed to produce a compound fabric structure, by which the colourful digital jacquard fabric created enables the number of mixed colours exhibited on the face of fabric to increase up to mega level.

7.2.2 Contributions in Practical Research

A few crucial technical know-how invented through the course of practical research are crucial to digital jacquard design and production. The major findings and contributions in the stage of practical research in this study can be classified into: 1) structure design, 2) colour mixture theory, 3) design practice in colourless mode, and 4) design practice in colourful mode.

7.2.2.1 Structure design

Fabric structure design is the key process of jacquard textile design. Thus, much of efforts are devoted to reinventing a new design method of fabric structure for digital jacquard textile in the stage of practical research. Significant findings have been obtained in the design practices. These include an optimal design method for gamut weaves design addressing the technical requirements of balanced interlacement, three types of compound structures - backed compound fabric structure, partial backed fabric structure and non-backed (full-colour) compound fabric structure, and the single-layer and compound fabric structure design under layered-combination design mode from the colourless mode to the colourful mode. Worth particular mentioning is the original design method of full-colour compound structure invented in this study. This invention is of great advantage to design creations of digital jacquard fabrics under the layered-combination design mode. It can be regarded as one of most important breakthroughs in the field of jacquard textile design by which digital jacquard fabric is able to express accurate mega-level colour effect.

In short, the results and findings in structure design obtained from practical research replaced the traditional single plane design mode by the layered-combination design mode, by which the design and production of digital jacquard fabric have been revolutionized and lead to a new era of digitalization.

7.2.2.2 Colour mixture theory

The colour mixture theory of woven fabric is different from that of printing and screen display. Since jacquard fabric is a woven fabric of demanding technical requirements in the course of design and production, such fabric can only express limited colour effect if they were to be designed in a traditional plane mode, with little reference to colour mixing properties. However, when layered-combination design mode is used to design and produce digital jacquard fabric, the number of available mixed colours can be up to mega level. The colour mixture effect *per se* becomes a determining factor of the overall aesthetic appeal of the digital jacquard fabrics.

The phenomenon of mixed colour effect had been investigated and a few findings were obtained in the present research. First, due to the existence of various factors affecting colour performance, there is a gap between the theoretical and practical aspects of colour. The colour mixture performance of digital jacquard textile design under the layered-combination design mode is basically in line with the juxtaposition colour mixture that is one of the optical colour mixtures. Second, the digitized structure design of digital jacquard textile requires conversions between digital colour modes. Seamless conversion between digital colours of digital images and digitized structure of jacquard fabric were realised by combining different colour modes of digital image, e.g., CMYK digital colour processing. Third, with the design method of full-colour compound structure, digital jacquard fabric thus created is capable of expressing mixed colour effect accurately with colours up to mega level. Fourth, through the employment of threads in primary colours, digital jacquard textile can realise both simulation and innovation ends. Last but not the least, the results of practical research on the colouring phenomenon of digital jacquard fabric not only revealed the distinctive quality of the colour mixture theory of digital jacquard fabric, but also offered an original design concept for structure digitisation design with reference to colour science and primary colour theory that are of both commercial and artistic values.

7.2.2.3 Colourless and colourful digital jacquard textile design

Lack of prior knowledge and experience in digital jacquard textile design in a layered-combination design mode posed certain challenges in the design process. The design practice of colourless design mode and colourful mode were carried out to discover, invent and resolve technical problems that arose along the study. Some useful findings gained from practical research are summarised as follows. First, in the design of colourless digital jacquard fabric, in addition to the technical requirement of interlacing balance for mass production, disparity existed between black-and-white effect of gamut weaves and that of the produced fabric. Such disparity could be minimized by a tailor-made design method of gamut weaves according to the contents of an objective image. Second, in the design of colourful digital jacquard textile, the compound structure of jacquard fabric combined by single-layer fabric structures designed by the normal design method of gamut weaves were capable of expressing mega level mixed colours on the face of fabric. Yet, in practice, the broken streaks appeared in the structural design. Consequently, colour deviation resulted, and the simulative effect design of digital jacquard fabric was affected. The proposed design method of full-colour compound structure in this study enabled production of digital jacquard fabric expressing fine colour shading effect, and the simulation design of digital jacquard textile with accurate colour reproduction could be realised. The success of creating smooth woven colour spectrum evidenced the very merit and superiority of having fine jacquard textiles produced by the layered-combination design mode proposed in this study.

7.2.3 Design Creations of Digital Jacquard Fabrics

Unlike jacquard textiles produced by the traditional plane design mode, the digital jacquard textile produced by the proposed layered-combination design mode exhibited two major merits: colour expression at mega-level and finer colour shading. These two features opened new creative horizons in jacquard textile design. The design creations introduced in Chapters 5 and 6 illustrate the simulative effects and innovative effects that were made possible by the two said technical inventions. As for simulative effect design, the present research introduced three methods available to the design of black-and-white simulated effect of digital jacquard fabric (the design method with single-layer fabric structure, the design method with compound fabric structure, and the design method through decolourizing of true-colour simulative design) and one method of designing colourful simulative effect jacquard fabric through double colour separation based on CMYK primary colours. Regarding innovative effect design, this study proposed two design methods. One was the design method of figured shot-effect jacquard fabric that shows contrasting figure and contrasting colour effects at the same time on the face of fabric; another was the design method of the figured double-face effect jacquard fabric that shows full-colour figured effects independently on both face and reversed sides of the fabric. All the design creations of digital jacquard fabrics introduced can be applied to fashion and interior design. Similar to digital printing, the jacquard fabric designed through digitisation technology and by layered-combination design mode proposed in this study has manifested a new era of design creations of jacquard fabrics, i.e., digital jacquard textile design, of which the technical and artistic merits are being optimized in one creation. More commercial designs with pure silk are shown in C.10 of Appendix C.

7.3 Recommendations

The layered-combination design mode for digital jacquard textile design proposed in this study through theoretical and practical research as well as design creations has proven to be most beneficial to the design innovation of jacquard fabric. Yet, compared with the traditional plane design mode that has been lasted for thousands of years, the new design concept of layered-combination design mode is still in its infancy. Further research is imperative for extending the creative and technical boundaries of digital jacquard textile design and production. It is envisaged that results of this study will induce further research in this area.

7.3.1 Limitations

While the study made significant contributions to digital jacquard textile design and production through theoretical and practical investigations, there have been certain constraints that are listed below.

First, as mentioned in the practical research of structural design, there existed a few methods by which gamut weaves with single-layer fabric structures could be designed. The present research adopted a typical design method. Had there been more time, it would have been desirable for experiments to be done on other structural design methods so as to identify more valuable results with regard to the interrelationship between fabric structural design method and final fabric effect.

Second, due to the differences in colour mixture theories between woven fabric and other colouring means such as additive colour mixture or subtractive colour mixture, there exists no single colour mixture principle that is suitable for digital jacquard fabrics designed under the layered-combination mode. The colour reproduction of true-colour simulation design could barely simulate faithfully that of the original image. In particular, the black colour effect generated by colour mixture is unsatisfactory. More time and energy would be needed to further investigate and formulate the colour principles for colour reproduction of jacquard textiles.

Third, although the present research used several images for specimen production to illustrate various novelties, the scope of experiments in terms of fabric structure and material remained relatively narrow.

Fourth, since the layered-combination design mode is a new design concept for jacquard design and production, there had not been any CAD system designed for this purpose. The design creations presented in this study integrated several CAD systems from various design fields.

7.3.2 Future Research

In this study, the design concept and principles and methods of digital jacquard textile design have been invented and validated. It is envisaged that research of digital jacquard textiles under the proposed layered-combination design mode can be developed further in the following directions:

1) To further explore the relationship between fabric structures and fabric effects under the layered-combination design mode.

2) To further experiment with the design of gamut weaves and corresponding weave-databases by other design methods.

3) To further study colour mixture theory, in particular, the inter-relationship between colour appearance and digitisation structure toward simulative effect and innovative effect of digital jacquard textiles.

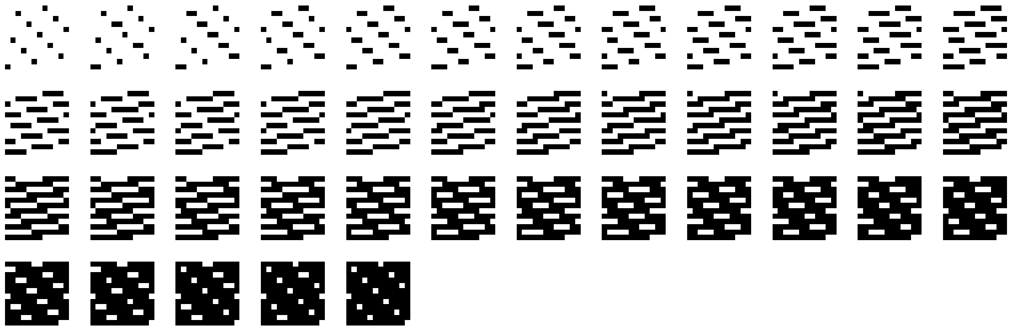
4) To further explore the potential applications of the simulative effect and innovative effect of digital jacquard textiles with different design methods and materials; and

5) To design and enhance CAD system interface for design and production of complex digital jacquard textiles using the proposed layered-combination design mode.

Finally, to conduct future research on intelligent jacquard fabric design system (IJFD) based on the layered-combination design mode.

Appendix A – Gamut Weaves and Weave-databases

A.1 Gamut Weaves and Weave-databases of 12-thread Satin



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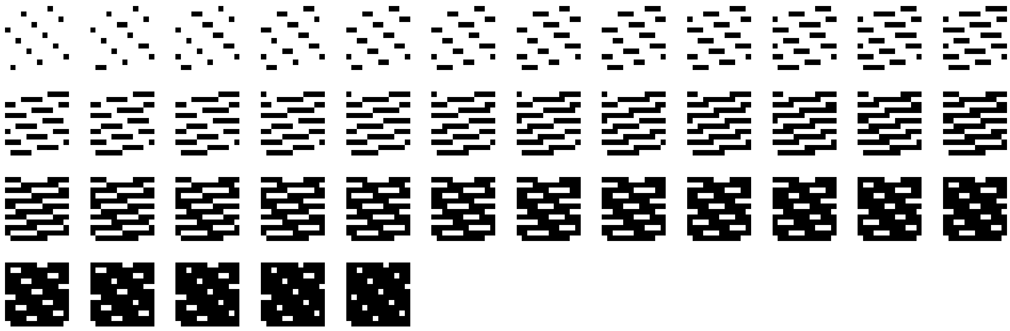

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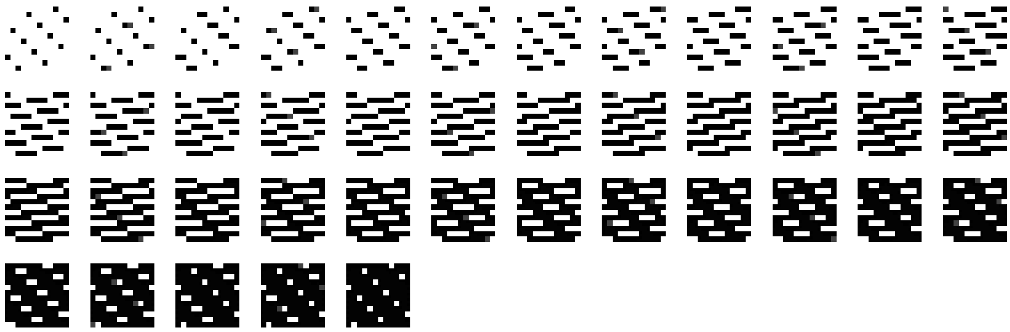

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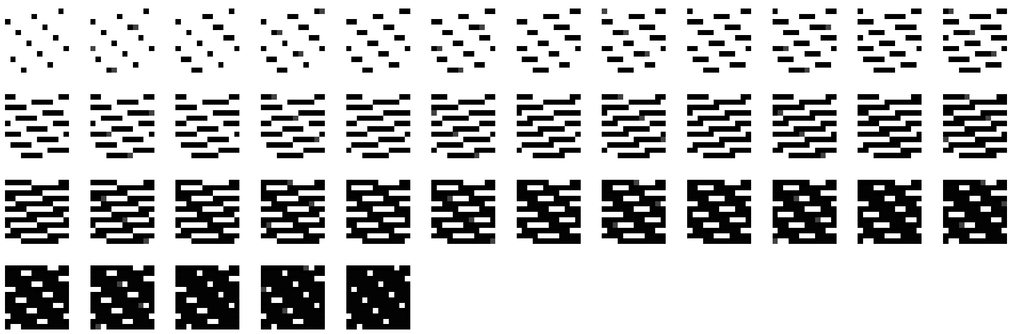

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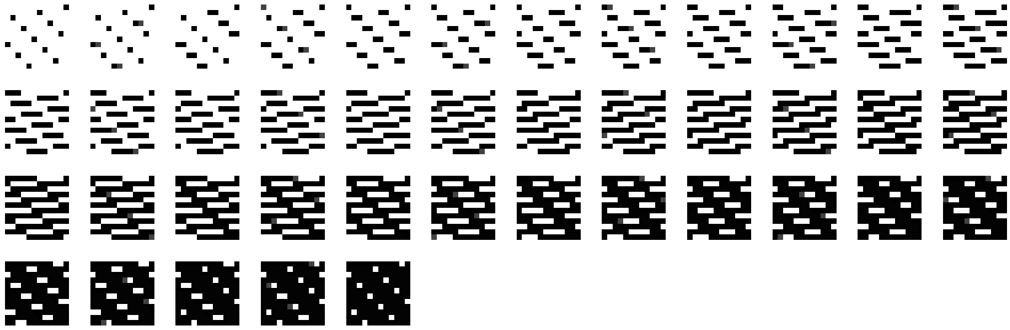

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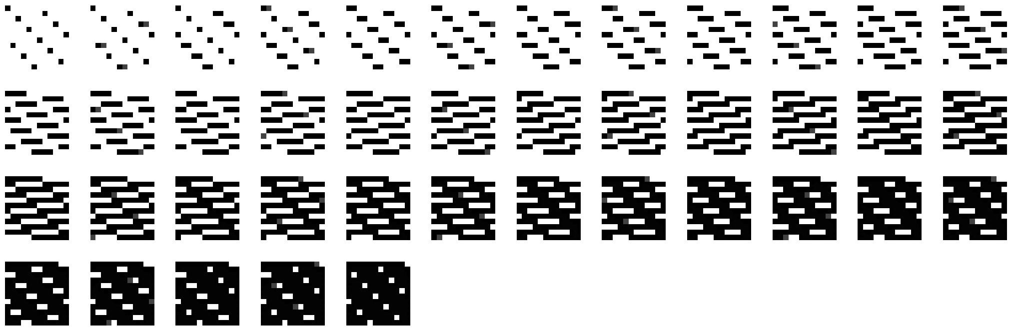

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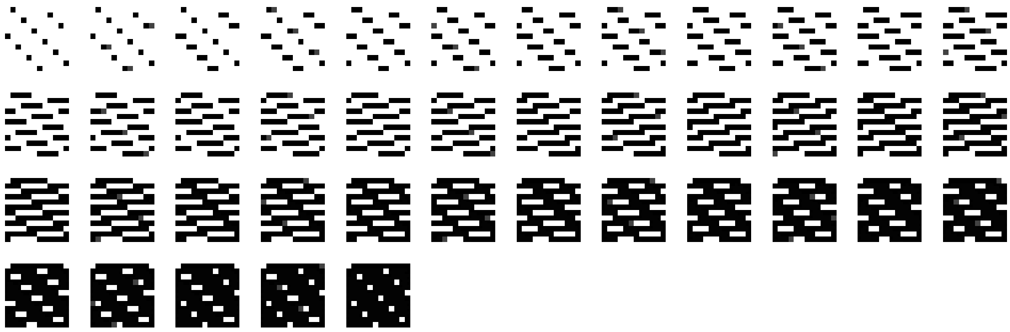

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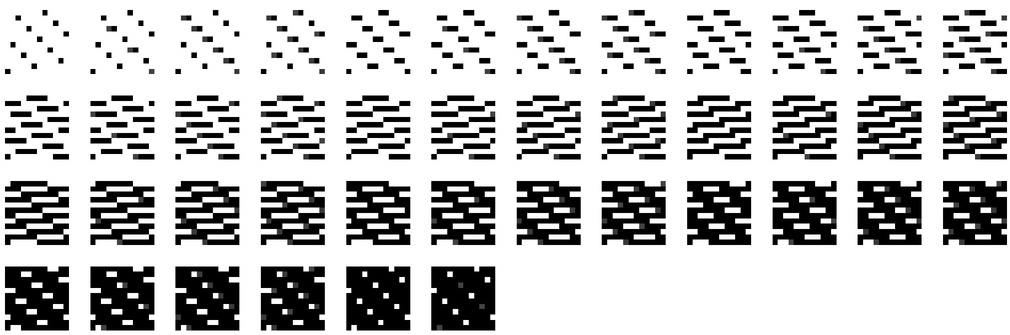

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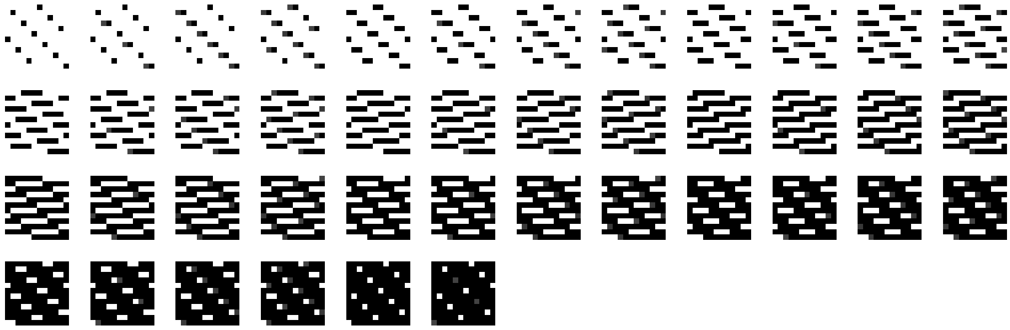

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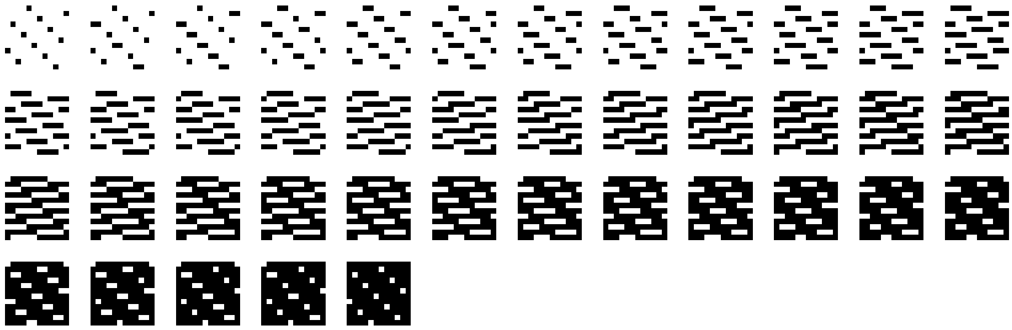

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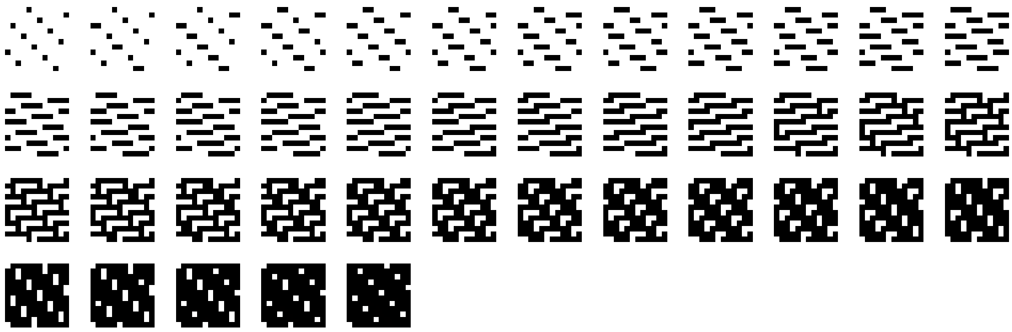

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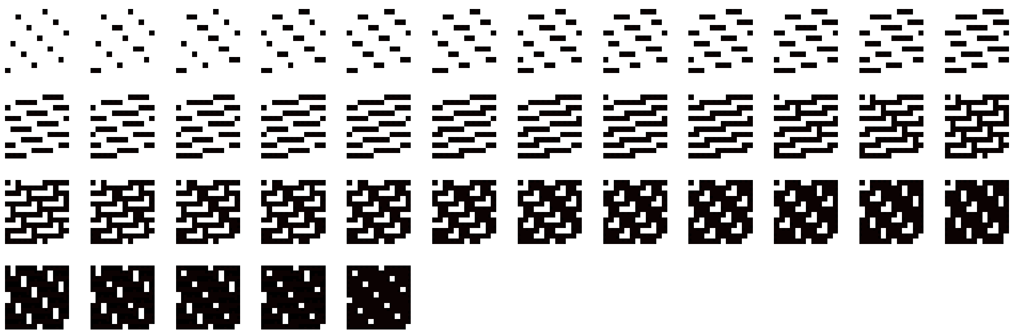

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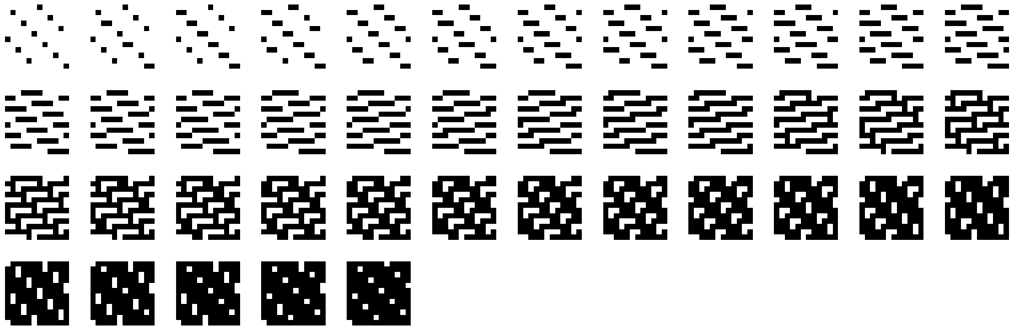

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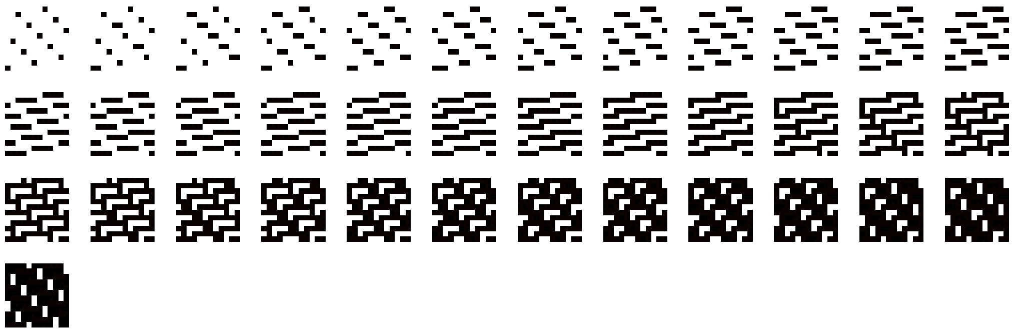

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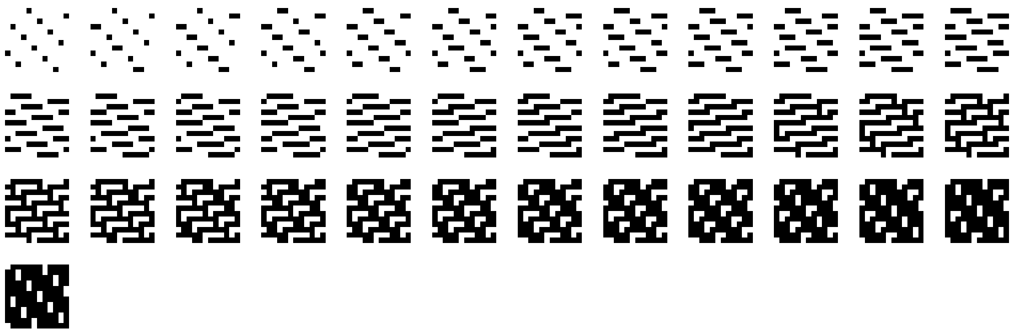

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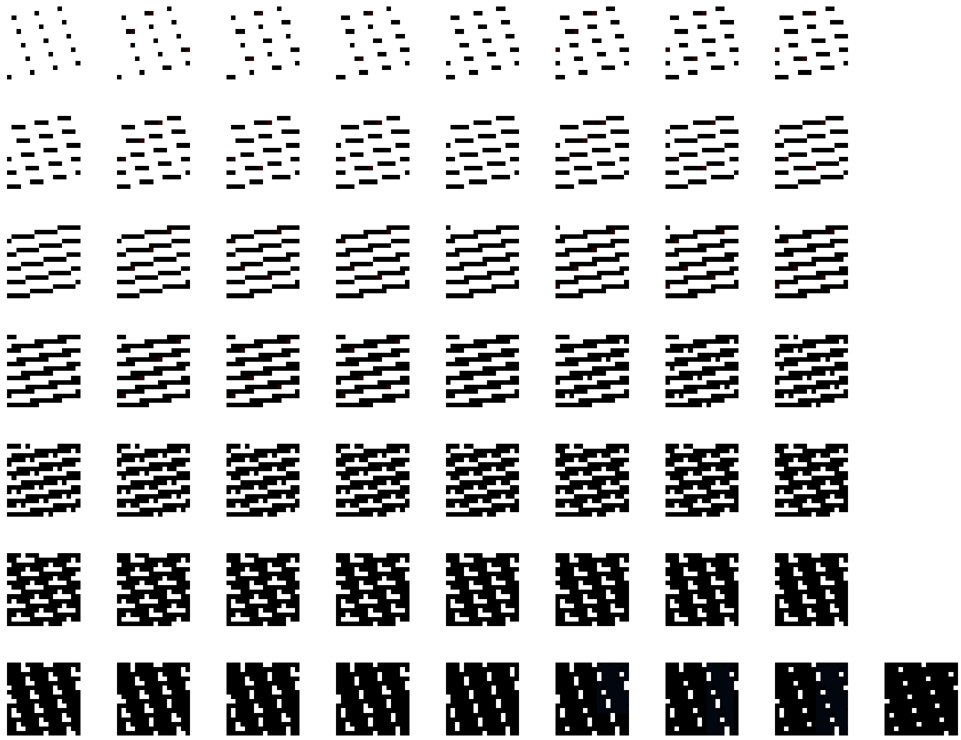
A.2 Gamut Weaves and Weave-databases of 16-thread Satin



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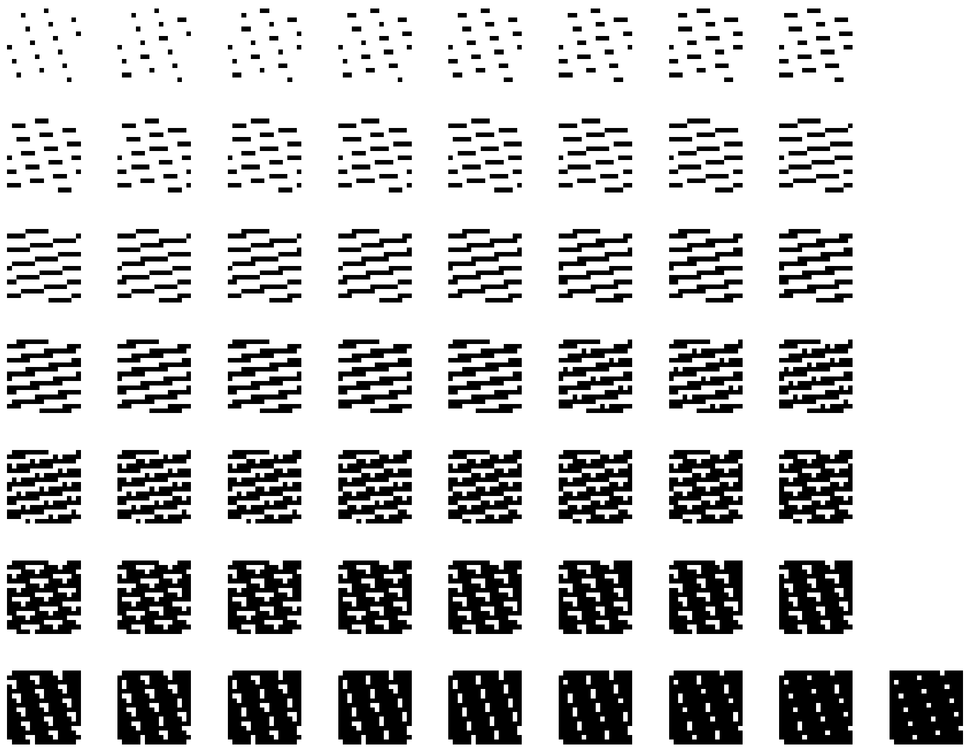
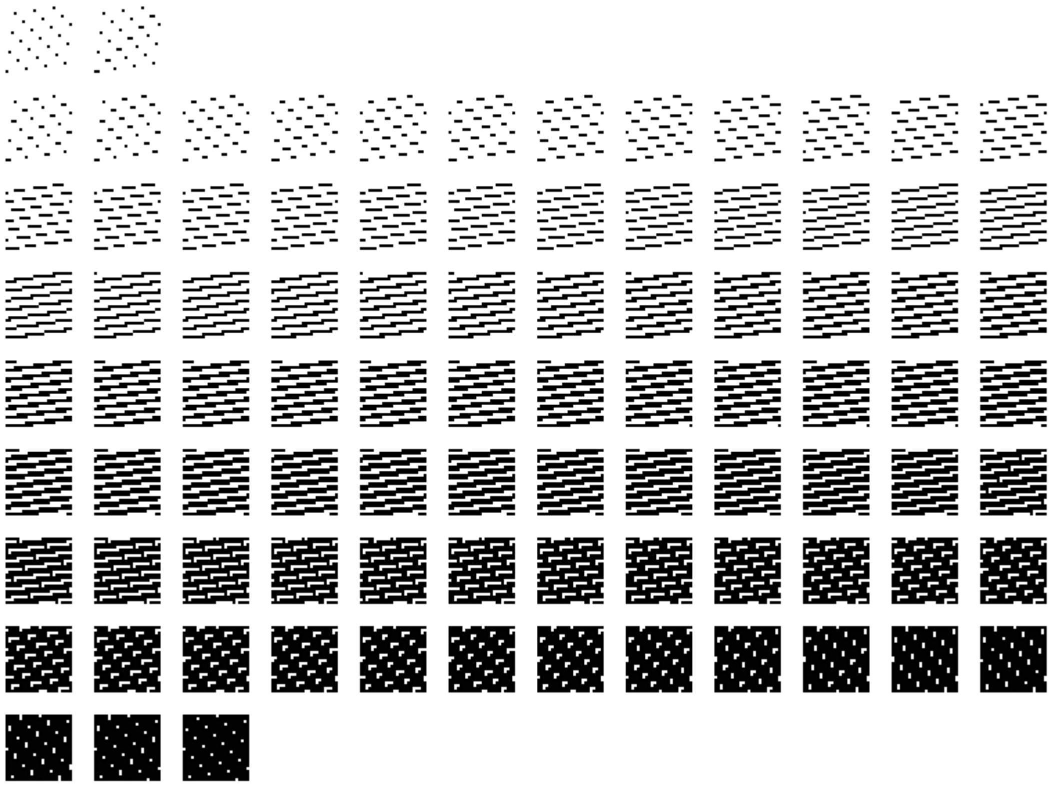


C16-4w-j-z53

A.3 Gamut Weaves and Weave-databases of 24-thread Satin



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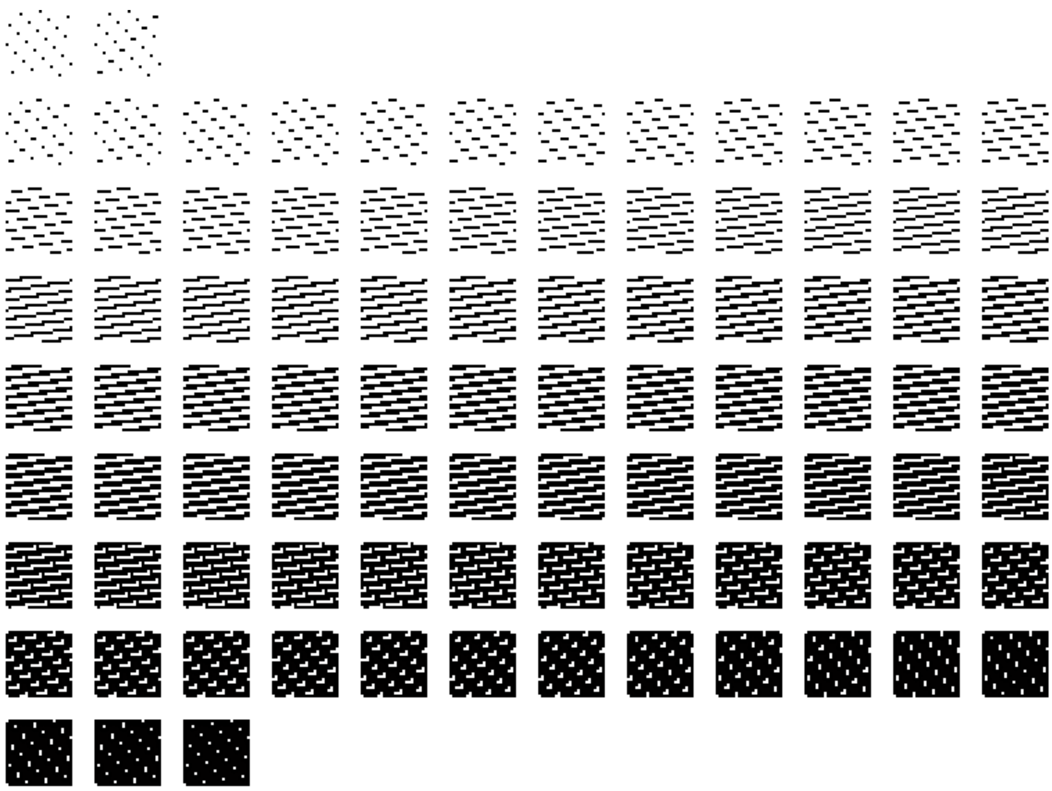
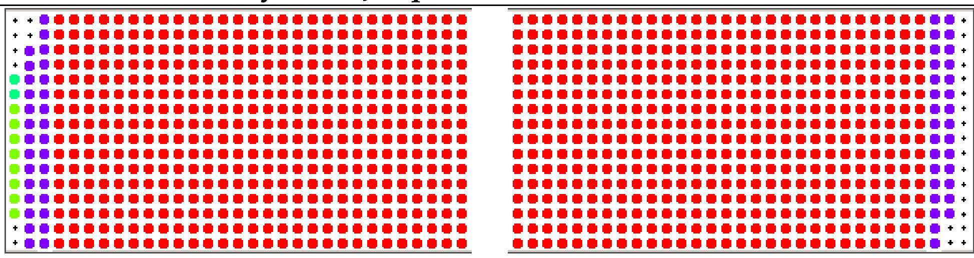
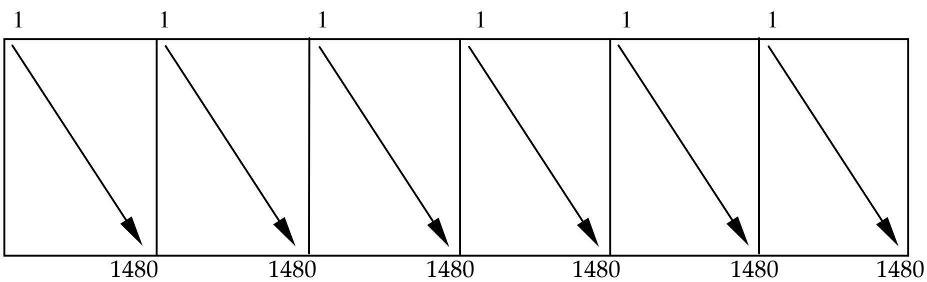


C24-7w-j-z89-z-y

Appendix B –Technical Specifications of Jacquard Textile

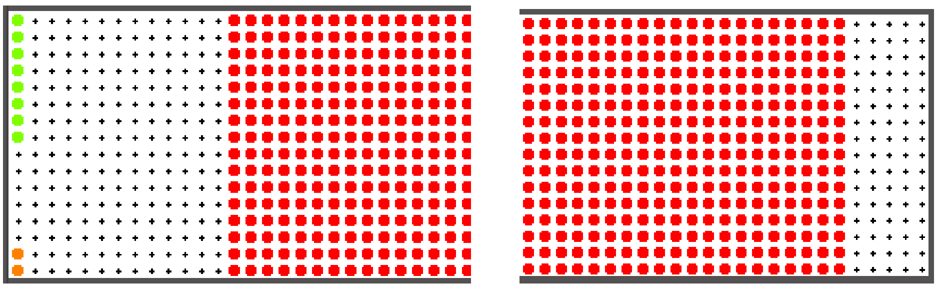
B.1 Fabric Technical Specification with Lower Warp Density

Weaving Parameters			
Needles (Figuring)	1480	**Reed Size**	11.25 dents/cm
Hook-Harness	1-6(lift)	**Reed Width**	144 cm
Warps in Mounting	8800 threads	**Denting** (per dent)	4 threads
Harness-Warp	1-1(lift)	**Weft Pickers/Needles**	8
Major Fabric Parameters			
Warp (Fineness)	111.1-166.7 dtex	**Weft** (Fineness)	111.1-333.3 dtex
Fabric Width	132.06 cm	**Weave Repeat**	12-16 threads
Selvage Width	1×2 cm	**Gamut weaves**	53
Warp Density	45 threads/cm	**Fabric Weight**	200-350 g/m²
Weft Density	45-120 threads/cm	**Weft Groups**	1-4
Pattern/Structure Design			
Pattern Repeat	22.01cm (width)	**Max. Grey scales**	53
Colour Fringe	Free drawing	**Float Cutting**	Free drawing
Point Paper	48×48		
Software applied	Photoshop cs/EAT Germany/Jcad China		
Needles' Layout of Jacquard Machine (Staubli CX870 1248/1344)			
			
Stop roll: 5,6; Colour Selection: 7-14; Selvage: 19-48/1297-1326; Figuring: 49-1296			
Harness Mounting			
			
Warp Threading	From back to front / left to right		
Supported by weaving lab of ITC, The Hong Kong Polytechnic University			

B.2 Fabric Technical Specification with Higher Warp Density

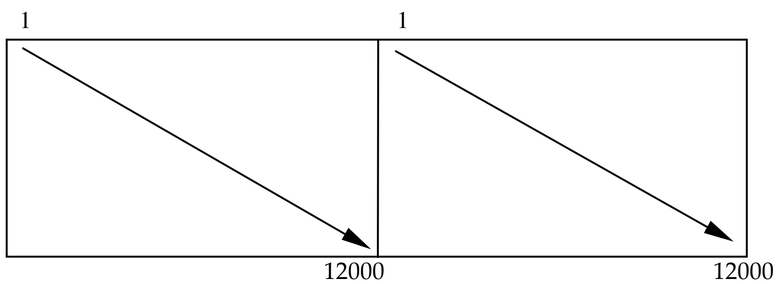
Weaving Parameters			
Needles (Figuring)	12000	**Reed Size**	28.8 dents/cm
Hook-Harness	1-2(lift)	**Reed Width**	216 cm
Warps in Mounting	24000 threads	**Denting** (per dent)	4 threads
Harness-Warp	1-1(lift)	**Weft Pickers/Needles**	8
Major Fabric Parameters			
Warp (Fineness)	44.4-55.6 dtex	**Weft** (Fineness)	44.4-166.7 dtex
Fabric Width	210 cm	**Weave Repeat**	16-24 threads
Selvage Width	Nil	**Gamut weaves**	85
Warp Density	115 threads/cm	**Fabric Weight**	122-161 g/m²
Weft Density	90-200 threads/cm	**Weft Groups**	1-4
Pattern/Structure Design			
Pattern Repeat	105cm (width)	**Max. Grey scales**	85
Colour Fringe	Free drawing	**Float Cutting**	Free drawing
Point Paper	48×48		
Software applied	Photoshop cs/EAT Germany/Jcad China		

Needles' Layout of Jacquard Machine ((Staubli LX3200 12000/12288)



Stop roll: 15,16; Colour Selection: 1-8; Figuring: 209-12208

Harness Mounting



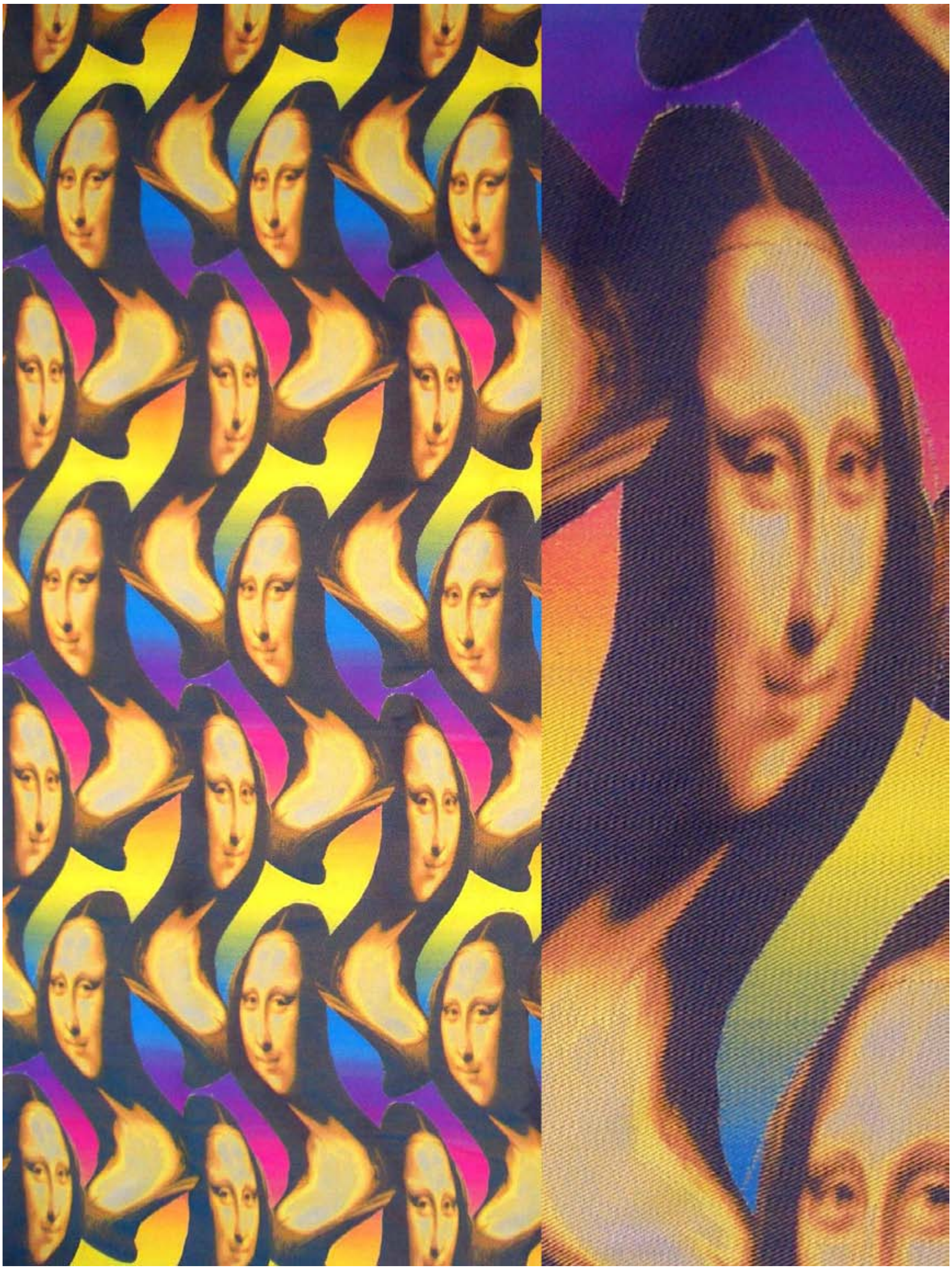
Warp Threading	From back to front / left to right

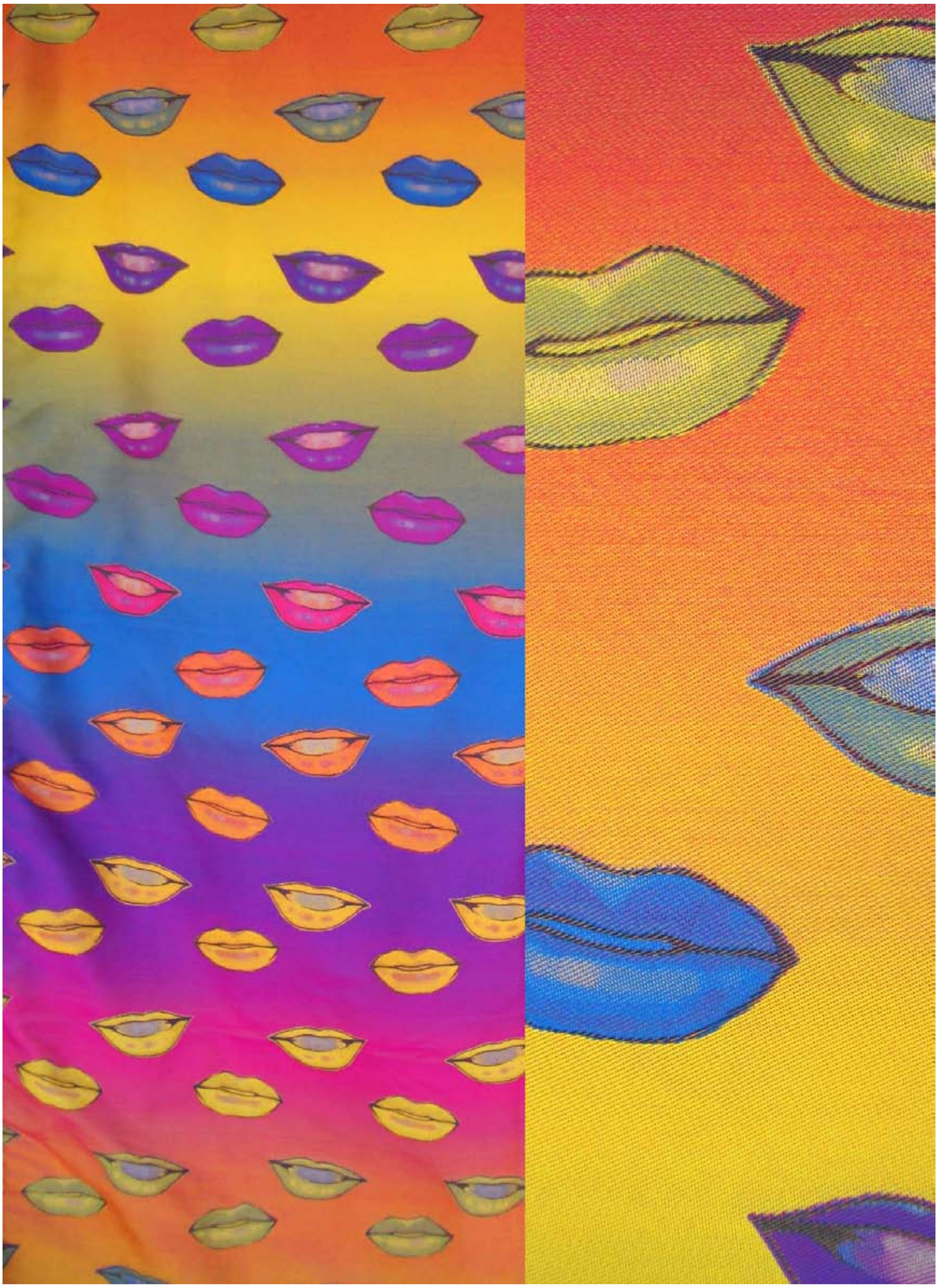
Supported by Zhejiang Sic-Tech University and Babei (China) Garment & Ornaments Co., Ltd

Appendix C – Colour Plates of Design Creations

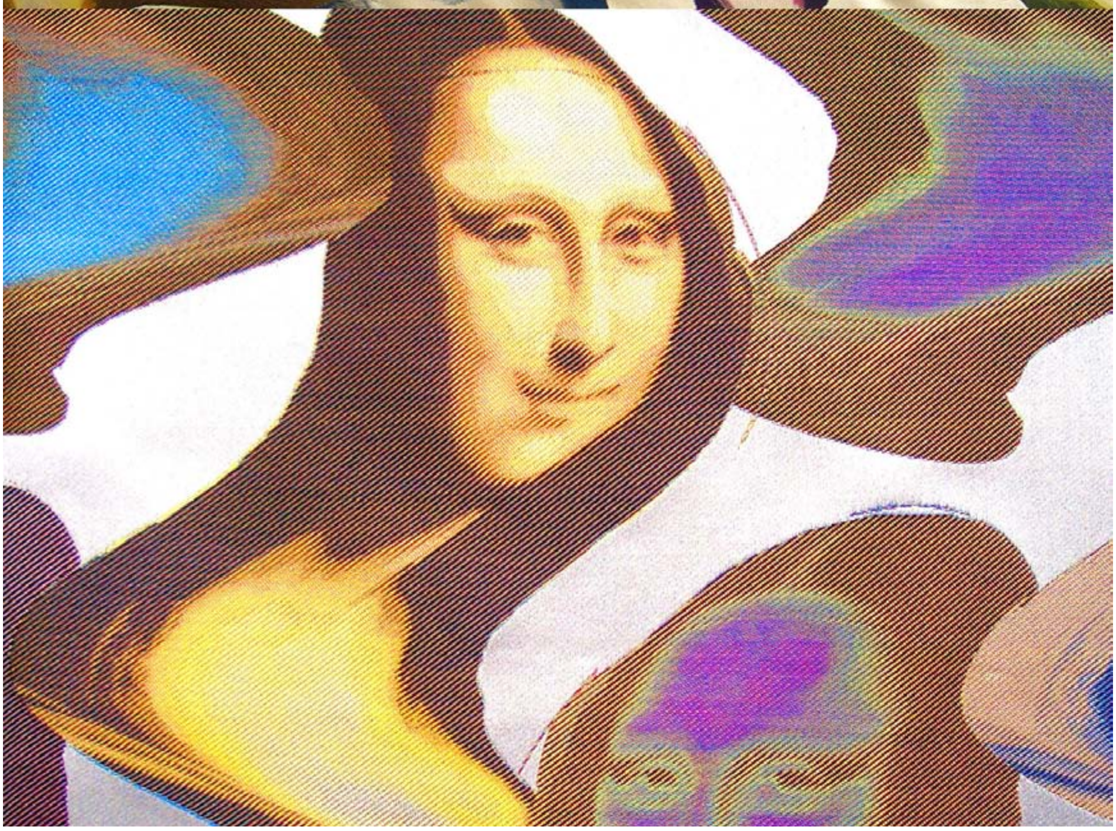
C.1 Design Creations with Smooth Colour Shading Effect (lower warp density)

C.2 Design Creations with Colourful Simulative Effect (lower warp density)

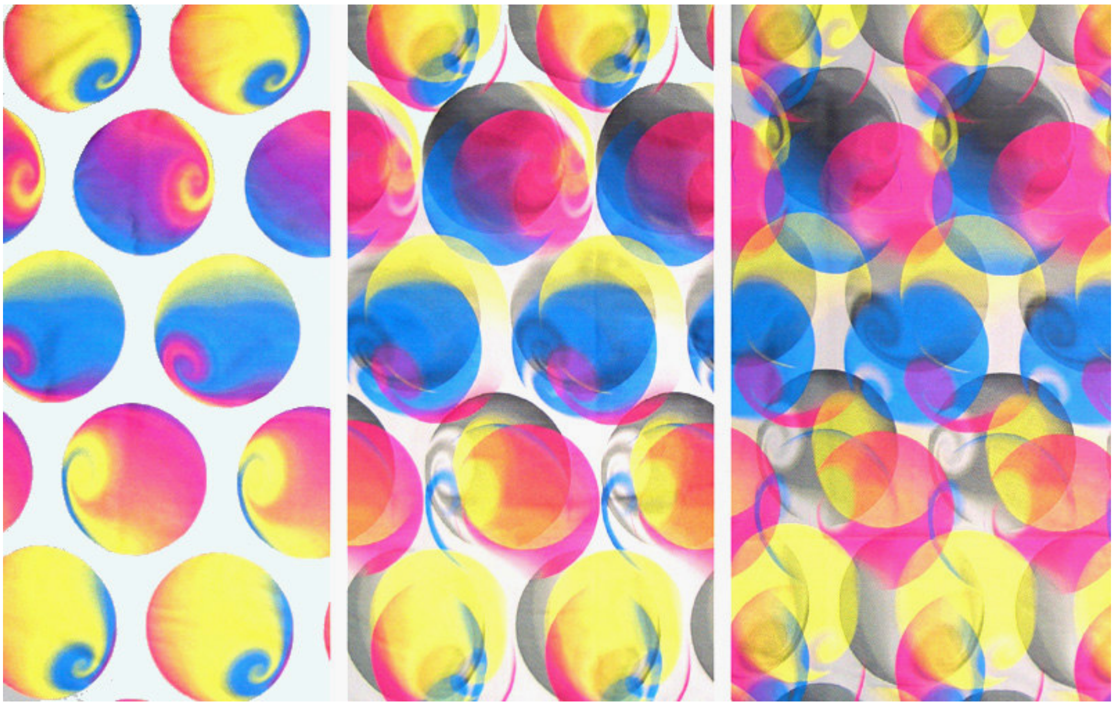


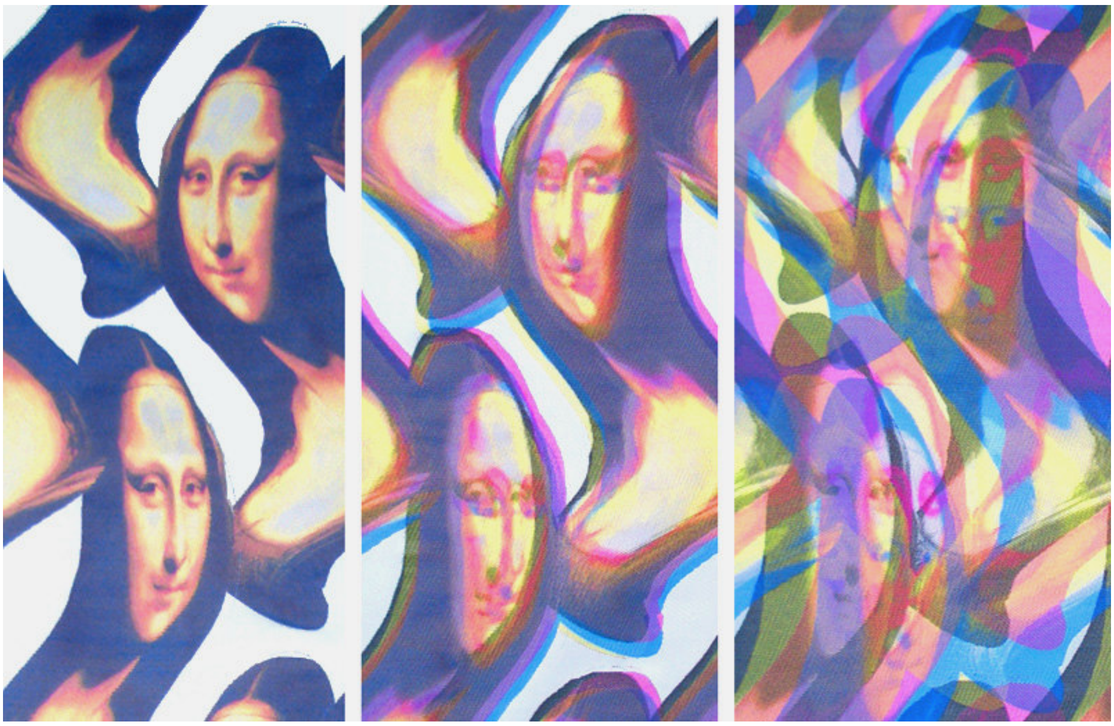


C.3 Design Creation with Changeable Colour Layer Effect (higher warp density)



C.4 Design Creations with Movable Colour Layer Effect (lower warp density)

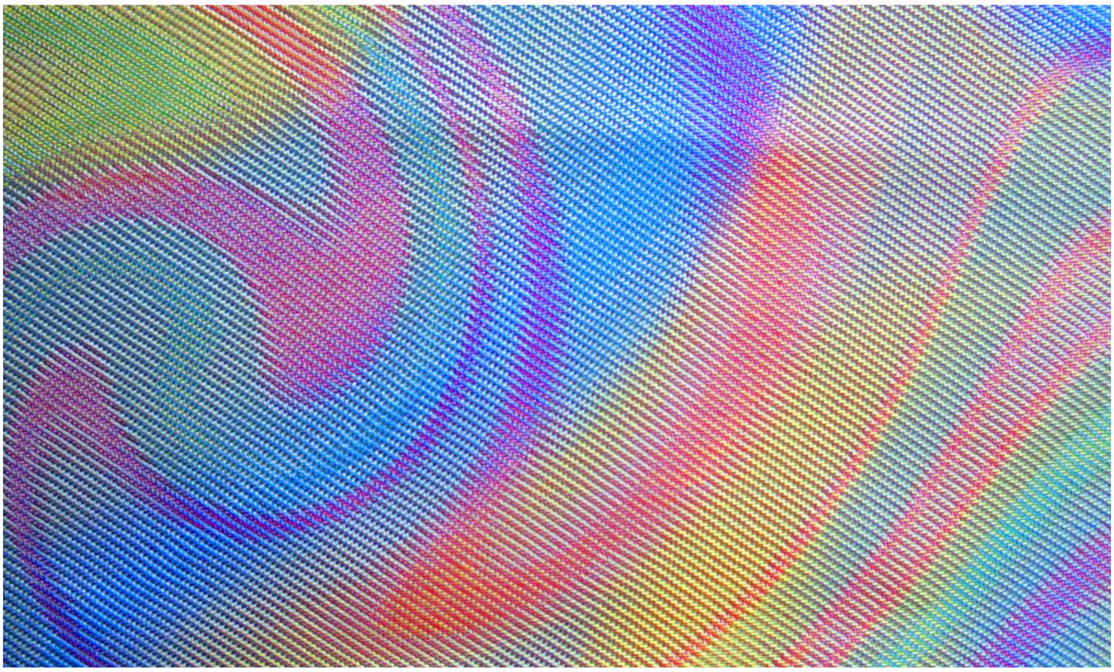




C.5 Design Creations from True-colour to Black-and-white (higher warp density)

C.6 Design Creation with Figured Shot-effect (objective design with lower warp density)

C.7 Design Creation with Figured Shot-effect (abstract design with higher warp density)



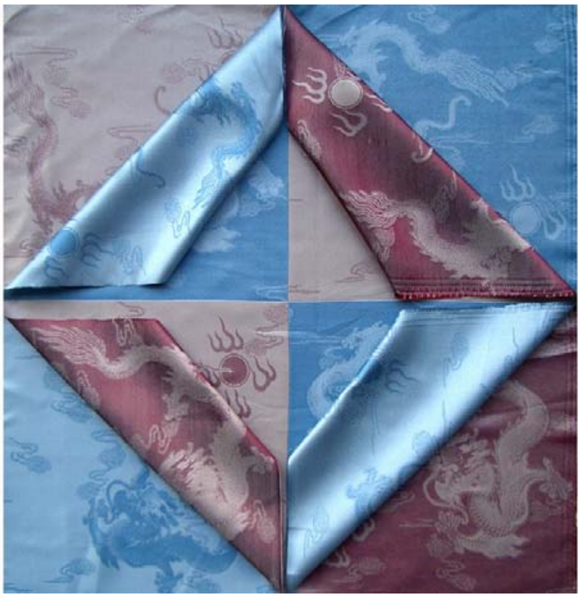
C.8 Design Creation with Figured Double-face Effect (lower warp density)

Face side

Reversed side

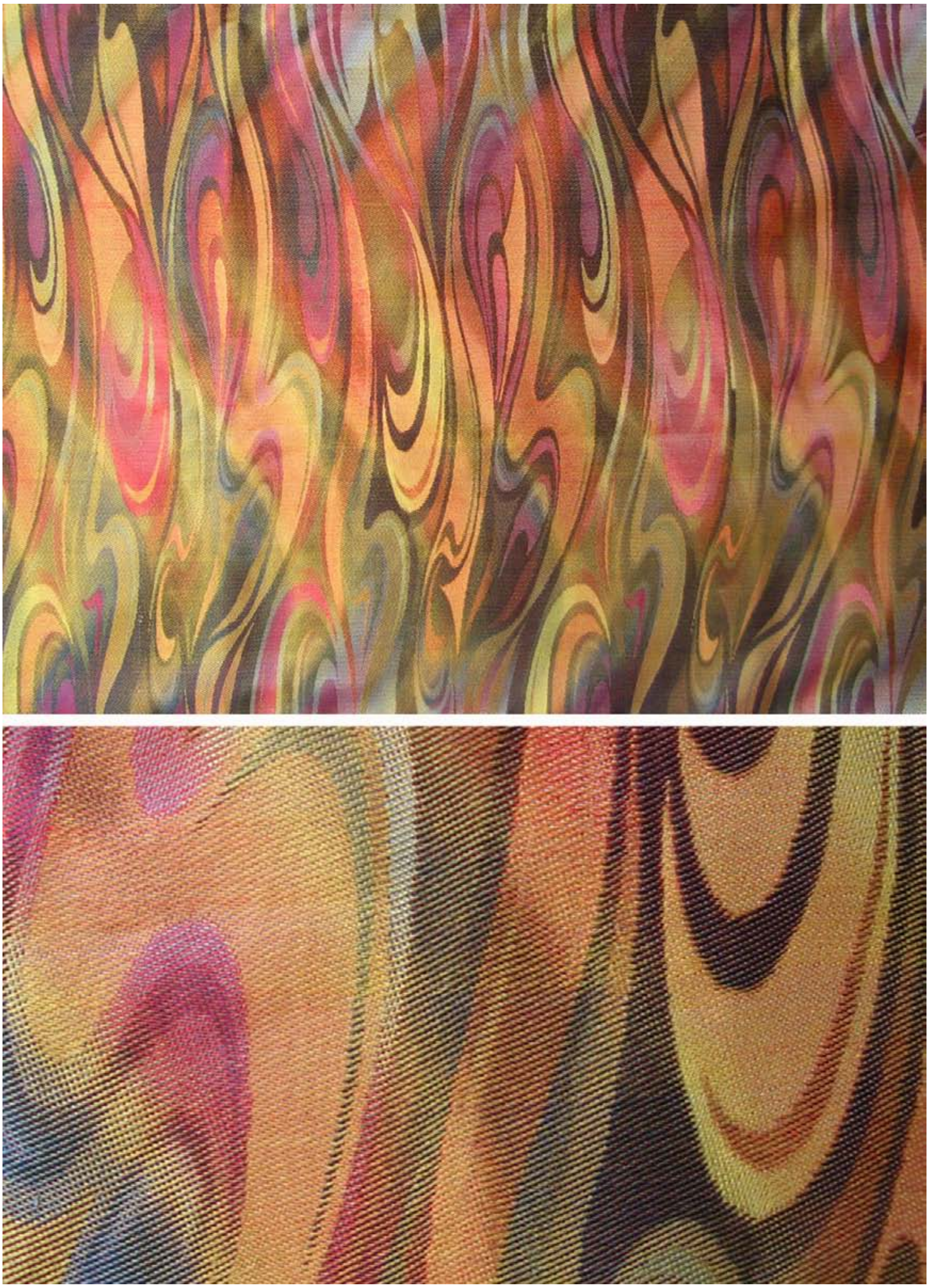
C.9 Design Creation with Layer-figured Double-face Effect (higher warp density)

Face side



Reversed side

C.10 Design Creations with Print-like Effect (silk design with higher warp density)



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