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Appearance & Measurement, Modeling & Rendering of the Visual Texture of Automotive Paints
Detroit Color Council, 13 March 2013
Contents

• Color and Texture of automotive paints
• The effect of Texture on perceived color differences
• Models for predicting Texture
• Rendering (color and) Texture
• Conclusions
Color and texture of automotive paints
Color and texture of automotive paints
Very small color difference: $dE_{cmc} < 1.1$

Glint difference = 3!

Honda Odyssee  

Honda Pilot
Color and texture of automotive paints

“Mix 60% red + 40% orange-pearl”
Color and texture of automotive paints

New multi-angle Spectrophotometer: BYK-mac
Color and texture of automotive paints

Audi A8

Sparkle. Glint impression.

Image courtesy of Merck
Color and texture of automotive paints

Before 2000: McCamy’s seminal papers

Macro appearance – micro appearance

- Depth
- Glitter
- Glint frequency
- Graininess
- Granularity
- Blending distance
- Coarse vs fine flake-panel
- One eye vs two eye observations
- Binocular luster
- Binocular directionality
- Binocular glitter
- Sample size
- Binocular mottle
- Intensity of light
- Directional – broader – diffuse light
- Syzygetic difference
- Coherent vs incoherent light

Lightness flop
Shade flop
Glamour
Luster
Sparkle
Brilliance
Metallic effect
Color and Texture of car paints

Glint impression ("sparkle")
Color and texture of automotive paints

Diffuse Coarseness
- Anchor scale with 8 panels
- Score 0 – 9 with step size 0.25
- Diffuse illumination
- Light intensity ±2000 Lux
- Illumination/Observation angle fixed

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Glint impression

- Color temperature 5600 K
- Angular diameter of light source: 3°, i.e. quite unidirectional.
- Light intensity ±12000 Lux
- Illumination/Observation angle fixed
Color and texture of automotive paints

Measure color…

…and sparkle at 3 angles

… and diffuse coarseness
Color and texture of automotive paints

Accurate measurement of Diffuse Coarseness

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The effect of Texture on perceived color differences
The effect of Texture on perceived color differences

CIE Guidelines for Coordinated Future Work on Industrial Colour-Difference Evaluation

h) Sample surface structure (texture) is another parameter of high industrial relevance. Parametric factor values in the textile industry are believed to be influenced by this variable. However, a quantitative relationship between texture parameters and visual colour-difference tolerances has not been developed.

Study the Effects of Changes from Reference Conditions
Reference conditions are specified as:

- Illumination: D65 simulator
- Illuminance: 1000 lx
- Observer: Normal colour vision
- Background: Uniform neutral grey, \( L^* = 50 \)
- Viewing mode: Object
- Sample size: \( >4^\circ \) subtended visual angle
- Sample separation: Nearest possible contact
- Magnitude of colour difference: 0–3 CIELAB units
- Sample structure: Visually homogeneous


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The effect of Texture on perceived color differences

Main target: how do the tolerance-parameters $k$ depend on texture?

$$dE_{94} = \sqrt{\left( \frac{\Delta L^*}{k_L S_L} \right)^2 + \left( \frac{\Delta C^*_{ab}}{k_C S_C} \right)^2 + \left( \frac{\Delta H^*_{ab}}{k_H S_H} \right)^2}$$
The effect of Texture on perceived color differences

Major obstacles to study effects from texture:

- Obtain samples with wide variety of color/texture and differences in color/texture
- Texture, and texture differences are hard to measure

Almost all past investigations deal with CRT images!
The effect of Texture on perceived color differences

The effect of Texture on perceived color differences

How to generate set of pairs with prescribed color/texture (differences)?

For physical samples, we can now use BYK-mac®. Co-developed by BYK-Gardner, AkzoNobel and Merck. Color-measurement for 6 angles, plus texture measurement.
The effect of Texture on perceived color differences

1000s of panels, reflections & texture data

1477 panels

405 panel pairs

- 18 different color areas
- evenly distributed in texture

- $dE_{cmc(1.5:1)} < 2.0$ at 45° angle
- $dTexture < 2$ on 9-point scale
The effect of Texture on perceived color differences

Visual test in commercial lightbooth (Atlas Xenolux)
Texture: coarseness
inspection at 5 angles, then give 1 overall color score

9 observers
405 panel pairs (incl. 54 replicates)
3645 visual judgments
The effect of Texture on perceived color differences

Acceptable difference?

yes

no

Acceptable difference?

yes

no

Visual score:

2

1

0
The effect of Texture on perceived color differences

Overall score: scale runs from 0 to 2

Observer reproducibility: 0.27 units
(difference individual observer versus average observer)

Observer repeatability: 0.28 units
(difference replicate with original pair)
The effect of Texture on perceived color differences

In our analysis, the visual results are leading.

Investigate parametric factors by Ridge Regression of visual color score against measured dE at 6 angles.

\[
dE_{94} = \sqrt{ \left( \frac{\Delta L^*}{k_L S_L} \right)^2 + \left( \frac{\Delta C_{ab}^*}{k_C S_C} \right)^2 + \left( \frac{\Delta H_{ab}^*}{k_H S_H} \right)^2 }\]

For \(k_L\), \(k_C\) and \(k_H\):

\[
k = a_0 + a_1 \Gamma + a_2 \Gamma^2
\]

\(\Gamma = \text{average measured coarseness}\)
The effect of Texture on perceived color differences

\[
dE_{94} = \sqrt{\left(\frac{\Delta L^*}{k_L S_L}\right)^2 + \left(\frac{\Delta C_{ab}^*}{k_C S_C}\right)^2 + \left(\frac{\Delta H_{ab}^*}{k_H S_H}\right)^2}
\]

For \( k_L \), \( k_C \) and \( k_H \):

\[
k = a_0 + a_1 \Gamma + a_2 \Gamma^2
\]

\( \Gamma = \) average measured coarseness

\[
DiF = \sum_{i=1}^{6} a_i \cdot dE_i
\]
The effect of Texture on perceived color differences

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The effect of Texture on perceived color differences

Especially lightness-tolerance becomes less tight when samples are more coarse.

Tolerances for Chroma and Hue are hardly affected.

These results extend earlier studies, e.g. by Han, Huertas, Montag, Xin and TePas.

Texture effect is largest for the most coarse samples. This was also found by Huertas.
The effect of Texture on perceived color differences

On the other hand, making parametric factors depend on coarseness leads to only small improvement in adjusted-$R^2$: from 49.2 to 52.0%.

$$DiF = \sum_{i=1}^{6} a_i \cdot dE_i$$
The effect of Texture on perceived color differences

We investigated a different way of combining color and texture.

Much better correlation with visual data was found.

\[ TADiF = \sum_{i=1}^{6} b_i \cdot dE_i + \sum_{i=1}^{3} c_i \cdot \Delta GI_i + d \cdot \Delta DC \]

COLOR Research & Application 36 (2011) 4-14
Models for predicting Texture
Models for predicting Texture

First type: convert captured images into “measured texture”

Glint impression

1. \( R(\lambda) \rightarrow L^*, a^*, b^* \)
2. 2
3. 3
4. 4
5. 5
6. 6
7. 7
8. 8

Diffuse coarseness

1. 1
2. 2
3. 3
4. 4
5. 5
6. 6
7. 7
8. 8

Cf. for color:

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Models for predicting Texture

Second type: use constituents as input, to predict Texture.

Concentrations $c_i$ of colorants $i$; Model constants for each colorant

Texture Model

Diffuse coarseness
Glint impression at 25°, 45°, 75°
Coarseness

Cf. for color

Kubelka-Munk

Concentrations of colorant $i$;
$K_i(\lambda)$, $S_i(\lambda)$

$R(\lambda)$
Models for predicting Texture

Physics + perception approach

Physically characterize the coating

- Absorption coefficient of pigments
- Scattering coefficient of pigments
- Flake diameter distribution
- Flake orientation distribution

Models for predicting Texture

- Absorption coefficient of pigments
- Scattering coefficient of pigments
- Flake diameter distribution
- Flake orientation distribution

Contrast Sensitivity Function


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Models for predicting Texture

Physics + perception approach

Physically characterize the coating

Account for visual perception

Predict what texture people will see

• Absorption coefficient of pigments
• Scattering coefficient of pigments
• Flake diameter distribution
• Flake orientation distribution

• Contrast Sensitivity Function

Not accurate enough

Models for predicting Texture

- Physics + simulation approach
- Physically characterize the coating
- Create simulated image of the coating
- Use the same image analysis algorithms as developed for BYK-mac!
- Predict what texture people will see

Takes too much time
Statistical approach

- Use colorant parameters from existing optical model
- Statistically determine most relevant parameters
- Predict what texture people will see

...like $K_i(\lambda)$, $S_i(\lambda)$ from Kubelka-Munk

...like $K_i(\lambda)/S_i(\lambda)$ summed over all colorants, or summed over flake colorants only, or ...

Best results
Glint Impression at 25° =

\[ \alpha_0 + \alpha_1 \text{ConcC} + \alpha_2 \text{ConcPearl} + \alpha_3 \text{OM} + \alpha_4 \text{Solid} + \alpha_5 \text{OM}_{110} \sum K_{\text{Metallic}} + \alpha_6 \text{OM}_{110} \sum R^2 + \alpha_7 \text{OM}_{110} \sum S_{\text{pearl}} + \alpha_8 \text{OM}_{110} \sum \sqrt{R} + \]

\[ + \alpha_9 \text{OM}_{110} \sum R + \alpha_{10} \text{OM}_{110} \sum K_{\text{solid}} + \alpha_{11} \text{OM}_{110} \sum S_{\text{metallic}} + \alpha_{12} \text{OM}_{110} \sum S_{\text{solid}} + \alpha_{13} \text{OM}_{110} X + \alpha_{14} \text{OM}_{110} Y + \alpha_{15} \text{OM}_{25} \sum K_{\text{Metallic}} + \alpha_{16} \text{OM}_{25} \sum S_{\text{Metallic}} + \alpha_{17} \text{OM}_{25} \sum S_{\text{Cieh}} + \alpha_{18} \text{OM}_{25} \sum S_{\text{Ciea}} + \alpha_{19} \text{OM}_{45} \sum \sqrt{R} + \alpha_{20} \text{OM}_{45} \sum R + \alpha_{21} \text{OM}_{45} \sum K_{\text{solid}} + \alpha_{22} \text{OM}_{45} \sum S_{\text{metallic}} + \alpha_{23} \text{OM}_{45} \sum S_{\text{pearl}} + \alpha_{24} \text{OM}_{45} \sum S_{\text{Cieh}} + \alpha_{25} \text{OM}_{45} \sum S_{\text{Ciea}} + \alpha_{26} \text{OM}_{45} \sum K_{\text{Metallic}} + \alpha_{27} \text{OM}_{45} \sum S_{\text{Metallic}} + \alpha_{28} \text{OM}_{45} \sum S_{\text{Cieh}} + \alpha_{29} \text{OM}_{45} \sum S_{\text{Ciea}} + \alpha_{30} \text{OM}_{45} \sum R + \alpha_{31} \text{OM}_{45} \sum K_{\text{solid}} + \alpha_{32} \text{OM}_{45} \sum S_{\text{metallic}} + \alpha_{33} \text{OM}_{45} \sum S_{\text{pearl}} + \alpha_{34} \text{OM}_{45} \sum \sqrt{R} + \alpha_{35} \text{OM}_{45} \sum S_{\text{solid}} + \alpha_{36} \text{OM}_{45} \sum K_{\text{solid}} + \alpha_{37} \text{OM}_{25} \sum K/\sum S + \alpha_{38} \text{OM}_{45} \sum K/\sum S \]

Account for *significance* and *complexity-reduction*.

This leaves 21 terms.
Models for predicting Texture

1826 samples waterborne coating (Autowave MM).
Training phase: half of the panels
Testing phase: other half
Accuracy = %max difference 1 unit w.r.t. measured value.

<table>
<thead>
<tr>
<th>Texture parameter</th>
<th>Model accuracy (Waterborne)</th>
<th>Visual observer Accuracy (Reference set)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diffuse Coarseness</td>
<td>79%</td>
<td>84%</td>
</tr>
<tr>
<td>Glint impression 25°</td>
<td>71%</td>
<td>81%</td>
</tr>
<tr>
<td>Glint impression 45°</td>
<td>77%</td>
<td>87%</td>
</tr>
<tr>
<td>Glint impression 75°</td>
<td>82%</td>
<td>90%</td>
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</tbody>
</table>
## Models for predicting Texture

Different set: solventborne coating (Autobase Plus).

4109 panels, split by 2000+2109; analyze test set.

<table>
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<th>Model accuracy (Solventborne)</th>
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<td>74%</td>
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Conclusions on Texture Model

• “Digitization of color”: replace human observer.
• The accuracy of the Texture Models developed here is good, and comparable to the accuracy of a human observer.
• Many useful applications for these texture predictions:
  • When repairing a car (check database result)
  • When formulating paints (like Kubelka-Munk for color)
  • Creating images representative of a paints
Rendering (color and) Texture

Glint impression

Diffuse coarseness

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Rendering (color and) Texture

Integra

ColorViz

CI-Navigator

Sphon

Univ. of Bonn

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Two types of approach

Fast but not accurate.
- Use only a few measurements.
- Interpolate, or use simplified physics.
- Short processing time.

Slow but accurate.
- BRDF measurements.
- BTF measurements.
- Long measurement time.
- Large disk storage space.

M. Rump et al, EUROGRAPHICS 27 (2008) 527-536
Our new approach:

• Measure reflection curves for only a few (say, 6) geometries, and measure diffuse coarseness and glint impression.
• Create grey-scale image with correct diffuse coarseness.
• Create grey-scale image with correct glint impression.
• Create image with correct color.
• Combine the images, depending on diffuseness factor.
Rendering (color and) Texture

Create grey-scale image for diffuse coarseness:
Iteratively superimpose patches in an image:

• **Size** of patch
• **Grey-level** of patch
• **Count** number of patches (per pixel)
• **Sparkler**: renormalize grey levels in image.

For diffuse coarseness,
\[ \text{size} = A + B \text{ (diffuse coarseness)}^C \]

For glint impression,
\[ \text{size} = 1 + 100/[1+\text{EXP}\{A + B \text{(glint impression)}^C\}] \]
Parameters are fitted by optimizing similarity of histogram parameters with respect to BYK-mac images of anchor panels.

Finetuning step: visual tests.
Find out if simulations are representative.
Rendering (color and) Texture

Glint impression

<table>
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<th>Sample</th>
<th>Simulated image</th>
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Increasing glint impression

Diffuse coarseness

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Increasing diffuse coarseness

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Increasing diffuse coarseness →

Increasing glint impression →

Rendering (color and) Texture

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Increasing diffuse coarseness →

Increasing glint impression →
Rendering (color and) Texture

Lighting: directional + diffuse
Rendering (color and) Texture
Rendering (color and) Texture
Rendering (color and) Texture
Rendering (color and) Texture
Rendering (color and) Texture
Rendering (color and) Texture
Conclusions on Texture Rendering

Pros:
• Accurate in displaying color and texture.
• Perceptually based method: optimized through visual tests.
• Short measurement time.
• Requires small disk storage.
• Fast algorithm.

Cons
• Speed of algorithm slows down for complex scenery.
• The illumination field is approximated by interpolating between directional and diffuse conditions.
Some key references

• Kirchner, van den Kieboom, Njo, Supèr and Gottenbos, "The Appearance of Metallic and Pearlescent Materials", Color Research and Application 32;4 (2007) 256-266


• Dekker, Kirchner, Supèr, van den Kieboom and Gottenbos, “Total appearance differences for metallic and pearlescent materials: contributions from color and texture”, Color Research and Application 36 (2011) 4-14


• Kirchner and Ravi, “Predicting and measuring the perceived texture of car paints”, Proceedings of the 3rd international conference on Appearance “Predicting Perceptions”, Edinburgh 17-19 April 2012