Predicting Perceptions: Proceedings of the 3rd International Conference on Appearance, pp. 149-154, Edinburgh, UK, ISBN 978-1-4716-6869-2, April 2012.

Appearance Measurements of Goniochromatic Colours

Tatsiana Atamas, Kai-Olaf Hauer and Andreas Höpe
Physikalisch-Technische Bundesanstalt (PTB)
Bundesallee 100, 38116 Braunschweig, Germany +49 (0)531 592-4520
{ tatsiana.atamas, kai-olaf.hauer, andreas.hoepe } @ptb.de

ABSTRACT

Effect pigments with their angular dependent colour impression entering more and more the portfolio of commercial products. Caused by the goniochromatic behaviour of the appearance of such objects, the spectral reflection properties in three-dimensional space must be determined in order to describe these objects appropriately. For this purpose a gonioreflectometer is needed with the ability to perform measurements of the spectral radiance factor respectively the BRDF within the full half-space (2π sr) above the device under test. At the Physikalisch-Technische Bundesanstalt (PTB), the National Metrology Institute (NMI) of Germany, such a facility for measuring appearance-related quantities has been built up. The system is named ARGon³ which stands for "3D Appearance Robot-based Gonioreflectometer". The main features within the set-up are a photometric luminance camera with a spatial resolution of 28 μm on the device under test and a line-scan camera mounted to a spectrograph, which provides measurements of spectral resolved reflection in full $V(\lambda)$-range with arbitrary angles of irradiation and detection relative to the surface normal. Within this publication goniometric measurements of reflection within 3D-space and subsequent colorimetric representation of the obtained data of a special effect pigment called Viola Fantasy from MERCK KGaA, Darmstadt, Germany are presented.

1. INTRODUCTION

The visual appearance of commercial products is becoming more and more relevant to industry. There are increasing requirements from such different branches like for instance automotive, cosmetics and printing industry. Driving force behind this common ground are new goniochromatic materials which have a strong angular dependent reflection behaviour and hence show a colour impression that depends on the spatial arrangement of illumination and observation relative to the surface of the artefact, as can be seen in Figure 1. The basis of such goniochromatic materials are special effect pigments, which colours are based on the interference effect and exhibit different colours from different perspectives. So far, however, they have been a problem for metrology as also their hue, saturation and brightness change according to the visual perspective and the light conditions.

Figure 1. Car painted with special-effect varnishing "Metallic Fantasy Emerald Green", according to the visual perspective and the light conditions, the colour impression changes.

Predicting Perceptions: The 3rd International Conference on Appearance, 17-19 April, 2012, Edinburgh, UK. Conference Proceedings Publication ISBN: 978-1-4716-6869-2, Pages: 149-154 *@2012 Authors & Predicting Perceptions. All Rights Reserved.*

The spectral radiance factor respectively the BRDF are measurands describing the reflection properties of an object. They are dependent on a multiplicity of parameters, namely the wavelength, the solid angles and the geometrical directions of the irradiation/reflection pair of variates of the sample. This means, if one wants to get information about the visual appearance of a sample one has to collect the multitude of spectral radiance factor curves in $V(\lambda)$ region for a certain angle of irradiation and all possible angles of reflection within the half-space above the sample.

2. MEASUREMENT SET-UP

The ARGon³ facility at PTB was built for the measurement of appearance related quantities of objects [1]. The essential mechanical parts of the system are a large rotation stage (Ø = 130 cm) carrying the irradiating lamps and a small 5-axis industrial robot (shoulder height 65 cm) located in the centre of the rotation stage, serving as the sample holder, as shown in Figure 2. Due to the combined interaction of these two parts it is possible to realise any required directed irradiation and observation geometry for a sample within the full half-space above [2]. For the irradiation of the sample two different light sources can be applied. These are a homogeneous light source consisting of a small integrating sphere equipped with an internal 400 W quartz halogen lamp and a luminous source producing a D65-like illuminant, realised by a filtered lamp system.

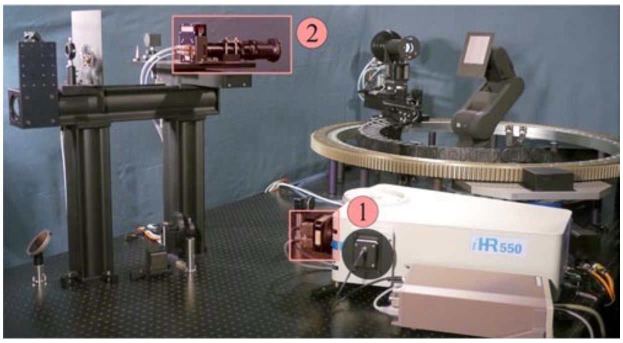

Figure 2. Photo showing the set-up of the ARGon³ facility. ① is a line-scan camera module attached to an imaging spectrograph. ② is a high-resolution combined Imaging Luminance Measurement Device/Imaging Color Measuring Device.

For the detection of the reflected radiation two distinct camera systems are utilised. The first one is a line-scan CCD-camera (1036 Pixel, 16 Bit) which is attached to an imaging grating-spectrograph, see ① in Figure 2. The spectral coverage of the recording is 290 nm in a single-shot. With two mappings centred at wavelengths of 500 nm and 700 nm, as indicated by the small blue arrows in the reflection spectra in Figures 4.a-d and displayed with a green line for the "short-wave" part and a red line for the "long-wave" part, it is possible to measure the absolute spectral radiance factor of the sample under test in the given reflection geometry in full $V(\lambda)$-range (360 nm to 830 nm) within a time frame of 2 minutes. The second camera system is a combined Imaging Luminance Measurement Device/Imaging Color Measuring Device (ILMD/ICMD) [3] with an implemented CCD- sensor with 1364 × 1030 pixels, having a field of view of 38 mm × 28 mm, see ② in Figure 2. This luminance camera has High Dynamic Range capability, enabling measurements with a ratio of up to $1{:}10^7$. It is able to measure spatially resolved luminance distributions $L(x,y)$ with a resolution on the sample under test of approximately 28 μm. By means of the built-in filter wheel also tristimulus values can be determined. This enables imaging related measurements of chromaticity coordinates with the same spatial resolution, which can be specified in user-defined colour spaces [4].

3. EFFECT PIGMENT MEASUREMENTS

Effect pigments are predominantly flaky particles consisting of a substrate coated with a thin intense refracting layer which can be oriented parallel to the object surface. The goniochromatic colours produced by special effect pigments are based on the interference effect in which the incoming light is partly reflected from the particle surface and partly refracted trough it. Dependent on the coating thickness and variation of the angle of incidence of the applied radiation, a colourful appearance of the reflected light at various spatial directions is produced.

The measurements presented here were performed on a black primed metal sheet coated with Viola Fantasy, an effect pigment from the MERCK Colorstream® family, which is based on synthetically produced transparent silicon dioxide platelets coated with titanium dioxide. The angle-dependent colour travel spans the range from lilac through silver and green to blue.

The measurements performed can be distinguished into two parts, so-called "in-plane" and "out-of-plane" measurements. The differentiation between both configurations is based on the orientation of the vectors of incident and reflected radiation as well as on the orientation of the sample normal. If all three vectors are in one plane this is the "in-plane" configuration. If they are not in a common plane, which is in fact valid for most of "real live" geometrical configurations, this is denoted as "out-of-plane".

Extensive "in-plane" measurements were performed at three different incident angles of θ_i = 15°, 45° and 65°, according to the fact that these angles are to some extend realised in commercial multi-angle spectrophotometers. While the incident angle θ_i was fixed, the reflection angle θ_r was varied ranging from +70° to −70° (except of the corresponding specular positions) relative to the surface normal in steps of 5° (Figure 3.a). These data-points are forming the so-called aspecular line.

Also the 15°-interference lines in Cis- and Trans-configuration for varying incident angles θ_i = 0° to 85° (step size also 5°) were determined (Figure 3.b). The notation Cis- and Trans- comes from chemistry and denotes again the orientation relative to the specular peak. Here 15°-Cis means the measurement at an angle of 15° in the direction of the light source and 15°-Trans denotes an angle in the opposite direction, away from the source.

From the measured spectra CIELAB colour coordinates were calculated. In Figures 4.a-d, four examples of the recorded spectra are shown. In Figure 4.e the resulting colour coordinates for the 10° standard observer under D65-illumination are plotted. The spectra show absolute values of the radiance factor of up to β(λ) = 7. This is a factor of seven higher than for the perfectly reflecting diffuser (PRD), which supposed to have a lambertian reflection characteristic with β(λ) always equal to unity, independent of wavelength and reflection geometry [5]. The four displayed spectra are highlighted with 4 different colours (green, red, orange, blue) correlating them to the evenly coloured lines in Figure 4.e. The exact position in these lines is indicated by a circle around this measuring point where also the reflection geometry is specified. The coloured ellipses, inserted in the upper right corner in Figures 4.a-d, show subsets of real pictures taken with the camera system ② of the ARGon³ facility operated in "Imaging Color Measuring"-mode, where the colour impression for the human eye under the conditions according to the 10°-standard observer under D65-illumination are displayed.
The data recorded in the different geometrical configurations span a wide range within the a*b*-plane, exceeding values of ± 75 and covering thereby all four quadrants and showing the need for multi-geometry measurements in order to fully describe the goniochromatic behaviour of effect pigments. In a next step the three-dimensional reflection behaviour for various incident angles was determined. As an example the result for an incident angle of 45° is displayed in Figure 5. The spectral radiance factor was measured at 187 positions spread over half of the hemisphere above the sample surface, except the specular reflection position. The angular range was θ_r = 0 to 67.5° (angular spacing $\Delta\theta_r$ = 7.5°) for the polar angle and φ_r = 0 to 180° for the azimuth angle (with a variable angular spacing). Figure 5 shows in a three-dimensional representation the L*a*b*-values (D65, 10° observer) of this 187 geometrical positions. Prominent are the L*-values up to a maximum of about 177.6, considerably exceeding the conventional limit of L* =100 (gray plane in Figure 5) of absorptive pigments. For a better understanding of the orientation and extension of the point cloud the projections onto the three axis of L*, a*, b* are plotted as semitransparent areas, whereupon the projected points are displayed as small dots in the a*b*-, L*a*- and L*b*-plane, respectively.

4. RESULTS AND OUTLOOK

At PTB, a new facility for measuring quantities related to optical appearance has been set up. It is capable to make measurements within the full hemisphere above the sample under test. Two camera systems give a great flexibility in spectrally and spatially highly resolved measurements of visual appearance of test objects. In order to demonstrate the technical skills of the facility, first measurements of the spectral radiance factor β(λ) in three-dimensional space for an effect pigmented metal sheet coated with the MERCK Colorstream® pigment Viola Fantasy were performed.
The measured data in the different geometrical "in-plane" configurations span a wide range within the a*b*-plane, covering all four quadrants within the plane and thereby showing the need for multi-geometry measurements in order to fully describe the goniochromatic behaviour of effect pigments.
The angular resolved surface colour data measured in three-dimensional space for an incident angle of 45° onto the sample for Viola Fantasy as displayed in Figure 5 covers for the lightness coordinate L* the range from 11.7 to 177.6. This high values for L*, even outside of the specular reflection direction, demonstrate the need for adapted concepts in order to describe colour and lightness in CIELAB colour space [6].

5. ACKNOWLEDGMENTS

The authors thank B. Campe and D. Hünerhoff for construction, building and programming several parts of .the new facility. Tatsiana Atamas appreciates the support of the Braunschweig International Graduate School of Metrology (IGSM).

6. REFERENCES

[1] Höpe, A., Atamas, T., Hünerhoff, D., Teichert, S. and Hauer, K.-O., ARGon³ – "3D Appearance Robot-based Gonioreflectometer" at PTB, In *Proceedings 11th International Conference on New Developments and Applications in Optical Radiometry* (Hawaii, USA, September 13 – 21, 2011).

[2] Hünerhoff, D., Grusemann, U., Höpe, A. 2006. New robot-based gonioreflectometer for measuring spectral diffuse reflection, *Metrologia*, 43, S11-S16.

[3] CIE TC 2-59: *Characterization of Imaging Luminance Measurement Devices (ILMDS)*, Draft No: 1.5 (2011)

[4] Höpe, A., Hauer, K.-O., Atamas, T., Kehren, K. 2010 Appearance of printed interference effect ink in commercially used multi-geometry configurations. In *Proceedings 2nd CIE Expert Symposium on Appearance - When appearance meets lighting…* (Ghent, Belgium, September 08 – 10, 2010).

[5] Höpe, A., Hauer, K.-O. 2010. Three-dimensional appearance characterisation of diffuse standard reflection materials, *Metrologia*, 47, 295-304

[6] Simonot, L., Hébert, M., Dupraz, D. 2011. Gonio-colorimetry: From Measurement to Representation in the CIELAB Color Space, *Color Research and Application*, 36, 169-178.

Predicting Perceptions: Proceedings of the 3rd International Conference on Appearance, pp. 149-154, Edinburgh, UK, ISBN 978-1-4716-6869-2, April 2012.

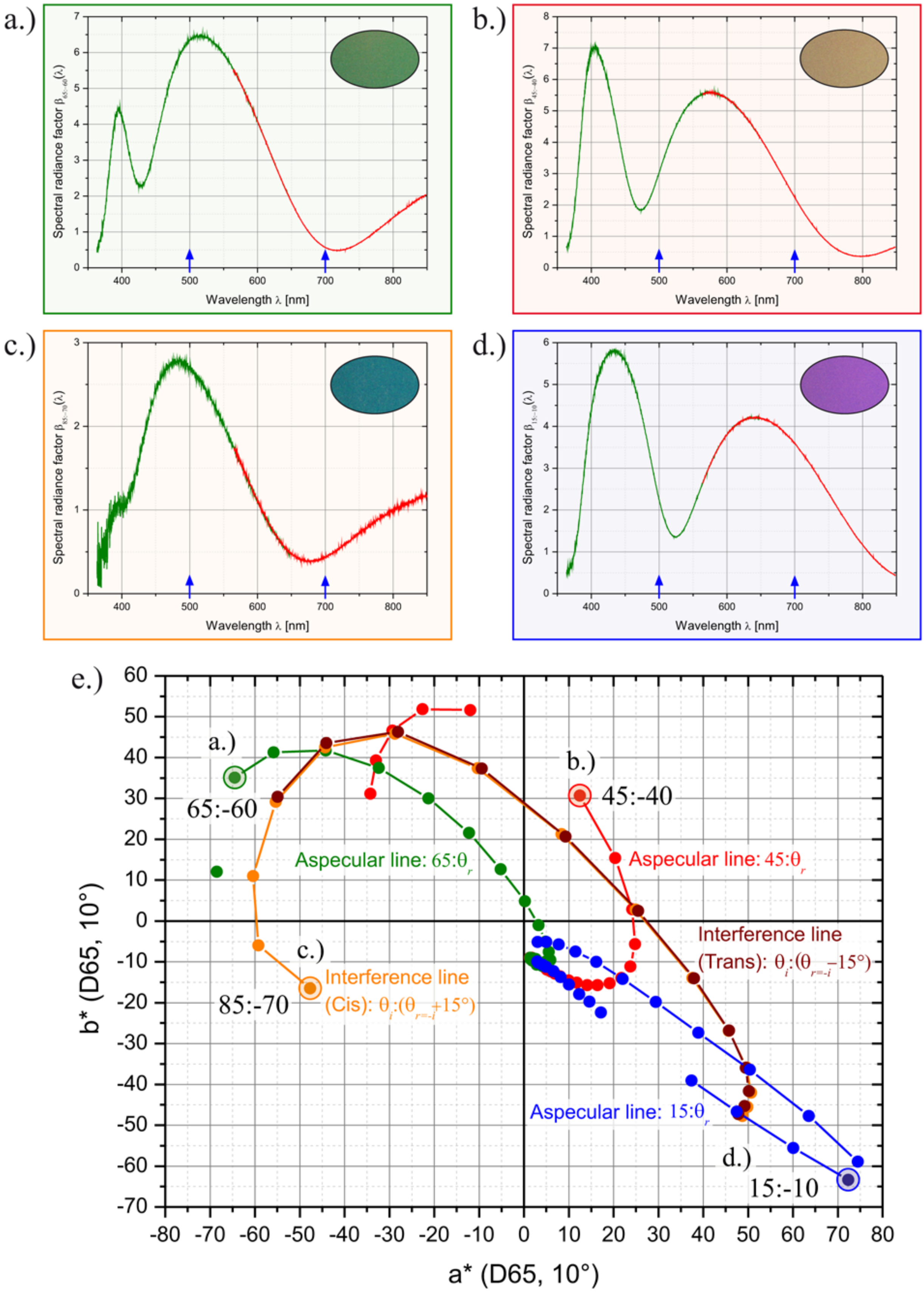

Figure 4. Spectral radiance factors and CIELAB colour coordinates of an effect pigment (MERCK Colorstream® Viola Fantasy applied on a black background) measured in different geometrical configurations.

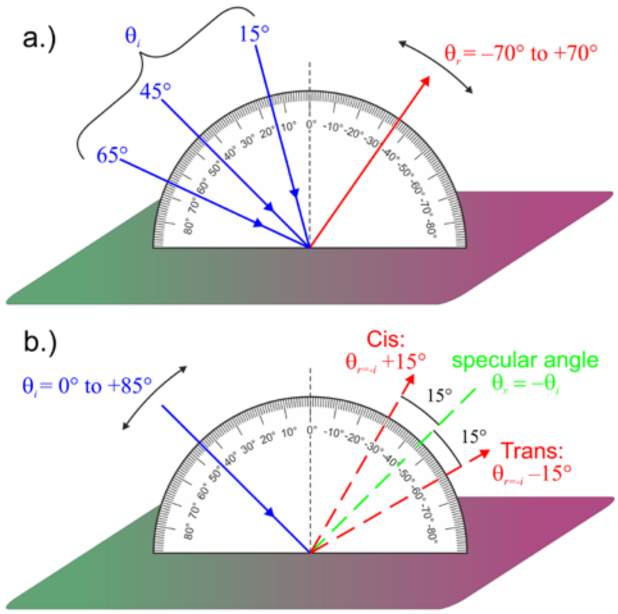

Figure 3. Sketches showing the geometrical configurations for measurements of the aspecular line a). and interference line in Cis- and Trans-configuration b).

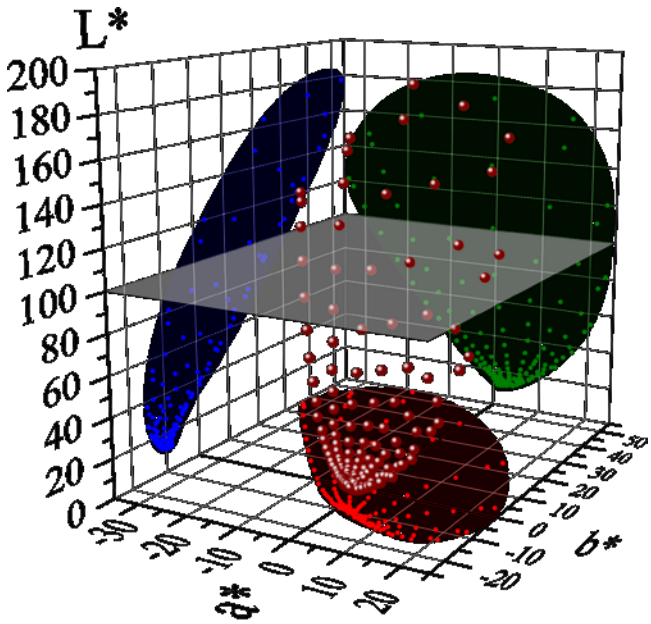

Figure 5. Three-dimensional representation of Lab-values of MERCK Colorstream® Viola Fantasy measured at 187 positions in the quarter-plane above the sample at an incident angle of 45°.