COLOUR MEASUREMENT CORRECTION MODEL

FOR

IMPROVING INTER-INSTRUMENTAL AGREEMENT

A Thesis Presented for the

Degree of Doctor of Philosophy

CHUNG Yiu-sing

Institute of Textiles and Clothing

The Hong Kong Polytechnic University

2003

TO

MY FAMILY

ACKNOWLEDGEMENT

I would like to express my very great appreciation to Dr John H. Xin, Associate Professor of the Institute of Textiles and Clothing at The Hong Kong Polytechnic University, for his very valuable and constructive suggestions during the planning and development of this research work. His willingness to spend his time so generously has been very much appreciated.

I would also like to thank Dr K.M. Sin, Associate Professor of the Institute of Textiles and Clothing at The Hong Kong Polytechnic University, for invaluable advice and a sustained interest and encouragement throughout the period of my research work.

In addition, I would like to express my thanks to all the staff and technicians in the textile chemistry laboratory and evaluation and objective laboratory. I would like to express my thanks to all the lecturers especially Ms Gail Taylor, research students and research assistants in the Institute of Textiles and Clothing at The Hong Kong Polytechnic University for their fully support in the past three years.

Finally, I would like to thank my family and Rise for their great support during the whole study period.

ABSTRACT

Accurate colour measurement is a very important factor to determine the quality of finished products in the colour-related industries, such as paint, printing or textiles. In the past, visual colour assessment was used to match colours and physical samples played an important role. The drawback of the visual colour assessment is that, even in the case of well trained colourists, performance is influenced by a number of parameters including psychological, medical and environmental factors. In addition, during the transportation and assessment of the physical samples, there is the risk of soiling. These factors may account for mistakes in colour identification, even in the case of well trained and experienced colourists.

The objective colour communication method is an alternative method to enhance both colour matching and colour assessment. Because of advances in spectrophotometry and information technology, colour quality may be expressed in a digital format and communicated to other parties by electronic means. This format of colour communication represents the trend in view of the regionalisation and globalisation of the textile and apparel industries.

The spectrophotometer is one of the important instruments for colour matching and colour measurement. It performs at a finite level of accuracy but, as an electro-mechanical-optical device, it exhibits measurement errors relative to a theoretically error-free instrument that users must accept. Most of the modern spectrophotometers have satisfactory repeatability and the suppliers of these instruments claim that the repeatability of the measurement on the same instrument is lower than 0.01 CIELAB ΔE units. In this research project, it was found that the repeatability of the advanced spectrophotometers ranged from 0.044 to 0.112 CIELAB ΔE units for the dual beam spectrophotometers while, for the single beam spectrophotometer, the repeatability ranged from 0.115 to 0.377 CIELAB ΔE units.

When considering the inter-instrumental agreement of different makes of spectrophotometers, the manufacturers also claim that the inter-instrumental agreement of those of similar design is lower than 0.15 CIELAB ΔE units. However, in this research, it was found that the inter-instrumental agreement between the spectrophotometers manufactured by the same manufacturer ranged from 0.526 to 0.611 CIELAB ΔE units. The inter-instrumental agreement between the spectrophotometers manufactured by different manufacturers ranged from 0.575 to 0.854 CIELAB ΔE units.

Since the inter-instrumental agreement of the spectrophotometers is very low, various mathematical models have been developed in order to improve the inter-instrumental agreement between spectrophotometers. In past research, those mathematical models were developed using calibration data from the GLOSSY Ceramic Tiles which may not be suitable for application to textile and paper samples.

For the above-stated reasons, in this project a new mathematical model, named the R-Model, was developed using both GLOSSY and MATT Ceramic Tiles. Spectral data from 400 – 700 nm was analysed using the concept of bandpass correction as well as the multilinear regression method. The performance of R-Model was found to be better than that of the previous models. The improvement of the inter-instrumental agreement was up to 90% for the ceramic tiles. Moreover, the inter-instrumental agreement for the other coloured samples such as textile and paper samples also improved accordingly, from 26.1% to 57.6% and 13.7% to 61.1% respectively. Using this model, the global colour communication between designers, coloration companies and buyers can be further enhanced, and also the non-physical sample communication method through the use of digital reflectance data can become feasible.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PUBLICATION

1. "Study of Reproducibility of state-of-art of Spectrophotometer", Sidney Y.S. Chung, John H. Xin, and Patrick T.F. Chong, "AIC Midterm Meeting 99"
2. "顏色量度的準確性", 宗耀昇,忻浩忠,莊德虎, "全國染色專業委員會年會"
3. "New Regression Models For the Measurement of Textiles by Spectrophotometer", Sidney Y.S. Chung, John H. Xin, and Patrick T.F. Chong, "The 5th Asian Textiles Conference"
4. "Comparison of The Different Mathematical Models For Inter-instrument Agreement Between Spectrophotometerss", Sidney Y.S. Chung, John H. Xin, and Patrick T.F. Chong, "Colour and Visual Scales 2000, National Physical Laboratory, United Kingdom, 3-5 April, 2000"
5. "Study of New Regression Model For Inter-instrument Agreement", Sidney Y.S. Chung, John H. Xin, and K. M. Sin, "2000 AIC Meeting Seoul"
6. "Comprehensive Comparison Between Different Mathematical Models for Inter-instrument Agreement of Reflectance Spectrophotometers", Sidney Y.S. Chung, John H. Xin, and K.M. Sin, "AIC Color 01 Rochester"
7. "The Factors Affecting the Accuracy of Instrument Colour Measurement", Sidney Y.S. Chung, John H. Xin, K.M. Sin, "The 6th Asian Textiles Conference"
8. "The Application of Modern Colour Measurement Dervices In Coloration

Industries", Y. S. Chung, John H. Xin and K. M. Sin, Submitted to Journal of China Textile University

9. "The Study of the Repeatability and Reproducibility of the State-of-Art Spectrophotometers", Yiu-sing CHUNG, John H. XIN and K. M. SIN, Submitted to Coloration Technology

10. "The Development of the New Inter-instrumental Agreement For Reflectance Spectrophotometers, Part I – Development of The Model", Yiu-sing CHUNG, John H. XIN and K. M. SIN, Submitted to Coloration Technology

11. "The Development of the New Inter-instrumental Agreement For Reflectance Spectrophotometers, Part II – Testing of The Model", Yiu-sing CHUNG, John H. XIN and K. M. SIN, Submitted to Coloration Technology

CHAPTER 1

INTRODUCTION

1.1 Research Background

1.2 Objectives

1.3 Scope Of Study

1.1 Research Background

It is often difficult to achieve accurate colour communication because the perception of colour is subject to the influence of at least three different elements: the light source, the object and the visual system. The variation in either the radiant quantity or the spectral distribution of the source can alter the observed colour. For this reason, the objective quantitative tools and communication method are highly significant when evaluating colour. Using advanced computer systems and electronic devices, colour measurement has become increasingly more accurate, especially in the case of spectrophotometric measurement.

Traditionally, physical samples played an important role in colour matching and communication. Unfortunately, sample soiling and notoriously unreliable visual assessments account for 17% of "wrong decisions" made by both trained and experienced colourists[44]. In addition, the performance of the trained colourist can be influenced by a number of parameters such as psychological, medical and environment factors. There are also factors such as the variability between visual observers and within observers, the variability between light cabinets and light sources[44]. All these influences make colour matching and communication more difficult.

An alternative method for achieving colour quality assessment is using a colour measuring system. Because of advances in spectrophotometry and information technology, colour quality may be expressed in digital format and communicated to the opposite parties by electronic means. This form of colour communication or "colour by number" represents the trend in view of the regionalisation and globalisation of the textile and apparel industry, as well as other colour related industries. A clear message from the leading retailer Marks & Spencer plc to the suppliers in this region is that instrumental results and digital data exchange are a necessity.

In general, spectrophotometers for colour measurement perform at a finite level of accuracy but, being electro-mechanical-optical devices, they exhibit measurement errors relative to a theoretical error-free instrument that users must accept. Most modern spectrophotometers have satisfactory repeatability, but the measurements are not necessarily accurate. In a research study carried out by the Spectrophotometry and Colorimetry Club of the National Physical Laboratory (NPL) of the UK[106,107], twenty-four participants were asked to measure the colour of a set of NPL ceramic colour standards using their in-house spectrophotometers. Even the state-of-art instruments showed variance from the standard in the region of 0.7 to 1.6 CIELAB units. Larger differences in excess of 3 CIELAB units were also obtained for some instruments. However, the human eye can identify differences in colour of between 0.5 and 1.0 CIELAB units, depending on the colour. This result strongly suggests that the accuracy of the instrument and the inter-instrumental agreement between spectrophotometers present problems where meeting the requirements for industrial digital colour communication is concerned.

If measurement errors can be quantified and corrected, then the accuracy of the measurement task can be improved. In the design of the spectrophotometer, there are inherent problems which lead to both systematic and random error, affecting the

accuracy of results. As a consequence, such errors must be analysed and quantified mathematically in order to improve the accuracy and to promote globalised digital colour communication for a variety of commercial and industrial applications. The colour measurement spectrophotometers have performed satisfactorily and provided useful colour information for over 10 years. However they exhibit several deficiencies, primarily due to age, poor inter-instrumental agreement and limited software flexibility and capabilities.

Earlier researchers have shown the effectiveness of the improvement of the inter-instrumental agreement[2,8,9,84]. However, systematic studies which focus on the requirement of digital colour communication have not yet been conducted. The research project described served to develop a methodology and an algorithm aiming at improving the accuracy of the colour communication based on spectrophotometric measurement so that commerce and industry may gain immediate benefits from the results obtained.

In surface colour measurement related industries, colour measurement systems are widely used to both measure colour and evaluate colour quality. Reflectance

spectrophotometers are one of the popular instruments used in colour measurement related industries in order to measure the surface colour accurately. Spectral reflectance data of a colour can be measured using reflectance spectrophotometers. In addition, the spectrophotometer can provide higher accuracy with its high precision sensor and measure colour for a variety of illuminant conditions.

In the textile or other colour related industries, for example textile coloration and printing *et al.*, objective colour difference evaluation is now far more important than ever before. Colour quality control is one of the most important parameters to determine whether the finished goods are acceptable or not in textile or other colour related industries. In addition, objective colour difference specification for quantitative colour comparison is also very important to promote quick response to the market place and is an efficient means of in-house colour quality control. Reflectance spectrophotometers are one of the most important devices for checking the colour quality of textile products.

With the development in electronic devices and machine design, the repeatability of spectrophotometric measurements has become more and more accurate in practice. For this reason, different manufacturers claim that the repeatability of measurement on the

same instrument is lower than 0.01 CIELAB ΔE units[29,70,71]. The manufacturers also claim that the inter-instrumental agreement of the spectrophotometers of similar design is lower than 0.15 CIELAB ΔE units[29,70,71]. However, in the investigation under discussion, it was found that even the reflectance spectrophotometers produced by the same manufacturers had an inter-instrumental agreement range from 0.526 to 0.611 CIELAB ΔE units. In the case of instruments produced by different manufacturers, the inter-instrumental agreement ranged from 0.575 to 0.854 CIELAB ΔE units. For this reason, the first objective of this research project was to study the inter-instrumental agreement of the commercial reflectance spectrophotometers using Ceramic Colour Standards – Series II tiles (CCS-II Tiles). Both the GLOSSY and MATT types of the CCS-II tiles were chosen for use in the experimental work. The results of this study illustrate that improvement in the communication between instruments should be achieved in order to enhance inter-instrumental agreement.

In previous studies, the development and the tests for the mathematical models were based on GLOSSY type ceramic tiles. For this reason, both GLOSSY and MATT types of ceramic tiles were used to develop the mathematical models separately in this project. In addition to ceramic tiles, textile samples and also paper samples were used to test the newly developed mathematical models.

1.2 Objectives

The objectives of this research study are summarized as follows:

I. To study the repeatability and inter-instrumental agreement of spectrophotometers.

II. To analyse the causes of the poor inter-instrumental agreement between spectrophotometers.

III. To develop a mathematical model in order to improve inter-instrumental agreement between spectrophotometers.

IV. To test the new developed mathematical models using different types of samples.

1.3 Scope Of Study

This research project focused on the study of the measurement results of spectrophotometers and the development of new mathematical models to improve inter-instrumental agreement. Experiments were carried out to develop the appropriate mathematical models. A comparison between the newly developed mathematical models and the previously reported mathematical models was also carried out in this research project. The emphasis of the research was to develop a new mathematical model in order to improve the inter-instrumental agreement of the reflectance spectrophotometers. In addition, the performance of the newly developed models was of major importance, thus the testing of the previously reported and newly developed mathematical models are also summarised in this thesis.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Colorimetry[85,95] is the science of measuring or evaluating colour and colour is defined as the sensation experienced or caused by light reflected from or transmitted through objects. The appearance of colour is subject to the influence of three different phenomena: the light source, the object and the visual system. If the above three factors can be quantified, the sensation of colour can be measured and finally calculated even though the perceived colour cannot be directly measured. In the textile industries, especially in textile coloration, it would be very beneficial if the colour properties of textile materials could be quantified.

Colour measurement is achieved using instruments such as the tristimulus colorimeter and spectrophotometer. Video cameras[21,22] have also been employed in the field of colour measurement and control. The tristimulus colorimeter measures the CIE tristimulus data directly[18]; the spectrophotometer measures the spectral reflectance factors or transmittance factors, and the video camera is mainly used for on-line colour monitoring.

In general, the tristimulus colorimeter[17] is easy to use and cheaper than the

spectrophotometer. Although it is less accurate in practical application than the modern spectrophotometer, the tristimulus colorimeter can also express colours numerically according to international standards, for example as seen in the CIE system[7,18]. For this reason, the tristimulus colorimeter is primarily used for colour quality monitoring.

In order to measure colour accurately, the modern spectrophotometer[17] is widely used in colour science related industries. Using spectrophotometers, not only the numerical data obtained from the tristimulus colorimeters, but also the spectral reflectance graph for the colour can be obtained. The spectrophotometer also offers greater accuracy with its high precision sensor and the inclusion of data for a variety of illuminant conditions.

2.2 Historical Development Of Colour Measurement Instruments

Colour quality control has become far more important recently, since colour is the first parameter in evaluating the quality of coloured, finished goods. Visual assessment is the traditional method to evaluate the colour quality, but this method has many drawbacks. For instance, sample soiling and notoriously unreliable visual assessment account for 17% of "wrong decisions" made by colour experts[44]. In addition, visual assessments are qualitative, debatable, vary according to viewing conditions and are

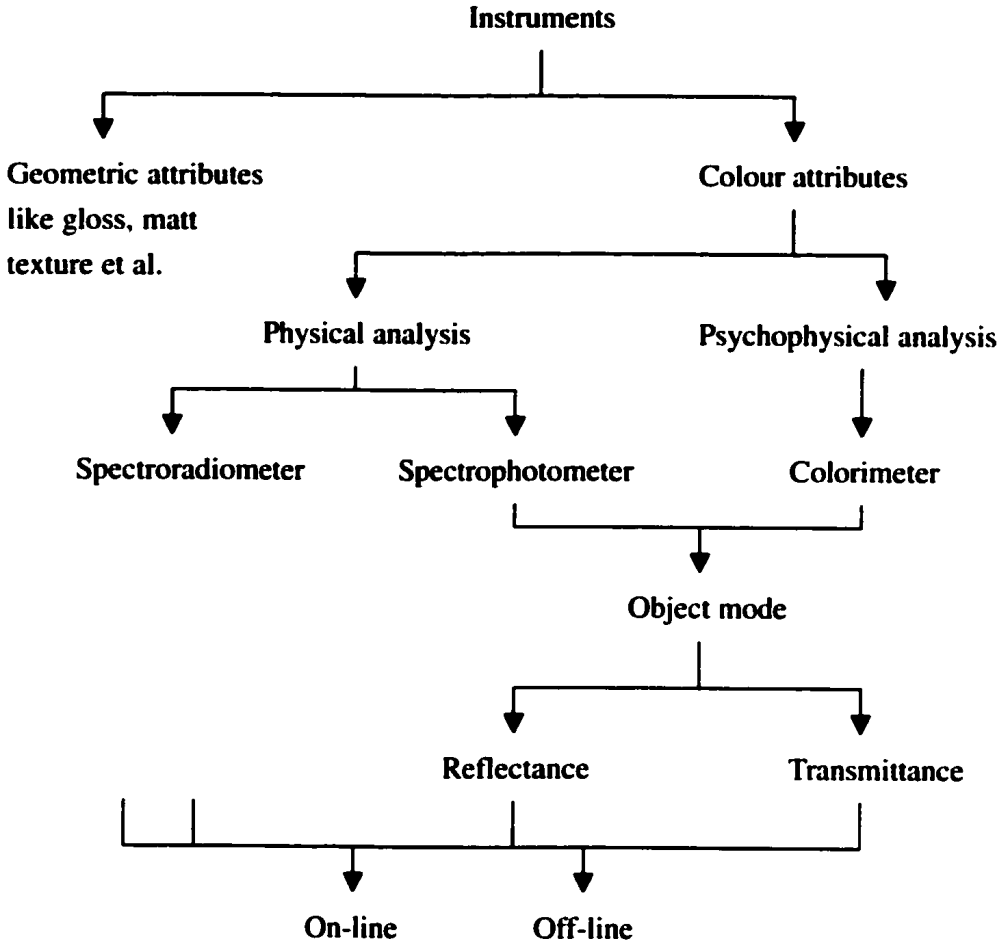
observer-dependent.

In 1931 CIE[18] defined the standard observer and illuminants, which became the basis for instrumental colour measurement. The first generation instrument for this task measured point-to-point reflectance, and the results were calculated using conventional techniques available at the time. Between 1936 and 1946, Prof A.C. Hardy introduced automatic mechanical calculators, and these became known as the second-generation instruments. The commercialisation of the analog computer led to the third generation of the instruments. With the development of personal computers, the measurement speed and calculation time became progressively faster and the fourth generation of colour measurement instruments arrived.

2.3 Classification Of Colour Measurement Instruments

Colorimetric instruments can be divided into three basic types, these being the colorimeter, spectroradiometer and spectrophotometer. The classification of those three types of machines are summarised in the table below:

Table 2.1 General Classification Of Colour Measurement Instruments (Source: Modern Concepts Of Color And Appearance)



2.3.1 Colorimeter

Colorimeters[17] were the first colour measurement instruments to be used in the colour related industries. Colorimeters were also known as "Three-filter Colour Measurement Instruments". The three-filters simulated the human eye's cone cell, red, green and blue photo-detectors, measuring the tristimulus values. The light source for these

colorimeters was a quartz halogen bulb, which illuminated the sample at 45° to the norm.

The colorimeter is primarily used for measuring CIE tristimulus values (CIE colorimetric coordinates) for a stimulus. In general, there are two different types of colorimeter, one being visual and the other photoelectric[64]. Visual colorimeters were traditionally of two types, the earliest ones being visual absorptionmeters or colour comparators. Such instruments are mainly used to measure liquid colour and they are employed for chemical analysis, concentration determination or grading on the basis of colour. The other type of colorimeter was a true colorimeter that emphasised visual equivalence or psychophysical estimation. This type of visual colorimeter compared the colour of the samples with the colour of the standard and matched the two. The other type was a true colorimeter that emphasised visual equivalent or psychophysical estimation.

True colorimeters define colours in terms of their own primaries. A number of colorimeters were specially developed for colour vision research. These were very complex, costly and highly specialised to serve one or a limited number of purposes.

The earliest true colorimeter was Clerk Maxwell's colour box, which consisted of a prism unit with adjustable slits in the appropriate parts of a light path to independently control the amount of red, green and blue light beams viewed as a homogeneous colour in an optical viewing unit to match the colour of the sample shown in the other half of the optical unit. The relative aperture areas x, y and z were recorded as the amount of the three primaries, x, y and z.

The earliest tristimulus colorimeters, such as those developed by Guild[49], Wright[109], Donaldson[31,32], MacAdam[69] and Wyszecki[110,111], were used mainly for research purposes where more than two visual fields were necessary to examine colour difference matching, colour matching ellipses, hue matching etc. The Burnham colorimeter[12] was relatively simple in construction and utilized additive mixing of primary stimuli made up of coloured filters and a light source. Figure 2.1 shows the arrangement of the three filters and aperture plate. The lower two adjacent filters are red and green, while the upper filter is blue. The horizontal and vertical movements of the filter control the proportion of red-green and yellow-blue components respectively. The scales actuated by the two movements gave the proportion of the three primary colours. A shutter on the test field allowed the luminosity of the two fields to be equalised.

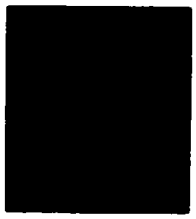


Figure 2.1 Burnham Colorimeter With Red, Green And Blue Filters And Aperture Plate

The Lovibond colorimeter[16,65] was a popular commercial visual colorimeter even 100 years after its use and development. This colorimeter was based on the subtractive colour mixing of coloured glass filters. For each of the three primaries, magenta, yellow and cyan, there were 250 Lovibond glass filters. The filters are graduated in the way that two "1.0" glasses match a "2.0" glass plus a colorless glass. An equal value of all three together gave a grey series down to the black. There are around nine million colours of varying brightness which can be matched by putting suitable Lovibond filters in the light filters in the light path for whole visible colour or saturation.

Modern colorimeters directly measure colorimetric quantities, and the detector system of the colorimeters consists of a glass filter and a photodetector, usually a silicon photodiode.

In common practise, the measurement results of the tristimulus colorimeter are less accurate when compared with the modern reflectance spectrophotometer. The tristimulus colorimeter expresses colours numerically according to CIE standards[18] and it is mainly used in colour quality monitoring.

2.3.2 Spectroradiometer

The spectroradiometer is mainly used to measure self-illuminant objects such as television and video displays. Inside the spectroradiometer, the light source is integral and shielded from external light sources whereas a spectroradiometer can accept light from external sources. Spectroradiometers measure radiometric quantities of light sources as a function of wavelength. The measurement involves the comparison of the test source with a suitable reference source of known spectral power distribution. Standardised tungsten filament lamps are the most often-used reference source. In the case of a tungsten or tungsten-halogen lamp, the bandwidth can be large ($\Delta\lambda$ = 5 or 10 nm) for light sources with continuous spectra, but for discontinuous line spectra, such as fluorescent lamps, the interval should not be more than 2 nm. However if the wavelength of emission lines is known, separate measurements can be made at those wavelengths and then the data combined with those taken at 10 nm bandwidth. An

elaborate spectroradiometer and sophisticated illumination standards can provide accurate colorimetric information for coloured samples. However some good estimates of chromaticity values can be obtained from a broad band device such as a colour video camera, provided it is properly calibrated by measuring R, G and B values of suitably chosen colour standards and by reconstructing reflectance accordingly[64].

2.3.3 Spectrophotometer

The spectrophotometer[17] mainly measures reflectance, transmittance, or absorbance at different wavelengths in the spectrum. The quantity of reflectance measured is referred to as the reflectance factor (RF) and is defined as the reflectance of the sample at a specific wavelength range compared to the reflectance of the perfect diffuse white measured under the exact same conditions. The mathematical expression is as follows:

$$RF(\lambda) = R(\lambda)_{(sample)} / R(\lambda)_{(standard)} \text{ ----- E.Q. 2.1}$$

In common practice, the reflectance factors are expressed as a percentage, %R.

Some important principle components of the spectrophotometer are discussed in the

following paragraphs.

2.3.3.1 *Spectral Range*[5.13.51.89.96.97]

According to the Sandoz Colorimetry Manual, the reflectance factor is the ratio of the reflected to the incident light at a given wavelength. Based on the CIE recommendations[18.87], it is preferable that the measurement data of spectrophotometer should have a spectral range from 380 to 780 nm available at 5-nm intervals. In general practice, the spectral range from 400 to 700 nm with minimum data available at 10-nm intervals is sufficient.

2.3.3.2 *Illuminating System*[5.13.51.59.89.96.97.98]

The primary considerations for the illuminating system, also the light sources, for spectrophotometers are stability, life, directibility and spectral energy distribution. Incandescent lamps are mostly preferred because of the following features:

i. Low cost

ii. Continuous SPD as sunlight

iii. Steady output of light

iv. Output controllable by changing electrical input

v. Small compact size allowing concentrated light beam that can be directed by mirror etc.

No specifications are made for the light source used in the spectrophotometer because they measure the ratio of incident to reflected light due to the size as well as the absence of a concentrated light beam.

Quartz halogen lamps are used only for illuminant A. Such lamps emit very limited UV hence they do not excite a fluorescent brightening agent to the same extent as daylight. On the other hand, these lamps produce too much energy in the IR region but many colorants are sensitive to light (known as photochromic) or to heat (known as thermochromic). Thus the samples are heated by the emitted energy, potentially leading to errors in the measurements of thermochromic samples. In addition, colour fading may occur after prolonged exposure to the strong light beam.

In order to overcome these problems, pulsed xenon light sources are employed in modern spectrophotometers, since the physical characteristics of the pulsed xenon light are almost ideal and have a spectral power distribution (SPD) close to daylight. The pulsed xenon lights are easily filtered to approximate illuminant D_{65} from the UV to the IR end of the spectrum. Pulsed xenon light releases a flash of light of a few nanoseconds duration during each measurement instead of supplying a constantly illuminating light source. This kind of light is used for electrical discharge lamps that emit a large quantity of radiant power for a very short duration of time. The drawback is that the pulsed xenon light provides a line spectrum of discontinuous nature and the output stability is poor. Fluorescent samples can also be measured by such sources and the samples may not be heated by such sources. In addition, pulsed xenon light is suitable for the measurement of dark colours.

2.3.3.3 Monochromator[5,13,51,89,96,97]

The monochromator, or so-called spectral analyser, is a device that splits light into its spectral components so that it can be measured. It is a key component of the spectrophotometer, setting most of the performance characteristics.

In the earliest spectrophotometer, a photomultiplier tube was commonly used as a monochromator. It used mechanical techniques to scan the spectrum over a single light detector. Thus the measurements were made sequentially, and it could take several minutes to scan from 400 to 700 nm.

Prisms, the classic devices for splitting white light into its component colours, were the most popular monochromator used in many early spectrophotometers. They consisted of an entrance slit, a collimator lens for producing parallel beam, a prism for dispersion of light and a second telescopic lens for focusing in the plane of the exit slit. As the exit slit is in a fixed position, monochromatic radiation can be selected by moving a narrow exit slit or by rotating the prism.

Both the entrance and the exit slit should be extremely narrow, but a compromise can be made by allowing a minimum amount of monochromatic light to pass into the detector. In addition the exit slit should be of adjustable width because the separation of equal wavelength intervals is inconstant. Most importantly the bandwidth of radiation depends on the construction of the monochromator and varies between different spectrophotometers. In most of the modern spectrophotometers, the manufacturers will

not use prism monochromators because of the limited supply of natural materials required to make them.

Diffraction grating is one substitute for the prism. A grating is a film or surface containing close equidistant and parallel lines used for producing spectra by diffraction. The price for diffraction grating monochromators is lower than that for prism monochromators and their dispersion power is independent of wavelength, therefore the wavelength selection is much simpler than in the case of the prism.

2.3.3.4 Equipment Mode[5.13.51.89.96.97]

There are two equipment modes for colour measurement, one being polychromatic and the other monochromatic.

In the polychromatic mode, the light source is directed onto the sample first and the reflected light is then monochromated. In monochromatic mode, the light source is monochromated first and the selected monochromatic light is then directed onto the

sample. In principle, the monochromatic mode is suitable for the measurement of the nonfluorescent sample but not for the fluorescent sample and vice versa.

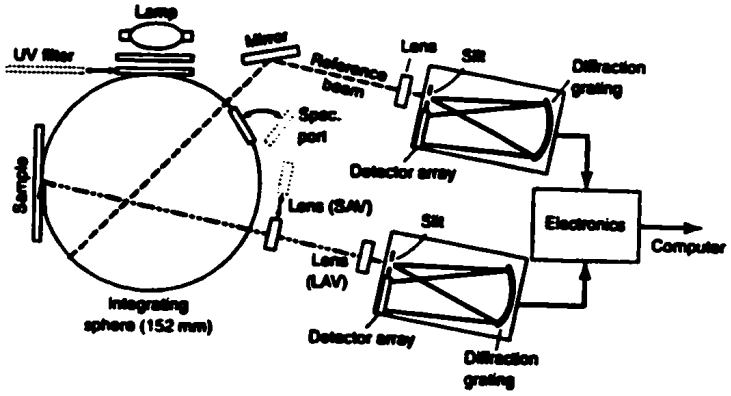


Fig. 2.2 Simplified Optical Diagram Of The Dual-Beam Spectrophotometer (Source: Colour Physics For Industry, 2nd Edition)

2.3.3.5 Illumination and Viewing Geometries[5,13,51,89,96,97]

The term geometry refers to the placement of a sample relative to the light source and measuring lens in a spectrophotometer. There are four geometries defining the direction of the incident light and the direction of detecting the reflected light based on the recommendation of CIE. In general, the four geometries can be further divided into two groups, these being the bi-diection type and sphere type.

The bi-direction type is suitable for the measurement of a sample with a smooth surface. In this type of geometry, the light beam at one angle illuminates the sample and the reflected beam is detected at an angle of 45/0 or 0/45 geometries. If the samples used in the measurement process do not have a smooth surface, circumferential 45/0 or 0/circumferential 45 are preferred.

The geometry of the sphere type is designated as Diffuse/0 (D/0) or 0/Diffuse (0/D) according to CIE recommendation. These two geometries are suitable for the measurement of textile samples since they generally have matt surface. The Diffuse/8 (D/8) or 8/Diffuse (8/D) sphere type provides the option to include or exclude the specular port measurement of the flat samples.

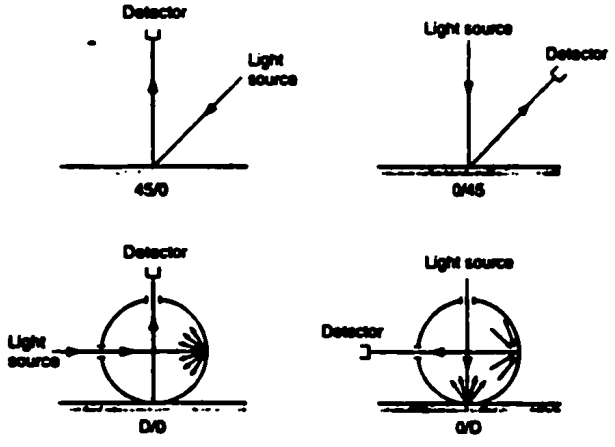


Figure 2.3 CIE Illuminating And Viewing Geometries (Source: Colour Physics For Industry, 2nd Edition)

2.3.3.6 Detector System[5,13,51,89,96,97]

The spectral analyser is a device that splits light into its spectral components so that they can be measured.

The photomultiplier is a traditional type of light-detecting device updated using the tiny solid-state silicon diode photodetector array. An array of silicon diodes ensures that measurements can be made in a few seconds and, since there are no moving parts, the reliability is greater.

MC90 is a dual-channel, holographic grating based spectrometer which uses two custom photodiode linear arrays for the reference and sample beams.

In order to enhance the measurement accuracy, the hardware has been progressively modified[20]. The first modification was the addition of a motorised adjustable UV control. The UV content should be automatically adjusted once the UV calibration has been achieved and the UV filter adjustment made accordingly.

In order to measure dark or highly saturated colours, a high intensity pulsed xenon light was adopted for the purpose of improving the accuracy of readings. In addition, a removable thin film sample holder was added to the instrument for the measurement of diffusion or transmission of the liquid or solution. It is advantageous for the spectrophotometer to adjust the lens automatically once the aperture is changed, and to measure the reflectance of the surface coloured objects with greater accuracy. Recently, video cameras have also used for colour measurement, mainly in the course of on-line colour monitoring.

The performance of an instrument is important when obtaining measurement data which is consistent, repeatable or error free. Regular checks can help to ensure the accuracy of the measurement results. Documentation also assists the user to compare experimentally-derived data with the standard data provided by the manufacturer, or data obtained at an early stage after purchase of the apparatus.

2.4 Commonly Used Types Of Spectrophotometers

There are four different types of spectrophotometers commonly in use, these being the Single-Beam Spectrophotometer[96,97], Dual-Beam Spectrophotometer[96,97], Double-Beam Spectrophotometer[96,97] and Portable Hand-Held Spectrophotometer[26,27,90,91].

2.4.1 Single-Beam Spectrophotometer[96,97]

In the case of the single-beam spectrophotometer, two measurements must be made in sequence. For this reason, time is required between the two measurements in order to keep the measurement system stable. The time requirement is mainly for the stabilisation of the light sources and conversion of the small electrical signals coming from various detectors into large signals which may be collected by the amplifiers. Although the single-beam spectrophotometer is simpler in its construction, it is harder to calibrate. The long-term repeatability is inferior to that of the dual-beam and also the double-beam spectrophotometers if calibration is not done carefully and on a regular basis.

2.4.2 Dual-Beam Spectrophotometer[96,97]

The reference beam of the dual-beam spectrophotometer measures light that is reflected from the integrating sphere wall. This gives a measurement of light in the sphere that is incident on the sample. The measurement is generally more accurate because both the incident and reflected light from the sample is measured. The measurement stability of instrument is increased with the use of a reference beam so that any drift of the electronics or light source intensity is cancelled out as both beams will be equally affected. A dual-beam spectrophotometer is less sensitive to the dis-colouring of barium sulphate in the integrating sphere with age. Errors caused by the drift of the measurement electronics or variation in the light source is eliminated because dual-beam measurement mainly involves the measurement of a ratio rather than an absolute value.

2.4.3 Double-Beam Spectrophotometer[96,97]

There are two types of double-beam spectrophotometers. The main difference between the two instruments is that one uses two detectors while the other uses one only. The light beam from the monochromator is split to follow two paths in the former type of spectrophotometer. The sample is placed in one, whilst the other contains all the

components except the sample. The light intensity/response curves of the two detectors must be accurately matched and two signals are obtained by electrical switching between the two detectors or by using a chopping device to interrupt the light beam alternately in the two beams. The requirement to match the two detectors is obviously in the single detector systems. In these, a chopper is used to allow the light to traverse the sample and solvent paths alternately. There should be identical components in each path.

2.4.4 Portable Hand-Held Colour Measuring Instruments[26,27,90,91]

As a consequence of advances in integrated electronics and smaller optical components, portable, hand-held colour measuring instruments[90,91] have been introduced into the market in recent years. Assisting in the matter of of quality control, portable hand-held colour measuring instruments become increasingly more popular for simple colour measurement and communication. The advantages of the portable hand-held colour measuring instrument are that the computer is not required as the communication interface. The built-in microprocessors can calculate colour differences, pass/fail, shade sorting, whiteness, grades of fastness, and many other indices of colour and appearance. Besides, the prices for the portable models are lower than those for the laboratory. According to D. Scott Reininger[26,27], there are four requirements for portable hand-held

colour measuring instruments; these being accuracy, precision, durability and lastly functionality.

Of the four different spectrophotometers, portable hand-held machines are the most commonly used in quality control because of their light weight (two to four pounds) and ease of use. Bench top models have better functions than portable ones, but because of their size and the requirement of a computer as the communication interface, they are more commonly used in laboratories or factories.

2.5 Colour Difference Formulae Used In Textile Industry

In this project, colour difference was used to evaluate both the colour measurement and inter-instrumental agreement results. There are many colour difference formulae and those most commonly used in the textile industry are CIELAB Color Space[1], CMC(l:c)[10,11,19,72] and CIE 1994(ΔL^* ΔC^*_{ab} ΔH^*_{ab}) colour-difference formula[73,83].

2.5.1 CIELAB Color Space[1]

CIELAB is the modification of the Adams-Nickerson formula (ANLAB)[4,64], and it was recommended by CIE in 1976. This color space included three attributes L*, a* and b* which are calculated based on the CIE tristimulus values, CIE X, Y and Z. L* represents the lightness, a* represents the redness and greenness and b* represents the yellowness and blueness.

The general CIELAB colour difference formula is as follows:

$$\Delta E^*_{ab} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \text{ ----- EQ 2.2}$$

or

$$\Delta E^*_{ab} = [(\Delta L^*)^2 + (\Delta C^*_{ab})^2 + (\Delta H^*)^2]^{1/2} \text{ ----- EQ. 2.3}$$

Where

$L^* = 116(Y/Y_n)^{1/3} - 16$ if $Y/Y_n > 0.008856$

$a^* = 500\,[(X/X_n)^{1/3} - (Y/Y_n)^{1/3}]$ if $X/X_n > 0.008856$

$$b^* = 0.4 \times 500\,[(Y/Y_n)^{1/3} - (Z/Z_n)^{1/3}] \text{ if } Z/Z_n > 0.008856$$

OR

$$L^* = 903.3(Y/Y_n) \text{ if } Y/Y_n \leq 0.008856$$

$$a^* = 500 \times [7.787 \times (X/X_n - Y/Y_n) + 16/116] \text{ if } X/X_n \leq 0.008856$$

$$b^* = 500 \times [7.787 \times (Y/Y_n - Z/Z_n) + 16/116] \text{ if } Z/Z_n \leq 0.008856$$

$$C^*_{ab} = [(a^*)^2 + (b^*)^2]^{1/2}$$

$$h_{ab} = \tan^{-1}(b^*/a^*)$$

$$\Delta L^* = L^*_{sample} - L^*_{standard}$$

$$\Delta a^* = a^*_{sample} - a^*_{standard}$$

$$\Delta b^* = b^*_{sample} - b^*_{standard}$$

$$\Delta C^*_{ab} = C^*_{ab,\,sample} - C^*_{ab,\,standard}$$

$$\Delta H^* = [(\Delta E^*_{ab})^2 - (\Delta L^*)^2 - (\Delta C^*_{ab})^2]^{1/2}$$

OR

$$\Delta H^* = 2(C^*_1 \times C^*_2)^{1/2} \times \sin(\Delta h/2)$$ [87,102]

2.5.2 CMC(l:c) Colour-Difference Formula

The CMC(l:c) colour-difference formula was derived from the JPC79 colour-difference formula, developed by J & P Coats[19]. The general formula of CMC(l:c) is as follows:

$$\Delta E_{CMC(l:c)} = [(\Delta L^*/lS_L)^2 + (\Delta C^*_{ab}/cS_C)^2 + (\Delta H^*_{ab}/S_H)^2]^{1/2} \text{ ----- EQ. 2.4}$$

Where

$S_L = 0.040975L^*_{standard}/ (1 + 0.01765L^*_{standard})$ if $L^* \geq 16$

$S_L = 0.511$ if $L^* < 16$

$S_C = 0.638 + 0.0638C^*_{ab.\ standard}/ (1+0.0131C^*_{ab.\ standard})$

$S_H = S_C (TF + 1 - F)$

$F = \{(C^*_{ab.\ standard})^4 / [(C^*_{ab.\ standard})^4 + 1900]\}$

$T = 1$ when $C^*_{ab.\ standard} < 0.638$ or

$T = 0.56 + |0.2 \cos (\theta + 168°)|$ or

$T = 0.56 + |0.4 \cos (\theta + 35°)|$ when $164° < \theta < 345°$

2.5.3 CIE 1994($\Delta L^* \Delta C^*_{ab} \Delta H^*_{ab}$) Colour-Difference Formula

In 1995, the CIE Technical Committee (TCI-29) recommended a new colour difference formula CIE94[73], which was a modification of CMC(l:c) formula and CIE Color Space. In this new colour-difference formula, there was a new term (ΔV) for the visually perceived magnitude of a colour difference.

$$\Delta V = k_E^{-1} \Delta E^*_{94} \text{ ----- EQ. 2.5}$$

Where k_E is an overall visual sensitivity factor, set to unity under the conditions usually applying in industrial assessment.

The basic conditions are as follows:

i. The specimens are homogeneous in colour

ii. The colour difference between them is such that $\Delta E^*_{ab} \leq 5$

iii. They are placed in direct edge contact

iv. Each subtends an angle greater than 4° to the assessor

v. The assessor's colour vision is normal

vi. They are illuminated at 1000 lux and viewed in object mode, against a uniform neutral grey bakground of L* = 50, under illumination simulating D65

The general formula of CIE94 colour-difference formula is as follows:

$$\Delta E^*_{94} = [(\Delta L^*/ k_L S_L)^2 + (\Delta C^*_{ab}/k_C S_C)^2 + (\Delta H^*_{ab}/ k_H S_H)^2]^{1/2} \text{ ----- EQ. 2.6}$$

Where

ΔL^*, ΔC^*_{ab} and ΔH^*_{ab} are the compoments of the CIELAB formula,

k_L, k_C and k_H are parameters factors - under usual condition, $k_L = k_C = k_H = 1$, while in textile assessment $k_L = 2$ and $k_C = k_H = 1$

S_L, S_C and S_H are the weighting functions, where

$S_L = 1$

$S_C = 1 + 0.045C^*_{ab,X}$

$S_H = 1 + 0.014C^*_{ab,X}$

Where

$C^*_{ab,X} = C^*_{ab,standard}$ if there is a clear difference distinguished between the sample and standard, and

$C^*_{ab,X} = (C^*_{ab,standard} \times C^*_{ab,sample})^{1/2}$ when there is no difference distinguished between the standard and sample.

In general, CMC(l:c) seems similar to CIE94, which is to define ellipsoids in CIELAB space, but the ways in which the two formula are expressed are different[83]. The differences are:

i. In the CMC(l:c) formula, S_L increases with the $L^*_{standard}$, but this is not recommended in the case of the CIE94 formula.

ii. CMC(l:c) formula shows non-linear expansion of S_C and S_H with C^*_{ab} but in the case of CIE94 formula the relationship is linear.

iii. In CMC(l:c) formula, S_H shows systematic variation with h_{ab}, but in the case of CIE94, it is independent.

There are still many different colour difference formulae, such as ANLAB Color Space[41], CIELUV Color Space[11], M&S colour-difference formula and BFD(l:c) Color-difference Formula[66,67], and all of these are specially designed to fit a particular set of data, which may result in poor correlation between ΔE and other visual data.

In this project CIELAB Color Space was selected to evaluate the colour difference of the measured data and also the inter-instrumental agreement. This is because CIELAB is one of the colour difference formulae that approximate uniform colour spaces and colour-difference calculations.

2.6 Colouring By Numbers

Traditionally, physical samples played an important role in colour matching and communication, but even experienced colourists make errors in their visual assessment[44]. Their performance is affected by medical, psychological and environmental factors such as the light booth, lighting and so forth.

As a result of advances in the development of personal computers and networked systems, as well as spectrophotometry and information technology, objective colour judgement[28,41,42,45,46] has become more useful and important in monitoring the colour acceptability of a product by customers and sellers during the various stages of the production cycle. In addition, colour quality may be assessed in digital format, i.e., spectral reflectance factors, and sent to another party by electronic means rather than physical samples. This communication format is commonly known as "Colouring by Numbers".

Although "Colouring by Numbers" has become popular in colour measuring and colour matching, there are still many difficulties to be overcome. One problem is that a spectrophotometer performs at a finite level of accuracy but it exhibit measurement errors relative to a theoretically error free instrument that the user must accept [39,40,52,61,62]. The other problem is the repeatability[23,24,47,93] and inter-instrumental agreement[24,47,86] of the spectrophotometer. Repeatability and inter-instrumental agreement can be checked using the Ceramic Colour Standards (CCS)[14,15] developed by the National Physical Laboratory (NPL) in the UK[82,106,107]. Besides repeatability and inter-instrumental agreement, CCS can also be used to diagnose the spectrophotometer and improve inter-instrumental agreement.

2.7 Inter-Instrumental Agreement[105]

Inter-instrumental agreement is the agreement between two or more spectrophotometers achieved using the same measuring and operation system.

In a study conducted by the NPL in 1995[82,106,107], it was found that colour measurement results ranged from 0.1 to 3.0 CIELAB units among twenty participants. In another research project conducted by NPL, it was discovered that only 50% of measurements made by four national laboratories agreed to within a range of 0.5 CIELAB units.

According to James Rodgers, Kaye Wolf, Norm Willis, Don Hamilton, Ralph Ledbetter and Curtis Stewart[57,58], the major studies of inter-instrumental agreement were the development of inter-instrumental agreement, software development and computer interface. The inter-instrumental systems were compared with an instrument matrix, a decision matrix, and a product matrix.

In 1987, A. R. Robertson[2] proposed a mathematical model for inter-instrumental agreement. He divided the errors into the categories of Photometric Zero Error,

Photometric Scale Error, Wavelength Shift Error, Bandwidth Error and lastly other Error.

According to Robertson's definition, the errors can be summarised as follows:

Photometric Zero Error:

$$R_t(\lambda) - R(\lambda) = e_1 \text{ ----- EQ. 2.7}$$

Photometric Scale Error:

$$R_t(\lambda) - R(\lambda) = e_2 R(\lambda) \text{ ----- EQ. 2.8}$$

Wavelength Shift Error:

$$R_t(\lambda) - R(\lambda) = e_3 R'(\lambda) \text{ ----- EQ. 2.9}$$

Bandwidth Error:

$$R_t(\lambda) - R(\lambda) = e_4 R''(\lambda) \text{ ----- EQ. 2.10}$$

Other Error:

$$R_t(\lambda) - R(\lambda) = e_j F_j \text{ ----- EQ. 2.11}$$

Symbols:

λ	=	Wavelength
$R(\lambda)$	=	True or standard value of spectral reflectance factor at wavelength, λ
$R_i(\lambda)$	=	Spectral reflectance factor measured in the instrument to be tested
$R'(\lambda)$	=	First derivative of $R(\lambda)$ with respect to λ. This is the slope of the reflectance factor curve
$R''(\lambda)$	=	Second derivative of $R(\lambda)$ with respect to λ. This is a measure of the curvature of the reflectance factor curve
e_j	=	A measure of the magnitude of a particular type of error. Photometric zero error are indicated by j=1, photometric scale error by j=2, wavelength shift error by j=3 *et al*
F_j	=	Any function of λ, R, R', R''

Where $R'(\lambda)$ and $R''(\lambda)$ can be estimated by 1). Matrix Method or 2). Selection Method. Based on their research results, both the matrix method and the selection method performed well, and the matrix was preferable if it could be inverted accurately.

In 1988, Roy S. Berns and Kelvin H. Peterson[8] modified Robertson's equation adding more detail to describe the errors of inter-instrumental agreement. Besides the above-mentioned errors, Photometric Nonlinear Scale Error and Wavelength Nonlinear Scale Error were included, and each of the errors was represented by one equation.

Photometric Nonlinear Scale Error:

$$R_i(\lambda) - R(\lambda) = e_5[100 - R(\lambda)]R(\lambda) \text{ ----- EQ. 2.12}$$

Wavelength Nonlinear Scale Error:

$$R_t(\lambda) - R(\lambda) = e_6 w_1(\lambda) R'(\lambda) \text{ ----- EQ. 2.13}$$

$$w_1(\lambda) = [(\lambda - \lambda_{first})/(\lambda_{last} - \lambda_{first})]\{1 - [(\lambda - \lambda_{first})/(\lambda_{last} - \lambda_{first})]\} \text{ ----- EQ. 2.14}$$

$$R_t(\lambda) - R(\lambda) = e_7 w_2(\lambda) R'(\lambda) \text{ ----- EQ. 2.15}$$

$$w_2(\lambda) = \sin 2\pi (\lambda / 200) \text{ ----- EQ. 2.16}$$

Where e_6 and e_7 are non-linear wavelength scale errors. Weighting function $w_1(\lambda)$ is identical to the quadratic function described in EQ. 2.9, except scaled to wavelength. Weighting function $w_2(\lambda)$ is a one-and one-half-cycle sine wave. This would represent an instrument with both positive and negative wavelength errors.

In 1994, Lisa Reniff[63] successfully applied the equations to transfer the 45/0 reflectance factor and the average ΔE^*_{ab} was about 0.2 units. The average reflectance factor error consistently found between the corrected measurement of the National Institute of Standards and Technology (NIST) standards and their certificate values was 0.0006.

In 1997, further studies by Roy S. Berns and Lisa Reniff[9],resulted in the integration of all the equations, and the Abridged Technique to Diagnose Spectrophotometric Errors was developed. The integrated equation is as follows:

$$R_s(\lambda) = R(\lambda) - \beta_o - \beta_1 R(\lambda) - \beta_2 d\, R(\lambda)/d\lambda \text{ ------ EQ. 2.17}$$

Symbols:

$R_s(\lambda)$	=	Simulated error
$R(\lambda)$	=	True or standard value of spectral reflectance factor at wavelength, λ
β_o	=	Black photometric error
β_1	=	White photometric error
β_2	=	Wavelength error

For reference white error (β_1) affects the upper portion of photometric scale more and for reference black error (β_o) affects the photometric scale equally. EQ. 2.17 defining a straight line, reference white affects the slope while reference black affects the intercept. Wavelength errors (β_2) affect the portion of the reflectance factor curve where there is the greatest rate of change $d\, R(\lambda)/d\lambda$.

Based on EQ. 2.17, if a flat curve occurs there is no error, if a slight curve occurs there is a small error and, once a steep curve occurs, a large error is evident.

There was the limitation for EQ. 2.17 and once applied, there was an assumption: three errors equally throughout the spectrum ----- β_o, β_1, β_2 assumed to be wavelength independent, but the assumption failed when the white calibration plaque was wavelength dependent because of soiling, yellowing and abrasion

Morovic and et. al[84], proposed three modifications to the Berns and Petersen's model to calculate the inter-instrumental agreement. According to their model, the errors could be summarised as follows:

Zero-offset

$$e_0(\lambda) = 1 \text{ ----- EQ. 2.18}$$

Linearity

$$e_1(\lambda) = Rm(\lambda) \text{ ----- EQ. 2.19}$$

Non-linearity

$$E_2(\lambda) = (100 - R_m(\lambda))R_m(\lambda) \text{ ----- EQ. 2.20}$$

For correcting wavelength scale, equations 2.21 – 2.23 were used

Linearity

$$e_3(\lambda) = dR_m(\lambda) / d\lambda \text{ ----- EQ. 2.21}$$

Non-linearity (Quadratic)

$$e_4(\lambda) = w_1(\lambda)dR_m(\lambda) / d\lambda \text{ ----- EQ.2.22}$$

Where $w_1(\lambda)$ is a quadratic weighting function

Non-linearity (Sine Wave)

$$E5(\lambda) = w_2(\lambda)dR_m(\lambda) / d\lambda \text{ ----- EQ.2.23}$$

Where $w_2(\lambda)$ is a sine wave weighting function

Bandwidth Error

$$e_6(\lambda) = d^2R_m(\lambda) / d\lambda^2 \text{ ----- EQ. 2.24}$$

In order to solve the coefficients, they proposed three different methods:

Method I: The same seven coefficients for all wavelengths (7 x 1)

7 coefficients were obtained by the use of EQ. 2.18 to EQ. 2.24, and those coefficients were used to correct the reflectance for all wavelengths.

Method II: Seven coefficients for each wavelength (7 x 31 or 16)

A different set of seven coefficients was obtained to correct the reflectance for each wavelength by the use of EQ. 2.18 to EQ. 2.24.

Method III: Three coefficients for each wavelength (3 x 31 or 16)

A different set of three coefficients was obtained to correct the photometric scale by the use of EQ. 2.18 to EQ. 2.20. This set of coefficients was used to correct reflectance at each wavelength.

The performance of Model II was expected to be the best because of the higher number of degree of freedom than that found in the case of the other models. Model I assumed the same degree of discrepancy across all wavelengths. Model III assumed that a majority of discrepancies occurred as a result of photometric error. According to their reported data, their method and their model resulted in approximately forty percent improvement in the inter-instrumental agreement.

In 1998, the neural networks method was developed to calibrate the spectrophotometer. According to H. P. Lee, G. Qiu and M. R. Luo[50], the experimental result for two different spectrophotometers are presented which show good improvement in inter-instrumental agreement for both the training and testing samples. Using this neural networks method, the systemic errors proposed by Berns and Petersen were included in the study and the results showed a significant improvement in the inter-instrumental

agreement. The results show that after the eight hidden training process, the average colour difference was lowered from 0.65 to 0.24 CIELAB units.

2.8 Band-Pass Correction[6,33, 34, 35]

In 1981[34], Stearns proposed the influence of spectrophotometer slits on the tristimulus calculations. The slit function is defined as photoreceptor response as a function of wavelength during a single radiance-factor measurement. In 1987 and 1988, Stearns[33,35] proposed another factor affecting the accuracy of tristimulus data ----- Band-pass. Based on Stearns' report, there was a significance of the difference in tristimulus values with CIELAB colour difference formula. In this project, the concept of the mathematical models was based on Band-Pass Correction.

Stearns' equation is shown as follows:

$$ZR_a = 1.2MR_a - 0.1MR_{a-1} - 0.1MR_{a+1} \text{ ----- EQ. 2.25}$$

The method of application of EQ. 2.25 is to take 1.2 times the measured radiance at any wavelength and subtract from it a tenth of radiance at the adjoining wavelengths. This gives an estimate of the zero bandwidth radiance at the central wavelength.

CHAPTER 3

EXPERIMENTAL DESIGN AND METHODOLOGY

3.1 Introduction

In this chapter, the physical standards used for colour measurement and colour measuring instruments are discussed. The method of selection of experimental standard[30], experimental sample[36], and also the selection of the spectrophotometers are also outlined[94,99]. The concept of the mathematical models used to predict the colour measurement results are also described.

3.2 Physical Standards

The first Ceramic Colour Standard was produced in 1968[38,39]. It was mainly used to meet the demand for permanent reflectance standards. To date, the British Ceramic Research Association - National Physical Laboratory (BCRA-NPL) Ceramic Colour Standard Series II (CCS-II) is one of the most common and popularly used standards for the colour-related industries[37]. British Ceramic Research Ltd and the National Physical Laboratory developed a collaborative project for this set of standards, with the supporting work on colour difference pairs from the Society of Dyers and Colourists[75]. CCS-II tiles are mainly used to check the consistency of operation and accuracy of the colour-measuring instruments over a long period of time. The tiles are commonly divided into two types, "GLOSSY" and "MATT".

"GLOSSY" tiles are the ceramic tiles that have the whole smooth surface on the whole area, while "MATT" tiles are the ceramic tiles that have the smooth surface on the edge of the tiles but have the non-smooth surface in the center position of the tile.

3.2.1 Production of Ceramic Measurement Standards[14,15,101]

These two sets of CCS-II Tiles contain three neutral grey standards that are used to test the linearity of response, and seven chromatic standards for checking the spectral response of the instruments. All of these standards are sealed into black protective trays. Two colour difference standards, one grey and one green completes the sets and which are sealed into white protective trays. They are used to compare with the middle grey standard and the green standard to provide the two colour difference pairs respectively. All the tiles of the same colour should be produced in the same batch in order to minimize the variation in the spectral properties of the standard. When subsequent batches are needed, they must be clearly labeled, and treated as separate colours for calibration purposes.

During production, careful control is applied to preserve a smooth, slightly convex surface profile, to ensure that the standard fits the aperture of an instrument precisely.

3.2.2 Care of Standards[54,100]

The standards should be held by the edges in order to avoid touching the face with the fingers as this may leave marks on the surface. If the standard becomes soiled, it should

be cleaned by breathing on the surface and wiping it gently with a clean cloth or tissue. If it becomes badly finger-marked or soiled, the glazed surface may be wiped with a pad of tissue moistened with mild detergent solution or a solution of laboratory grade detergent that contains no additives such as bleaching agents, thickeners or colouring agents. After cleaning, the standard can be wiped with a pad moistened with clean water and given a final wipe dry. If this is not sufficient, a pad of tissue lightly moistened with Propanol can be applied and then dried off[14,15]. Most importantly, the standard should not be immersed in water. Care should be taken in handling and cleaning the standard to avoid scratching the glazed surface. At all times, care should be taken not to apply undue pressure when cleaning, to avoid a polishing action or the deposition of lint from the tissue onto the surface.

3.2.3 Use of Standards[53]

In order to obtain the most reproducible results, measurements should be restricted to the central 60mm region of the standard. Ideally a jig should be used to locate the standard centrally over the measuring aperture of instrument. However, the back pattern on each standard is designed to help in locating it in the same position for each measurement.

A strongly coloured standard shows the effect of thermochromism or photochromism[56,68], therefore the standard should always be allowed to stabilise at room temperature before measurement, and care should be taken to avoid undue heating during measurement. Thermochromism is a reversible change of transmittance, reflectance or absorptance caused by a change of temperature, and photochromism is the corresponding effect induced by optical radiation. Such effects can occur when the reflectance standard is used, because they may undergo a considerable temperature rise when subjected to the polychromatic irradiation used by many measuring instruments. A neutral standard does not exhibit thermochromism[56,68]. According to past research[59,92], the red and orange tiles show significant colour change when the temperature changes, and the colour difference is in the range of 1.18 CIELAB ΔE units when the temperature increases from 25°C to 35°C.

The effects of thermochromism and photochromism can occur in the use of reflectance standards, as they may undergo a considerable temperature rise when subjected to the polychromatic irradiation used by many measuring instruments.

After the measurement of standards, the reflectance curves of the standards were plotted

as follows:

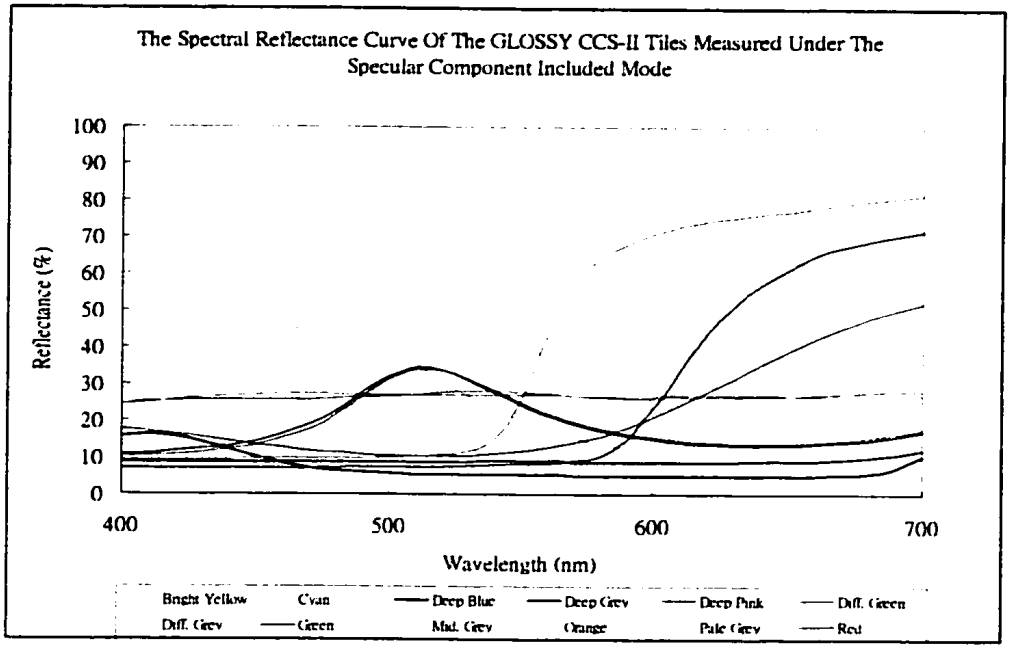


Figure 3.1 The Standard Calibrated Reflectance Curve Of The GLOSSY Type Standard Tiles Measured Using Specular Component Included Mode By CE-7000A

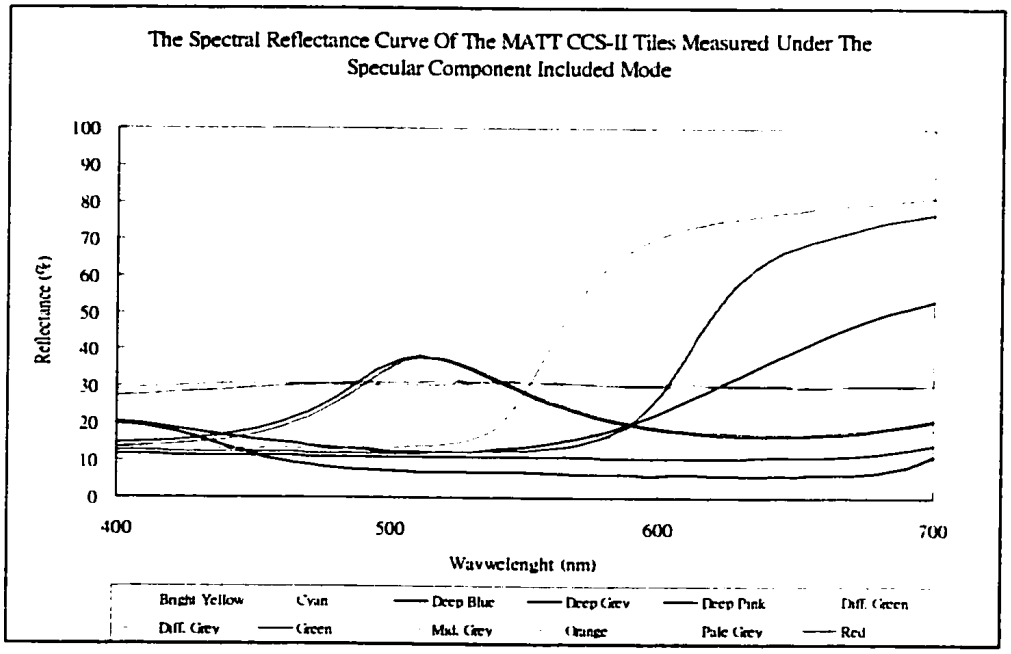


Figure 3.2 The Standard Calibrated Reflectance Curve Of The MATT Type Standard Tiles Measured Using Specular Component Included Mode By CE-7000A

3.2.4 Other Testing Samples

In this project, BCRA-NPL CCS-II tiles were the main calibrating standards and the data input for building up the mathematical models. After the development of mathematical models, two different types of samples were selected to test the performance of the mathematical models. One was a textile sample and the other was a selected ColorCurve sample.

The distribution of the textile samples and ColorCurve samples are plotted as follows:

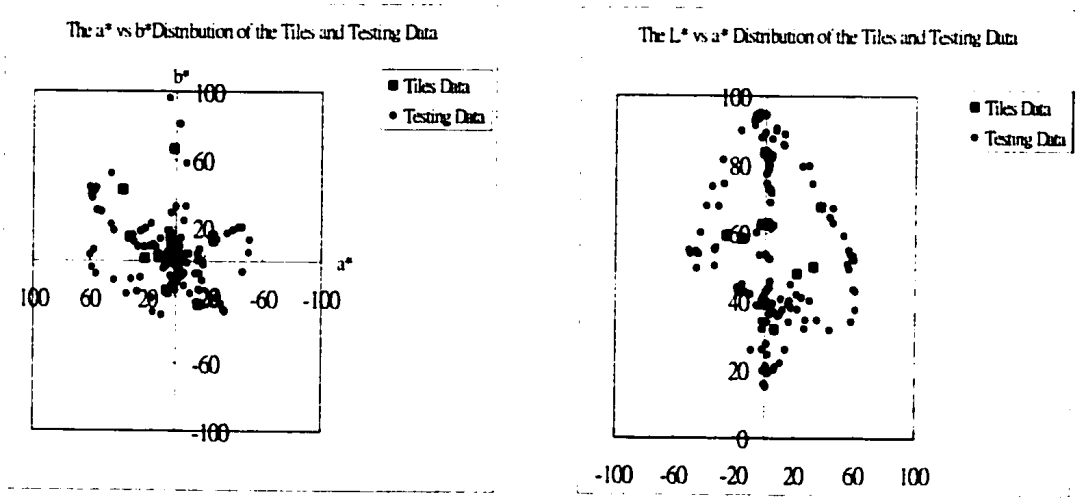


Figure 3.3 The CIE L*, a* And b* Space Distribution Of The Textile Samples

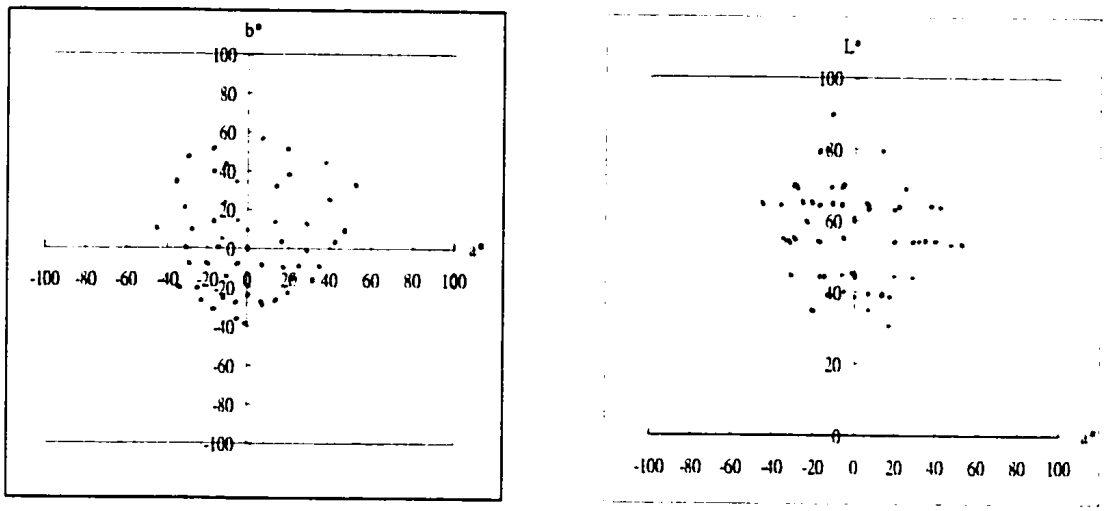


Figure 3.4 The CIE L*, a* And b* Space Distribution Of The ColorCurve Samples

3.3 Colour Measuring Instruments[55,102]

The objective of this project was to determine the inter-instrumental agreement between different reflectance spectrophotometers, thus the colour measurement instruments were the most important control during the whole study period.

The historical development and the internal parts and designs of spectrophotometers were discussed in the previous chapter.

In this project, three different spectrophotometers were used to study inter-instrumental agreement. They were:

-Spectraflash 600 PLUS (SF-600) from Datacolor International[29]

-COLOR-EYE 7000A (CE-7000A) from GretagMacbeth[71]

-COLOR-EYE 2180 (CE-2180) from GretagMacbeth[70]

All of three different reflectance spectrophotometers work on the principles of sphere type measuring geometry. Both SF-600 and CE-7000A are dual-beam type spectrophotometers, while CE-2180 is a single-beam type spectrophotometer. Table 3.1 describes the major features of these three instruments in terms of their optical design, illumination, optical geometry configuration, spectral range, aperture size, wavelength interval, dynamic range, baud rate and working environment.

Table 3.1: Comparison Of the Three Different Types Of Spectrophotometer Used In This Research

	CE-2180	*CE-7000A*	*SF-600*
Optical Design	Single-beam	Dual-beam	Dual-beam
Illumination	Pulsed Xenon Flashlamp	Pulsed Xenon Flashlamp	Pulsed Xenon Flashlamp
Optical Geometry Configuration	D/8 (diffuse)	D/8 (diffuse)	D/8 (diffuse)
Spectral Range	360 – 750 nm	360 – 750 nm	360 – 700 nm
Aperture Size	LAV – 14 mm SAV 5 mm	LAV – 25.4 mm MAV – 15 mm SAV – 10 mm USAV – 3 mm	LAV – 26 mm SAV – 5 mm USAV 2.5 mm
Wavelength Interval	10 nm	10 nm	10 nm
Photometric Range / Dynamic Range	0% - 150%	0% - 200%	0% - 200%
Baud Rate	9600	9600	9600 / 19200
Measurement Cycle Time	-----	1 second	<= 4 sec
Operating Environment	15 to 32°C, 0 – 80%Relative Humidity, non-condensing	15 to 32°C, 25 – 80%Relative Humidity, non-condensing	5 to 40°C, 20 – 85%Relative Humidity, non-condensing

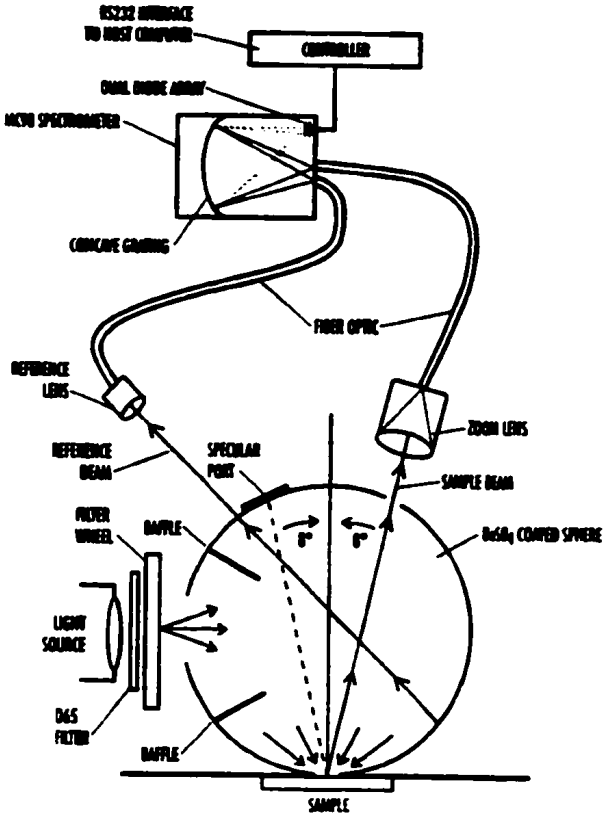


Figure 3.5 Optical Block Diagram For Dual Beam Spectrophotometer (Source: Datacolor International, Spectraflash® 600 PLUS Operators Manual, April 1997)

3.4 Methodology

3.4.1 Instrument Setting

All the colour measuring instruments were set according to the following:

- large area of view;
- wavelength range: 400nm to 700nm at 10nm intervals.

Since all spectrophotometers are of sphere type, the specular component excluded (SCE) or specular component included (SCI) should be specified in advance of the measurement process.

3.4.2 Sample Conditioning

All the CCS II tiles, textile sample, Color Curve sample and reflectance spectrophotometers were conditioned according to standard temperature and humidity levels in the laboratory (20±1°C and 68% relative humidity) 24 hours before the measurements took place to eliminate variables caused by temperature and humidity change.

3.4.3 Instrument Calibration[60]

Before measuring the tiles, all colour measuring instruments were warmed up for a period of 30 to 60 minutes, according to the recommendation provided by the instrumental suppliers. In the research under discussion, all the colour measurement instruments were left to warm up for 30 minutes before measurement and then calibrated according to the manufacturer's guide using both the black and the white standard.

3.4.4 Measurement Procedure

Each tile, textile sample and Color Curve sample was measured once at the centre position for spectral reflectance factor from 400nm to 700nm at 10nm intervals using the advanced colour control software, SCOPE.

3.4.5 Evaluation of the Performance of the Models

After the measurement of tiles, textile samples and Color Curve samples, the average ΔE^*_{ab} units were reported in order to evaluate the performance of the colour measuring instruments. (All the colorimetric data[18] used in this project was calculated by use of the CIELAB colour difference formula under D_{65} and CIE 1964 standard observer conditions).

3.5 Mathematical Model Development[92]

In order to enhance the inter-instrumental agreement among spectrophotometers, many different mathematical models have been developed in the past years but, to date, no reliable mathematical models have been proposed for inter-instrumental agreement. In Bern's and Petersen's mathematical models, cyan tiles were used as the calibrating

standards and the other eleven tiles were used for the tested samples. Their model did not cover other physical samples. In this project, a new mathematical model was developed based on the concept of band-pass correction[6,33,34,35] and using the computer programme SPSS[79,80,81]. The twelve ceramic tiles were used as the calibration standards and the textile samples and the paper samples were used as the tested samples in this newly developed model.

The reflectance data for the twelve tiles at specific wavelength measured by CE-7000A were fitted as the dependent valuable for the purpose of SPSS application. The reflectance data for the twelve tiles at specific wavelength, and the reflectance data for the twelve tiles at 10nm before and after specific wavelength for the twelve tiles for SF-600 or CE-2180 were fitted as the independent valuable. Using the "Stepwise" method, a set of the coefficients was calculated, and the regression coefficient was used to evaluate the goodness of fit.

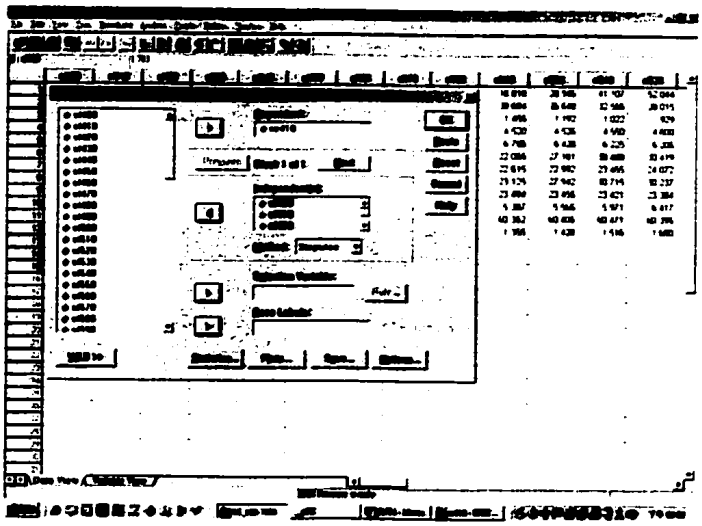


Figure 3.6 The Regression Method Used To Develop The Mathematical Model

CHAPTER 4

SPECTROPHOTOMETRIC MEASUREMENT RESULTS

4.1 Introduction

4.2 Repeatability

4.3 Wavelength Shift

4.4 Inter-Instrumental Agreement

4.5 Differences In The Summation Of The Relative Spectral Reflectance Difference Of CCS-II Tiles For Visual Spectrum Measured Using Different Spectrophotometers

4.1 Introduction

This chapter provides preliminary findings on the different spectral reflectance results for Ceramic Tiles within the visual spectrum measured using different spectrophotometers. The repeatability and the inter-instrumental agreement of the spectrophotometers are also reported here.

4.2 Repeatability

Repeatability is the closeness of agreement between the results of successive measurements of the same test specimen, or of test specimens taken at random from a homogeneous supply, carried out using a single instrument, the same method of measurement, operator, and measurement method, with repetition over a specified period of time.

CCS-II tiles were used to evaluate the repeatability and inter-instrumental agreement of the reflectance spectrophotometers. In this research project, long-term repeatability was studied for a period of three years. Repeatability and inter-instrumental agreement were quantified by evaluating their lightness difference (ΔL^*), a* difference (Δa^*), b*

difference (Δb*), chroma difference (ΔC*), Hue difference (ΔH*) and also colour difference values ΔE^*_{ab}. The results are summarized below.

The lightness difference, a* difference, b* difference, chroma difference and hue difference and colour difference of the repeatability is the difference between the average of the measurement data and measurement results taken at weekly intervals. The average of the lightness difference, a* difference, b* difference, chroma difference, hue difference and colour difference for the last 60 weeks was calculated using the following equation and the results were reported in Appendix II:

$$\text{Sample avge} = \Sigma \Delta p / 60 \text{ where } p = L^*, a^*, b^*, C^*, H^* \text{ or } E^*_{ab} \text{ ----- EQ. 4.1}$$

$$\Delta p = P_{\text{late Measurement}} - P_{\text{Average Measurement}} \text{ ----- EQ. 4.2}$$

The average ΔE^*_{ab} is the average of the summation of average colour difference values for the twelve tiles.

$$\text{Average } \Delta E^*_{ab} = \Sigma \Delta E^*_{ab} / 12 \text{ ----- EQ. 4.3}$$

Those values and standard derivation are summarized as follows:

Table 4.1: Summary Of The Repeatability Of The CCS-II Tiles Measured Using Gretag Macbeth CE-7000A

Tile	*GE*[1]	*SD*[5]	*GI*[2]	*SD*	*ME*[3]	*SD*	*MI*[4]	*SD*
Pale Grey								
Sample avge	0.024	0.010	0.018	0.011	0.024	0.018	0.030	0.017
Mid Grey								
Sample avge	0.020	0.009	0.018	0.007	0.023	0.009	0.019	0.010
Diff Grey								
Sample avge	0.020	0.008	0.021	0.009	0.031	0.013	0.025	0.010
Deep Grey								
Sample avge	0.083	0.015	0.038	0.012	0.045	0.015	0.035	0.013
Deep Pink								
Sample avge	0.046	0.016	0.030	0.012	0.047	0.012	0.037	0.011
Red								
Sample avge	0.332	0.081	0.045	0.020	0.056	0.019	0.068	0.020
Orange								
Sample avge	0.120	0.032	0.080	0.022	0.109	0.039	0.067	0.024
Bright Yellow								
Sample avge	0.155	0.041	0.102	0.033	0.052	0.024	0.055	0.019
Green								
Sample avge	0.047	0.019	0.033	0.020	0.047	0.016	0.054	0.016
Diff Green								
Sample avge	0.054	0.015	0.035	0.019	0.036	0.016	0.037	0.013
Cyan								
Sample avge	0.054	0.015	0.043	0.013	0.050	0.021	0.047	0.017
Deep Blue								
Sample avge	0.389	0.109	0.100	0.021	0.068	0.017	0.057	0.017
Average ΔE^*_{ab}	***0.112***		***0.047***		***0.049***		***0.044***	

1 = GLOSSY Tiles Measured using Specular Component Excluded Mode

2 = GLOSSY Tiles Measured using Specular Component Included Mode

3 = MATT Tiles Measured using Specular Component Excluded Mode

4 = MATT Tiles Measured using Specular Component Included Mode

5 = Standard Deviation

Table 4.1 shows that the repeatability of the CCS-II tiles measured using Gretag Macbeth CE-7000A, except in the case of GLOSSY tiles measured under specular component excluded mode, was satisfactory for the measurement combinations. In the case of GLOSSY tiles measured using the specular component excluded mode, the repeatability for the red, orange, bright yellow and deep blue was larger than 0.1 CIELAB ΔE units. In those cases, the poor repeatability may have been caused by the high reflection inside the integrated sphere, in addition to which some of the reflected beam may have been lost through the opening of the specular component port. The repeatability for deep blue was also poor as a result of the low signal-to-noise ratio, which reduced the repeatability.

Table 4.2: Summary Of The Repeatability Of The CCS-II Tiles Measured Using Gretag Macbeth CE-2180

Tile	*GE*[1]	*SD*[5]	*GI*[2]	*SD*	*ME*[3]	*SD*	*MI*[4]	*SD*
Pale Grey								
Sample avge	0.118	0.042	0.124	0.032	0.120	0.039	0.123	0.034
Mid Grey								
Sample avge	0.133	0.088	0.057	0.077	0.173	0.048	0.093	0.023
Diff Grey								
Sample avge	0.071	0.087	0.073	0.074	0.237	0.055	0.106	0.024
Deep Grey								
Sample avge	0.342	0.333	0.140	0.217	0.363	0.085	0.073	0.063
Deep Pink								
Sample avge	0.272	0.247	0.097	0.195	0.336	0.076	0.083	0.050
Red								
Sample avge	0.802	1.494	0.197	0.357	0.364	0.085	0.104	0.070
Orange								
Sample avge	0.269	0.498	0.272	0.315	0.236	0.119	0.228	0.086
Bright Yellow								
Sample avge	0.187	0.467	0.156	0.320	0.101	0.084	0.116	0.080
Green								
Sample avge	0.190	0.245	0.146	0.195	0.186	0.062	0.090	0.052
Diff Green								
Sample avge	0.250	0.271	0.136	0.198	0.151	0.059	0.141	0.061
Cyan								
Sample avge	0.127	0.153	0.110	0.150	0.271	0.061	0.175	0.045
Deep Blue								
Sample avge	0.806	1.822	0.150	0.388	0.582	0.114	0.081	0.120
Average ΔE^*_{ab}	**0.297**		**0.140**		**0.260**		**0.118**	

1 = GLOSSY Tiles Measured using Specular Component Excluded Mode

2 = GLOSSY Tiles Measured using Specular Component Included Mode

3 = MATT Tiles Measured using Specular Component Excluded Mode

4 = MATT Tiles Measured using Specular Component Included Mode

5 = Standard Deviation

Table 4.2 shows the repeatability of the CCS-II tiles measured using Gretag Macbeth CE-2180, and the repeatability of the four measurement combinations ranged from 0.118 to 0.297 CIELAB ΔE units. The repeatability results show that the stability of the CE-2180 was inferior. The results were affected by either the drift of the measurement electronics or variation in the light sources.

When the GLOSSY tiles were measured using the specular component excluded mode, the repeatability for the red and deep blue was larger than 1 CIELAB ΔE unit. In the case of red, the repeatability result may have been caused by the high reflection inside the integrated sphere, and some of the reflected beam may have been lost through the opening of the specular component port. The deep blue result was also disappointing because of the low signal to noise ratio, thus the repeatability was unsatisfactory.

Table 4.3: Summary Of The Repeatability Of The CCS-II Tiles Measured Using Datacolor SF-600

Tile	*GE*[1]	*SD*[5]	*GI*[2]	*SD*	*ME*[3]	*SD*	*MI*[4]	*SD*
Pale Grey								
Sample avge	0.038	0.023	0.035	0.012	0.039	0.022	0.024	0.017
Mid Grey								
Sample avge	0.047	0.024	0.035	0.020	0.039	0.022	0.028	0.016
Diff Grey								
Sample avge	0.053	0.025	0.044	0.019	0.035	0.020	0.039	0.020
Deep Grey								
Sample avge	0.099	0.055	0.043	0.015	0.050	0.036	0.041	0.021
Deep Pink								
Sample avge	0.083	0.033	0.041	0.019	0.063	0.033	0.054	0.020
Red								
Sample avge	0.254	0.190	0.052	0.024	0.057	0.029	0.051	0.019
Orange								
Sample avge	0.116	0.055	0.060	0.023	0.081	0.045	0.067	0.028
Bright Yellow								
Sample avge	0.125	0.071	0.075	0.036	0.060	0.040	0.066	0.036
Green								
Sample avge	0.050	0.031	0.048	0.020	0.057	0.028	0.053	0.025
Diff Green								
Sample avge	0.059	0.033	0.048	0.019	0.042	0.029	0.049	0.017
Cyan								
Sample avge	0.042	0.013	0.033	0.010	0.045	0.010	0.032	0.013
Deep Blue								
Sample avge	0.250	0.099	0.048	0.019	0.052	0.033	0.050	0.020
Average ΔE^*_{ab}	***0.101***		***0.047***		***0.052***		***0.046***	

1 = GLOSSY Tiles Measured using Specular Component Excluded Mode

2 = GLOSSY Tiles Measured using Specular Component Included Mode

3 = MATT Tiles Measured using Specular Component Excluded Mode

4 = MATT Tiles Measured using Specular Component Included Mode

5 = Standard Deviation

Table 4.3 shows that the repeatability of the CCS-II tiles measured using Datacolor International SF-600, except in the case of GLOSSY tiles measured using specular component excluded mode, was satisfactory for the measurements combination. The repeatability for the red, orange, bright yellow, deep grey and deep blue of the GLOSSY tiles measured using specular excluded mode was larger than 0.1 CIELAB ΔE units. In the case of red, orange and bright yellow, the poor repeatability may have been caused by the high reflection inside the integrated sphere and some of the reflected beam may have been lost through the opening of the specular component port. The repeatability for deep blue and deep grey was also very poor because of the low signal-to-noise ratio.

According to the results shown in Table 4.2, it may be concluded that the stability of the CE-2180 was poor because the average ΔE^*_{ab} values ranged from 0.115 to 0.377 units. The other two measurement results, shown in Tables 4.1 and 4.3, show that the stability was good because the average ΔE^*_{ab} values for SF-600 ranged from 0.046 to 0.101 units and the average ΔE^*_{ab} values for CE-7000A ranged from 0.044 to 0.112 units. The good repeatability of the SF-600 and CE-7000A was due to the presence of a second beam, the reference beam, in these two dual-beam spectrophotometers. The second beam was used to allow direct measurement of the reflectance between the ratio of reflected and incident light. Dual-beam measurements are preferred for use in

industry as a result of their inherent stability, as the measurement is of a ratio rather than an absolute value.

Of the three spectrophotometers, red, orange and bright yellow, had the higher ΔE^*_{ab} values (>0.1 ΔE^*_{ab}) even though the measurements were carried out inside a room with controlled temperature and humidity. This was because of the different size of the integrated sphere and the position of the specular component port. During the measurement of the tiles, some of the reflected beam was emitted through the opening of the specular component port. In addition, the random reflectance resulted in poor measurement results for sensitive colours.

Based on the average ΔE^*_{ab} values of the three spectrophotometers, it was concluded that the repeatability of the CE-2180 needed further improvement using better calibration procedures. The repeatability of the other two spectrophotometers was satisfactory and the colorimetric values were further used to evaluate the inter-instrumental agreement. According to the results shown in Table 4.1, the repeatability for CE-7000A was the best of all the three spectrophotometers;

CE-7000A was used as the reference instrument to evaluate the inter-instrumental agreement of three spectrophotometers.

In addition to the above repeatability results, long term repeatability was important in this study. The results of the long term repeatability are plotted in the following figures.

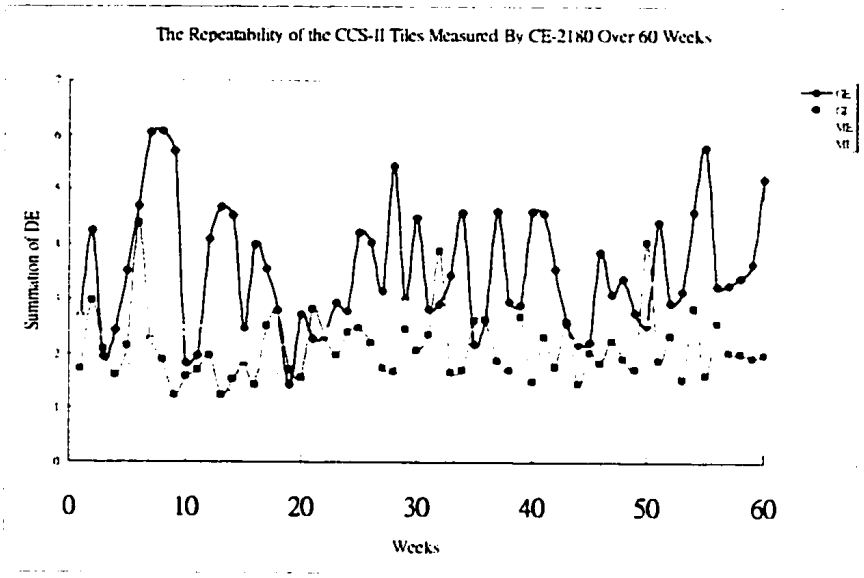


Figure 4.1 The Repeatability Of The CCS-II Tiles Measured Using CE-2180 Over A Period of 60 Weeks

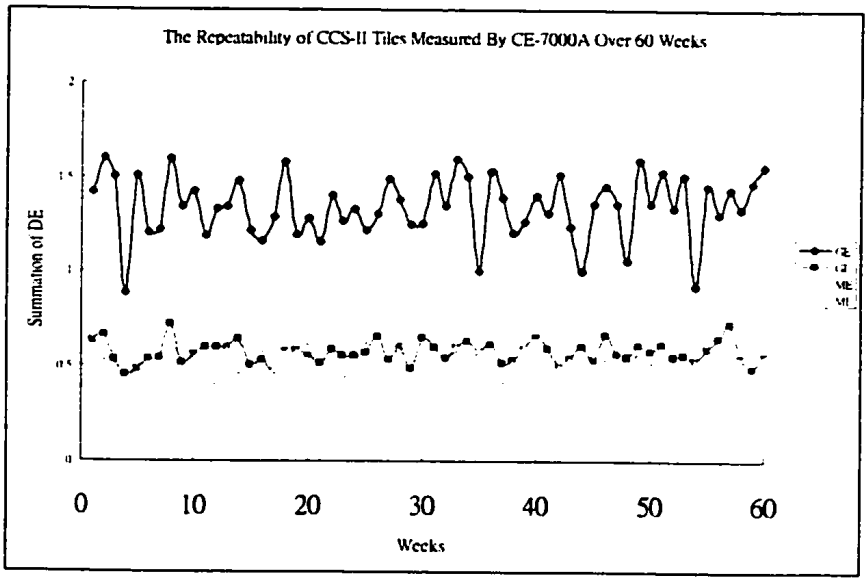


Figure 4.2 The Repeatability Of The CCS-II Tiles Measured Using CE-7000A Over A Period of 60 Weeks

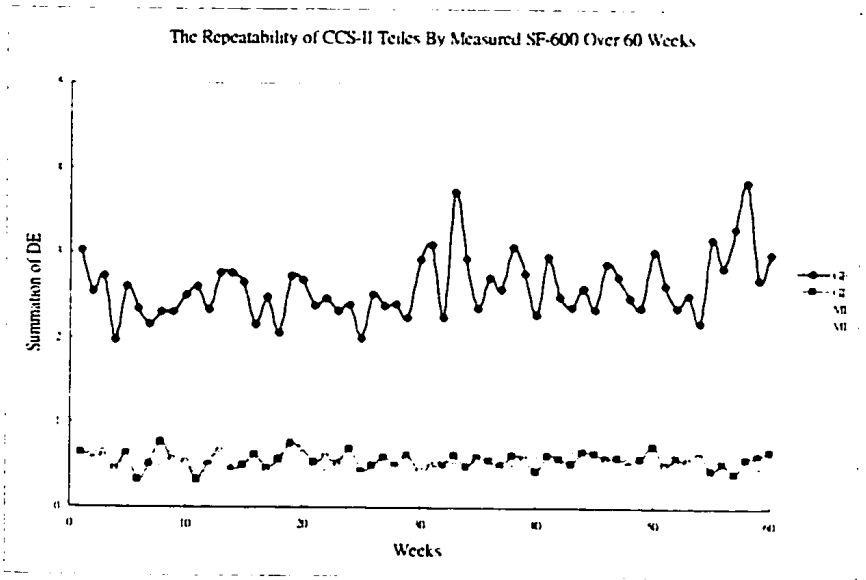


Figure 4.3 The Repeatability Of The CCS-II Tiles Measured Using SF600 Over A Period of 60 Weeks

The three figures above, which show results for the repeatability of the CCS-II tiles measured using different spectrophotometers, indicate that long-term repeatability was satisfactory over a long period of time. The results imply that the three spectrophotometers were stable for the duration of the whole study period.

4.3 Wavelength Shift

In addition to the colour difference of the spectrophotometer, wavelength shift is another parameter to determine repeatability. The equations used for wavelength calculation are shown as follows:

$$\text{Wavelength shift} = dR_{(\lambda)}/d\lambda \text{ ----- EQ. 4.4}$$

Difference of Wavelength Shift between spectrophotometric measurement =

$$(dR_{(\lambda)}/d\lambda)_{\text{last measuement}} - (dR_{(\lambda)}/d\lambda)_{\text{initial measurement}} \text{ ----- EQ. 4.5}$$

Where,

initial measurement is the measurement results measured at the beginning of the repeatability study,

while,

last measurement is the measurement results at the end of the repeatability study.

The wavelength shift for the visual spectrum was obtained using equations 4.4 and 4.5. The wavelength shift results of the three different spectrophotometers were plotted as follows:

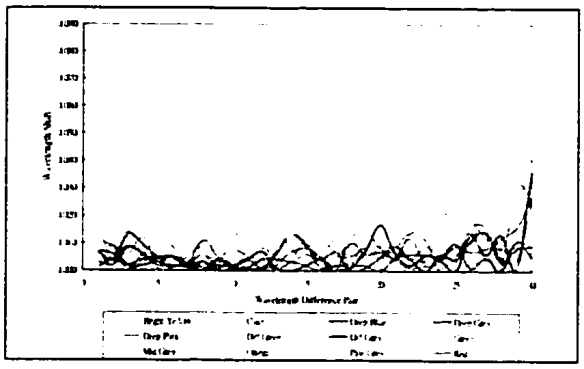


Figure 4.4 The Wavelength Shift Of The GLOSSY Tiles Measured Using The Specular Component Excluded Mode Of CE-2180

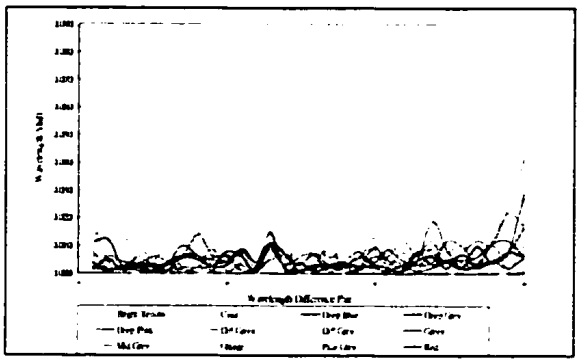


Figure 4.5 The Wavelength Shift Of The GLOSSY Tiles Measured Using The Specular Component Included Mode Of CE-2180

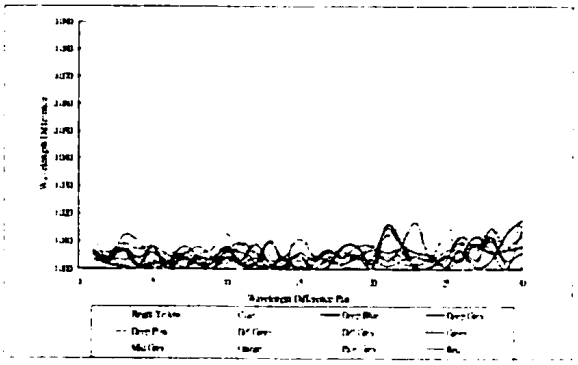


Figure 4.6 The Wavelength Shift Of The MATT Tiles Measured Using The Specular Component Excluded Mode Of CE-2180

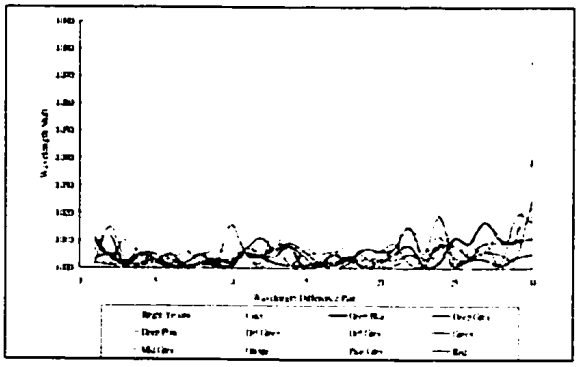


Figure 4.7 The Wavelength Shift Of The MATT Tiles Measured Using The Specular Component Included Mode Of CE-2180

From Figures 4.3 – 4.7, showing the wavelength shift of the CCS-II tiles, it may be seen that the difference in wavelength between the initial and the last measurement of CE-2180 did not exceed 0.09 units. This indicates that the repeatability along the whole experience period was within an acceptable range. In addition to Table 4.2, those results imply the repeatability was poor when results are compared with the other two spectrophotometers.

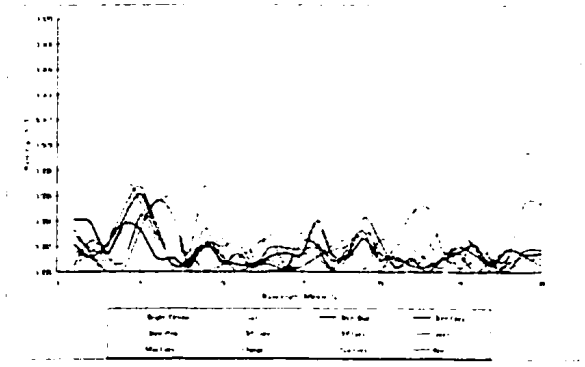


Figure 4.8 The Wavelength Shift Of The GLOSSY Tiles Measured Using The Specular Component Excluded Mode Of CE-7000A

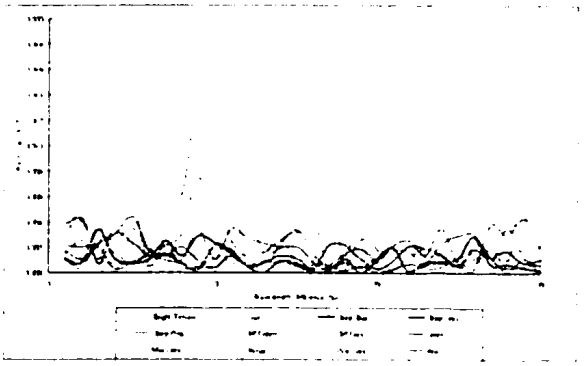


Figure 4.9 The Wavelength Shift Of The GLOSSY Tiles Measured Using The Specular Component Included Mode Of CE-7000A

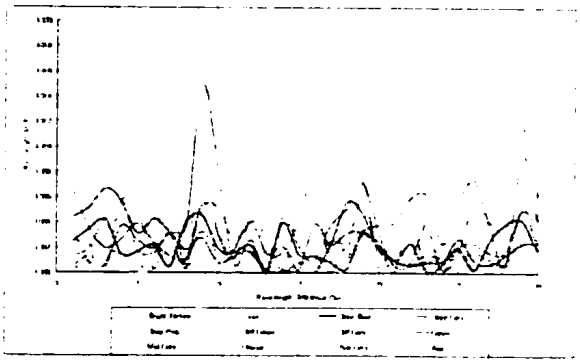


Figure 4.10 The Wavelength Shift Of The MATT Tiles Measured Using The Specular Component Excluded Mode Of CE-7000A

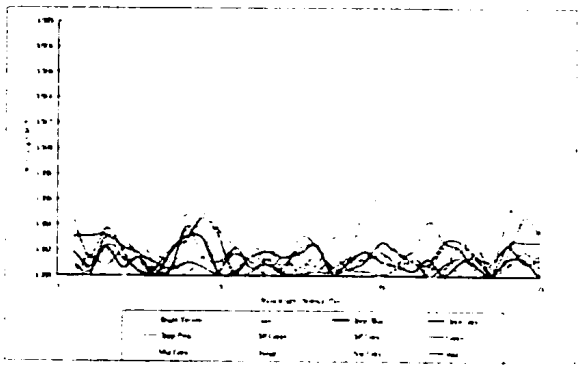


Figure 4.11 The Wavelength Shift Of The MATT Tiles Measured Using Specular Component Included Mode Of CE-7000A

Figures 4.8 – 4.11, showing the wavelength shift of the CCS-II tiles, demonstrate that the different wavelength between the initial measurement of CE-7000A and the last measurement of CE-7000A did not exceed 0.02 units. The repeatability for the whole experience period was considered to be satisfactory. In addition to results shown in Table 4.1, those results imply that the repeatability was good when compared with the other CE-2180.

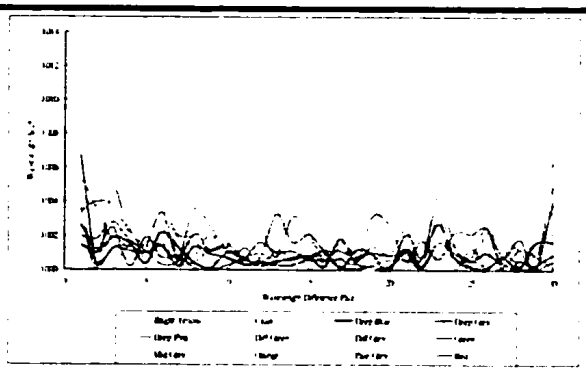


Figure 4.12 The Wavelength Shift Of The GLOSSY Tiles Measured Using The Specular Component Excluded Mode Of SF-600

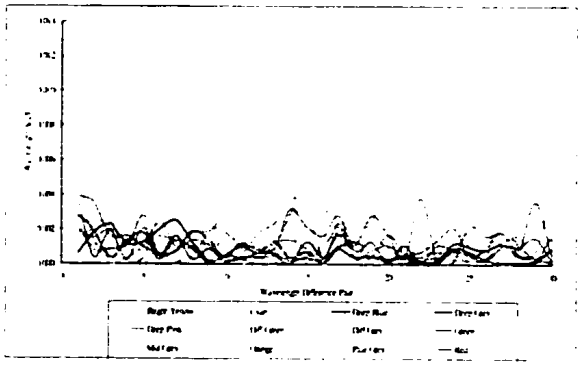


Figure 4.13 The Wavelength Shift Of The GLOSSY Tiles Measured Using The Specular Component Included Mode Of SF-600

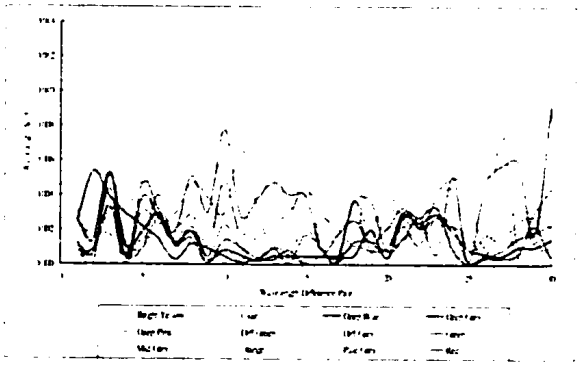


Figure 4.14 The Wavelength Shift Of The MATT Tiles Measured Using Specular Component Excluded Mode Of SF-600

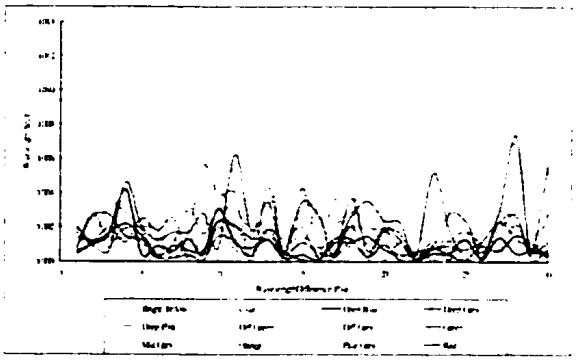


Figure 4.15 The Wavelength Shift Of The MATT Tiles Measured Using Specular Component Included Mode Of SF-600

Figures 4.12 – 4.15, which show the wavelength shift of the CCS-II tiles, demonstrate that the difference in wavelength between the initial measurement of SF-600 and the last measurement of SF-600 did not exceed 0.014 units. The repeatability for the whole experience period is seen to be satisfactory. In addition to Table 4.3, the results imply that the repeatability was good compared with those for CE-2180 but similar to those of CE-7000A.

Tables 4.1 – 4.3 and Figures 4.4 – 4.15 shows that the colour difference and the wavelength shift were satisfactory for CE-7000A. CE-7000A was selected as the reference spectrophotometer to evaluate the inter-instrumental agreement by comparing the measurement results with CE-2180 and SF-600.

4.4 Inter-Instrumental Agreement

Inter-instrumental agreement is the closeness of agreement between the results of successive measurements of the same test specimen, or of test specimens between two or more spectrophotometers achieved using the same measuring and operation system.

As discussed, the repeatability for CE7000A was found to be satisfactory, therefore CE-7000A was selected as a reference spectrophotometer to evaluate the inter-instrumental agreement of CE-7000A and SF-600 as well as CE-7000A and CE-2180.

The lightness difference, a* difference, b* difference, chroma difference and hue difference and colour difference of the inter-instrumental agreement was the difference between average of the measurement data measured against each week's measurement results. The average of the lightness difference, a* difference, b* difference, chroma difference, hue difference and colour difference across the last 60 weeks of the experimental work was calculated using the equation below and the results were reported in Appendix III.

$$\text{Sample avge} = \Sigma \Delta p / 60 \text{ where } p = L^*, a^*, b^*, C^*, H^* \text{ or } E^*_{ab} \text{ ----- EQ. 4.6}$$

$$\Delta p = P_{\text{Late Measurement from SF-600 or 2180}} - P_{\text{Average Measurement from CE7000A}} \text{ ----- EQ. 4.7}$$

Average ΔE^*_{ab} is the average of the summation of average colour difference values for the twelve tiles.

$$\text{Average } \Delta E^*_{ab} = \Sigma \Delta E^*_{ab} / 12 \text{ ----- EQ. 4.8}$$

4.4.1 The Inter-Instrumental Agreement of SF-600 compared to CE-7000A

Table 4.4: Summary Of The Inter-Instrumental Agreement Of SF-600 And CE-7000A Using CCS-II Tiles

Tile	*GE*[1]	*GI*[2]	*ME*[3]	*MI*[4]
Pale Grey				
Sample avge	0.690	0.428	0.590	0.361
Mid Grey				
Sample avge	0.459	0.269	0.422	0.182
Diff Grey				
Sample avge	0.495	0.293	0.395	0.166
Deep Grey				
Sample avge	0.196	0.217	0.183	0.074
Deep Pink				
Sample avge	0.756	0.737	0.633	0.603
Red				
Sample avge	0.650	1.263	0.713	0.890
Orange				
Sample avge	1.050	1.084	0.874	0.968
Bright Yellow				
Sample avge	1.437	0.930	0.749	0.768
Green				
Sample avge	1.120	0.775	0.867	0.762
Diff Green				
Sample avge	1.095	0.749	0.788	0.652
Cyan				
Sample avge	1.232	1.004	0.903	0.824
Deep Blue				
Sample avge	1.028	0.849	0.890	0.677
Average ΔE^*_{ab}	***0.851***	***0.717***	***0.667***	***0.577***

1 = GLOSSY Tiles Measured using Specular Component Excluded Mode

2 = GLOSSY Tiles Measured using Specular Component Included Mode

3 = MATT Tiles Measured using Specular Component Excluded Mode

4 = MATT Tiles Measured using Specular Component Included Mode

As may be seen in Table 4.4, which shows the inter-instrumental agreement between SF-600 and CE-7000A of the CCS-II tiles, the average ΔE^*_{ab} values ranged from 0.577 to 0.851 units. The results were poor because, in past research, the ΔE^*_{ab} value of different spectrophotometers was found to range from 0.1 to 3 units[82]. The main reason for the poor inter-instrumental agreement was that instrumental design of spectrophotometers varied according to different manufacturers.

The optical design for both CE-7000A and SF-600 is the same: both are dual-beam in nature, but the size of integrated sphere differs. In addition, the position of the specular component port and the detector is also different. For these reasons, the difference between the measurement results for each tile also varies and the inter-instrumental agreement between these two machines is disappointing.

4.4.2 The Inter-Instrumental Agreement of CE-2180 compared with CE-7000A

Table 4.5: Summary Of The Inter-Instrumental Agreement Of CE-2180 And CE-7000A Using CCS-II Tiles

Tile	*GE*[1]	*GI*[2]	*ME*[3]	*MI*[4]
Pale Grey				
Sample avge	0.666	0.795	0.928	0.952
Mid Grey				
Sample avge	0.707	0.758	0.535	0.576
Diff Grey				
Sample avge	0.453	0.280	0.760	0.361
Deep Grey				
Sample avge	0.239	0.100	0.446	0.352
Deep Pink				
Sample avge	0.700	0.723	0.713	0.718
Red				
Sample avge	0.719	0.634	0.680	0.755
Orange				
Sample avge	0.119	0.114	0.414	0.436
Bright Yellow				
Sample avge	0.689	0.628	0.516	0.552
Green				
Sample avge	0.130	0.143	0.444	0.500
Diff Green				
Sample avge	0.790	1.023	0.852	0.997
Cyan				
Sample avge	0.140	0.195	0.454	0.428
Deep Blue				
Sample avge	1.134	1.285	0.679	0.968
Average ΔE^*_{ab}	***0.541***	***0.557***	***0.618***	***0.633***

1 = GLOSSY Tiles Measured using Specular Component Excluded Mode

2 = GLOSSY Tiles Measured using Specular Component Included Mode

3 = MATT Tiles Measured using Specular Component Excluded Mode

4 = MATT Tiles Measured using Specular Component Included Mode

With reference to Table 4.5, showing the inter-instrumental agreement for CE-2180 and CE-7000A using CCS-II tiles, it was found that the average ΔE^*_{ab} values ranged from 0.541 to 0.633 units. The results were better than those for SF-600 and CE-7000A because the same manufacturer manufactures both the CE-2180 and CE-7000A. Although the optical design is different, the overall design principles are similar, thus their inter-instrumental agreement between CE-2180 and CE-7000A is better than in the case of CE-7000A and SF-600.

Different spectrophotometers have their own systemic errors, therefore a series of new regression models were developed in this study in order to improve the inter-instrumental measurement agreement.

4.5 Differences In The Summation Of The Relative Spectral Reflectance Difference Of CCS-II Tiles For Visual Spectrum Measured Using Different Spectrophotometers

Irrespective of the inter-instrumental agreement of CE-2180 or SF-600 and CE-7000A, the worst results were obtained when the GLOSSY tiles were measured using the specular component excluded mode. Beside the CIELAB colour difference values (ΔE^*_{ab}), the summation of the relative spectral reflectance difference is an alternative method to evaluate the inter-instrumental agreement of different spectrophotometers.

Summation of Relative Spectral Reflectance Difference:

$$\Sigma\ [[R_{\lambda CE\text{-}2180\ or\ SF\text{-}600A} - R_{\lambda CE\text{-}7000A}]/\ R_{\lambda CE\text{-}7000A}] \text{----- EQ. 4.9}$$

The plot of the summation of the relative spectral reflectance difference values against the tiles is shown as follows:

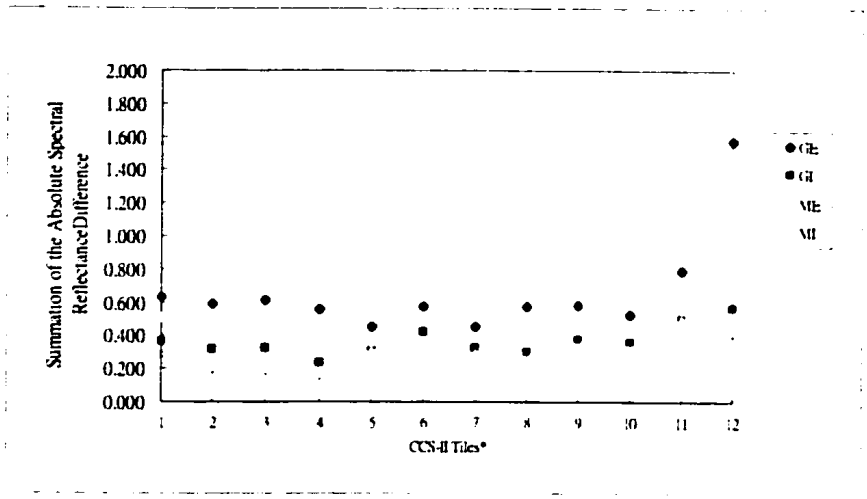


Figure 4.16 The Distribution Of The Summation Of The Relative Spectral Reflectance Difference For The CCS-II Tiles Comparing SF-600 And CE-7000A

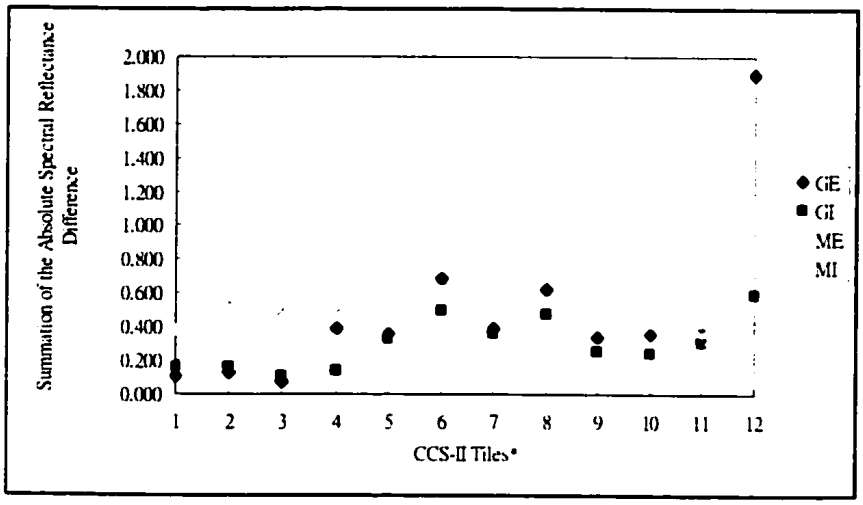


Figure 4.17 The Distribution Of The Summation Of The Relative Spectral Reflectance Difference For The CCS-II Tiles Comparing CE-2180 And CE-7000A

**Note:*

1. Pale Grey	*2. Middle Grey*	*3. Diff. Grey*	*4. Deep Grey*
5. Deep Pink	*6. Red*	*7. Orange*	*8. Bright Yellow*
9. Green	*10. Diff Green*	*11. Cyan*	*12. Deep Blue*

From Figure 4.16, it may be seen that GLOSSY tiles measured according to the specular component excluded mode showed the greater summation of the relative spectral reflectance difference. With reference to Table 4.4, which provides a summary of the inter-instrumental agreement when comparing SF-600 and CE-7000A using CCS-II tiles, a similar trend may be observed: that the higher the summation of the relative spectral reflectance difference, the higher the CIELAB colour difference, ΔE^*_{ab}.

From Figure 4.17, it may be seen that MATT tiles measured under specular component included mode show the greater summation of the relative spectral reflectance difference. With reference to Table 4.5, which shows the summary for the inter-instrumental agreement between CE-2180 and CE-7000A of the CCS-II tiles, a similar trend may be observed, that being that the higher the summation of the relative spectral reflectance difference, the higher the CIELAB colour difference, ΔE^*_{ab}.

Based on the results shown in Tables 4.4 and 4.5 and results in Figures 4.13 and 4.14, it may be concluded that the summation of the relative spectral reflectance difference is a good indication of colour difference. The higher the summation of the summation of the relative spectral reflectance, the higher the colour difference.

CHAPTER 5

DEVELOPMENT OF THE FIRST MATHEMATICAL MODEL (L-Model)

5.1 Introduction

In this chapter, the development of the first mathematical model (L-Model) is outlined. L-Model was developed based on the colorimetric data, L*, a* and b*. The inter-instrumental agreement showed improvement after applying the mathematical model.

5.2 Development Of The First Mathematical Model (L-Model)

As the inter-instrumental agreement was poor for the three different models of spectrophotometers, SF-600 vs CE-7000A and CE-2180 vs CE-7000A, a series of new mathematical models was developed in order to improve the inter-instrumental agreement. The simplest way to develop the mathematical models was the correction of the colorimetric data, CIE L*, a* and b* values for the spectrophotometers. SPSS was used to analyse the data for the L*, a* and b* values and a series of mathematical models were developed using linear regression.

For GLOSSY samples, two different series of mathematical models were developed. One series was for specular component included measurement, while the other series was for specular component excluded measurement. In addition, another two series of models were developed for "MATT" samples. As the spectral reflectance is different for "GLOSSY" and "MATT" samples, different models were developed for each in order to meet the requirements for different types of materials. As a result, the inter-instrumental agreement of the different samples became more concise and accurate.

5.2.1 SF-600 vs CE-7000

For GLOSSY samples measured using the specular component excluded mode, three different equations were formulated:

$$\text{Predicted } L^*_{600} \text{ value } (PL^*_{600}) = 1.008L^*_{600} - 0.008a^*_{600} - 0.006b^*_{600} + 0.061 \text{ ----- EQ.5.1}$$

$$\text{Predicted } a^*_{600} \text{ value } (Pa^*_{600}) = 1.008a^*_{600} + 0.006b^*_{600} - 0.074 \text{ ----- EQ. 5.2}$$

$$\text{Predicted } b^*_{600} \text{ value } (Pb^*_{600}) = -0.005L^*_{600} - 0.024a^*_{600} + 1.014b^*_{600} + 0.17 \text{ ----- EQ. 5.3}$$

Where

PL^*_{600}, Pa^*_{600} and Pb^*_{600} are the predicted value which is calculated by substituting the original data measured by the SF-600, L^*_{600}, a^*_{600} and b^*_{600} into the above equations.

For GLOSSY samples measured using the specular component included mode, a further three different equations were formulated:

$$\text{Predicted } L^*_{600} \text{ value } (PL^*_{600}) = 1.006L^*_{600} - 0.005a^*_{600} - 0.003b^*_{600} - 0.086 \text{ ----- EQ. 5.4}$$

$$\text{Predicted } a^*_{600} \text{ value } (Pa^*_{600}) = -0.007L^*_{600} + 1.001a^*_{600} + 0.008b^*_{600} - 0.252 \text{ ----- EQ. 5.5}$$

$$\text{Predicted } b^*_{600} \text{ value } (Pb^*_{600}) = - 0.016a^*_{600} + 1.012b^*_{600} - 0.086 \text{ ----- EQ. 5.6}$$

For MATT samples measured using the specular component excluded mode, three different equations were formulated:

$$\text{Predicted } L^*_{600} \text{ value } (PL^*_{600}) = 1.009L^*_{600} - 0.009a^*_{600} - 0.006b^*_{600} - 0.219 \text{ ----- EQ. 5.7}$$

$$\text{Predicted } a^*_{600} \text{ value } (Pa^*_{600}) = -0.004L^*_{600} + 1.005a^*_{600} + 0.009b^*_{600} + 0.161 \text{ ----- EQ. 5.8}$$

$$\text{Predicted } b^*_{600} \text{ value } (Pb^*_{600}) = - 0.024a^*_{600} + 1.011b^*_{600} - 0.175 \text{ ----- EQ. 5.9}$$

For MATT samples measured using the specular component included mode, another three different equations were formulated:

$$\text{Predicted } L^*_{600} \text{ value } (PL^*_{600}) = 1.007L^*_{600} - 0.008a^*_{600} - 0.005b^*_{600} - 0.257 \text{ ----- EQ. 5.10}$$

$$\text{Predicted } a^*_{600} \text{ value } (Pa^*_{600}) = -0.005L^*_{600} + 1.001a^*_{600} - 0.011b^*_{600} + 0.180 \text{ ----- EQ. 5.11}$$

$$\text{Predicted } b^*_{600} \text{ value } (Pb^*_{600}) = 0.002L^*_{600} - 0.023a^*_{600} + 1.018b^*_{600} - 0.203 \text{ ----- EQ. 5.12}$$

5.2.2 CE-2180 vs CE-7000

For GLOSSY samples measured using the specular component excluded mode, three different equations were formulated:

$$\text{Predicted } L^*_{2180} \text{ value } (PL^*_{2180}) = 1.010L^*_{2180} - 0.007a^*_{2180} - 0.01b^*_{2180} + 0.059 \text{ ----- EQ.5.13}$$

$$\text{Predicted } a^*_{2180} \text{ value } (Pa^*_{2180}) = 1.009a^*_{2180} + 0.057b^*_{2180} - 0.085 \text{ ----- EQ. 5.14}$$

$$\text{Predicted } b^*_{2180} \text{ value } (Pb^*_{2180}) = -0.068L^*_{2180} - 0.035a^*_{2180} + 1.007b^*_{2180} + 0.098 \text{ ----- EQ. 5.15}$$

Where

PL^*_{2180}, Pa^*_{2180} and Pb^*_{2180} are the predicted value which is calculated by substituting the original data measured by the CE-2180, L^*_{2180}, a^*_{2180} and b^*_{2180} into the above equations.

For GLOSSY samples measured using the specular component included mode, a further three different equations were formulated:

$$\text{Predicted } L^*_{2180} \text{ value } (PL^*_{2180}) = 1.015L^*_{2180} - 0.058a^*_{2180} - 0.001b^*_{2180} - 0.096 \text{ ----- EQ. 5.16}$$

$$\text{Predicted } a^*_{2180} \text{ value } (Pa^*_{2180}) = -0.011L^*_{2180} + 1.045a^*_{2180} + 0.007b^*_{2180} - 0.053 \text{ ----- EQ. 5.17}$$

$$\text{Predicted } b^*_{2180} \text{ value } (Pb^*_{2180}) = -0.027a^*_{2180} + 1.048b^*_{2180} - 0.075 \text{ ----- EQ. 5.18}$$

For MATT samples measured using the specular component excluded mode, three different equations were formulated:

$$\text{Predicted } L^*_{2180} \text{ value } (PL^*_{2180}) = 1.014L^*_{2180} - 0.018a^*_{2180} - 0.001b^*_{2180} - 0.157 \text{ ----- EQ. 5.19}$$

$$\text{Predicted } a^*_{2180} \text{ value } (Pa^*_{2180}) = -0.007L^*_{2180} + 1.027a^*_{2180} + 0.008b^*_{2180} + 0.297 \text{ ----- EQ. 5.20}$$

$$\text{Predicted } b^*_{2180} \text{ value } (Pb^*_{2180}) = -0.009a^*_{2180} + 1.027b^*_{2180} - 0.398 \text{ ----- EQ. 5.21}$$

For MATT samples measured using the specular component included mode, another three different equations were formulated:

$$\text{Predicted } L^*_{2180} \text{ value } (PL^*_{2180}) = 1.024L^*_{2180} - 0.014a^*_{2180} - 0.009b^*_{2180} - 0.168 \text{ ----- EQ. 5.22}$$

$$\text{Predicted } a^*_{2180} \text{ value } (Pa^*_{2180}) = -0.005L^*_{2180} + 1.008a^*_{2180} - 0.001b^*_{2180} + 0.098 \text{ ----- EQ. 5.23}$$

$$\text{Predicted } b^*_{2180} \text{ value } (Pb^*_{2180}) = -0.036a^*_{2180} + 1.058b^*_{2180} - 0.169 \text{ ----- EQ. 5.24}$$

Based on equations 5.1 – 5.24, a series of predicted L^*_{600}, a^*_{600} and b^*_{600} values (i.e. PL^*_{600}, Pa^*_{600} and Pb^*_{600}) and a series of predicted L^*_{2180}, a^*_{2180} and b^*_{2180} values (i.e. PL^*_{2180}, Pa^*_{2180} and Pb^*_{2180}) was calculated. Those values were then compared with

the actual measured values of CE-7000A by calculating the CIE colour difference value ΔE^*_{ab} (EQ. 5.25).

$$\Delta E^*_{ab} = ((L^*_{sample}-L^*_{standard})^2+(a^*_{sample}-a^*_{standard})^2+(b^*_{sample}-b^*_{standard})^2)^{1/2} \text{ ----- EQ. 5.25}$$

$$\text{i.e. } \Delta E^*_{ab} = ((PL^*_x-L^*_{CE\text{-}7000A})^2+(Pa^*_x-a^*_{CE\text{-}70000A})^2+(b^*_x-b^*_{CE\text{-}7000A})^2)^{1/2} \text{ ----- EQ. 5.26}$$

where x= 600 or 2180

5.3 The Improvement Of The Inter-Instrumental Agreement After Applying L-Model

After the mathematical models had been developed, the measurement data of the CCS-II tiles from SF-600 and CE-2180 were then substituted into the equations and the corrected ΔE^*_{ab} were calculated. In addition, comparisons between the original ΔE^*_{ab} and the corrected ΔE^*_{ab} were also calculated and expressed as the percentage improvement of the inter-instrumental agreement. All the results are summarised in the tables below:

Table 5.1: Summary Of The Inter-Instrumental Agreement For The CCS-II GLOSSY Tiles Using Specular Component Excluded Mode Between SF-600 And CE-7000A

	Original ΔE^*_{ab}	*Corrected* ΔE^*_{ab}	*% Improvement*
Pale Grey	0.690	0.387	43.913
Middle Grey	0.459	0.26	43.355
Diff. Grey	0.495	0.286	42.222
Deep Grey	0.196	0.228	-16.327
Deep Pink	0.650	0.508	21.846
Red	0.650	0.892	-37.231
Orange	1.046	0.599	42.734
Bright Yellow	1.437	0.649	54.836
Green	1.120	0.312	72.143
Diff. Green	1.095	0.329	69.954
Cyan	1.232	0.552	55.195
Deep Blue	1.028	0.649	36.868
*Average**	0.842	0.471	44.038

Table 5.2: Summary Of The Inter-Instrumental Agreement For The CCS-II GLOSSY Tiles Using Specular Component Included Mode Between SF-600 And CE-7000A

	Original ΔE^*_{ab}	*Corrected* ΔE^*_{ab}	*% Improvement*
Pale Grey	0.428	0.274	35.981
Middle Grey	0.269	0.158	41.264
Diff. Grey	0.293	0.288	1.706
Deep Grey	0.217	0.158	27.189
Deep Pink	0.737	0.356	51.696
Red	1.263	0.497	60.649
Orange	1.084	0.311	71.310
Bright Yellow	0.930	0.277	70.215
Green	0.775	0.203	73.806
Diff. Green	0.749	0.153	79.573
Cyan	1.004	0.630	37.251
Deep Blue	0.849	0.583	31.331
*Average**	0.717	0.324	54.780

Table 5.3: Summary Of The Inter-Instrumental Agreement For The CCS-II MATT Tiles Using Specular Component Excluded Mode Between SF-600 And CE-7000A

	Original ΔE^*_{ab}	*Corrected ΔE^*_{ab}*	*% Improvement*
Pale Grey	0.590	0.227	61.525
Middle Grey	0.422	0.153	63.744
Diff. Grey	0.395	0.113	71.392
Deep Grey	0.183	0.100	45.355
Deep Pink	0.633	0.109	82.780
Red	0.713	0.695	2.525
Orange	0.874	0.248	71.625
Bright Yellow	0.749	0.088	88.251
Green	0.867	0.206	76.240
Diff. Green	0.788	0.106	86.548
Cyan	0.903	0.394	56.368
Deep Blue	0.890	0.610	31.461
*Average**	0.667	0.254	61.921

Table 5.4: Summary Of The Inter-Instrumental Agreement For The CCS-II MATT Tiles Using Specular Component Included Mode Between SF-600 And CE-7000A

	Original ΔE^*_{ab}	*Corrected ΔE^*_{ab}*	*% Improvement*
Pale Grey	0.361	0.225	37.673
Middle Grey	0.182	0.154	15.385
Diff. Grey	0.166	0.109	34.337
Deep Grey	0.074	0.101	-36.486
Deep Pink	0.603	0.103	82.919
Red	0.890	0.701	21.236
Orange	0.968	0.286	70.455
Bright Yellow	0.768	0.066	91.406
Green	0.762	0.192	74.803
Diff. Green	0.652	0.111	82.975
Cyan	0.824	0.373	54.733
Deep Blue	0.677	0.553	18.316
*Average**	0.577	0.248	57.067

Table 5.5: Summary Of The Inter-Instrumental Agreement For The CCS-II GLOSSY Tiles Using Specular Component Excluded Mode Between CE-2180 And CE-7000A

	Original ΔE^*_{ab}	*Corrected ΔE^*_{ab}*	*% Improvement*
Pale Grey	0.666	0.723	-8.559
Middle Grey	0.707	0.625	11.598
Diff. Grey	0.453	0.667	-47.241
Deep Grey	0.239	0.444	-85.774
Deep Pink	0.700	0.302	56.857
Red	0.719	0.457	36.439
Orange	0.119	0.416	-249.580
Bright Yellow	0.689	0.397	42.380
Green	0.130	0.394	-203.077
Diff. Green	0.790	0.265	66.456
Cyan	0.140	0.497	-255.000
Deep Blue	1.134	0.425	62.522
*Average**	0.541	0.468	13.475

Table 5.6: Summary Of The Inter-Instrumental Agreement For The CCS-II GLOSSY Tiles Using Specular Component Included Mode Between CE-2180 And CE-7000A

	Original ΔE^*_{ab}	*Corrected ΔE^*_{ab}*	*% Improvement*
Pale Grey	0.795	0.057	92.830
Middle Grey	0.758	0.414	45.383
Diff. Grey	0.280	0.066	76.429
Deep Grey	0.100	0.091	9.000
Deep Pink	0.723	0.407	43.707
Red	0.634	0.631	0.473
Orange	0.114	0.387	-239.474
Bright Yellow	0.628	0.623	0.796
Green	0.143	0.320	-123.776
Diff. Green	1.023	0.349	65.885
Cyan	0.195	0.545	-179.487
Deep Blue	1.285	1.078	16.109
*Average**	0.557	0.414	25.606

Table 5.7: Summary Of The Inter-Instrumental Agreement For The CCS-II MATT Tiles Using Specular Component Excluded Mode Between CE-2180 And CE-7000A

	Original ΔE^*_{ab}	*Corrected ΔE^*_{ab}*	*% Improvement*
Pale Grey	0.928	0.220	76.293
Middle Grey	0.535	0.282	47.290
Diff. Grey	0.760	0.503	33.816
Deep Grey	0.446	0.165	63.004
Deep Pink	0.713	0.421	40.954
Red	0.680	0.372	45.294
Orange	0.414	0.093	77.536
Bright Yellow	0.516	0.362	29.845
Green	0.444	0.055	87.613
Diff. Green	0.852	0.215	74.765
Cyan	0.454	0.155	65.859
Deep Blue	0.679	0.354	47.865
*Average**	0.618	0.266	56.920

Table 5.8: Summary Of The Inter-Instrumental Agreement For The CCS-II MATT Tiles Using Specular Component Included Mode Between CE-2180 And CE-7000A

	Original ΔE^*_{ab}	*Corrected ΔE^*_{ab}*	*% Improvement*
Pale Grey	0.952	0.156	83.613
Middle Grey	0.576	0.225	60.938
Diff. Grey	0.361	0.324	10.249
Deep Grey	0.352	0.140	60.227
Deep Pink	0.718	0.256	64.345
Red	0.755	0.236	68.742
Orange	0.436	0.079	81.881
Bright Yellow	0.552	0.231	58.152
Green	0.500	0.077	84.600
Diff. Green	0.997	0.093	90.672
Cyan	0.428	0.127	70.327
Deep Blue	0.968	0.310	67.975
*Average**	0.633	0.188	70.323

Note * = (Average Original ΔE^*_{ab} – Average Corrected ΔE^*_{ab})/ Average Original $\Delta E^*_{ab} \times 100$

Tables 5.1 – 5.4, which show the summary of the inter-instrumental agreement for the CCS-II Tiles when comparing SF-600 and CE-7000A indicate that after application of the mathematical models to calculate the predicted L*, a* and b* values, the colour difference improved. The average percentage improvement of the colour difference ranged from 44.0 –61.9%.

Tables 5.5 – 5.8, summarizing the inter-instrumental agreement for the CCS-II Tiles for CE-2180 and CE-7000A show that, after applying the mathematical models to calculate the predicted L*, a* and b* values, the colour difference also improved accordingly. The average percentage of the colour difference improved in the range from 13. 5 – 70.3%.

Regardless of whether "GLOSSY" tiles were measured using the specular component excluded mode or not, the percentage improvement for the inter-instrumental agreement between CE-2180 and CE-7000A was less than that for SF-600 and CE-7000A. This was due to the fact that measurements of the spectral reflectance of the "GLOSSY" tiles are depended more on the optical system of the spectrophotoeter, especially when using a single-beam spectrophotometer, if the calibration procedure is

not good. For "MATT" Tiles, the inter-instrumental agreements between CE-2180 and CE-7000A and between SF-600 and CE-7000A were satisfactory because the measurements were easier to obtain compared to the "GLOSSY" tiles.

The poor measurement results for the GLOSSY tiles were due to the high reflection inside the integrated sphere. Besides the size of the integrated sphere, the position of the specular component port and the signal receiver are factors which may have affected the measurement results.

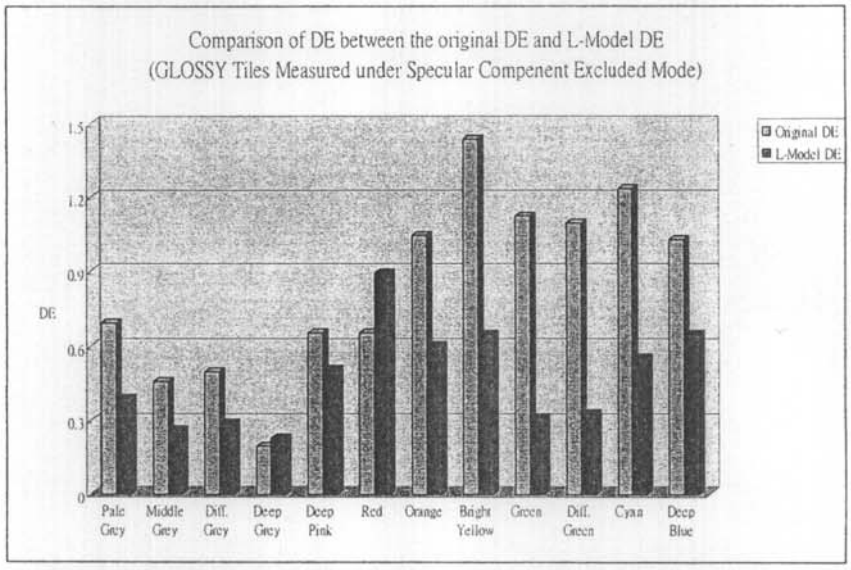


Figure 5.1 The Comparison Of The DE Between The Original DE and L-Model For SF-600 And CE-7000A (GLOSSY Tiles Measured Using Specular Component Excluded Mode)

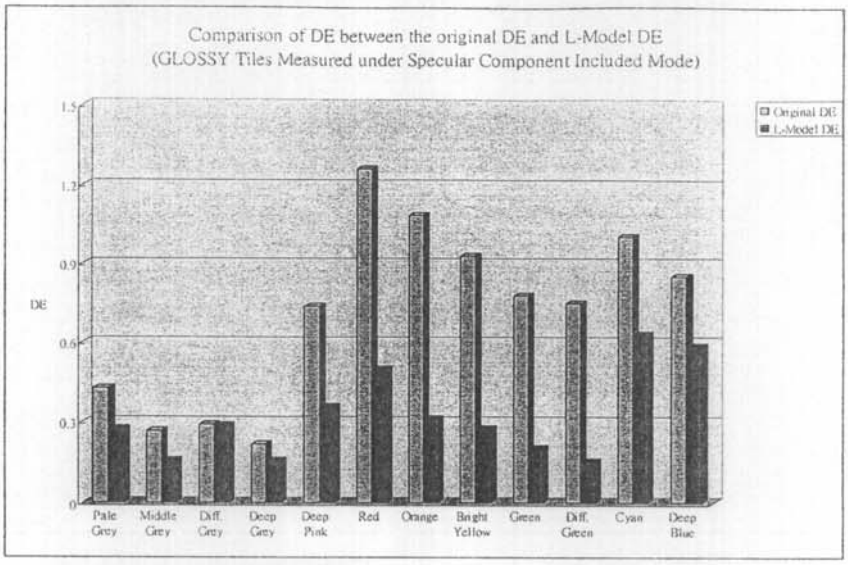


Figure 5.2 The Comparison Of The DE Between The Original DE and L-Model For SF-600 And CE-7000A (GLOSSY Tiles Measured Using Specular Component Included Mode)

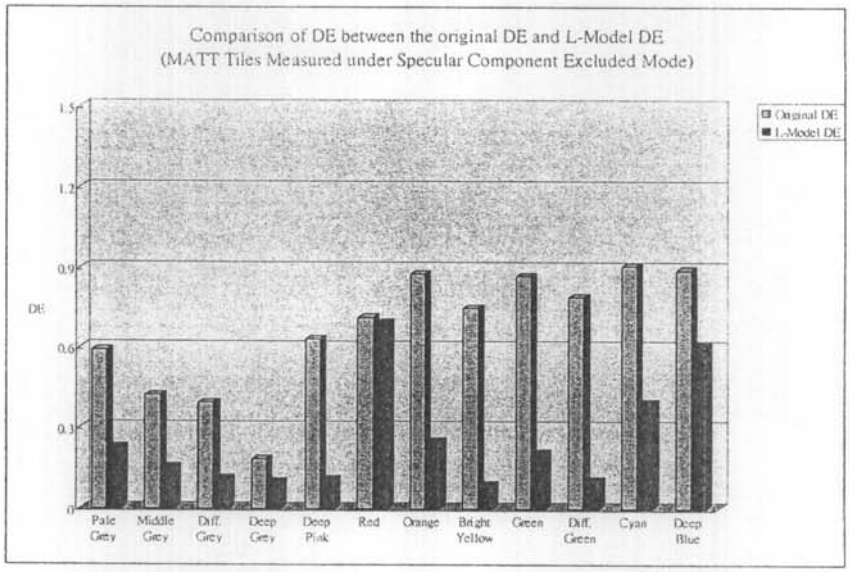


Figure 5.3 The Comparison Of The DE Between The Original DE and L-Model For SF-600 And CE-7000A (MATT Tiles Measured Using Specular Component Excluded Mode)

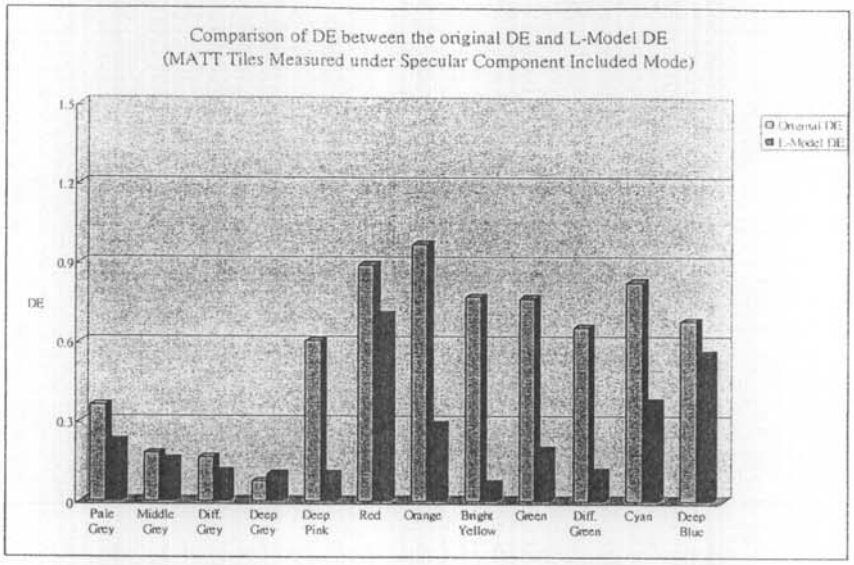


Figure 5.4 The Comparison Of The DE Between The Original DE and L-Model For SF-600 And CE-7000A (MATT Tiles Measured Using Specular Component Included Mode)

Figure 5.1 shows the comparison between the colour difference and L-Model for SF-600 and CE-7000A (GLOSSY tiles measured in specular component excluded mode), and it was found that the colour difference of red after modeling was higher than that of the original measurement. Red is considered to be one of the most sensitive colours compare with the others, thus the modeling result was unsatisfactory and also worse than the original result. Sensitive colour means that the colour is easily affected by the change of temperature and humidity even the change of the above factors are not significant[56,68].

Figure 5.2 shows the comparison of the colour difference between the original colour difference and L-Model for SF-600 and CE-7000A (GLOSSY tiles measured using specular component included mode), and in Figure 5.3, which shows the comparison of the colour difference between the original colour difference and L-Model for SF-600 and CE-7000A (MATT tiles measured under specular component excluded mode), it may be seen that the entire colour difference improves after modeling. This implies that L-Model functioned well in these two combinations.

For Figure 5.4, the comparison of the colour difference between the original colour difference and L-Model for SF-600 and CE-7000A (MATT tiles measured under specular component included mode), it was found that the colour difference of deep grey after modeling was higher than that of the original measurement. This is because the signal measured by the spectrophotometer was low, thus the modeling result was unsatisfactory and also worse than the original result.

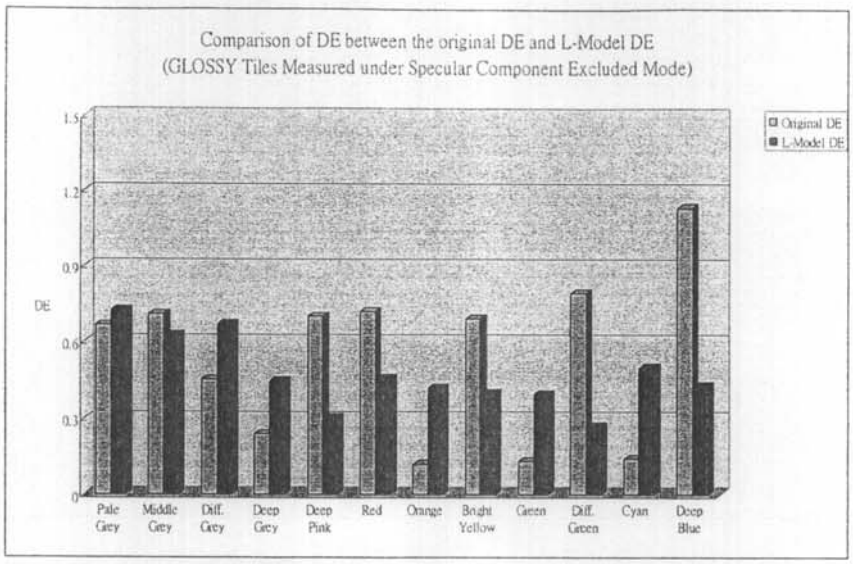


Figure 5.5 The Comparison Of The DE Between The Original DE and L-Model For CE-2180And CE-7000A (GLOSSY Tiles Measured Using Specular Component Excluded Mode)

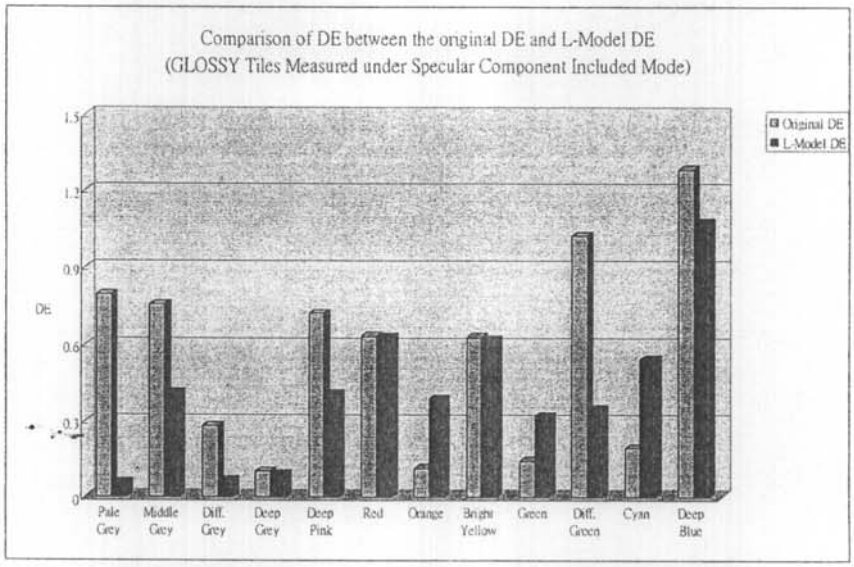


Figure 5.6 The Comparison Of The DE Between The Original DE and L-Model For CE-2180And CE-7000A (GLOSSY Tiles Measured Using Specular Component Included Mode)

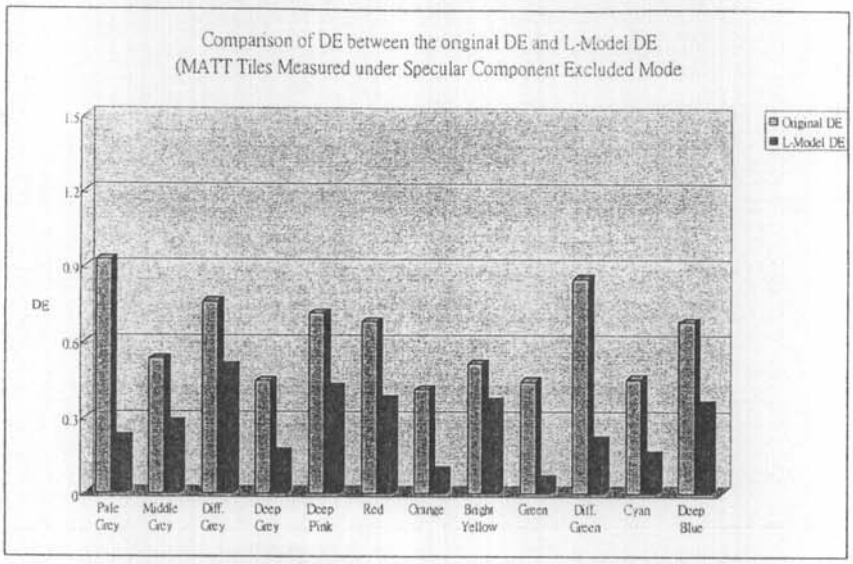


Figure 5.7 The Comparison Of The DE Between The Original DE and L-Model For CE-2180And CE-7000A (MATT Tiles Measured Using Specular Component Excluded Mode)

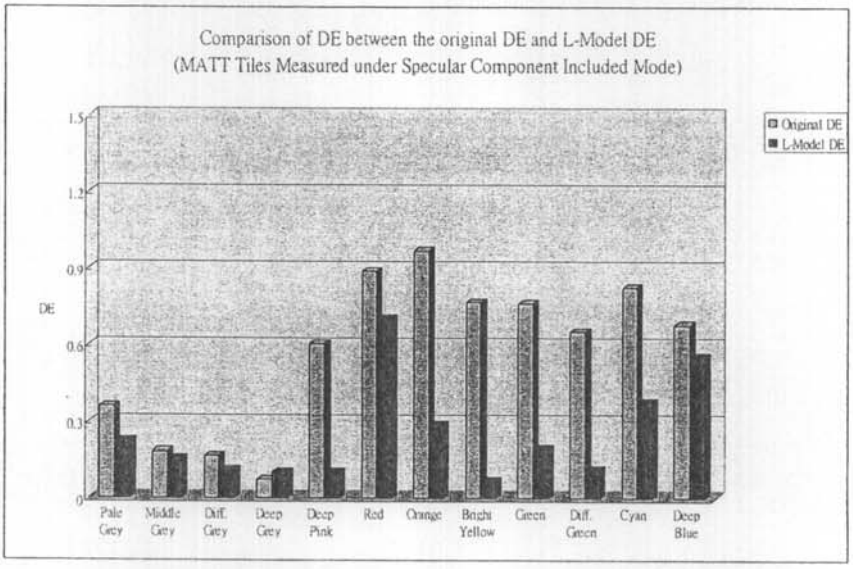


Figure 5.8 The Comparison Of The DE Between The Original DE and L-Model For CE-2180And CE-7000A (MATT Tiles Measured Using Specular Component Included Mode)

Figure 5.5, showing the comparison of the colour difference between the original colour difference and L-Model for CE-2180 and CE-7000A (GLOSSY tiles measured under specular component excluded mode), demonstrates that the colour difference of pale grey, different grey, deep grey, orange, green and cyan after modeling was higher than that of the original measurement. This indicated that the L-Model was not suitable for the GLOSSY tiles measured under specular component excluded conditions and further improvement is required in order to enhance the inter-instrumental agreement.

In Figure 5.6, which shows the comparison of the colour difference between the original colour difference and L-Model for CE-2180 and CE-7000A (GLOSSY tiles measured under specular component excluded mode), it may be seen that the colour difference of orange, green and cyan after modeling was higher than that of the original measurement. This shows that the L-Model was also unsuitable for the GLOSSY tiles measured under specular component included conditions especially for the sensitive colours and further improvement was required in order to enhance the inter-instrumental agreement.

For Figure 5.7, the comparison of the colour difference between the original colour difference and L-Model for CE-2180 and CE-7000A (MATT tiles measured under specular component excluded mode), all the colour differences improved after modeling. This implies that L-Model functioned well in this combination.

Figure 5.8, which show the comparison of the colour difference between the original colour difference and L-Model for SF-600 and CE-7000A (MATT tiles measured under specular component included mode), indicates that the colour difference of deep grey after modeling was higher than that of the original measurement. Since the signal for the deep colour measured by the spectrophotometer was low, the modeling result was unsatisfactory and also worse than the original result.

CHAPTER 6

DEVELOPMENT OF THE SECOND MATHEMATICAL MODEL (R-Model)

6.1 Introduction

The application of L-Model was found to be limited, since it was not a robust mathematical model for inter-instrumental agreement. For this reason, a powerful and robust model was developed in order to further enhance the inter-instrumental agreement between spectrophotometers.

6.2 Development Of The Second Mathematical Model (R-Model)

As indicated in the inter-instrumental agreement table, the colour differences among the spectrophotometers are very high (up to 1.554 CIELAB units), implying that further correction is necessary to further enhance the inter-instrumental agreement among the spectrophotometers. Although the "L-Model" was well developed, it was not a robust mathematical model and the overall improvement of inter-instrumental agreement was insignificant. The "L-Model" was therefore ineffective in the correction of the inter-instrumental agreement.

The "R-Model", another mathematical model, was developed to improve the inter-instrumental agreement. It was based on the correction of the reflectance value across the visual spectrum. According to the preliminary findings, the tendency of the relative reflectance difference for twelve ceramic tiles was similar. Therefore bandpass correction was deemed one of the methods for the correction of the inter-instrumental agreement[6.33, 34, 35]. The equations used in the R-Model are summarised as follows:

At 400nm

$$\text{Corrected } R_{(400)} = n \times R_{(400)} + o \times R_{(410)} + q \text{ ----- EQ.6.1}$$

At 410nm – 690nm where $\lambda = 410, 420, \ldots, 690, 700$

$$\text{Corrected } R_{(\lambda)} = m \times R_{(\lambda-10)} + n \times R_{(\lambda)} + o \times R_{(\lambda+10)} + q \text{ ----- EQ.6.2}$$

At 700nm

$$\text{Corrected } R_{(700)} = m \times R_{(690)} + n \times R_{(700)} + q \text{ ----- EQ.6.3}$$

Where m, n, o and q are wavelength dependent constant.

For the coefficients m, n, o and p, please refer to Appendix I for details.

6.3 The Improvement Of The Inter-Instrumental Agreement After Applying R-Model

The spectral reflectance factors of SF-600 and CE-2180 were substituted into the above equations (EQ. 6.1 to EQ. 6.3) to calculate the predicted spectral reflectance factors. The colour difference between predicted and measured reflectance values was then calculated. The inter-instrumental agreement of the CCS-II tiles is summarized in Tables 6.1 – 6.8.

Table 6.1: Summary Of The Inter-Instrumental Agreement For The CCS-II GLOSSY Tiles Using Specular Component Excluded Mode Between SF-600 And CE-7000A After Applying The R-Model

	Original ΔE^*_{ab}	*Corrected* ΔE^*_{ab}	*% Improvement*
Pale Grey	0.690	0.110	84.058
Middle Grey	0.459	0.095	79.303
Diff. Grey	0.495	0.175	64.646
Deep Grey	0.196	0.232	-18.367
Deep Pink	0.650	0.243	62.615
Red	0.650	0.773	-18.923
Orange	1.046	0.418	60.038
Bright Yellow	1.437	0.269	81.280
Green	1.120	0.089	92.054
Diff. Green	1.095	0.101	90.776
Cyan	1.232	0.601	51.218
Deep Blue	1.028	0.598	41.829
*Average**	0.842	0.309	63.341

Table 6.2: Summary Of The Inter-Instrumental Agreement For The CCS-II GLOSSY Tiles Using Specular Component Included Mode Between SF-600 And CE-7000A After Applying The R-Model

	Original ΔE^*_{ab}	*Corrected* ΔE^*_{ab}	*% Improvement*
Pale Grey	0.428	0.108	74.766
Middle Grey	0.269	0.051	81.041
Diff. Grey	0.293	0.057	80.546
Deep Grey	0.217	0.113	47.926
Deep Pink	0.737	0.115	84.396
Red	1.263	0.216	82.898
Orange	1.084	0.036	96.679
Bright Yellow	0.930	0.347	62.688
Green	0.775	0.232	70.065
Diff. Green	0.749	0.232	69.025
Cyan	1.004	0.187	81.375
Deep Blue	0.849	0.127	85.041
*Average**	0.717	0.152	78.821

Table 6.3: Summary Of The Inter-Instrumental Agreement For The CCS-II MATT Tiles Using Specular Component Excluded Mode Between SF-600 And CE-7000A After Applying The R-Model

	Original ΔE^*_{ab}	*Corrected* ΔE^*_{ab}	*% Improvement*
Pale Grey	0.590	0.096	77.570
Middle Grey	0.422	0.067	75.093
Diff. Grey	0.395	0.068	76.792
Deep Grey	0.183	0.071	67.281
Deep Pink	0.633	0.058	92.130
Red	0.713	0.084	93.349
Orange	0.874	0.033	96.956
Bright Yellow	0.749	0.055	94.086
Green	0.867	0.032	95.871
Diff. Green	0.788	0.062	91.722
Cyan	0.903	0.148	85.259
Deep Blue	0.890	0.055	93.522
*Average**	0.667	0.069	90.358

Table 6.4: Summary Of The Inter-Instrumental Agreement For The CCS-II MATT Tiles Using Specular Component Included Mode Between SF-600 And CE-7000A After Applying The R-Model

	Original ΔE^*_{ab}	*Corrected* ΔE^*_{ab}	*% Improvement*
Pale Grey	0.361	0.066	81.717
Middle Grey	0.182	0.046	74.725
Diff. Grey	0.166	0.05	69.880
Deep Grey	0.074	0.061	17.568
Deep Pink	0.603	0.280	53.566
Red	0.890	0.636	28.539
Orange	0.968	0.069	92.872
Bright Yellow	0.768	0.267	65.234
Green	0.762	0.139	81.759
Diff. Green	0.652	0.031	95.245
Cyan	0.824	0.169	79.490
Deep Blue	0.677	0.208	69.276
*Average**	0.577	0.169	70.810

Table 6.5: Summary Of The Inter-Instrumental Agreement For The CCS-II GLOSSY Tiles Using Specular Component Excluded Mode Between CE-2180 And CE-7000A After Applying The R-Model

	Original ΔE^*_{ab}	*Corrected* ΔE^*_{ab}	*% Improvement*
Pale Grey	0.140	0.220	-57.143
Middle Grey	0.130	0.111	14.615
Diff. Grey	0.119	0.112	5.882
Deep Grey	0.239	0.152	36.402
Deep Pink	0.700	0.459	34.429
Red	1.134	0.362	68.078
Orange	0.790	0.290	63.291
Bright Yellow	0.666	0.267	59.910
Green	0.689	0.474	31.205
Diff. Green	0.719	0.481	33.102
Cyan	0.707	0.325	54.031
Deep Blue	0.453	0.965	-113.024
*Average**	0.541	0.352	34.968

Table 6.6: Summary Of The Inter-Instrumental Agreement For The CCS-II GLOSSY Tiles Using Specular Component Included Mode Between CE-2180 And CE-7000A After Applying The R-Model

	Original ΔE^*_{ab}	*Corrected* ΔE^*_{ab}	*% Improvement*
Pale Grey	0.195	0.478	-145.128
Middle Grey	0.143	0.281	-96.503
Diff. Grey	0.114	0.332	-191.228
Deep Grey	0.100	0.091	9.000
Deep Pink	0.723	0.369	48.963
Red	1.285	0.729	43.268
Orange	1.023	0.205	79.961
Bright Yellow	0.795	0.377	52.579
Green	0.628	0.461	26.592
Diff. Green	0.634	0.454	28.391
Cyan	0.758	0.383	49.472
Deep Blue	0.280	0.154	45.000
*Average**	0.557	0.360	35.400

Table 6.7: Summary Of The Inter-Instrumental Agreement For The CCS-II MATT Tiles Using Specular Component Excluded Mode Between CE-2180 And CE-7000A After Applying The R-Model

	Original ΔE^*_{ab}	*Corrected* ΔE^*_{ab}	*% Improvement*
Pale Grey	0.454	0.129	71.586
Middle Grey	0.444	0.102	77.027
Diff. Grey	0.414	0.098	76.329
Deep Grey	0.446	0.116	73.991
Deep Pink	0.713	0.124	82.609
Red	0.679	0.042	93.814
Orange	0.852	0.081	90.493
Bright Yellow	0.928	0.039	95.797
Green	0.516	0.120	76.744
Diff. Green	0.680	0.210	69.118
Cyan	0.535	0.146	72.710
Deep Blue	0.760	0.139	81.711
*Average**	0.618	0.112	81.862

Table 6.8: Summary Of The Inter-Instrumental Agreement For The CCS-II MATT Tiles Using Specular Component Included Mode Between CE-2180 And CE-7000A After Applying The R-Model

	Original ΔE^*_{ab}	*Corrected ΔE^*_{ab}*	*% Improvement*
Pale Grey	0.428	0.123	71.262
Middle Grey	0.500	0.099	80.200
Diff. Grey	0.436	0.091	79.128
Deep Grey	0.352	0.095	73.011
Deep Pink	0.718	0.095	86.769
Red	0.968	0.094	90.289
Orange	0.997	0.053	94.684
Bright Yellow	0.952	0.072	92.437
Green	0.552	0.170	69.203
Diff. Green	0.755	0.219	70.993
Cyan	0.576	0.182	68.403
Deep Blue	0.361	0.091	74.792
*Average**	0.633	0.115	81.777

Note * = (Average Original ΔE^*_{ab} – Average Corrected ΔE^*_{ab})/ Average Original $\Delta E^*_{ab} \times 100$

Tables 6.1 to 6.4 show the significant improvements in the inter-instrumental agreement between spectrophotometers, especially in the case of the MATT tiles measured using the specular component excluded mode. The average percentage improvement of the colour difference was up to 90 percent. For the other sets of data and results, the colour differences between spectrophotometers ranged from 63 to 78 percent. The results imply that the R-Model showed a good improvement of the inter-instrumental agreement between SF-600 and CE-7000A when compared with the L-Model. From tables 6.5 – 6.8, it may be seen that the percentage improvement of the inter-instrumental agreement for the "GLOSSY" tiles measured under both the specular component excluded mode and the specular component included mode was disappointing when compared with the

"MATT" tiles. This is because CE-2180 is a single-beam spectrophotometer and lacks the reference beam to overcome the glossy effect during the measurement process.

The comparison of the colour difference (ΔE^*_{ab}) between the two different newly developed models for SF600 vs CE-7000A is summarised in the figures below:

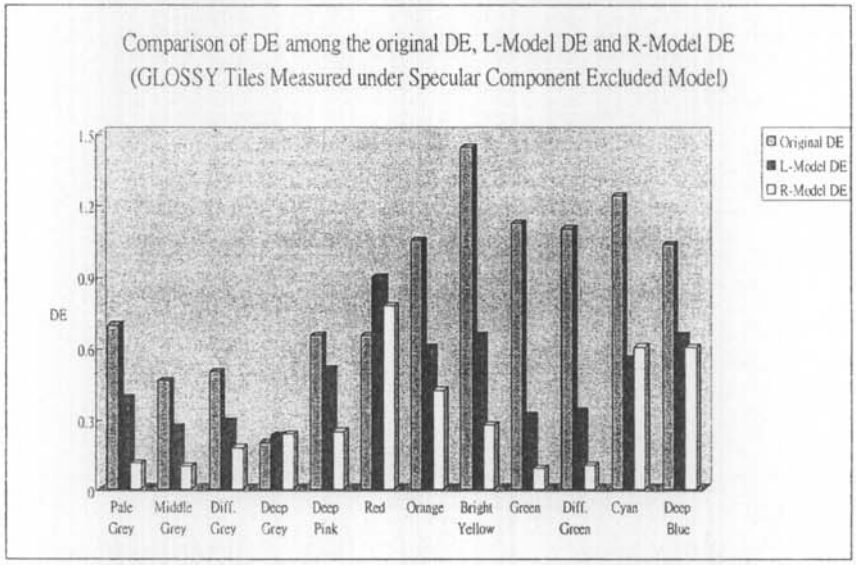


Figure 6.1 The Comparison Of The DE Between The Two Different Developed Models (GE) For SF-600 And CE-7000A

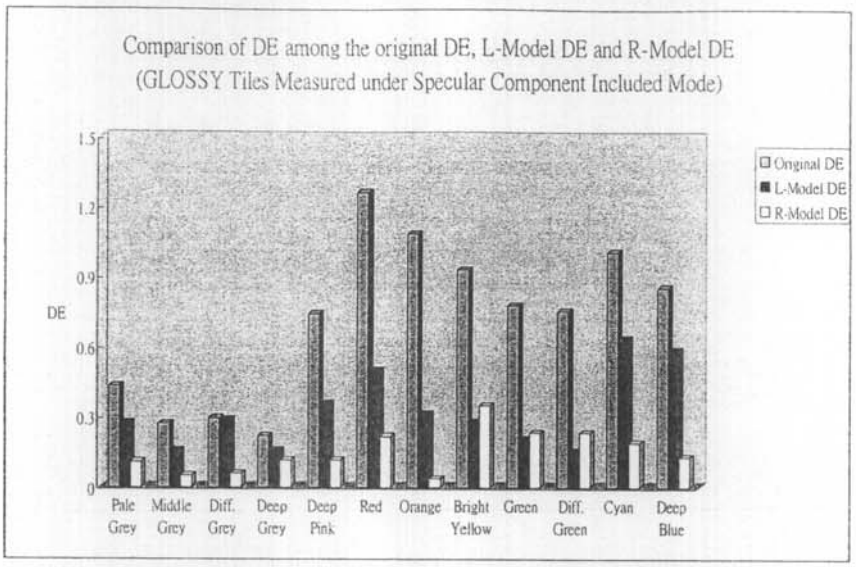


Figure 6.2 The Comparison Of The DE Between The Two Different Developed Models (GI) For SF-600 And CE-7000A

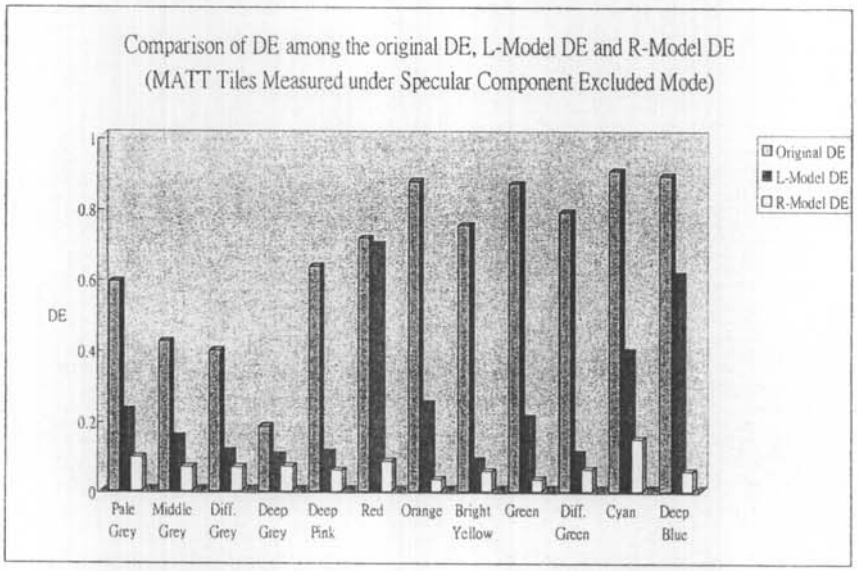


Figure 6.3 The Comparison Of The DE Between The Two Different Developed Models (ME) For SF-600 And CE-7000A

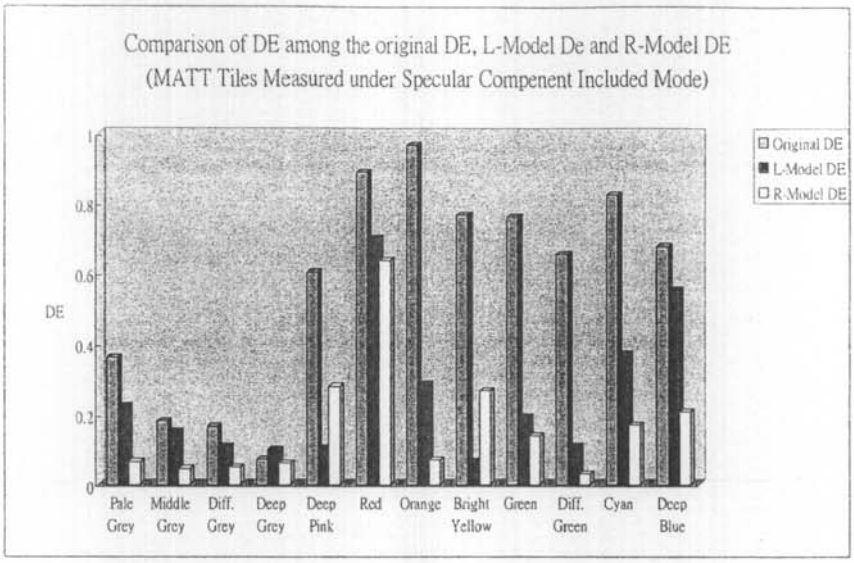


Figure 6.4 The Comparison of the DE Between The Two Different Developed Models (MI) For SF-600 And CE-7000A

Figure 6.1, which shows results for the GLOSSY tiles measured using the specular component mode, indicates that the overall performance of "R-Model" was better than that of the "L-Model". The average improvement of "R-Model" for the twelve tiles was 63%, while the average improvement of "L-Model" for the twelve tiles was 44%. In this figure, irrespective of whether the L-Model or R-Model is used, the inter-instrumental agreement for deep grey and red may be seen to be unsatisfactory. Red, as previously discussed, is a sensitive colour and easily affected by changes in temperature. Deep grey is also difficult to measure because the signal for the measurement is insignificant and the result for inter-instrumental agreement is poor.

Figure 6.2, which shows results for the GLOSSY tiles measured using specular component included mode, indicates that the overall performance of R-Model" is also better than that of the "L-Model" and all the colours showed improvement after applying the R-Model and L-Model. The average improvement of "R-Model" for the twelve tiles was 79%, while the average improvement of "L-Model" for the twelve tiles was 55%.

In Figure 6.3, which shows the results for the MATT tiles measured using the specular component excluded mode, it may be seen that the overall performance for the "R-Model" was better than that of the "L-Model" and all the colours showed improvement after applying both the R-Model and L-Model. The average improvement for the "R-Model" for the twelve tiles was 90%, whereas the average improvement for the "L-Model" for the twelve tiles was 62%.

In Figure 6.4, which shows the results for the MATT tiles measured using the specular component included mode, it may be seen that the overall performance for the R-Model" was also better than that of the "L-Model". The average improvement of "R-Model" for the twelve tiles was 71%, whereas the average improvement of "L-Model" for the twelve tiles was 57%.

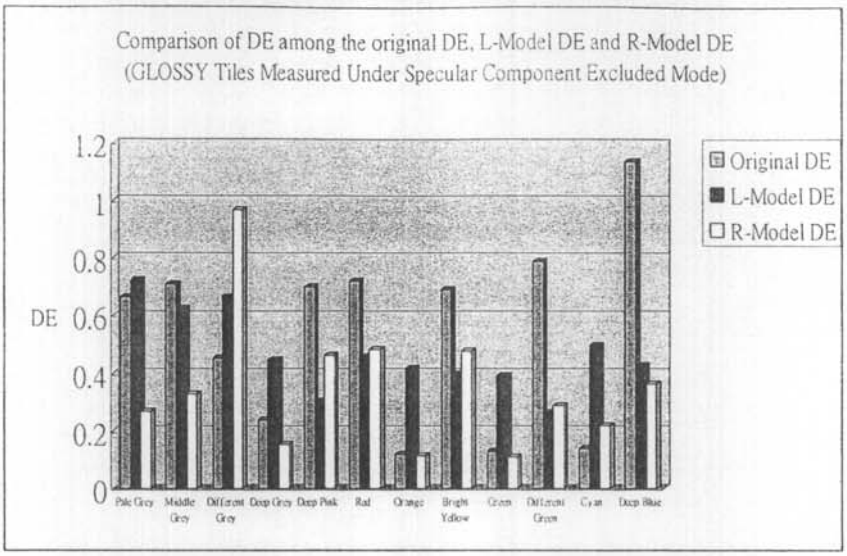


Figure 6.5 The Comparison Of The DE Between The Two Different Developed Models (GE) For CE-2180 And CE-7000A

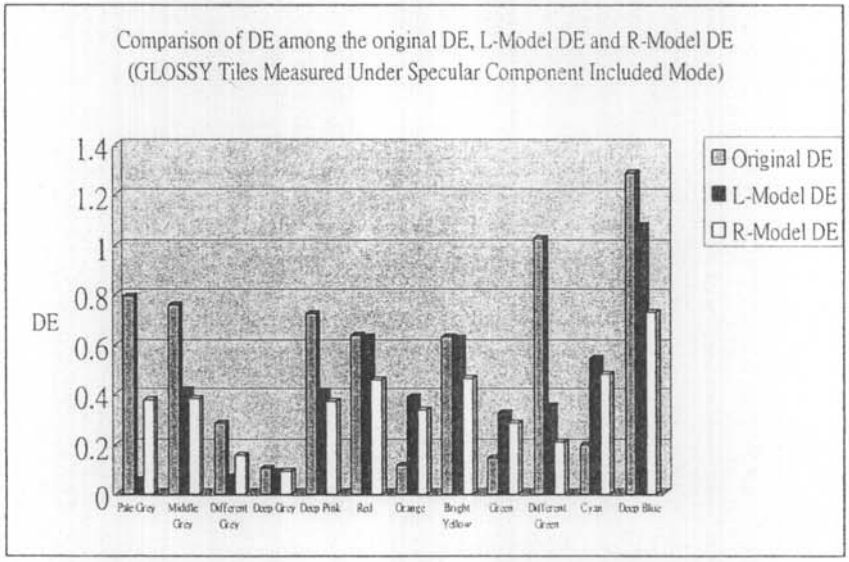


Figure 6.6 The Comparison Of The DE Between The Two Different Developed Models (GI) For CE-2180 And CE-7000A

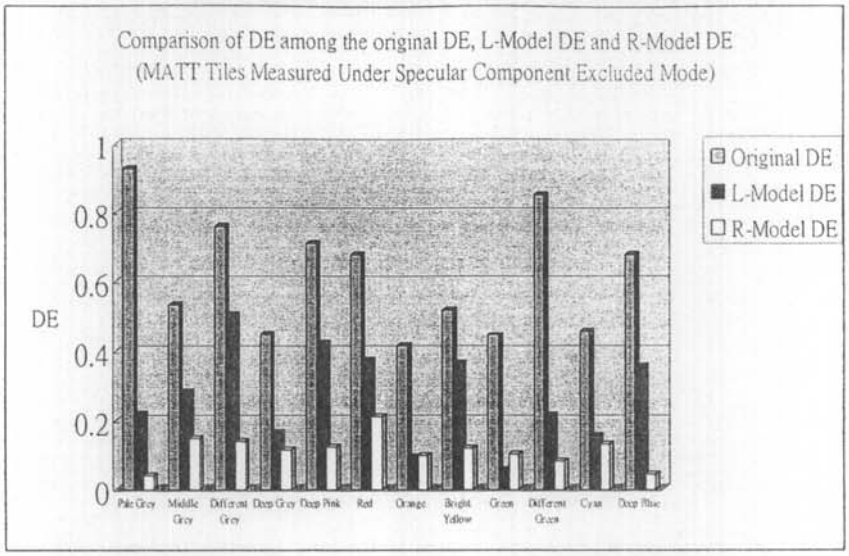


Figure 6.7 The Comparison Of The DE Between The Two Different Developed Models (ME) For CE-2180 And CE-7000A

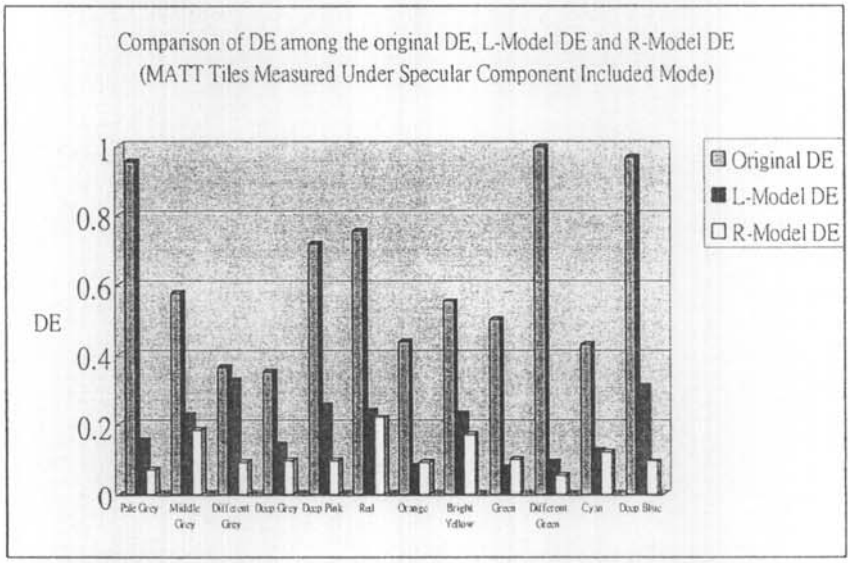


Figure 6.8 The Comparison Of The DE Between The Two Different Developed Models (MI) For CE-2180 And CE-7000A

In Figure 6.5, which shows the results for the GLOSSY tiles measured using the specular component excluded mode, it may be seen that the overall performance of "R-Model" was better than that of the "L-Model". The average improvement of "R-Model" for the twelve tiles was 35%, while the average improvement of the "L-Model" for the twelve tiles was 13%. The inter-instrumental agreement for different grey and cyan was worse than the original results after applying the R-Model because the optical design for CE-2180 and CE-7000A is different.

Figure 6.6 shows the results for the GLOSSY tiles measured using the specular component included mode, and it may be seen that the overall performance for the R-Model" was also better than that of the "L-Model". The average improvement of the "R-Model" for the twelve tiles was 36%, whereas the average improvement of the "L-Model" for the twelve tiles was 26%. After modeling it was found that the colour difference in the case of orange, green and cyan was higher than that of the original measurement, indicating that the R-Model was not suitable for application in the case of gloss-finish colours.

Figure 6.7, which shows the results for the MATT tiles measured under specular component excluded mode, indicates that the overall performance for "R-Model" was better than that of the "L-Model". The average improvement of "R-Model" for the twelve tiles was 82%, while the average improvement of "L-Model" for the twelve tiles was 57%. All the tiles showed improvement in the inter-instrumental agreement regardless of whether they were applied to the L-Model or R-Model.

In Figure 6.8, showing the results for the MATT tiles measured under specular component included mode, it may be seen that the overall performance of the R-Model" was better than that of the "L-Model". The average improvement of "R-Model" for the twelve tiles was 82%, while the average improvement of "L-Model" for the twelve tiles was 70%. All the tiles also showed improvement in the inter-instrumental agreement regardless of whether results were applied to the L-Model or R-Model.

Results shown in Figures 6.1 – 6.8 indicate that the "R-Model" resulted in greater improvement in the inter-instrumental agreement. Basically, the "R-Model" was developed in line with the concept of the bandpass correction and using multi linear

regression. However, the "L-Model" involved the use of linear regression only and its main purpose was to correct the colorimetric data (L*, a* and b*).

From the above, it may be seen that the "R-Model" was a powerful, flexible and robust model when compared with the "L-Model" in the improvement of the inter-instrumental agreement. The fundamental data for this model were from the spectral reflectance factors and, once the spectral reflectance factors were corrected, the relative spectral reflectance difference errors were eliminated.

Figures 6.1 to 6.8 show that the performance of the "R-Model" was better than that of the "L-Model". Of all the data sets, the MATT tiles measured under the specular component excluded mode showed the best improvement in inter-instrumental agreement. In addition, the MATT tiles measured under the specular component included mode also showed satisfactory improvement in inter-instrumental agreement.

The results obtained for the GLOSSY tiles, either in specular component excluded mode or in specular component included mode, were not as good as those for the MATT tiles.

In addition to the above results, the spectral reflectance factor for SF-600 and CE-2180 was calculated after applying the R-Model. The comparison of the colour difference between SF-600 and CE-2180 before and after applying the model is another important indication to test whether the newly developed mathematical models were successful or not. The comparison results are listed below:

Table 6.9: Summary Of The Inter-Instrumental Agreement For The CCS-II GLOSSY Tiles Ussing Specular Component Excluded Mode Between CE-2180 And SF-600 Before And After Applying The R-Model

	Before Modelling ΔE^*_{ab}	*After Modelling* ΔE^*_{ab}	*% Improvement*
Pale Grey	0.771	0.024	96.887
Middle Grey	0.561	0.117	79.144
Diff. Grey	0.500	0.125	75.000
Deep Grey	0.367	0.159	56.676
Deep Pink	0.445	0.325	26.966
Red	1.152	0.628	45.486
Orange	1.058	0.880	16.824
Bright Yellow	1.554	0.432	72.201
Green	1.134	0.380	66.490
Diff. Green	1.156	0.390	66.263
Cyan	0.887	0.234	73.619
Deep Blue	0.598	0.562	6.020
*Average**	0.849	0.355	58.205

Table 6.10: Summary Of The Inter-Instrumental Agreement For The CCS-II GLOSSY Tiles Using Specular Component Included Mode Between CE-2180 And SF-600 Before And After Applying The R-Model

	Before Modelling ΔE^*_{ab}	*After Modelling ΔE^*_{ab}*	*% Improvement*
Pale Grey	0.582	0.260	55.326
Middle Grey	0.414	0.352	14.976
Diff. Grey	0.368	0.128	65.217
Deep Grey	0.261	0.079	69.732
Deep Pink	0.915	0.476	47.978
Red	0.504	0.168	66.667
Orange	0.904	0.142	84.292
Bright Yellow	1.168	0.121	89.640
Green	0.883	0.448	49.264
Diff. Green	0.846	0.464	45.154
Cyan	1.627	0.721	55.685
Deep Blue	1.718	0.814	52.619
*Average**	0.849	0.348	58.046

Table 6.11: Summary Of The Inter-Instrumental Agreement For The CCS-II MATT Tiles Using Specular Component Excluded Mode Between CE-2180 And SF-600 Before And After Applying The R-Model

	Before Modelling ΔE^*_{ab}	*After Modelling ΔE^*_{ab}*	*% Improvement*
Pale Grey	0.724	0.064	91.160
Middle Grey	0.646	0.072	88.854
Diff. Grey	0.600	0.011	98.167
Deep Grey	0.374	0.057	84.759
Deep Pink	0.434	0.105	75.806
Red	0.297	0.125	57.912
Orange	0.793	0.089	88.777
Bright Yellow	1.106	0.239	78.391
Green	0.857	0.116	86.464
Diff. Green	1.045	0.237	77.321
Cyan	0.791	0.192	75.727
Deep Blue	0.529	0.132	75.047
*Average**	0.683	0.120	82.443

Table 6.12: Summary Of The Inter-Instrumental Agreement For The CCS-II MATT Tiles Using Specular Component Included Mode Between CE-2180 And SF-600 Before And After Applying The R-Model

	Before Modelling ΔE^*_{ab}	*After Modelling* ΔE^*_{ab}	*% Improvement*
Pale Grey	0.970	0.462	52.371
Middle Grey	0.830	0.416	49.880
Diff. Grey	0.817	0.361	55.814
Deep Grey	0.583	0.288	50.600
Deep Pink	0.598	0.317	46.990
Red	0.412	0.265	35.680
Orange	0.891	0.264	70.370
Bright Yellow	1.167	0.050	95.716
Green	1.077	0.156	85.515
Diff. Green	1.248	0.183	85.337
Cyan	0.961	0.522	45.682
Deep Blue	0.632	0.470	25.633
*Average**	0.849	0.313	63.145

Note * = (Average Original ΔE^*_{ab} – Average Corrected ΔE^*_{ab})/ Average Original ΔE^*_{ab} ×100

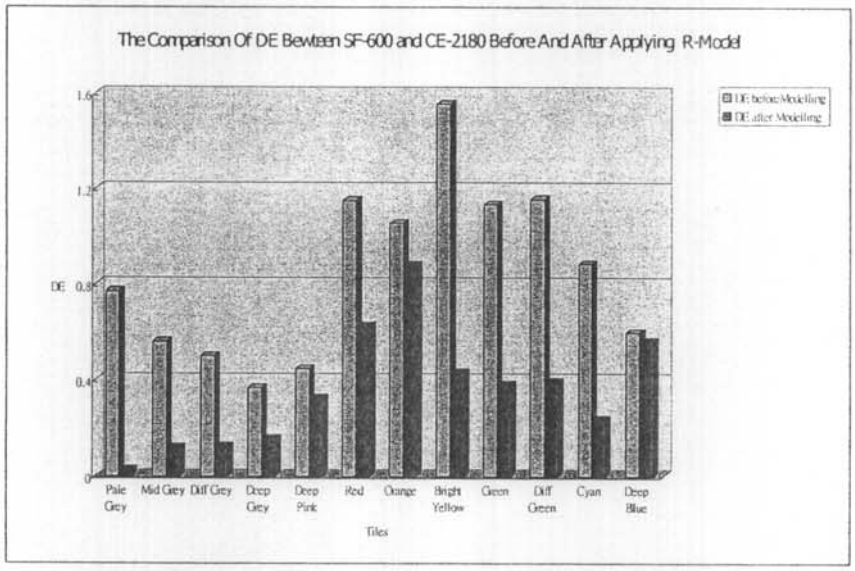


Figure 6.9 The Comparison Of The DE Between SF-600 And CE-2180 Before After Applying R-Model (GE)

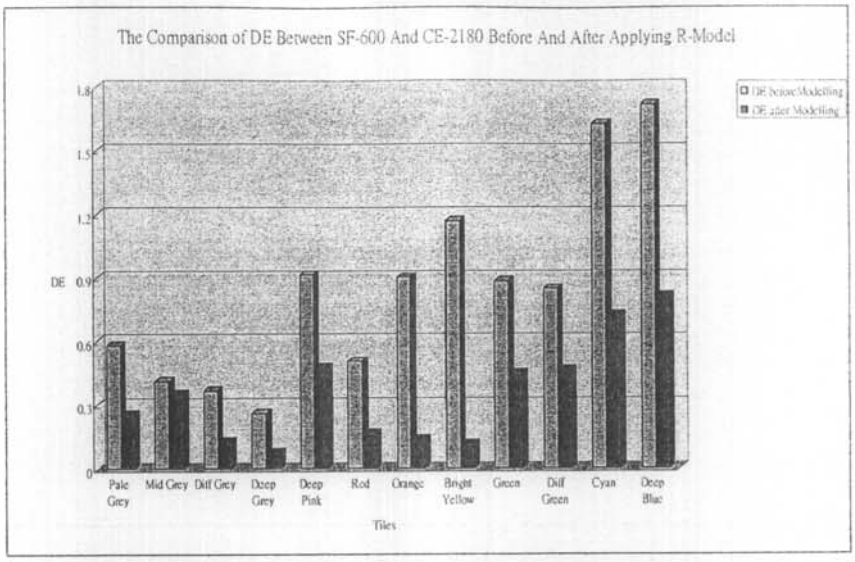


Figure 6.10 The Comparison Of The DE Between SF-600 And CE-2180 Before After Applying R-Model (GI)

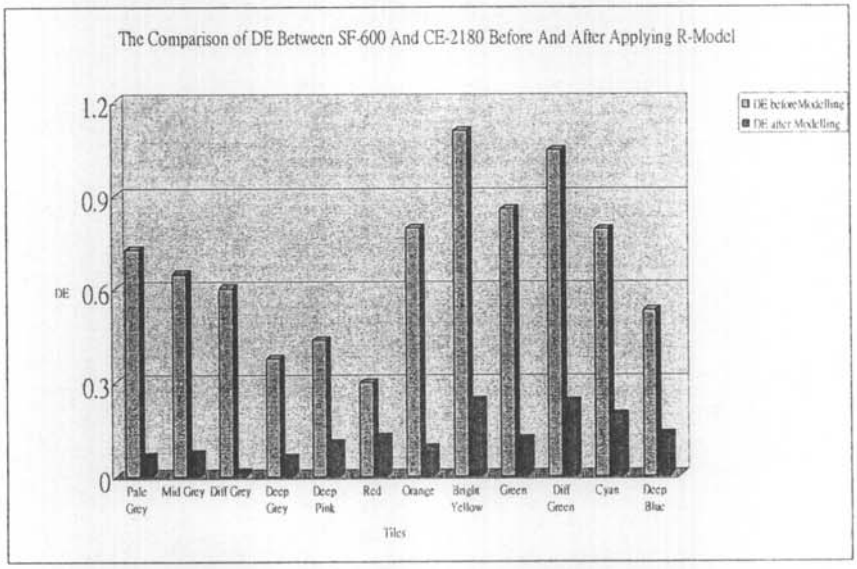


Figure 6.11 The Comparison Of The DE Between SF-600 And CE-2180 Before After Applying R-Model (ME)

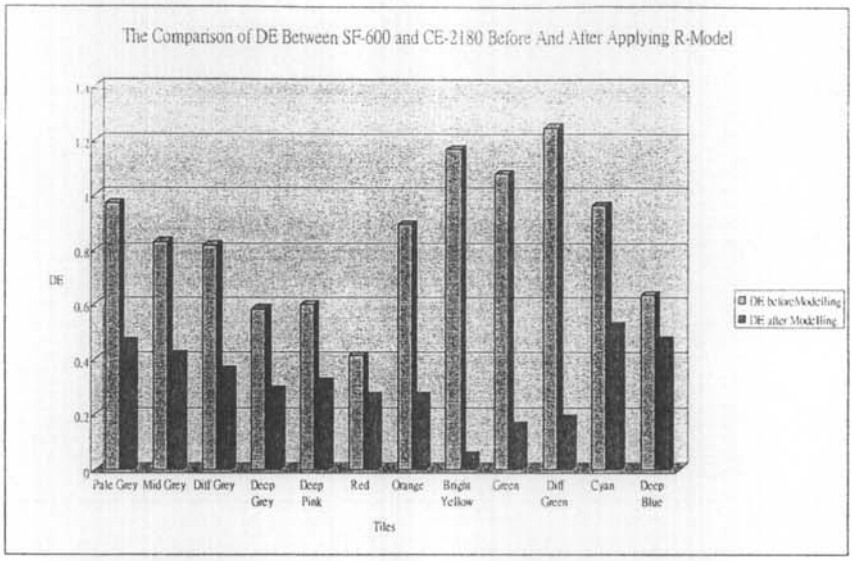


Figure 6.12 The Comparison Of The DE Between SF-600 And CE-2180 Before After Applying R-Model (MI)

Tables 6.9 to 6.12 and Figures 6.9 to 6.12 show the improvement of the average colour difference between SF-600 and CE-2180 before and after application of the R-Model in a range from 58.1% to 82.4%. These results indicate that the application of the R-Model to the correction of the inter-instrumental agreement was successful. This also implies that the profile between CE-7000A and SF-600 and also the profile between CE-7000A and CE-2180 were successfully developed.

Lastly, the ultimate aim of this project was to develop a corrective inter-instrumental agreement model which could be applied to other colour-related products such as textiles and paper samples. Most textile products have a matt surface therefore, following on from the above results, textile samples were selected to test the "R-Model" in order to investigate the actual performance in the textile industry.

CHAPTER 7

TESTING OF DEVELOPED MODELS

7.1 Introduction

In this chapter, results for the performance of the R-Model using textile and paper samples are summarised.

7.2 Testing Of The R-Model Using Textile Samples

As described in Chapter 3, textile samples were selected to test the performance of the newly developed mathematical model – the "R-Model". Textile samples are generally matt in nature, and to date no results of any inter-instrumental agreement models for textile samples have been published.

129 textile samples were selected to test the performance of the "R-Model" and the results are summarised as follows:

Table 7.1, Inter-Instrumental Agreement In Terms Of ΔE Using GLOSSY Tiles Measured Using Specular Component Excluded Mode R-Model SF-600 Vs CE-7000A To Test The Performance Of Selected Textile Samples

	Original ΔE	*Corrected ΔE*	*% Improvement*
Maximum	2.450	2.072	
Minimum	0.277	0.159	
Sum	134.031	78.432	41.500
Average	1.039	0.608	41.500

Table 7.2, Inter-Instrumental Agreement In Terms Of ΔE Using GLOSSY Tiles Measured Using Specular Component Included Mode R-Model SF-600 Vs CE-7000A To Test The Performance Of Selected Textile Samples

	Original ΔE	*Corrected ΔE*	*% Improvement*
Maximum	1.901	1.402	
Minimum	0.269	0.152	
Sum	130.677	96.921	26.061
Average	1.013	0.749	26.061

Table 7.3, Inter-Instrumental Agreement In Terms Of ΔE Using MATT Tiles Measured Using Specular Component Excluded Mode R-Model SF-600 Vs CE-7000A To Test The Performance Of Selected Textile Samples

	Original ΔE	*Corrected ΔE*	*% Improvement*
Maximum	2.450	2.506	
Minimum	0.277	0.067	
Sum	134.031	56.889	57.555
Average	1.039	0.441	57.555

Table 7.4, Inter-Instrumental Agreement In Terms Of ΔE Using MATT Tiles Measured Using Specular Component Included Mode R-Model SF-600 Vs CE-7000A To Test The Performance Of Selected Textile Samples

	Original ΔE	*Corrected ΔE*	*% Improvement*
Maximum	1.901	1.212	
Minimum	0.269	0.129	
Sum	130.677	76.626	41.400
Average	1.013	0.594	41.400

Tables 7.1 to 7.4, which show the inter-instrumental agreement of the textile samples when the R-Model was applied, indicate that the colour differences between the two spectrophotometers SF-600 and CE-7000A were corrected and lowered when compared with the original values. This implies that all the four models can be applied to textile samples for inter-instrumental agreement. In the case of the MATT tiles measured using specular component included mode, the R-Model showed the best performance in the

inter-instrumental agreement. This was due to the fact that textile samples are matt in nature, thus the percentage improvement was higher and the results were better when compared with those for the other three models.

Table 7.5, Inter-Instrumental Agreement In Terms Of ΔE Using GLOSSY Tiles Measured Using Specular Component Excluded Mode R-Model CE-2180 Vs CE-7000A To Test The Performance Of Selected Textile Samples

	Original ΔE	*Corrected ΔE*	*% Improvement*
Maximum	2.680	2.317	
Minimum	0.308	0.089	
Sum	111.585	98.427	11.792
Average	0.865	0.763	11.792

Table 7.6, Inter-Instrumental Agreement In Terms Of ΔE Using GLOSSY Tiles Measured Using Specular Component Included Mode R-Model CE-2180 Vs CE-7000A To Test The Performance Of Selected Textile Samples

	Original ΔE	*Corrected ΔE*	*% Improvement*
Maximum	1.448	1.003	
Minimum	0.538	0.152	
Sum	112.746	96.621	14.302
Average	0.874	0.749	14.302

Table 7.7, Inter-Instrumental Agreement In Terms Of ΔE Using MATT Tiles Measured Using Specular Component Excluded Mode R-Model CE-2180 Vs CE-7000A To Test The Performance Of Selected Textile Samples

	Original ΔE	*Corrected ΔE*	*% Improvement*
Maximum	2.680	2.216	
Minimum	0.308	0.143	
Sum	111.585	69.271	37.919
Average	0.865	0.537	37.919

Table 7.8, Inter-Instrumental Agreement In Terms Of ΔE Using MATT Tiles Measured Under Specular Component Included Mode R-Model CE-2180 Vs CE-7000A To Test The Performance Of Selected Textile Samples

	Original ΔE	*Corrected ΔE*	*% Improvement*
Maximum	1.448	1.024	
Minimum	0.538	0.277	
Sum	112.746	82.173	27.117
Average	0.874	0.637	27.117

From the above four tables (Tables 7.5 to 7.8), showing results for the inter-instrumental agreement of the textile samples when the R-Model was applied, the colour differences between the two spectrophotometers CE-2180 and CE-7000A were also corrected and lowered when compared with the original values. This implies that all four models could be applied to the textile samples for the inter-instrumental agreement. And of the four models, the R-Model showed the best performance in the inter-instrumental agreement

for the MATT tiles measured using specular component excluded mode. Since textile samples are matt in nature, the percentage improvement was higher and the results were better when compared with the other three models.

7.3 Testing Of The R-Model Using Paper Samples

As described in Chapter 3, besides textile samples, ColorCurve paper samples were also selected to test the performance of the newly developed mathematical model – the "R-Model". ColorCurve paper samples are mainly matt in nature and, to date; no results related to inter-instrumental agreement model for correction of the measurement results of the paper samples have been published.

400 ColorCurve paper samples were selected to test the performance of the "R-Model" and the results are summarized below:

Table 7.9, Inter-Instrumental Agreement In Terms Of ΔE Using GLOSSY Tiles Measured Using Specular Component Excluded Mode R-Model SF-600 Vs CE-7000A To Test The Performance Of Selected ColorCurve Paper Samples

	Original ΔE	*Corrected ΔE*	*% Improvement*
Maximum	2.026	2.211	
Minimum	0.290	0.041	
Sum	81.200	52.400	35.516
Average	0.203	0.131	35.516

Table 7.10, Inter-Instrumental Agreement In Terms Of ΔE Using GLOSSY Tiles Measured Using Specular Component Included Mode R-Model SF-600 Vs CE-7000A To Test The Performance Of Selected ColorCurve Paper Samples

	Original ΔE	*Corrected ΔE*	*% Improvement*
Maximum	1.579	1.183	
Minimum	0.565	0.500	
Sum	385.200	332.400	13.707
Average	0.963	0.831	13.707

Table 7.11, Inter-Instrumental Agreement In Terms Of ΔE Using MATT Tiles Measured Using Specular Component Excluded Mode R-Model SF-600 Vs CE-7000A To Test The Performance Of Selected ColorCurve Paper Samples

	Original ΔE	*Corrected ΔE*	*% Improvement*
Maximum	2.026	1.866	
Minimum	0.290	0.013	
Sum	81.200	31.600	61.084
Average	0.203	0.079	61.084

Table 7.12, Inter-Instrumental Agreement In Terms Of ΔE Using MATT Tiles Measured Using Specular Component Included Mode R-Model SF-600 Vs CE-7000A To Test The Performance Of Selected ColorCurve Paper Samples

	Original ΔE	*Corrected ΔE*	*% Improvement*
Maximum	1.579	0.986	
Minimum	0.565	0.201	
Sum	385.200	238.400	38.103
Average	0.963	0.596	38.103

From the above four tables (Table 7.9 to Table 7.12), which show the results for the inter-instrumental agreement of the paper samples when applied to the R-Model, it may be seen that the colour differences between the two spectrophotometers SF-600 and CE-7000A were corrected and lowered when compared with the original values. This implies that all the four models could be applied to the ColorCurve paper samples for the inter-instrumental agreement. Of the four models, the R-Model shows the best performance in the inter-instrumental agreement for the MATT tiles measured using the specular component excluded mode. This was because the ColorCurve paper samples are matt in nature, thus the percentage improvement was better when compared with the other three models.

Table 7.13, Inter-Instrumental Agreement In Terms Of ΔE Using GLOSSY Tiles Measured Using Specular Component Excluded Mode R-Model CE-2180 Vs CE-7000A To Test The Performance Of Selected ColorCurve Paper Samples

	Original ΔE	*Corrected ΔE*	*% Improvement*
Maximum	5.326	4.957	
Minimum	0.290	0.275	
Sum	239.200	173.600	27.419
Average	0.598	0.434	27.419

Table 7.14, Inter-Instrumental Agreement In Terms Of ΔE Using GLOSSY Tiles Measured Using Specular Component Included Mode R-Model CE-2180 Vs CE-7000A To Test The Performance Of Selected ColorCurve Paper Samples

	Original ΔE	*Corrected ΔE*	*% Improvement*
Maximum	4.115	3.724	
Minimum	0.520	0.500	
Sum	272.800	180.400	33.871
Average	0.682	0.451	33.871

Table 7.15, Inter-Instrumental Agreement In Terms Of ΔE Using MATT Tiles Measured Using Specular Component Excluded Mode R-Model CE-2180 Vs CE-7000A To Test The Performance Of Selected ColorCurve Paper Samples

	Original ΔE	*Corrected ΔE*	*% Improvement*
Maximum	5.326	4.627	
Minimum	0.290	0.276	
Sum	239.200	152.400	36.358
Average	0.598	0.381	36.358

Table 7.16, Inter-Instrumental Agreement In Terms Of ΔE Using MATT Tiles Measured Using Specular Component Included Mode R-Model CE-2180 Vs CE-7000A To Test The Performance Of Selected ColorCurve Paper Samples

	Original ΔE	*Corrected ΔE*	*% Improvement*
Maximum	4.115	3.724	
Minimum	0.520	0.500	
Sum	272.800	179.600	34.229
Average	0.682	0.449	34.229

From the above four tables (Table 7.13 to Table 7.16), which show the results for the inter-instrumental agreement of the paper samples when the R-Model was applied, it may be seen that the colour differences between the two spectrophotometers CE-2180 and CE-7000A were also corrected and lowered when compared with the original values. This implies that all the four models could be applied to the ColorCurve paper samples for the inter-instrumental agreement. Of the four models, the R-Model showed best performance in the inter-instrumental agreement when the MATT tiles were measured using specular component excluded mode. Since the ColorCurve paper samples are matt in nature, the percentage improvement was correspondingly better when compared with the other three models.

From the results of the textile samples and ColorCurve paper samples tested, it is evident that the MATT tiles measured using specular component included mode gave the best performance in the inter-instrumental agreement.

CHAPTER 8

COMPARISON OF THE R-MODEL WITH OTHER INTER-INSTRUMENTAL AGREEMENT MODELS

8.1 Introduction

In this chapter, the comparisons are drawn between the various mathematical models. The comparisons include MATT tiles, textile and paper samples which measured using specular component excluded mode.

8.2 Comparison Of The R-Model With Other Inter-instrumental Agreement Models Using Tiles

As discuss in Section 2.7, past research has yielded few inter-instrumental agreement models, and only two are commonly known, these being:

i). Berns and Petersen's Model

ii) Morovic's Model – Method II

The results in Chapter 6 showed that the MATT tiles measured using specular component excluded model demonstrate the best performance among the different models. The general comparison using MATT Tiles measured under specular component excluded Model among R-Model, Berns and Petersen's Model and Morovic's Model – Method II are shown as follows:

Table 8.1: Inter-instrument Agreement In Terms Of ΔE Using 12 MATT BCRA-NPL Series II Tiles Using Specular Component Excluded Mode (SF-600 vs CE-7000A)

		Luo's Model – Method II		Berns and Petersen's Model		R Model	
Tiles	Un-corrected ΔE	Corrected ΔE	% Improvement	Corrected ΔE	% Improvement	Corrected ΔE	% Improvement
Pale Grey	0.577	0.478	17.226	1.005	-40.311	0.094	83.709
Middle Grey	0.434	0.393	9.450	0. 299	31.152	0.066	84.793
Diff. Grey	0.419	0.375	10.564	0. 243	41.934	0.069	83.532
Deep Grey	0.209	0.173	17.048	0.209	0.027	0.092	55.981
Deep Pink	0.649	0.056	91.373	0.068	89.510	0.086	86.749
Red	0.711	0.115	85.251	0.138	82.288	0.067	90.577
Orange	0.909	0.022	94.669	0.049	88.262	0.076	91.639
Bright Yellow	0.716	0.092	89.185	0.111	86.988	0.242	66.201
Green	0.854	0.110	74.561	0.166	61.753	0.159	81.382
Diff. Green	0.78	0.374	58.906	0.492	45.919	0.234	70.000
Cyan	0.923	0.201	65.126	0.286	50.413	0.169	81.690
Deep Blue	0.871	0.421	40.840	0.499	29.824	0.241	72.331
Average ΔE	**0.671**	**0.314**	**54.517**	**0.347**	**47.313**	**0.133**	**79.049**

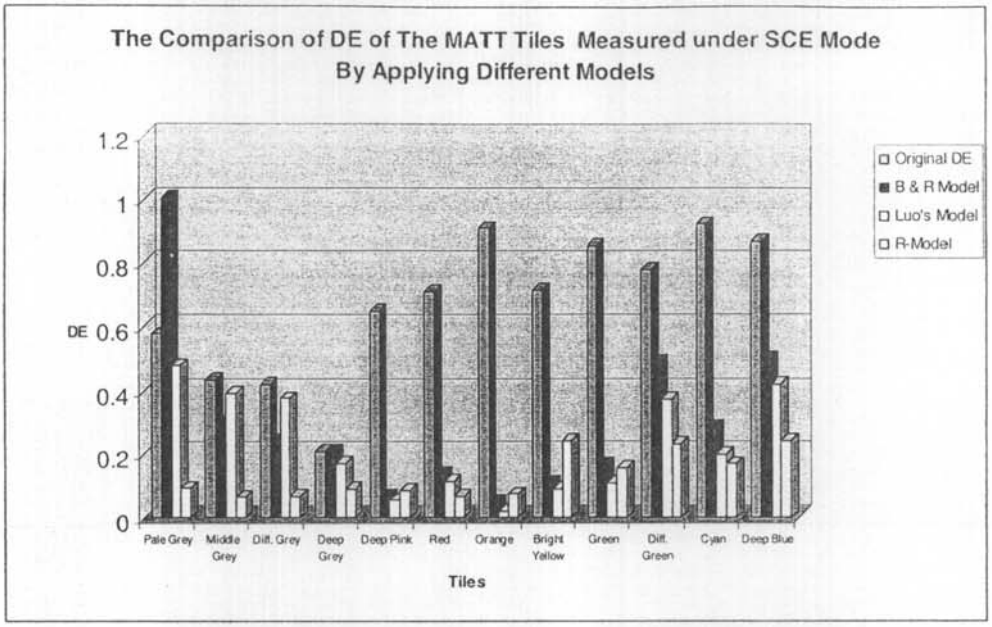


Figure 8.2 The Comparison Of The DE For MATT Tiles Measured Using Specular Component Excluded Mode

Based on the results in Table 8.1 and Figure 8.1, it may be concluded that after applying the different mathematical models to the MATT tiles, the colour difference is lowered than that of the original colour difference. R-Model shows the best performance among the three models. The overall improvement of R-Model is about 80% which is better than the rest two models.

8.3 Comparison Of The R-Model With Other Inter-Instrumental Agreement Models Using Textile Samples And Paper Samples

As discussed in section 7.2 and 7.3, the R-Model showed the best corrective performance in inter-instrumental agreement in terms of ΔE for both the textile samples and ColorCurve paper samples for the MATT tiles measured using specular component excluded mode.

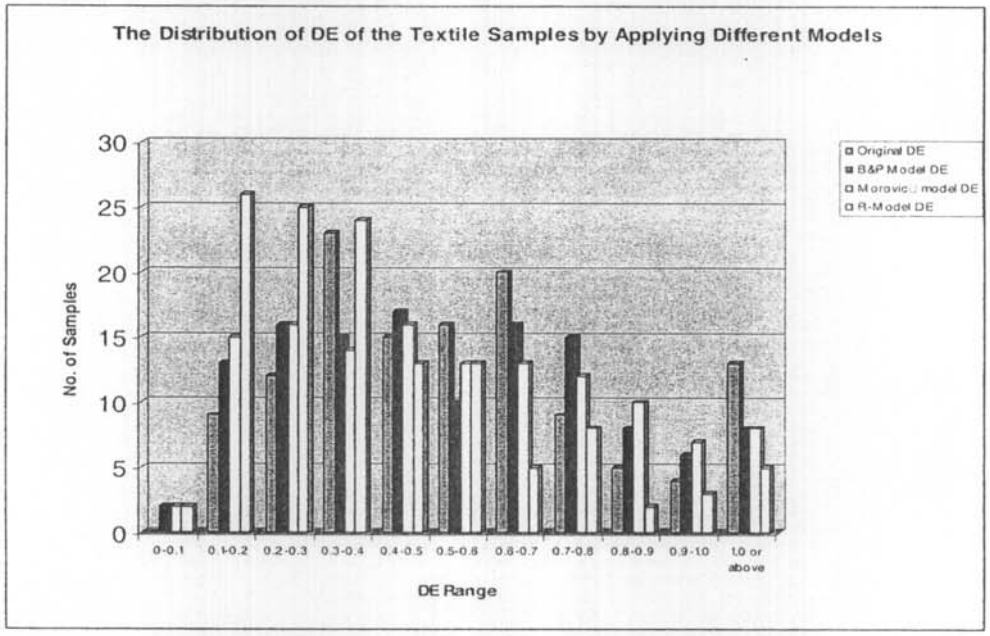


Figure 8.2 The Distribution Of The DE For The Textile Samples By Applying To Different Models Using Matt Tiles Measured Using Specular Component Excluded Mode

Table 8.2 The Distribution Of The DE For The Textile Samples By Applying To Different Models Using Matt Tiles Measured Using Specular Component Excluded Mode

ΔE Range	Original ΔE	B&P Model ΔE	Morovic's model ΔE	R-Model ΔE
0-0.1	0	2	2	2
0.1-0.2	9	13	15	26
0.2-0.3	12	16	16	25
0.3-0.4	23	15	14	24
0.4-0.5	15	17	16	13
0.5-0.6	16	10	13	13
0.6-0.7	20	16	13	5
0.7-0.8	9	15	12	8
0.8-0.9	5	8	10	2
0.9-1.0	4	6	7	3
1.0 or above	13	8	8	5

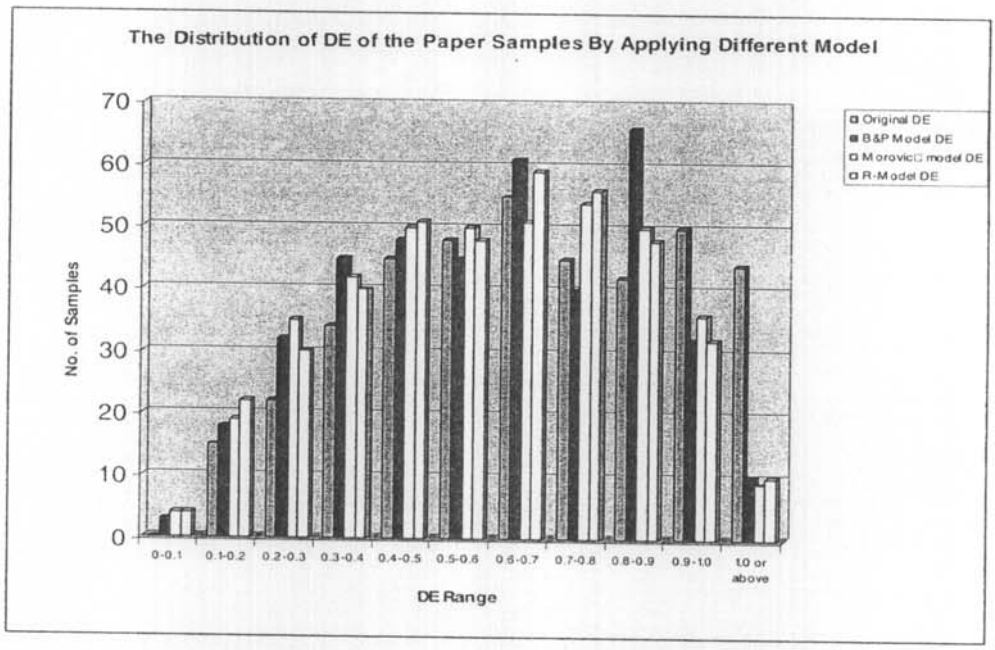


Figure 8.3 The Distribution Of The DE For The Paper Samples By Applying To Different Models Using Matt Tiles Measured Using Specular Component Excluded Mode

Table 8.3 The Distribution Of The DE For The Paper Samples By Applying To Different Models Using Matt Tiles Measured Using Specular Component Excluded Mode

ΔE Range	Original ΔE	B&P Model ΔE	Morovic's model ΔE	R-Model ΔE
0-0.1	0	3	4	4
0.1-0.2	15	18	19	22
0.2-0.3	22	32	35	30
0.3-0.4	34	45	42	40
0.4-0.5	45	48	50	51
0.5-0.6	48	45	50	48
0.6-0.7	55	61	51	59
0.7-0.8	45	40	54	56
0.8-0.9	42	66	50	48
0.9-1.0	50	32	36	32
1.0 or above	44	10	9	10

From Figure 8.2 and Table 8.2, it may be seen that the colour difference value ΔE shifted to the left hand side, i.e. the lower colour difference range, when the mathematical models were applied. When the performance of the three models was compared, it was found that the "R-Model" was better than the other two inter-instrumental mathematical models.

Figure 8.3 and Table 8.3 also indicates that the colour difference value ΔE shifted to the left hand side, i.e., the lower colour difference range, when the mathematical models were applied. Of the three models, the "R-Model" showed the best performance in this case.

8.4 Conclusion

In this chapter, the test results and the performance of the "R-Model" were described. Basically, the "R-Model" was demonstrated to be effective in the experimental work on inter-instrumental agreement across a range of samples including tiles, textile samples and Colorcurve paper samples correlations. The concept of the "R-Model" was based on bandpass error correction. In 1987, E.I. Stearns proposed the influence of spectral bandpass on the accuracy of tristimulus values. The fundamental premise of the "R-Model" is based on Stearns' concept but the coefficients of Stearns' correction model were fixed whereas the "R-Model" has flexible coefficients in order to fit different materials calculation. For this reason, the performance of the "R-Model" was better than that of the other, earlier models.

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

9.1 Introduction

In this chapter conclusions are drawn about the significance of the research project and suggestions are made for future research and development activities.

9.2 Conclusions Of The Research Issue.

In general, spectrophotometers perform at a finite level of accuracy but as electron-mechanical-optical devices, they exhibit measurement errors relative to a theoretically error-free instrument that users must accept. If such measurement errors can be quantified and corrected, the accuracy of measurement and the inter-instrumental agreement can be further enhanced. Thus colouring by numbers can be successfully

used in digital colour communication.

At the outset of the research, it was found that the inter-instrumental agreement of the three selected spectrophotometers was unsatisfactory because the average colour difference was larger than 0.5 ΔE^*_{ab} units. The results imply that the origin of the errors and also the options for improvement should be investigated; hence the mathematical models for the inter-instrumental agreement, which should be applied in order to improve the inter-instrumental agreement. Once the inter-instrumental agreement of the spectrophotometers has been improved, the inter-instrumental agreement and non-physical sample colour communication can be further enchanced.

After the application of the "L-Model", the colour measurement results improved but the results were not significant. Nevertheless this mathematical model gave a very good indication that mathematical correction was a good method to control the colour measurement results.

The L-Model represented a first stage in the development of the successful model for the inter-instrumental agreement. According to the concept of bandpass correction and

using the multi linear regression method, a powerful and robust mathematical model, this being termed the R-Model, was developed.

The R-Model was based on the concept of the correction of the bandpass error. When applied to the experimental results, it performed well in the inter-instrumental agreement case, the average percentage improvement having been approximately 90%, which is better than the other well developed models when tested with the CCS-II tiles.

In general, when the R-Model was used to test textile samples, the colour measurements also showed an improvement when compared with the other well known mathematical models. Such an improvement of the colour measurement in the spectral data will lead to improvements in the global colour communication between designers, coloration companies and buyers.

In the study of the inter-instrumental agreement, the variation of the colour measurements was very high, from 0.575 to 0.854 CIELAB ΔE units when using different spectrophotometers. Because of this poor inter-instrumental agreement, different mathematical models were developed to improve the results. An empirical

model, named the "L-Model" was developed to improve the inter-instrumental agreement between spectrophotometers up to 62% based on the ceramic tile results. In addition, the "R-Model" was also developed, based on the analysis of spectral data from 400 – 700 nm and the concept of bandpass correction using the multi linear regression method. The performance of the "R-Model" was better than that of the "L-Model" and also some of the previously developed mathematical models. The improvement of the inter-instrumental agreement was found to be as high as 90% for the ceramic tiles. When the models are applied to the measurement of the coloured samples, the inter-instrumental agreement can be improved accordingly. The inter-instrumental agreement in spectral data should benefit the global colour communication between designers, coloration companies and buyers, and also improve non-physical sample communication.

9.3 Recommendations

The following recommendations are made for further study.

9.3.1 Calibration Sample

Besides the CCS-II tiles, other standard materials, such as paper samples or textile samples, can be used for calibration purposes, thus the coverage of the colour range will be more than only twelve tiles.

9.3.2 Quantifying Measurement Error for Hardware

The accuracy of the measurements achieved using spectrophotometers was affected by many different factors, such as sample preparation, bandpass error, photometric error, photometric zero error etc. In this project, the instrument profile was quantified, but for other errors, further quantification is required as they are very important in colour measurement. The design of the spectrophotometers was also one of the important parameters affecting the colour measurement result. It also requires quantification in order to find out the causes of the measurement errors.

9.3.3 Other Mathematical Models

In addition to the multi-linear regression method, there are many other different mathematical methods, such as simple and multi non-linear regression methods which can be used to develop new mathematical models. If a simple yet powerful mathematical method can be used, the inter-instrumental agreement for colour communication will be further enhanced in addition to the global colour communication among the designers, merchandisers and buyers.

REFERENCE

1. A. R. Robertson, The CIE 1976 Color Difference Formulae, Color Research and Application, Vol. 2, P. 7 – 11, Spring 1977
2. A.R. Robertson, Diagnostic Performance Evaluation of Spectrophotometers, Advances in Standaeds and Methodology in Spectrophotometry, P.277-286, 1987
3. Absolute Measurement of Reflectance, A New Precise Technique, Color Engineering, P. 38-39
4. Adams, E.Q. X-Z Planes in the 1931 ICI system of Colorimetery, J. of Opt. Soc. Am. 32: P. 168-178, 1942
5. Anni Berger-Schunn, Practical Color Measurement, John Wiley & Sons, Inc, 1994
6. ASTM E 925 – 83 (Reapproved 1994), Standard Practice for the Periodic Calibration of Narrow Band-Pass spectrophotometers.
7. ASTM Standards on Color and Appearance, 1996
8. Berns R et al, An Abridged Technique to Diagnose Spectrophotometric Errors, Color Research and Application, Vol. 22, No. 1, P.51-60, Feb. 1997
9. Berns R et al, Empirical Modelling of Systematic Spectrophotometric Errors, Color Research and Application, Vol. 13, No. 4, P.243-256, Aug. 1988
10. Brill, M.H. Suggested Modification of CMC Formula for Acceptability, Col. Res. Appl. 17: P. 402-404, 1992
11. British standard method for calculation of small color difference, BS 6923: 1988.
12. Burnham, R.W. A colorimeter for research in color vision, Am.J. Physiol. 65: P. 603, 1952
13. C. Burgess and K. D. Mielenz, Advances in Standards and Methodology in Spectrophotometry, Analytical Spectroscopy Library, 1987
14. Ceramic Colour Stadnards, British Ceramic Research Associatin Ltd.
15. Ceramic Colour Standards Series II, British Ceramic Research Associatin Ltd.
16. Chamberlin, G.J. and Chamberlin, G.J Color, its measurement, computation and application, Heyen, London, 1980
17. Chong T.F., Instrumental Measurement and Control of Colour, Review of Progress of Coloration, Vol. 18, P. 47-55, 1988
18. CIE Publishion No 15,2 (TC-1.3), Colorimetry, Offical Recommendation, International Commission on Illumination, Wien 3. Bezirk, Kegelgass 27/1, Austria, 1986, 2nd ed.
19. Clarke, F.J.J., MacDonald, R. and Rigg, B. (1984). Modification to the JPC79 Formula, J. Soc. Dyers Col. 100: P. 128-132, 1978

20. Colour at the Centre of Everything, International Dyer, P. 9-14, Jan 1997
21. Connolly C et al, Colour Measurement by Video Camera, Journal of the Society of Dyers and Colourists, Vol. 111, P. 373-375, Dec. 1995
22. Connolly C et al, The Use of Video Camera for Remote Colour Measurement, Journal of the Society of Dyers and Colourists, Vol. 112, P. 40-43, Feb. 1996
23. D. C. Rich et al, Evaluation of the Long –Term Repeatability of Reflectance Spectrophotometers, Spectrophotometry, Luminesence and Colour, P.137-153, 1995
24. D. C. Rich, Colorimetric Repeatability and Reproducibility of CHROMA-SENSOR Spectrocolorimeters, Die Farbe 37, P.247-261, 1990
25. D. C. Rich, The Chroma Sensor CS-5: A Tradition of Improved Performance, Color Research and Application, Vol. 16, No. 5, P.322-336, Oct 1991
26. D. Scott Reininger, Recent Developments in Portable Color Measurement Instruments and Applications in the Textile Industry, AATCC 1994 International Conference and Exhibition Book of Papers, P. 273 – 280
27. D. Scott Reininger, Textile Application for Hand-Held Color Measuring Instruments, Textile Chemists and Colorists, Vol. 29, No. 2, P. 13 – 17, February 1997
28. Dan Randall, Instruments for the Measurement of Color, Textile Chemist and Colorist, Vol. 30, No. 2, P. 20 – 26, February 1998
29. Datacolor International, Spectraflash® 600 PLUS Operators Manual, April 1997
30. Development of Standards for Inter-instrument Calibration of spectrophotometer in Computer Colour Systems, Colourage, P. 29 – 34, December 1995
31. Donaldson, R. A colorimeter with six matching stimuli, Proc. Phys. Soc. (London) 59: P. 554, 1947
32. Donaldson, R. A trichromatic colorimeter, Proc. Phys. Soc. (London) 47: P.1068, 1927
33. E. I. Stearns and R. E. Stearns, An Example of a Method for Correcting Radiance Data for Bandpass Error, Vol. 13, No. 4, P. 257 – 259, August 1988
34. E. I. Stearns, Influence of spectrophotometer Slits on Tristimulus Calculation, Color Research and Application, Vol. 6, No. 2, P. 78 – 84, Summer 1981
35. E. I. Stearns, The Influence of Spectral Bandpass on Accuracy of Tristimulus Data, Color Research and Application, Vol. 12, No. 5, P. 282 – 284, October, 1997
36. Ellen C. Carter et al, Material Standards and Their Use in Color Measurement, Color Research and Application, Vol. 4, No. 2, P.97-100, Summer 1979
37. F. J. J. Clarke and P.S. Samways, The Spectrophotometric Properties of a Selection of Ceramic Tiles, National Physical Laboratory Report MC2, August

1968

38. F. J. J. Clarke et al, Development of a New Series of Ceramic Colour Standards, Journal of the Society of Dyers and Colourists, Vol. 97, P.503-504, Dec. 1981
39. F. J. J. Clarke, Problem of Spectrofluorimetric Standards for Reflection and Colorimetric Use, National Physical Laboratory Report MOM 12, August 1968
40. F. W. Billmeyer, Jr et al, Assessment of Color-Measuring Instruments, Color Research and Application, Vol. 6, No. 4, Winter 1981
41. F. W. Billmeyer, Jr et al, Instrumentation for Colour Measurement and its Performance, Golden Jubilee of Colour in the CIE, The Society of Dyers and Colourists, Bradford, England, 1981, P.98-112
42. F. W. Billmeyer, Jr. and H. Hemmendinger, Instrumentation for Color Measurement and its Performance, Golden Jubillee of Colour in the CIE, P. 98 – 112, 1981
43. Fairchild, M.D. and Pirrota, E. Predicting the Lightness of Chromatic Object Colors using CIELAB, Col. Res. Appl. 16: P. 385-392, 1991
44. Fenn R et al, The Use of Non-physical Standards in Colour Communication and Matching, Journal of the Society of Dyers and Colourists, Vol. 113, P.56-58, Feb. 1997
45. Fred W. Billmeyer, Jr. and Assessment of Color-Measuring Instruments, Colour Research and application, Vol. 6, No. 4, P. 195 – 202, Winter 1981
46. Fred W. Billmeyer, Jr., An Objective Approach to Coloring, Color Engineering, P. 10 – 13, September, 1963
47. Fred W. Billmeyer, Jr., The Precision of Spectrophotometry As Practiced in Industry, Color Engineering, Vol. 3 No. 4, P. 16 – 20, July – august, 1965
48. Fred W. Billmeyer, Jr., The Present and Future of Industrial Color Measurement, Color Engineering, Vol. 4, No. 4,P. 14 – 18, July – August 1996
49. Guild J. A trichromatic colorimeter suitable for standardization work, Trans. Opt. Soc. (London) 27: P. 106, 1925
50. H. P. Lee et al, Calibrating Spectrophotometers Using Neural Networks, SPIE Vol. 3300, P. 274-282, 1998
51. H. S. Shan and R. S. Gandhi, Instrumental Colour Measurement and Computer Aided Colour Matching for Textiles, Mahajan BookDistributors, 1990
52. Henry Hemmendinger, Colorimetric Information and Colorimetric Errors, Color Technology in the Textile Industry. P. 2 – 23
53. Hugh R. Davidson and Henry Hemmendinger, Specification and Control of Color, Color Engineering, P. 15 – 28, April, 1963
54. Hugh S. Fairman and Henry Hemmendinger, Stability of Ceramic Color Reflectance standards, Color Research and Application, Vol. 23, No. 6, P. 408 –

415, December 1998

55. Isadore Nimeroff, The Variability of Color Measurement, Color Engineering, P. 24 –44, March – April, 1967
56. J. Anne Compton, The Thermochromic Properties of the Ceramic Colour Standards, Color Research and Application, Vol. 9, No. 1, P.15-22, Spring 1984
57. James R. Vasconcellos, Supply Chain Management of Color and appearance: Evolution vs. Revolution, AATCC Review P. 14 – 37, June, 2001
58. James Rodgers et al, A Comparative Study of Color Measurement Intstrumentation, Color Research and Application, Vol. 19, No. 5, Oct 1994
59. James T. DeGroff, Developments In Color Instrument Design Utilizing LED Technology For Textile Applications, AATCC 1995 International Conference and Exhibition Book of Papers, P. 477 – 481
60. Joanne C. Zwinkels, Colour-measuring Instruments and Their Calibration, Display, Vol, 16, No. 4, P. 163 – 171, 1996
61. Joanne C. Zwinkels, Errors in Colorimetry Caused by the Measuring Instrument, Textile chemist and Colorist, Vol. 21, No. 2, P. 23 – 29, February 1989
62. Konrad Hoffmann, Chromatic Integrating-Sphere Error In Tristimulus Colorimeters, Journal of Color & Appearance, Vol. 1, No.2, P. 16 – 41, September/ October 1971
63. L. Reniff, Transferring the 45/0 Spectral Reflectance Factor Scale, Color Research and Application, Vol. 19, No. 5, P.332-340, Oct 1994
64. Lee, R.L. Jr., Col. Res. Appl., 13: P. 180-186, 1988
65. Lovibond, J.W. The tintometer, a new instrument ...measurement of color, J. Soc. Dyers Col. III (2) 26 Dec, 1887
66. Lueo, M.R. and Rigg, B. Uniform color space based on the CMC (l:c) color-difference formula, J. Soc. Dyers Col. 102: 164-171, 1996
67. Luo, M.R. and Rigg, B. BFD (l:c) Color Difference Formula, Part 1.J.Soc. Dyer Col., 103: P. 86-94, 1987
68. M. D. Fairchild et al, Thermochromism of Ceramic Reference Tiles, Applied Optics, Vol. 24, No. 21, P.3432-3433, Nov. 1985
69. MacAdam, D.L. Loci of constant hue and brightness determined with various surrounding colors, J. Opt. Soc. Am. 40: P. 589, 1950
70. Macbeth® COLOR-EYE® 2180 Spectrophotometer Operation Manual, February 1996
71. Macbeth® COLOR-EYE® 7000A Spectrophotometer Operation Manual, October 1996
72. MacDonal, R. Industrial pass/fail Color Matching Part II., J. Soc. Dyers. Col. 96: P. 418-433, 1980

73. MacDonald, R. and Smith, K.J. CIE94-a new color difference formula, J. Soc. Dyer Col., 111: P. 376-379, 1995
74. MacDonald, R. Industrial Pass/ Fail Color Matching Part I., J. Soc. Dyers. Col. 96: P. 372-376, 1980
75. Malkin F. et al, The BCRA-NPL Ceramic Colour Standards, Series II – Master Spectral Reflectance and Thermochromism Data, Journal of the Society of Dyers and Colourists, Vol. 113, P.84-94, Mar. 1997
76. McDonald, R. Industrial pass/fail color matching, part III. Development of a pass/fail formula for use with instrumental measurement of color difference, J.Soc.Dyers.Col., 96: P. 486-46, 1980
77. McLaren, K. In: "AIC Color 77", Bristol: Adam-Hilger, 503 pp.
78. Nayatani, Y., Umemura, Y., Sobagachi, H., Takahama, K. and Hashimoto, K. Lightness Perception of Chromatic Object Colors, Col. Res. Appl. 16: P. 16-25, 1991
79. Norusis M. J., SPSS Advanced Statistics™ 6.1, SPSS Inc. – Chicago, 1994
80. Norusis M. J., SPSS® for Windows™ Base system User's Guide Release 6.0, SPSS Inc. – Chicago, 1993
81. Norusis M. J., The SPSS Guide to Data Analysis for SPSS / PC+TM, Second Edition, SPSS Inc. – Chicago, 1991
82. NPL (National Physical Laboratory), Optical Radiation Measurement Newsletter, issue 1. Spring, 1996
83. Oglesby, S. The effectiveness of CIE94- compared with CMC equation, J. Soc. Dyer Col., 111: P. 380-382, 1995
84. P. Morovic, H. Xu and M. R. Luo, Inter-Comparison of Colour Measuring Instruments
85. Patrick T. F. Chong, Colorimetry for Textile Applications, Modern Textile Characterisation Methods, P. 355 391, 1996
86. Patrick T. F. Chong, Reproducibility of Color Difference Measurements On Textile Samples, AATCC 1993 International Conference and Exhibition Book of Papers, P. 323 – 332
87. Proceedings of the Eighth Session (Cambridge, English, 1931), International Commission on Illumination, Wien 3. Bezirk, Kegelgass 27/1, Austria
88. R. Seve, New Formula for the computation of CIE 1976 Hue Difference, Colour Research and Application, Vol. 16, P. 217 – 218, June, 1991
89. R. W. G. Hunt, Measuring Colour (2nd Edition), Ellis Horwood Limited, 1991
90. Randall D, Instruments for the Measuring of Color, Textile Chemist and Colorist, Vol. 30, No. 2, P.20-26, Feb. 1998
91. Reining D.S., Textile Applicatins fr Hand-Held Colour Measuring Instruments,

Textile Chemist and Colorist, Vol. 29, No.2, P. 13-17, Feb. 1997

92. Robert T. Marcus and Fred W. Billmeyer, Jr., Statistical Study of Color-Measurement Instrucmentation, Applied Optics, Vol. 13, No.6, P. 1519 – 1531, June 1974
93. Robert T. Marcus, Long-Term Repeatability of Color-Measuring Instrumentation: Storing Numerical Standards, Color Research and Application, Vol. 3, No. 1, spring 1978
94. Robert Willis, Instrumentation for Color Measurement, AATCC Workshop, Color Measurement Principles and the Textile Industry, 1988
95. Roderick McDonald, Color Communication in the 90s, AATCC 1991 International Conference and Exhibition Book of Papers, P. 148 – 152
96. Roderick McDonald, Colour Physics for Industry (2nd Edition), Society of Dyers and Colourists, 1997
97. Roderick McDonald, Colour Physics for Industry, Society of Dyers and Colourists, 1987
98. Roland Derby, Studies of Illuminating and Viewing Conditions in Colorimetry of Reflecting Materials, Color Engineering, P. 14 – 23
99. Ruth Johnston, Analysis and Description of Color With Spectrophotometry, Color Engineering, Vol. 3, No. 3, P. 12-18, May – June 1965
100. Ruth M. Johnston and Robert P. Ericson, Control of Color Standards, Color Engineering, Vol. 2, No. 11 – 12, P. 10 – 23, November – December 1964
101. Ruth M. Johnston, and et. al., Preparation and Use of Stable Secondary Standards for Colorimetry, Color Engineering, Vol. 6 No. 2, P. 34 – 38, March – April, 1968
102. Ruth M. Johnston, Color Measuring Instruments: A Guide To Their Selection, Journal of Color and Appearance, Vol. 1 No. 2, P. 27 – 38, September/ October, 1971
103. Seve, R. New Formula for Computation of CIE 1976 Hue Difference, Col. Res. Appl. 16: P. 217-218, 1991
104. Stroke, M. and Brill, M.H. Col. Res. Appl. 17: P. 410-411, 1992
105. Verill, JF and et al., New Methods of Disgonsing Errors in Colour Measuring Instruments, Die Fabre, Vol. 39, P. 285 – 295, 1993
106. Verrill F. J. et al, European Project on Intercomparison of Colour Measurement, EUR14982EN, 1993
107. Verrill F. J. et al, Intercomparison of Colour Measurements, NPL Spectrophotometry and Colorimetry Club, NPL Report QU 113, 1995
108. Witt, K. Col. Res. Appl., 19: (1994), P. 273, 1994
109. Wright, W.D. A trichromatic colorimeter with spectral stimuli, Trans. Opt. Soc. (London) 29: P. 225, 1927

110. Wyszecki, G. Matching color differences, J. Opt. Soc. Am. 55: P. 1319-1324, 1965

111. Wyszecki, G. Reanalysis of the NRC field trial of color-matching functions, J. Opt. Soc. Am. 54: P. 710-714, 1964

APPENDIX I:
The Coefficient m, n, o and q used in R-Model.

Table 1: The coefficient m, n, o, and q for the EQ. 6.1, 6.2 and 6.3 of the CCS-II GLOSSY Tiles under the condition of Specular Component Excluded SF-600 vs CE-7000A

Wavelength	m	n	o	q
400	0.000	1.117	-0.951	-0.097
410	-0.058	1.198	-0.111	-0.064
420	0.000	1.125	-0.095	-0.098
430	0.000	1.164	-0.136	-0.046
440	0.000	1.145	-0.118	-0.041
450	0.000	1.131	-0.106	-0.033
460	0.000	1.121	-0.097	-0.023
470	0.000	1.127	-0.105	-0.008
480	0.000	0.944	0.080	-0.040
490	0.086	1.017	-0.079	-0.041
500	0.089	1.000	-0.065	0.035
510	0.052	1.043	-0.070	-0.043
520	0.067	1.008	-0.053	-0.029
530	0.068	0.990	-0.037	-0.027
540	0.097	0.954	-0.033	-0.016
550	0.106	0.951	-0.040	-0.011
560	0.000	0.913	0.106	-0.034
570	0.000	0.937	0.081	-0.018
580	0.000	1.141	-0.126	0.057
590	0.047	1.044	-0.075	0.030
600	0.000	1.187	-0.017	0.069
610	0.198	0.819	0.000	0.036
620	0.146	0.872	0.000	0.028
630	0.014	0.877	0.000	0.013
640	0.136	0.880	0.000	0.006
650	0.116	0.910	0.000	0.022
660	0.093	0.925	0.000	-0.001
670	0.000	1.016	0.000	-0.047
680	0.000	1.014	0.000	-0.046
690	0.263	0.747	0.000	0.046
700	0.483	0.000	0.520	0.244

Table 2: The coefficient m, n, o, and q for the EQ. 6.1, 6.2 and 6.3 of the CCS-II GLOSSY Tiles under the condition of Specular Component Included SF-600 vs CE-7000A

Wavelength	m	n	o	q
400	0.000	1.072	-0.060	-0.028
410	-0.081	1.224	-0.125	-0.040
420	0.569	0.000	0.453	-0.039
430	0.575	0.000	0.448	-0.075
440	0.576	0.000	0.445	-0.142
450	0.598	0.000	0.424	-0.221
460	-0.016	1.143	-0.112	-0.030
470	0.000	1.122	-0.107	-0.031
480	-0.060	1.076	0.000	-0.060
490	0.086	1.013	-0.083	-0.074
500	0.092	0.993	-0.068	-0.096
510	0.049	1.043	-0.077	-0.078
520	0.069	1.001	-0.055	-0.071
530	0.064	0.994	-0.046	-0.074
540	0.090	0.960	-0.038	-0.064
550	0.106	0.949	-0.043	-0.067
560	0.000	0.111	0.901	-0.071
570	0.055	1.006	-0.051	-0.052
580	0.058	1.023	-0.069	-0.040
590	0.067	0.999	-0.057	-0.014
600	0.000	1.176	-0.167	-0.029
610	0.201	0.810	0.000	-0.032
620	0.149	0.862	0.000	-0.024
630	0.143	0.867	0.000	-0.024
640	0.143	0.866	0.000	-0.035
650	0.119	0.891	0.000	-0.024
660	0.091	0.919	0.000	-0.041
670	0.000	1.009	0.000	-0.067
680	0.000	1.007	0.000	-0.073
690	0.241	0.763	0.000	0.009
700	0.050	0.500	0.000	0.249

Table 3: The coefficient m, n, o, and q for the EQ. 6.1, 6.2 and 6.3 of the CCS-II MATT Tiles under the condition of Specular Component Excluded SF-600 vs CE-7000A

Wavelength	m	n	o	q
400	0.000	1.132	-0.111	-0.210
410	0.000	1.108	-0.080	-0.207
420	0.000	1.124	-0.097	-0.195
430	0.157	0.870	0.000	-0.164
440	0.142	0.883	0.000	-0.146
450	0.140	0.883	0.000	-0.161
460	0.124	0.899	0.000	-0.155
470	0.144	0.878	0.000	-0.154
480	0.071	0.095	0.000	-0.158
490	0.065	1.046	-0.091	-0.119
500	0.069	1.037	-0.085	-0.141
510	0.041	1.064	-0.085	-0.129
520	0.070	1.010	-0.060	-0.126
530	0.076	0.987	-0.044	-0.124
540	0.092	0.970	-0.046	-0.088
550	0.168	0.847	0.000	-0.124
560	0.113	0.902	0.000	-0.084
570	0.107	0.907	0.000	-0.069
580	0.125	0.888	0.000	-0.060
590	0.140	0.874	0.000	-0.053
600	0.188	0.825	0.000	-0.028
610	0.143	0.869	0.000	0.018
620	0.130	0.882	0.000	0.017
630	0.109	0.903	0.000	-0.006
640	0.094	0.917	0.000	-0.009
650	0.091	0.920	0.000	-0.004
660	0.000	1.095	-0.083	-0.004
670	0.000	1.011	0.000	-0.045
680	0.000	1.009	0.000	-0.009
690	0.000	1.007	0.000	-0.183
700	0.510	0.499	0.000	0.340

Table 4: The coefficient m, n, o, and q for the EQ. 6.1, 6.2 and 6.3 of the CCS-II MATT Tiles under the condition of Specular Component Included SF-600 vs CE-7000A

Wavelength	m	n	o	q
400	0.000	1.116	-0.105	-0.136
410	0.000	1.090	-0.073	-0.164
420	0.000	1.124	-0.106	-0.183
430	0.159	0.858	0.000	-0.162
440	0.145	0.871	0.000	-0.160
450	0.136	0.877	0.000	-0.161
460	0.116	0.896	0.000	-0.136
470	0.151	0.863	0.000	-0.167
480	0.085	0.931	0.000	-0.167
490	0.100	0.975	-0.063	-0.145
500	0.093	0.984	-0.063	-0.151
510	0.057	1.206	-0.071	-0.129
520	0.000	0.895	0.119	-0.125
530	0.107	0.904	0.000	-0.164
540	0.072	0.991	-0.054	-0.126
550	0.063	1.028	-0.083	-0.097
560	0.000	1.126	0.118	-0.078
570	0.104	0.905	0.000	-0.122
580	0.083	0.983	-0.056	-0.100
590	0.075	0.990	0.057	-0.058
600	0.139	0.911	-0.043	-0.049
610	0.016	0.850	0.000	-0.041
620	0.000	0.864	0.145	-0.060
630	0.000	0.885	0.121	-0.037
640	0.121	0.884	0.000	-0.046
650	0.107	0.899	0.000	-0.036
660	0.085	0.920	0.000	-0.040
670	0.060	0.940	0.000	-0.057
680	0.000	1.004	0.000	-0.044
690	0.241	0.760	0.000	0.040
700	0.482	0.512	0.000	0.304

Table 5: The coefficient m, n, o, and q for the EQ. 6.1, 6.2 and 6.3 of the CCS-II GLOSSY Tiles under the condition of Specular Component Excluded CE-2180 vs CE-7000A

Wavelength	m	n	o	q
400	0.000	0.907	0.0862	-0.0108
410	0.000	0.920	0.07505	-0.104
420	0.000	0.913	0.0886	-0.0614
430	0.000	0.906	0.09773	-0.120
440	-0.102	1.104	0.000	-0.0825
450	-0.0918	1.094	0.000	-0.0601
460	-0.100	1.104	0.000	-0.0422
470	-0.117	1.122	0.000	-0.0418
480	-0.0968	1.102	0.000	-0.0488
490	-0.127	1.135	0.000	-0.0293
500	-0.110	1.111	0.000	-0.0374
510	-0.0979	1.101	0.000	-0.0214
520	-0.087	1.090	0.000	-0.0822
530	-0.0486	1.057	0.000	-0.0651
540	-0.0557	1.064	0.000	-0.0952
550	-0.0695	1.075	0.000	-0.0809
560	0.000	0.997	0.02991	-0.136
570	0.000	0.973	0.03471	-0.105
580	0.000	0.945	0.06327	-0.167
590	-0.074	1.081	0.000	-0.155
600	-0.116	1.122	0.000	-0.0733
610	-0.0723	1.080	0.000	-0.146
620	-0.0685	1.077	0.000	-0.134
630	-0.107	1.114	0.000	-0.118
640	-0.131	1.140	0.000	-0.246
650	-0.144	1.155	0.000	-0.0609
660	-0.128	1.140	0.000	-0.279
670	0.000	0.786	0.227	-0.268
680	0.000	0.769	0.247	-0.335
690	-0.359	1.380	0.000	-0.410
700	0.000	1.023	0.000	-0.321

Table 6: The coefficient m, n, o, and q for the EQ. 6.1, 6.2 and 6.3 of the CCS-II GLOSSY Tiles under the condition of Specular Component Included CE-2180 vs CE-7000A

Wavelength	m	n	o	q
400	0.000	0.957	0.0484	-0.111
410	-0.0558	1.065	0.000	-0.116
420	-0.0779	1.078	0.000	-0.0527
430	-0.0988	1.107	0.000	-0.0833
440	-0.101	1.107	0.000	-0.0922
450	-0.0828	1.091	0.000	-0.0684
460	-0.104	1.107	0.000	-0.0441
470	0.000	0.917	0.08891	-0.133
480	-0.105	1.109	0.000	-0.0408
490	-0.144	1.147	0.000	-0.0133
500	-0.131	1.143	0.000	-0.135
510	-0.116	1.126	0.000	-0.160
520	-0.0981	1.107	0.000	-0.155
530	-0.0546	1.059	0.000	-0.0285
540	-0.0675	1.075	0.000	-0.121
550	-0.0987	1.109	0.000	-0.058
560	-0.0566	1.069	0.000	-0.221
570	0.000	0.933	0.07939	-0.234
580	-0.0707	1.083	0.000	-0.209
590	-0.102	1.112	0.000	-0.165
600	-0.139	1.151	0.000	-0.195
610	0.000	0.901	0.111	-0.205
620	-0.102	1.112	0.000	-0.173
630	-0.135	1.143	0.000	-0.121
640	0.000	0.828	0.186	-0.245
650	-0.165	1.175	0.000	-0.179
660	-0.161	1.176	0.000	-0.303
670	-0.225	1.240	0.000	-0.286
680	-0.221	1.237	0.000	-0.304
690	-0.274	1.283	0.000	-0.337
700	0.000	1.021	0.000	-0.141

Table 7: The coefficient m, n, o, and q for the EQ. 6.1, 6.2 and 6.3 of the CCS-II MATT Tiles under the condition of Specular Component Excluded CE-2180 vs CE-7000A

Wavelength	m	n	o	q
400	0.000	0.933	0.07099	0.187
410	-0.0913	1.095	0.000	0.01656
420	-0.0855	1.093	0.000	0.104
430	-0.104	1.115	0.000	0.03505
440	-0.112	1.122	0.000	0.04694
450	-0.109	1.116	0.000	0.169
460	-0.118	1.128	0.000	0.137
470	-0.120	1.131	0.000	0.128
480	-0.0888	1.102	0.000	0.134
490	-0.130	1.144	0.000	0.138
500	-0.119	1.129	0.000	0.141
510	-0.104	1.115	0.000	0.199
520	-0.0849	1.096	0.000	0.118
530	-0.0583	1.075	0.000	0.140
540	-0.0654	1.082	0.000	0.09268
550	-0.0678	1.082	0.000	0.03527
560	-0.0488	1.063	0.000	0.04185
570	-0.043	1.058	0.000	0.0393
580	-0.0604	1.075	0.000	0.009935
590	-0.0691	1.084	0.000	0.002368
600	-0.112	1.127	0.000	0.0972
610	-0.0556	1.069	0.000	0.159
620	0.000	0.975	0.04183	0.05131
630	0.000	0.947	0.06727	0.101
640	0.000	0.910	0.107	0.01904
650	0.000	0.882	0.134	0.131
660	0.000	1.020	0.000	-0.0042
670	0.000	1.020	0.000	-0.0565
680	0.000	1.022	0.000	-0.00453
690	0.000	0.828	0.197	-0.217
700	-0.311	1.341	0.000	-0.437

Table 8: The coefficient m, n, o, and q for the EQ. 6.1, 6.2 and 6.3 of the CCS-II MATT Tiles under the condition of Specular Component Included CE-2180 vs CE-7000A

Wavelength	m	n	o	q
400	0.000	0.943	0.06714	0.0027
410	-0.0898	1.101	0.000	0.05033
420	-0.0801	1.084	0.000	0.133
430	-0.089	1.102	0.000	0.04999
440	-0.0989	1.109	0.000	0.05568
450	-0.0902	1.104	0.000	0.09046
460	-0.0997	1.110	0.000	0.09568
470	-0.132	1.144	0.000	0.105
480	-0.104	1.111	0.000	0.187
490	-0.130	1.136	0.000	0.194
500	-0.123	1.141	0.000	0.07708
510	-0.112	1.130	0.000	0.04547
520	-0.0992	1.114	0.000	0.05354
530	-0.0596	1.068	0.000	0.115
540	-0.0625	1.075	0.000	0.110
550	0.000	0.953	0.06575	0.02639
560	-0.0647	1.081	0.000	-0.0126
570	-0.0573	1.073	0.000	0.01328
580	-0.0733	1.091	0.000	0.0145
590	-0.101	1.116	0.000	0.02241
600	-0.148	1.163	0.000	-0.0459
610	-0.101	1.117	0.000	-0.0445
620	0.000	0.917	0.0992	-0.0332
630	0.000	0.878	0.137	0.002278
640	-0.109	1.128	0.000	-0.0624
650	-0.147	1.163	0.000	-0.0142
660	-0.118	1.138	0.000	-0.154
670	0.000	0.864	0.158	-0.241
680	0.000	1.023	0.000	-0.128
690	0.000	0.811	0.211	-0.362
700	-0.273	1.300	0.000	-0.420

APPENDIX II:

Summary For The Repeatability in terms of ΔL^*, Δa^*, Δb^*, ΔC^*, ΔH^* and ΔE^*_{ab} of the CCS-II Tiles Measured By Different Spectrophotometers

Table 1: Summary For The Repeatability Of The CCS-II GLOSSY Tiles Measured By Gretag Macbeth CE-2180 With Specular Component Excluded Mode

Tile	*ΔL**	*Δa**	*Δb**	*ΔC**	*ΔH**	ΔE^*_{ab}
Pale Grey						
Sample avge	-0.020	0.032	0.112	0.063	0.098	0.118
Mid Grey						
Sample avge	0.022	-0.053	0.120	0.099	0.086	0.133
Diff Grey						
Sample avge	-0.002	-0.027	0.066	0.066	0.027	0.071
Deep Grey						
Sample avge	-0.028	-0.159	0.301	0.322	0.110	0.342
Deep Pink						
Sample avge	0.017	-0.006	0.271	0.036	0.269	0.272
Red						
Sample avge	0.103	-0.141	0.783	0.374	0.702	0.802
Orange						
Sample avge	0.014	-0.071	0.259	0.174	0.205	0.269
Bright Yellow						
Sample avge	0.001	-0.018	0.186	0.186	0.018	0.187
Green						
Sample avge	-0.013	-0.156	0.108	0.188	0.026	0.190
Diff Green						
Sample avge	-0.019	-0.222	0.113	0.249	0.007	0.250
Cyan						
Sample avge	0.016	-0.019	0.125	-0.095	0.083	0.127
Deep Blue						
Sample avge	0.140	-0.678	0.412	-0.709	0.356	0.806
					Average ΔE^*_{ab}	***0.297***

Table 2: Summary For The Repeatability Of The CCS-II GLOSSY Tiles Measured By Gretag Macbeth CE-2180 With Specular Component Included Mode

Tile	*ΔL**	*Δa**	*Δb**	*ΔC**	*ΔH**	ΔE^*_{ab}
Pale Grey						
Sample avge	0.073	-0.076	0.065	0.100	0.001	0.124
Mid Grey						
Sample avge	0.015	-0.047	-0.028	0.033	0.044	0.057
Diff Grey						
Sample avge	0.048	-0.047	-0.029	0.010	0.054	0.073
Deep Grey						
Sample avge	-0.037	-0.017	-0.134	-0.133	0.024	0.140
Deep Pink						
Sample avge	0.015	0.091	0.029	0.095	0.010	0.097
Red						
Sample avge	0.033	0.192	0.026	0.181	0.069	0.197
Orange						
Sample avge	0.105	-0.016	0.250	0.188	0.166	0.272
Bright Yellow						
Sample avge	0.096	-0.098	0.074	0.072	0.099	0.156
Green						
Sample avge	0.064	-0.123	0.045	0.129	0.023	0.146
Diff Green						
Sample avge	0.074	-0.102	-0.051	0.061	0.096	0.136
Cyan						
Sample avge	0.036	-0.095	-0.041	0.084	0.060	0.110
Deep Blue						
Sample avge	-0.025	0.060	-0.135	0.148	0.000	0.150
					Average ΔE^*_{ab}	***0.140***

Table 3: Summary For The Repeatability Of The CCS-II MATT Tiles Measured By Gretag Macbeth CE-2180 With Specular Component Excluded Mode

Tile	*ΔL**	*Δa**	*Δb**	*ΔC**	*ΔH**	ΔE^*_{ab}
Pale Grey						
Sample avge	0.042	0.054	0.099	0.063	0.094	0.120
Mid Grey						
Sample avge	0.094	0.016	0.144	0.019	0.144	0.173
Diff Grey						
Sample avge	0.135	0.040	0.191	0.100	0.168	0.237
Deep Grey						
Sample avge	0.257	0.047	0.252	-0.256	0.013	0.363
Deep Pink						
Sample avge	0.219	-0.081	0.241	-0.057	0.248	0.336
Red						
Sample avge	0.256	-0.107	0.235	0.000	0.258	0.364
Orange						
Sample avge	0.140	-0.114	0.152	0.040	0.186	0.236
Bright Yellow						
Sample avge	0.079	-0.063	-0.005	-0.006	0.063	0.101
Green						
Sample avge	0.133	0.101	0.081	-0.058	0.116	0.186
Diff Green						
Sample avge	0.114	-0.005	0.099	0.055	0.082	0.151
Cyan						
Sample avge	0.156	0.103	0.196	-0.221	0.014	0.271
Deep Blue						
Sample avge	0.332	-0.099	0.468	-0.474	0.064	0.582
					Average ΔE^*_{ab}	***0.260***

Table 4: Summary For The Repeatability Of The CCS-II MATT Tiles Measured By Gretag Macbeth CE-2180 With Specular Component Included Mode

Tile	*ΔL**	*Δa**	*Δb**	*ΔC**	*ΔH**	ΔE^*_{ab}
Pale Grey						
Sample avge	0.047	-0.087	0.073	0.113	0.011	0.123
Mid Grey						
Sample avge	0.072	-0.052	0.028	0.047	0.036	0.093
Diff Grey						
Sample avge	0.069	-0.053	0.061	0.079	0.017	0.106
Deep Grey						
Sample avge	-0.008	-0.069	0.022	-0.014	0.071	0.073
Deep Pink						
Sample avge	0.020	-0.039	0.070	-0.032	0.073	0.083
Red						
Sample avge	0.068	0.071	0.035	0.080	0.000	0.104
Orange						
Sample avge	0.125	-0.024	0.189	0.126	0.143	0.228
Bright Yellow						
Sample avge	0.052	-0.104	-0.007	-0.010	0.104	0.116
Green						
Sample avge	0.057	-0.070	0.004	0.065	0.026	0.090
Diff Green						
Sample avge	0.040	-0.134	-0.019	0.105	0.085	0.141
Cyan						
Sample avge	0.058	-0.151	0.068	0.019	0.165	0.175
Deep Blue						
Sample avge	0.003	-0.080	-0.015	-0.015	0.080	0.081
				Average ΔE^*_{ab}		***0.118***

Table 5: Summary For The Repeatability Of The CCS-II GLOSSY Tiles Measured By DataColor SF-600 With Specular Component Excluded Mode

Tile	ΔL^*	Δa^*	Δb^*	ΔC^*	ΔH^*	ΔE^*_{ab}
Pale Grey						
Sample avge	0.011	0.009	-0.029	-0.019	0.031	0.038
Mid Grey						
Sample avge	0.022	0.013	-0.037	-0.018	0.037	0.047
Diff Grey						
Sample avge	0.012	0.018	-0.047	-0.045	0.025	0.053
Deep Grey						
Sample avge	0.055	0.018	-0.071	-0.073	0.041	0.100
Deep Pink						
Sample avge	0.030	-0.008	-0.072	-0.017	0.075	0.083
Red						
Sample avge	0.050	-0.030	-0.239	-0.170	0.182	0.254
Orange						
Sample avge	0.015	-0.016	-0.104	-0.095	0.065	0.116
Bright Yellow						
Sample avge	0.010	-0.014	-0.118	-0.118	0.040	0.125
Green						
Sample avge	0.017	0.009	-0.029	-0.021	0.042	0.050
Diff Green						
Sample avge	0.028	0.001	-0.029	-0.016	0.049	0.059
Cyan						
Sample avge	0.026	0.020	-0.014	0.001	0.033	0.042
Deep Blue						
Sample avge	0.188	-0.116	0.095	-0.142	0.084	0.250
					Average ΔE^*_{ab}	***0.101***

Table 6: Summary For The Repeatability Of The CCS-II GLOSSY Tiles Measured By DataColor SF-600 With Specular Component Included Mode

Tile	*ΔL**	*Δa**	*Δb**	*ΔC**	*ΔH**	ΔE^*_{ab}
Pale Grey						
Sample avge	0.012	0.003	-0.027	-0.012	0.031	0.035
Mid Grey						
Sample avge	0.011	0.005	-0.029	-0.005	0.033	0.035
Diff Grey						
Sample avge	0.012	0.000	-0.039	-0.028	0.032	0.044
Deep Grey						
Sample avge	0.027	-0.006	-0.027	-0.027	0.020	0.043
Deep Pink						
Sample avge	0.005	0.018	-0.027	0.014	0.038	0.041
Red						
Sample avge	0.031	0.022	0.005	0.022	0.035	0.052
Orange						
Sample avge	0.019	-0.034	-0.018	-0.035	0.045	0.060
Bright Yellow						
Sample avge	0.011	-0.029	-0.062	-0.062	0.041	0.075
Green						
Sample avge	0.022	-0.023	-0.020	0.012	0.041	0.048
Diff Green						
Sample avge	0.027	-0.013	-0.023	0.000	0.040	0.048
Cyan						
Sample avge	0.021	-0.002	-0.013	0.012	0.022	0.033
Deep Blue						
Sample avge	0.021	0.013	-0.033	0.035	0.025	0.048
					Average ΔE^*_{ab}	***0.047***

Table 7: Summary For The Repeatability Of The CCS-II MATT Tiles Measured By DataColor SF-600 With Specular Component Excluded Mode

Tile	*ΔL**	*Δa**	*Δb**	*ΔC**	*ΔH**	ΔE^*_{ab}
Pale Grey						
Sample avge	-0.006	0.019	-0.032	-0.034	0.018	0.039
Mid Grey						
Sample avge	0.010	0.006	-0.035	0.014	0.035	0.039
Diff Grey						
Sample avge	0.007	0.014	-0.029	-0.029	0.018	0.035
Deep Grey						
Sample avge	0.025	0.009	-0.033	0.031	0.030	0.050
Deep Pink						
Sample avge	0.033	0.001	-0.050	-0.004	0.054	0.063
Red						
Sample avge	0.018	-0.001	-0.041	-0.017	0.051	0.057
Orange						
Sample avge	0.010	-0.034	-0.058	-0.066	0.046	0.081
Bright Yellow						
Sample avge	0.005	-0.019	-0.019	-0.020	0.056	0.060
Green						
Sample avge	0.023	0.009	-0.042	-0.026	0.045	0.057
Diff Green						
Sample avge	0.002	0.002	-0.030	-0.017	0.038	0.042
Cyan						
Sample avge	0.038	0012	0.010	-0.015	0.019	0.045
Deep Blue						
Sample avge	0.025	0.018	-0.033	0.038	0.025	0.052
					Average ΔE^*_{ab}	***0.052***

Table 8: Summary For The Repeatability Of The CCS-II MATT Tiles Measured By DataColor SF-600 With Specular Component Included Mode

Tile	*ΔL**	*Δa**	*Δb**	*ΔC**	*ΔH**	ΔE^*_{ab}
Pale Grey						
Sample avge	-0.005	0.002	-0.014	-0.010	0.021	0.024
Mid Grey						
Sample avge	0.005	0.001	-0.024	0.009	0.026	0.028
Diff Grey						
Sample avge	0.003	0.013	-0.035	-0.032	0.022	0.039
Deep Grey						
Sample avge	0.012	0.018	-0.032	0.029	0.026	0.041
Deep Pink						
Sample avge	0.022	0.021	-0.041	0.017	0.046	0.054
Red						
Sample avge	0.021	0.035	-0.003	0.031	0.035	0.051
Orange						
Sample avge	0.028	-0.034	-0.018	-0.035	0.040	0.060
Bright Yellow						
Sample avge	-0.007	-0.040	-0.034	-0.035	0.056	0.066
Green						
Sample avge	0.024	-0.001	-0.038	-0.015	0.045	0.053
Diff Green						
Sample avge	0.013	-0.031	-0.004	0.025	0.040	0.049
Cyan						
Sample avge	0.021	-0.006	0.007	-0.002	0.024	0.032
Deep Blue						
Sample avge	0.012	0.031	-0.035	0.044	0.020	0.050
					Average ΔE^*_{ab}	***0.046***

Table 9: Summary For The Repeatability Of The CCS-II GLOSSY Tiles Measured By Gretag Macbeth CE-7000A With Specular Component Excluded Mode

Tile	ΔL^*	Δa^*	Δb^*	ΔC^*	ΔH^*	ΔE^*_{ab}
Pale Grey						
Sample avge	-0.015	-0.002	0.000	0.001	0.019	0.024
Mid Grey						
Sample avge	0.004	0.007	-0.006	-0.009	0.017	0.020
Diff Grey						
Sample avge	0.000	0.003	-0.003	-0.005	0.019	0.020
Deep Grey						
Sample avge	0.062	0.025	-0.029	-0.035	0.043	0.083
Deep Pink						
Sample avge	0.020	-0.012	-0.029	-0.017	0.038	0.046
Red						
Sample avge	0.050	-0.061	-0.320	-0.246	0.217	0.332
Orange						
Sample avge	0.002	-0.054	-0.096	-0.110	0.048	0.120
Bright Yellow						
Sample avge	-0.031	-0.025	-0.144	-0.144	0.048	0.155
Green						
Sample avge	0.006	0.021	-0.008	-0.023	0.041	0.047
Diff Green						
Sample avge	-0.005	0.019	-0.027	-0.030	0.045	0.054
Cyan						
Sample avge	-0.002	0.022	0.027	-0.035	0.041	0.054
Deep Blue						
Sample avge	0.181	-0.254	0.228	-0.328	0.105	0.389
					Average ΔE^*_{ab}	***0.098***

Table 10: Summary For The Repeatability Of The CCS-II GLOSSY Tiles Measured By Gretag Macbeth CE-7000A With Specular Component Included Mode

Tile	*ΔL**	*Δa**	*Δb**	*ΔC**	*ΔH**	ΔE^*_{ab}
Pale Grey						
Sample avge	-0.008	-0.003	0.004	0.005	0.015	0.018
Mid Grey						
Sample avge	0.006	-0.002	-0.004	0.000	0.017	0.018
Diff Grey						
Sample avge	0.002	-0.001	-0.006	-0.004	0.021	0.021
Deep Grey						
Sample avge	0.027	-0.010	-0.010	-0.005	0.026	0.038
Deep Pink						
Sample avge	0.000	-0.005	-0.005	-0.005	0.030	0.030
Red						
Sample avge	0.018	-0.018	-0.014	-0.023	0.034	0.045
Orange						
Sample avge	-0.001	-0.054	-0.043	-0.067	0.044	0.080
Bright Yellow						
Sample avge	-0.021	-0.020	-0.091	-0.091	0.041	0.102
Green						
Sample avge	0.014	0.002	-0.011	-0.007	0.029	0.033
Diff Green						
Sample avge	0.018	-0.004	-0.004	0.002	0.030	0.035
Cyan						
Sample avge	0.019	-0.001	0.021	-0.018	0.034	0.043
Deep Blue						
Sample avge	0.067	-0.036	0.059	-0.068	0.030	0.100
					Average ΔE^*_{ab}	***0.047***

Table 11: Summary For The Repeatability Of The CCS-II MATT Tiles Measured By Gretag Macbeth CE-7000A With Specular Component Excluded Mode

Tile	*ΔL**	*Δa**	*Δb**	*ΔC**	*ΔH**	ΔE^*_{ab}
Pale Grey						
Sample avge	-0.015	-0.002	0.000	0.001	0.019	0.024
Mid Grey						
Sample avge	0.011	-0.002	-0.006	0.001	0.020	0.023
Diff Grey						
Sample avge	0.024	-0.006	-0.005	0.002	0.020	0.031
Deep Grey						
Sample avge	0.039	-0.002	0.003	-0.002	0.022	0.045
Deep Pink						
Sample avge	0.035	-0.020	-0.013	-0.021	0.023	0.047
Red						
Sample avge	0.045	-0.002	-0.012	-0.007	0.033	0.056
Orange						
Sample avge	-0.006	-0.033	-0.098	-0.096	0.051	0.109
Bright Yellow						
Sample avge	0.008	-0.023	-0.026	-0.027	0.044	0.052
Green						
Sample avge	0.019	0.025	-0.020	-0.031	0.030	0.047
Diff Green						
Sample avge	0.003	-0.015	-0.016	0.005	0.036	0.036
Cyan						
Sample avge	0.018	-0.006	0.031	-0.024	0.040	0.050
Deep Blue						
Sample avge	0.057	-0.015	0.021	-0.025	0.027	0.068
					Average ΔE^*_{ab}	***0.049***

Table 12: Summary For The Repeatability Of The CCS-II MATT Tiles Measured By Gretag Macbeth CE-7000A With Specular Component Included Mode

Tile	*ΔL**	*Δa**	*Δb**	*ΔC**	*ΔH**	*ΔE^*_{ab}*
Pale Grey						
*Sample avg**	-0.020	-0.004	0.018	0.017	0.015	0.030
Mid Grey						
Sample avge	-0.007	-0.006	0.003	0.007	0.016	0.019
Diff Grey						
Sample avge	-0.002	0.002	0.020	0.011	0.022	0.025
Deep Grey						
Sample avge	0.030	0.006	-0.005	0.004	0.018	0.035
Deep Pink						
Sample avge	0.025	-0.006	-0.016	-0.008	0.026	0.037
Red						
Sample avge	0.038	-0.023	-0.039	-0.037	0.043	0.068
Orange						
Sample avge	0.037	-0.025	-0.013	-0.026	0.049	0.067
Bright Yellow						
Sample avge	0.031	-0.017	-0.009	-0.009	0.045	0.055
Green						
Sample avge	0.030	0.021	-0.023	-0.029	0.034	0.054
Diff Green						
Sample avge	0.017	-0.002	-0.010	-0.004	0.033	0.037
Cyan						
Sample avge	0.026	0.003	0.016	-0.015	0.036	0.047
Deep Blue						
Sample avge	0.050	-0.001	0.016	-0.015	0.023	0.057
					Average ΔE^*_{ab}	***0.044***

APPENDIX III:

Summary For The Inter-Instrumental Agreement in terms of ΔL^*, Δa^*, Δb^*, ΔC^*, ΔH^* and ΔE^*_{ab} of the CCS-II Tiles Measured By Different Spectrophotometers

Table 1: Summary For The Inter-Instrumental Agreement Of The CCS-II GLOSSY Tiles Measured Under The Condition Of Specular Component Excluded Mode Between SF-600 And CE-7000A

Tile	*ΔL**	*Δa**	*Δb**	*ΔC**	*ΔH**	ΔE^*_{ab}
Pale Grey						
Sample avge	-0.641	0.009	0.253	0.134	0.217	0.690
Mid Grey						
Sample avge	-0.448	0.012	0.099	0.014	0.099	0.459
Diff Grey						
Sample avge	-0.483	-0.031	0.101	0.094	0.054	0.495
Deep Grey						
Sample avge	-0.177	-0.037	0.067	0.075	0.038	0.196
Deep Pink						
Sample avge	-0.065	-0.027	0.752	0.087	0.748	0.756
Red						
Sample avge	0.622	0.088	0.144	0.158	0.103	0.650
Orange						
Sample avge	0.049	-0.991	0.327	-0.288	1.009	1.050
Bright Yellow						
Sample avge	-0.342	-0.551	-1.282	-1.289	0.535	1.437
Green						
Sample avge	-0.581	0.277	-0.916	-0.655	0.698	1.120
Diff Green						
Sample avge	-0.535	-0.226	-0.928	-0.666	0.685	1.095
Cyan						
Sample avge	-0.782	0.922	-0.233	-0.288	0.907	1.232
Deep Blue						
Sample avge	-0.196	-0.531	0.853	-1.005	0.091	1.028
					Average ΔE^*_{ab}	***0.851***

Table 2: Summary For The Inter-Instrumental Agreement Of The CCS-II GLOSSY Tiles Measured Under The Condition Of Specular Component Included Mode Between SF-600 And CE-7000A

Tile	*ΔL**	*Δa**	*Δb**	*ΔC**	*ΔH**	ΔE^*_{ab}
Pale Grey						
Sample avge	-0.389	0.052	0.171	0.040	0.174	0.428
Mid Grey						
Sample avge	-0.242	-0.004	0.117	0.025	0.115	0.269
Diff Grey						
Sample avge	-0.263	-0.049	0.119	0.119	0.050	0.293
Deep Grey						
Sample avge	-0.051	-0.102	0.183	0.192	0.087	0.217
Deep Pink						
Sample avge	0.060	0.072	0.730	0.175	0.713	0.737
Red						
Sample avge	0.387	0.671	0.998	1.059	0.569	1.263
Orange						
Sample avge	0.223	-0.865	0.612	-0.045	1.060	1.084
Bright Yellow						
Sample avge	-0.108	-0.579	-0.719	-0.727	0.570	0.930
Green						
Sample avge	-0.362	0.162	-0.666	-0.437	0.528	0.775
Diff Green						
Sample avge	-0.330	0.119	-0.661	-0.434	0.514	0.749
Cyan						
Sample avge	-0.547	0.806	-0.243	-0.199	0.818	1.004
Deep Blue						
Sample avge	-0.068	-0.374	0.759	-0.845	0.046	0.849
					Average ΔE^*_{ab}	***0.717***

Table 3: Summary For The Inter-Instrumental Agreement Of The CCS-II MATT Tiles Measured Under The Condition Of Specular Component Excluded Mode Between SF-600 And CE-7000A

Tile	*ΔL**	*Δa**	*Δb**	*ΔC**	*ΔH**	ΔE^*_{ab}
Pale Grey						
Sample avge	-0.534	0.019	0.251	0.176	0.179	0.590
Mid Grey						
Sample avge	-0.382	-0.031	0.175	0.018	0.178	0.422
Diff Grey						
Sample avge	-0.383	0.005	0.093	0.057	0.078	0.395
Deep Grey						
Sample avge	-0.129	-0.058	0.114	-0.099	0.084	0.183
Deep Pink						
Sample avge	-0.036	0.009	0.632	0.073	0.628	0.633
Red						
Sample avge	0.204	0.422	0.536	0.605	0.317	0.713
Orange						
Sample avge	0.149	-0.703	0.496	-0.087	0.857	0.874
Bright Yellow						
Sample avge	-0.151	-0.498	-0.538	-0.547	0.489	0.749
Green						
Sample avge	-0.476	0.303	-0.658	-0.551	0.471	0.867
Diff Green						
Sample avge	-0.452	0.169	-0.623	-0.458	0.455	0.788
Cyan						
Sample avge	-0.551	0.705	-0.118	-0.259	0.667	0.903
Deep Blue						
Sample avge	-0.074	-0.410	0.786	-0.880	0.111	0.890
					Average ΔE^*_{ab}	***0.667***

Table 4: Summary For The Inter-Instrumental Agreement Of The CCS-II MATT Tiles Measured Under The Condition Of Specular Component Included Mode Between SF-600 And CE-7000A

Tile	*ΔL**	*Δa**	*Δb**	*ΔC**	*ΔH**	ΔE^*_{ab}
Pale Grey						
Sample avge	-0.326	0.057	0.145	0.069	0.139	0.361
Mid Grey						
Sample avge	-0.157	-0.015	0.090	0.002	0.092	0.182
Diff Grey						
Sample avge	-0.164	0.024	0.008	-0.013	0.022	0.166
Deep Grey						
Sample avge	-0.019	-0.046	0.052	-0.042	0.058	0.074
Deep Pink						
Sample avge	0.134	0.119	0.575	0.176	0.561	0.603
Red						
Sample avge	0.353	0.578	0.577	0.763	0.292	0.890
Orange						
Sample avge	0.353	-0.676	0.595	0.005	0.901	0.968
Bright Yellow						
Sample avge	0.045	-0.566	-0.516	-0.527	0.557	0.768
Green						
Sample avge	-0.258	0.201	-0.687	-0.470	0.541	0.762
Diff Green						
Sample avge	-0.228	0.049	-0.609	-0.346	0.503	0.652
Cyan						
Sample avge	-0.359	0.685	-0.283	-0.105	0.734	0.824
Deep Blue						
Sample avge	-0.021	-0.329	0.592	-0.669	0.102	0.677
					Average ΔE^*_{ab}	***0.577***

Table 5: Summary For The Inter-Instrumental Agreement Of The CCS-II GLOSSY Tiles Measured Under The Condition Of Specular Component Excluded Mode Between CE-2180 And CE-7000A

Tile	*ΔL**	*Δa**	*Δb**	*ΔC**	*ΔH**	ΔE^*_{ab}
Pale Grey						
Sample avge	-0.399	0.475	-0.243	-0.236	-0.478	0.666
Mid Grey						
Sample avge	0.224	-0.299	0.6	-0.355	-0.569	0.707
Diff Grey						
Sample avge	0.436	0.051	-0.114	0.124	-0.018	0.453
Deep Grey						
Sample avge	0.126	0.173	-0.106	-0.139	-0.148	0.239
Deep Pink						
Sample avge	-0.105	-0.345	-0.600	-0.434	-0.539	0.700
Red						
Sample avge	-0.035	0.631	0.341	-0.371	-0.614	0.719
Orange						
Sample avge	-0.011	0.104	-0.058	-0.114	-0.034	0.119
Bright Yellow						
Sample avge	-0.038	0.550	0.412	-0.311	-0.613	0.689
Green						
Sample avge	-0.101	0.073	-0.038	-0.082	0.010	0.130
Diff Green						
Sample avge	-0.267	-0.048	-0.742	-0.642	-0.376	0.790
Cyan						
Sample avge	-0.110	0.067	-0.056	-0.087	-0.006	0.140
Deep Blue						
Sample avge	-0.374	-0.496	-0.949	-0.976	-0.440	1.134
					Average ΔE^*_{ab}	***0.541***

Table 6: Summary For The Inter-Instrumental Agreement Of The CCS-II GLOSSY Tiles Measured Under The Condition Of Specular Component Included Mode Between CE-2180 And CE-7000A

Tile	*ΔL**	*Δa**	*Δb**	*ΔC**	*ΔH**	ΔE^*_{ab}
Pale Grey						
Sample avge	-0.492	0.493	-0.384	-0.377	-0.498	0.795
Mid Grey						
Sample avge	0.190	-0.331	0.655	-0.399	-0.615	0.758
Diff Grey						
Sample avge	0.277	0.023	0.037	-0.024	0.036	0.280
Deep Grey						
Sample avge	0.051	0.054	0.066	0.060	-0.061	0.100
Deep Pink						
Sample avge	-0.187	-0.477	-0.511	-0.547	-0.434	0.723
Red						
Sample avge	-0.086	0.529	0.339	-0.288	-0.558	0.634
Orange						
Sample avge	-0.075	0.085	0.010	-0.051	-0.069	0.114
Bright Yellow						
Sample avge	-0.085	0.523	0.336	-0.323	-0.531	0.628
Green						
Sample avge	-0.138	0.027	0.026	-0.016	-0.034	0.143
Diff Green						
Sample avge	-0.448	-0.023	-0.919	-0.744	-0.541	1.023
Cyan						
Sample avge	-0.188	-0.005	-0.052	-0.027	0.045	0.195
Deep Blue						
Sample avge	-0.244	-1.057	-0.689	-1.257	-0.110	1.285
					Average ΔE^*_{ab}	***0.557***

Table 7: Summary For The Inter-Instrumental Agreement Of The CCS-II MATT Tiles Measured Under The Condition Of Specular Component Excluded Mode Between CE-2180 And CE-7000A

Tile	*ΔL**	*Δa**	*Δb**	*ΔC**	*ΔH**	ΔE^*_{ab}
Pale Grey						
Sample avge	-0.719	0.528	-0.257	-0.246	-0.533	0.928
Mid Grey						
Sample avge	-0.237	-0.255	0.407	-0.222	-0.426	0.535
Diff Grey						
Sample avge	-0.449	0.260	-0.555	0.611	0.049	0.760
Deep Grey						
Sample avge	-0.410	0.022	-0.174	0.164	0.061	0.446
Deep Pink						
Sample avge	-0.486	-0.181	-0.490	-0.231	-0.468	0.713
Red						
Sample avge	-0.543	0.389	0.125	-0.275	-0.302	0.680
Orange						
Sample avge	-0.407	0.048	-0.062	-0.077	0.015	0.414
Bright Yellow						
Sample avge	-0.355	0.266	0.263	-0.132	-0.350	0.516
Green						
Sample avge	-0.433	0.011	-0.101	-0.024	0.099	0.444
Diff Green						
Sample avge	-0.695	-0.032	-0.492	-0.393	-0.296	0.852
Cyan						
Sample avge	-0.437	0.056	-0.110	-0.122	0.013	0.454
Deep Blue						
Sample avge	-0.494	-0.331	-0.327	-0.437	-0.162	0.679
					Average ΔE^*_{ab}	***0.618***

Table 8: Summary For The Inter-Instrumental Agreement Of The CCS-II MATT Tiles Measured Under The Condition Of Specular Component Included Mode Between CE-2180 And CE-7000A

Tile	*ΔL**	*Δa**	*Δb**	*ΔC**	*ΔH**	ΔE^*_{ab}
Pale Grey						
Sample avge	-0.717	0.522	-0.347	-0.336	-0.529	0.952
Mid Grey						
Sample avge	-0.199	-0.190	0.506	-0.341	-0.419	0.576
Diff Grey						
Sample avge	-0.234	0.225	-0.157	0.226	0.156	0.361
Deep Grey						
Sample avge	-0.316	0.132	-0.083	0.061	0.144	0.352
Deep Pink						
Sample avge	-0.479	-0.300	-0.443	-0.344	-0.409	0.718
Red						
Sample avge	-0.523	0.516	0.173	-0.362	-0.407	0.755
Orange						
Sample avge	-0.428	0.086	-0.006	-0.069	-0.052	0.436
Bright Yellow						
Sample avge	-0.303	0.336	0.317	-0.173	-0.428	0.552
Green						
Sample avge	-0.494	0.062	-0.053	-0.057	0.059	0.500
Diff Green						
Sample avge	-0.739	-0.016	-0.668	-0.516	-0.424	0.997
Cyan						
Sample avge	-0.417	-0.014	-0.095	-0.065	0.071	0.428
Deep Blue						
Sample avge	-0.542	-0.671	-0.439	-0.792	-0.124	0.968
				Average ΔE^*_{ab}		***0.633***

APPENDIX IV:

The Repeatability of CCS-II Tiles Measured Among The Spectrophotometers Over 60 Weeks

Table 1: The Repeatability of GLOSSY Tiles Measured Under Specular Component Excluded Mode By CE-2180 Over 60 Weeks

Week	Pale Grey	Middel Grey	Diff. Grey	Deep Grey	Deep Pink	Red	Orange	Bright Yellow	Green	Diff. Green	Cyan	Deep Blue
1	0.051	0.039	0.045	0.207	0.174	0.735	0.269	0.183	0.042	0.179	0.049	0.734
2	0.151	0.080	0.026	0.113	0.213	1.290	0.764	0.244	0.125	0.272	0.124	0.850
3	0.073	0.075	0.072	0.169	0.081	0.506	0.123	0.144	0.069	0.239	0.093	0.316
4	0.071	0.059	0.059	0.341	0.130	0.588	0.099	0.134	0.190	0.109	0.036	0.624
5	0.119	0.133	0.071	0.280	0.272	0.802	0.269	0.187	0.213	0.250	0.127	0.805
6	0.067	0.080	0.090	1.033	0.157	0.990	0.189	0.202	0.720	0.368	0.137	0.665
7	0.041	0.258	0.220	0.099	0.735	0.368	0.560	1.481	0.147	0.923	0.421	0.805
8	0.043	0.412	0.039	1.517	0.152	0.513	0.282	0.209	1.131	1.273	0.096	0.414
9	0.115	0.082	0.415	0.119	0.169	0.077	1.198	1.687	0.560	0.138	0.732	0.409
10	0.036	0.012	0.115	0.204	0.113	0.491	0.082	0.094	0.058	0.184	0.074	0.376
11	0.074	0.061	0.054	0.308	0.071	0.402	0.104	0.116	0.137	0.283	0.116	0.241
12	0.093	0.085	0.065	0.283	0.159	1.003	0.171	0.273	0.153	0.236	0.085	1.501
13	0.144	0.200	0.219	0.579	0.193	0.793	0.269	0.199	0.366	0.551	0.305	0.852
14	0.074	0.117	0.110	0.359	0.200	1.446	0.388	0.388	0.248	0.347	0.143	0.699
15	0.018	0.039	0.030	0.161	0.131	0.771	0.202	0.043	0.113	0.157	0.025	0.785
16	0.105	0.097	0.081	0.386	0.063	0.619	0.132	0.116	0.242	0.360	0.188	1.613
17	0.012	0.087	0.063	0.280	0.137	1.005	0.284	0.452	0.323	0.412	0.119	0.382
18	0.030	0.054	0.079	0.060	0.264	1.469	0.386	0.059	0.080	0.110	0.092	0.122
19	0.054	0.132	0.042	0.142	0.055	0.226	0.050	0.238	0.077	0.165	0.115	0.142

20	0.039	0.021	0.021	0.200	0.226	0.836	0.315	0.209	0.170	0.211	0.095	0.376
21	0.018	0.101	0.039	0.180	0.195	0.632	0.262	0.039	0.132	0.239	0.065	0.376
22	0.107	0.074	0.063	0.107	0.109	0.542	0.191	0.119	0.091	0.164	0.127	0.624
23	0.073	0.075	0.072	0.119	0.098	0.342	0.113	0.134	0.720	0.272	0.124	0.805
24	0.071	0.059	0.059	0.204	0.200	0.588	0.269	0.187	0.147	0.239	0.093	0.665
25	0.119	0.133	0.071	0.308	0.131	0.802	0.368	0.202	1.131	0.109	0.036	0.805
26	0.067	0.080	0.090	0.283	0.063	0.990	0.123	1.481	0.077	0.250	0.127	0.414
27	0.041	0.258	0.220	0.579	0.098	0.668	0.099	0.209	0.058	0.368	0.137	0.409
28	0.043	0.412	0.039	0.359	0.264	0.513	0.269	1.687	0.137	0.923	0.421	0.376
29	0.115	0.082	0.415	0.161	0.055	0.137	0.189	0.094	0.153	1.273	0.096	0.241
30	0.036	0.012	0.115	0.386	0.226	0.491	0.368	0.116	0.366	0.138	0.732	1.501
31	0.074	0.061	0.054	0.280	0.195	0.402	0.123	0.273	0.248	0.184	0.074	0.852
32	0.093	0.085	0.065	0.060	0.109	1.003	0.099	0.199	0.113	0.283	0.116	0.699
33	0.144	0.039	0.219	0.142	0.098	0.793	0.269	0.388	0.242	0.236	0.085	0.785
34	0.030	0.080	0.110	0.200	0.174	1.446	0.189	0.043	0.323	0.283	0.093	1.613
35	0.054	0.075	0.030	0.180	0.213	0.226	0.560	0.116	0.080	0.236	0.036	0.376
36	0.039	0.059	0.081	0.107	0.081	0.836	0.282	0.183	0.042	0.551	0.127	0.241
37	0.018	0.133	0.045	0.119	0.130	0.632	1.168	0.244	0.125	0.347	0.137	1.501
38	0.107	0.080	0.026	0.204	0.272	0.542	0.082	0.144	0.069	0.157	0.421	0.852
39	0.073	0.258	0.072	0.308	0.157	0.342	0.202	0.134	0.190	0.360	0.096	0.699
40	0.071	0.412	0.059	0.283	0.735	0.588	0.132	0.187	0.213	0.412	0.732	0.785

41	0.119	0.200	0.071	0.207	0.152	0.802	0.284	0.202	0.720	0.110	0.074	1.613
42	0.067	0.117	0.090	0.113	0.169	0.990	0.386	0.199	0.147	0.165	0.732	0.382
43	0.051	0.039	0.063	0.169	0.113	0.159	0.050	0.388	1.131	0.211	0.074	0.122
44	0.151	0.097	0.079	0.341	0.071	0.513	0.315	0.043	0.077	0.239	0.116	0.142
45	0.073	0.087	0.042	0.280	0.169	0.513	0.262	0.116	0.058	0.164	0.085	0.376
46	0.071	0.054	0.021	1.033	0.193	0.674	0.191	0.452	0.137	0.368	0.305	0.376
47	0.119	0.132	0.045	0.359	0.137	0.491	0.113	0.059	0.153	0.923	0.143	0.414
48	0.067	0.021	0.026	0.161	0.264	0.402	0.123	0.238	0.366	1.273	0.025	0.409
49	0.041	0.054	0.072	0.386	0.055	1.003	0.099	0.209	0.137	0.138	0.188	0.376
50	0.043	0.132	0.059	0.280	0.226	0.793	0.269	0.039	0.153	0.184	0.119	0.241
51	0.071	0.021	0.071	0.060	0.195	1.446	0.189	0.119	0.366	0.283	0.092	1.501
52	0.119	0.101	0.090	0.142	0.109	0.226	0.560	0.134	0.248	0.236	0.115	0.852
53	0.067	0.074	0.220	0.200	0.098	0.836	0.282	0.187	0.113	0.283	0.095	0.699
54	0.041	0.075	0.039	0.180	0.174	0.632	1.927	0.202	0.242	0.236	0.065	0.785
55	0.043	0.059	0.415	0.107	0.213	0.764	0.082	1.481	0.323	0.551	0.127	1.613
56	0.115	0.133	0.115	0.180	0.081	1.290	0.202	0.209	0.080	0.347	0.124	0.376
57	0.036	0.080	0.065	0.107	0.130	0.506	0.132	1.687	0.042	0.157	0.093	0.241
58	0.074	0.258	0.219	0.119	0.272	0.588	0.284	0.094	0.125	0.360	0.305	0.699
59	0.093	0.412	0.110	0.204	0.159	0.802	0.386	0.116	0.069	0.368	0.143	0.785
60	0.144	0.412	0.030	0.308	0.193	0.990	0.099	0.273	0.190	0.923	0.025	1.613

Table 2: The Repeatability of GLOSY Tiles Measured Under Specular Component Included Mode By CE-2180 Over 60 Weeks

Week	Pale Grey	Middel Grey	Diff. Grey	Deep Grey	Deep Pink	Red	Orange	Bright Yellow	Green	Diff. Green	Cyan	Deep Blue
1	0.055	0.039	0.078	0.131	0.147	0.240	0.294	0.214	0.104	0.136	0.107	0.176
2	0.124	0.080	0.351	1.029	0.995	1.783	1.663	0.133	0.989	0.972	0.679	0.150
3	0.102	0.075	0.051	0.129	0.141	0.244	0.305	0.155	0.193	0.191	0.160	0.333
4	0.064	0.059	0.067	0.144	0.057	0.196	0.147	0.461	0.113	0.075	0.082	0.148
5	0.060	0.133	0.073	0.140	0.097	0.598	0.271	0.230	0.145	0.136	0.109	0.150
6	0.084	0.080	0.232	0.584	0.462	0.279	0.478	0.175	0.141	0.384	0.439	1.053
7	0.066	0.258	0.070	0.195	0.195	0.204	0.292	0.090	0.172	0.124	0.135	0.469
8	0.074	0.412	0.056	0.146	0.182	0.033	0.237	0.161	0.115	0.134	0.058	0.287
9	0.036	0.082	0.023	0.124	0.098	0.176	0.114	0.189	0.162	0.045	0.067	0.119
10	0.098	0.012	0.074	0.053	0.131	0.141	0.235	0.258	0.116	0.137	0.089	0.239
11	0.123	0.061	0.061	0.149	0.128	0.277	0.292	0.184	0.186	0.027	0.041	0.164
12	0.021	0.085	0.082	0.207	0.224	0.213	0.220	0.083	0.128	0.153	0.116	0.443
13	0.040	0.200	0.042	0.053	0.123	0.132	0.064	0.124	0.089	0.079	0.078	0.216
14	0.060	0.117	0.116	0.208	0.130	0.119	0.149	0.122	0.096	0.100	0.082	0.231
15	0.084	0.039	0.034	0.095	0.120	0.243	0.252	0.395	0.142	0.053	0.110	0.267
16	0.066	0.097	0.044	0.135	0.190	0.183	0.158	0.099	0.088	0.049	0.051	0.263
17	0.074	0.087	0.033	0.112	0.194	0.488	0.416	0.174	0.302	0.307	0.084	0.237
18	0.036	0.054	0.162	0.402	0.324	0.098	0.172	0.205	0.110	0.043	0.315	0.865
19	0.049	0.132	0.033	0.101	0.090	0.149	0.201	0.534	0.099	0.085	0.081	0.138

20	0.065	0.021	0.050	0.133	0.106	0.263	0.231	0.161	0.106	0.105	0.049	0.267
21	0.066	0.101	0.047	0.184	0.185	0.587	0.520	0.133	0.357	0.333	0.040	0.264
22	0.074	0.074	0.107	0.067	0.322	0.076	0.305	0.155	0.126	0.112	0.240	0.666
23	0.098	0.133	0.056	0.195	0.100	0.196	0.147	0.461	0.145	0.191	0.073	0.175
24	0.123	0.080	0.351	0.146	0.141	0.598	0.271	0.230	0.141	0.075	0.058	0.176
25	0.021	0.258	0.051	0.124	0.057	0.279	0.478	0.175	0.172	0.136	0.067	0.666
26	0.066	0.412	0.067	0.053	0.097	0.204	0.292	0.090	0.115	0.384	0.089	0.333
27	0.074	0.082	0.073	0.149	0.462	0.033	0.237	0.161	0.162	0.124	0.041	0.148
28	0.036	0.012	0.232	0.207	0.195	0.176	0.114	0.189	0.116	0.134	0.116	0.150
29	0.098	0.061	0.070	0.053	0.182	0.141	0.235	0.258	0.186	0.045	0.078	1.053
30	0.123	0.085	0.056	0.208	0.098	0.277	0.220	0.184	0.128	0.136	0.082	0.469
31	0.021	0.054	0.023	0.095	0.131	0.240	0.064	0.258	0.104	0.972	0.110	0.287
32	0.040	0.132	0.074	0.135	0.128	1.687	0.149	0.184	0.989	0.191	0.051	0.119
33	0.074	0.021	0.061	0.112	0.224	0.244	0.252	0.083	0.193	0.075	0.084	0.239
34	0.036	0.101	0.082	0.144	0.123	0.196	0.158	0.124	0.113	0.136	0.315	0.164
35	0.049	0.074	0.042	0.140	0.120	0.598	0.416	0.122	0.145	0.384	0.082	0.443
36	0.065	0.133	0.116	0.584	0.190	0.279	0.271	0.395	0.141	0.124	0.110	0.216
37	0.066	0.012	0.074	0.195	0.194	0.204	0.478	0.099	0.142	0.137	0.051	0.231
38	0.021	0.061	0.061	0.146	0.324	0.183	0.292	0.155	0.088	0.027	0.084	0.267
39	0.081	0.085	0.082	0.124	0.090	0.488	0.237	0.461	0.302	0.153	0.315	0.263
40	0.055	0.200	0.042	0.053	0.190	0.098	0.114	0.230	0.110	0.079	0.081	0.237

41	0.124	0.117	0.116	0.149	0.194	0.149	0.235	0.133	0.099	0.100	0.049	0.865
42	0.102	0.039	0.034	0.207	0.324	0.263	0.292	0.155	0.106	0.053	0.040	0.138
43	0.064	0.097	0.044	0.124	0.090	0.587	0.220	0.461	0.357	0.049	0.240	0.267
44	0.040	0.087	0.033	0.053	0.106	0.076	0.064	0.230	0.126	0.307	0.073	0.264
45	0.060	0.039	0.162	0.149	0.185	0.196	0.149	0.175	0.145	0.045	0.058	0.666
46	0.084	0.080	0.033	0.207	0.322	0.213	0.252	0.090	0.172	0.136	0.067	0.175
47	0.066	0.075	0.050	0.053	0.100	0.132	0.158	0.161	0.115	0.972	0.089	0.267
48	0.074	0.059	0.047	0.208	0.141	0.119	0.416	0.189	0.162	0.191	0.041	0.263
49	0.098	0.133	0.107	0.095	0.147	0.243	0.271	0.083	0.116	0.075	0.107	0.237
50	0.123	0.080	0.056	0.135	0.995	0.183	0.478	0.124	0.186	0.136	0.679	0.865
51	0.021	0.012	0.078	0.112	0.141	0.279	0.292	0.122	0.128	0.384	0.160	0.138
52	0.025	0.061	0.351	0.402	0.057	0.204	0.235	0.395	0.141	0.124	0.082	0.267
53	0.036	0.085	0.051	0.101	0.097	0.183	0.220	0.099	0.142	0.137	0.109	0.264
54	0.049	0.200	0.067	0.124	0.462	0.488	0.064	0.174	0.088	0.027	0.439	0.666
55	0.065	0.117	0.073	0.053	0.195	0.098	0.149	0.099	0.302	0.136	0.135	0.175
56	0.080	0.054	0.232	0.149	0.182	0.149	0.252	0.155	0.110	0.972	0.058	0.176
57	0.046	0.132	0.070	0.207	0.098	0.263	0.158	0.461	0.099	0.191	0.067	0.237
58	0.036	0.021	0.056	0.053	0.131	0.587	0.416	0.090	0.106	0.075	0.110	0.333
59	0.084	0.101	0.023	0.208	0.141	0.263	0.252	0.161	0.357	0.136	0.051	0.148
60	0.021	0.074	0.074	0.095	0.057	0.587	0.158	0.189	0.126	0.384	0.084	0.150

Table 3: The Repeatability of MATT Tiles Measured Under Specular Component Excluded Mode By CE-2180 Over 60 Weeks

Week	Pale Grey	Middel Grey	Diff. Grey	Deep Grey	Deep Pink	Red	Orange	Bright Yellow	Green	Diff. Green	Cyan	Deep Blue
1	0.076	0.050	0.165	0.362	0.247	0.261	0.318	0.158	0.165	0.120	0.221	0.560
2	0.120	0.046	0.222	0.247	0.204	0.169	0.602	0.167	0.157	0.062	0.123	0.431
3	0.121	0.173	0.119	0.230	0.163	0.132	0.135	0.059	0.125	0.125	0.145	0.129
4	0.103	0.106	0.164	0.245	0.083	0.075	0.195	0.102	0.082	0.141	0.271	0.376
5	0.133	0.100	0.173	0.448	0.336	0.364	0.151	0.155	0.186	0.087	0.168	0.583
6	0.136	0.102	0.087	0.275	0.181	0.211	0.238	0.144	0.107	0.087	0.170	0.449
7	0.170	0.050	0.179	0.117	0.254	0.283	0.242	0.165	0.146	0.062	0.104	0.493
8	0.081	0.046	0.170	0.253	0.235	0.439	0.253	0.490	0.101	0.124	0.233	0.310
9	0.085	0.173	0.192	0.360	0.386	0.179	0.237	0.152	0.346	0.126	0.194	0.474
10	0.087	0.106	0.164	0.271	0.180	0.221	0.262	0.130	0.219	0.127	0.196	0.439
11	0.089	0.100	0.180	0.260	0.189	0.234	0.505	0.110	0.216	0.063	0.186	0.420
12	0.105	0.102	0.151	0.247	0.229	0.195	0.192	0.106	0.169	0.152	0.142	0.544
13	0.118	0.245	0.257	0.240	0.225	0.046	0.297	0.158	0.043	0.100	0.047	0.493
14	0.076	0.101	0.071	0.194	0.108	0.191	0.192	0.167	0.203	0.120	0.158	0.310
15	0.120	0.152	0.075	0.049	0.272	0.216	0.068	0.059	0.208	0.062	0.168	0.474
16	0.121	0.076	0.237	0.362	0.245	0.203	0.236	0.102	0.185	0.125	0.171	0.439
17	0.103	0.059	0.174	0.247	0.244	0.242	0.109	0.155	0.186	0.141	0.191	0.420
18	0.133	0.128	0.165	0.230	0.237	0.151	0.196	0.144	0.154	0.087	0.132	0.256
19	0.136	0.093	0.222	0.245	0.173	0.230	0.068	0.165	0.202	0.087	0.320	0.494

20	0.170	0.108	0.119	0.448	0.400	0.169	0.236	0.490	0.091	0.109	0.140	0.425
21	0.081	0.153	0.164	0.275	0.198	0.100	0.109	0.152	0.149	0.118	0.094	0.368
22	0.085	0.096	0.173	0.302	0.158	0.256	0.297	0.130	0.208	0.149	0.154	0.376
23	0.087	0.205	0.087	0.342	0.245	0.216	0.192	0.110	0.203	0.161	0.123	0.583
24	0.089	0.069	0.046	0.256	0.244	0.203	0.068	0.106	0.208	0.098	0.145	0.449
25	0.086	0.073	0.179	0.117	0.237	0.242	0.236	0.106	0.185	0.151	0.271	0.493
26	0.091	0.137	0.170	0.253	0.235	0.151	0.109	0.177	0.186	0.114	0.168	0.310
27	0.098	0.096	0.192	0.360	0.386	0.230	0.196	0.147	0.154	0.107	0.170	0.474
28	0.142	0.205	0.164	0.271	0.180	0.211	0.318	0.175	0.186	0.109	0.104	0.439
29	0.187	0.106	0.180	0.260	0.189	0.283	0.602	0.256	0.107	0.161	0.233	0.420
30	0.064	0.100	0.233	0.211	0.229	0.439	0.135	0.143	0.146	0.063	0.194	0.544
31	0.016	0.102	0.177	0.314	0.225	0.179	0.195	0.119	0.101	0.152	0.047	0.415
32	0.045	0.245	0.115	0.136	0.108	0.221	0.151	0.078	0.346	0.100	0.158	0.172
33	0.086	0.101	0.149	0.205	0.386	0.234	0.238	0.094	0.219	0.120	0.168	0.411
34	0.091	0.152	0.192	0.285	0.180	0.195	0.175	0.152	0.216	0.062	0.171	0.483
35	0.098	0.076	0.164	0.205	0.189	0.046	0.176	0.130	0.154	0.125	0.191	0.379
36	0.142	0.059	0.180	0.285	0.189	0.191	0.242	0.110	0.202	0.141	0.132	0.310
37	0.187	0.128	0.151	0.117	0.229	0.283	0.253	0.106	0.082	0.087	0.233	0.474
38	0.064	0.093	0.257	0.253	0.225	0.439	0.237	0.106	0.186	0.087	0.194	0.439
39	0.016	0.108	0.071	0.360	0.108	0.179	0.262	0.177	0.107	0.109	0.196	0.420
40	0.118	0.050	0.071	0.271	0.247	0.221	0.505	0.130	0.146	0.118	0.186	0.256

41	0.076	0.046	0.075	0.260	0.204	0.234	0.192	0.110	0.101	0.125	0.142	0.494
42	0.120	0.173	0.174	0.211	0.163	0.261	0.124	0.106	0.346	0.141	0.047	0.310
43	0.121	0.106	0.165	0.285	0.083	0.169	0.192	0.158	0.219	0.087	0.158	0.474
44	0.103	0.100	0.222	0.117	0.336	0.132	0.192	0.167	0.216	0.087	0.168	0.439
45	0.133	0.102	0.119	0.253	0.235	0.075	0.068	0.059	0.169	0.062	0.171	0.420
46	0.136	0.050	0.164	0.360	0.386	0.364	0.236	0.102	0.186	0.124	0.191	0.544
47	0.170	0.046	0.173	0.271	0.180	0.211	0.109	0.155	0.107	0.126	0.132	0.415
48	0.170	0.069	0.164	0.260	0.189	0.283	0.196	0.144	0.146	0.127	0.320	0.172
49	0.081	0.073	0.180	0.211	0.229	0.439	0.068	0.152	0.101	0.063	0.158	0.411
50	0.085	0.137	0.151	0.314	0.225	0.179	0.236	0.130	0.346	0.152	0.168	0.483
51	0.087	0.096	0.257	0.230	0.108	0.221	0.109	0.110	0.219	0.100	0.171	0.474
52	0.089	0.205	0.071	0.245	0.272	0.221	0.297	0.106	0.216	0.120	0.191	0.439
53	0.086	0.106	0.075	0.448	0.245	0.234	0.192	0.106	0.169	0.062	0.132	0.420
54	0.091	0.100	0.237	0.275	0.244	0.242	0.068	0.177	0.154	0.125	0.320	0.256
55	0.098	0.102	0.174	0.302	0.237	0.151	0.236	0.165	0.202	0.141	0.140	0.494
56	0.142	0.245	0.149	0.342	0.173	0.230	0.109	0.490	0.082	0.087	0.094	0.310
57	0.187	0.050	0.192	0.256	0.400	0.211	0.196	0.152	0.101	0.087	0.154	0.560
58	0.064	0.046	0.164	0.117	0.247	0.283	0.318	0.130	0.346	0.109	0.123	0.431
59	0.016	0.173	0.180	0.253	0.204	0.283	0.602	0.110	0.219	0.118	0.145	0.129
60	0.045	0.106	0.222	0.360	0.163	0.439	0.192	0.106	0.216	0.149	0.271	0.376

Table 4: The Repeatability of MATT Tiles Measured Under Specular Component Included Mode By CE-2180 Over 60 Weeks

Week	Pale Grey	Middel Grey	Diff. Grey	Deep Grey	Deep Pink	Red	Orange	Bright Yellow	Green	Diff. Green	Cyan	Deep Blue
1	0.037	0.054	0.074	0.066	0.024	0.165	0.281	0.127	0.207	0.073	0.196	0.171
2	0.077	0.084	0.086	0.070	0.085	0.180	0.290	0.141	0.130	0.140	0.186	0.137
3	0.123	0.078	0.104	0.065	0.046	0.299	0.055	0.182	0.085	0.327	0.142	0.063
4	0.048	0.084	0.054	0.094	0.088	0.040	0.227	0.063	0.232	0.200	0.047	0.081
5	0.028	0.082	0.059	0.090	0.067	0.087	0.345	0.206	0.068	0.087	0.158	0.540
6	0.035	0.096	0.042	0.238	0.090	0.036	0.329	0.149	0.141	0.247	0.168	0.038
7	0.045	0.040	0.054	0.104	0.036	0.167	0.246	0.170	0.036	0.116	0.171	0.399
8	0.077	0.101	0.119	0.078	0.038	0.069	0.468	0.087	0.089	0.082	0.191	0.117
9	0.075	0.093	0.054	0.143	0.083	0.039	0.199	0.168	0.088	0.066	0.132	0.171
10	0.061	0.090	0.106	0.076	0.204	0.135	0.243	0.123	0.086	0.140	0.320	0.137
11	0.123	0.076	0.093	0.073	0.143	0.110	0.140	0.079	0.090	0.187	0.140	0.063
12	0.048	0.096	0.095	0.312	0.036	0.135	0.279	0.085	0.207	0.092	0.170	0.081
13	0.028	0.040	0.043	0.189	0.227	0.158	0.129	0.063	0.130	0.142	0.104	0.540
14	0.035	0.101	0.035	0.022	0.046	0.105	0.166	0.206	0.085	0.194	0.233	0.038
15	0.045	0.093	0.106	0.238	0.059	0.249	0.196	0.149	0.232	0.073	0.194	0.399
16	0.077	0.090	0.093	0.104	0.079	0.165	0.262	0.170	0.068	0.140	0.196	0.117
17	0.075	0.076	0.045	0.066	0.062	0.180	0.254	0.087	0.141	0.327	0.186	0.065
18	0.061	0.054	0.064	0.129	0.114	0.299	0.233	0.168	0.089	0.200	0.142	0.082
19	0.089	0.084	0.086	0.066	0.057	0.040	0.198	0.123	0.088	0.087	0.047	0.089

20	0.167	0.078	0.074	0.070	0.057	0.087	0.259	0.079	0.086	0.247	0.158	0.107
21	0.084	0.084	0.086	0.065	0.024	0.036	0.152	0.085	0.090	0.116	0.196	0.061
22	0.034	0.082	0.104	0.094	0.085	0.167	0.141	0.140	0.207	0.143	0.186	0.081
23	0.088	0.114	0.054	0.090	0.046	0.069	0.468	0.127	0.130	0.097	0.142	0.061
24	0.051	0.033	0.059	0.121	0.088	0.039	0.199	0.141	0.085	0.109	0.047	0.076
25	0.077	0.073	0.042	0.101	0.067	0.089	0.243	0.182	0.232	0.082	0.158	0.120
26	0.027	0.065	0.054	0.093	0.087	0.088	0.140	0.063	0.068	0.066	0.123	0.053
27	0.037	0.075	0.119	0.101	0.075	0.129	0.279	0.169	0.141	0.140	0.145	0.164
28	0.061	0.031	0.054	0.101	0.143	0.095	0.129	0.054	0.036	0.187	0.123	0.105
29	0.089	0.030	0.055	0.073	0.036	0.091	0.166	0.116	0.061	0.167	0.145	0.055
30	0.167	0.076	0.045	0.022	0.227	0.166	0.196	0.335	0.105	0.095	0.271	0.540
31	0.084	0.096	0.034	0.238	0.046	0.022	0.262	0.230	0.052	0.144	0.168	0.038
32	0.034	0.040	0.062	0.104	0.059	0.072	0.281	0.075	0.068	0.116	0.170	0.399
33	0.088	0.101	0.063	0.066	0.088	0.039	0.290	0.366	0.090	0.107	0.104	0.117
34	0.051	0.093	0.086	0.129	0.067	0.089	0.055	0.075	0.088	0.110	0.123	0.065
35	0.077	0.090	0.104	0.066	0.090	0.088	0.227	0.366	0.059	0.109	0.145	0.082
36	0.045	0.076	0.054	0.070	0.036	0.129	0.345	0.102	0.061	0.082	0.271	0.089
37	0.077	0.082	0.059	0.065	0.038	0.095	0.329	0.140	0.044	0.066	0.168	0.107
38	0.075	0.114	0.042	0.094	0.083	0.158	0.246	0.127	0.029	0.140	0.221	0.061
39	0.061	0.033	0.054	0.090	0.204	0.105	0.468	0.141	0.009	0.247	0.123	0.081
40	0.123	0.073	0.119	0.121	0.143	0.249	0.199	0.169	0.085	0.116	0.145	0.061

41	0.048	0.065	0.054	0.104	0.036	0.165	0.243	0.054	0.232	0.082	0.271	0.076
42	0.028	0.075	0.055	0.078	0.227	0.180	0.259	0.116	0.068	0.066	0.168	0.107
43	0.035	0.031	0.045	0.143	0.046	0.299	0.152	0.335	0.105	0.140	0.170	0.061
44	0.045	0.030	0.119	0.076	0.059	0.040	0.141	0.230	0.052	0.116	0.104	0.081
45	0.077	0.096	0.054	0.073	0.083	0.087	0.468	0.075	0.068	0.082	0.233	0.061
46	0.075	0.040	0.055	0.312	0.204	0.036	0.199	0.366	0.036	0.066	0.194	0.076
47	0.061	0.101	0.045	0.189	0.143	0.087	0.243	0.102	0.061	0.140	0.196	0.120
48	0.123	0.093	0.034	0.066	0.036	0.036	0.140	0.140	0.105	0.187	0.186	0.053
49	0.048	0.090	0.062	0.070	0.227	0.167	0.279	0.127	0.052	0.092	0.142	0.164
50	0.028	0.076	0.063	0.065	0.046	0.069	0.129	0.141	0.068	0.142	0.047	0.105
51	0.035	0.096	0.054	0.094	0.059	0.039	0.166	0.182	0.141	0.194	0.158	0.055
52	0.167	0.040	0.059	0.090	0.079	0.089	0.196	0.063	0.036	0.073	0.168	0.540
53	0.084	0.101	0.042	0.238	0.062	0.039	0.262	0.206	0.061	0.140	0.171	0.038
54	0.034	0.054	0.054	0.104	0.114	0.135	0.281	0.149	0.105	0.327	0.191	0.399
55	0.088	0.084	0.119	0.078	0.057	0.110	0.290	0.170	0.052	0.200	0.132	0.540
56	0.051	0.078	0.054	0.143	0.057	0.135	0.055	0.087	0.068	0.087	0.320	0.038
57	0.077	0.084	0.106	0.076	0.088	0.158	0.227	0.168	0.090	0.082	0.140	0.399
58	0.075	0.082	0.093	0.073	0.067	0.105	0.345	0.123	0.088	0.066	0.094	0.117
59	0.061	0.076	0.095	0.022	0.087	0.249	0.345	0.079	0.059	0.140	0.154	0.171
60	0.123	0.082	0.119	0.238	0.075	0.165	0.329	0.085	0.061	0.187	0.158	0.137

Table 5: The Repeatability of GLOSSY Tiles Measured Under Specular Component Excluded Mode By SF-600 Over 60 Weeks

Week	Pale Grey	Middel Grey	Diff. Grey	Deep Grey	Deep Pink	Red	Orange	Bright Yellow	Green	Diff. Green	Cyan	Deep Blue
1	0.102	0.454	0.063	0.309	0.185	0.042	0.217	0.155	0.158	0.177	0.915	0.245
2	0.038	0.456	0.079	0.142	0.099	0.201	0.173	0.013	0.053	0.081	0.920	0.286
3	0.056	0.478	0.042	0.063	0.108	0.460	0.099	0.183	0.062	0.068	0.828	0.286
4	0.020	0.495	0.021	0.071	0.038	0.096	0.106	0.060	0.037	0.044	0.914	0.076
5	0.039	0.482	0.039	0.080	0.082	0.339	0.101	0.114	0.067	0.085	0.867	0.314
6	0.014	0.450	0.063	0.101	0.043	0.177	0.106	0.090	0.045	0.059	1.086	0.115
7	0.022	0.431	0.045	0.051	0.042	0.118	0.131	0.130	0.005	0.034	0.971	0.183
8	0.042	0.460	0.026	0.151	0.105	0.135	0.049	0.147	0.071	0.077	0.848	0.200
9	0.023	0.457	0.072	0.096	0.090	0.233	0.058	0.189	0.048	0.023	0.862	0.160
10	0.055	0.447	0.059	0.077	0.085	0.262	0.115	0.090	0.006	0.054	0.920	0.335
11	0.014	0.460	0.071	0.079	0.065	0.375	0.202	0.130	0.054	0.033	0.828	0.294
12	0.020	0.450	0.090	0.134	0.106	0.105	0.090	0.147	0.070	0.062	0.914	0.150
13	0.051	0.478	0.220	0.062	0.099	0.163	0.112	0.189	0.068	0.079	0.867	0.379
14	0.033	0.445	0.039	0.125	0.084	0.274	0.126	0.125	0.074	0.067	1.086	0.283
15	0.015	0.454	0.415	0.096	0.073	0.042	0.071	0.186	0.032	0.065	0.971	0.230
16	0.023	0.462	0.115	0.062	0.064	0.201	0.108	0.086	0.038	0.028	0.848	0.130
17	0.029	0.450	0.054	0.076	0.082	0.460	0.033	0.136	0.034	0.040	0.862	0.222
18	0.031	0.450	0.065	0.046	0.039	0.096	0.082	0.083	0.040	0.047	0.896	0.183
19	0.040	0.459	0.219	0.068	0.070	0.339	0.230	0.155	0.049	0.033	0.898	0.167

20	0.096	0.449	0.110	0.104	0.074	0.177	0.074	0.377	0.022	0.016	0.840	0.335
21	0.036	0.463	0.030	0.067	0.051	0.118	0.129	0.148	0.038	0.059	0.906	0.343
22	0.043	0.466	0.081	0.063	0.120	0.215	0.200	0.060	0.060	0.081	0.857	0.222
23	0.038	0.431	0.063	0.071	0.042	0.065	0.202	0.114	0.067	0.068	0.868	0.286
24	0.020	0.460	0.079	0.080	0.105	0.233	0.090	0.090	0.045	0.044	0.864	0.286
25	0.039	0.457	0.042	0.101	0.090	0.071	0.112	0.130	0.005	0.085	0.784	0.076
26	0.014	0.447	0.021	0.051	0.085	0.310	0.126	0.147	0.071	0.059	0.875	0.314
27	0.022	0.460	0.039	0.151	0.065	0.305	0.071	0.189	0.068	0.034	0.860	0.115
28	0.042	0.450	0.054	0.096	0.106	0.135	0.108	0.125	0.074	0.077	0.953	0.183
29	0.023	0.478	0.065	0.077	0.099	0.233	0.033	0.072	0.032	0.023	0.914	0.200
30	0.055	0.445	0.219	0.079	0.084	0.262	0.082	0.083	0.038	0.551	0.867	0.160
31	0.014	0.454	0.110	0.134	0.073	0.375	0.230	0.045	0.034	0.347	1.086	0.200
32	0.020	0.462	0.030	0.062	0.064	0.105	0.074	0.101	0.040	0.157	0.971	0.160
33	0.051	0.450	0.081	0.125	0.082	0.163	0.992	0.186	0.049	0.360	0.848	0.335
34	0.033	0.450	0.063	0.187	0.084	0.274	0.173	0.086	0.022	0.412	0.862	0.294
35	0.015	0.459	0.079	0.266	0.073	0.042	0.099	0.136	0.038	0.110	0.896	0.150
36	0.102	0.449	0.042	0.210	0.064	0.201	0.106	0.083	0.060	0.165	0.898	0.343
37	0.038	0.463	0.021	0.194	0.082	0.042	0.101	0.155	0.067	0.360	0.840	0.222
38	0.056	0.466	0.039	0.201	0.039	0.201	0.106	0.377	0.045	0.412	0.848	0.286
39	0.020	0.431	0.063	0.175	0.070	0.460	0.131	0.148	0.005	0.110	0.862	0.286
40	0.039	0.454	0.039	0.194	0.074	0.096	0.049	0.136	0.071	0.165	0.896	0.076

41	0.014	0.456	0.415	0.062	0.051	0.339	0.058	0.083	0.062	0.211	0.898	0.314
42	0.022	0.478	0.115	0.076	0.120	0.177	0.115	0.155	0.037	0.239	0.840	0.115
43	0.042	0.495	0.054	0.046	0.074	0.118	0.202	0.013	0.067	0.164	0.906	0.183
44	0.055	0.482	0.065	0.068	0.051	0.215	0.090	0.183	0.045	0.283	0.857	0.200
45	0.014	0.450	0.063	0.104	0.120	0.065	0.202	0.060	0.005	0.236	0.868	0.160
46	0.020	0.431	0.079	0.067	0.042	0.305	0.090	0.114	0.071	0.551	0.864	0.245
47	0.051	0.460	0.042	0.063	0.105	0.135	0.112	0.090	0.048	0.412	0.920	0.286
48	0.033	0.457	0.021	0.071	0.185	0.233	0.126	0.130	0.006	0.110	0.828	0.286
49	0.015	0.447	0.039	0.080	0.099	0.262	0.071	0.147	0.054	0.165	0.914	0.076
50	0.023	0.450	0.063	0.101	0.108	0.375	0.108	0.189	0.070	0.360	0.867	0.314
51	0.029	0.450	0.045	0.051	0.038	0.177	0.033	0.125	0.067	0.412	1.086	0.115
52	0.031	0.459	0.026	0.191	0.082	0.118	0.082	0.072	0.045	0.110	0.971	0.183
53	0.022	0.449	0.072	0.182	0.043	0.215	0.230	0.083	0.005	0.165	0.848	0.200
54	0.042	0.463	0.039	0.188	0.042	0.065	0.106	0.045	0.071	0.109	0.862	0.160
55	0.023	0.466	0.415	0.193	0.105	0.233	0.101	0.101	0.062	0.250	0.896	0.335
56	0.055	0.431	0.115	0.189	0.090	0.071	0.106	0.186	0.037	0.368	0.898	0.294
57	0.014	0.454	0.054	0.190	0.085	0.310	0.131	0.086	0.067	0.923	0.840	0.150
58	0.020	0.456	0.065	0.191	0.065	0.305	0.049	0.095	0.045	1.273	0.906	0.379
59	0.051	0.478	0.063	0.178	0.106	0.135	0.058	0.128	0.005	0.360	0.857	0.283
60	0.033	0.495	0.079	0.187	0.099	0.233	0.115	0.086	0.071	0.412	0.868	0.321

Table 6: The Repeatability of GLOSSY Tiles Measured Under Specular Component Included Mode By SF-600 Over 60 Weeks

Week	Pale Grey	Middel Grey	Diff. Grey	Deep Grey	Deep Pink	Red	Orange	Bright Yellow	Green	Diff. Green	Cyan	Deep Blue
1	0.054	0.066	0.071	0.045	0.056	0.027	0.094	0.019	0.073	0.020	0.045	0.081
2	0.051	0.030	0.048	0.033	0.045	0.057	0.052	0.106	0.053	0.060	0.033	0.036
3	0.025	0.045	0.062	0.028	0.052	0.062	0.070	0.043	0.061	0.022	0.049	0.077
4	0.036	0.011	0.018	0.062	0.048	0.033	0.045	0.094	0.017	0.047	0.014	0.023
5	0.016	0.046	0.064	0.020	0.030	0.073	0.081	0.088	0.068	0.052	0.039	0.058
6	0.025	0.010	0.015	0.039	0.006	0.024	0.051	0.011	0.037	0.072	0.023	0.011
7	0.048	0.015	0.019	0.034	0.059	0.054	0.042	0.084	0.040	0.054	0.036	0.027
8	0.022	0.041	0.049	0.031	0.030	0.133	0.098	0.130	0.089	0.059	0.041	0.051
9	0.051	0.060	0.020	0.059	0.045	0.052	0.037	0.092	0.056	0.026	0.025	0.030
10	0.014	0.020	0.060	0.045	0.017	0.043	0.045	0.072	0.038	0.069	0.048	0.064
11	0.024	0.012	0.030	0.028	0.012	0.039	0.047	0.020	0.022	0.027	0.018	0.039
12	0.036	0.042	0.022	0.043	0.029	0.026	0.029	0.128	0.078	0.037	0.028	0.030
13	0.039	0.053	0.057	0.045	0.059	0.077	0.089	0.019	0.071	0.084	0.039	0.030
14	0.022	0.020	0.057	0.035	0.019	0.065	0.072	0.011	0.026	0.039	0.034	0.073
15	0.031	0.027	0.030	0.066	0.049	0.030	0.030	0.084	0.047	0.039	0.022	0.042
16	0.043	0.032	0.042	0.044	0.056	0.067	0.080	0.106	0.031	0.033	0.022	0.060
17	0.030	0.017	0.049	0.020	0.029	0.047	0.056	0.049	0.054	0.020	0.030	0.064
18	0.027	0.024	0.031	0.039	0.036	0.073	0.069	0.088	0.032	0.060	0.027	0.065
19	0.060	0.091	0.044	0.081	0.089	0.058	0.042	0.103	0.074	0.022	0.026	0.068

20	0.039	0.043	0.091	0.051	0.051	0.058	0.104	0.060	0.048	0.047	0.054	0.044
21	0.036	0.026	0.053	0.041	0.043	0.044	0.057	0.066	0.031	0.052	0.032	0.054
22	0.043	0.046	0.039	0.063	0.036	0.024	0.029	0.127	0.031	0.052	0.032	0.068
23	0.051	0.010	0.052	0.028	0.052	0.033	0.055	0.107	0.040	0.032	0.035	0.023
24	0.014	0.015	0.049	0.062	0.048	0.133	0.081	0.045	0.089	0.091	0.014	0.058
25	0.024	0.041	0.020	0.020	0.030	0.052	0.051	0.051	0.056	0.051	0.039	0.011
26	0.036	0.060	0.060	0.039	0.006	0.043	0.042	0.092	0.038	0.036	0.023	0.027
27	0.039	0.020	0.030	0.034	0.059	0.039	0.098	0.130	0.022	0.037	0.036	0.051
28	0.022	0.060	0.022	0.031	0.030	0.026	0.037	0.092	0.078	0.054	0.041	0.030
29	0.031	0.020	0.057	0.059	0.045	0.077	0.045	0.072	0.071	0.059	0.025	0.064
30	0.036	0.012	0.057	0.045	0.017	0.065	0.047	0.020	0.026	0.026	0.048	0.039
31	0.016	0.042	0.030	0.028	0.012	0.027	0.029	0.128	0.053	0.069	0.018	0.030
32	0.025	0.053	0.042	0.043	0.029	0.057	0.089	0.019	0.061	0.027	0.028	0.030
33	0.048	0.020	0.064	0.045	0.056	0.062	0.072	0.106	0.017	0.037	0.039	0.051
34	0.022	0.027	0.015	0.035	0.045	0.033	0.051	0.043	0.068	0.084	0.034	0.030
35	0.051	0.032	0.019	0.066	0.052	0.073	0.042	0.094	0.037	0.039	0.022	0.064
36	0.014	0.017	0.049	0.045	0.048	0.024	0.098	0.088	0.040	0.047	0.045	0.039
37	0.054	0.066	0.020	0.033	0.030	0.054	0.037	0.011	0.089	0.052	0.033	0.030
38	0.051	0.030	0.060	0.028	0.006	0.133	0.045	0.084	0.056	0.052	0.049	0.030
39	0.025	0.045	0.030	0.062	0.059	0.052	0.047	0.106	0.038	0.032	0.014	0.073
40	0.036	0.011	0.022	0.020	0.029	0.043	0.029	0.049	0.022	0.091	0.039	0.042

41	0.016	0.046	0.057	0.028	0.059	0.030	0.089	0.088	0.073	0.051	0.023	0.060
42	0.025	0.010	0.057	0.043	0.019	0.067	0.072	0.103	0.053	0.036	0.036	0.064
43	0.036	0.024	0.030	0.045	0.049	0.047	0.030	0.060	0.061	0.037	0.041	0.065
44	0.039	0.091	0.042	0.035	0.056	0.073	0.080	0.066	0.017	0.069	0.025	0.068
45	0.022	0.043	0.057	0.066	0.029	0.058	0.056	0.127	0.068	0.027	0.048	0.044
46	0.031	0.026	0.057	0.044	0.036	0.058	0.069	0.107	0.037	0.037	0.018	0.060
47	0.043	0.046	0.030	0.020	0.089	0.044	0.042	0.045	0.040	0.084	0.048	0.064
48	0.030	0.010	0.042	0.039	0.051	0.024	0.104	0.051	0.089	0.039	0.018	0.065
49	0.027	0.015	0.049	0.081	0.029	0.033	0.057	0.127	0.026	0.039	0.028	0.068
50	0.060	0.041	0.031	0.051	0.056	0.133	0.094	0.107	0.047	0.033	0.039	0.044
51	0.039	0.060	0.044	0.034	0.045	0.052	0.052	0.045	0.031	0.020	0.034	0.054
52	0.036	0.020	0.091	0.031	0.052	0.043	0.070	0.051	0.054	0.060	0.022	0.068
53	0.043	0.060	0.053	0.059	0.048	0.057	0.045	0.092	0.032	0.022	0.022	0.023
54	0.051	0.020	0.039	0.045	0.030	0.062	0.081	0.130	0.074	0.047	0.030	0.058
55	0.014	0.027	0.052	0.028	0.006	0.033	0.051	0.092	0.048	0.052	0.027	0.011
56	0.024	0.032	0.049	0.043	0.059	0.073	0.042	0.072	0.031	0.052	0.026	0.027
57	0.036	0.017	0.020	0.045	0.029	0.024	0.047	0.020	0.031	0.032	0.054	0.051
58	0.039	0.066	0.060	0.035	0.059	0.054	0.029	0.128	0.040	0.020	0.018	0.030
59	0.022	0.030	0.044	0.028	0.019	0.133	0.089	0.019	0.089	0.060	0.028	0.060
60	0.036	0.045	0.091	0.043	0.049	0.052	0.072	0.106	0.056	0.022	0.039	0.064

Table 7: The Repeatability of MATT Tiles Measured Under Specular Component Excluded Mode By SF-600 Over 60 Weeks

Week	Pale Grey	Middel Grey	Diff. Grey	Deep Grey	Deep Pink	Red	Orange	Bright Yellow	Green	Diff. Green	Cyan	Deep Blue
1	0.093	0.046	0.094	0.184	0.026	0.169	0.154	0.055	0.039	0.142	0.061	0.154
2	0.042	0.012	0.040	0.097	0.074	0.064	0.063	0.024	0.064	0.039	0.046	0.085
3	0.042	0.020	0.050	0.058	0.033	0.050	0.052	0.082	0.038	0.046	0.063	0.067
4	0.009	0.022	0.013	0.042	0.036	0.056	0.086	0.044	0.037	0.044	0.038	0.009
5	0.039	0.061	0.032	0.033	0.085	0.037	0.037	0.025	0.083	0.060	0.056	0.033
6	0.014	0.019	0.012	0.040	0.079	0.032	0.080	0.044	0.053	0.014	0.040	0.018
7	0.044	0.058	0.021	0.053	0.022	0.063	0.164	0.077	0.065	0.044	0.040	0.021
8	0.019	0.016	0.044	0.029	0.048	0.027	0.096	0.148	0.063	0.061	0.051	0.072
9	0.054	0.046	0.018	0.060	0.090	0.034	0.079	0.032	0.010	0.030	0.035	0.065
10	0.030	0.107	0.050	0.020	0.019	0.021	0.079	0.024	0.078	0.043	0.048	0.020
11	0.026	0.054	0.005	0.026	0.053	0.055	0.013	0.082	0.038	0.020	0.030	0.032
12	0.047	0.046	0.024	0.056	0.040	0.067	0.039	0.044	0.041	0.059	0.036	0.090
13	0.042	0.012	0.043	0.056	0.043	0.070	0.089	0.025	0.070	0.085	0.038	0.097
14	0.024	0.020	0.014	0.020	0.054	0.040	0.154	0.044	0.021	0.052	0.052	0.035
15	0.028	0.022	0.023	0.054	0.090	0.046	0.063	0.077	0.077	0.027	0.032	0.045
16	0.020	0.061	0.033	0.030	0.019	0.067	0.052	0.148	0.033	0.013	0.048	0.031
17	0.040	0.019	0.030	0.010	0.053	0.026	0.086	0.032	0.035	0.020	0.044	0.026
18	0.037	0.058	0.026	0.023	0.040	0.054	0.037	0.024	0.096	0.006	0.035	0.039
19	0.098	0.016	0.073	0.029	0.043	0.061	0.080	0.018	0.029	0.044	0.042	0.044

20	0.054	0.014	0.043	0.060	0.054	0.068	0.164	0.069	0.039	0.034	0.064	0.055
21	0.051	0.052	0.052	0.020	0.026	0.081	0.096	0.022	0.064	0.054	0.042	0.079
22	0.038	0.042	0.033	0.026	0.074	0.055	0.072	0.108	0.038	0.023	0.060	0.030
23	0.044	0.020	0.021	0.056	0.033	0.050	0.093	0.037	0.037	0.046	0.041	0.018
24	0.019	0.032	0.044	0.056	0.036	0.056	0.087	0.057	0.083	0.044	0.056	0.021
25	0.054	0.025	0.018	0.020	0.085	0.037	0.044	0.012	0.053	0.060	0.040	0.072
26	0.030	0.024	0.050	0.184	0.079	0.032	0.042	0.025	0.065	0.014	0.040	0.065
27	0.026	0.032	0.005	0.084	0.022	0.063	0.096	0.044	0.047	0.044	0.051	0.020
28	0.047	0.062	0.024	0.050	0.048	0.067	0.021	0.077	0.065	0.061	0.035	0.032
29	0.042	0.040	0.043	0.054	0.073	0.026	0.079	0.148	0.063	0.030	0.048	0.090
30	0.024	0.050	0.014	0.040	0.044	0.054	0.013	0.032	0.010	0.043	0.030	0.097
31	0.028	0.035	0.023	0.058	0.050	0.061	0.039	0.024	0.078	0.020	0.036	0.035
32	0.020	0.061	0.033	0.042	0.082	0.034	0.110	0.082	0.038	0.059	0.038	0.045
33	0.040	0.019	0.030	0.033	0.069	0.021	0.040	0.044	0.041	0.085	0.052	0.031
34	0.037	0.058	0.030	0.040	0.090	0.055	0.087	0.025	0.070	0.052	0.032	0.026
35	0.024	0.016	0.026	0.053	0.033	0.067	0.044	0.044	0.021	0.142	0.061	0.026
36	0.028	0.046	0.073	0.097	0.036	0.070	0.042	0.077	0.077	0.039	0.046	0.039
37	0.020	0.107	0.043	0.058	0.085	0.032	0.096	0.148	0.096	0.046	0.063	0.044
38	0.040	0.054	0.052	0.042	0.079	0.063	0.021	0.032	0.029	0.044	0.038	0.055
39	0.037	0.046	0.033	0.033	0.022	0.027	0.079	0.077	0.039	0.060	0.056	0.079
40	0.098	0.012	0.021	0.040	0.048	0.034	0.013	0.148	0.064	0.014	0.040	0.030

41	0.054	0.020	0.044	0.053	0.090	0.021	0.039	0.032	0.038	0.044	0.040	0.018
42	0.051	0.022	0.018	0.029	0.019	0.055	0.089	0.024	0.037	0.006	0.036	0.021
43	0.093	0.061	0.050	0.060	0.053	0.067	0.079	0.018	0.083	0.044	0.038	0.072
44	0.042	0.058	0.005	0.029	0.040	0.070	0.013	0.148	0.053	0.034	0.052	0.065
45	0.042	0.016	0.094	0.060	0.043	0.037	0.039	0.032	0.065	0.054	0.032	0.020
46	0.009	0.014	0.040	0.020	0.054	0.032	0.089	0.024	0.047	0.023	0.048	0.154
47	0.039	0.052	0.050	0.026	0.090	0.063	0.154	0.082	0.047	0.046	0.044	0.085
48	0.014	0.042	0.013	0.056	0.085	0.067	0.063	0.044	0.065	0.044	0.035	0.067
49	0.040	0.020	0.032	0.056	0.079	0.026	0.052	0.025	0.063	0.060	0.042	0.009
50	0.037	0.032	0.012	0.020	0.022	0.054	0.086	0.044	0.010	0.014	0.064	0.033
51	0.024	0.035	0.021	0.054	0.048	0.021	0.037	0.077	0.078	0.044	0.042	0.018
52	0.028	0.061	0.043	0.030	0.073	0.055	0.080	0.148	0.038	0.061	0.060	0.021
53	0.020	0.019	0.014	0.010	0.044	0.067	0.164	0.032	0.041	0.030	0.041	0.072
54	0.040	0.058	0.023	0.023	0.050	0.070	0.182	0.024	0.070	0.043	0.056	0.065
55	0.037	0.016	0.033	0.084	0.082	0.032	0.127	0.018	0.021	0.059	0.040	0.020
56	0.098	0.046	0.030	0.050	0.069	0.063	0.110	0.077	0.038	0.085	0.038	0.032
57	0.054	0.052	0.030	0.054	0.090	0.027	0.040	0.148	0.037	0.052	0.052	0.018
58	0.051	0.042	0.026	0.040	0.033	0.034	0.087	0.032	0.083	0.027	0.032	0.021
59	0.093	0.020	0.073	0.010	0.036	0.067	0.044	0.024	0.053	0.013	0.061	0.072
60	0.040	0.019	0.043	0.023	0.085	0.070	0.042	0.018	0.065	0.020	0.046	0.065

Table 8: The Repeatability of MATT Tiles Measured Under Specular Component Included Mode By SF-600 Over 60 Weeks

Week	Pale Grey	Middel Grey	Diff. Grey	Deep Grey	Deep Pink	Red	Orange	Bright Yellow	Green	Diff. Green	Cyan	Deep Blue
1	0.075	0.067	0.073	0.075	0.058	0.036	0.015	0.147	0.100	0.034	0.044	0.071
2	0.025	0.026	0.042	0.051	0.088	0.041	0.089	0.051	0.063	0.053	0.020	0.066
3	0.046	0.044	0.061	0.057	0.020	0.064	0.088	0.097	0.087	0.015	0.038	0.067
4	0.009	0.050	0.011	0.012	0.077	0.022	0.104	0.017	0.013	0.046	0.018	0.013
5	0.025	0.016	0.061	0.081	0.022	0.076	0.037	0.069	0.072	0.047	0.026	0.083
6	0.019	0.019	0.016	0.012	0.032	0.070	0.093	0.055	0.046	0.051	0.023	0.017
7	0.017	0.027	0.009	0.003	0.053	0.091	0.015	0.103	0.062	0.081	0.053	0.047
8	0.029	0.010	0.036	0.022	0.034	0.074	0.089	0.030	0.041	0.057	0.026	0.042
9	0.008	0.038	0.013	0.031	0.076	0.050	0.088	0.096	0.101	0.056	0.040	0.027
10	0.041	0.008	0.057	0.065	0.037	0.038	0.120	0.052	0.027	0.037	0.030	0.075
11	0.008	0.017	0.027	0.027	0.034	0.041	0.056	0.030	0.025	0.056	0.022	0.033
12	0.021	0.036	0.021	0.023	0.059	0.066	0.081	0.113	0.065	0.054	0.035	0.047
13	0.022	0.035	0.043	0.041	0.078	0.060	0.091	0.084	0.068	0.049	0.026	0.049
14	0.013	0.026	0.051	0.061	0.054	0.050	0.042	0.045	0.042	0.024	0.023	0.071
15	0.018	0.024	0.038	0.058	0.072	0.061	0.100	0.057	0.054	0.043	0.015	0.065
16	0.017	0.015	0.040	0.057	0.039	0.017	0.087	0.027	0.034	0.062	0.019	0.063
17	0.016	0.014	0.039	0.032	0.054	0.061	0.025	0.052	0.026	0.044	0.035	0.015
18	0.008	0.027	0.028	0.034	0.060	0.047	0.059	0.048	0.047	0.029	0.056	0.046
19	0.063	0.066	0.037	0.043	0.086	0.055	0.029	0.137	0.094	0.085	0.039	0.054

20	0.023	0.017	0.087	0.067	0.027	0.047	0.085	0.042	0.035	0.049	0.058	0.073
21	0.023	0.030	0.027	0.033	0.055	0.012	0.058	0.034	0.039	0.071	0.040	0.041
22	0.017	0.026	0.024	0.020	0.054	0.041	0.074	0.039	0.058	0.028	0.033	0.037
23	0.025	0.027	0.046	0.046	0.032	0.091	0.044	0.096	0.046	0.049	0.017	0.057
24	0.019	0.010	0.073	0.081	0.053	0.074	0.059	0.052	0.062	0.024	0.023	0.017
25	0.017	0.038	0.042	0.012	0.034	0.050	0.035	0.030	0.041	0.043	0.053	0.047
26	0.029	0.008	0.061	0.003	0.076	0.038	0.056	0.113	0.101	0.062	0.026	0.042
27	0.008	0.017	0.011	0.022	0.037	0.041	0.081	0.084	0.027	0.044	0.040	0.027
28	0.041	0.036	0.016	0.031	0.034	0.066	0.091	0.147	0.025	0.029	0.030	0.075
29	0.075	0.035	0.009	0.065	0.059	0.066	0.042	0.051	0.065	0.085	0.022	0.033
30	0.025	0.026	0.036	0.027	0.078	0.060	0.100	0.097	0.068	0.034	0.035	0.047
31	0.046	0.024	0.013	0.023	0.054	0.050	0.087	0.017	0.100	0.053	0.026	0.049
32	0.009	0.026	0.057	0.041	0.072	0.061	0.025	0.069	0.063	0.015	0.023	0.071
33	0.025	0.024	0.027	0.075	0.039	0.017	0.059	0.055	0.087	0.046	0.015	0.065
34	0.019	0.015	0.021	0.051	0.054	0.061	0.029	0.137	0.013	0.047	0.044	0.071
35	0.017	0.014	0.043	0.057	0.054	0.047	0.085	0.042	0.072	0.051	0.020	0.065
36	0.029	0.027	0.051	0.012	0.060	0.055	0.058	0.034	0.046	0.056	0.038	0.063
37	0.008	0.066	0.038	0.081	0.086	0.047	0.015	0.039	0.062	0.037	0.018	0.015
38	0.041	0.017	0.040	0.012	0.027	0.012	0.089	0.096	0.041	0.056	0.026	0.046
39	0.008	0.030	0.039	0.003	0.055	0.041	0.088	0.052	0.042	0.054	0.023	0.054
40	0.008	0.026	0.028	0.022	0.054	0.091	0.120	0.030	0.054	0.049	0.053	0.073

41	0.021	0.027	0.061	0.031	0.032	0.074	0.056	0.113	0.034	0.024	0.026	0.041
42	0.022	0.010	0.011	0.041	0.053	0.036	0.081	0.084	0.026	0.043	0.040	0.037
43	0.013	0.038	0.061	0.061	0.034	0.041	0.091	0.147	0.047	0.049	0.035	0.057
44	0.018	0.067	0.016	0.058	0.076	0.064	0.059	0.051	0.094	0.024	0.026	0.017
45	0.017	0.026	0.009	0.057	0.037	0.022	0.029	0.097	0.035	0.043	0.023	0.047
46	0.016	0.044	0.036	0.032	0.058	0.076	0.085	0.017	0.039	0.062	0.015	0.042
47	0.008	0.050	0.013	0.034	0.088	0.070	0.058	0.069	0.058	0.044	0.019	0.027
48	0.063	0.016	0.051	0.043	0.020	0.091	0.074	0.017	0.046	0.029	0.035	0.071
49	0.023	0.019	0.038	0.081	0.077	0.074	0.044	0.069	0.062	0.085	0.056	0.066
50	0.008	0.027	0.040	0.012	0.022	0.050	0.059	0.055	0.062	0.049	0.039	0.067
51	0.021	0.010	0.039	0.003	0.032	0.041	0.035	0.103	0.041	0.071	0.058	0.013
52	0.022	0.038	0.028	0.022	0.053	0.066	0.056	0.030	0.101	0.028	0.040	0.083
53	0.013	0.008	0.037	0.031	0.034	0.066	0.081	0.096	0.027	0.049	0.033	0.017
54	0.018	0.017	0.087	0.065	0.076	0.060	0.091	0.052	0.025	0.024	0.017	0.047
55	0.017	0.036	0.027	0.027	0.037	0.050	0.042	0.030	0.013	0.043	0.026	0.042
56	0.025	0.035	0.024	0.023	0.034	0.061	0.056	0.113	0.072	0.062	0.023	0.027
57	0.046	0.027	0.046	0.041	0.059	0.017	0.081	0.084	0.046	0.051	0.053	0.075
58	0.063	0.066	0.073	0.075	0.039	0.061	0.091	0.096	0.062	0.056	0.026	0.033
59	0.023	0.017	0.042	0.003	0.054	0.074	0.042	0.052	0.041	0.037	0.040	0.047
60	0.023	0.030	0.038	0.022	0.054	0.036	0.100	0.113	0.041	0.056	0.030	0.037

Table 9: The Repeatability of GLOSSY Tiles Measured Under Specular Component Excluded Mode By CE-7000A Over 60 Weeks

Week	Pale Grey	Middel Grey	Diff. Grey	Deep Grey	Deep Pink	Red	Orange	Bright Yellow	Green	Diff. Green	Cyan	Deep Blue
1	0.014	0.033	0.026	0.120	0.054	0.354	0.141	0.195	0.010	0.028	0.061	0.386
2	0.011	0.019	0.010	0.070	0.005	0.499	0.120	0.207	0.038	0.061	0.081	0.481
3	0.044	0.022	0.019	0.067	0.033	0.327	0.144	0.177	0.047	0.042	0.053	0.526
4	0.019	0.031	0.032	0.075	0.035	0.378	0.062	0.062	0.050	0.059	0.052	0.028
5	0.043	0.034	0.033	0.088	0.038	0.349	0.136	0.209	0.024	0.030	0.065	0.457
6	0.007	0.022	0.020	0.094	0.035	0.347	0.092	0.117	0.050	0.044	0.046	0.333
7	0.011	0.019	0.016	0.106	0.039	0.327	0.088	0.124	0.055	0.080	0.080	0.278
8	0.018	0.017	0.033	0.103	0.066	0.378	0.154	0.147	0.076	0.071	0.037	0.497
9	0.008	0.012	0.036	0.080	0.052	0.202	0.178	0.180	0.066	0.064	0.038	0.425
10	0.022	0.016	0.016	0.070	0.074	0.424	0.096	0.175	0.022	0.048	0.066	0.397
11	0.008	0.026	0.022	0.067	0.052	0.398	0.115	0.117	0.032	0.047	0.038	0.267
12	0.019	0.022	0.021	0.076	0.057	0.181	0.088	0.142	0.067	0.057	0.055	0.546
13	0.029	0.014	0.019	0.100	0.048	0.350	0.133	0.137	0.056	0.060	0.070	0.328
14	0.013	0.022	0.028	0.077	0.029	0.284	0.130	0.202	0.051	0.051	0.065	0.527
15	0.007	0.019	0.018	0.065	0.061	0.260	0.108	0.118	0.054	0.062	0.048	0.398
16	0.031	0.017	0.009	0.092	0.051	0.300	0.087	0.123	0.038	0.026	0.039	0.346
17	0.020	0.012	0.011	0.090	0.038	0.354	0.138	0.120	0.055	0.050	0.031	0.369
18	0.015	0.016	0.015	0.086	0.035	0.499	0.127	0.215	0.043	0.064	0.068	0.398
19	0.013	0.026	0.012	0.073	0.067	0.327	0.089	0.130	0.028	0.054	0.031	0.345

20	0.017	0.019	0.005	0.082	0.032	0.378	0.074	0.151	0.050	0.050	0.061	0.362
21	0.015	0.017	0.016	0.081	0.048	0.202	0.149	0.112	0.032	0.040	0.036	0.404
22	0.016	0.012	0.016	0.086	0.034	0.240	0.179	0.202	0.095	0.065	0.056	0.404
23	0.019	0.016	0.018	0.106	0.064	0.459	0.141	0.209	0.055	0.088	0.064	0.028
24	0.043	0.026	0.020	0.103	0.066	0.256	0.120	0.117	0.043	0.044	0.039	0.457
25	0.007	0.022	0.016	0.080	0.052	0.301	0.144	0.124	0.028	0.080	0.031	0.333
26	0.011	0.006	0.033	0.070	0.074	0.432	0.062	0.147	0.050	0.071	0.068	0.278
27	0.018	0.032	0.036	0.067	0.052	0.349	0.136	0.180	0.032	0.064	0.031	0.497
28	0.008	0.022	0.016	0.076	0.057	0.347	0.092	0.175	0.055	0.048	0.061	0.425
29	0.022	0.009	0.022	0.100	0.029	0.264	0.127	0.117	0.076	0.047	0.036	0.397
30	0.008	0.019	0.021	0.077	0.061	0.392	0.089	0.142	0.066	0.057	0.056	0.267
31	0.014	0.014	0.019	0.120	0.051	0.343	0.074	0.195	0.022	0.060	0.064	0.546
32	0.011	0.014	0.028	0.070	0.038	0.300	0.149	0.207	0.032	0.051	0.061	0.386
33	0.044	0.033	0.018	0.067	0.035	0.354	0.179	0.177	0.067	0.062	0.081	0.481
34	0.019	0.019	0.009	0.075	0.067	0.499	0.092	0.062	0.056	0.026	0.053	0.526
35	0.043	0.022	0.010	0.088	0.032	0.327	0.088	0.209	0.051	0.050	0.052	0.028
36	0.007	0.031	0.019	0.094	0.005	0.378	0.154	0.202	0.054	0.064	0.065	0.457
37	0.008	0.034	0.032	0.065	0.033	0.459	0.178	0.118	0.010	0.064	0.046	0.346
38	0.019	0.022	0.033	0.092	0.035	0.256	0.096	0.123	0.038	0.054	0.066	0.369
39	0.029	0.019	0.020	0.090	0.038	0.301	0.115	0.120	0.047	0.050	0.038	0.398
40	0.013	0.026	0.016	0.086	0.035	0.432	0.088	0.215	0.050	0.040	0.055	0.345

41	0.007	0.022	0.033	0.073	0.039	0.349	0.133	0.130	0.024	0.065	0.070	0.362
42	0.031	0.006	0.036	0.082	0.066	0.347	0.130	0.215	0.043	0.088	0.065	0.404
43	0.007	0.032	0.016	0.081	0.074	0.264	0.108	0.130	0.028	0.044	0.048	0.404
44	0.031	0.022	0.022	0.086	0.052	0.349	0.088	0.151	0.050	0.080	0.039	0.028
45	0.020	0.009	0.018	0.073	0.057	0.347	0.133	0.112	0.032	0.028	0.031	0.497
46	0.015	0.019	0.020	0.082	0.048	0.327	0.130	0.202	0.055	0.061	0.068	0.425
47	0.013	0.014	0.016	0.081	0.029	0.378	0.108	0.175	0.076	0.042	0.031	0.397
48	0.017	0.014	0.033	0.086	0.061	0.202	0.087	0.117	0.066	0.059	0.046	0.267
49	0.015	0.033	0.036	0.106	0.051	0.424	0.138	0.112	0.022	0.030	0.080	0.546
50	0.016	0.019	0.016	0.103	0.038	0.398	0.127	0.202	0.032	0.044	0.037	0.328
51	0.019	0.016	0.022	0.080	0.035	0.347	0.089	0.209	0.067	0.080	0.038	0.527
52	0.043	0.026	0.021	0.070	0.067	0.264	0.074	0.117	0.038	0.071	0.066	0.481
53	0.007	0.022	0.019	0.067	0.066	0.392	0.144	0.124	0.055	0.050	0.038	0.526
54	0.011	0.014	0.028	0.076	0.052	0.343	0.062	0.147	0.043	0.064	0.055	0.028
55	0.031	0.022	0.018	0.100	0.074	0.300	0.136	0.180	0.028	0.054	0.053	0.457
56	0.007	0.019	0.009	0.076	0.052	0.354	0.092	0.175	0.050	0.050	0.052	0.369
57	0.031	0.017	0.010	0.100	0.057	0.499	0.127	0.062	0.032	0.040	0.065	0.398
58	0.020	0.012	0.019	0.077	0.029	0.327	0.089	0.209	0.095	0.065	0.046	0.345
59	0.017	0.016	0.032	0.120	0.061	0.378	0.074	0.202	0.055	0.088	0.066	0.362
60	0.015	0.026	0.033	0.070	0.051	0.424	0.149	0.120	0.043	0.044	0.038	0.546

Table 10: The Repeatability of GLOSSY Tiles Measured Under Specular Component Included Mode By CE-7000A Over 60 Weeks

Week	Pale Grey	Middel Grey	Diff. Grey	Deep Grey	Deep Pink	Red	Orange	Bright Yellow	Green	Diff. Green	Cyan	Deep Blue
1	0.022	0.012	0.014	0.050	0.037	0.054	0.081	0.113	0.040	0.060	0.061	0.088
2	0.043	0.034	0.031	0.038	0.053	0.050	0.112	0.091	0.028	0.016	0.032	0.133
3	0.037	0.012	0.037	0.014	0.041	0.037	0.105	0.086	0.018	0.014	0.032	0.096
4	0.007	0.019	0.013	0.038	0.035	0.022	0.014	0.127	0.021	0.028	0.062	0.068
5	0.018	0.017	0.016	0.044	0.020	0.030	0.072	0.115	0.010	0.018	0.027	0.096
6	0.023	0.032	0.013	0.032	0.027	0.019	0.085	0.130	0.027	0.025	0.021	0.104
7	0.021	0.011	0.014	0.048	0.021	0.083	0.077	0.100	0.013	0.012	0.042	0.099
8	0.018	0.015	0.033	0.031	0.045	0.038	0.115	0.121	0.091	0.084	0.032	0.097
9	0.006	0.025	0.015	0.047	0.009	0.076	0.080	0.074	0.018	0.028	0.036	0.098
10	0.014	0.025	0.025	0.047	0.010	0.040	0.103	0.154	0.031	0.027	0.048	0.045
11	0.009	0.019	0.012	0.059	0.039	0.087	0.062	0.091	0.019	0.011	0.062	0.124
12	0.011	0.017	0.028	0.026	0.039	0.030	0.065	0.086	0.052	0.064	0.052	0.125
13	0.033	0.020	0.032	0.052	0.030	0.054	0.087	0.130	0.020	0.033	0.043	0.060
14	0.016	0.010	0.028	0.053	0.043	0.069	0.089	0.091	0.033	0.058	0.039	0.114
15	0.018	0.012	0.033	0.023	0.021	0.011	0.055	0.141	0.014	0.038	0.038	0.100
16	0.007	0.034	0.010	0.048	0.015	0.032	0.099	0.106	0.024	0.023	0.027	0.103
17	0.017	0.012	0.012	0.036	0.020	0.036	0.057	0.074	0.043	0.020	0.046	0.096
18	0.034	0.024	0.008	0.019	0.033	0.046	0.069	0.125	0.048	0.045	0.048	0.098
19	0.027	0.021	0.025	0.044	0.033	0.054	0.093	0.003	0.054	0.048	0.059	0.121

20	0.013	0.027	0.023	0.028	0.016	0.035	0.085	0.113	0.023	0.056	0.041	0.096
21	0.004	0.025	0.018	0.037	0.025	0.025	0.098	0.100	0.017	0.032	0.038	0.095
22	0.006	0.025	0.022	0.044	0.032	0.055	0.073	0.085	0.051	0.020	0.046	0.127
23	0.014	0.032	0.017	0.032	0.039	0.038	0.072	0.142	0.031	0.042	0.027	0.068
24	0.021	0.011	0.013	0.048	0.039	0.076	0.085	0.091	0.019	0.033	0.021	0.096
25	0.018	0.015	0.014	0.031	0.030	0.040	0.077	0.086	0.052	0.058	0.042	0.104
26	0.006	0.006	0.033	0.047	0.043	0.087	0.115	0.127	0.020	0.038	0.032	0.099
27	0.014	0.018	0.015	0.047	0.021	0.030	0.080	0.115	0.033	0.023	0.036	0.097
28	0.009	0.021	0.025	0.059	0.020	0.054	0.103	0.130	0.014	0.020	0.048	0.098
29	0.011	0.005	0.012	0.026	0.027	0.069	0.062	0.100	0.024	0.045	0.062	0.045
30	0.033	0.019	0.028	0.052	0.021	0.036	0.099	0.121	0.021	0.048	0.043	0.124
31	0.007	0.012	0.032	0.053	0.045	0.046	0.057	0.113	0.010	0.056	0.039	0.125
32	0.017	0.034	0.028	0.023	0.039	0.054	0.069	0.091	0.027	0.032	0.038	0.088
33	0.034	0.012	0.014	0.048	0.039	0.035	0.093	0.086	0.013	0.060	0.027	0.133
34	0.027	0.024	0.031	0.036	0.030	0.025	0.081	0.127	0.091	0.016	0.046	0.096
35	0.023	0.021	0.037	0.019	0.043	0.055	0.112	0.115	0.018	0.014	0.048	0.068
36	0.021	0.027	0.013	0.044	0.021	0.038	0.105	0.130	0.031	0.028	0.059	0.096
37	0.018	0.025	0.016	0.028	0.015	0.076	0.014	0.100	0.040	0.018	0.061	0.104
38	0.006	0.025	0.013	0.037	0.020	0.040	0.072	0.121	0.028	0.025	0.032	0.114
39	0.022	0.032	0.014	0.050	0.037	0.087	0.085	0.100	0.018	0.012	0.032	0.100
40	0.043	0.011	0.033	0.038	0.053	0.054	0.077	0.085	0.021	0.084	0.062	0.103

41	0.037	0.015	0.015	0.014	0.041	0.050	0.115	0.142	0.010	0.028	0.027	0.096
42	0.007	0.025	0.012	0.038	0.035	0.037	0.085	0.091	0.027	0.023	0.021	0.098
43	0.018	0.019	0.008	0.044	0.033	0.022	0.077	0.089	0.051	0.020	0.042	0.121
44	0.017	0.017	0.025	0.032	0.033	0.030	0.115	0.130	0.031	0.045	0.032	0.096
45	0.034	0.020	0.023	0.048	0.016	0.019	0.080	0.091	0.019	0.048	0.036	0.095
46	0.027	0.010	0.018	0.036	0.025	0.038	0.085	0.141	0.052	0.056	0.048	0.127
47	0.023	0.012	0.022	0.019	0.021	0.076	0.077	0.106	0.020	0.032	0.062	0.096
48	0.021	0.006	0.017	0.044	0.045	0.040	0.115	0.074	0.033	0.020	0.036	0.095
49	0.018	0.018	0.013	0.028	0.039	0.087	0.080	0.091	0.014	0.042	0.048	0.127
50	0.034	0.021	0.014	0.037	0.039	0.030	0.103	0.089	0.019	0.060	0.062	0.068
51	0.027	0.005	0.033	0.044	0.053	0.054	0.062	0.130	0.052	0.016	0.043	0.096
52	0.018	0.019	0.017	0.032	0.041	0.069	0.085	0.091	0.020	0.014	0.039	0.104
53	0.006	0.012	0.013	0.048	0.025	0.036	0.077	0.141	0.033	0.028	0.038	0.099
54	0.014	0.034	0.014	0.031	0.032	0.046	0.115	0.086	0.014	0.018	0.027	0.097
55	0.009	0.019	0.033	0.047	0.039	0.054	0.080	0.127	0.024	0.025	0.046	0.088
56	0.011	0.017	0.015	0.047	0.039	0.083	0.081	0.115	0.043	0.012	0.048	0.133
57	0.033	0.020	0.025	0.059	0.030	0.038	0.112	0.130	0.048	0.084	0.048	0.096
58	0.016	0.010	0.012	0.026	0.043	0.076	0.105	0.100	0.021	0.028	0.059	0.068
59	0.018	0.012	0.028	0.038	0.021	0.040	0.014	0.121	0.010	0.028	0.061	0.096
60	0.007	0.034	0.032	0.014	0.015	0.087	0.072	0.130	0.027	0.023	0.032	0.104

Table 11: The Repeatability of MATT Tiles Measured Under Specular Component Excluded Mode By CE-7000A Over 60 Weeks

Week	Pale Grey	Middel Grey	Diff. Grey	Deep Grey	Deep Pink	Red	Orange	Bright Yellow	Green	Diff. Green	Cyan	Deep Blue
1	0.029	0.026	0.049	0.063	0.068	0.064	0.117	0.024	0.054	0.055	0.089	0.054
2	0.014	0.024	0.013	0.068	0.059	0.046	0.098	0.045	0.028	0.029	0.040	0.080
3	0.031	0.010	0.036	0.029	0.055	0.031	0.174	0.030	0.012	0.047	0.075	0.080
4	0.016	0.034	0.015	0.026	0.032	0.017	0.091	0.017	0.026	0.028	0.008	0.100
5	0.077	0.010	0.025	0.019	0.029	0.087	0.137	0.052	0.061	0.035	0.088	0.051
6	0.019	0.023	0.031	0.051	0.046	0.053	0.058	0.086	0.058	0.058	0.042	0.066
7	0.016	0.031	0.028	0.046	0.045	0.068	0.112	0.020	0.019	0.031	0.031	0.061
8	0.019	0.018	0.044	0.055	0.032	0.067	0.072	0.074	0.048	0.047	0.058	0.067
9	0.006	0.024	0.020	0.045	0.068	0.106	0.231	0.067	0.058	0.062	0.042	0.091
10	0.029	0.025	0.052	0.051	0.052	0.062	0.089	0.038	0.049	0.033	0.064	0.054
11	0.014	0.038	0.051	0.059	0.060	0.060	0.092	0.056	0.059	0.040	0.037	0.080
12	0.031	0.038	0.015	0.022	0.040	0.048	0.111	0.023	0.035	0.040	0.046	0.080
13	0.016	0.022	0.017	0.049	0.046	0.047	0.104	0.038	0.048	0.062	0.044	0.100
14	0.012	0.022	0.040	0.041	0.050	0.051	0.107	0.056	0.050	0.018	0.034	0.051
15	0.010	0.024	0.034	0.031	0.032	0.034	0.059	0.050	0.037	0.027	0.056	0.063
16	0.077	0.021	0.040	0.055	0.047	0.066	0.135	0.074	0.079	0.043	0.046	0.064
17	0.019	0.030	0.013	0.028	0.022	0.040	0.079	0.067	0.034	0.056	0.040	0.051
18	0.019	0.005	0.054	0.071	0.062	0.063	0.088	0.077	0.051	0.026	0.041	0.058
19	0.040	0.038	0.018	0.034	0.050	0.041	0.137	0.025	0.059	0.007	0.047	0.077

20	0.057	0.012	0.036	0.059	0.050	0.061	0.061	0.091	0.048	0.014	0.033	0.065
21	0.017	0.018	0.030	0.042	0.049	0.056	0.111	0.086	0.051	0.029	0.042	0.066
22	0.008	0.013	0.026	0.047	0.040	0.054	0.120	0.020	0.065	0.028	0.045	0.061
23	0.013	0.028	0.044	0.019	0.052	0.106	0.137	0.074	0.058	0.031	0.064	0.075
24	0.018	0.010	0.020	0.051	0.060	0.062	0.058	0.067	0.019	0.047	0.037	0.066
25	0.038	0.023	0.052	0.046	0.040	0.060	0.112	0.038	0.048	0.062	0.046	0.061
26	0.050	0.031	0.051	0.055	0.046	0.048	0.072	0.056	0.058	0.033	0.044	0.067
27	0.011	0.018	0.015	0.068	0.050	0.047	0.231	0.050	0.049	0.040	0.034	0.091
28	0.025	0.021	0.034	0.029	0.032	0.051	0.089	0.079	0.012	0.040	0.008	0.054
29	0.019	0.030	0.040	0.026	0.047	0.040	0.092	0.040	0.026	0.062	0.088	0.080
30	0.029	0.005	0.013	0.019	0.032	0.063	0.174	0.077	0.061	0.018	0.042	0.051
31	0.014	0.038	0.036	0.051	0.029	0.041	0.091	0.025	0.058	0.027	0.031	0.058
32	0.031	0.012	0.015	0.046	0.068	0.061	0.137	0.091	0.034	0.018	0.058	0.077
33	0.016	0.018	0.025	0.022	0.059	0.047	0.089	0.086	0.051	0.027	0.089	0.065
34	0.012	0.026	0.015	0.049	0.055	0.051	0.092	0.020	0.059	0.043	0.040	0.066
35	0.010	0.024	0.017	0.041	0.032	0.034	0.111	0.074	0.048	0.056	0.075	0.061
36	0.019	0.010	0.040	0.031	0.029	0.066	0.104	0.067	0.051	0.026	0.008	0.087
37	0.019	0.034	0.034	0.055	0.046	0.040	0.107	0.087	0.012	0.007	0.088	0.084
38	0.040	0.010	0.049	0.028	0.040	0.063	0.117	0.048	0.026	0.014	0.058	0.020
39	0.057	0.023	0.013	0.071	0.046	0.064	0.098	0.032	0.061	0.029	0.042	0.060
40	0.017	0.023	0.036	0.063	0.050	0.046	0.174	0.058	0.058	0.028	0.064	0.075

41	0.008	0.031	0.015	0.068	0.032	0.031	0.091	0.023	0.019	0.058	0.037	0.100
42	0.013	0.018	0.025	0.029	0.047	0.017	0.137	0.038	0.048	0.031	0.046	0.051
43	0.016	0.024	0.031	0.026	0.046	0.061	0.058	0.056	0.058	0.047	0.044	0.063
44	0.019	0.025	0.018	0.019	0.050	0.056	0.120	0.050	0.058	0.062	0.034	0.064
45	0.006	0.038	0.036	0.051	0.032	0.054	0.137	0.024	0.049	0.033	0.056	0.051
46	0.029	0.038	0.030	0.059	0.047	0.106	0.058	0.045	0.012	0.040	0.047	0.058
47	0.014	0.022	0.026	0.022	0.022	0.062	0.112	0.030	0.026	0.055	0.033	0.077
48	0.008	0.012	0.044	0.049	0.062	0.060	0.174	0.017	0.061	0.029	0.042	0.065
49	0.013	0.018	0.044	0.041	0.050	0.048	0.091	0.052	0.058	0.047	0.045	0.077
50	0.018	0.013	0.020	0.031	0.050	0.087	0.137	0.077	0.034	0.028	0.064	0.065
51	0.038	0.028	0.052	0.055	0.032	0.053	0.089	0.025	0.049	0.062	0.037	0.066
52	0.050	0.021	0.051	0.046	0.068	0.068	0.120	0.091	0.059	0.018	0.046	0.061
53	0.011	0.030	0.015	0.055	0.052	0.067	0.137	0.086	0.035	0.027	0.044	0.087
54	0.025	0.005	0.017	0.045	0.060	0.106	0.058	0.020	0.048	0.018	0.034	0.084
55	0.018	0.012	0.040	0.051	0.040	0.061	0.112	0.074	0.050	0.027	0.046	0.020
56	0.038	0.018	0.034	0.049	0.032	0.056	0.072	0.067	0.037	0.058	0.040	0.063
57	0.050	0.010	0.040	0.041	0.047	0.054	0.098	0.087	0.079	0.031	0.041	0.064
58	0.011	0.023	0.013	0.031	0.032	0.106	0.174	0.048	0.026	0.018	0.047	0.051
59	0.025	0.023	0.054	0.055	0.047	0.062	0.091	0.032	0.061	0.027	0.033	0.058
60	0.019	0.031	0.030	0.028	0.022	0.060	0.137	0.067	0.059	0.018	0.042	0.077

Table 12: The Repeatability of MATT Tiles Measured Under Specular Component Included Mode By CE-7000A Over 60 Weeks

Week	Pale Grey	Middel Grey	Diff. Grey	Deep Grey	Deep Pink	Red	Orange	Bright Yellow	Green	Diff. Green	Cyan	Deep Blue
1	0.016	0.025	0.021	0.034	0.026	0.134	0.075	0.054	0.061	0.051	0.073	0.071
2	0.059	0.013	0.045	0.032	0.030	0.039	0.044	0.084	0.060	0.027	0.036	0.054
3	0.059	0.034	0.031	0.023	0.032	0.051	0.074	0.059	0.047	0.033	0.079	0.043
4	0.019	0.017	0.014	0.024	0.038	0.054	0.074	0.054	0.024	0.034	0.032	0.024
5	0.052	0.006	0.025	0.031	0.030	0.082	0.067	0.064	0.029	0.011	0.042	0.054
6	0.011	0.017	0.031	0.047	0.034	0.045	0.043	0.036	0.065	0.032	0.053	0.041
7	0.040	0.007	0.021	0.015	0.015	0.067	0.075	0.048	0.046	0.054	0.027	0.055
8	0.015	0.043	0.037	0.043	0.045	0.051	0.077	0.034	0.047	0.045	0.026	0.039
9	0.073	0.028	0.026	0.027	0.055	0.072	0.108	0.060	0.077	0.035	0.045	0.047
10	0.013	0.016	0.040	0.041	0.028	0.134	0.085	0.041	0.038	0.033	0.029	0.048
11	0.013	0.026	0.011	0.043	0.036	0.048	0.021	0.061	0.043	0.021	0.021	0.044
12	0.046	0.014	0.019	0.003	0.019	0.054	0.021	0.085	0.035	0.025	0.056	0.038
13	0.020	0.015	0.047	0.037	0.040	0.082	0.102	0.069	0.074	0.021	0.052	0.036
14	0.019	0.025	0.024	0.022	0.032	0.045	0.084		0.042	0.051	0.024	0.088
15	0.023	0.013	0.017	0.046	0.046	0.085	0.044		0.076	0.043	0.065	0.049
16	0.016	0.034	0.016	0.046	0.044	0.085	0.102		0.056	0.061	0.042	0.072
17	0.022	0.017	0.017	0.044	0.052	0.085	0.045		0.073	0.031	0.058	0.072
18	0.030	0.033	0.020	0.046	0.046	0.048	0.090		0.073	0.061	0.053	0.071
19	0.025	0.010	0.025	0.059	0.058	0.054	0.059		0.070	0.041	0.057	0.073

20	0.023	0.017	0.035	0.043	0.040	0.082	0.059	0.085	0.053	0.037	0.053	0.084
21	0.040	0.006	0.017	0.026	0.029	0.045	0.046	0.069	0.054	0.044	0.031	0.070
22	0.031	0.017	0.026	0.048	0.036	0.067	0.063	0.085	0.065	0.018	0.041	0.062
23	0.015	0.007	0.021	0.027	0.046	0.051	0.021	0.034	0.047	0.036	0.053	0.080
24	0.073	0.012	0.026	0.041	0.044	0.072	0.021	0.019	0.077	0.032	0.027	0.054
25	0.013	0.030	0.040	0.043	0.052	0.134	0.102	0.046	0.038	0.054	0.026	0.041
26	0.013	0.009	0.011	0.003	0.046	0.039	0.084	0.076	0.043	0.045	0.045	0.055
27	0.046	0.020	0.019	0.037	0.045	0.051	0.044	0.056	0.035	0.035	0.029	0.039
28	0.059	0.013	0.047	0.022	0.055	0.054	0.102	0.075	0.074	0.033	0.021	0.047
29	0.019	0.033	0.024	0.037	0.028	0.068	0.045	0.085	0.070	0.025	0.056	0.048
30	0.052	0.010	0.020	0.022	0.036	0.076	0.090	0.034	0.053	0.021	0.052	0.044
31	0.011	0.017	0.025	0.046	0.026	0.072	0.067	0.019	0.054	0.051	0.024	0.038
32	0.040	0.006	0.035	0.046	0.030	0.078	0.043	0.046	0.065	0.043	0.036	0.049
33	0.015	0.017	0.017	0.044	0.032	0.067	0.075	0.060	0.035	0.061	0.079	0.072
34	0.073	0.007	0.014	0.031	0.038	0.089	0.077	0.041	0.074	0.031	0.032	0.072
35	0.020	0.012	0.025	0.047	0.030	0.081	0.108	0.061	0.042	0.051	0.042	0.024
36	0.019	0.030	0.031	0.015	0.034	0.072	0.085	0.048	0.076	0.027	0.053	0.054
37	0.023	0.009	0.021	0.043	0.015	0.062	0.044	0.034	0.056	0.033	0.027	0.041
38	0.016	0.013	0.021	0.034	0.045	0.079	0.102	0.060	0.073	0.034	0.056	0.055
39	0.022	0.034	0.045	0.032	0.040	0.067	0.045	0.041	0.073	0.011	0.052	0.071
40	0.030	0.017	0.031	0.023	0.032	0.051	0.090	0.061	0.061	0.051	0.024	0.054

41	0.025	0.006	0.014	0.024	0.046	0.072	0.059	0.085	0.060	0.043	0.065	0.043
42	0.023	0.017	0.025	0.003	0.044	0.134	0.059	0.069	0.047	0.061	0.042	0.024
43	0.040	0.007	0.026	0.037	0.052	0.039	0.046	0.085	0.029	0.031	0.058	0.054
44	0.019	0.043	0.021	0.022	0.046	0.051	0.063	0.034	0.065	0.061	0.053	0.080
45	0.052	0.043	0.026	0.046	0.058	0.054	0.044	0.019	0.046	0.041	0.057	0.054
46	0.011	0.028	0.040	0.046	0.040	0.068	0.074	0.046	0.047	0.037	0.053	0.041
47	0.040	0.016	0.026	0.044	0.029	0.076	0.074	0.076	0.077	0.044	0.031	0.055
48	0.015	0.026	0.040	0.046	0.036	0.076	0.067	0.056	0.038	0.031	0.041	0.044
49	0.073	0.014	0.011	0.059	0.046	0.072	0.043	0.075	0.043	0.061	0.026	0.038
50	0.013	0.015	0.019	0.043	0.046	0.078	0.075	0.054	0.035	0.041	0.045	0.049
51	0.025	0.033	0.011	0.031	0.044	0.067	0.021	0.084	0.074	0.037	0.029	0.072
52	0.023	0.010	0.019	0.047	0.052	0.089	0.102	0.059	0.042	0.044	0.021	0.072
53	0.040	0.017	0.021	0.015	0.046	0.081	0.084	0.054	0.076	0.018	0.056	0.024
54	0.031	0.006	0.045	0.043	0.045	0.072	0.044	0.064	0.056	0.027	0.052	0.055
55	0.015	0.030	0.031	0.027	0.055	0.134	0.102	0.036	0.074	0.033	0.024	0.039
56	0.073	0.009	0.014	0.041	0.032	0.039	0.045	0.048	0.070	0.034	0.065	0.047
57	0.020	0.020	0.025	0.043	0.038	0.051	0.090	0.069	0.053	0.011	0.042	0.048
58	0.019	0.013	0.031	0.031	0.030	0.054	0.067	0.085	0.054	0.032	0.058	0.044
59	0.023	0.033	0.021	0.047	0.034	0.068	0.043	0.034	0.065	0.054	0.053	0.038
60	0.016	0.010	0.037	0.015	0.015	0.076	0.077	0.019	0.035	0.041	0.057	0.049