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Thorough characterization and analysis of a multispectral imaging system developed for colour measurement

Thesis

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13 Conclusions and Future Work

The main contributions achieved in the development of this work can be summarized in the following points:

1. An experimental methodology to correct the noise sources inherent to the performance of a CCD camera has been developed. This methodology establishes the fundamental stages to be followed in the correction of the several noise sources inherent to the performance of an imaging system based on a CCD camera.

2. A linear algorithm for the spatial non-uniformity correction of the system's response has been optimized. The algorithm optimized is based on the calculation of gain and offset matrixes from a dark image and a uniform field image. The optimization of this algorithm has been carried out depending on the variables of these matrixes. A correction gain matrix calculated at a certain radiance level (preferably a high radiance level – low exposure time range) is proved to allow to achieve a high quality spatial non-uniformity correction when applying the optimized algorithm to images corresponding to any radiance level (any exposure time range) and radiance spectrum, therefore proving the wide applicability of the optimized linear correction algorithm.

3. The spectral characterization of an imaging system based on a colour 10-bits CCD camera QImaging QICAM, and of the colorimetric configuration (3 acquisition channels) of an imaging system based on a monochrome 12-bits cooled CCD camera QImaging QICAM Fast 1394, has been carried out to determine their absolute and relative spectral sensitivity functions, being these last necessary to perform the colorimetric characterization of the imaging system based on spectral sensitivities.

4. The colorimetric characterization based on spectral sensitivities has been only applied to the imaging system based on a colour 10-bits CCD camera QImaging QICAM, and to the colorimetric configuration (3 acquisition channels) of the imaging system based on a monochrome 12-bits cooled CCD camera QImaging QICAM Fast 1394, due to its growing complexity when the number of acquisition channels is increased.

    - A quite low accuracy on the estimation of the XYZ tristimulus values is obtained for most of colour samples of the GretagMacbeth ColorChecker DC (CCDC) chart, for the two imaging systems considered.

    - Slightly better results are achieved using the monochrome 12-bits cooled CCD camera than using the colour 10-bits CCD camera.

    - The quite low accurate results obtained are due to the fact that, despite of all the steps on this method are very clear conceptually, their application involved several fittings of experimental data and simulations using parameters obtained from these fittings, which make it possible a considerably amount of errors to be easily accumulated on the estimations of the XYZ tristimulus values.

- The colorimetric characterization based on spectral sensitivities applied results to be a non-advisable method for colorimetric characterization.

5. Apart from the previously mentioned method based on the spectral sensitivities, applied only to the colorimetric configuration, two methods for colour measurement (colorimetric characterization) based on a training set of colour samples have been compared for the two configurations (colorimetric and multispectral) of the imaging system based on a monochrome 12-bits cooled CCD camera QImaging QICAM Fast 1394: the pseudoinverse method for XYZ (PSE_{XYZ}) and the second order non-linear method for XYZ ($NLIN(2)_{XYZ}$).

   - Best results are always obtained using the CCDC chart as training and test set.

   - The most advisable methods for colour measurement for the colorimetric configuration are the $NLIN(2)_{XYZ}$ and the PSE_{XYZ} methods. Both of them are recommended due to the fact that both lead to similar results when different sets of colour samples are used as training and test sets, which will be the more common situation for an imaging system that is going to be used as an instrument for colour measurement.

   - The most advisable method for colour measurement for the multispectral configuration is the PSE_{XYZ} method. The $NLIN(2)_{XYZ}$ method would be also advisable but it presents some restrictions on the minimum number of colour samples of the training set depending on the number of acquisition channels of the imaging system.

   - Comparing both configurations, better results are obtained using the PSE_{XYZ} and $NLIN(2)_{XYZ}$ methods for the multispectral configuration than for the colorimetric configuration.

6. Three methods for spectral reconstruction have been compared for the two configurations (colorimetric and multispectral) of the imaging system based on a monochrome 12-bits cooled CCD camera QImaging QICAM Fast 1394: the pseudoinverse method (PSE), the second order non-linear method (NLIN(2)), and the Principal Component Analysis (PCA).

   - Best results, in terms of accuracy of both colour measurement and spectral reconstruction, are always obtained using the CCDC chart as training and test set.

   - The most advisable method for spectral reconstruction for the colorimetric configuration, in terms of accuracy of both colour measurement and spectral reconstruction, is the NLIN(2), followed by the PSE method.

   - The most advisable methods for spectral reconstruction for the multispectral configuration, in terms of accuracy of both colour measurement and spectral reconstruction, are the PSE and the PCA methods. Just as for methods for colour measurement, the NLIN(2) method would be also advisable but it is not considered because of having restrictions on the minimum number of colour samples of the training set, depending on the number of acquisition channels of the imaging system, which seriously limits its applicability.

- Comparing both configurations, better results are obtained using the PSE, NLIN(2) and PCA methods for the multispectral configuration than for the colorimetric configuration.

7. Methods finally selected to characterize the imaging system are methods for spectral reconstruction for the two configurations of the imaging system. These methods allow one to perform not only colour measurement, but also spectral reconstruction of reflectance and/or radiance spectra, providing a complete information about the colour independently of the illuminant and the colour space used. The PSE method is selected for the colorimetric configuration for its wide applicability independently of the training set considered, and the PCA method is selected for the multispectral configuration because of performing rather similarly to the PSE method and being commonly used in literature for multispectral imaging systems.

8. The influence of the number of principal vectors considered as a basis of the reflectance spectra when applying the PCA method on system's performance has been analyzed for the multispectral configuration. Neither the accuracy of colour measurement nor the accuracy of spectral reconstruction is significantly improved by increasing the number of principal components in the PCA basis from the number of acquisition channels on. Therefore, the minimum number of principal vectors that must be considered in the PCA basis in order to achieve the best system's performance using the PCA method, in terms of accuracy of both colour measurement and spectral reconstruction, should be equal to the number of acquisition channels, as it is traditionally done in literature.

9. A Luminance Adaptation Model (LAM) has been proposed to increase the dynamic range of the imaging system which is actually limited by the useful (linear) dynamic range of the CCD camera used. This model is based on capturing images at different exposure times in order to obtain useful digital levels for all pixels in the image, which are subsequently transformed to a reference exposure time common to all pixels.

   - The LAM proposed, apart from its proved validity for limited exposure conditions, is also proved to be a very useful method to increase the dynamic range of the imaging system, allowing to widen its applicability to images having zones with extreme exposure conditions, for the two configurations of the imaging system.

   - The application of the LAM proposed is greatly advisable mainly on images having zones with an outstandingly wide range of exposures, in order to make useful all zones over the image, either for colour measurement or for spectral reconstruction.

10. The influence of the number of samples of the training set on the accuracy of colour measurement and spectral reconstruction has been analyzed, not only considering the system's performance depending on the size of the training set, but also considering

the dependency of system's performance on the concrete set of colour samples of the training set for each size. System's performance seems to become independent of the training set used, in terms of both the number of samples of the training set and the training set itself, when increasing the number of samples over 110 samples for the colorimetric configuration, and over 120 samples for the multispectral configuration, proving the existence of a minimum and/or 'sufficient number of colour samples' for both configurations of the imaging system. These results hold in terms of accuracy of both colour measurement and spectral reconstruction.

11. Colour measurement and spectral reconstruction performed using both configurations of the imaging system have been analyzed depending on the colour ranges measured, using an incandescent lamp illuminant and a D65 simulator illuminant, and the same set of colour samples as training and test sets.

    - Accuracy of colour measurement and spectral reconstruction is proved to depend not only on the illuminant but also on the training and test sets considered.

    - Comparing results obtained using all Munsell's colour patches and sets of Munsell's colour patches grouped in hues and sub-hues as training and test sets, homogeneity in hue of the training set allows to improve outstandingly the accuracy of both colour measurement and spectral reconstruction for all colour ranges.

    - Comparing results obtained using a multi-colour range CCDC chart and sets of Munsell's hues and sub-hues as training and test sets, homogeneity in hue of the training set does not assure an improvement in accuracy neither of colour measurement nor of spectral reconstruction, for all colour ranges.

    - The best combination of system's configuration and illuminant is the multispectral configuration and the D65 simulator illuminant.

12. For the best combination of system's configuration and illuminant, using the same sets of Munsell's colour patches as training and test sets, and varying the degree of homogeneity in hue of the training set, the more homogeneous the training set is, the better results are obtained in terms of accuracy of both colour measurement and spectral reconstruction.

13. Using different training and test sets, the homogeneity in hue of the training set (Munsell's hues) and the classification of the colour samples of the test set (CCDC chart) in hues tends to improve the accuracy of both colour measurement and spectral reconstruction, in general for all hues, with regard to results obtained using a multi-colour range training set, as it is the set of all Munsell's colour patches.

14. The complete training set (comprised by the training sets homogeneous in hue) must cover the whole CIELAB space and/or the reflectance spectra space of samples to be used as test set in order to be able to train the imaging system in the widest way possible hue by hue.

15. System's performance depends on the classification of the test samples in hues. Methods tested in this work pretend to classify the colour samples of a known test set (known CIELAB coordinates, reflectance spectra) in hues in order to obtain the best system's performance and prove that system's performance is improved when different training sets homogeneous in hue are used. The best performance is obtained applying the *a*b* classification method*.

16. Analyzing the accuracy of colour measurement and spectral reconstruction depending on the Munsell value and chroma coordinates, larger CIELAB colour differences are obtained for samples having a Munsell value V < 5 – 6, and CIELAB colour differences tend to increase slightly for samples having a Munsell Value V > 7 - 8, as a general tendency for all Munsell sub-hues, both system's configurations and both illuminants. RMSE values, although do not decrease with an increasing value of the Munsell value coordinate, also tend to increase slightly for samples having a Munsell Value V > 7 – 8, being not so sensitive to the Munsell value coordinate as the CIELAB colour difference is, for the low light and lower colourful patches (low Munsell value and chroma).

17. The accuracy of colour measurement and spectral reconstruction has been analyzed depending on the Area Under the Curve (AUC) and the Discrete Fourier Transform (DFT) of the reflectance spectra of the colour samples measured.

    - Considering the AUC analysis, the accuracy of colour measurement tends to improve for the colour samples with higher AUCs of their reflectance spectra, whereas this tendency is not observed for the accuracy of spectral reconstruction. Any direct relationship cannot be established either between the accuracy of colour measurement and the AUC of the reflectance spectra of colour samples.

    - Considering the DFT analysis, the accuracy of colour measurement seems to be independent of the shape and/or the smoothness of the reflectance spectra, whereas the best accuracy of spectral reconstruction is frequently associated to a smooth reflectance spectrum, although any general correlation cannot be established between them.

18. A simulation study of an optimum multispectral imaging system for colour measurement and spectral reconstruction has been carried out. It consists of an exhaustive search of the optimum set of commercially available interference filters, considering all possible combinations of filters on the database used, for a fixed number of filters or acquisition channels (from 3 to 9). The CIELAB colour difference has been used as the cost function for the accuracy of colour measurement, and the RMSE for the accuracy of spectral reconstruction. System's performance is improved in terms of accuracy of both colour measurement and spectral reconstruction with an increasing number of interference filters. Nevertheless, this improvement is limited and tends to be insignificant for more than 8 filters. These results have been obtained using the CCDC chart as training and test set, but results could be notably different when using another set of colour samples.

19. When designing a multispectral imaging system, a simulation study of the optimum multispectral imaging system considering the commercially available filters can be

very useful in order to get an idea of the specific characteristics of the optimum filters, but not decisive in the sense that results of simulations depend greatly on the real spectral transmittances of filters, which not always can be easily simulated from the specifications provided by suppliers.

20. Optimum filters tend to make up for the spectral response of the CCD camera over the whole visible range, but considering the drawback the unknown real spectral transmittances of filters supposes, the selection of a set of gaussian interference filters having equidistant peak positions covering the whole visible range, equal FWHMs that allow a slight overlapping between them, and the higher transmittance possible, as it was done in this work, constitutes an acceptable option to obtain a worthy multispectral imaging system.

21. Regarding the number of filters in a multispectral imaging system, although increasing the number of filters tends to improve theoretically the accuracy of the system's performance, it also introduces experimental errors involving a longer sequence of measurements, increases the mechanical complexity of the experimental setup to fit the filters in a wheel, or a similar assembly, and automate it, and also increases the final cost of the system. Therefore, some kind of compromise should also be reached among real accuracy, complexity, and cost.

22. The applicability of the multispectral imaging system developed has been tested using a set of 56 textile samples grouped in 28 pairs, which were made specifically to test the applicability of colour difference formulas to textile samples, and the D65 simulator illuminant.

    - Regarding the accuracy of system's performance when applied to textile samples, best results in terms of both colour measurement and spectral reconstruction are obtained using the textile samples as training and test set. Using different training and test sets, best results are mostly obtained in average using the sets of Munsell's hues as training sets, and classifying the textile samples in hues to reconstruct them. These results are even better than those obtained using the textile samples themselves as training set.

    - Regarding the accuracy of system's performance in detecting both the colour and the spectral differences between pairs of textile samples, firstly, the multispectral imaging system developed is able to detect slight differences both in colour and in reflectance spectra between real samples, making it useful for applications that require discrimination. On the other hand, the accuracy of system's performance in detecting both the colour differences and the spectral differences between pairs of textile samples obtained is quite low, and different in terms of the CIELAB colour difference values and the RMSE values depending on the training set used.

    - Deviations of general results and low accuracy in detecting both the colour differences and the spectral differences between pairs of textile samples are attributed firstly, to use different type of colour samples as training and test sets such are the textile samples and the standardized colour charts. Secondly, to the known limitations of the hue classification method applied and the limited gamut defined by the training sets homogeneous in hue used, which cannot cover at all the gamut defined by the textile samples used as test set. Finally, to the differences between the textile samples and the rest of colour samples considered (CCDC's and Munsell's) in the measuring instruments and the measuring geometry used to determine the reflectance spectra of samples.

Regarding the work developed in this PhD thesis, some research lines can be suggested for future work:

1. Considering the imaging system used in this work, studying the system's performance when using the colorimetric configuration and the two illuminants as a multispectral imaging system, and studying if the performance of the multispectral imaging system developed could be improved considering combinations of the present acquisition channels and an illuminant as new acquisition channels constituting a new combined multispectral imaging system.

2. Defining and optimizing a general classification of colour samples in well delimited colour ranges, or hues, based on some measurable characteristic of colour and applicable to any kind of colour samples, in order that any measured colour sample (known XYZ tristimulus values, CIELAB coordinates, reflectance spectra, etc.) can be easily classified in some well defined colour range, independently of the type of colour samples it is.

3. Starting from standardized colour samples (CCDC, CCCR, and Munsell Book of Colour charts) and considering the properties of the colour samples of the training set that influence system's performance, optimizing the homogeneous training sets associated to each previously defined and delimited colour ranges, in order to be able to train the imaging system in the widest way possible hue by hue, covering the whole CIELAB space and/or reflectance space of the samples to be used as test sets.

4. Designing and implementing an automatic classification method that allows one to classify any colour sample measured by the multispectral imaging system in a well delimited colour range automatically from the system's digital response, in order it can be reconstructed using the training set corresponding to the colour range associated to the sample.

5. Testing the colour range classification and performance of the multispectral imaging system using real samples, defining and delimiting the colour ranges depending on the colour samples considered, and determining the optimum training sets associated to these colour ranges.

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APPENDIXES

10-bit colour CCD camera QImaging QICAM

QIMAGING™

QICAM

Monochrome and Color High Performance FireWire™ Digital CCD Cameras

QICAM

The QImaging QICAM digital camera system is designed for high resolution brightfield scientific and industrial imaging applications. A progressive scan interline CCD sensor gives a resolution of 1.4 million pixels in a 10-bit digital output. High-speed low-noise electronics provide linear digital data for rapid image capture.

The FireWire IEEE 1394 digital interface allows ease of use and installation with a single wire requiring no framegrabber or external power supply. The QICAM includes QCapture Software for Windows® or Mac® based systems for real time image preview and capture. A Software Development Kit (SDK) is available for easy interfacing with custom software.

features	benefits
1360 x 1024 pixels	High resolution
High-speed low-noise electronics	10 fps full resolution 8-bit, 5 fps in 10-bit, higher speeds with binning and ROI functions
FireWire IEEE 1394 Digital Interface	Simple connectivity Portability with laptop computer use Control of multiple cameras from one controller
Exposure/Integration Control 40 μseconds to 15 minutes	Variable integration control
10-bit digitization / 30-bit color digitization	1024 gray levels for precise gray level discrimination
Real time image previewing	Fast preview, preview and capture images identical
External synchronization and trigger	Capability for highly synchronized imaging
Third party software compatible	A large selection of life science and industrial software are available for microscope, machine vision and video streaming applications

camera models

Includes FireWire cable, QCapture software and access to SDK

QICAM: CCD Digital Camera, Monochrome, 10-bit

QICAM: CCD Digital Camera, Color; 10-bit

Option: RGB Liquid Crystal Color Slider Filter Module for use with Monochrome cameras (F mount interface required)

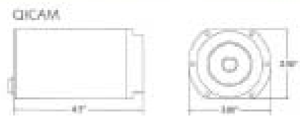
Now available: QICAM-UV – see separate Product Sheet

10-bit colour CCD camera QImaging QICAM

specifications

SENSOR	
Type	1/2" progressive scan interline CCD Monochrome or Color (Bayer Mosaic)
Light Sensitive Pixels	1360 x 1024
Pixel Size	4.65 µm x 4.65 µm
Quantum Efficiency	400nm 30%; 500nm 43%; 600nm 30%
Digital Output	10-bit
Readout Frequency	20 MHz
Frame Rate	10 fps full resolution 8-bit, 5 fps in 10-bit, higher speeds with binning and ROI (region of interest) functions

DIMENSIONS



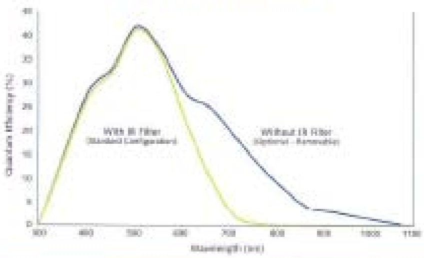
USER CONTROLS	
Integration Time	40 µseconds to 15 minutes in 1 µseconds increments
Binning Modes	2x2, 3x3 and 4x4
Shutter Control	Electronic shutter; no moving parts
External Trigger	TTL input
External Sync	TTL output
ROI	Size and position control, through on-screen click & drag
Gain & Offset Control	0 to 10x optimum gain
Digital/Electrical Interface	FireWire IEEE 1394 interface, requires OHCI compliant IEEE 1394 PCI card; single FireWire 6-pin cable connection for desktop or laptop computers*
Optical Interface	C-mount; 1/2" optical format
Power Requirements	450 milliamps @ 12 volts (5.5 watts)
Size	2.5 x 3 x 4.5 inches
Weight	596g
Warranty	2 years

APPLICATIONS

Brightfield and Phase Contrast Microscopy
Live Cell Imaging
Pathology, Histology, Cytology
Motility and Motion Analysis
DNA Analysis
Metallurgical Microscopy
Semiconductor Inspection
Industrial Imaging
Failure Analysis
Forensic Analysis

*Windows-based laptop computers have a 4-pin FireWire port and are unable to provide power to the camera, therefore requiring an auxiliary power supply for the camera and a FireWire 4-pin cable connection to the laptop.

spectral response



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QICAM *FAST1394*

High-Performance IEEE 1394 FireWire™ Digital CCD Camera – Monochrome or Color

The QImaging QICAM digital camera is designed for high-resolution, brightfield scientific and industrial applications. A progressive-scan interline CCD sensor gives a resolution of 1.4 million pixels in a 12-bit digital output. High-speed, low-noise electronics provide linear digital data at frame rates up to 110 fps with binning and ROI. The IEEE 1394 FireWire™ digital interface allows ease of use and installation with a single wire. No framegrabber or external power supply is required. The QICAM includes QCapture software (Windows® and Mac OS) for real-time image preview and capture. A Software Development Kit (SDK) is available upon request for interfacing with custom software.

Note: Lenses are shown for illustration only and are not included.

CAMERA MODELS

Includes: IEEE 1394 FireWire™ cable, IEEE 1394 PCI card, QCapture software, & access to SDK

- **Monochrome QICAM Cooled** Model: QIC-F-M-12-C
- **Monochrome QICAM Non-Cooled** Model: QIC-F-M-12
  CCD Digital Camera, 12 Bits
- **Color QICAM Cooled** Model: QIC-F-CLR-12-C
- **Color QICAM Non-Cooled** Model: QIC-F-CLR-12
  CCD Digital Camera, 12 Bits

CAMERA OPTIONS

- **RGB Color Filter** for monochrome cameras (F-mount interface required), refer to spec sheet for more details

- **Extended Warranty**

FEATURES	BENEFITS
High-Resolution, 1.4-Million-Pixel Sensor	• Highly detailed, sharp images
High-Speed Readout	• Previewing & focusing in real time • 165fps maximum frame rate • 110fps with 4x4 binning & ROI • 10fps full resolution • Ideal for automated imaging applications
Flexible Exposure Control from 12µs to 17.9min	• Optimal integration over a wide range of light levels
12-Bit Digitization/ 36-Bit Color Digitization	• 4096 grey levels for precise light-intensity discrimination • 4096 levels per channel for superior color images
External Sync & Trigger	• Tight synchronization with flashlamps, automated filters, shutters, & microscope stages
Peltier Cooling	• Minimizes thermal noise during low-light imaging
ROI (Region of Interest)	• Higher frame rates for precise analysis of rapidly changing specimens
Binning	• Increases sensitivity for quantitation & imaging of very low light levels • Increases frame rate
IEEE 1394 FireWire™ QImaging Fast 1394 Technology	• Simple connectivity • Ease of use & installation • Portability with laptop computer • Simultaneous use of multiple cameras through a single port • Single-cable operation (no external power supply or control unit)
Extensive Third-Party Software Support	• Choose from a large selection of life science & industrial software for microscopy, machine vision, & video-streaming applications

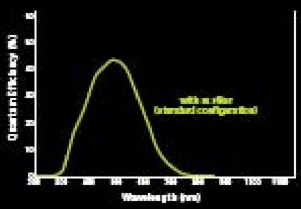
12-bit cooled monochrome CCD camera QImaging QICAM Fast 1394

QICAM FAST1394 SPECIFICATIONS

APPLICATIONS

- Brightfield and Phase-Contrast Microscopy
- Live-Cell Imaging
- Pathology, Histology, & Cytology
- Motility & Motion Analysis
- DNA Analysis
- Metallurgical Microscopy
- Semiconductor Inspection
- Failure Analysis
- Forensic Analysis

SPECTRAL RESPONSE



CCD SENSOR	
Light-Sensitive Pixels	1.4 million; 1392 x 1040
Binning Modes	2x2, 4x4, 8x8
ROI (Region of Interest)	From 1x1 pixels up to full resolution, continuously variable in single-pixel increments
Exposure/Integration Control	12µs to 17.9min in 1µs increments
Sensor Type	Sony* ICX205 progressive-scan interline CCD (monochrome or color)
Pixel Size	4.65µm x 4.65µm
Linear Full Well	10,000e⁻
Read Noise	12e⁻
Cooling Available	Yes (optional)
Cooling Type	Peltier thermoelectric cooling to 25°C below ambient
Digital Output	12 bits
Readout Frequency	20, 10, 5, 2.5MHz
Frame Rate	10fps full resolution @ 12 bits (165fps maximum with binning and ROI)
CAMERA	
Computer Platforms/Operating Systems	Windows* & Mac OS**
Digital Interface	IEEE 1394 FireWire™
Sustained Data Rate	40MB/s
Shutter Control	Electronic shutter, no moving parts
External Trigger	TTL Input
Trigger Types	Internal, Software, External
External Sync	TTL Output
Gain Control	0.6 to 15x
Offset Control	-2048 to 2047
Optical Interface	1/2", C-mount optical format
Threadmount	1/4" — 20 mount
Power Requirements	7W (non-cooled); 13W (cooled); 8-24V
Weight	635g (non-cooled); 915g (cooled)
Warranty	2 years
Operating Environment	0 to 50°C (32 to 122°F)
Storage Temperature	-10 to 60°C
Humidity	Less than 80% non-condensing at 35°C (95°F)

*Refer to QImaging website for detailed listing of supported operating systems.
Note: Specifications are nominal and subject to change.

FireWire and Mac OS are trademarks of Apple Computer, Inc., registered in the U.S. and other countries. Sony is a registered trademark of Sony Corporation. Windows is a registered trademark of Microsoft Corporation in the United States and other countries. Other brand and product names are the trademarks or registered trademarks of their respective owners and manufacturers.

QIMAGING

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www.qimaging.com

Partners in Innovation™ — Microimaging Applications Group MAG™

RGB tunable filter QImaging RGB-HM-NS

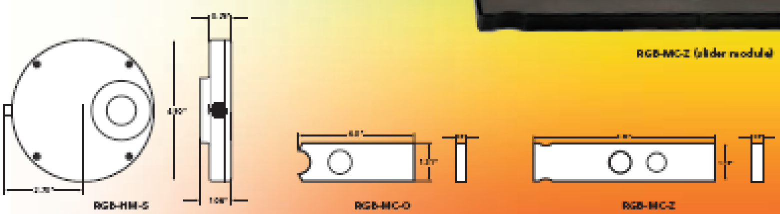
QIMAGING

HIGH PERFORMANCE DIGITAL IMAGING made easy

RGB COLOR FILTER

Allows Monochrome Cameras to Produce High-Quality Color Images

The RGB Color Filter modules are designed for use with QImaging's line of high-resolution monochrome CCD cameras to capture high-quality color images. Color information is captured by sequentially acquiring full-resolution images in each of the color planes. The filter is switched through its red, green, and blue states under direct control of the camera hardware. The camera hardware provides highly synchronized and precise timing to the filter module. The result is artifact-free imaging at frame rates much faster than most mechanically selected filters and acousto-optical or liquid-crystal filters that require software control. White balance is controlled easily through software. The RGB Color Filter is connected to the camera's electronics with a single cable.



FILTER FORMATS

- **RGB Color Filter (Slider Modules)**
  Sliders allow easy switching between color and monochrome imaging.

  Model: RGB-HM-S
  This module allows the color filter element to be moved in and out of the field of view.

  Model: RGB-MC-O
  This module (for Olympus® BX and IX series microscopes) slides easily in and out of the optical path through the nosepiece.

  Model: RGB-MC-Z
  This module (for Carl Zeiss® Axioplan® microscopes) slides easily in and out of the optical path through the analyzer slot.

- **RGB Color Filter (Non-Slider Module)**

  Model: RGB-HM-NS
  This module is compact and can be easily removed for monochrome imaging.

FEATURES	BENEFITS
Liquid-Crystal Filter Element	• High-quality color images with high-resolution monochrome CCD cameras • Filter color changes with no moving parts • No vibration • No optical-registration problems
Single-Cable Connection to QImaging Cameras	• Easy to install and use • Controlled by QImaging cameras
Sequential Acquisition of Color	• Full-resolution image in each color plane
Provides Color Even When Camera Is In Binning Modes	• High sensitivity and speed
Filter Element Easily Slides Out of Optical Path (Slider Modules)	• Enables quick switch between full-color imaging and high-sensitivity monochrome imaging without refocusing
Hot-Mirror Filter	• Integrated filtering of infrared light provides better color fidelity

RGB tunable filter QImaging RGB-HM-NS

RGB Color Filter Specifications

APPLICATIONS

- Brightfield Microscopy
- Fluorescence Microscopy
- Pathology, Histology, & Cytology
- FISH
- DNA Analysis
- Metallurgical Microscopy
- Forensic Analysis

Color States	Red, green, blue
Transmission	30 min*
Maximum Optical Input	500 mW/cm²
Module Control	Camera-controlled functionality
Temperature Range	10 to 45°C
Optical Mount	Slider modules or Nikon® F-mount (C-mount to camera)

**Transmission is doubled for polarized light.*
Note: Specifications are nominal and subject to change.

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www.qimaging.com

Partners in Innovation™ — MicroImaging Applications Group MAG™

Tele-spectracolorimeter PhotoResearch PR650

PHOTO RESEARCH®

PR®-650 SpectraScan® Colorimeter

The right instrument - . When battery-powered portability, ease-of-use, connectability and spectrally accurate measurement results are important criteria when selecting a photometer or colorimeter, the PR-650 SpectraScan is the instrument of choice.

Battery powered portability – The PR-650 is the only truly portable spot spectroradiometer available. The standard NiCad battery makes the PR-650 ideal for making measurements in remote areas where an AC power source is unavailable. Combine this portability with a laptop running the optional *SpectraWin* Windows® based software, and you have a full-featured measurement system that can be transported in your briefcase.

Ease of use - The PR-650 is as easy to use as point-and-shoot. The world famous Pritchard® optics make target alignment as easy as aim and focus. When you are ready to make a measurement, simply press the measure button. The results are displayed on the back-lit 4 x 20 character LCD display.

Connectability - Each PR-650 is equipped with an RS-232 cable that lets you link to the outside world from just about any platform (PC, Mac, Sun Workstation etc.) to just about any type of host. We've also included, as standard equipment, *Remote Mode* control language. This simple to use text based language lets you make measurements with the PR-650 and retrieve calculated measurement results – all from your custom software application (e.g. Visual C++, Visual Basic etc).

SpectraWin software - For an easy-to-use, graphics based link to the PR-650, the optional Windows ('95, '98 or NT) *SpectraWin* software package provides a fully functional control, display and calculation platform. Features such as automated measurement sequences (reflectance, transmittance etc.), go/no go color measurements and a built in macro recorder make your measurement task as easy as click and go. After the measurement, cut-and-paste data tables or graphics displays (e.g. spectral or CIE charts) to other Windows applications.

Typical Applications

- Colorimetry or automotive / aerospace displays
- Colorimetry of paper, textile and printed samples
- Source color temperature
- Spectral reflectance and transmittance
- Human factors / vision research
- Incoming inspection
- Production (on line) testing
- LED color measurement
- Automated testing
- Medical / dental color measurements
- Source refresh rate

Spectral Accuracy. Unlike other instruments in its price range, the PR-650 measures optical radiation spectrally instead of relying on filter technology. To accurately deliver important measurement results such as luminance and chromaticity – the PR-650 determines these parameters by measuring the absolute intensity at each wavelength, then calculating the result. So, regardless of the source, the result is accuracy time after time after time…………

AutoSync® – The built-in AutoSync® feature takes the worry out of accurately measuring high intensity refreshing sources such as CRT's by adjusting the exposure time to the source refresh rate - and simultaneously reports the refresh rate of the source.

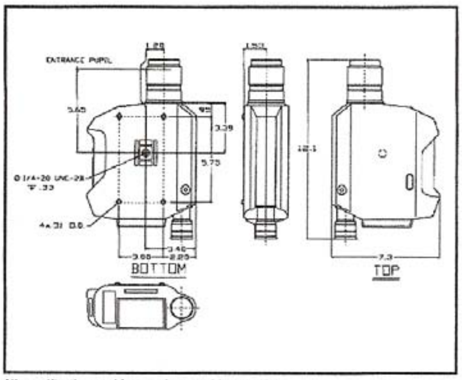
Tele-spectracolorimeter PhotoResearch PR650

PHOTO RESEARCH®, Inc.

9731 Topanga Canyon Place Chatsworth, CA 91311-4125
PH: (818) 725-9750 • FAX: (818) 725-9770
www.photoresearch.com
e-mail: sales.pr@photoresearch.com

Specifications

Spectral Range	380 – 780 nm
Spectral Bandwidth	8 nm
Spectral Accuracy	± 2 nm
Wavelength Resolution	< 3.5 nm / pixel
Luminance Accuracy	± 2% of calculated luminance at 2856K @ 23° C
Color Accuracy when Measuring Illuminant A	±.0015 CIE 1931 x, ± .001 CIE 1931 y (.006 CIE 1931 xy for CRT's typical)
Digital Resolution	14 bit (1 part in 16,000)
AutoSync Range	40 – 250 Hz
Measuring and Viewing Field	1° (measuring) and 7° (viewing) with MS-75 lens at infinity focus
Battery	Rechargeable NiCad. Recharge rate – 1.5 hrs. from full discharge with CD-650
Interfaces	RS-232, IEEE-488 (optional)
Operating Temperature	34° to 95° F (1° to 35° C)
Operating Humidity	≤90% non-condensing
Size (approx. including MS-75 lens)	12" (305 mm)L x 7"(178 mm)W x 3" (76 mm) H
Weight (approx.)	4 lbs. 12 oz. (2.15 kg.) with MS-75 lens and battery



All specifications subject to change without notice.

Field Coverage / Sensitivity Chart

Accessory	Focus Distance	Spot Size	Sensitivity
MS-75 (14" to ∞)	14 " (355 mm) 1000 ft (305 m)	.208" (5.25 mm) 209" (5.32 m)	≥1.0 - ≤5,000 fl ≥3.4 - <17,000 cd/m²
SL-0.5X	3.6" (91.4 mm) to 5.4" (137 mm)	0.059" (1.5 mm) to 0.10" ((2.54 mm)	≥1.0 - ≤5,000 fl ≥3.4 - ≤17,000 cd/m²
SL-1X	1.8" (46 mm) to 2.6" (66 mm)	0.035" (0.89 mm) to 0.052" (1.32 mm)	≥1.0 - ≤5,000 fl ≥3.4 - ≤17,000 cd/m²
MS-2.5X	1.81" (46 mm)	0.020" (0.51 mm)	≥3.0 - ≤10,000 fl ≥10.3 - ≤51,400 cd/m²
MS-5X	1.11 in. (28 mm)	0.011 in. (0.289 mm)	≥ 4 - ≤15, 000 fL ≥13.7-≤51, 400 cd*m⁻²
CR-600 Cosine Receptor	N/A	N/A	≥2.0 - ≤12,000 fc ≥21.5 - ≤107,700 lux
LA-600 Luminance Adapter	Contact	0.52" (13.2 mm)	≥1.0 - ≤5,000 fl ≥3.4 - <17,000 cd/m²
FP-600 Fiber Probe	Contact	0.125" (3.17 mm)	≥2.5 - ≤12,000 fl ≥8.6 - ≤43,000 cd/m²

NOTES:
1. For the ND-650-2 (Used only with the MS-75 or SL-1X or SL-0.5X), multiply the Sensitivity by 100.
2. All values calculated measuring Illuminant A at @ ≥ 100:1 signal to noise (1% precision).

CVI Laser Digikrom DK 240 Monochromator

Instrument Specifications

Type. The Digikrom 240 is a *Czerny-Turner Scanning Monochromator* with a focal length of 240mm.

Effective Aperture Ratio. The Digikrom 240 has an effective aperture ratio of f/3.9.

Collimating/Focusing Mirrors. These mirrors are 84mm round aluminized with a protective overcoat.

Gratings. Plane reflective gratings of 64mmx64mm, replicated are standard. 64mm(height)x84mm(width) replicated, or broadband holographic are available as options.

Spectral Coverage. The grating is usable to ~75 degrees angle of incidence with an 84mm-wide grating, and the aperture ratio is maintained to 42 degrees. The aperture ratio is maintained to approximately 1.2 microns, and with a 1200g/mm grating, the grating is usable to approximately 1.5 microns.

Grating Mount. A reversible, two-grating mount with either one or two gratings mounted and calibrated is standard o the Digikrom 240. An optional three-grating turret mount is available. Any mounted grating may be stepped into position for use, auto-calibrated, and used without opening the monochromator.

Reciprocal Linear Dispersion. The reciprocal linear dispersion of the Digikro 240 is 3.2nm/mm with a 1200g/mm grating, in first order.

Resolution. The spectral resolution of the Digikron 240 is 0.06nm with 20 micron slits and a 1200g/mm grating in first order.

Stray Light. Stray light is less than 0.02% at 220nm (NaI).

Wavelength Drive. A direct digital wavelength drive is standard.

The Digikrom 240 has a self-contained, microprocessor controlled stepper motor drive. The motor is coupled to the rotating grating table via a worm/worm-wheel engagement. This mechanism is a new type for a monochromator drive.

Bearings and Gears. All bearings and gears are precision quality and have been pre-loaded to optimize gear engagement and minimize backlash. Standard gear assembly, stepper motor, and driver electronics are configured to yield a grating rotational increment of 44 microradians per motor step. With a 1200g/mm grating in first order, the monochromator has a wavelength increment of approximately 0.07nm per step. A microstep option which permits operation of the stepper motor at 1/10 of a standard step is available. This option will produce a wavelength increment of 0.007nm per step.

Wavelength Initialization. During power-up, the microprocessor invokes an initialization routine. This routine uses a two stage method to stablish a true 'home' position for the stepper motor. Using 'home' as the reference point, a look-up table located in the PROM permits the grating to be rotated to select the precise monochromator wavelength output.

Wavelength Accuracy. After initialization, the microprocessor displays the output wavelength on the LCD display. The displayed output wavelength is accurate to plus-or-minus one motor step (plus or minus 0.07nm for a 1200g/mm grating in first order – Digikrom 240). If, after long usage or severe treatment, the wavelength accuracy is not within one motor step, it can be returned to original accuracy by using a keyboard routine to adjust the 'home' wavelength offset.

Wavelength Precision. The motor step differences between lines of the Hg spectrum are constant. Thus, wavelength precission is better than 0.07nm or one motor step.

Wavelength Scan. The microprocessor controlled-motor combination has been designed for a maximum stepping rate of 1000 steps/sec., providing a slew speed of 84nm/sec. (with 1200g/mm grating in first order), or about 4000nm/min. Scan speeds are selected from the keypad by entering the desired value, in units of nm/min, and the user can specify any value from 1nm/min to 4000nm/min. Real-time display of the instantaneous wavelength is available only for scan speeds lees than 900nm/min, although output of the data to a computer is available for all scan speeds.

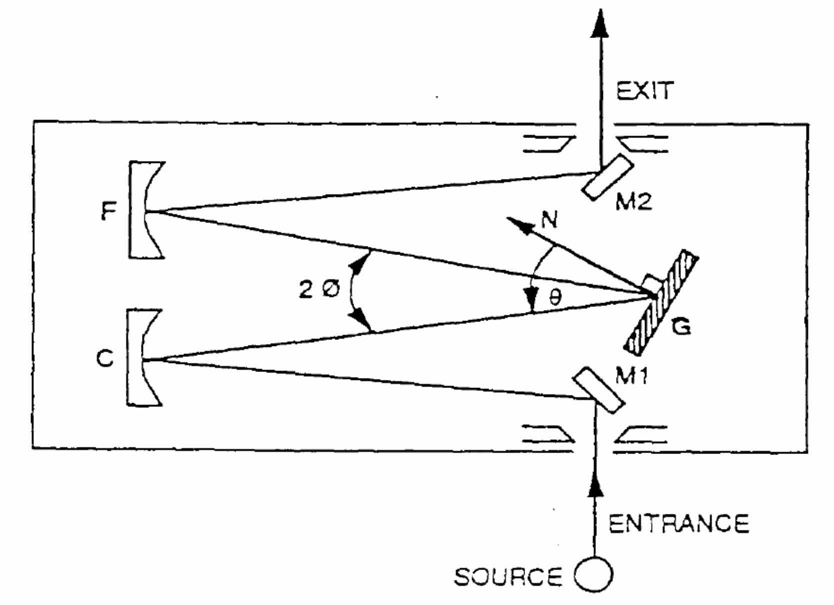
Entrance/Exit Slits. Unilaterally adjustable-width curved jaw slits are standard on the Digikrom. Adjustable straight-jaw slits are also available. Adjustable slits are stepper motor driven with microprocessor control.

Adjustable Slit Assembly. The microprocessor-controlled stepper motor-driven slits are adjustable in 1 micron increments from 20 microns to 2000 microns. Fail-safe electronic design prevents accidental closure of the slits to values less than 10microns. Slit jaws are 1 inch high and are photoetched from 0.0015" thick stainless steel. The etching process produces a sharp edge on the slit jaws. A thickness profile of the slit edge shows a decrease in metal thickness to a dimension of about 1/3 of the thickness, followed by a sharp truncation. Thus, the true 'edge' thickness is about 10 microns.

Slit Width Accuracy. The slit is adjusted manually to produce a 'home' initialization value between 40 and 60 microns as measured by the diffraction of a HeNe laser beam. The exact value of this 'home' width for each slit assembly is stored in PROM. Selected slit width values are then offsets from this calibrated value. Adjusted slit width uniformity from top to bottom is better than 2 dust and other debris, and the user does not make his/her own adjustments, the slit width accuracy and uniformity is guaranteed to be plus-or-minus 3 microns. Slits having different resolutions (i.e. different increments of microns per motor-step) can be furnished on request.

Optical Diagram

The Digikrom 240 is a classical *Czerny-Turner* monochromator in its optical configuration, with a 240mm focal length.



Appendix 2 Fluctuations of system's performance depending on the number of samples of the training set

Table A2.1 (1) ***Colorimetric Configuration****: mean, minimum, maximum and standard deviation of the* ***CIELAB colour difference values*** *obtained using the five different training sets selected from an initial randomly selected colour sample for all sizes considered, and using the CCCR chart as test set.*

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
10 colour samples	*Random 1*	4.892	1.401	12.675	3.109
	Random 2	5.224	1.160	12.817	3.017
	Random 3	5.083	1.121	12.963	3.156
	Random 4	4.698	0.392	11.900	3.054
	Random 5	5.197	1.288	12.364	2.918
	mean	5.019	1.072	12.544	3.051
	std. dev.	0.222	0.396	0.423	0.091
	% fluct.	4.422	36.932	3.369	2.988

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
20 colour samples	*Random 1*	5.428	1.380	13.054	3.321
	Random 2	5.593	1.231	13.500	3.406
	Random 3	6.389	0.753	18.228	4.243
	Random 4	5.877	1.580	14.125	3.441
	Random 5	6.041	1.627	14.601	3.527
	mean	5.866	1.314	14.702	3.588
	std. dev.	0.378	0.352	2.058	0.374
	% fluct.	6.439	26.759	13.996	10.418

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
30 colour samples	*Random 1*	5.897	1.032	14.319	3.580
	Random 2	5.860	1.145	14.248	3.545
	Random 3	5.694	1.046	13.805	3.495
	Random 4	5.963	1.562	14.682	3.560
	Random 5	5.872	1.255	14.256	3.542
	mean	5.857	1.208	14.262	3.544
	std. dev.	0.100	0.217	0.312	0.031
	% fluct.	1.700	17.981	2.186	0.887

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
40 colour samples	*Random 1*	6.141	2.423	14.268	3.422
	Random 2	6.232	2.309	14.480	3.491
	Random 3	6.162	2.517	14.262	3.434
	Random 4	5.892	2.007	14.058	3.408
	Random 5	6.206	2.243	14.355	3.453
	mean	6.127	2.300	14.285	3.442
	std. dev.	0.136	0.195	0.154	0.032
	% fluct.	2.219	8.459	1.080	0.935

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
50 colour samples	*Random 1*	5.869	1.799	14.217	3.521
	Random 2	5.609	1.516	13.942	3.446
	Random 3	5.903	1.805	14.337	3.530
	Random 4	5.869	1.799	14.217	3.521
	Random 5	5.869	1.799	14.217	3.521
	mean	5.824	1.744	14.186	3.508
	std. dev.	0.121	0.127	0.146	0.035
	% fluct.	2.077	7.299	1.029	0.991

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
60 colour samples	*Random 1*	5.732	2.197	14.077	3.452
	Random 2	5.653	2.117	13.912	3.455
	Random 3	5.772	2.331	14.100	3.465
	Random 4	5.782	2.329	14.110	3.466
	Random 5	5.800	2.308	14.148	3.478
	mean	5.748	2.256	14.069	3.463
	std. dev.	0.059	0.095	0.092	0.010
	% fluct.	1.019	4.231	0.651	0.297

Appendix 2 Fluctuations of system's performance depending on the number of samples of the training set

Table A2.1 (2) ***Colorimetric Configuration****: mean, minimum, maximum and standard deviation of the* ***CIELAB colour difference values*** *obtained using the five different training sets selected from an initial randomly selected colour sample for all sizes considered, and using the CCCR chart as test set.*

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
70 colour samples	*Random 1*	5.896	2.398	14.124	3.429
	Random 2	5.896	2.415	14.120	3.428
	Random 3	5.896	2.398	14.124	3.429
	Random 4	5.903	2.256	14.148	3.426
	Random 5	5.829	2.472	14.039	3.423
	mean	5.884	2.388	14.111	3.427
	std. dev.	0.031	0.080	0.042	0.003
	% fluct.	0.525	3.338	0.296	0.074

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
80 colour samples	*Random 1*	5.736	2.236	13.994	3.451
	Random 2	5.682	2.235	13.943	3.434
	Random 3	5.682	2.235	13.943	3.434
	Random 4	5.682	2.235	13.943	3.434
	Random 5	5.677	2.257	13.948	3.429
	mean	5.692	2.240	13.954	3.436
	std. dev.	0.025	0.010	0.022	0.008
	% fluct.	0.436	0.435	0.160	0.246

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
90 colour samples	*Random 1*	5.710	2.291	13.891	3.411
	Random 2	5.681	2.261	13.815	3.368
	Random 3	5.710	2.291	13.891	3.411
	Random 4	5.720	2.279	13.918	3.421
	Random 5	5.710	2.291	13.891	3.411
	mean	5.706	2.282	13.881	3.404
	std. dev.	0.015	0.013	0.039	0.021
	% fluct.	0.260	0.568	0.278	0.619

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
100 colour samples	*Random 1*	5.527	2.112	13.716	3.393
	Random 2	5.507	1.968	13.680	3.384
	Random 3	5.523	1.998	13.681	3.387
	Random 4	5.560	2.072	13.723	3.391
	Random 5	5.412	2.095	13.641	3.371
	mean	5.506	2.049	13.688	3.385
	std. dev.	0.056	0.063	0.033	0.009
	% fluct.	1.015	3.065	0.240	0.256

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
110 colour samples	*Random 1*	5.535	2.236	13.737	3.322
	Random 2	5.628	2.225	13.794	3.333
	Random 3	5.616	2.185	13.765	3.325
	Random 4	5.552	2.235	13.747	3.325
	Random 5	5.613	2.131	13.752	3.332
	mean	5.589	2.202	13.759	3.327
	std. dev.	0.043	0.045	0.022	0.005
	% fluct.	0.761	2.045	0.159	0.145

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
120 colour samples	*Random 1*	5.575	2.224	13.788	3.359
	Random 2	5.623	2.265	13.833	3.365
	Random 3	5.627	2.248	13.832	3.363
	Random 4	5.621	2.246	13.826	3.362
	Random 5	5.621	2.246	13.826	3.362
	mean	5.613	2.246	13.821	3.362
	std. dev.	0.022	0.014	0.019	0.002
	% fluct.	0.385	0.638	0.134	0.053

Appendix 2 Fluctuations of system's performance depending on the number of samples of the training set

Table A2.1 (3) ***Colorimetric Configuration****: mean, minimum, maximum and standard deviation of the* ***CIELAB colour difference values*** *obtained using the five different training sets selected from an initial randomly selected colour sample for all sizes considered, and using the CCCR chart as test set.*

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
130 colour samples	*Random 1*	5.746	2.301	13.945	3.393
	Random 2	5.738	2.287	13.922	3.387
	Random 3	5.746	2.301	13.945	3.393
	Random 4	5.746	2.301	13.945	3.393
	Random 5	5.730	2.316	13.942	3.393
	mean	5.741	2.301	13.940	3.392
	std. dev.	0.007	0.010	0.010	0.003
	% fluct.	0.125	0.446	0.072	0.079

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
140 colour samples	*Random 1*	5.712	2.264	13.855	3.408
	Random 2	5.728	2.260	13.901	3.420
	Random 3	5.726	2.255	13.858	3.409
	Random 4	5.726	2.255	13.858	3.409
	Random 5	5.726	2.255	13.858	3.409
	mean	5.724	2.258	13.866	3.411
	std. dev.	0.007	0.004	0.020	0.005
	% fluct.	0.114	0.181	0.141	0.148

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
150 colour samples	*Random 1*	5.749	2.211	13.877	3.404
	Random 2	5.749	2.211	13.877	3.404
	Random 3	5.749	2.211	13.877	3.404
	Random 4	5.749	2.211	13.877	3.404
	Random 5	5.749	2.211	13.877	3.404
	mean	5.749	2.211	13.877	3.404
	std. dev.	0.000	0.000	0.000	0.000
	% fluct.	0.000	0.000	0.000	0.000

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
160 colour samples	*Random 1*	5.777	2.219	13.905	3.410
	Random 2	5.777	2.219	13.905	3.410
	Random 3	5.777	2.219	13.905	3.410
	Random 4	5.777	2.219	13.905	3.410
	Random 5	5.777	2.219	13.905	3.410
	mean	5.777	2.219	13.905	3.410
	std. dev.	0.000	0.000	0.000	0.000
	% fluct.	0.000	0.000	0.000	0.000

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
166 colour samples	*Random 1*	5.886	2.241	13.962	3.414
	Random 2	5.886	2.241	13.962	3.414
	Random 3	5.886	2.241	13.962	3.414
	Random 4	5.886	2.241	13.962	3.414
	Random 5	5.886	2.241	13.962	3.414
	mean	5.886	2.241	13.962	3.414
	std. dev.	0.000	0.000	0.000	0.000
	% fluct.	0.000	0.000	0.000	0.000

Appendix 2 Fluctuations of system's performance depending on the number of samples of the training set

Table A2.2 (1) ***Colorimetric Configuration****: mean, minimum, maximum and standard deviation of* ***RMSE values*** *obtained using the five different training sets selected from an initial randomly selected colour sample for all sizes considered, and using the CCCR chart as test set.*

		mean RMSE	min RMSE	max RMSE	stddev RMSE
10 colour samples	*Random 1*	5.777E-02	3.174E-02	1.708E-01	3.003E-02
	Random 2	5.638E-02	3.420E-02	1.692E-01	2.740E-02
	Random 3	6.288E-02	3.263E-02	1.684E-01	3.093E-02
	Random 4	5.811E-02	3.299E-02	1.739E-01	3.098E-02
	Random 5	6.491E-02	2.899E-02	1.563E-01	3.344E-02
	mean	6.001E-02	3.211E-02	1.677E-01	3.056E-02
	std. dev.	3.676E-03	1.955E-03	6.722E-03	2.172E-03
	% fluct.	6.126	6.088	4.008	7.109

		mean RMSE	min RMSE	max RMSE	stddev RMSE
20 colour samples	*Random 1*	5.762E-02	3.455E-02	1.733E-01	2.945E-02
	Random 2	5.625E-02	3.395E-02	1.687E-01	2.732E-02
	Random 3	5.861E-02	3.533E-02	1.724E-01	2.871E-02
	Random 4	5.706E-02	3.235E-02	1.696E-01	2.791E-02
	Random 5	5.671E-02	3.275E-02	1.697E-01	2.797E-02
	mean	5.725E-02	3.379E-02	1.707E-01	2.827E-02
	std. dev.	9.102E-04	1.238E-03	1.991E-03	8.228E-04
	% fluct.	1.590	3.664	1.166	2.910

		mean RMSE	min RMSE	max RMSE	stddev RMSE
30 colour samples	*Random 1*	5.612E-02	3.434E-02	1.701E-01	2.824E-02
	Random 2	5.786E-02	3.523E-02	1.749E-01	3.073E-02
	Random 3	5.604E-02	3.454E-02	1.699E-01	2.829E-02
	Random 4	5.600E-02	3.427E-02	1.694E-01	2.799E-02
	Random 5	5.643E-02	3.454E-02	1.694E-01	2.782E-02
	mean	5.649E-02	3.458E-02	1.707E-01	2.861E-02
	std. dev.	7.842E-04	3.806E-04	2.346E-03	1.198E-03
	% fluct.	1.388	1.100	1.374	4.187

		mean RMSE	min RMSE	max RMSE	stddev RMSE
40 colour samples	*Random 1*	5.828E-02	3.584E-02	1.748E-01	3.026E-02
	Random 2	5.851E-02	3.610E-02	1.749E-01	3.033E-02
	Random 3	5.856E-02	3.609E-02	1.751E-01	3.040E-02
	Random 4	5.851E-02	3.610E-02	1.749E-01	3.033E-02
	Random 5	5.777E-02	3.566E-02	1.743E-01	3.002E-02
	mean	5.833E-02	3.596E-02	1.748E-01	3.027E-02
	std. dev.	3.293E-04	2.003E-04	3.000E-04	1.472E-04
	% fluct.	0.565	0.557	0.172	0.486

		mean RMSE	min RMSE	max RMSE	stddev RMSE
50 colour samples	*Random 1*	5.694E-02	2.783E-02	1.739E-01	3.056E-02
	Random 2	5.723E-02	3.136E-02	1.738E-01	3.022E-02
	Random 3	5.729E-02	3.084E-02	1.738E-01	3.024E-02
	Random 4	5.729E-02	3.084E-02	1.738E-01	3.024E-02
	Random 5	5.672E-02	2.812E-02	1.730E-01	3.002E-02
	mean	5.709E-02	2.980E-02	1.737E-01	3.026E-02
	std. dev.	2.544E-04	1.681E-03	3.715E-04	1.936E-04
	% fluct.	0.446	5.641	0.214	0.640

		mean RMSE	min RMSE	max RMSE	stddev RMSE
60 colour samples	*Random 1*	5.617E-02	2.890E-02	1.733E-01	3.008E-02
	Random 2	5.615E-02	3.031E-02	1.732E-01	2.995E-02
	Random 3	5.617E-02	2.890E-02	1.733E-01	3.008E-02
	Random 4	5.627E-02	3.052E-02	1.732E-01	2.997E-02
	Random 5	5.627E-02	3.052E-02	1.732E-01	2.997E-02
	mean	5.621E-02	2.983E-02	1.732E-01	3.001E-02
	std. dev.	5.899E-05	8.533E-04	5.477E-05	6.442E-05
	% fluct.	0.105	2.861	0.032	0.215

Appendix 2 Fluctuations of system's performance depending on the number of samples of the training set

Table A2.2 (2) ***Colorimetric Configuration****: mean, minimum, maximum and standard deviation of* ***RMSE values*** *obtained using the five different training sets selected from an initial randomly selected colour sample for all sizes considered, and using the CCCR chart as test set.*

		mean RMSE	min RMSE	max RMSE	stddev RMSE
70 colour samples	*Random 1*	5.619E-02	3.365E-02	1.731E-01	2.963E-02
	Random 2	5.620E-02	3.219E-02	1.729E-01	2.964E-02
	Random 3	5.628E-02	3.152E-02	1.731E-01	2.975E-02
	Random 4	5.587E-02	3.108E-02	1.719E-01	2.923E-02
	Random 5	5.615E-02	2.974E-02	1.722E-01	2.940E-02
	mean	5.614E-02	3.164E-02	1.726E-01	2.953E-02
	std. dev.	1.571E-04	1.439E-03	5.550E-04	2.106E-04
	% fluct.	0.280	4.548	0.321	0.713

		mean RMSE	min RMSE	max RMSE	stddev RMSE
80 colour samples	*Random 1*	5.605E-02	3.185E-02	1.717E-01	2.918E-02
	Random 2	5.578E-02	3.227E-02	1.720E-01	2.929E-02
	Random 3	5.594E-02	3.301E-02	1.730E-01	2.978E-02
	Random 4	5.590E-02	3.189E-02	1.727E-01	2.968E-02
	Random 5	5.583E-02	3.208E-02	1.720E-01	2.933E-02
	mean	5.590E-02	3.222E-02	1.723E-01	2.945E-02
	std. dev.	1.042E-04	4.722E-04	5.450E-04	2.620E-04
	% fluct.	0.186	1.466	0.316	0.890

		mean RMSE	min RMSE	max RMSE	stddev RMSE
90 colour samples	*Random 1*	5.561E-02	3.035E-02	1.711E-01	2.898E-02
	Random 2	5.561E-02	3.105E-02	1.710E-01	2.891E-02
	Random 3	5.561E-02	3.035E-02	1.711E-01	2.898E-02
	Random 4	5.562E-02	3.029E-02	1.712E-01	2.903E-02
	Random 5	5.561E-02	3.035E-02	1.711E-01	2.898E-02
	mean	5.561E-02	3.048E-02	1.711E-01	2.898E-02
	std. dev.	4.472E-06	3.208E-04	7.071E-05	4.278E-05
	% fluct.	0.008	1.053	0.041	0.148

		mean RMSE	min RMSE	max RMSE	stddev RMSE
100 colour samples	*Random 1*	5.506E-02	2.931E-02	1.717E-01	2.945E-02
	Random 2	5.532E-02	3.046E-02	1.716E-01	2.928E-02
	Random 3	5.504E-02	2.880E-02	1.715E-01	2.942E-02
	Random 4	5.504E-02	2.880E-02	1.715E-01	2.942E-02
	Random 5	5.537E-02	3.067E-02	1.719E-01	2.938E-02
	mean	5.517E-02	2.961E-02	1.716E-01	2.939E-02
	std. dev.	1.646E-04	9.011E-04	1.673E-04	6.633E-05
	% fluct.	0.298	3.044	0.097	0.226

		mean RMSE	min RMSE	max RMSE	stddev RMSE
110 colour samples	*Random 1*	5.545E-02	3.114E-02	1.705E-01	2.885E-02
	Random 2	5.569E-02	3.213E-02	1.706E-01	2.872E-02
	Random 3	5.571E-02	3.284E-02	1.706E-01	2.870E-02
	Random 4	5.550E-02	3.139E-02	1.705E-01	2.882E-02
	Random 5	5.574E-02	3.313E-02	1.707E-01	2.871E-02
	mean	5.562E-02	3.213E-02	1.706E-01	2.876E-02
	std. dev.	1.329E-04	8.706E-04	8.367E-05	6.964E-05
	% fluct.	0.239	2.710	0.049	0.242

		mean RMSE	min RMSE	max RMSE	stddev RMSE
120 colour samples	*Random 1*	5.547E-02	2.984E-02	1.715E-01	2.937E-02
	Random 2	5.556E-02	2.984E-02	1.715E-01	2.934E-02
	Random 3	5.560E-02	3.014E-02	1.716E-01	2.939E-02
	Random 4	5.557E-02	3.014E-02	1.716E-01	2.936E-02
	Random 5	5.557E-02	3.014E-02	1.716E-01	2.936E-02
	mean	5.555E-02	3.002E-02	1.716E-01	2.936E-02
	std. dev.	4.930E-05	1.643E-04	5.477E-05	1.817E-05
	% fluct.	0.089	0.547	0.032	0.062

Table A2.2 (3) ***Colorimetric Configuration***: *mean, minimum, maximum and standard deviation of* ***RMSE values*** *obtained using the five different training sets selected from an initial randomly selected colour sample for all sizes considered, and using the CCCR chart as test set.*

		mean RMSE	min RMSE	max RMSE	stddev RMSE
130 colour samples	*Random 1*	5.586E-02	3.080E-02	1.715E-01	2.929E-02
	Random 2	5.589E-02	3.039E-02	1.717E-01	2.938E-02
	Random 3	5.590E-02	3.036E-02	1.717E-01	2.938E-02
	Random 4	5.590E-02	3.036E-02	1.717E-01	2.938E-02
	Random 5	5.586E-02	3.080E-02	1.715E-01	2.929E-02
	mean	5.588E-02	3.054E-02	1.716E-01	2.934E-02
	std. dev.	2.049E-05	2.358E-04	1.095E-04	4.930E-05
	% fluct.	0.037	0.772	0.064	0.168

		mean RMSE	min RMSE	max RMSE	stddev RMSE
140 colour samples	*Random 1*	5.592E-02	3.016E-02	1.710E-01	2.912E-02
	Random 2	5.596E-02	3.025E-02	1.711E-01	2.914E-02
	Random 3	5.592E-02	3.016E-02	1.710E-01	2.912E-02
	Random 4	5.593E-02	3.012E-02	1.709E-01	2.910E-02
	Random 5	5.596E-02	3.025E-02	1.711E-01	2.914E-02
	mean	5.594E-02	3.019E-02	1.710E-01	2.912E-02
	std. dev.	2.049E-05	5.891E-05	8.367E-05	1.673E-05
	% fluct.	0.037	0.195	0.049	0.057

		mean RMSE	min RMSE	max RMSE	stddev RMSE
150 colour samples	*Random 1*	5.623E-02	3.158E-02	1.716E-01	2.928E-02
	Random 2	5.623E-02	3.158E-02	1.716E-01	2.928E-02
	Random 3	5.623E-02	3.158E-02	1.716E-01	2.928E-02
	Random 4	5.623E-02	3.158E-02	1.716E-01	2.928E-02
	Random 5	5.623E-02	3.158E-02	1.716E-01	2.928E-02
	mean	5.623E-02	3.158E-02	1.716E-01	2.928E-02
	std. dev.	0.000E+00	4.657E-10	0.000E+00	0.000E+00
	% fluct.	0.000	0.000	0.000	0.000

		mean RMSE	min RMSE	max RMSE	stddev RMSE
160 colour samples	*Random 1*	5.633E-02	3.118E-02	1.723E-01	2.963E-02
	Random 2	5.633E-02	3.118E-02	1.723E-01	2.963E-02
	Random 3	5.633E-02	3.118E-02	1.723E-01	2.963E-02
	Random 4	5.633E-02	3.118E-02	1.723E-01	2.963E-02
	Random 5	5.633E-02	3.118E-02	1.723E-01	2.963E-02
	mean	5.633E-02	3.118E-02	1.723E-01	2.963E-02
	std. dev.	0.000E+00	4.657E-10	0.000E+00	0.000E+00
	% fluct.	0.000	0.000	0.000	0.000

		mean RMSE	min RMSE	max RMSE	stddev RMSE
166 colour samples	*Random 1*	5.658E-02	3.215E-02	1.728E-01	2.972E-02
	Random 2	5.658E-02	3.215E-02	1.728E-01	2.972E-02
	Random 3	5.658E-02	3.215E-02	1.728E-01	2.972E-02
	Random 4	5.658E-02	3.215E-02	1.728E-01	2.972E-02
	Random 5	5.658E-02	3.215E-02	1.728E-01	2.972E-02
	mean	5.658E-02	3.215E-02	1.728E-01	2.972E-02
	std. dev.	0.000E+00	0.000E+00	0.000E+00	0.000E+00
	% fluct.	0.000	0.000	0.000	0.000

Appendix 2 Fluctuations of system's performance depending on the number of samples of the training set

Table A2.3 (1) ***Multispectral Configuration****: mean, minimum, maximum and standard deviation of the* ***CIELAB colour difference values*** *obtained using the five different training sets selected from an initial randomly selected colour sample for all sizes considered, and using the CCCR chart as test set.*

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
10 colour samples	*Random 1*	10.053	1.356	52.588	13.363
	Random 2	13.453	1.772	81.830	18.681
	Random 3	14.096	1.404	120.078	26.135
	Random 4	9.222	1.838	41.372	8.748
	Random 5	17.760	2.078	168.453	34.654
	mean	12.917	1.690	92.864	20.316
	std. dev.	3.427	0.305	52.081	10.299
	% fluct.	26.534	18.062	56.083	50.693

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
20 colour samples	*Random 1*	5.573	0.945	25.194	5.233
	Random 2	10.259	0.923	123.656	24.575
	Random 3	5.908	0.819	28.088	5.841
	Random 4	5.592	1.116	18.717	4.593
	Random 5	5.148	0.864	16.427	3.702
	mean	6.496	0.933	42.416	8.789
	std. dev.	2.121	0.113	45.659	8.860
	% fluct.	32.649	12.155	107.644	100.813

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
30 colour samples	*Random 1*	6.991	1.092	38.312	8.668
	Random 2	6.895	1.390	29.378	7.316
	Random 3	5.526	1.391	22.348	5.408
	Random 4	6.837	1.182	36.898	8.382
	Random 5	6.107	1.186	25.052	6.038
	mean	6.471	1.248	30.398	7.162
	std. dev.	0.634	0.135	7.059	1.425
	% fluct.	9.803	10.834	23.221	19.893

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
40 colour samples	*Random 1*	6.030	1.556	23.121	4.769
	Random 2	5.834	1.979	22.508	4.640
	Random 3	6.036	1.587	22.872	4.734
	Random 4	5.834	1.979	22.508	4.640
	Random 5	5.630	2.067	18.898	3.991
	mean	5.873	1.834	21.981	4.555
	std. dev.	0.168	0.242	1.743	0.320
	% fluct.	2.866	13.209	7.930	7.032

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
50 colour samples	*Random 1*	5.651	1.649	24.345	4.874
	Random 2	5.657	1.469	24.964	4.994
	Random 3	5.644	1.547	24.677	4.923
	Random 4	5.644	1.547	24.677	4.923
	Random 5	5.266	1.686	21.102	4.131
	mean	5.572	1.580	23.953	4.769
	std. dev.	0.171	0.087	1.609	0.359
	% fluct.	3.075	5.528	6.716	7.532

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
60 colour samples	*Random 1*	5.182	1.567	22.027	4.319
	Random 2	5.197	1.583	22.499	4.420
	Random 3	5.182	1.567	22.027	4.319
	Random 4	5.490	1.520	23.400	4.639
	Random 5	5.490	1.520	23.400	4.639
	mean	5.308	1.551	22.671	4.467
	std. dev.	0.166	0.029	0.693	0.162
	% fluct.	3.129	1.895	3.058	3.630

Appendix 2 Fluctuations of system's performance depending on the number of samples of the training set

Table A2.3 (2) ***Multispectral Configuration***: *mean, minimum, maximum and standard deviation of the* ***CIELAB colour difference values*** *obtained using the five different training sets selected from an initial randomly selected colour sample for all sizes considered, and using the CCCR chart as test set.*

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
70 colour samples	*Random 1*	5.232	1.704	21.114	4.145
	Random 2	5.362	1.582	23.693	4.722
	Random 3	5.374	1.646	23.501	4.675
	Random 4	5.503	1.539	22.697	4.555
	Random 5	5.428	1.522	24.064	4.789
	mean	5.380	1.599	23.014	4.577
	std. dev.	0.100	0.076	1.174	0.256
	% fluct.	1.852	4.749	5.100	5.599

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
80 colour samples	*Random 1*	5.401	1.440	24.908	4.983
	Random 2	5.205	1.658	21.506	4.224
	Random 3	5.402	1.500	23.689	4.709
	Random 4	5.377	1.562	23.483	4.675
	Random 5	5.358	1.598	23.786	4.736
	mean	5.349	1.552	23.474	4.665
	std. dev.	0.082	0.085	1.232	0.275
	% fluct.	1.539	5.459	5.249	5.896

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
90 colour samples	*Random 1*	5.218	1.587	22.196	4.353
	Random 2	5.156	1.653	20.719	4.035
	Random 3	5.218	1.587	22.196	4.353
	Random 4	5.194	1.601	22.144	4.343
	Random 5	5.218	1.587	22.196	4.353
	mean	5.201	1.603	21.890	4.287
	std. dev.	0.027	0.029	0.655	0.141
	% fluct.	0.521	1.784	2.993	3.292

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
100 colour samples	*Random 1*	5.146	1.654	19.514	3.786
	Random 2	5.175	1.596	20.541	3.977
	Random 3	5.143	1.612	19.614	3.809
	Random 4	5.143	1.612	19.614	3.809
	Random 5	5.158	1.610	20.739	4.028
	mean	5.153	1.617	20.004	3.882
	std. dev.	0.014	0.022	0.586	0.112
	% fluct.	0.267	1.351	2.929	2.886

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
110 colour samples	*Random 1*	4.913	1.705	19.108	3.720
	Random 2	4.951	1.320	19.858	3.894
	Random 3	4.959	1.160	19.739	3.872
	Random 4	4.909	1.744	19.136	3.731
	Random 5	4.987	1.585	19.879	3.877
	mean	4.944	1.503	19.544	3.819
	std. dev.	0.033	0.253	0.389	0.086
	% fluct.	0.664	16.859	1.991	2.243

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
120 colour samples	*Random 1*	4.888	1.118	19.108	3.717
	Random 2	4.929	1.064	19.576	3.815
	Random 3	4.922	1.124	19.440	3.785
	Random 4	4.925	1.129	19.496	3.794
	Random 5	4.925	1.129	19.496	3.794
	mean	4.918	1.113	19.423	3.781
	std. dev.	0.017	0.028	0.183	0.037
	% fluct.	0.342	2.485	0.941	0.990

Table A2.3 (3) ***Multispectral Configuration****: mean, minimum, maximum and standard deviation of the* ***CIELAB colour difference values*** *obtained using the five different training sets selected from an initial randomly selected colour sample for all sizes considered, and using the CCCR chart as test set.*

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
130 colour samples	*Random 1*	4.970	1.160	19.687	3.830
	Random 2	4.999	1.137	19.787	3.847
	Random 3	5.005	1.125	19.819	3.853
	Random 4	5.005	1.125	19.819	3.853
	Random 5	4.970	1.160	19.687	3.830
	mean	4.990	1.141	19.760	3.843
	std. dev.	0.018	0.018	0.068	0.012
	% fluct.	0.366	1.548	0.343	0.306

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
140 colour samples	*Random 1*	5.078	1.230	19.907	3.853
	Random 2	5.070	1.249	19.947	3.855
	Random 3	5.078	1.230	19.907	3.853
	Random 4	5.082	1.213	19.978	3.867
	Random 5	5.070	1.249	19.947	3.855
	mean	5.076	1.234	19.937	3.857
	std. dev.	0.005	0.015	0.030	0.006
	% fluct.	0.106	1.231	0.152	0.153

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
150 colour samples	*Random 1*	5.104	1.149	20.011	3.871
	Random 2	5.104	1.149	20.011	3.871
	Random 3	5.104	1.149	20.011	3.871
	Random 4	5.104	1.149	20.011	3.871
	Random 5	5.104	1.149	20.011	3.871
	mean	5.104	1.149	20.011	3.871
	std. dev.	0.000	0.000	0.000	0.000
	% fluct.	0.000	0.000	0.000	0.000

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
160 colour samples	*Random 1*	5.141	1.379	20.339	3.918
	Random 2	5.141	1.379	20.339	3.918
	Random 3	5.141	1.379	20.339	3.918
	Random 4	5.141	1.379	20.339	3.918
	Random 5	5.141	1.379	20.339	3.918
	mean	5.141	1.379	20.339	3.918
	std. dev.	0.000	0.000	0.000	0.000
	% fluct.	0.000	0.000	0.000	0.000

		mean ΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}	stddev ΔE^*_{ab}
166 colour samples	*Random 1*	5.285	1.794	21.005	3.971
	Random 2	5.285	1.794	21.005	3.971
	Random 3	5.285	1.794	21.005	3.971
	Random 4	5.285	1.794	21.005	3.971
	Random 5	5.285	1.794	21.005	3.971
	mean	5.285	1.794	21.005	3.971
	std. dev.	0.000	0.000	0.000	0.000
	% fluct.	0.000	0.000	0.000	0.000

Appendix 2 Fluctuations of system's performance depending on the number of samples of the training set

Table A2.4 (1) ***Multispectral Configuration****: mean, minimum, maximum and standard deviation of* **RMSE values** *obtained using the five different training sets selected from an initial randomly selected colour sample for all sizes considered, and using the CCCR chart as test set.*

		mean RMSE	min RMSE	max RMSE	stddev RMSE
10 colour samples	*Random 1*	8.494E-02	2.252E-02	3.352E-01	8.290E-02
	Random 2	7.503E-02	1.334E-02	2.420E-01	5.543E-02
	Random 3	7.423E-02	1.297E-02	2.614E-01	6.821E-02
	Random 4	8.569E-02	2.381E-02	3.218E-01	6.392E-02
	Random 5	9.211E-02	1.903E-02	3.240E-01	8.692E-02
	mean	8.240E-02	1.833E-02	2.969E-01	7.148E-02
	std. dev.	7.626E-03	5.042E-03	4.212E-02	1.317E-02
	% fluct.	9.255	27.503	14.187	18.432

		mean RMSE	min RMSE	max RMSE	stddev RMSE
20 colour samples	*Random 1*	6.636E-02	2.212E-02	1.712E-01	3.565E-02
	Random 2	5.428E-02	2.212E-02	1.460E-01	2.983E-02
	Random 3	6.537E-02	2.029E-02	1.545E-01	3.224E-02
	Random 4	5.795E-02	2.305E-02	1.491E-01	3.013E-02
	Random 5	5.703E-02	2.183E-02	1.450E-01	2.925E-02
	mean	6.020E-02	2.188E-02	1.532E-01	3.142E-02
	std. dev.	5.358E-03	1.002E-03	1.074E-02	2.620E-03
	% fluct.	8.901	4.578	7.014	8.340

		mean RMSE	min RMSE	max RMSE	stddev RMSE
30 colour samples	*Random 1*	5.169E-02	2.289E-02	1.155E-01	2.482E-02
	Random 2	5.369E-02	2.257E-02	1.188E-01	2.448E-02
	Random 3	4.724E-02	2.408E-02	9.709E-02	1.864E-02
	Random 4	5.175E-02	2.264E-02	1.167E-01	2.509E-02
	Random 5	5.290E-02	2.562E-02	1.162E-01	2.421E-02
	mean	5.145E-02	2.356E-02	1.129E-01	2.345E-02
	std. dev.	2.500E-03	1.303E-03	8.900E-03	2.708E-03
	% fluct.	4.858	5.530	7.886	11.551

		mean RMSE	min RMSE	max RMSE	stddev RMSE
40 colour samples	*Random 1*	5.469E-02	2.582E-02	9.375E-02	1.813E-02
	Random 2	5.297E-02	2.480E-02	9.107E-02	1.711E-02
	Random 3	5.464E-02	2.576E-02	9.318E-02	1.800E-02
	Random 4	5.297E-02	2.480E-02	9.107E-02	1.711E-02
	Random 5	5.454E-02	2.840E-02	8.969E-02	1.667E-02
	mean	5.396E-02	2.592E-02	9.175E-02	1.740E-02
	std. dev.	9.072E-04	1.474E-03	1.674E-03	6.313E-04
	% fluct.	1.681	5.689	1.825	3.627

		mean RMSE	min RMSE	max RMSE	stddev RMSE
50 colour samples	*Random 1*	5.011E-02	2.606E-02	8.540E-02	1.605E-02
	Random 2	5.064E-02	2.402E-02	9.653E-02	1.755E-02
	Random 3	5.078E-02	2.518E-02	9.435E-02	1.713E-02
	Random 4	5.078E-02	2.518E-02	9.435E-02	1.713E-02
	Random 5	5.005E-02	2.545E-02	8.245E-02	1.569E-02
	mean	5.047E-02	2.518E-02	9.062E-02	1.671E-02
	std. dev.	3.630E-04	7.404E-04	6.260E-03	7.960E-04
	% fluct.	0.719	2.941	6.908	4.764

		mean RMSE	min RMSE	max RMSE	stddev RMSE
60 colour samples	*Random 1*	4.785E-02	2.188E-02	8.243E-02	1.533E-02
	Random 2	4.804E-02	2.090E-02	8.520E-02	1.563E-02
	Random 3	4.785E-02	2.188E-02	8.243E-02	1.533E-02
	Random 4	4.767E-02	2.119E-02	8.777E-02	1.611E-02
	Random 5	4.767E-02	2.119E-02	8.777E-02	1.611E-02
	mean	4.782E-02	2.141E-02	8.512E-02	1.570E-02
	std. dev.	1.542E-04	4.468E-04	2.670E-03	3.921E-04
	% fluct.	0.323	2.087	3.137	2.497

Appendix 2 Fluctuations of system's performance depending on the number of samples of the training set

Table A2.4 (2) ***Multispectral Configuration****: mean, minimum, maximum and standard deviation of* ***RMSE values*** *obtained using the five different training sets selected from an initial randomly selected colour sample for all sizes considered, and using the CCCR chart as test set.*

		mean RMSE	min RMSE	max RMSE	stddev RMSE
70 colour samples	*Random 1*	4.863E-02	2.228E-02	7.735E-02	1.535E-02
	Random 2	4.906E-02	2.008E-02	8.802E-02	1.669E-02
	Random 3	4.928E-02	2.119E-02	8.698E-02	1.659E-02
	Random 4	5.073E-02	2.083E-02	8.581E-02	1.773E-02
	Random 5	4.908E-02	2.004E-02	8.900E-02	1.678E-02
	mean	4.936E-02	2.088E-02	8.543E-02	1.663E-02
	std. dev.	8.038E-04	9.225E-04	4.671E-03	8.480E-04
	% fluct.	1.629	4.417	5.468	5.100

		mean RMSE	min RMSE	max RMSE	stddev RMSE
80 colour samples	*Random 1*	4.937E-02	1.795E-02	9.562E-02	1.802E-02
	Random 2	4.857E-02	2.125E-02	8.004E-02	1.567E-02
	Random 3	4.918E-02	1.942E-02	8.912E-02	1.728E-02
	Random 4	4.929E-02	1.952E-02	8.847E-02	1.720E-02
	Random 5	4.925E-02	2.090E-02	8.910E-02	1.684E-02
	mean	4.913E-02	1.981E-02	8.847E-02	1.700E-02
	std. dev.	3.216E-04	1.319E-03	5.545E-03	8.593E-04
	% fluct.	0.655	6.658	6.268	5.054

		mean RMSE	min RMSE	max RMSE	stddev RMSE
90 colour samples	*Random 1*	4.890E-02	2.099E-02	8.267E-02	1.569E-02
	Random 2	4.867E-02	2.248E-02	7.671E-02	1.484E-02
	Random 3	4.890E-02	2.099E-02	8.267E-02	1.569E-02
	Random 4	4.867E-02	2.076E-02	8.248E-02	1.568E-02
	Random 5	4.890E-02	2.099E-02	8.267E-02	1.569E-02
	mean	4.881E-02	2.124E-02	8.144E-02	1.552E-02
	std. dev.	1.260E-04	6.992E-04	2.645E-03	3.790E-04
	% fluct.	0.258	3.292	3.248	2.443

		mean RMSE	min RMSE	max RMSE	stddev RMSE
100 colour samples	*Random 1*	4.834E-02	2.300E-02	7.217E-02	1.468E-02
	Random 2	4.861E-02	2.245E-02	7.640E-02	1.485E-02
	Random 3	4.830E-02	2.285E-02	7.199E-02	1.468E-02
	Random 4	4.830E-02	2.285E-02	7.199E-02	1.468E-02
	Random 5	4.853E-02	2.211E-02	7.750E-02	1.503E-02
	mean	4.842E-02	2.265E-02	7.401E-02	1.478E-02
	std. dev.	1.443E-04	3.654E-04	2.713E-03	1.560E-04
	% fluct.	0.298	1.613	3.666	1.055

		mean RMSE	min RMSE	max RMSE	stddev RMSE
110 colour samples	*Random 1*	4.699E-02	2.420E-02	6.972E-02	1.375E-02
	Random 2	4.742E-02	2.400E-02	7.233E-02	1.389E-02
	Random 3	4.740E-02	2.468E-02	7.172E-02	1.383E-02
	Random 4	4.705E-02	2.431E-02	6.927E-02	1.364E-02
	Random 5	4.750E-02	2.397E-02	7.257E-02	1.386E-02
	mean	4.727E-02	2.423E-02	7.112E-02	1.379E-02
	std. dev.	2.340E-04	2.873E-04	1.526E-03	1.006E-04
	% fluct.	0.495	1.186	2.145	0.730

		mean RMSE	min RMSE	max RMSE	stddev RMSE
120 colour samples	*Random 1*	4.679E-02	2.383E-02	7.254E-02	1.401E-02
	Random 2	4.692E-02	2.363E-02	7.215E-02	1.407E-02
	Random 3	4.693E-02	2.375E-02	7.213E-02	1.400E-02
	Random 4	4.695E-02	2.378E-02	7.224E-02	1.402E-02
	Random 5	4.695E-02	2.378E-02	7.224E-02	1.402E-02
	mean	4.691E-02	2.375E-02	7.226E-02	1.402E-02
	std. dev.	6.723E-05	7.503E-05	1.645E-04	2.702E-05
	% fluct.	0.143	0.316	0.228	0.193

Table A2.4 (3) ***Multispectral Configuration****: mean, minimum, maximum and standard deviation of* **RMSE values** *obtained using the five different training sets selected from an initial randomly selected colour sample for all sizes considered, and using the CCCR chart as test set.*

		mean RMSE	min RMSE	max RMSE	stddev RMSE
130 colour samples	*Random 1*	4.760E-02	2.414E-02	7.272E-02	1.369E-02
	Random 2	4.753E-02	2.420E-02	7.266E-02	1.377E-02
	Random 3	4.755E-02	2.423E-02	7.285E-02	1.378E-02
	Random 4	4.755E-02	2.423E-02	7.285E-02	1.378E-02
	Random 5	4.760E-02	2.414E-02	7.272E-02	1.369E-02
	mean	4.757E-02	2.419E-02	7.276E-02	1.374E-02
	std. dev.	3.209E-05	4.550E-05	8.573E-05	4.764E-05
	% fluct.	0.067	0.188	0.118	0.347

		mean RMSE	min RMSE	max RMSE	stddev RMSE
140 colour samples	*Random 1*	4.814E-02	2.454E-02	7.450E-02	1.401E-02
	Random 2	4.822E-02	2.469E-02	7.459E-02	1.396E-02
	Random 3	4.814E-02	2.454E-02	7.450E-02	1.401E-02
	Random 4	4.816E-02	2.447E-02	7.483E-02	1.404E-02
	Random 5	4.822E-02	2.469E-02	7.459E-02	1.396E-02
	mean	4.818E-02	2.459E-02	7.460E-02	1.400E-02
	std. dev.	4.099E-05	9.915E-05	1.352E-04	3.507E-05
	% fluct.	0.085	0.403	0.181	0.251

		mean RMSE	min RMSE	max RMSE	stddev RMSE
150 colour samples	*Random 1*	4.852E-02	2.430E-02	7.593E-02	1.410E-02
	Random 2	4.852E-02	2.430E-02	7.593E-02	1.410E-02
	Random 3	4.852E-02	2.430E-02	7.593E-02	1.410E-02
	Random 4	4.852E-02	2.430E-02	7.593E-02	1.410E-02
	Random 5	4.852E-02	2.430E-02	7.593E-02	1.410E-02
	mean	4.852E-02	2.430E-02	7.593E-02	1.410E-02
	std. dev.	0.000E+00	0.000E+00	0.000E+00	2.328E-10
	% fluct.	0.000	0.000	0.000	0.000

		mean RMSE	min RMSE	max RMSE	stddev RMSE
160 colour samples	*Random 1*	4.851E-02	2.380E-02	7.729E-02	1.443E-02
	Random 2	4.851E-02	2.380E-02	7.729E-02	1.443E-02
	Random 3	4.851E-02	2.380E-02	7.729E-02	1.443E-02
	Random 4	4.851E-02	2.380E-02	7.729E-02	1.443E-02
	Random 5	4.851E-02	2.380E-02	7.729E-02	1.443E-02
	mean	4.851E-02	2.380E-02	7.729E-02	1.443E-02
	std. dev.	0.000E+00	0.000E+00	1.317E-09	0.000E+00
	% fluct.	0.000	0.000	0.000	0.000

		mean RMSE	min RMSE	max RMSE	stddev RMSE
166 colour samples	*Random 1*	4.835E-02	2.380E-02	7.873E-02	1.457E-02
	Random 2	4.835E-02	2.380E-02	7.873E-02	1.457E-02
	Random 3	4.835E-02	2.380E-02	7.873E-02	1.457E-02
	Random 4	4.835E-02	2.380E-02	7.873E-02	1.457E-02
	Random 5	4.835E-02	2.380E-02	7.873E-02	1.457E-02
	mean	4.835E-02	2.380E-02	7.873E-02	1.457E-02
	std. dev.	0.000E+00	0.000E+00	9.313E-10	0.000E+00
	% fluct.	0.000	0.000	0.000	0.000