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Effects of Surface Anisotropy on Perception of Car Body Attractiveness

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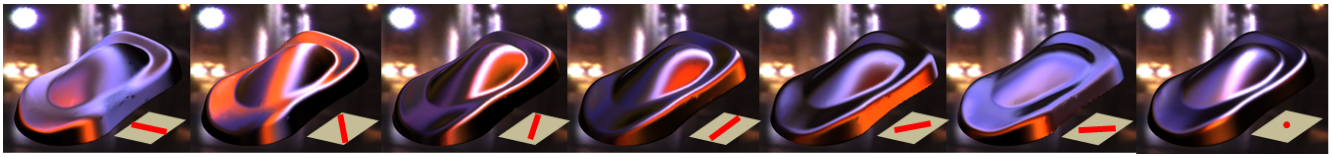

Figure 1: *Material appearance as a function of anisotropy axis alignment shown schematically in the inset image.*

Abstract

In the automotive industry effect coatings are used to introduce customized product design, visually communicating the unique impression of a car. Industrial effect coatings systems achieve primarily a globally isotropic appearance, i.e., surface appearance that does not change when material rotates around its normal. To the contrary, anisotropic appearance exhibits variable behavior due to oriented structural elements. This paper studies to what extent anisotropic appearance improves a visual impression of a car body beyond a standard isotropic one. We ran several psychophysical studies identifying the proper alignment of an anisotropic axis over a car body, showing that regardless of the illumination conditions, subjects always preferred an anisotropy axis orthogonal to car body orientation. The majority of subjects also found the anisotropic appearance more visually appealing than the isotropic one.

1. Introduction

Various industries are continue to strive to create cutting edge, unique visual properties so as to achieve a value-added and customized product design. This allows for the creation of visual and functional properties of a product, thus positioned so that it stands out from the masses and leaves a unique perceptual impression. In automotive design color selection is a crucial factor defining the future success of a particular model. Apart from the rest of production process running from engineered blue-prints, the body shape and color design are main stages involving demanding and costly iterative design cycles of an experienced designer. The goal of this process is to achieve visual harmony between the body shape and its color. Nowadays, a majority of automotive coatings use effect pigments, which are in fact flakes of variable size and orientation distributions, where special effects are achieved by light interaction within layers containing these flakes. Designers choose different base coating colors, flakes distribution sizes, layer thickness, or a pigment deposition process to control the final appearance of the car body. While current industrial coating application procedures can relatively well control and predict the inclination of flakes within the coating layer, they cannot orient them in a particular azimuthal direction. Due to this random azimuthal distribution of flakes designers can achieve, at a macroscopic level the same appearance regardless of the rotation of the material (or simultaneous rotation of light and camera over the material). Due to this fact the coating industry uses only an in-plane geometry in arbitrary direction for data collection for quality control. We call this constant azimuthal behavior isotropic.

In contrast, a majority of real world materials; including individual coating flakes, have variable appearance when rotated along their normal. For instance fabric materials contain threads of fibers in combination with weaving patterns, wood or hair contain fibers, polished metals have unidirectional scratches. All these microscopic structural elements interact with incoming light depending on its direction. We call such behavior anisotropic. Fig. 2 compares an isotropic appearance (left) to the anisotropic one for variable orientation of structure elements. We observe that while for isotropic

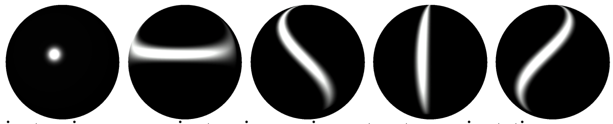

Figure 2: *Isotropic (left) and anisotropic appearances.*

appearance, a main visual feature is specular highlight whose location depends purely on the mutual position of light and camera, for anisotropic appearance, the shape and location of highlight is dependent on the azimuthal orientation of structural elements over the material's structure. We call the orientation orthogonal to anisotropic highlight peak as an *anisotropic axis alignment*. This

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parameter has a significant impact in material appearance and thus on product design, as appropriate alignment of anisotropic highlights over a product's surface can accent its visual appearance. Anisotropic materials vastly expand visual variability of isotropic appearance, due to the variable location of an anisotropic highlight. On the other hand, as the anisotropic highlight changes position for different directions of lights representing the illumination environment, the purely anisotropic material without specular coating layer looks more attractive for scenes with several major illuminants than for diffuse-like ones [Fil15]. Although anisotropic behavior is present to some extent in a majority of natural materials, its application to man-made ones is limited by material type and its production process.

In this paper, we ran a series of psychophysical experiments obtaining human judgments of the visual anisotropy.

Main contribution of our work are psychophysical studies: (1) identifying approximately the most attractive car shape pose, (2) assessing a visual importance of anisotropy axis alignment in car shape design, (3) comparing isotropic with optimized anisotropic appearance.

2. Related Work

Past research studied psychophysical aspects of visual anisotropy [HHE08], [OVW11] and created statistical models describing the relationship between perceived and computational textural anisotropy [Koe84], [OVW11]. The prediction of anisotropic highlights locations has already been studied [LKK00] and recently further extended to arbitrary geometry with interactive tangents editing [RGB*14]. A simplified method of anisotropic highlight detection for the purpose of anisotropic materials adaptive measurement was shown in [FV15] and analysis of human sensitivity to visual anisotropy in renderings in [Fil15].

Ferwerda et al. [FWSP04] analyzed to what extent virtual reality rendering methods can be used for discriminating differences in car body shapes under different viewpoints. Shimizu et al. [SM15] suggested a computer aided system for designing the color appearance of metallic automotive coatings. The final design is specified in terms of industrial measurement standards for metallic color appearance, and paint formulations are determined by employing an automotive refinish system.

One of the first applications allowing users to create anisotropic effects by controlled orientation of metallic pigments using magnetic field was cosmetics for nail polishing. However, due to fast drying of the solvent between the flakes the manipulation time was rather limited. In contrast, Pereira et al. [PLMR17] suggested fabrication of printing a custom based anisotropic BRDFs by using time-varying magnetic field and photo-cured resin.

In this paper we are analyzing the impact of anisotropy axis alignment over the object surface on visual perception of its attractiveness and we are not aware of any such study to date.

3. Material appearance and illumination models

Textureless materials are commonly represented using a Bidirectional Reflectance Distribution Function (BRDF) introduced by Nicodemus et al. [NRH*77]. Material appearance within this paper was represented by an anisotropic BRDF model [FHV15] based on anisotropic stencils allowing an intuitive control of main features of anisotropic highlights. Within this work the BRDF model is used to represent both isotropic and anisotropic appearance as shown in Fig. 2. To reflect natural color of environment, we set the model parameters to produce achromatic high contrast between highlights and other regions. Fig. 2 compares an isotropic appearance (left) to the anisotropic one for variable orientation of structural elements. For object illumination, we used a point-light and seven illumination environment from the Light Probe Image Gallery [DRWP06] shown in Fig 3. Each environment map is represented by 128 directional lights using the median cut algorithm. We analyzed properties of all lights representing the environments. First, we approximated their mean chromaticity by computing mean difference between RGB colors and corresponding gray-scale value (see Fig. 4-a). Then, the uniformity of light distribution over the environment was approximated by computing for each light a geodetic distance to the closest light. Then the nonuniformity is proportional to variance of such distance values across all lights. Results of our analysis are shown in Fig. 4-b. One can observe that the highest chromaticity is present for *grace* and *kitchen* environments, the highest directional nonuniformity was obtained for *galieo*, *grace* and *kitchen* environments. In representing a car body, we used a demo car-like shape common in the coating industry for assessing effect coatings. The shape 3D geometry was acquired by a laser scanner, and we used an OpenGL rendering to obtain stimuli images with the BRDF model on the geometry (see Fig. 6).

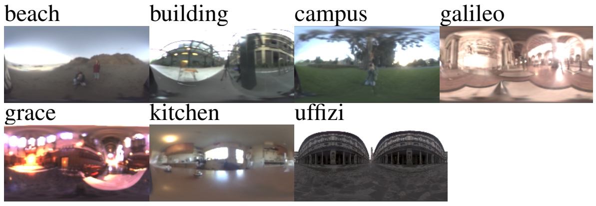

Figure 3: *Environment illuminations used in our experiments.*

4. Car body orientation estimation

As a first step in our work, we ran a psychophysical study to identify the most visually attractive orientation of a car body owing to the viewer. Such orientation is further used for an analysis of anisotropy orientation. We preselected five different orientations of our 3D model between frontal and lateral ones as shown in Fig. 6 for isotropic BRDF. We ran two experiments: in a controlled environment (C) and uncontrolled web-based study (U). To adjust visual scales in both experiments, subjects were shown an image containing all variants of car shape rendered for different orientation and anisotropy axis alignments. The individual images were shown to them one by one and their task was to rank their visual attractiveness on a scale 1-5, where 1 was the best and 5, the worst. In total 21 subjects participated in the controlled experiment. There was consistent office lighting and stimuli were shown on a calibrated 24" screen. Subjects observed a screen from the distance of 0.6m and stimuli subtended visual angle 25°. In the uncontrolled web-based experiment 85 subjects participated. They were advised to run the experiment with dim office illumination and stimuli shown in full screen mode. One session in both experiments took approximately 2.5 minutes. From the subjects responses, we obtained mean opinion scores and standard errors as shown in Fig. 5. The controlled

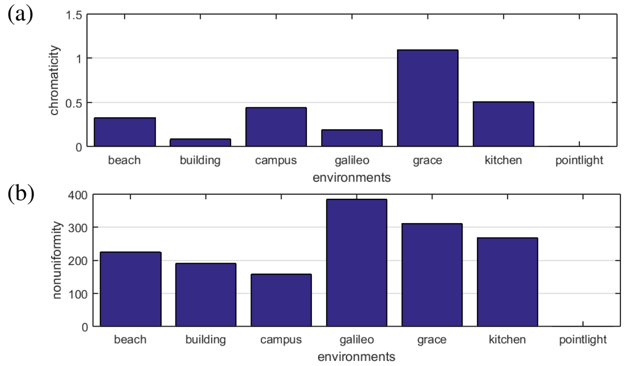

Figure 4: *Chromaticity and nonuniformity of light distribution of the tested environments.*

experiment was performed in an*kitchen* illumination environment (red outlines), while a web-based one was performed in *kitchen* and *uffizi* environments (blue and green outlines). There were two types of data for each test – the full outline represents an average across anisotropic appearance for a different orientation of main axis of anisotropy, while the dashed outline is for isotropic appearance. In general we observe a decrease in value between the frontal

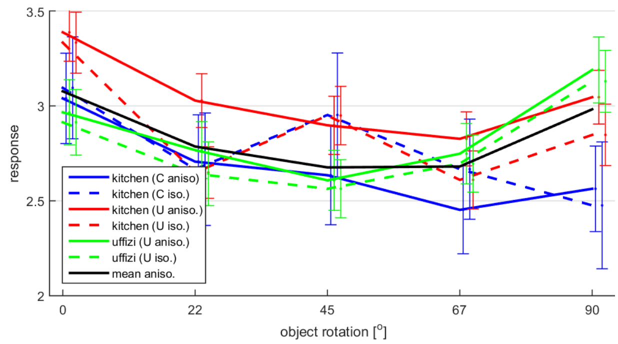

Figure 5: *Result of object attractiveness assessment for different orientations.*

and lateral object orientation. Interestingly, there are two minima for isotropic appearance in the *kitchen* environment (recorded for both controlled and uncontrolled experiments). This minima might be due two different lights of different color (windows and ceiling), producing multicolored appearance behavior (see e.g., Fig.6). A statistical analysis using Kruskal-Wallis test (see supplementary material) revealed higher statistical significance for results of anisotropic appearance than isotropic one. Therefore, in searching for the best object orientation, we focus on anisotropic appearance only. The average of full outlines obtained for anisotropic appearances is shown in black outline. Here we received similar minimal values for orientations 45° and 67° and we decided to use a car shape orientation of 45° for further experiments. All stimuli images with color-coded mean opinion scores of visual attractiveness for both controlled and uncontrolled experiments and both tested environments are shown in a supplementary material.

5. Anisotropy orientation analysis

Next, we analyzed subjects' judgement of a fixed car body appearance as a function of orientation of an anisotropy axis over a car body. Again we restricted the tested orientations to five variants (orientation step 30°), where 0° represented axis alignment with frontal and 90° with lateral side of the car body (see Fig. 1). In the first step, we rendered these five orientations (0°, 30°, 60°, 90°, 120°, 150°) in six illumination environments and a pointlight as shown in Fig. 6.

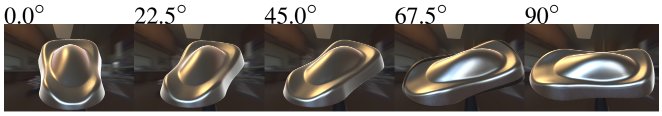

Figure 6: *Car shape 3D model orientations tested in the experiment (isotropic BRDF).*

We performed a web-based study in the same manner as in the previous experiment, i.e., subjects were asked to assess the attractiveness of shape in each image on a scale 1-5, where 1 is the best and 5 is the worst. In total 61 subjects participated in the controlled experiment. Mean opinion scores showing typical subject's response as a function of anisotropy axis alignment are shown in Fig. 7-a, where errorbars depict standard errors. Here one can observe higher attractiveness (i.e., lower values) for anisotropy alignments close to the 90°. This effect was even more pronounced for illumination environments having strong spatially nonuniform behavior, i.e., represented by several main illuminating directions (*galileo, grace*) Statistical testing using the Kruskal-Wallis test suggests a high significance of data differences.

As results for static images are impacted by actual lighting conditions, i.e., the selected azimuthal orientation of the object in the scene, we replicated the experiment in a dynamic settings. We used the same environments as in the static scenes experiment plus *pointlight* illumination. Illumination rotated around the fixed object in a loop. The study was again web-based with 90 screened subjects. For each environment illumination they were shown all anisotropy alignments in one movie and were asked to adjust attractiveness of each of them using an interface with sliders. The order of anisotropy alignments in the stimuli videos was random and there was no time restriction for responses. Mean duration time of a video stimuli with animation of one environment was 70 seconds. The obtained mean opinion scores are shown in Fig. 7-b. When we compare these results with the results for static stimuli (left), we can see the same increase of perceived attractiveness for anisotropy alignment near 90°. However, in contrast to static stimuli, we observed similar behavior regardless of the illumination environment.

In the final validation experiment, we compared visual perception of isotropic appearance with the best anisotropic alignment found in all illumination environments (i.e., 90°). Again, we used a dynamic stimuli where illumination rotated around a fixed object. Each stimuli contained two sequences, with isotropic and anisotropic appearance in random order. A total of 110 subjects participated in a web-based study evaluating appearance attractiveness of both appearance variants and selecting the one that looks more attractive. Normalized mean opinion scores for individual environments are shown in a form of bar graph in Fig. 8 with errorbars showing standard errors. The anisotropic appearance was judged as more visually attractive for a majority of illumination environments except for *grace* and *kitchen*. Based on the results and environments properties analysis in Section 3 we hypothesize that

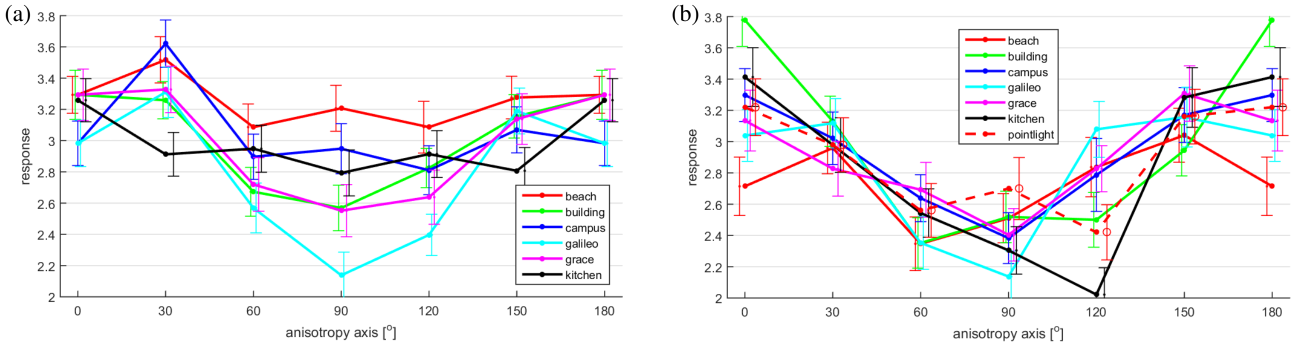

Figure 7: *Perception of car-body attractiveness as a function of anisotropy axis alignment for (a) static stimuli and (b) dynamic stimuli.*

the isotropic appearance was more appreciated for colorful lighting environments having a higher non-uniformity of lights distribution. (i.e., a higher contrast between dark and bright regions) e.g. *galileo*, *grace* and *kitchen*. In such conditions the isotropic appearance can be viewed as visually interesting with smooth transitions, while an anisotropic appearance might be too unusual and thus disruptive for observes (see the videos in a supplementary material).

6. Discussion

To our knowledge, this is one of the first exploratory studies of visual effects of anisotropic material appearance on a car body. Although one can rely on intuitive concept of the anisotropic axis alignment with object contours to be accented, it has to be noted that perception of an anisotropic appearance is strongly linked to a shape of the object and the anisotropy axis alignment is related to shape's tangential mapping; therefore, our conclusions are strictly related to a car-like shape. Second, the anisotropic BRDF used in our experiments was of extreme contrast between highlighted and remaining areas, which is unlikely in natural scenarios. Therefore, in follow up studies we are going to explore for what ranges of intensities and material types is the alignment of anisotropic appearance visually important.

7. Conclusions

We studied visual attractiveness of anisotropic appearance (represented using BRDF model) as a function of anisotropic elements orientation over the car body shape. Four psychophysical studies were performed using both static and dynamic stimuli and seven illumination scenarios. We conclude that subjects preferred anisotropy axis orientation aligned with lateral axis of the car body. As for car body orientation, subjects preferred orientations between frontal and lateral. Finally, when subjects compared baseline isotropic and an optimized anisotropic appearance, they preferred the anisotropic appearance for a majority of illumination environments with exception of highly colorful and directionally non-uniform ones. These results demonstrate that anisotropic materials represent an abundant source of attractive appearance variations to be explored and applied in product design.

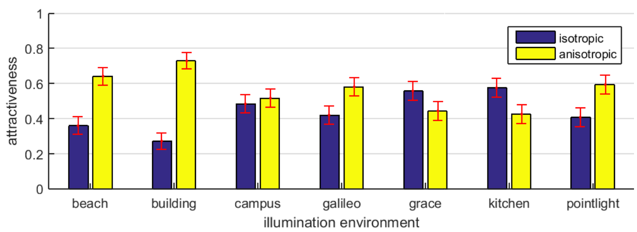

Figure 8: *A comparison of visual attractiveness of isotropic and anisotropic car body appearance.*

Acknowledgments

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