



Colour Systems for Texture in Textile CAD

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FINAL REPORT
Project GR/J91852

'COLOUR SYSTEMS FOR TEXTURE IN TEXTILE CAD'

CONTENTS	Page No.
1.0 Achievements of the project	1
1.1. Achievements in the Image capture/image processing field	2
1.2. Achievements in methods of defining and characterising texture	2
1.21. MDD and MVD Value Quantification of 'Texture'.	2
1.3. Achievements in Colour Communication Systems	5
1.4. Achievements in defining, meeting, and delivering solutions to industrial problems.	5
1.5 Achievements in software and systems development.	5
1.51 Quality and novelty of on-screen Simulation and analysis	5
1.52 Delivery of Industrial Benefits	6
1.53 Wider Exploitation	6
1.6 References	7

Appendix 1 Project Discoveries, Results, and Experimental Verification of Functionality

Appendix 2 The Background, Deliverables, and the Scientific Basis for Texture Simulation

1.0 Achievements of the project

Introduction

The achievements of the project are best understood by reference to its background and origins. The project arose from the needs of supporting industrial consortium members to solve the problems of long lead times, inadequate colour control, and sampling costs in new product development. A basis for potential solutions to these problems was available via calibrated on-screen colour reproduction to CIE colour specifications. The proposed solution was improved colour communication, using on-screen visualisation of colour and texture, backed by precise numeric specification of colour, and hopefully also of texture. The route to exploitation of new knowledge was expected to be via existing CAD systems, which address reduction of lead times and sampling costs, but are in general very weak in the area of precision colour. Ref [1].

The Objectives addressed

The original objectives stated in the project proposal have remained valid throughout the project, and have proved in large measure achievable. They are re-stated as follows :-

1. To develop a scientific basis for generating texture rich images.
2. To develop an understanding of the relationship between image colour and product colour specifications.
3. To enable the generation of product colour specifications directly from computer images and models of appearance.

These objectives were addressed in the series of Work Packages listed in Appendix 2, where detailed deliverables are also reviewed. The work packages are defined in detail in Ref [11].

Against the above central objectives, the investigators list as **Headline Achievements** :-

- Development of a new branch of *Colour Appearance Modelling* concerned with quantifying appearance modification of intrinsic colour, by the action of texture.
- Separation characterisation, and quantification of *texture and intrinsic colour as independent contributing variables* of colour appearance.
- Development of a reversible mapping which allows simulation of colour appearance, calculated from intrinsic colour (1:M mapping), and calculation of intrinsic colour from simulated colour appearance (M:1 mapping).
- Development and *observer-trial validation of accurate colour* photo-realistic simulations of texture.
- Development of a new class of CAD system dedicated to creating and communicating photo-realistic images of 'virtual products' in precisely specified colour.
- Exploitation of the technology developed in the project, via a new start-up company called Colorite Ltd, which currently employs six people, and has products developed exclusively from the project demonstrator.
- Senior management level follow-up teams steering the introduction of new working practices into consortium member companies based on the new technology developed.

We believe a near optimum balance has been achieved between meeting the demands for practical applicability of the new technology developed, and enduring scientific advance, on which further technological solutions can be built.

Scientific Advances

The investigators are able to report new knowledge in four major areas of scientific investigation.

These are grouped under the following headings :-

- New methods for the capture and analysis of information about the colour appearance of different surface textures.
- New methods for defining texture as an independent variable of colour appearance
- Novel predictive methods for quantifying the intrinsic colour of an object or surface texture, and for the inverse phenomenon, which is prediction of how a given intrinsic colour will appear, viewed with an alternative texture.
- The development of a quantitative basis for simulating texture and object appearance.

These scientific advances are summarised in Sections 1.1 and 1.2 below.

Advances in Practical Technology

In addition to the scientific advances, a strong feature of the project is the delivery of practical, and commercially important applications of the these advances.

Sections 1.3 to 1.5 summarise achievements in :-

- Development of Colour Communication Systems with wide industrial applications.
- Delivery of solutions to the industrial problems of consortium members, particularly relating to new product lead times and sampling costs.

And

- Delivery of engineered software solutions and systems development, as a basis for exploitation.

1.1. Achievements in the Image capture/image processing field

The investigators first postulated a definition of texture, based on the detailed (sub-millimetre level) colorimetric and spatial distribution of light fluxes incident on an observer's eye, when a coloured object or surface texture is being observed. The implications of this definition were met by :-

- Use of light-flux definitions, specified by both spectral power distribution, and by CIE colour-identity Ref [2].
- Use of imaging methods designed to deliver objective measurement of light fluxes at each point in the image, or at a minimum the relative differences between them (see Appendix 2 section 2.4).
- Storage, and analysis of images based on their pixel colour, defined by CIE co-ordinate colour identity of each pixel. Colour has been adopted as the key attribute of a pixel, and collectively of a texture or object within an image. The location of all pixels of a given colour is stored as a secondary attribute (see appendix 1 sections 3.2/3.3).

The characteristics of the postulated model were then tested as an on-screen simulation of colour appearance, and as an analogue of the coloration process.

A key confirmation of model correctness was the demonstration in visual trials, of the independence of the texture variable from the intrinsic colour variable, as separate, quantifiable components of the overall phenomenon of colour appearance. The texture is validated as an analogue of a fabric, and the intrinsic colour as an analogue of the colorant formulation. (see Appendix 1 section 6.0)

The correctness of the proposed texture definition has been further validated by confirming accurate differentiation of objects as logically separate components of an image Ref [3] 'Differentiating objects within images' in preparation), and section 3.11 of Appendix 1.

1.2 Achievements in methods of defining and characterising texture

The investigators have established colour, and its detailed micro-level distribution *as a defining measure of texture*. The phenomenon of 'colour appearance' is modelled as having two independent variables, texture and intrinsic colour. The intrinsic base colour of a texture colour-set becomes an independent variable which can be changed at will, and is a direct analogue and simulation of applying a dye to a fabric with the given texture. The variable 'texture' has two components. The first component models the modification of intrinsic colour to produce a closely related set of texture-colour-set member colours. The second component places these colours in a spatial distribution characteristic of the visual appearance of the texture.

This definition leads to a simulation of texture as a set of possibly many thousand colour definitions, called a 'colour-set'. Colour sets with in excess of 100 thousand member point-colour definitions occur frequently in high resolution image analysis. In the image simulation, many colour definitions each have a frequency of occurrence, and a set of locations distributed spatially across the texture, at which this colour is present.

1.21 MDD and MVD Value Quantification of 'Texture'.

A mathematical and statistical analysis has been made, of object and texture colour-sets abstracted from images, and the resulting colour-sets have been characterised by a new scalar measure of colour distribution within the colour-set. This has been given the name 'Mean Directional Deviation' (MDD), and it relates colour-set members to intrinsic colour in each intuitive component dimension of colour difference, by means of a mathematical function.

As the members of a colour-set are distributed in a colour-space to which vector properties can be ascribed, a second powerful measure of the properties of a texture colour-set becomes available. It has been given the name 'Mean Vector Displacement Value' (MVD). The adopted 'independent texture variable' is thus defined as a function which operates on

an **intrinsic colour definition** to produce a **modified colour appearance**. The MVD Value specifies the result of applying the function, and thus has both diagnostic and predictive power that can be directly tested Refs [4,5,6].

The derivation of MDD and MVD values

MDD and MVD values characterise colour appearance change due to texture, and are defined as follows :-

Mean Directional Deviation' (MDD) of a colour-set in each of three dimensions is defined as the mean sum of all the (many thousand) individual point-colour deviations :-

For example in the lightness dimension

$$MDD_L = (\sum \Delta L)/n$$

where n is the number of set members, and ΔL is an individual point-colour lightness difference from the intrinsic colour L^* value.

MDD_L defines the *mean directional deviation* of all the members of a colour-set from the intrinsic colour, in the lightness dimension of difference, and is measured in colour-difference units i.e. CIEL*a*b* units.

Identical measures, MDD_C , and MDD_H are defined for the hue and chroma definitions of difference.

DD_L the *direction of deviation in lightness* is a *basis vector* of a three-dimensional colour-difference space, whose other two dimensions are DD_C DD_H . Individual set-member deviations, and mean colour-set deviations are scalar measures in this colour space which have both direction and magnitude.

Directional Hue difference ΔH_D is a signed scalar variable in this space, defined as

$$\Delta H_D = \Delta H^{\circ} (\Delta h^{\circ} / (|\Delta h^{\circ}|))$$

where Δh° is the signed Hue angle change, and $|\Delta h^{\circ}|$ is its absolute value, and ΔH is metric Hue difference.

Mean Vector Displacement, MVD.

The three vector-component scalars are combined to produce a composite colour appearance change in all three dimensions of colour :-

$$MVD = (MDD_L, MDD_C, MDD_H)$$

The MVD is a vector in colour-difference space, and it is thus valid to quote a colour difference in this space analogous to ΔE as the Root Mean Square (RMS) distance calculated as follows :-

$$CD_{MVD} = (MDD_L^2, MDD_C^2, MDD_H^2)^{1/2}$$

The units of the CD_{MVD} of a Mean Vector Displacement, are CIEL*a*b* colour difference units.

MDD and MVD are in principle constant for a given texture, and are independent of any variation in intrinsic colour. The colour-set, from whose colour definitions MVD values are calculated is an analogue of a textured substrate, to which any intrinsic colour can be applied. The intrinsic colour is an analogue of a colorant formulation that might be applied to the substrate.

An MVD plus an Intrinsic colour definition reflectance curve, combine to give a direct simulation and quantification of the colour appearance for a given texture, and given colorant formulation.

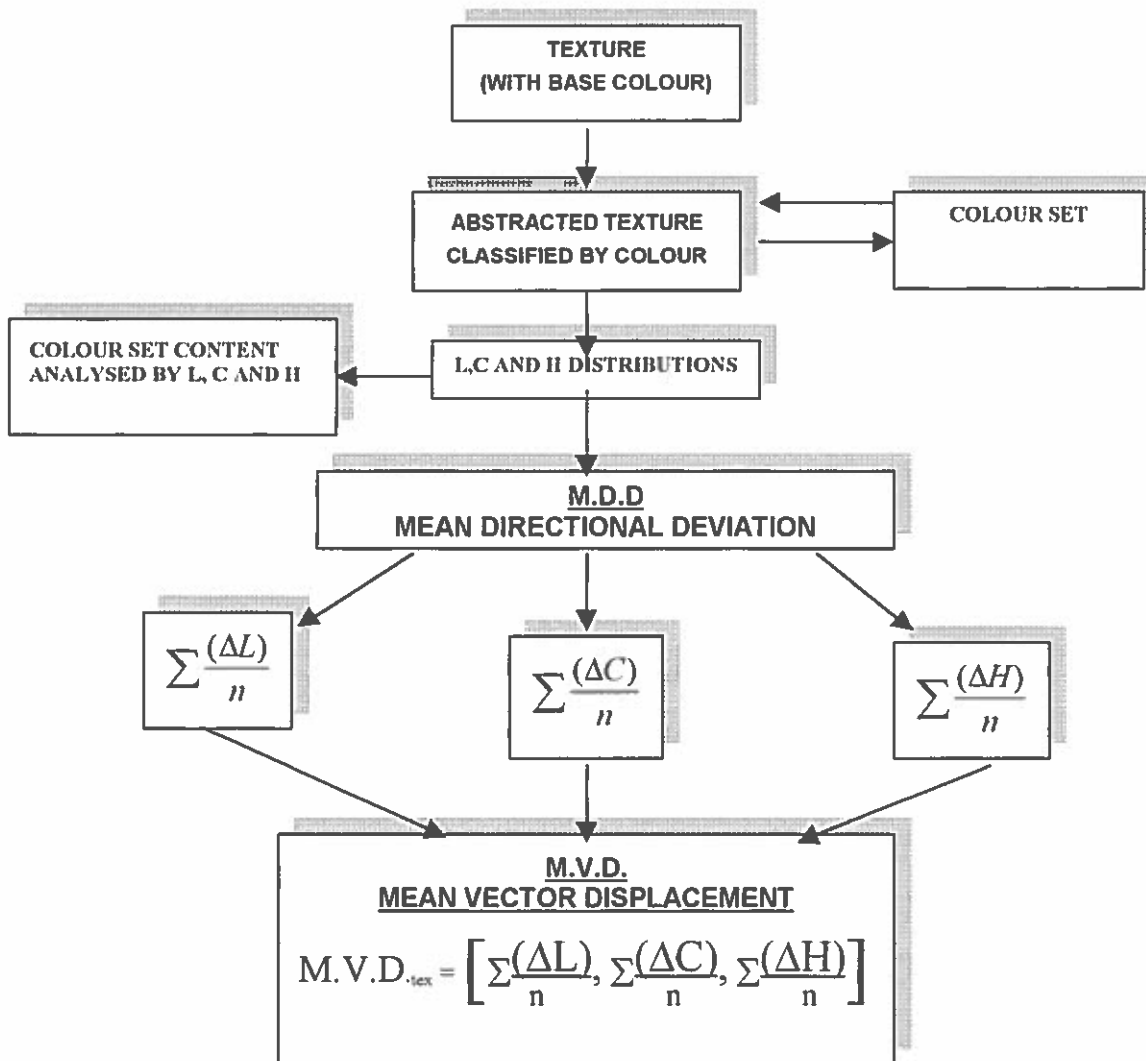


Figure 1 Derivation of MDD and MVD values

The validity and independence of an MVD value has been demonstrated in series 1 and 3 of the multi-observer trials (see Appendix 1 section 6.1 and 6.3), where it successfully predicts the appearance of a knitted fabric in 20 different intrinsic colours.

MDD and MVD values are used in a different context to test their validity as a constant characteristic of 63 similar instances of texture. Having established that MDD and MVD are indeed consistent across 63 instances, to the limits of experimental error, the measure is applied to the ranking of alternative base colour generators (see series 1 & 2 observer trials in section 6.1 and 6.2).

MDD and MVD values encapsulate the vector principle of mapping multi-dimensional variables (in the above case colour-set membership) onto a meaningful three dimensional definition of their effect (displacement of colour identity in colour-space). The process is directly analogous to the identification of metameric matching pairs, based on the multi-dimensional spectral colour definition given by a reflectance curve.

The investigators speculate that MDD and MVD values may be found applicable to identifying 'texture metamers', which when dyed to the same reflectance curve will have identical appearance. It is further speculated that MVD values might be established characterising such colour appearance differences as parallel yarn/end-tuft effects, and that by controlled experiment, the sensitivity of sphere-geometry colour measurement to texture variation may be quantified.

1.3. Achievements in Colour Communication Systems

The project has delivered and verified colour communication systems *based on precision colour imaging of full colour and texture of lace, woven, and knitted textiles*. This enables the accurate communication of colour appearance. Refs [7,8 & 9]

The system developed can specify :-

- The precise colour required, as selected by a designer or technical colourist.
- The appearance of this colour under any illuminant,
- The colour appearance, when viewed as a simulation including surface texture, glossiness, and translucent qualities.

Novel methods of simulating on-screen, all three of these aspects of colour appearance have been demonstrated, and subjected to controlled testing and verification experiments to substantiate these claims. Ref [10] 'On screen simulation of surface Texture' in preparation)

The new methods of colour communication developed are expected to prove an important contribution to the field of colour communication. *Major changes in the industrial colour communication practice used by consortium companies are contemplated as a result of this project, and of its delivered solutions.*

1.4. Achievements in defining, meeting, and delivering solutions to industrial problems.

An important feature of the project has been the close interaction with industrial requirements, and the influence of those requirements on the solutions developed.

The project has achieved :-

- Definition and delivery of industrially relevant solutions to the problems of development and manufacture of new products and colour ranges.
- Formal verification of the solutions developed, allowing them to be evaluated quantitatively.
- Detailed industrial evaluation of commercial applicability and value of derived solutions.

The Interim Report 'Imagemaster: The experimental basis, industrial relevance, and deliverables' Ref [11] gives full details of the interaction with industrial requirements.

The investigators believe, that the industrial expectations have been largely met, and in some cases surpassed. A significantly wider set of industrial problems than that conceived in the original project specification has been addressed, and in large measure solved by the wider general applicability of the new knowledge generated. This aspect is considered in more detail in Appendix 2 section 3 (Imagemaster functionality) and section 4 (Exploitation) of this report.

*Although colour hard-copy output was a significant wish of industrialists, and absorbed significant work effort in the project, the investigators cannot provide the hoped for solutions. The industrially perceived need for hard-copy output arises from the need to communicate the results of on-screen product development. Significant project work-effort has been devoted to promoting the preferred concept, of numerically specified colour in the form of reflectance curve and CIE co-ordinate specifications, backed by accurate on-screen visualisation, and if required by *illustrative but not definitive* hard copy.*

1.5 Achievements in software and systems development.

A controlled and structured software engineering effort, representing a significant component of the total work-effort has been expended in this area, which has delivered :-

- Full visual trial validation of adopted algorithms.
- The functionality necessary to meet both the industrial and academic requirements of image capture, analysis and image-object manipulation.
- A set of fully modular, library based, re-useable code, providing a clear exploitation path for the results of the project.

1.51 Quality and novelty of on-screen Simulation and analysis

The quality of both simulation and image analysis outputs was the subject of a full experimental programme towards the end of the project, intended to validate formally the delivered quality of simulation. (See Appendix 1 section 6.0

Experimental results). A universally positive response by potential users has been found, to the use of photo-realistic images for colour communication.

The need to simulate texture, through its precise micro-level colour variation characteristics, as opposed to simulating and presenting an overall pleasing picture of an object, cannot however be over-stressed.

Scientifically accurate image capture and analysis, have been shown to depend fundamentally on identifying the micro-level variations in colour, characteristic of a surface texture. They are acquired during an appropriate image capture process, used in image analysis, and enable on-screen simulation.

The colorimetric separation of logical image components, has been demonstrated to be a well defined scientific procedure, readily automated, and based on well established colorimetric principles. Its significance lies in its powerful analytical and diagnostic capability, relating simulation content directly to the properties of the objects imaged. Ref [3]

The investigators have achieved *six key demonstrations* during the project :-

- That it is possible to capture images which contain accurate information concerning texture
- That it is possible to separate such images into logical components by colorimetric methods.
- That the resulting image colour-sets have an analysable intrinsic base-colour which is an appropriate analogue of the innate colour of the object (whether it can be measured or not).
- That the quality of an object described by the term surface texture, is a characteristic variable, which can be defined and simulated. Independence is demonstrated by freely changing the base-colour of a colour-set without significantly affecting the appearance of the texture in any way other than its apparent colour.
- That a screen simulation of texture is a close visual match to a physical sample with the same measured colour specification and the same texture, under a specified prime illuminant.
- That a simulation correctly emulates a physical sample, changing visually in the same direction, and with the same magnitude of change, when the intrinsic colour of the sample, and of its simulation on screen are changed by the same amount. When the simulation is made for an alternative illuminant, and the sample is viewed under that illuminant, they also maintain a good appearance match, provided that they have the same intrinsic reflectance curve colour definition.

The success of these demonstrations is substantiated in part by their industrial acceptance, and in part by quantitative testing.

A key confirmation of model correctness is its use to generate simulations on-screen which are judged to be of high quality. **This confirmation has been delivered**, and substantiated by statistically tested multi-observer trial results.

Publications listed in the References Section, already in the public domain, and in preparation, will provide detailed dissemination of project results and achievements.

1.52 Delivery of Industrial Benefits

In a remarkably short time scale, the central discoveries of the project have been validated as useful in industry by consortium members. Several industrial project teams have been formed, after presentations by the investigators to consortium companies at group management level. The typical pattern, exemplified by the Courtaulds Group, is of central main board co-ordination of a multi-company task group with installation of a prototype Imagemaster at one factory site. As new working practices develop based on the new technology, they will be disseminated through the group via multiple installations and new working methods.

The system developed offers *accurate multi-site colour communication networking*. Such a development is expected to realise greatest benefit, when adopted within a large collaborating supplier/buyer network. An example is that of Marks and Spencer, who are active in promoting the concept both within and outside the consortium.

The results of the project look likely to be exploited with minimum delay and significant benefit to those companies that supported the project throughout. The software development team at the start-up company Colorite Ltd, have converted the building blocks furnished by the Imagemaster demonstrator into a range of commercial products in under six months. That this proved possible is a significant endorsement of the quality and structure of the demonstrator code.

1.53 Wider Exploitation

Much wider generic benefits outside textile CAD are in prospect. The development of applications for precision-colour image analysis are well advanced for food technology research, and under active discussion with the cosmetics and other

industries. The relevance of the technology to these industries has been established almost entirely through presentations by the investigators at international conferences. Applications in these new fields are described in more detail in Appendix 2 section 4.3

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