# Imagemaster : Precision Colour Communication based on CIE Calibrated Monitor Screens

# IMAGEMASTER : PRECISION COLOUR COMMUNICATION BASED ON CIE CALIBRATED MONITOR SCREENS

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Introduction

Colour communication is a significant problem, contributing to long lead times in the design and production processes for a wide range of products. Colour is also an important component in image analysis, surface texture appearance simulation, and in diagnostic medicine. Two problems are common to all the above areas of colour use. The first problem is how to define colour precisely enough to avoid mistakes. The second problem is the visualisation and communication of precise colour specifications.

CIE colour specification [1] is widely accepted as a precise powerful and accurate method of specifying colour. This is reflected by its wide use together with spectro-photometry in industrial colour measurement and control. It has also more recently lead to the adoption of CIELab in a number of image specification formats ( e.g. TIFF 6.0 ).

The UMIST Colour Communication Research Group has five years of experience in applying colour communication systems to the problems of colour management in the textile industry. The use of CIE co-ordinates, synthetic and measured reflectance curves, has been shown [2,3,4] to give significantly reduced lead times in bringing new colour ranges into bulk production.

CIE co-ordinate specified 4000 by 2000 pixel colour images, representing full texture and surface detail have recently been added to the simulations available for precision colour communication. The project ' Colour Systems for Texture in Textile CAD' [5] has generated a range of image, analysis, specification and manipulation systems described in the following sections. Some of the applications researched are also described.

**The essential building blocks for precision colour imaging.**

The use of computer systems to generate and manipulate coloured images is well established. To turn such computer systems into precision colour communication tools, far reaching changes are necessary. They are :-

1. To standardise and base computer simulation on device independant colour definitions.
2. To use CIE co-ordinate colour reproduction on-screen, accurate to within a just visible difference.
3. To specify, storage and manipulation of pixel colour as CIE co-ordinate definitions.
4. To use image capture systems that are essentially free from colour artefact generation, are linear in receptor response, and have a high dynamic lightness range.
5. To analyse images into logical object, and sub-object hierarchies in order to relate measured object colour to object image colour-sets.

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6. To define intrinsic object colour using reflectance curves, enabling simulation of appearance change, under a range of illuminants.
7. To use a simulation model containing both intrinsic colour definitions, and photo-realistic surface texture simulation.

**CIE Co-ordinate Colour Reproduction.**

We give below ( Table 1. ) The results ( Delta E CMC (2:1) $D_{65}$ $10^{O}$ Observer differences [10] ) of an exhaustive test of the UMIST 'Adaptive Driver' screen colour calibration system. Nine full calibrate / test cycles were carried out, in which 124,968 CIE colour specifications on 72 Hue pages were measured, covering the full gamut of reproducible colours.

| Co-ordinate Set | Min Error ( DE CMC 2:1) | Max Error ( DE CMC 2:1) | Mean Error ( DE CMC 2:1) |
|---|---|---|---|
| Hue page H = $30^{o}$ (1908 samples ) | 0.025 | 1.348 | 0.487 |
| Full monitor gamut | 0.01 | 1.969 | 0.484 |

Table 1. Monitor screen calibration performance.

The Adaptive Driver calibration system [6] has now been in use in industry via the Shademaster system [9] for commercial colour range development for four years.

**Specification, storage and manipulation of pixel colour as CIE co-ordinate definitions**

In the Imagemaster Demonstrator [5] the plain colour simulations of Shademaster are enhanced to include full surface texture simulation.

Novel image definition formats are used, to enable :-

a) the specification of each pixel colour by a CIE co-ordinate definition

b) grouping of pixels into logical object and sub-object hierarchies

c) definition of an intrinsic colour for each object and sub-object in the image

d) maintenance of a 1:M mapping between intrinsic and colour-set definitions.

Thus each image consists of a simulated viewing environment, with a a specified ' virtual illuminant' . In the environment is a set of logical objects. Each object or object component has an intrinsic colour definition in the form of a spectral reflectance curve. The position, shape, high-light, shade, and surface texture are simulated by an object image colour-set. Input images of photographic quality are analysed into sets of separate object images, then transferred into, and viewed in an appropriate on-screen environment, for comparison evaluation and analysis.

To-date, the specialised data structures have been used to store and analyse several hundred images ranging from multi-coloured textile fibre-blended materials, through lace, to images of lipsticks, and models wearing the lipstick.

Storage, processing and analysis have all been made computationally efficient and functionally easier by using CIE co-ordinate based, rather than bit-map oriented data structures.

## Image Capture Systems

Typical 'photo-processing packages', allow manipulation of image content by gamma correction, response function control and colour balancing in order to create a pleasing colour that 'looks like' that of the object imaged. This is the direct opposite to a precision colour imaging process, which strives for a colorimetrically correct image.

The minimum requirement is for an image capture system that is colorimetrically consistent image to image, and does not distort intra-image colour relationships. Note that colorimetric consistency, not correctness is specified at this level.

An important additional requirement is a minimum introduction of 'colour noise' by the imaging system. Such colour noise is seen, particularly in near neutrals, as a population of multiple closely related colours in part of an image of an object, which has demonstrably a single colour.

In our investigations to-date, no commercial electronic camera either under or over £50,000 has been found to meet these criteria.

Colorimetric consistency, and colorimetric correctness are separate and distinct issues. It is very desirable to preserve intra-object colour consistency in the imaging process. An object image with an internally consistent set of colours can be readily separated from other image components, by the colorimetric image analysis processes described later.

Colorimetric correctness, in which the CIE specifications of all image components are captured directly ( imaging spectrometry and / or colorimetry ) is being developed, but is not yet available commercially [7].

We have found that good quality professional slide film, ( positive or negative ) correctly exposed, and digitised by the photo-CD route yields reasonably high quality input images, at a resolution of 4000 by 2000 pixels in 24 Bit colour. Adequate response linearity, balance, dynamic range, and image to image colour consistency are provided.

Attempts to calibrate conventional imaging devices ( e.g. video ) [8] have only had limited success, and have not produced colorimetrically correct image specifications.

It should be noted that the full benefits of precision colour imaging can only be realised, when mean colorimetric accuracy reaches CIELab Delta E 2 or better, across the full colour gamut, at least in the reference visualisation or 'soft colour proofing' system. Device characterisation systems typical of current commercial ' colour management ' offerings are a long way short of this level.

## CIE co-ordinate based image analysis

The systems developed for colorimetric image analysis in the ' Imagemaster ' project [5], are based on the following principles.

1. That a colorimetrically consistent input image contains and preserves information about internal colour differences in the object imaged.
2. That the human eye / brain visual differentiation mechanisms for light, shade, and texture, are mainly colour related, and modelled quite closely by CIE colour-space dimensions L, C, and H.
3. That by reversing the monitor calibration mapping, an image defined as image capture RGB triplets, can be reconstructed as a reasonably consistent ( although not colorimetrically accurate ) CIE co-ordinate representation of the original object.

The authors have now carried out numerous image analysis exercises based on these principles. The tools developed allow very powerful object differentiation within an image. Objects can be differentiated on any component, magnitude and combination of colour dimensions in CIE colour-space. The resulting objects can be linked, combined, sorted and merged easily, to give highly differentiated logical hierarchies of objects. These can be stored and brought into the simulation environment in any combination.

Figure 1 ( a - f ) illustrates some of the results of colour image analysis and manipulation.

Fig No. .

1 a ) Shows an image of a two-colour lace sample isolated from its background image, and presented against black, white, and flesh-tone coloured areas.

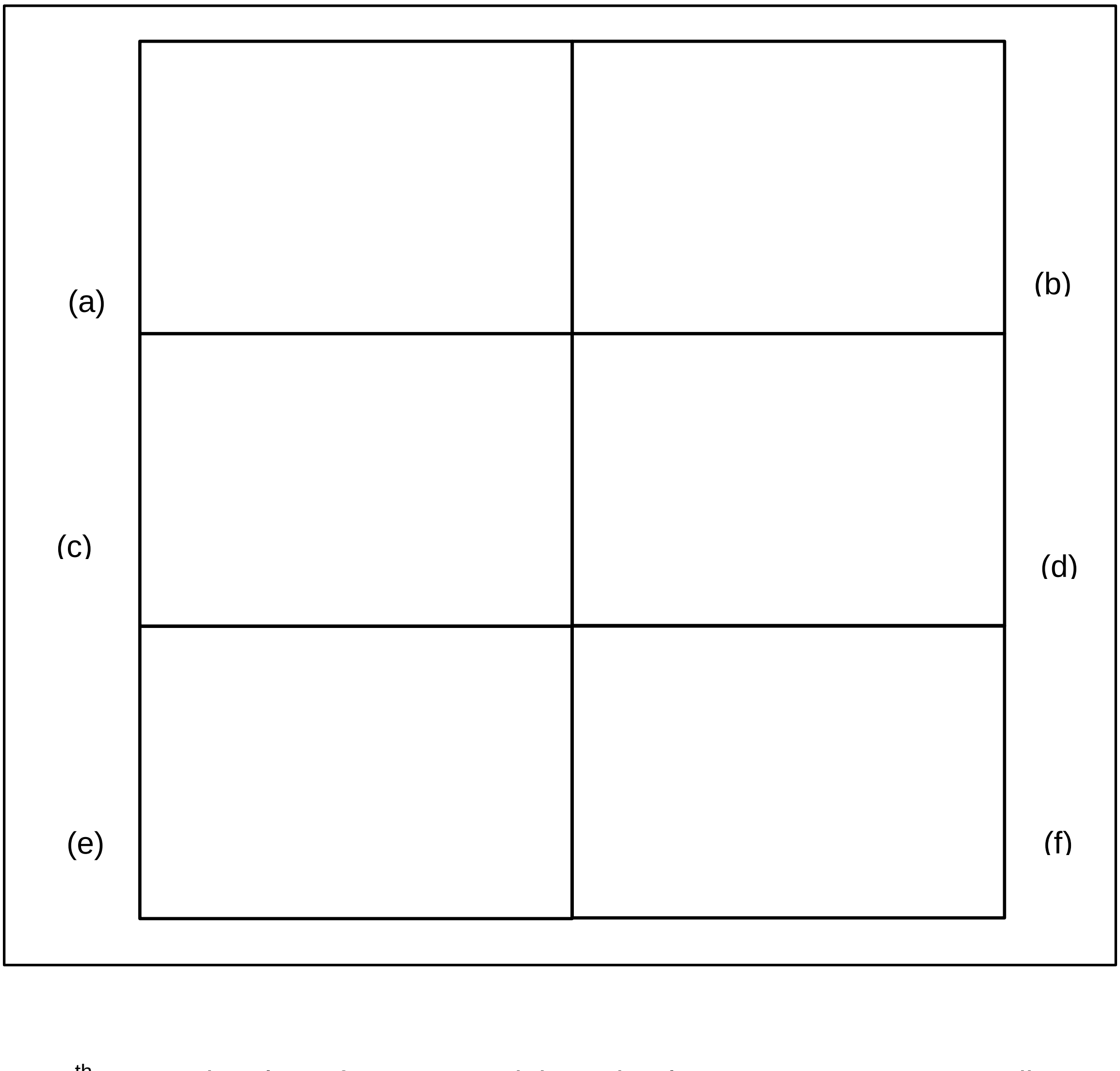
1 b ) Shows a cut-out of the sample in ( a ) analysed into its components and with a sub-object recoloured in two alternative ways.

1 c ) Shows paired lace and satin fabrics before and after the satin is recoloured to an alternative blue CIE colour specification.

1 d ) Shows a single lipstick image replicated and re-coloured to four alternative reflectance curve specified intrinsic colour specifications.

1 e ) Shows four alternative lipstick colour specifications applied to lip images.

1 f ) Shows a model and garments in alternative known colour specifications.

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**Intrinsic Object Colour**

Once an object has been separated from its unrelated surroundings, we have shown that it is possible to

1. Define, manipulate and store a base intrinsic colour definition for each object.
2. Measure the original object and input the result into the intrinsic colour definition.
3. Simulate the object in the measured or alternative colours on screen without loss of shading or texture.
4. Show the effect on colour of changing the illuminant, based on changes in CIE co-ordinates calculated from the spectral reflectance curve intrinsic colour definition.

The reverse process is also valid. Here an image colour-set may be changed in colour as a unit, maintaining all pixels in their relative positions to one another in colour-space. The use of CIE, particularly CIELab colour space is vital for this process, as it approximates visual uniformity quite closely [1].

The object now has a new intrinsic colour and this is output as a synthetic reflectance curve [4]. A 'virtual product' has been created with the original shape and surface texture, in a new colour.

During the project, it has been shown possible to use the above output reflectance curves as input to computer colorant formulation systems enabling the manufacture of the ' virtual product ' as a closely matching sample of production fabrics and lace.

Figure 2. illustrates three image-objects each with a different texture, but identical intrinsic colour specification. The output reflectance curve was sent by fax to three remote dye houses, and the visual difference result was replicated successfuly with a measured colour difference from specification of less than Delta E 2 ( CMC 2:1 ) under each of three different illuminants.

Figure 2. Three different textures with identical intrinsic colour definitions.

**Precision Colour Communication using images.**

The precision colour image visualisation system described above, can be set up at both ends of any required colour communication or remote diagnostic link. Images, and more importantly precise colour specifications, can be freely exchanged, discussed and developed.

It should be noted that the precision of the underlying simulation is not limited to the 24 bit colour resolution of the display system. It depends only on the decimal precision of the CIE co-ordinates recorded. It is thus possible to record and communicate colour information at higher levels of precision than it can be reproduced in a typical current computer system.

In practical terms the accuracy of visual on-screen simulation will be dependent on the accuracy of screen calibration, which should be good enough to ensure that visually identical images are viewed.

In Imagemaster the calibration system which ensures visual accuracy, currently uses a Minolta CA100 screen colour analyser and a dynamic three dimensional non-linear mapping algorithm to maintain screen colour within tolerance. The calibration procedure takes less than five minutes.

To make full use of precision colour communication, a ' Precision Colour Culture ' is necessary, including the use of carefully controlled ambient lighting, Standard Illuminant matching cabinets, and good quality Spectro-photometric colour measurements.

The systems described above run on a Silicon Graphics workstation running under Unix. All the programs are written in-house using ANSI standard C++, Open GL and X-Windows. A Minolta CM2002 Spectro-photometer is used to generate input spectral curve colour definitions, and ASTM Standard Illuminant data is used to calculate CIE specifications from reflectance curves, thus modelling appearance under different illuminants.

## Applications of Precision Colour Imaging

Two inherently different types of image have been studied. In the first, typified by dyed textiles, and solid plastics, the objects imaged and analysed are nominally of a single colour. The colour is usually measurable, and it is important, both to generate and communicate such measurable intrinsic colour definitions.

In the second type of image, the objects include natural products, biological and medical specimens. The object imaged has intrinsically heterogeneous colour, which is largely meaningless if reduced to a single 'intrinsic' colour specification. Some objects in this group however, of apparently heterogeneous colour, are infact finely mixed at the sub-millimetre level from components with an intrinsic colour whose nature is important.

Conventional colour and colour difference measurement techniques are difficult or impossible to apply to objects with heterogeneous colour, and have little to offer for analysing the colour of the object. Colorimetric image processing is expected to extend the application of precision colour analysis significantly in this field.

**Colour Communication** can be achieved at several levels of precision. At the lowest level it is achieved by use of colour atlases. These are limited by the accuracy of colour reproduction in the atlas, provide no information about the effects of change in illuminant, and are limited to at most a few thousand alternative colour definitions. Inspite of these limitations, a large section of colour using industry find this approach sufficiently accurate for their needs.

Scientific colour management, based on CIE specified colour, the use of spectral reflectance curves, and accurate colour measurement, has transformed the control of textile production in the UK textile manufacturing / retailing industry [9]. The methods are an order of magnitude more accurate for defining colour, and controlling coloured production.

The lack of an adequate system for visualising the colour specified, was until recently, a major drawback inhibiting the use of CIE specifications as a colour communication method. This has been overcome by the development of accurately calibrated monitor screens.

Colour communication, based on a combination of calibrated screen colour visualisation, CIE and reflectance curve colour definition, together with digital communication of colour specifications, has been the prime factor in substantial reductions in lead-time for bringing new colour ranges into production [9].

The addition of texture and shape simulation, digital transmission of images, and the ability to analyse colour specifications down to sub-millimetre dimensions are expected to widen the application of digital colour communication techniques significantly.

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