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MEASUREMENT OF "TOTAL VISUAL APPEARANCE": A CIE CHALLENGE OF SOFT METROLOGY

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Abstract: Presentation of the main ideas of the CIE 175:2006 Report suggesting a framework for and inviting the research community to explore new measuring methods for qualifying visual appearance of manufactured products.

Keywords: visual appearance, physiological optics, soft metrology.

1. CONTEXT

Visual appearance of objects can be one of the most critical parameters affecting customer choice and it needs therefore to be quantifiable to ensure reproducibility and uniformity in its description. All manufacturing industries are concerned with this problematic. We can just outline some important examples: chemicals, coatings, food, metals, paper, plastics, textiles.

The overall (or total) appearance of any object is a combination of its chromatic attributes (colour: declined e.g. in lightness, hue and saturation) and its geometric attributes (like gloss, translucency, texture, shape) in the environment in which the object is seen. The manner on how all these parameters interact to deliver a perception is complex: the physical parameters relating to objects are influenced, at the perception stage, by the physiological response of the visual system but also by the psychological aspects of human learning, culture and tradition! No consensus exists until now to uniformly describe the appearance and this topic requires much more reflection and research.

2. CIE REPORT

The CIE (Commission Internationale de l'Eclairage – International Commission on Illumination) initiated a reflection on this topic which has led to the production of the report CIE 175:2006 "A framework for the measurement of visual appearance" [1] written by the Technical Committee TC 1-65 'Visual Appearance Measurement' under the chairmanship of Michael R. Pointer, NPL, UK. The aim of this rich (and dense) 92 pages document, with as much as 254 references, is to fertilize new research in this domain at an international level. It describes a possible framework on which a set of measurements could be made to provide pertinent quantities about visual appearance. It is expected that the interest of industry for better and more complete characterization of the visual appearance of manufactured products will be sufficiently high to encourage the possible new developments pointed in this report. In continuation of this report, the CIE Division 1 (Vision and Colour) organized in October 2006 in Paris an Expert Symposium on "Visual Appearance" [2]. It was decided that every 2-3 years, a follow-up symposium will be organized on the same theme.

Due to its high potential to give rise to new instruments more adequately suiting the needs of industry, it is appropriate to present the main ideas of this document at the IMEKO TC7 community.

The measurement of visual appearance can be considered a part of the overall science of "soft metrology". This science covers the development of measurement techniques and mathematical models that enable objective quantification of the properties of materials, products and activities that are determined by human response (in any of the five senses : sight, smell, sound, taste and touch). What is generated is a measurement scale that allows the human, subjective response to be predicted from a physical, objective measure.

The report makes the departure between what can be measured at the present time and what might be measured after further investigation and research. Concerning the first pack, the characterization of visual appearance connected to optical properties of materials certainly plays a major role. Four paradigmatic parameters seem here to be appropriate: colour, gloss, translucency and texture. The paper will emphasize these aspects.

3. DEFINITION(S) OF VISUAL APPEARANCE

According to ASTM [3], appearance may be defined as:

- *the aspect of visual experience by which things are recognized,*
- *in psychophysical studies, perception in which the spectral and geometrical aspects of a visual stimulus are integrated with its illuminating environment.*

Members of TC 1-65 felt that the first definition was inadequate because appearance does not necessarily result in recognition. They moved towards accepting the following definition:

Appearance is the visual sensation through which an object is perceived to have attributes as size, shape, colour, texture, gloss, transparency, opacity etc.

This definition implies the pre-condition that there should be a desire in the observer to want to perceive various attributes of the object. We perceive an image of the outside world in our visual cortex and apply pre-learned rules to what we see in that image. This leads to perception and subsequent interpretation of the objects in the image.

Total appearance

They are however many different views of "appearance" and it is important to distinguish between the appearance of an object or of a scene, and appearance of expectations derived from the look of this object or scene. This leads to the concept of "total appearance" that John Hutchings defines as [4]:

Total appearance combines a description of the appearance of each element of a scene… with a personal interpretation of the total scene in term of its recognition and expectation.

More simply, the CIE report recommends the following definition:

The total appearance points out the visual aspects of objects and scenes.

With respect to the whole scene, expectations derived from the total appearance of that scene (which include our feelings as individuals) can be classified into the following:

- visually assessed safety (that is safety of our existence within the scene);
- visual identification of the scene;
- visually assessed usefulness of the scene;
- visually assessed satisfaction that we predict we shall get from the scene.

Further investigation of Lindsay MacDonald [2] suggests to refine the appearance in three successive stages of extraction of meaning from the visual stimulus: sensation, perception, cognition. Suggested definitions of these terms are :

Visual sensation: ''The response of the visual system to stimulation'

Visual perception: 'The normalisation of visual sensation in the context of the whole visual field'

Visual cognition: 'The interpretation of visual perception'

They are many factors affecting total appearance. The light source that illuminates the scene has a spectral power distribution that defines the colour and the level of that illumination. The object itself has physical properties (structure), optical properties, and temporal properties. The appearance response is influenced by the colour vision, the spatial vision and the age of the observer, and the responses from their other senses.

The final stage, that defines the expectation of the observer, is influenced by many factors including the pre-conceptions of what the object should look like based on memory, cultural difference, what is in fashion, as well as our preference.

"Total appearance" is thus a concept that is derived from a physical object under the influence of diverse factors and which leads to an "appearance image". Hutchings suggests there are two classes of appearance images: the impact (or Gestalt) image, and the sensory image. The impact image is the initial perception of the object plus an initial opinion or judgement. For the sensory image, three hedonic descriptors are suggested: perceptual, emotional and intellectual, that are used to prompt questions that should be asked on the image.

The measurement of appearance

The quantification of the appearance of an object or a scene is a very complicated issue [5]. One of the difficulties is that any appearance implies a judgement. Is this food safe/desirable to eat? Will this car improve my image? Is this surface finish adequate for the job? Thus pertinent quantitative measurements of appearance must help to ensure an affirmative answer to all these questions.

A goal of making measurements that ensures appropriate quality control in the manufacturing process is probably achievable, but the measurement process will be multidimensional, product specific and probably application specific.

It is unlikely that any physical scale called "appearance" will be possible and it is necessary to find physical parameters that can be measured and the most obvious area for exploitation is that described in terms of the optical properties.

4. OPTICAL PROPERTIES

It is possible to divide the characterization of the optical properties of materials into four paradigmatic parameters: colour, gloss, translucency, texture [4]. Figure 1 shows these groups and their interactions. For all these quantities, the actual state-of-the art will be presented and discussed by comparison with the actual needs.

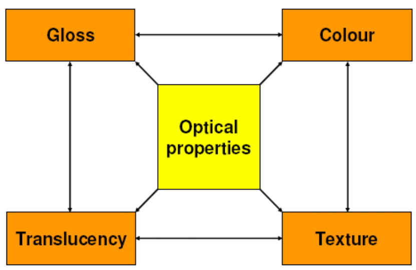

Fig.1 The suggested sub-division of the optical properties of materials into measurements groups, with their mutual interactions

4.1 Colour

Colour is involved in the perception of all optical properties. This human perceptual attribute of a sample can be "measured" by the well proved CIE colorimetric system. The fundamental components of this methodology are a light source (CIE illuminant), the object (usually a reflecting surface) and a 3-channel detector (the CIE standard observer). By integrating the spectral reflectance data $R(\lambda)$, with that of the illuminant $S(\lambda)$ and the observer $x_{bar}(\lambda)$, $y_{bar}(\lambda)$, $z_{bar}(\lambda)$, three numbers, the tristimulus values, X, Y, Z are obtained that uniquely define a perceived colour as viewed in the given environment:

$$X = k\int R(\lambda)S(\lambda)x_{bar}(\lambda)d\lambda$$
$$Y = k\int R(\lambda)S(\lambda)y_{bar}(\lambda)d\lambda$$
$$Z = k\int R(\lambda)S(\lambda)z_{bar}(\lambda)d\lambda$$

Where $k = 100 / \int S(\lambda)y_{bar}(\lambda)d\lambda$

The Y tristimulus value correlates with brightness.

The chromaticity attributes are related to the relative magnitudes of the tristimulus values and are defined by the chromaticity coordinates x, y:

$$x = X / (X + Y + Z) \quad ; \quad y = Y / (X + Y + Z)$$

The CIE 1931 x, y chromaticity diagram provides a convenient way of mapping coloured samples (figure 2). The boundary of this diagram, the spectrum locus, is the locus of points that represent monochromatic stimuli.

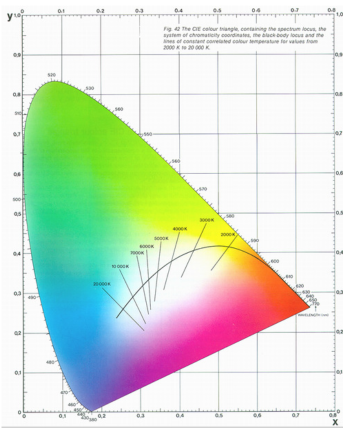

Fig.2 The CIE 1931 x,y chromaticity diagram

It has been found that the sensitivity of the eye to colour differences varies in different parts of the chromaticity diagram. To correct this, the diagram can be altered in shape so that equal distances more nearly represent equal perceptual steps. This has led to the recommendation of the CIE *u',v'* diagram as a more uniform chromaticity diagram.

Chromaticity diagrams are only applicable to compare stimuli having the same luminance (same brightness). To cope with the luminance variability, a 3D representation is needed: i.e. a colour space. The CIE has recommended two colour spaces: the CIELAB colour space and the CIELUV colour space. These spaces correlate to the perceptual quantities of lightness, chroma and hue. The coordinates of these spaces are related to the tristimulus coordinates by appropriate formulas.

It has been pointed out that even if the CIE system of colour measurement has proved to be of immense value in helping to solve many measurements problems, it does not in itself define the appearance of the colour. Within the last 25 years much progress has been made in deriving models of colour appearance of coloured surfaces. We can mention the Hunt model in 1982 and the CIECAM models in 1997 and 2002. These models, besides taking into account the illumination level and colour of the light source, integrate the effect of the surround. Other colour appearance models are in the development stage.

They are at least two other variables that influence the appearance of a coloured sample and that are not considered in the above description

- The effect of variation in angles of illumination and viewing

Indeed, surfaces generally are not perfectly diffuse nor uniform. To cope with this, CIE has recommended two basic configurations. The 45°:0° geometry: the specimen is illuminated at 45° (from the normal to that surface) and viewed normally. The converse geometry 0°:45° is also permitted; the d:8° geometry where the specimen is illuminated diffusely and viewed at 8° . Again the converse geometry 0°:d is permitted.

In many cases, these geometries are from far not sufficient e.g.. when a specular reflection is significant. The complete but very laborious solution is to measure the BRDF function (Bidirectional Reflection Distribution Function) which requires a goniometer enabling the position of both the illuminant and the detector in any angular value. Its definition will be recalled below.

- The effect of local variation, of non-uniformity of the physical surface that is being measured.

The presence of non-uniformity and surface texture can make the colour of the sample vary as it is rotated or translated in its own place. This will occur with any interlaced material as textiles, and with tufted materials as carpets.

4.2 Gloss

The CIE definition of gloss (of a surface) is [6]: *the mode of appearance by which reflected highlights of objects are perceived as superimposed on the surface due to the directionally selective properties of that surface*'. Gloss perception is particularly depending on the way that light is reflected from the surface of the object at and near the specular direction. An added complexity is due to surface non-uniformity leading to an effect known as orange peel.

After extensive studies, Harrison concluded in 1954 that the gloss of surfaces is not a simple physical property but a psychological Gestalt, that is an appraisal of the physical situation taken as a whole. Not only the total amount of light reflected from a surface but also the sharpness of images seen via this reflecting surface enter into account in this perception. Further refined study of visual gloss scaling was made by O'Donnel and Billmeyer in 1987 making the distinction between three type of gloss: distinctness-of-image gloss, specular gloss and reflection haze.

Measuring gloss – gloss meters

Gloss measurements with gloss meters quantify the amount of light reflected at the specular angle from an object's surface. There exists no unique way to measure gloss. However all gloss meters are configured so that the light generated is incident on the material at a particular angle relative to normal. The detector is then placed at the same angle on the other side of normal so that only the light reflected at the specular angle is collected. Many developments have been carried out by ASTM. We now know the ASTM method [7] which specifies three angles (20°, 60°, 85°) depending on the relative gloss of the surface. Measurements are made by comparison to a highly polished black glass standard.

The gloss of textile materials, better known as lustre, has been quantified in several ways but none of the methods has been standardised.

Measuring gloss – goniophotometers

As already mentioned, the BRDF (spectral or global through a V(λ) filter) is the only complete manner to characterize the reflectance of a surface. The reflected light intensity is measured by goniophotometry at different illumination (angle i) and viewing (angle r) angles.

$$\text{BRDF}(\theta_i, \varphi_i, \theta_r, \varphi_r, \lambda) = dL_{e,\lambda} / dE_{e,\lambda}$$

= Reflected radiance / incident irradiance

From this complete map, diverse gloss factors or gloss values can be derived. We can mention, the diffuse reflectance of the object, the energy of its specular component and the spread of the specular lobe.

The manner to characterize the gloss perception and the definition of gloss scales is still a very open study object!

4.3 Translucency

Translucency occurs between the extremes of complete transparency and complete opacity. Within the concept of total appearance, translucency has an important part to play because an object may appear different depending not just on its colour but also on the appearance of that colour due to the relationship between the light transmitted, the light reflected and the light scattered by the object.

If it is possible to see an object through a material, then that material is said to be transparent. If it is possible to see only a "blurred" image through the material (due to some diffusion effect), then it has a certain degree of transparency and we can speak about translucency. It appears that a single and simple definition of translucency is unlikely to be achieved. The property referred to as translucency can be linked to other objective properties such as opacity or transparency. The concept of translucency can perhaps be regarded as a generic and subjective term, combining the concepts of clarity ('ability to perceive the fine details of images through the material') and haze ('property of the material whereby objects viewed through it appear to be reduced in contrast') as descriptors of objective, or measurable, correlates. It is clear that the concept of translucency and its metrology remain challenging and need further research!

4.4 Surface texture

This concept is still more challenging. ASTM gives the following definition: *The surface texture is the visible surface structure depending on the size and organisation of small constituent parts of a material*. This definition is by no means complete: it is necessary to differentiate between texture associated with physical, topological, variability in a surface, and sub-surface texture, texture associated with spatial variation in appearance caused by non-uniformity of colorant. It might also be necessary to differentiate between two-dimensional and three-dimensional variations in a surface. Another consideration is the difference between a pattern and surface texture. A pattern is an inherent part of a surface whereas surface texture is concerned with the perception of that pattern and is thus a function of other variables including the direction of illumination and the viewing distance.

In order to put a number to the surface texture, a surface-measuring instrument must be used. This typically will consist of a stylus with a small tip (the fingernail), a gauge or transducer. As the stylus moves up and down along the surface, the transducer converts this movement into a signal exported to a processor which converts it into a number and usually a visual profile. They are also systems that measure the profile without contact.

The human response to texture can be characterized using terms like fine, coarse, grained. Alternatively, we can speak about roughness, smoothness, ripple.

Whichever the words used attempting to describe a variation, it is pertinent to try to establish what it is that is actually varying. The building blocks of texture can be considered as texture elements usually called texture primitives, and their relative spatial relationship, a process called texture classification. Numerous analysis techniques are used to achieve this classification. It includes the concepts of pattern recognition and feature analysis for images used in the worlds of medical diagnosis, seismology, geology, computer vision and many other scientific disciplines!

Surface texture is a complex subject that has no unique mathematical interpretation and certainly no defined method of measurement.

4.5. Discussion and opportunities

Measurement of the four paradigmatic parameters characterizing visual appearance associated to optical properties of the objects was investigated above. It is recognized that these measures are not necessarily independent: colour may influence gloss, colour will certainly influence translucency, and texture is probably a function of all three of the other measures.

Colour measurement, i.e. colorimetry, is based on the measurement of spectral reflectance and is an established science laying on the use of commercial instrumentation available at reasonable cost. Two shortcomings are identified. First, there are a number of modern materials where colour measurements made using a single pair of illumination/viewing angles is not sufficient to describe the perceived colorimetric effect. Second, the CIE recommended colorimetric parameters are not able to predict the absolute appearance of a coloured sample: colour appearance models (in progress) are being developed to do this.

The measurement of gloss is an established methodology but there is some doubt as to its scientific basis and attempts are being made to define alternatives approaches. The extension of gloss measurement to investigate the shape of the gloss peak should provide more information.

Translucency is a subjective term that relates to a scale of values going from total opacity to total transparency. This whole subject area needs investigation to find a rigorous measurement solution that will probably be industry specific.

Texture is a harder variable to measure. The advent of digital imaging systems makes the acquisition of images relatively easy and suitable analysis software on these files should be able to say something about the perceived texture. The idea of establishing a series of standard textures has been suggested.

The figure 3 is an attempting framework that includes expansion of the four basic components dealing with the optical properties of materials and an indication of possible connections between them.. This can serve as an indicator as to the areas that require additional research work.

5. CONCLUSION

We will conclude by an attempt to answering the question: “Is it possible to build an instrument that will measure visual appearance”? Probably no!

The only way that progress can be made is for new scales to be developed that correlate subjective data with objective measures. These will probably be industry specific and might be product specific. Appearance is formed in the visual cortex at a higher level than colour appearance, it is a cognitive effect. Another possible way forward is to start co-operating with physiological and psychological studies to obtain correlation between “optical property space” and “cortical mechanism space”.

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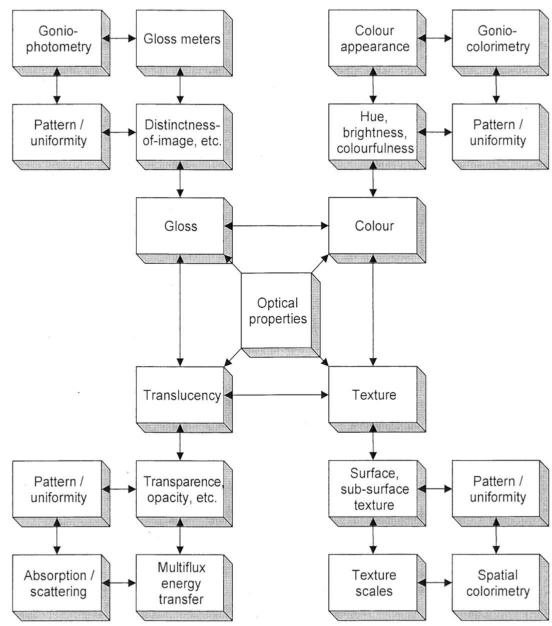

Fig.3 : An extended measurement framework showing expansion of, and possible linking between, the four basic components of visual appearance