Assessing colour differences for automobile coatings using CRT colours Part II: Evaluating colour difference of textured colours

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ABSTRACT

The research work here is a continuation of Part 1 of this series of this study[1]. In the earlier experiment, the colour difference assessments were carried out on a CRT to simulate those of the physical metallic samples. The results showed a good agreement between the two expeimental data sets. However, that work was based on the CRT solid colour without any texture information, which contribute large part of total appearance for metallic coatings. The current work applied CRT colours with the simulated texture details. It was found that the total appearance difference increases when texture difference are introduced into colour difference. Some advanced colour difference formulae were also tested using the present data sets.

1. INTRODUCTION

Colour difference evaluation for automobile coatings using solid, non-textured, colours duisplayed on a CRT was investigated in the first part of series of studies[1]. Their visual assessments were compared with those based on physical metallic samples by Chou *et al*[2]. A good agreement between the colour difference assessments on CRT solid colours and physical samples was found. This confirms that using CRT for simulating colour difference evaluation for metallic coatings is feasible. However, it is known that the perceived colour difference of metallic samples could also be affected by its texture. Thus, this study investigated the effect of texture for automobile coatings when colour difference was assessed. Again, colour difference assessments for metallic coatings with textured colours were carried out on a CRT. The visual results were compared with the data obtained from the first part of this article so as to discover the texture affecting the total appearance difference of metallic coatings. In addition, the performance of some existing colour difference formulae (CIELAB, CMC, CIE94, BFD, LCD and CIEDE2000) were also tested using the visual data accumulated in this study.

2. GENERATING TEXTURED CRT STIMULI

The texture effect for a metallic coating can also be considered as ‘coarseness’. A metallic panel can be described as “fine” or “coarse”. A finer texture of a metallic panel, a less coarseness degree it is. The texture patterns used here were based upon two grey physical metallic panels with quite different degree of coarseness (these are denoted as “fine” and “coarse” texture reference in this study). These panels were captured by a Nikon D1X camera under 45/0^{o} viewing condition with an high level luminance of diffusive illumination. Figure 1 shows the texture characteristics of the

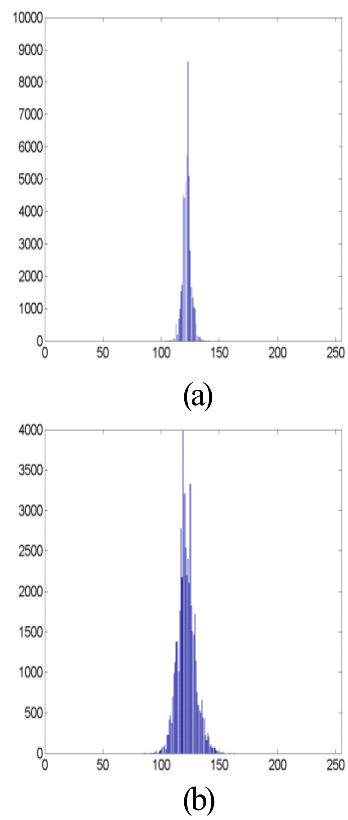

Figure 1: The histograms of (a) ‘fine’ and (b) ‘coarse’ textures.

two grey metallic panels in *Y* (luminance factor) channel. The standard deviation of pixel values for the "coarse" texture in *Y* channel were 4.12 and 8.85 for "fine" and "coarse" texture references, respectively. This indicates that the spread of the "coarse" texture is twice wider than that of the "fine" texture. The "fine" and "coarse" textures were then extracted from the *Y* channel of the two metallic grey samples, respectively. The extracted textures were then mapped onto each CRT colour by means of the texture mapping algorithm developed by Hong *et al*[3]. In other words, the texture effect of all metallic panels was simulated based on only the images of the 'fine' and 'coarse' panels.

3. VISUAL ASSESSMENT

Colour differences of the fifty pairs of metallic samples used in the previous study[1] and Chou *et al*[2] were reproduced on a Barco Reference Calibrator. Only the data under the 45^o aspecular angle were used because this angle shows the texture information most clearly and also this is the geometry recommended by CIE for assessing colour appaearance. The whole experiment was divided into five phases according to the textures applied in each pair. These are summarised in Table 1. Phase 5 was the visual results of CRT solid colours accumulated in the first part of this article[1].

Table 1 Summary of experimental phases for each pair.

Phases	Coarseness degree on two samples in a pair
1	Fine vs. Fine
2	Coarse vs. Coarse
3	Fine vs. Coarse
4	Fine vs. Coarse *
5	Non-textured solid colours

Note : * The positions of the "Fine" and "Coarse" samples in Phase 4 are interchanged with those in Phase 3. This was intended to investigate the uniformity of the display used.

The perceived colour difference of each metallic pair with different phases shown on CRT was scaled by observers using the same grey scale method as used in the first part of this article. The experimental conditions and the method of data analysis were also the same as in Part I[1] apart from the inclusion of texture information in sample pairs in this experiment. The relationship between grades and colour differences is given in Eq.(1).

$$\Delta V = 0.0634G^4 - 0.9525G^3 + 5.3382G^2 - 16.041G + 26.178 \qquad (1)$$

The equation was obtained to fit the data of grade values and CIEL*a*b* values of the grey scale used. The ΔV in Eq.(1) is in CIELAB* unit.

4. RESULTS AND DISCUSSIONS

4.1 OBSERVER ACCURACY AND REPEATABILITY

Majority of the nine observers in this experiment also attended the first part of this study. Four of them did experiment twice. Observer variation was measured by means of PF/3 as described in the Part I of this article. Each observer's visual results in terms of ΔV were compared with average values calculated from all observers. The agreement between them in terms of PF/3 was considered as observer accuracy. Each individual observer's repeatability was tested by comparing their two repeated assessments. Based on the visual results from Phases 1 to 4, the average observer accuracy and repeatability were 40 and 44 PF/3 units, respectively. The observer accuracy and repeatability under 45^o aspecular angle in Part I (or Phase 5 defined in Table 1) were 39 and 52, respectively. The results showed that the visual assessments on non-textured CRT colours had a similar degree of observer accuracy but a lower observer repeatability than these of textured metallic colours.

4.2 COMPARING VISUAL RESULTS BETWEEN DIFFERENT PHASES IN TERMS OF PF/3

Visual assessments on CRT colours with different texture combinations (Phases 1 to 4) were compared to those of CRT solid colours (Phase 5) in terms of PF/3 measure. The results showed that the disagreement between Phase 1 (a 'fine' texture used for the samples in a pair) and Phase 5 (solid colour) was 15 PF/3 units. When colours having a 'coarse' textures in a pair (Phase 2), the disagreement with Phase 5 slightly increased by 17%. This implies that as far as samples in a pair having same degree of coarseness, texture effect on the perceived colour difference is insignificant. This agrees with Han *et al's* study[4] based on textile samples. However, the previous work done by Montag *et al*[5] and Xin *et al*[6] based on textile samples discovered strong texture effect on the perceived colour differences and both concluded that the texture effect is a very important parametric effect on colour difference evaluation. The above discrepancy was found that the colour differences used in the Montag *et al*[5] and Xin *et al*[6]'s studies were dominated by lightness differences only. The colour differences of the metallic coatings chosen in the present study were mixtures of colour difference in lightness, chroma and hue. The texture has small effect on the perceived colour differences when the colour difference of a pair is not dominated by lightness difference.

For each pair in Phases 3 and 4, there exhibited a texture difference, or coarseness difference, in addition to their existing colour difference. It revealed that the disagreement of the visual assessments from Phases 3 and 4, against Phase 5 were 35% and 39%, respectively, which are almost doubled than those when comparing Phases 1 and 2, against Phase 5. The results suggest that, when there is a coarseness difference, the visual difference of metallic coatings increased by 200%. Referring to the texture mapping algorithm[2] adopted in this experiment, it is clear that the texture difference between two samples in a pair was caused by their difference in luminance factor only, i.e. the texture profile only stored the ΔY values. This explains why the perceived colour differences in Phases 3 and 4 increased comparing with those in Phases 1, 2 and 5, where the samples in each pair had same degree of texture.

Table 1 Visual results comparison between Phases 1 to 4 against Phase 5 in terms of PF/3

Phase 1 vs. Phase 5	15
Phase 2 vs. Phase 5	17
Phase 3 vs. Phase 5	35
Phase 4 vs. Phase 5	39

5. TESTING THE PERFORMANCE OF COLOUR DIFFERENCE FORMULAE

Six colour difference equations (CIELAB, CMC, CIE94, BFD, LCD and CIEDE2000) were used to calculate colour difference of each pair of CRT solid colours. The calculated colour differences were compared with the visual results from Phases 1 to 5, respectively. By setting chroma and hue parametric factors to one, lightness weighting factor in each colour difference formula was optimised to achieve a minimum PF/3 value between the calculated colour difference values and visual assessments. The results given in Table 2 show that the disagreement between these calculated colour differences and visual assessments was less than 20% under Phases 1 and 2 texture conditions. Under these two texture conditions, colour difference formula CIELAB performed the worst with a PF/3 value of almost 25 and the BFD formula performed the best with a PF/3 value of 15. The large disagreement between these calculated colour differences and visual assessments occurred under Phases 3 and 4 texture conditions. This was caused by the existence of texture differences in a pair. Adding texture difference onto a metallic pair increases the perceived difference of this pair while the conventional colour difference formulae are applicable only to calculate the colour difference of uniform solid colours. The testing results again showed that the CIELAB had the worst performance in calculating colour difference of metallic coatings. CIEDE2000 and BFD colour difference formulae outperformed the others. The optimised lightness parametric factors showed that for all the colour difference formulae tested, lightness difference contributed to the overall colour difference more than that of chromatic difference. (The results also showed that the optimised K_L values in Phases 1 and 2 are smaller than those in Phases 3 and 4. This implies that texture difference would cause the lightness difference to become less noticeable.)

Table 2 Testing the performance of difference colour difference formulae in terms of PF/3 with the optimised K_L values in bracket.

Phases	*CIELAB*	*CMC*	*CIE94*	*BFD*	*LCD*	*CIEDE2000*
1	**24** *(0.55)*	**18** *(0.98)*	**18** *(0.93)*	**15** *(0.73)*	**18** *(0.93)*	**16** *(0.74)*
2	**25** *(0.58)*	**18** *(1.03)*	**18** *(0.97)*	**15** *(0.77)*	**18** *(0.97)*	**20** *(1.00)*
3	**38** *(0.77)*	**27** *(1.44)*	**30** *(1.31)*	**27** *(1.06)*	**31** *(1.31)*	**25** *(1.07)*
4	**39** *(0.81)*	**29** *(1.51)*	**31** *(1.35)*	**27** *(1.10)*	**31** *(1.35)*	**26** *(1.09)*
5	**25** *(0.58)*	**19** *(1.08)*	**16** *(1.03)*	**15** *(0.82)*	**16** *(1.03)*	**18** *(1.00)*

6. CONCLUSIONS

By comparing the colour difference assessments on CRT textured sample pairs with those on CRT solid colour pairs, it was found that there is little texture effect on the perceived colour difference of metallic coatings having same degree of coarseness. The perceived differences are increased if there is a coarseness, or texture, difference between two metallic samples by 200%. Comparing the performances of colour difference formulae, it was found that all colour difference formulae gave good prediction to the visual results except CIELAB. BFD colour difference formula performed the best for the phases with no texture difference in a pair, and CIEDE2000 performed the best for the phases with different textures in a pair. The results also showed that lightness differences are less noticeable when texture differences are involved in a pair.

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