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Material Appearance Workshop

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Traceability and references for the measurement of appearance

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In daily life an object is identified through its shape and its visual attributes such as colour, gloss, texture and translucency. Together, these attributes define the appearance of the object. The visual appearance of a product is important for nearly all industrial sectors, including automotive, cosmetics, paper, 2D and 3D printing, packaging, and plastics. Appearance directly appeals to the customer. It is a parameter implicated in the purchase decision, because of the link to emotions, aesthetics and quality.

For this reason, within the last 20 years, substantial effort has been undertaken by industrial manufacturers to create attractive and sophisticated visual effects, for instance by use of interference or diffractive pigments, quasi-lambertian diffusers or high reflective flakes. These pigments create complex effects (iridescence, matte, sparkle, etc.) that cannot be adequately characterized by classic colorimeters or glossmeters, that use only two or three fixed angular measurement geometries. In fact the relevant radiometric quantities to be used are the Bidirectionnal Reflectance Distribution Function (BRDF), the Bidirectionnal Transmittance Distribution Function (BTDF) and the Bidirectionnal Surface Scattering Reflectance Distribution Function (BSSRDF).

Manufacturers of spectrophotometer systems are thus today developing a new generation of instruments using an increased number of fixed measurement geometries (called multi-angle spectrophotometers) or devices with the possibility to scan across arbitrary geometries using rotational stages (called goniospectrophotometers). To date, it is even possible to find multi-angle spectrophotometers that also include imaging systems to mimic the human visual strategy. All these devices usually work in a relative mode, by comparing the measured signal from the sample to that from a calibrated standard.

In order to meet the growing demand of calibrations for the instruments mentioned above and to support the research and development in new visual effects, National Metrological Institutes (NMI) have developed on their side absolute goniospectrophotometers to perform BRDF, BTDF and BSSRDF measurement with the lowest uncertainty, and have organized this metrology in Europe, thanks to EU Joint Research Projects (JRP) funded by the European Metrological Research Program (EMRP).

The first project, was "*Multidimensionnal Reflectometry for Inustry*" [xDReflect] (2013 - 2016) and aimed to validate the absolute BRDF scales developed independently at NMIs, to extend the spectral range, the angular resolution, and the dynamic range of absolute goniospectrophotometers and to develop measurement protocols and transfer standard artefacts for the characterization of goniochromatism, gloss, sparkle, graininess and fluorescence.

The second project is "*Bidirectionnal Reflectance Definitions*" [BiRD] (2017 - 2020). BiRD supports research actions that aims to feed CIE technical committees working on the normalization of how BRDF measurements (TC 2-85), sparkle measurement (JTC12) and gloss measurement (JTC 17) should be carried out. BiRD also defined a data format for BRDF measurements.

In may 2019, a third project has been launched. "*New quantities for the measurement of appearance*" [BxDiff] (2019 – 2023) will frame the development metrological references for the measurement of BTDF and BSSRDF of materials and will provide advanced technics for the measurements of BRDF.

My presentation that will go over these different projects, describing the objectives, the implementation of the research work and the main outcomes and publications achieved so far.

Keywords

Metrology, BRDF, BTDF, Goniospectrophotometer, Gloss, Sparkle, Goniochromatism, Euramet

Bidirectional Reflectance Measurement using Image-Based Measurement Setup

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Bidirectional reflectance distribution function (BRDF) describes how the light incident on an opaque and homogeneous material surface gets reflected. It is a ratio of outgoing radiance to incoming illuminance and can be used in obtaining photorealistic rendering of the material [1]. Analytical models have been proposed and presented to estimate material BRDF using bidirectional reflectance measurements of the material. [1] provides a detailed overview of different analytical BRDF models proposed and presented mainly within the computer graphics community. Gonio-spectrophotometers are commercially available to perform the bidirectional reflectance measurements. They measure at a broad number of the incident (θ_i) and viewing (θ_r) directions but can be slow due to moving light source and detector or measurement sample [2]. To address this, image-based measurement techniques are presented in the past [3, 4]. Image-based measurement setup uses a camera as a detector and takes photographs of the measurement sample either from several directions or by curving the measurement sample onto a cylinder or a sphere to obtain several bidirectional reflectance measurements in a single photograph [5].

An image-based measurement setup herein referred to as 'our measurement setup', was presented and used in [5-7] to estimate BRDF of flexible and homogeneous packaging materials with non-diffuse and Gonio-chromatic reflectance properties. Non-diffuse materials like shiny metals, plastics specularly reflect the incident light giving a glossy effect. Gonio-chromatic materials, like the packaging print materials produced using the pearlescent pigments and varnish coatings, show a change in visual appearance for change in the incident and viewing directions [8]. Measuring the visual appearance of materials with non-diffuse and Gonio-chromatic reflectance properties can be difficult.

The suitability of using our measurement setup to measure flexible and homogeneous materials with different reflectance properties and to analytically estimate material BRDF was investigated in [9]. In [2], the accuracy of our measurement setup was calculated by comparing the measurements made using our measurement setup with measurements from two commercially available gonio-spectrophotometers. Imprecise physical measurements within our measurement setup introduce large errors in estimating the incident (θ_i) and viewing (θ_r) directions. Our measurement setup can be used to measure flexible and homogeneous materials with different reflectance properties, but with a noticeable error. Based on the obtained results, which are similar to the findings from [10], using two illumination directions within our measurement setup could be sufficient to analytically estimate material BRDF.

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BRDF characterization of metallized plastics

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Metallization of plastics is an extensively exploited process in a large variety of industrial fields, such as chemistry, electronics and optics. The metal coating can enhance some of the surface properties and add new functionalities, as for instance electrical conductivity and optical reflectance. The automotive industry is much interested in characterizing the optical properties of aluminum coated plastic reflectors, since these constitute a fundamental component of car head and rear lamps.

In this work, the optical properties of flat substrates consisting of polycarbonate (PC) or acrylonitrile butadiene styrene (ABS) of different thickness (1.5 and 3 mm), metallized through a Physical Vapor Deposition (PVD) process, have been characterized by means of Bidirectional Reflectance Distribution Function (BRDF) and Total Integrated Scatter (TIS) measurements. Al coatings of different thickness ranging from 52 to 127 nm were prepared, on top of which a silicon-based protective layer was applied; the latter is used to preserve the aluminum film from damages induced by oxidation.

Theoretically, the BRDF measures the reflection properties of a material at any angle of illumination or viewing, thus yielding both a spectral and spatial optical characterization of the sample. In this work, the BRDF of 40 samples was measured at a fixed light incidence angle of 45°, the viewing angle ranging between 25° and 75° in the opposite half plane. Our data reveal interesting correlations between reflectivity and the sample preparation recipes. The experimental BRDF data can be validated by the simple *ABg* scatter model, the parameters of which can be related to the rms surface roughness when knowing the TIS. The maximum of the BRDF for increasing thickness of the Al coating was observed for an Al coating layer of about 100 nm, decreasing back for thicker films. This result holds for both substrate materials (PC and ABS).

Keywords

BRDF measurements, metallization of plastic, spectral properties, spatial properties, ABg model

Measurement and reproduction of human skin colour

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The colour of skin is probably one of the most familiar colours that we encounter through our life span and it plays an important role in many multidisciplinary applications. For over 70 years, CIE colorimetry has been successfully applied for the objective measurement of colour. The measurement of skin colour however, can be problematic and the comparison of measurements made using different techniques can show some variation. Two important contributions to this variation are the fact that the skin tends to be a non-flat, uneven surface and, secondly, that skin does not exhibit spatial uniformity over the measurement area. These two effects combine to make skin colour-measurement difficult and often unreliable. A third factor that contributes to the colour of skin is the fact that human skin is a complicated multi-layer material that is translucent; some of the incident light, as well as being reflected by the top surface of the skin, is transmitted by the top layer (the epidermis) and hence penetrates a sub-layer (the dermis) before being reflected back through the epidermis. This transparency effect impacts on the overall local colour appearance of the skin. Consequently, the measurement of skin colour may be affected by these various parameters.

There are also various of applications for the reproduction of human skin colour, for example, amateur and professional photography, cinematography, display, printing, and most recently 3D printing. For different applications, different desired levels of measurement accuracies exist. In this paper, different skin colour measurement technologies are introduced with particular focus on digital image measurement method. Reproduction of human skin using 3D printing technologies are reviewed. Recent research on the human perceptual sensitivity for skin colour is also reported.

Keywords

Skin colour measurement, skin colour reproduction and skin colour perception.

Manufactured surfaces appearance assessment using Reflectance Transformation Imaging

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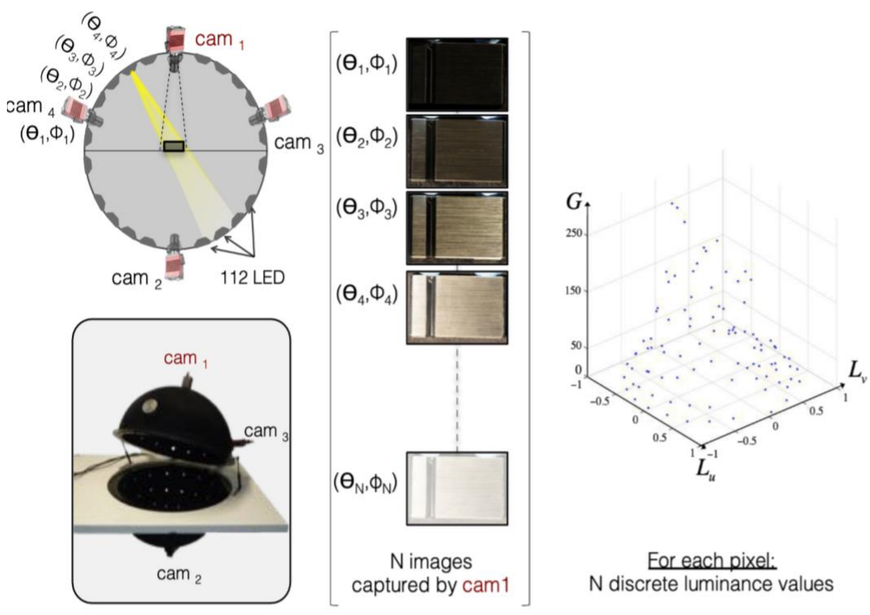
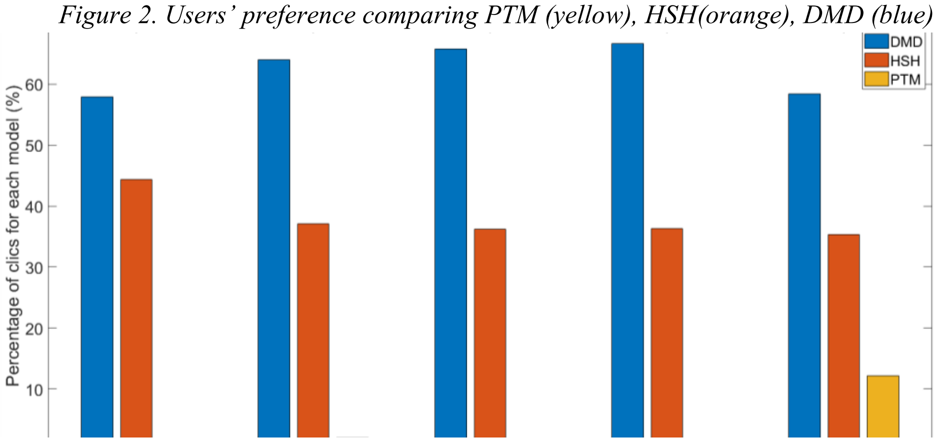
In this paper we propose a psycho-visual assessment of the quality of the relighted images from Reflectance Transformation Imaging (RTI). RTI consists in acquiring photometric stereo images corresponding to varying light positions in two directions (elevation and azimuth). From these sparse acquisitions, some approximation models are used to reconstruct continuous representations allowing the relighting process. In literature, three global approximation models are generally used : Polynomial Texture Mapping (PTM), Hemispherical Harmonics (HSH), Discrete Modal Decomposition (DMD). In this work, we propose to evaluate the relighted images (from the three models) through psycho-visual experiments (ranking, preference) on a web based application. The users' task in theses experiments were to choose the most similar relighted image to the original image (acquired one). The results show that DMD modelling outperforms the other methods in all experiments as shown in fig 2

Figure 1. Reflectance Transformation imaging protocol



keywords: Reflectance Transformation Imaging, psycho-physical experiment, Relighting.

Figure 2. Users' preference comparing PTM (yellow), HSH(orange), DMD (blue)



Reproducing Images: Colour and Texture

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For just over a year, I have undertaken a photographic exercise on Instagram entitled #colouraday. The aim - as it suggests – is to photograph colours in the world, posting them daily on Instagram. The photography has been unconstrained - no colour correction, un-edited, and largely in response to my day-to-day activities and travels, all unified by the square layout of the app. I have captured a range of materials belonging to all categories of animal, vegetable and mineral: fur and feathers; metals, glass and plastic; flowers, fruit and vegetables; painted surfaces on wood on metal, as well as intangibles such as sky, shadows, and inter-reflections. So far, it has resulted in a rich collection of colour or rather colours, as we know already, colour is complicated. The appearance of colour is impacted by the relationship of surface: the micro-structure of the surface and the illumination, and by changing the angle of the illumination can transform a seemingly smooth surface into a noisy surface of highlights and shadows.

This presentation will explore the relationship between the appearance of colour and materials and how these are captured as paintings and photographs. It will also explore parallels between paintings made by old masters of *Still Life* and *Trompe l'Oeil*, and photo-real artists working in the 20th and 21st century, all capable of rendering complex visual details using relatively few strokes of pigment and paint.

The motivation behind this study is to understand how to physically reproduce painterly styles and to produce visual effects that exploit the character and appearance of materials. This may well have an impact on how images can be reproduced eg. for fast rendering of convincing texture for moving images, (computer animation and games), printing images for visually impaired, or the reconstruction of artefacts for cultural heritage.

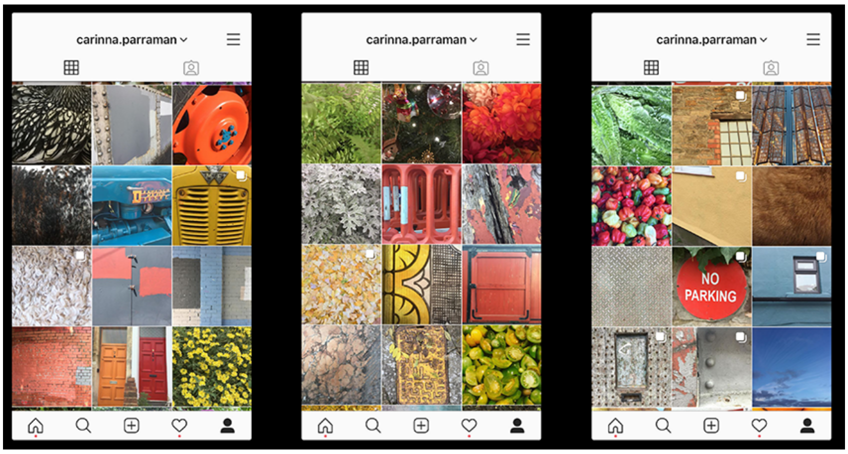

Figure 1. selection of images taken for #colouraday.

Keywords

2.5D printing, #colouraday, texture appearance, Still Life, Trompe l'Oeil

Appearance Attributes and Factors Impacting Their Perception

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Appearance is a multiplex visual phenomenon that is usually broken down to several appearance attributes for simplification of studying its nature. We have been conducting series of psychophysical experiments with various visual stimuli, in order to identify behavioral patterns in the visual appearance assessment process, as well as to outline the factors impacting perception of various appearance attributes. On the first stage of the study, we have proposed a qualitative model of the visual appearance assessment describing our data and generating the research hypotheses with future generalization prospects. Afterwards, we started studying each of the hypotheses quantitatively, and identified interesting interactions among the appearance attributes. While translucency, gloss, and color impact each other, shape of the objects, as well as the conditions of observation, including the illumination conditions, turned out to have significant impact on the appearance of the material. We present the preliminary qualitative and quantitative results of the ongoing research project. Furthermore, we compare and summarize advantages, as well as the challenges we faced while using the tangible physical (Figure 1) objects, as well as the synthetic images (Figure 2) displayed on a computer screen as stimuli. Finally, we propose future directions and framework to explore particular unanswered questions.

Figure 1. Physical objects have been widely used to observe on the appearance description process, as well as on the interaction between gloss, caustics, and translucency. Tactile information and possibility of direct interaction make assessment easier for the subjects.

Figure 2. Synthetic stimuli have been used to study impact of shape on perceived translucency differences. Advances in computer graphics give us an opportunity to study a broad spectrum of various materials.

Keywords

Translucency, Transparency, Gloss, Perception, Appearance attributes

Hyperspectral camera calibration and visual color difference metrics

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Abstract

The detailed information obtained from a hyperspectral image offers the possibility to combine visual analysis of the entire scene for studying the spatial distribution with knowledge of the spectral content. It is thus particularly relevant for research in color vision and especially for the vision of real complex scenes (indoor/outdoor) which require a simultaneous analysis of spatial distribution and the radiometric/colorimetric properties of the materials in the scene. Nevertheless, hyperspectral image acquisition and spectral calibration still remain a challenging task. Hyperspectral cameras are not usually factory calibrated, the raw radiance/reflectance values do not correspond to SI units. They are in arbitrary values which have some relation with the SI values but not necessarily linear. Thus, the raw data needs to be calibrated for spectral accuracy. Unlike a digital still camera, hyperspectral cameras usually do not come with an automatic exposure time setting to take into account the large variations of lighting conditions. At the same time it is also important to identify the minimum luminance levels for a hyperspectral capture to achieve a visually clean image with an acceptable signal-noise ratio. We propose a simplified methodology to enable accurate and reliable characterization of a commercial hyperspectral camera and spectral calibration of its output data.

To calibrate the raw radiance values, hyperspectral captures were taken at 40 ms of exposure time for a scene illuminated by a cool incandescent source (Ra= 92) and a luminance of 532 cd/m² (on diffuse white). The scene is composed of a Macbeth chart (24 color patches) and a diffuse white block (Spectralon) in a light booth. The raw spectral radiances were compared with the spectral radiances measured with a spectroradiometer (reference). A calibration coefficient was determined for the spectral acquisition range (400 nm-1000 nm) and native resolution (every 2,7 nm) to transform the raw hyperspectral data into spectral radiance in SI units (W.m-².sr per nm). This spectral calibration was validated under various LED and fluorescent sources within a 2300 K-6500 K range of correlated-color temperatures, with a mean color difference Delta Eab of 3,9. It was also observed that for certain Macbeth patches, even if the spectral difference is very small (~10^{-8} MSE), the Delta Eab could be as high as 8. This calibration curve was also compared to the manufacturer provided spectral calibration with different capture data types (UINT16 and Float) and was found to significantly reduce data size while maintaining similar precision.

To identify the minimum luminance levels that can be captured by our hyper spectral camera, a series of nine measures of the RGBYCM Macbeth squares (MCC 13-MCC 24), illuminated by an Equi-energy LED source (CRI Ra=92) were taken. The frame rate was fixed to 5 Hz and the exposure time fixed at 100 ms. The luminance was continuously increasing from 0,4 cd/m² - 61 cd/m² (measured on MCC White). A visual analysis of the calibrated hyperspectral images for overall image quality and amount of noise suggested a minimum of ~50 cd/m² on MCC White for a proper image.

The radiance calibration curve identified above, along-with a linear relation between exposure time and corresponding raw radiance values, was used to automatically determine exposure time that might over/under expose the camera sensors. Different spectral resolutions were also tested to minimize the data size and maintain spectral accuracy.

Keywords

Hyperspectral imaging, Spectral calibration, Visual color difference, Exposure setting.

Impact of background context for material recognition

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Abstract

Most material recognition studies mainly focus on the extraction of features from the material itself without accounting its background context. However, this background context is available in the real-world datasets and might provide useful and complementary information. In this paper, we are studying the impact of this context in the results of the material recognition task. We show that the context alone contains already some information about the material itself and that adding this context while extracting the features of the material improves the recognition results.

Keywords

Material recognition, deep learning, background context.

In order to study the impact of background context, we propose to run different experiments on a public material dataset for which the masks covering the material region in each image are provided. Thus, given one color image, we can decompose it into a *Material image* and a *Context image* as illustrated in Figure 1. This allows us to assess the recognition accuracy in 3 different settings by accounting: i/only the context, ii/only the material and iii/both material and context.

Material (M) + *Context (C)* = *Image (M+C)*

Figure 1. One image (glass) from the FMD dataset, decomposed into Material and Context.

Dataset: The Flickr Material Database (FMD) is used for testing. It contains 10 categories such as *Fabric*, *Folliage*, *Glass*, *Leather*, *Metal*, etc. Since not all images contain context, we have to consider a subset of this dataset with 35 images for each category, containing context background.

Method and settings: In order to extract and classify features from the images, we resort to the successful deep neural networks (DNN). Thus, we implement a VGG-19 DNN pre-trained on ImageNet as feature extractor and train the network's last Fully Connected (FC) layer as the classifier. We use a 5-fold cross validation procedure.

Results: The following Table summarizes the results we have obtained for the three different experiments. We can note that by accounting only the context in the image, 27.1 % of the images are correctly classified, which means that the context provides useful information about the material itself.

	Mean recognition accuracy (and std over the 5 runs)
Trained on C / Tested on C	27.1 ± 5.0 %
Trained on M / Tested on M	68.0 ± 6.7 %
Trained on M+C / Tested on M+C	$\mathbf{69.4 \pm 6.8}$ %

Then, by comparing the last two rows of this table, we note that a part of the context information is complementary with the material information, since adding the context to the material improves the recognition accuracy from 68.0 % to 69.4 %.

These results are very promising and help to imagine new approaches that could account differently the material and context regions and fuse their features in a relevant way.

Spectral Impact of Light on Visibility in a Tunnel with Typical Material Reflectances

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Motivation, specific objective

LEDs will progressively replace the High Pressure Sodium (HPS) light sources used in tunnels. Going from HPS to LED technology means accessing a wide range of spectra, quite different from the one of HPS light sources. White LEDs come at different color temperatures which means different spectra. Color LEDs can be mixed to produce almost any spectrum specifically designed to address the drivers' photoreceptors: the cones, the rods and/or the intrinsically photosensitive Retinal Ganglion Cells (ipRGCs). Exciting ipRGCs could affect visibility since they have been shown to impact pupil diameter.

For the time being, tunnel lighting design is only based on photopic luminance levels and it is not known whether the change of spectrum at the same photopic luminance level, affects drivers' visibility. If this were the case, this means that recommended luminance levels should vary with the spectral content of the source and with the spectral reflective properties of the different materials in the tunnel. This also means that more energy could be saved by selecting LED sources with a spectral content providing the same visibility at luminance levels lower than the recommended ones.

This study aims to find out (1) whether the change of spectrum due to the switch from HPS to LED technology impacts drivers' visibility in their central vision (for this, we compare visibility under three spectra "typical" to HPS and to white LED at 3000K and 5000K), (2) whether exciting ipRGCs impacts visibility (for this, we compare visibility between each of the three "typical" spectra and a metameric one exciting the ipRGCs). All spectra are designed to provide the same photopic luminance levels.

Methods

This study relies on a psychovisual experiment run under controlled conditions in laboratory using a 1:20-scale model of a tunnel. A screen showing simulated scenes could not be used since the spectra had to be real ones. The scale model is representative of a 100 m long section of a two-way 10 m wide, 5 m height road tunnel. It is fitted with 2 rows of 12 LED chips on board (COB) acting as luminaires (one every 8 m in the real tunnel). Each COB includes 7 different chips individually controlled to create a wide range of spectra. Surfaces of the model (road or sidewalls) can be removed to reflect changes in material reflectance. For this study, the road has a 9% reflectance, the sidewalls have a 43% reflectance over half of their height and a 6% reflectance over the other half, the ceiling has a 6% reflectance. All surfaces have a matt finish. A 1 cm by 1 cm target with a reflectance of 25% is positioned in the middle of the road at 4 m of the scale model entrance; this is equivalent to a real target of 0.2 m by 0.2 m located at a distance of 80 m (stopping distance for a speed limit of 90 km/h on a dry road surface and with a reaction time of the driver of 1 s).

As mentioned before, 6 spectra are used: 3 are "typical" of HPS and white LEDs at 3000K and 5000K, 3 are metameric of the others (same color temperature and same color rendering index) while doubling the energy content around 490 nm to stimulate ipRGCs. The 6 spectra are presented at 6 different levels leading to photopic luminances on the road surface (right in front of the target) varying from 0.5 to 4 cd/m². These spectra are produced from the 7 chips of the LED COB.

Around 40 observers with age ranging from 20 to 30 (50% male, 50% female) will be recruited for the experiment. The procedure will consist in finding the visibility threshold of the observers for the 6 different spectra. To do so, a constant stimuli method will be used. Each observer will be comfortably seated, his (her) head at the entrance of the scale model, positioned on a chinrest adjusted so that his (her) eyes be at an equivalent height of 1.50 m above the road surface (7.5 cm for the model). Each of the 6 spectra will be presented to the observer at the 6 different levels. Each spectrum/luminance level combination will be presented 6 times to the observer. Thus, the observers will see 216 light stimuli, presented in a randomized order, during the procedure. For each stimulus, the observer will simply have to state whether or not the target is visible.

The results will allow us to determine for each participant and each spectrum a psychometric function to quantify their visibility thresholds (corresponding for a given spectrum to the luminance level at which there is a 50 % probability detection). Some statistic tests will be finally run to understand the impact of light spectrum on the visibility threshold of the observers.

Optical modelling of transparent nanostructured butterfly wings

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Although seemingly simple, transparency of living organisms has mostly been studied in water and is barely investigated on land. Lepidoptera (from Ancient Greek *lepís* "scale" and *pterón* "wing") are generally coloured due to the scales covering their wings; nonetheless, multiple species have totally or partially transparent wings (Fig.1). Consequently, transparency is fully part of the visual message carried by the wings. In the interdisciplinary ANR-HFSP project called CLEARWING, we first addressed the issue of how transparency is structurally achieved: for 57 Lepidopteran species, we characterized the structures of the membrane at a microscopic and nanoscopic scale. We compared those characteristics with transmittance measurements in transparent areas of the wings: the observed correlations suggested that transparency arises as a consequence of modifications of wing structures (scales and nanostructures).

Figure 1. Hypomenitis enigma (Photo credit: Marianne Elias).

In this presentation, I will focus on the impact of membrane nanostructures on wing optical properties. Using a multilayer approach, I will introduce an optical modelling based on Abélès matrix formalism. The nanostructures contribution is taken into account according to the effective medium theory: the calculation of several refractive index profiles enables us to consider various shapes of nanostructures and to compute their randomness. After describing this modelling, I will detail the influence of the membrane structural parameters on reflectance spectra, which present distinctive interference patterns under verified coherence conditions (Fig. 2).

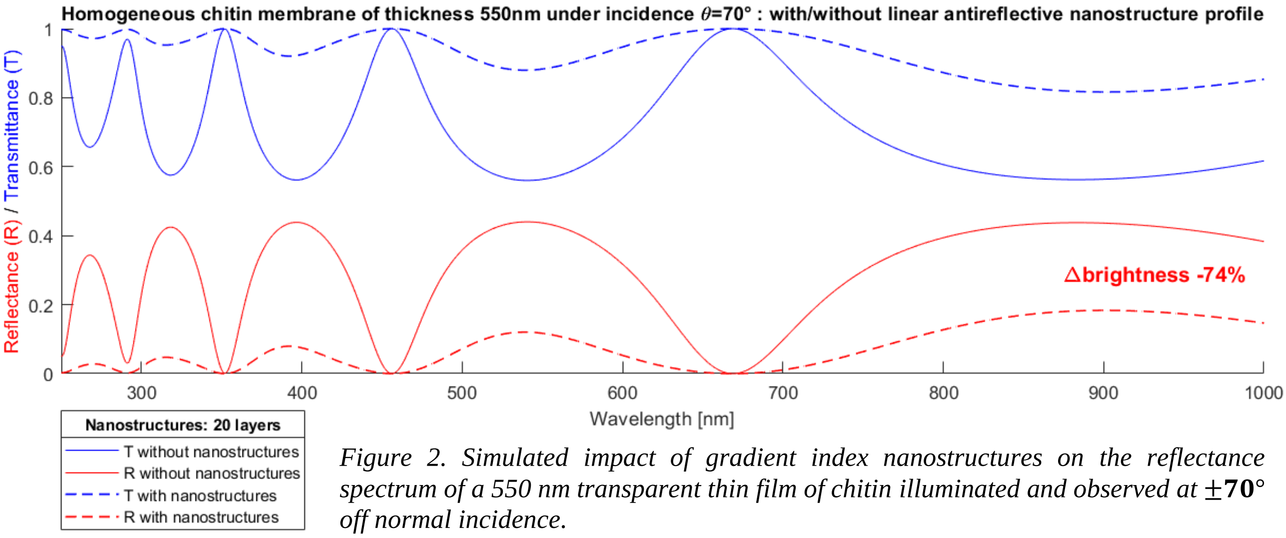

Figure 2. Simulated impact of gradient index nanostructures on the reflectance spectrum of a 550 nm transparent thin film of chitin illuminated and observed at $\pm 70°$ *off normal incidence.*

Keywords

Anti-reflective nanostructures, Multilayers, Effective index method, Abeles matrix formalism.

Tailoring the appearance of Ag:TiO_2 nanocomposite films : application to image multiplexing

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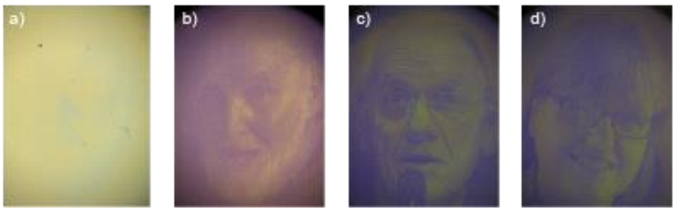

Figure 1 Three portraits multiplexed on the same sample viewed in (a) Reflection (b) Unpolarized Transmission (c) Transmission between crossed polarizers (d) Transmission between crossed polarizers at a different angle.

Structural colors have drawn a lot of interest in applications related to material appearance. Metallic nanoparticles have been used for centuries for their decorative properties, either in stained glasses or in lusters. However, recent advances in laser processing considerably increased their potential for innovative imaging. Laser scanning enables the processing of large areas with varying parameters in each point, allowing the production of images of centimeter size with a good resolution. Continuous and femtosecond laser irradiations of Ag:TiO_2 nanocomposite films have been shown to produce a wide range of visual effects, from plasmonic absorption colors with reflection/transmission dichroism, to diffraction by embedded nanoparticles gratings under the surface and polarization-dependent dichroism. These different visual effects can be observed on the same sample, and they are visible in various proportions according to the illumination-observation conditions (modes). We use this technique to produce multiplexed printed images, i.e. an area displaying several uncorrelated images according to the illumination-observation mode. The challenge is to make sure that each point in this area displays the wanted color in each mode, and therefore finding the right laser parameters to apply in each point during the marking process. We could produce several proofs of concept demonstrating different kinds of multiplexing. Figure 1 illustrates a sample showing 3 images in transmission and polarized transmission and a blank rectangle in specular reflection. Figure 2 illustrates a sample showing 2 images: one in transmission and the other one in diffraction, thus allowing an observation by using simply a white light source and the naked eye.

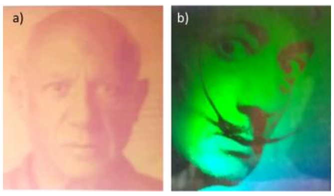

Figure 2 Left : two gray-level pictures used for the production of a versatile 2-image sample: (a) portrait of Picasso, (b) portrait of Dali. Right: these two portraits as rendered by the sample when it is observed (c) in transmission mode and (d) in diffraction

Keywords

Structural color, Nanoparticles, Image multiplexing, Laser processing.

Use of greyscale voxel values in continuous DLP printing

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Digital light processing (DLP) stereolithography is a technique for 3D printing using a DLP ultraviolet (UV) projector for curing photopolymer. The printed geometry is specified by a data volume that is sliced and projected layer-by-layer into a vat of liquid photoreactive resin. This produces objects of good precision, but each voxel value is conventionally either fully lit (1) or unlit (0). The printed objects therefore suffer from aliasing (staircase artifacts). Recently, systems have emerged that enable continuous 3D printing [1-3]. Although such systems may give rise to superior surface finishes as the staircase effect is greatly reduced or even removed (Figure 1, right), the discrete quantization artifact of the projector is still present. In other recent work [4], employing layered DLP printing, it was possible to control the growth of each voxel using greyscale values in the projector output (Figure 1, left). In this work, we adapt the use of greyscale voxel values to continuous DLP systems in order to create an artifact-free process. This enables 3D printing of geometries that resemble injection moulded parts. While the surface appearance of 3D printed objects is conventionally controlled in a post-processing step, we will explore development of innovative surface microstructure and appearance as an integrated part of the 3D printing process.

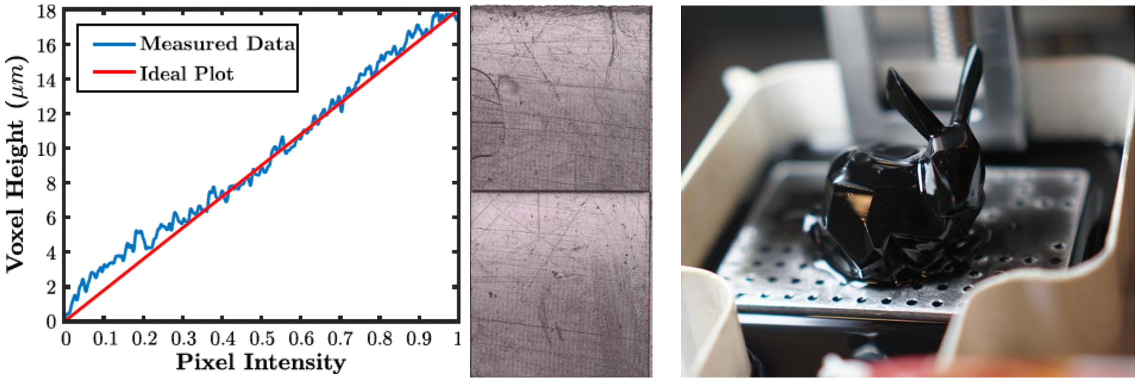

Figure 1. Left: subvoxel slopes printed in one layer with a DLP printer [4]. Right: example of a low poly Stanford bunny printed using a continuous DLP printing technique [2]. Although the continuous printer (right) does not print in layers, it still produces subtle aliasing artifacts due to voxels being fully lit or unlit.

Keywords

3D Printing, continuous printing, greyscale, appearance.

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Angular reflectance model for ridged specular surfaces, with comprehensive calculation of interreflections and polarization

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The color of a surface structured at the mesoscopic scale differs from the one of a flat surface of the same material because of the light interreflections taking place in the concavities of the surface, as well as shadowing effects. The color variation does not only arise in scattering materials, but also in absence of scattering, e.g. in metals and clear dielectrics, just as a consequence of multiple specular reflections between neighboring flat facets of the surface. In this paper, we investigate such color variation in the case of an infinitely long V-shaped groove, having in mind the visual appearance of a surface composed of many structures of that sort, all parallel and identical. In fact, studying one structure of the sort with a radiometric approach allows to predict the appearance of several of them. The observed aspect of many identical, parallel grooves is then similar to what is perceived from only one of them.

We develop a full model of multiple specular reflections, accounting for ray position and orientation and polarization effects occurring at each reflection. Because for each ray the incidence plane changes at each reflection, polarization has a significant influence on the spectral reflectance and color on the whole ridged surface. Spectral reflectance, then color, was predicted for each viewing direction of the hemisphere, by considering various materials, angles of cavities, always under diffuse illumination. They can be represented under the form of angular color maps, as shown in Figure 1b. This study might help achieving more physically-realistic rendering of dielectric or metallic ridged surfaces in computer graphics, and help to understand the influence of surface structure on color appearance for real objects.

a)

b)

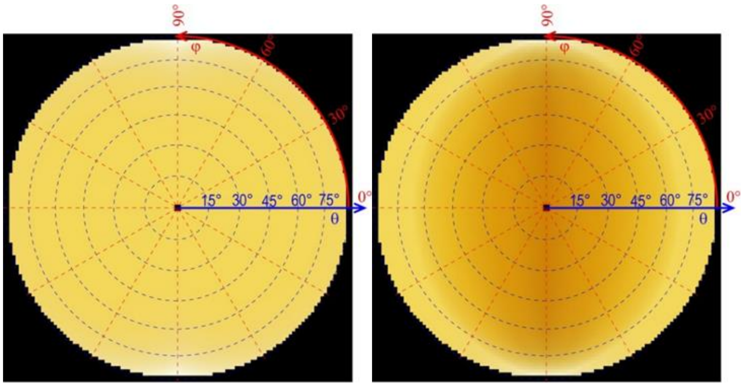

Figure 1 - a) Example of a specular cavity made of gold with a 45° angle. We perceive and predict the average color comprised in the red rectangle. b) examples of reflectance maps covering all directions (θ,φ) over the hemisphere, for a 120° angle of cavity on the left, and a 45° angle of cavity on the right.

Keywords

Reflectance computation, Appearance model, Surface reflection, Optics, Radiometry

Modeling-angle-dependent Appearance Reproduction of Inkjet 3D Printer

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Background and Purpose

Appearance managements of 3D printing have become one of the important issues in color engineering. Several studies have addressed appearance controls of 3D-printed objects in terms of color, transparency, and translucency. However, the appearance due to “staircase effect” which results from stacking planar layers in 3D printing processes has not been discussed well (Fig.1). In this paper, we present an appearance reproduction method of an inkjet 3D printer by considering modeling angles.

Proposed Method

Overview: First, we acquired surface normals of planar objects which were 3D-printed by changing modeling angles. Next, we measured the BRDF of the planar objects. Finally, we render computer graphics using the bump mapping technique with the measured data.

Surface normal acquisition: We measured surface normals of seven 3D-printed planar objects which were generated using the modeling angles of 0, 15, 30, 45, 60, 75, and 90 degrees. The surface normals were acquired based on the photometric stereo technique using nine directional light sources.

BRDF measurement: The BRDF of the 3D-printed planar object of 0-degree modeling was measured by the gonio-spectrometer (Murakami Color Research Laboratory GCMS-4). The incident and viewing angles range from 0 to 80 degrees with an interval of 2 degrees, respectively.

Rendering: For rendering computer graphics, we fitted the measured data to the Torrance-Sparrow reflection model. Then, we simulated the appearance of 3D-printed objects with different modeling angles based on CG rendering with the bump mapping technique.

Results

Figure 2 shows the rendering results of 3D-printed cubes with different modeling angles. As shown in Fig.2, the surface appearance related to bump and roughness is changed depending on the modeling angles. The appearance reproduction technique will be useful for designing 3D-printed objects.

Keywords

3D printer, staircase effect, surface normal, BRDF, rendering

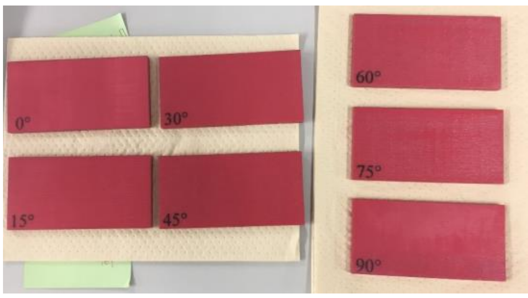

Figure 1. Real 3D-printed planar objects with different modeling angles.

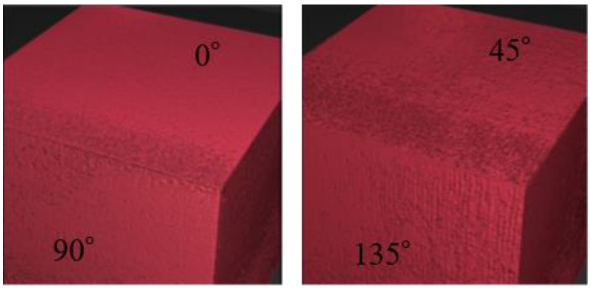

Figure 2. Appearance reproduction by CG rendering with different modeling angles.

Display of a 2D pattern with an illuminated continuous 3D surface. "Light sculpting".

Laurent Brunel[1]

[1]*PhotonLyX Technology.*

The main idea is to modulate the shape of an illuminated 3D surface, continuous or not, in order to create an illusion of a pattern or a photography for the observer.

If we consider a surface illuminated by a light source, for example the sun or a light spot, the brightness seen by the observer depends on the light spot position, the observer position and the surface orientation. For the particular case of so-called lambertian surface (mat paint surface), it is known that this brightness depends only on the light position and the surface orientation. Indeed, it depends on the angle between the surface normal vector and the incident light orientation. We show here how to calculate and produce a surface such that its orientation at each point will produce a particular brightness such that the ensemble create the same visual sensation than viewing a 2D pattern, a drawing or a gray levels photography. Practically it also works with surfaces that are not perfectly lambertian.

A dedicated iterative algorithm calculates the best shape for a determined illumination. This algorithm is in fact a simple renderer that deforms a virtual surface from a plane to the best adjusted surface.

The surface can be processed by CNC machining, 3D printing or other techniques of 3D objects production.

Examples of application: visual arts, advertisement, packaging, jewelery, building facade, civil art, low power consumption displays, "photograph" done in stone for very long term conservation, memorials.

We will present some physical examples.

Figure 1: example of gray-levels pattern to be displayed, realistic simulation with oriented illumination, same simulation with isotropic lightning, physical realization in concrete for the 2017 Lima Design Week, Perú.

Keywords

Visual art, light sculpting, shading, rendering.

Material Appearance Workshop

Appearance Analysis of Fluorescent Objects

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Norwegian University of Science and Technology / Nagano University

The use of fluorescent materials has increased in our daily lives. All kinds of everyday objects are made of such materials, including paint, dye, paper, plastic, and cloth. The usefulness of fluorescence is based on the effect that the visual appearance of the object surface is improved compared to a reflective surface based on non-fluorescent reflection. Because of fluorescent emissions, many fluorescent surfaces appear brighter and more vivid with respect to the original color of the surface.

The fluorescent characteristics are well-described in terms of their bispectral radiance factor as shown in Figure 1. The radiance factor is a function of two wavelength variables: the excitation wavelength of incident light and the emission/reflection wavelength. The bispectral radiance factor can be summarized as a Donaldson matrix, which is an illuminant independent matrix representing the bispectral radiance factor of a target object. Therefore, once we know the Donaldson matrix, the appearance of the object observed under arbitrary illumination can be spectrally reconstructed.

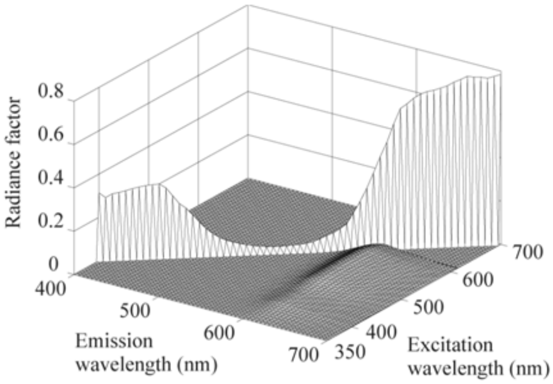

Figure 1. Example of Donaldson matrix.

First, we describe a method to estimate the bispectral Donaldson matrices of fluorescent objects in a scene with a spectral imaging system. Multiple ordinary light sources with continuous spectral-power distributions are projected sequentially onto object surfaces. The reflection, emission, and excitation spectral functions are estimated at each wavelength. An application to spectral analysis and reconstruction of a fluorescent image is demonstrated using a real scene, which includes different fluorescent and non-fluorescent materials.

Second, we describe appearance reconstruction of fluorescent objects with mutual illumination effects under different conditions of material and illumination. We reconstruct a realistic scene appearance, including mutual illumination effects, under different conditions of materials and illumination. We acquire spectral images of two closely located fluorescent objects under different illumination directions. The observed images are then decomposed into five components. Each component is expanded into spectral composition functions and geometric factors. The reference factors are estimated by taking the models of reflectance, luminescence, and mutual illumination into account. A novel appearance is rendered with different fluorescence materials, different illumination conditions, and the corresponding geometric factor estimates. The spectral image is reconstructed as a linear sum of the five components, combining the spectral functions and the geometric factors at the level of each component.

Keywords

Fluorescent object, Appearance analysis and reconstruction, Donaldson matrix, Mutual illumination.

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Nanoparticles obtained via solid state dewetting of silver thin films

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This contribution focuses on periodic arrays of silver nanoparticles of anisotropic shape obtained at a macroscopic scale. The scalable fabrication method used in this work relies on temperature-assisted solid-state dewetting of a continuous thin film of silver, deposited on a silica substrate patterned by the nanoimprint technique (Fig.1). The morphology of samples is examined both post-mortem and with in situ and real-time technique, precisely environmental SEM. The obtained nanoparticles are diamond-shaped and partially–embedded into the silica substrate. It is shown that, under identical conditions of both deposition and dewetting of thin silver film, an optimal initial film thickness does exist for each array period and organization; arguments based on thermodynamics and on grain density are put forward to explain this finding.

In case of arrays of plasmonics nanoparticles, optical properties vary not only with the shape of individual nanoparticle but also with the lattice period and the degree of order. Arrays of plasmonic nanoparticles can sustain constructive interferences of the scattered fields of all the nanoparticles in the array, known as Surface Lattice Resonances (SLR). Due to the transparency of glass-based samples, both integrated reflectance and transmittance spectra were measured for examined samples, which allowed exploring SLR-related features. Numerical FEM simulations confirmed these findings and suggested strong impact from partial embedding of the particles into silica substrate.

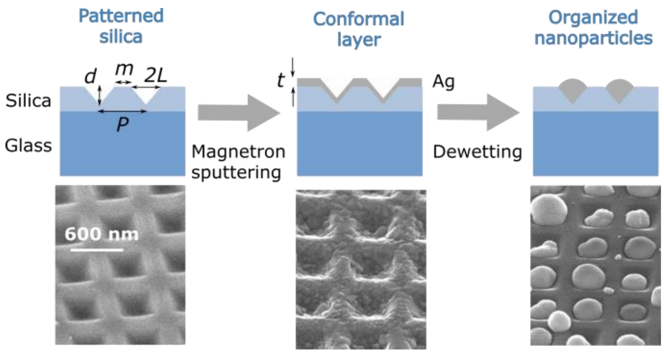

Figure 1. . Description of the fabrication protocol: (top panel) side view sketch defining geometrical parameters of the pattern; (bottom panel) corresponding SEM images obtained at a slight tilt from surface normal.

Keywords

Silver, anisotropic nanoparticles, dewetting.

Dew as a surface iridescence modifier

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Usually dew is seen as an unintended, if ever undesirable, effect. We cannot deny that it may change the appearance of the surface but , to some extend, it may also give an aesthetical value. Moreover, dew formation can be seen as a triggerable modification of the colour of the material.

Driven by the fascination of troubled panes, artists have used this to create transitory patterns without any theoretical background. However, most of the works are based on hydrophilicity control and patterning.

At macroscopic scale, playing on hydrophilic caracters of the surface may induce interesting breath figures. This phenomenon can be used on bathrooms mirrors to reveal hidden messages when the air is moist.

At microscopic scale, such a kind of hydrophilic/ hydrophobic patterning may lead to light diffraction. On Figure1, microscopic view of condensation on modified glass substrate and related diffraction patterns are presented[1]. These first results suggest that this method can be used to obtain controlled diffraction patterns, and by the way iridescence.

In this presentation, we will propose a short review on breath patterns control but also artistic applications of this phenomenon..

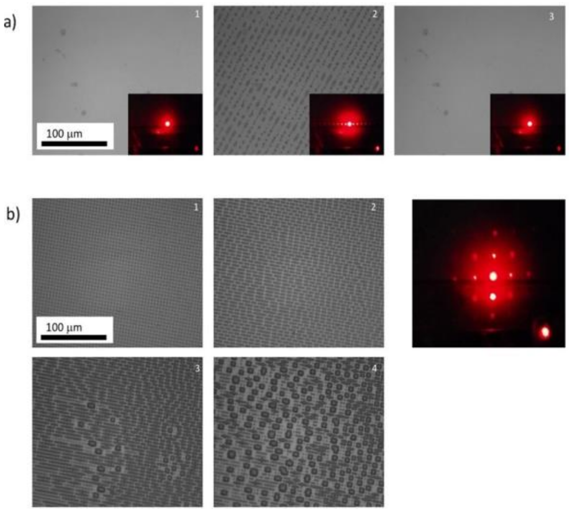

Figure 1 (from [1]). Condensation of water on a chemically patterned surface. (a) A 10 µm period mask. Microscopy images of the same sample, under room humidity conditions (left), under increased humidity (middle), and at the initial humidity content (right). (b) Sample prepared with an array of 2.5 µm × 2.5 µm hydrophobic squares separated by hydrophilic regions (SiOH). The sequence of microscopy images corresponds to increasing humidity in the atmosphere surrounding the sample. In each case, the insets correspond to the light patterns of a He:Ne laser transmitted through the sample.

Keywords

Iridescence. Surface patterning. Art and science.

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The appearance of film colors

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University of Zurich.

Cinema theaters around the globe have almost completely converted to digital projection. The access to the content of film reels relies largely on their digitization, which is supposed to accurately recreate the appearance of the cinematographic images.

The fruition of an analog film takes place as an ephemeral (audio-) visual event in cinema theaters. This creates a dichotomy between the material essence of a motion picture film (a sequence of small images impressed on a 35 mm film) and its visualization (the big moving picture), which must be considered carefully.

For instance, the highly scattering image particles contained in early color films (especially toned film prints) can generate remarkable chromatic differences between a film directly observed with diffuse backlighting and its image projected on screen. Despite this, all professional movie scanners available on the market to date use diffuse light to illuminate the film, leading to colors that might differ from those obtained with the highly directional illumination of film projectors.

In view of this, the team of researchers of the ERC Advanced Grant *Filmcolors* at the University of Zurich developed a multispectral film scanner that allows switching between condensed and diffuse illumination, aiming at a better reproduction of historical movies. A set of film samples was captured from a wide selection of film color processes (filmcolors.org) and the results of colorimetric computations were compared with the analog projection during simultaneous screenings (Fig. 1).

We would be glad to participate to the APPAMAT workshop and share the compelling (and sometimes surprising) experience gained from these experiments.

Figure 1. "Butterfly screening" of a chromogenic print: analog projection on the left (Kinoton FP38) and digital projection on the right (Christie CP2210). The sliding cut is achieved with a curtain mounted on a rail.

Keywords

Cinematography, Color, Light scattering, Multispectral imaging.

Multi-angle color prediction of anodized titanium

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Oxidized titanium is highly resistive to corrosion and biocompatible. Under certain conditions, oxidized titanium may have an interferential coloration. Both its biocompatibility and coloration properties make oxidized titanium a promising material to improve the esthetic rendering of dental implants abutments or prosthetic cornea backplates, for the creation of jewels with innovative designs. Oxidized titanium is also used for artistic paintings. The present study will focus on anodizing, as it is the best-suited method to generate uniform oxide films with homogeneous interferential colors.

Due to the interferential origin of its color, anodized titanium is a gonio-apparent material, with a color changing as a function of the illumination and/or observation directions. By using specular reflectance measurements at three different incidence angles and two different polarizations, we show that it is possible to predict the color of mirror polished anodized titanium samples in other specular geometries.

Two series of three mirror polished titanium samples have been prepared with two different R_a roughness parameters (15 nm for series 1 and 60 nm for series 2). Each series was then anodized at three different cell potentials (10 V, 20 V and 90 V) to generate three different oxide layer thicknesses and thus different colors. The samples reflectance spectra have been measured in specular condition at incidence angles of 15°, 20°, 30°, 40°, 45°, 60°, 65°, 70° and 75° for TE, TM and non-polarized light. The reflectance spectra for TE and TM polarizations at 15°, 45° and 75° have been used to determine the material parameters (layer thicknesses, refractive index and porosity) by using and 3-layers model material and an Abeles matrices optical model. These parameters have been then used to predict the non-polarized reflectance spectra and then the colors at all incidence angles. The average ΔE_{94} over all samples and incidence angles between measured and predicted colors is 1.9 and the maximum ΔE_{94} is 5.

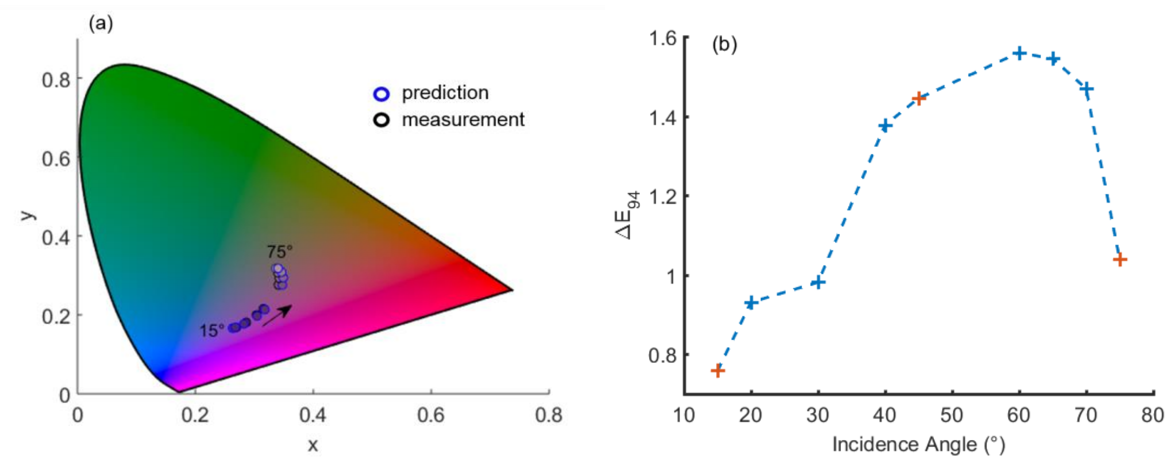

Figure 1. (a) Predicted and measured chromatic path in the CIE 1931-xy chromaticity diagram for the sample of series 2 anodized at 20 V. (b) Corresponding ΔE_{94} between predicted and measured colors as a function of the incidence angle (the angles used to determine the material parameters are highlighted in red).

Keywords

anodizing titanium, gonio-apparent, color prediction

Elementary colours

Patrick Callet[1,2],

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2019 has been declared International Year of the Periodic Table by UNESCO. That is the reason why we decided to publish our version of the periodic table figuring the alphabet of the Universe. A lot of elements were identified by their spectrocopic lines (absorption or emission) in and out of our terrestrial environment (e.g. He). The discovery of that important characteristic of the elements as a universal signature has founded a large part of astrophysical studies. The name « element » has its own history which can be inheritated from Democrite as he was probably one of the first philosopher to emit the atomic hypothesis.

Though we now know that « elementary particles » are not an achievement but themselves compounds of smaller ingredients, the materials properties mainly depends on electronic structure.

Colour, shininess, transparency, translucency, follows that way too in combination with physical and chemical mechanisms involving state of surface or internal interactions.

« lmn »...a short piece of the latin alphabet defined by a greek word has given the name « element ».

Elementary colours refers here to the « own » colours of the elements. Obviously, depending on lighting and viewing conditions the colour of an element is intimately linked to its electronic structure and band properties.

We give here examples of, as complete as possible, a periodic table where each element is represented in the visible domain using the more fundamental properties that are their complex indices of refraction. It is also interesting to show how the methods of investigations are useful for some combinations of elements as alloys and to accurately render their appearance in spectral normalized conditions for lighting and viewing according to CIE. The required optical data used for rendering were extracted from scientific publications or directly, while delicately and accurately, measured by spectroscopic ellipsometry. We also compared our data to *ab initio* modelling in a particular case. The first 3D spectrally computed images of the periodic table bringing the appearance of a lot of elements is then given in standard colorimetric conditions for viewing and lighting.

A short discussion on optical anysotropy and its application to natural crystal is started.

Keywords

Periodic table, complex index of refraction, photon mapping, spectroscopic ellipsometry, crystallography

Multi-Material 3D Printing for Appearance Fabrication

Vahid Babaei

Max Planck Institute for Informatics

Commercial multi-material 3D printers are becoming more and more available. In this talk, I discuss the opportunities and challenges in reproduction of appearance using multi-material 3D printing where I focus on a single application: fine art reproduction. Reproduction of fine art objects has been a topic of interest for many decades, pursued by many technologies. In general, the results have not been satisfactory as the quality bar is very high for this sensitive application. Multi-material 3D printing is the latest technology and a new hope for a physical reproduction with archival quality. Among fine art artifacts, paintings are excellent case-studies due to their rich appearance, unique challenges and rather convenient fabrication. I argue that multi-material 3D printing is not only able to reproduce the fine 3D geometry present in many forms of paintings, but also other appearance attributes, such as spectral color and gloss. I speak about both computational challenges, such as accurate volumetric prediction of appearance, and general challenges, such as the lack of an open hardware platform and thus inflexibility in tuning machines and materials.

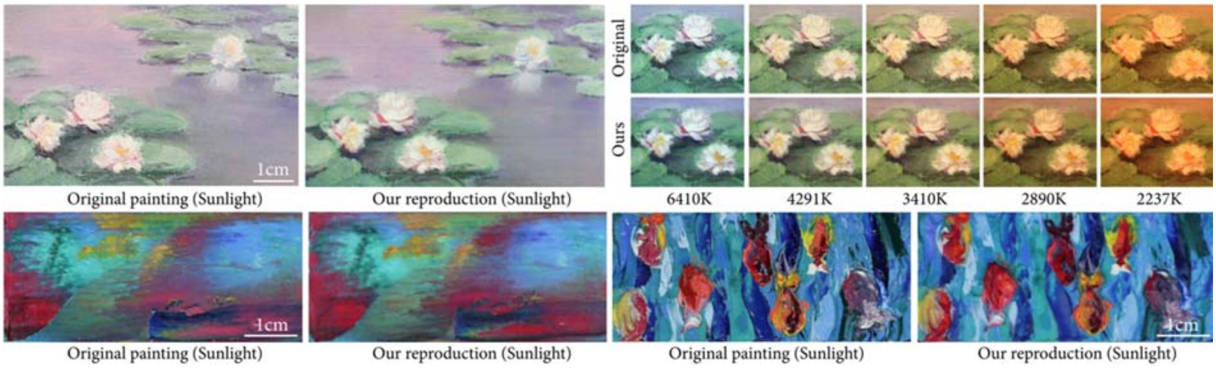

Figure 1. Multispectral painting reproduction.

Keywords

Appearance, 3D Printing, Fine Art.

Scanning and printing a painting's appearance – from documenting to reconstructing appearance

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A three-dimensional landscape of paint

A painting is not a solely a static depiction. The painting as an artefact is in fact a three-dimensional landscape of paint, with varying appearance properties across its surface, including color, topography, gloss and translucency variations. This effect can be intentional – for instance using paint to create a 3D effect – or the consequence of drying, hardening, or degradation. Aging, environmental influences, handling, but also conservation treatments have and will continue to influence the appearance of a painting. Currently, the documentation of a painting's complete appearance is generally limited to archival photography, representing it as a 2D image. A more extensive documentation of appearance – and changes over time – is generally not captured.

Appearance reproduction, reconstruction and documentation

Recent work has focused on capturing and reproducing a painting's appearance attributes including color, topography and gloss (e.g.[1], [2]) (see Figure 1 and Figure 2). Furthermore, a reconstruction of the original size of the painting Saul and David by Rembrandt van Rijn (c.1651-1654 and c.1655-1658) was exhibited at the Mauritshuis, The Netherlands [3]. More recently, three 3D scanning techniques were used to capture Johannes Vermeer's Girl with a Pearl Earring (c.1665), as part of the 'Girl in the Spotlight research initiative [4]. These techniques were compared and evaluated on their ability to support documentation and visualization of the craquelure of paintings (see Figure 3).

Future research directions

Work is continued on the (3D) scanning of appearance for documentation purposes, and further evaluated for their applicability to support conservation, restoration, and potentially the formulation of better substantiated preservation guidelines. Future work on appearance reproduction is envisioned regarding transparency capturing and reproduction. Furthermore, research will be directed to exploring more possibilities of appearance reconstruction and using appearance data in a virtual context.

Keywords

3D scanning, 3D printing, Cultural Heritage, Appearance Reproduction, Gloss

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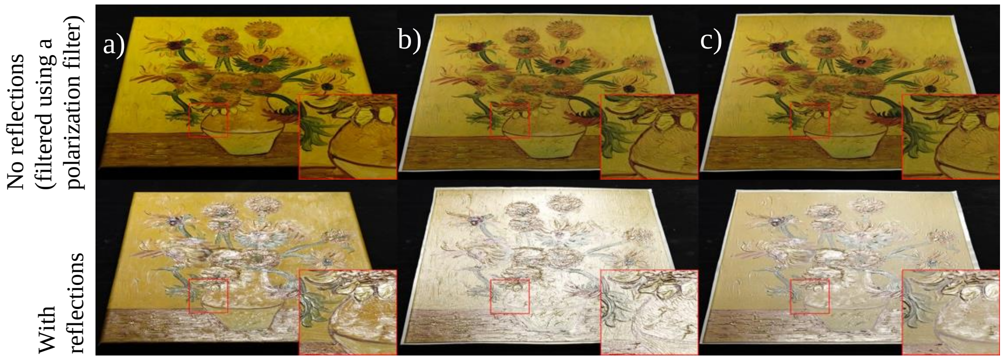

Figure 1: Appearance reproduction of (a) the painting 'Sunflowers' by W. Adam (in the style of Vincent van Gogh), compared to (b) a print without gloss modulation layers and (c) a print with gloss modulation layers.

Figure 2: Photographs of (a) the painting 'Fruit Still Life' by Cornelis de Heem (Courtesy of Mauritshuis/photographer Ellen Nigro), (b) a reproduction featuring color, topography and spatially-varying gloss, taken during restoration.

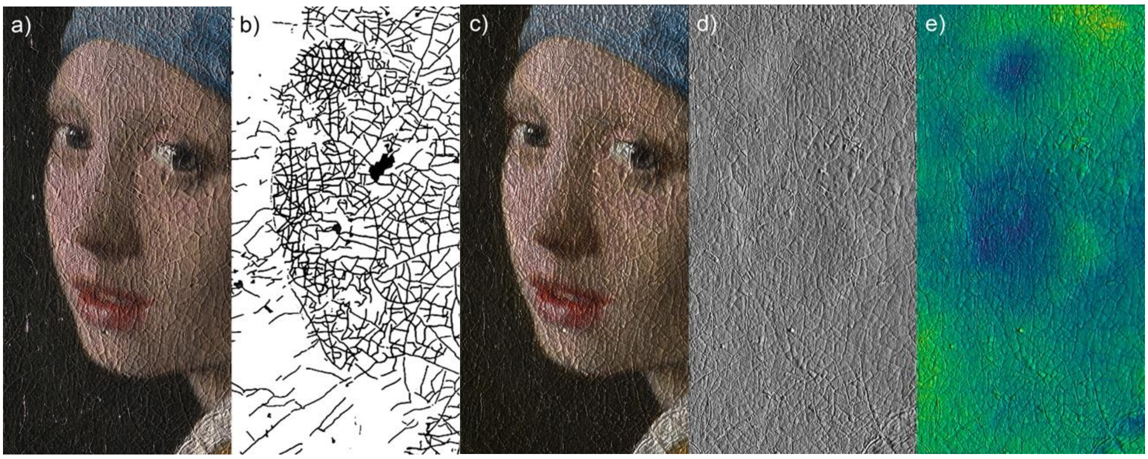

Figure 3: Comparison of original documentation (a-b) and virtual renderings (c-e), visualizing surface heightvariations of Johannes Vermeer's 'Girl with a Pearl Earring'. (a) Raking light photograph, (b) hand-traced crack image, (c) rendering (similar to raking light) using color and topography data, (d) rendered as a matte, white surface, and (e) rendered using a color map, to enhance the height variations. Note that for the renderings the height variations are exaggerated relative to the lateral scale, to increase their visibility.

Subvoxel Growth Control in DLP 3D Printing

A. Luongo, M. B. Doest, V. Falster, M. M. Ribo, E. R. Eiriksson, D. B. Pedersen, J. R. Frisvad

Technical University of Denmark

Figure 1. Hemispheres and bunnies with smooth and rough surfaces. Flat samples (smileys and QR code) with spatially varying anisotropic reflectance. The scene is observed from two directions to exhibit the anisotropy. The sun is the light source. Each item was printed in a one-step process using the presented technique.

The quality and capabilities of commercial 3D printers have increased significantly over the years, enabling the production of more and more complex geometries with higher and higher resolution. However, the surface appearance of a 3D printed object is usually controlled through the use of different print materials and special inks, and/or post-processing of the surface.

Digital Light Processing (DLP) stereolithography is a promising technique which enables us to print very high-resolution objects, however, it suffers from some of the same limitations as more classical 3D printing techniques.

In this presentation, we will describe how to include grayscale values in the layer images projected by a DLP printer in order to perform anti-aliasing and remove the layering effect typically introduced by 3D printers.

We will also present how to extend the use of grayscale values to control the photo-polymerization process and the growth of each surface voxel. We will show how this concept can then be used for editing surface microstructures to obtain 3D printed objects with customized surface roughness, anisotropic surface appearance, and reduced aliasing effects without introducing any post-processing step to the 3D printing pipeline.

Reference

Luongo, A., Falster, V., Doest, M. B., Ribo, M. M., Eiriksson, E. R., Pedersen, D. B., and Frisvad, J. R. Microstructure control in 3D printing with digital light processing. *Computer Graphics Forum*. 2019. To appear. DOI: https://doi.org/10.1111/cgf.13807

Keywords

3D printing, appearance, BRDF, reflectance, surface roughness.

Real time ray tracing display simulation based on emissive and reflective spectral measurements

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Most displays — phones, tablets, notebooks, in-vehicle screens, etc. — are commonly used in bright sunlight, a light condition that can cause problems for end users in the day-to-day use of these products. Even so, it still remains a common practice to measure the emissive properties of displays in darkroom environments even though these products are rarely ever used in total darkness by end users. To that end, we've already proposed measuring both the emissive and reflective properties of displays at various angles using Fourier optics instruments as a way of predicting display performance under parasitic illumination. This technique allows for the rapid measurement of color-emissive properties across a large angular aperture at high angular resolution. The multispectral version of the instrument can quickly and effectively measure the reflective properties of the display surface at various incidence angles. These measurements take into account incidence, reflected angles, and wavelength in order to predict the reflective properties of any display in any type of parasitic light. Combining these measurements make it possible to predict the overall performance of any display within any given parasitic illumination condition. This, in turn, makes it possible to accurately deduce, with or without illumination, the angular dependence of the luminance contrast, the color gamut, or the color volume, all essential for identifying the best displays for any given use case or application [1,2]. It has also enabled us to create physico-realistic simulations of displays under full diffused or collimated beam illuminations [3]. More recently, ray tracing simulations based on the measured optical properties of displays has been presented [4,5]. Standard ray tracing simulation of photo-realistic images uses an RGB representation to describe the optical properties. This can lead to color distortion and inaccurate results. Fortunately, full spectral ray tracing simulation is now possible thanks to the increased computing capacity of personal computers.

UVR (United Visual Researchers) has recently developed OMEN, a simulation software suite producing near-real-time "iso-photographic" rendering taking into account both spectral content and polarization state of the light [6]. In this paper, emissive and reflective measurement results obtained on a single automotive display and its photo-realistic simulations inside a vehicle with various lighting environments will be presented.

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5. P. Boher, T. Leroux, T. Muller, P. Porral, "Accurate physico-realistic ray tracing simulation of displays", Electronic Imaging Conference, San Francisco, 28 January - 2 February (2018)
6. P. Porral, L. Lucas, T. Muller & J. Randrianandrasana, "Iso Photographic Rendering", Workshop on Material Appearance Modeling (2018)

Keywords

Fourier optics, Spectral, Polarization, ray tracing.

Manipulating Object Appearance with Augmented Reality

Michael J. Murdoch

Munsell Color Science Laboratory, Rochester Institute of Technology

Recent and ongoing work has addressed the possibility of manipulating the appearance of real objects with optical overlays, using an optical see-through (OST) augmented reality (AR) system. The OST-AR system uses a large beamsplitter to overlay a displayed image onto the viewer's visual field, physically adding light to the scene in a manner conceptually similar to both head-mounted AR systems and projection-mapping systems. Understanding the perception of manipulated materials and objects is critical to AR applications such as medicine, education, and entertainment. This APPAMAT workshop presentation will share methods for creating AR overlays and measuring appearance perception via visual experiments, with hope of discussing novel material appearance models that might be applied to describe AR situations.

The perceived appearance of the optical mix of real background objects and AR-displayed virtual foreground colors diverges in some cases from an expected, physical summation. Experiments with 2D color patches show a consistent "discounting" of the background object, suggesting that viewers understand the overlay and partially ignore its effect [Hassani & Murdoch, Color Research & Application, 2019]. Additional experiments show that background discounting seems to be affected by the complexity of the virtual foreground object. Color matches made between foreground colors on different backgrounds in these experiments can be predicted using a modified CAM16 color appearance model that accounts for background discounting in linear XYZ tristimulus space [Hassani PhD dissertation, RIT, 2019].

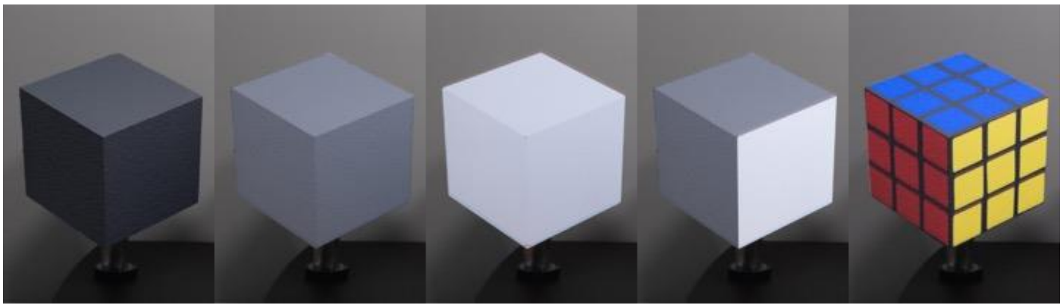

Figure: Examples of appearance manipulation using different AR overlays on a 3D gray-painted cube.

The interaction of the effect of the complexity of the real background object with the precision of the alignment of virtual foreground overlays was explored in a preliminary experiment with real 3D cubes (similar to the above Figure) [Leary & Murdoch, SAP 2018]. This work is currently being extended, with the hypothesis that the foreground overlay can be discounted to various extents due to visual cues including alignment and contrast. These observations are connected with older work on veiling luminance and lightness constancy [Fry & Alpern, Optometry and Vision Science, 1954], [Gilchrist & Jacobsen, Journal of Experimental Psychology, 1983]. Going forward, the apparent color, texture, and shape can be manipulated with AR overlays using a combination of 3D graphics and color processing. Models of color and material appearance are needed to predictably recreate the observed effects.

Keywords

Augmented reality, AR, color appearance, material appearance

Realistic rendering of automotive product : toward predictive simulation

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Sponsored by the Automotive Engineering Society (SIA), the two French car manufacturers collaborate to augment their capability to simulate the appearance of a vehicle in different life situations. These simulations aim at enabling the detection and the evaluation of perceived quality defects as early as possible in the design phase of the vehicles. Three challenges have been identified for which the carmakers make a call for contribution to the scientific community. The first two challenges deal with characterization and metrology of light and materials needed for modelling, whilst the third challenge aims at improving the confidence in the calculated images, taking into account visual perception phenomena.

Challenge 1: Modelling of materials – Some tools already exist on the market to characterize a physical material with a purpose of manufacturing quality control. They are also used for simulations and show their limits (scale factors, precision of measurements, specific parameter measurements). We want to progress toward the definition of a measurement standard (which physical quantity to be measured and with which measuring tools), and then toward a digital representation of materials, which would take into account their fabrication process (case of complex materials, e.g. with sparkling paint). The intended framework is to improve real-time performance of the simulations by using optimized models.

Challenge 2: Modelling of lighting sources – Another objective is to define the metrology needed to characterize a lighting source (which physical quantity to be measured and with which measuring instruments). To date, capturing an environment and its illuminants can be performed via an HDR image. In this context there is a need to normalize HDR images both in color and in luminance, by mapping measured values to them. Other techniques could be proposed.

Challenge 3: Confidence in the calculated images – It is also aimed to improve the confidence level of simulations with respect to reality. To do so, material conditions of observation of calculated images have to be made more rigorous. Secondly, we aim to develop a quantitative measurement approach of the deviation between simulation and reality. This would pave the way to "predictive simulation", going over the current "simulate & see" mode.

In this talk we will present the above-mentioned challenges in more details.

Keywords

Appearance & metrology of materials, visual simulation & perception, illuminants, Physically Based Rendering.

Appearance modification by nano-patterning

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[2] NAPA Technologies, 382 rue Louis Rustin – Archamps Technopole, F-74160 Archamps

Living organisms have developed many strategies to produce colors and to modify appearance. Even if the use of pigments is widely spread, the effects produced by micro/nano patterning allow a larger range of possibilities. Indeed, the structuration of materials on multiple levels combined with intrinsic material properties offer a wide range of visual effects such as: metallic effect (possible without metal layer), gonio-chromatic appearance, glossy or mat surfaces (which can lead to efficient contrast effects), or super water repealing surfaces (which can punctually and locally change the surface appearance). In this way, surface patterning can generate aesthetic mimicking the beetles which often show gold or metallic green chitin shell due to 3D photonic crystal structures. However, they can also lead to wider optical effects to mimic moth eyes, which are super effective at capturing light at night thanks to nano-cones preventing the reflection of light.

These effects are very attractive since they rely only on physical and topographical properties, bringing possibilities to create colors and optical effects without chemical modification or add-on. While, the patterning process is a bottom up approach for living creatures, it can easily be replicated using top down microelectronics production technologies. However, a key challenge is the scale of the patterning areas (from cm² up to m²) and flat surfaces.

We report here the use of such micro-nano patterns in order to change the visual aspect of common material over large surfaces. SILSEF and NAPA have developed together a range of processes to functionalize surfaces for hydrophobicity, diffraction or antireflection. These technologies can be used on areas from mm² to m² on flat and hemispheric surfaces. Combined with effective characterization process developed internally, we aim to bring micro nano patterning to a range of industrial applications from fashion textile to windows glass. We show here functional patterning for decoration using diffractive or diffusive optics or water repellent surfaces as depicted on Figure 1.

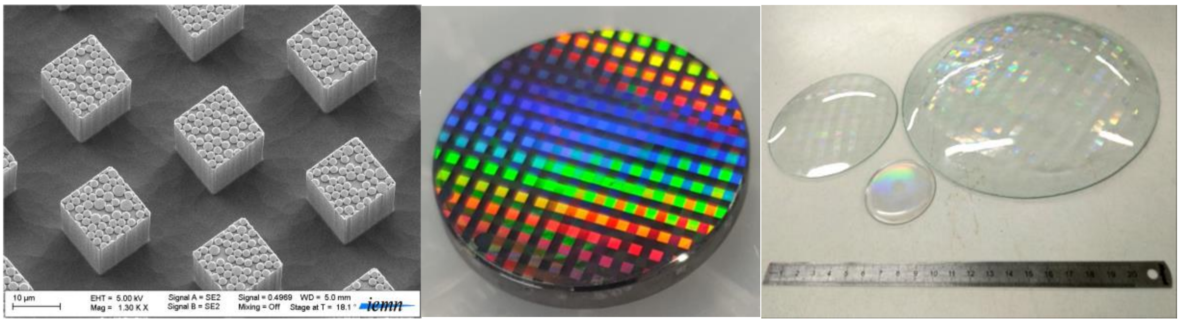

Figure 1. Double scale Micro-nano patterns (left), patterned glass on flat surface (middle) and on hemispheric surfaces (right).

Keywords

Micro patterning, Surface structuration, Nanoimprint, Surface functionalization, Biomimetics.

The Art and Science of Foundation Makeup

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[1]*Estee Lauder Companies*

For over 10 years, Estee Lauder has built a comprehensive understanding of human skin color by relating scientific measurements of skin color to that of our products. Every person's skin color is unique and has measurable L*a*b* values in color space. The same is true of all foundation shades. The objective is to understand the nuance of skin undertones (a* and b*), overtones (contrast), and intensity (L*); then explore how these not only link to the science of colorimetry, but also to the art of shade matching and foundation selection.

To better understand skin color across the globe, Estee Lauder initiated a long-term study that visited over 20 cities in Asia, Europe, South America, North America, and Africa; met with and collected skin color measurements from more than 7000 women (Asian, Black, Caucasian, Hispanic, Indian, and Middle Eastern), which resulted in the recording over 100 self-identified unique ethnicities. The color values (L*a*b*) were measured using a spectrophotometer on multiple facial areas and the data was used to create a unique database of skin tones.

Human skin color is one part of the equation, the second part is understanding the translation of the product's L*a*b* values to the appropriate skin color. We also determined the stretch of each shade/formula to understand the limits of a natural shade match. Understanding the relationship between skin and products from both a natural match and a preference selection allows us to determine where opportunities are for new shades to be created as well as evaluating existing shades.

With the understanding of shades and their natural placement in skin color space, there remains the difference between natural shade match and preference. Using facial recognition and virtual technology we can understand the directionality and magnitude of preference shades across the globe allowing product placement to be determined not only by the match, but by one's preference as well.

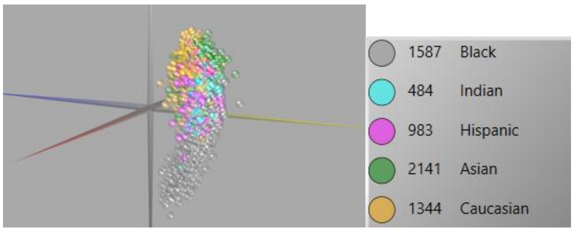

Figure 1 : Sample of Skin Tones Plotted in L*a*b* Color Space by Ethnicity

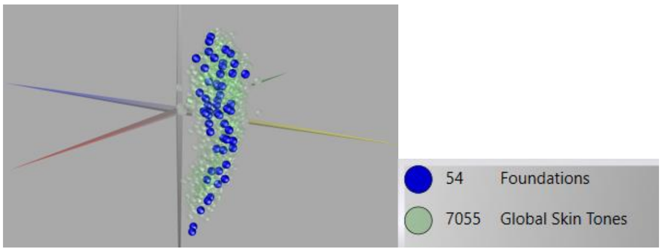

Figure 2: Overlay of Foundation Makeup Shades with Global Skin Tones

Keywords

Foundation, Match, Preference, Skin, Color

The boundary integral formalism for the scattering of light from rough multilayers on the 0.4-1μm band

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Optical coatings are a cornerstone technology with ever increasing design complexity and industrial applications. High quality thin film multilayers can today be deposited on superpolished substrates (roughness rms lower than 1nm), with an ultimate performance connected with scattering losses around a few ppm. The first-order Small Perturbation Method [1] is a perfect tool for slightly rough multilayers scattering modelization. It can cope with hundreds of layers, and is directly invertible. However, there are interesting cases [2] where higher order models provide supplementary insight. Very few methods [3] apply to the resonant domain where roughness parameters are comparable to the wavelength. However, designing challenges [3] also appear in this domain.

We present a boundary integral formalism for the electromagnetic wave scattering from rough multilayers [2]. The boundary integral system is well fitted for both smooth and rough surfaces. As a numerical solution of the rigorous scattering problem, this approach is numerically demanding. As a consequence, the theory is implemented with the Method of Moments for two-dimensional scattering. The rough multilayer is illuminated with a tapered wave, under S- or P-polarization.

Our approach is tested on several multilayers composed of quarter-wave plates at central wavelength 633nm. With air as a superstrate and glass as a substrate, two optical indices are used: 1.3 for low index and 2.3 for high index. Roughness is Gaussian correlated with length 300nm and normally distributed. The wavelength band from 400nm to 1μm is investigated. A six-interfaces dielectric mirror example is given in Figure 1.

Results find applications in remote sensing, cosmetics, stationary and textiles, imaging in complex media…

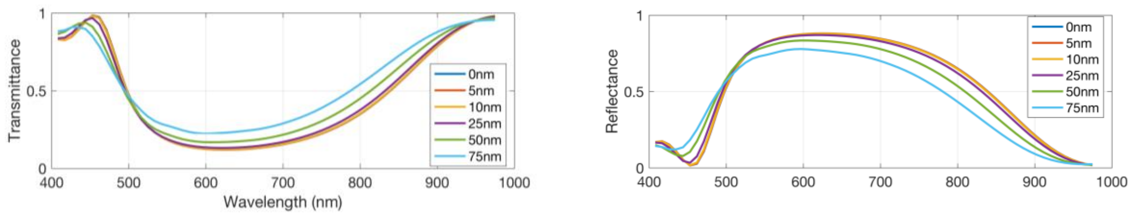

Figure 1. Numerical simulation for the spectral reflectance and transmittance of a rough dielectric mirror for a P-polarized illumination at 15° incidence. Design is HLHLH with height RMS varying from 0nm to 75nm. H and L designate high and low-index films that are quarter-wave at 633nm. Interfaces are perfectly cross-correlated.

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Keywords

Wave scattering, thin films, optical coating, rough surfaces, boundary integral formalism, numerical simulations.

Metal-dielectric thin-films for the control of color: application to art and design

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Color and its different associated parameters (contrast, hue, brightness…) are very important criteria to take into account in the development of art and design objects. Indeed, color will highly influence the appearance of an object and the feeling of the people who are observing it. While most of the colors rely on simple paintings with pigments, it is possible to achieve a wide range of new colors and effects by using thin-film structures. They are obtained by depositing very thin layers of dielectric materials and metals on different surfaces. By precisely controlling the thickness of each layer with nanometer precision, it then possible to produce bright colors that are angularly dependent. Such technology is now used in car paintings in order to produce artificial pigments or in banknotes in order to produce security features that cannot easily be easily counterfeited. Using todays simulating software, it is possible to calculate the structure that will allow producing a given color range and to fabricate. We illustrate in Figure 1 an example of various objects that have been fabricated by deposition of thin-film structures on different types of surfaces (wood, glass, metal…). In this paper, we will present into more details the approach that was implemented in order to produce these objects.

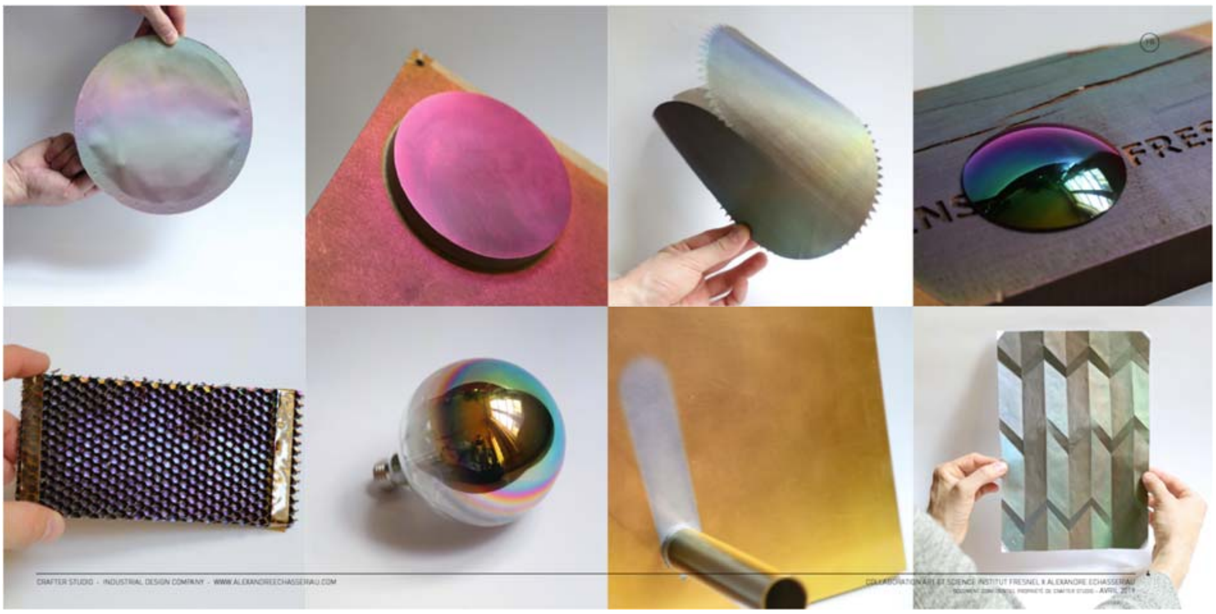

Figure 1. Example of design objects obtained after deposition of thin film structures.

Keywords

Thin-film structures, art and design, color.

HDR versus hyperspectral images for applied colour and lighting research

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For a long time, images have been employed in the architectural process to judge the aesthetic qualities of designed spaces, and to communicate with clients. They are now also increasingly used by colour and lighting researchers for investigating people's perception of lighting environments and daylit spaces. Among their advantages, we can cite the control of experimental conditions and of investigated parameters, and also the reduction of cost in comparison to real space, mock-up or reduced-scale model. Previous works have shown that, to some extent, both photographs and computer generated-pictures have the potential to predict how the not yet built environment will be experienced. As long as perceptual attributes induced by the displayed pictures are faithful to reality, and the physical world is accurately captured by the camera or rendered by the software, images can be used as visual stimuli in a psychophysical approach. Nevertheless, each step in the production of pictures – from scene creation to image visualisation – can lead to inaccuracies. The present study proposes to assess the colorimetric accuracy of three types of images:

- HDR photographs

  The main advantage of such images is that they can be produced with a simple digital camera. For more than ten years, high dynamic range (HDR) photography has increasingly been used as a luminance data acquisition tool by lighting researchers investigating quality of lighting and visual comfort. A deviation of luminance of less than 10% with peak values reaching up to 20% or sometimes higher can be expected from HDR photography. Few data are available in the literature regarding colour accuracy.

- Hyperspectral photographs

  Hyperspectral camera manufacturers claim to produce high definition images while capturing for each spatial pixel spectral information with an optical resolution equivalent to spot spectroradiometers. Such a technology is interesting for lighting and colour research in architecture because from the acquired radiances, spectral reflectances can be calculated. The initial scene can then be simulated under different real or virtual illuminants/glazing.

- Hyperspectral images computationally rendered

  In addition to the aforementioned advantages of hyperspectral imaging, simulation makes it possible to investigate not yet built spaces without requiring a real reference scene. Cost are thus further reduced and experimental conditions or investigated parameters can be better controlled. However, most software are complex and sometimes difficult to use. The current lack of material properties database can still lead to discrepancies between real and rendered materials.

In the present study, photometric and colorimetric accuracy is quantified on a Macbeth chart lit by sources with various CCTs. The reference is spot measurement with a spectroradiometer. Colour differences are calculated in CIELAB. Image sharpness is also analysed.

Keywords

Photometric and colorimetric accuracy, images, HDR, hyperspectral, sharpness

Accurate metrology of scattered light

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An accurate metrology of scattered light is a key point for the quantification of visual effects. The CONCEPT Group of the Institut Fresnel has been working for several decades on the metrology and modelization of light scattered by optical components and disordered media. In this context, they developed several instrumental tools dedicated to the accurate metrology of BSDF (Bidirectionnal Scattering Distribution Function) with different specificities. All these instruments are now gathered in the DIFFUSIF platform [1], a metrological platform of Aix-Marseille University dedicated to light scattering metrology.

In terms of metrology, the key instruments if DIFFUSIF are a Spectral and Angular Light Scattering characterization Apparatus (SALSA) and a spatially resolved scatterometer (OSA – Optical Surface analyzer).

SALSA today allows the measurement of BSDF patterns in reflection and transmission in the whole visible range (400 nm-1100 nm) with a spectral resolution of 0.1 nm and an angular resolution which can reach 0.05°. The detectivity of the set-up is about 10^{-8} str^{-1}, the air diffraction level and the accuracy of measurement is better than 1% for any point of acquisition [2,3].

The Optical Surface Analyzer allows the spatially resolved measurement of the BRDF of a 20x20 mm^2 surface. This set-up is based on the application of the memory effect and the use of telecentric optics. It allows the measurement of about one million BRDF patterns recorded simultaneously and independently. Each of them results in the acquisition of the scattering parameters of a 26x26 μm^2 elementary area of the sample surface. [4-6]

In the case of perturbative media, the scattered electromagnetic fields can be modelized taking into account the illuminations conditions, the inhomogeneity of the material and also the deposition of optical coatings up to several hundreds of layers with excellent agreement with metrology.[7-9]

In this poster, we will present a selection of numerical and instrumental tools available in DIFFUSIF platform which can be relevant for the quantification of visual effects.

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Keywords

Light scattering, metrology & modeling.

High Dynamic Range Reflectance Transformation Imaging: An Adaptive Multi-Light Approach for Visual Surface Quality Assessment

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Keywords: RTI imaging, HDR imaging, Visual appearance, Quality inspection

Reflectance Transformation Imaging (RTI) is an imaging approach that is increasingly used for visual inspection of surfaces. A limitation of this method is related to the reduced dynamics (Low Dynamic Range) of the sensor when measuring the light response of the inspected surface, which therefore generates a large number of saturated areas when the surfaces are non-Lambertian. The reconstruction of the appearance of the surface is then dependent on the non-robust choice of the exposure time used during the acquisition. Thus, we propose an innovative implementation based on the RTI technique by augmented it with an acquisition and a processing in high dynamics (HDR), adapted and adaptive based on the response curve of the camera.

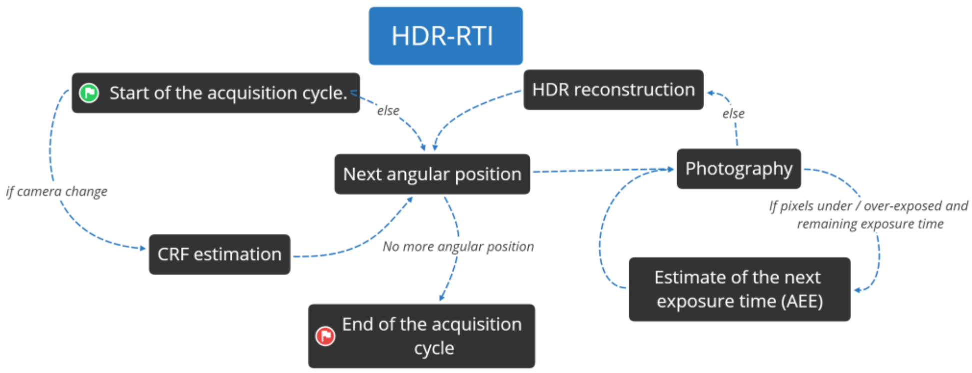

Figure 1. Pipeline of an HDR-RTI acquisition.

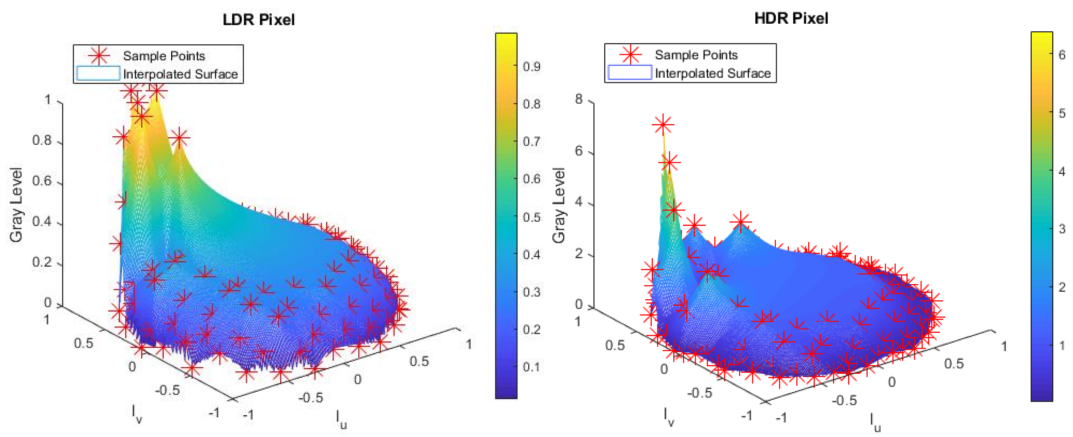

Figure 2. Representations of the behavior of a point of the surface during an acquisition LDR-RTI (on the left) and HDR-RTI (to the right).