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Appearance Control for Human Material Perception Manipulation

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Abstract

We describe a new concept of human visual perception manipulation using illumination projection. The idea is to alternate material appearance of an object using projector camera feedback and a manipulation technique of an image-based material appearance. Unlike the simple display technique, our approach can manipulate human material perception for any object using the appearance control technique in real time without scene modeling. The experimental results show the ability of manipulating both human translucent perception and gloss perception.

1. Introduction

The human visual perception of materials from objects is influenced by their appearance. Moreover, the appearance is decided by not only the object's own reflection characteristics but also its environmental illumination, and it can be controlled by precisely designed illumination.

In the pioneering studies of appearance control, the radiometric compensation of the projection for the non-uniform screen [12] and the changes in the appearance of the textured object so as to look similar to another object were shown by projection [7]. In a later study, Fujii et al. [6] applied this radiometric compensation technique in a dynamic scene with a co-axial device configuration. The radiometric compensation was also implemented with smart calibration [4], and it was also attempted from the viewpoint of human perception [3].

Unlike the radiometric compensation, the appearance control techniques can enhance, change, and replace the visible appearance according to the original appearance. The superimposed dynamic range technique allowed us a high dynamic range (HDR) display and color compensation on the printed media by the illumination projection [5]. The feedback framework of the projector camera enabled not only color saturation enhancement and contrast boosting but also color phase shift, posterization, and edge enhancement using dynamic process [2].

In this study, we attempt to implement image processing based on the knowledge of the human material perception and show that using the projector camera system, image processing can manipulate human material perception.

2. Related Works

In related works, we discuss a display technique by projecting material appearance display on a 3D surface. Raskar et al. proposed the Shader Lamp that can represent virtual texture and animate shading on the physical model of Taj Mahal [14]. Mukaigawa et al. applied the Bidirectional Reflectance Distribution Function (BRDF) for improving the projection quality [11]. Employing BRDF for the optical property model enabled high quality material representation. In addition, another approach of high quality display technique with accurate modeling was proposed [13]. A combined structure of light projection that employed photometric stereo and surface normal smoothing obtained a highly accurate 3D model.

In all the abovementioned studies, a white and Lambert reflection surface object has been used for the target. However, Aliga et al. applied an overlay projection on a degenerated ancient base for virtual restoration [1], and their group later proposed an appearance editing system [8].

Shimazu et al. employed a textured object, which was made by a 3D printer or Rapid Prototyping for a 3D HDR display system [15]. The overlaid projection on the textured object boosts its contrast and shows an HDR appearance on the object by precisely calculated projection. These techniques are remarkable because of

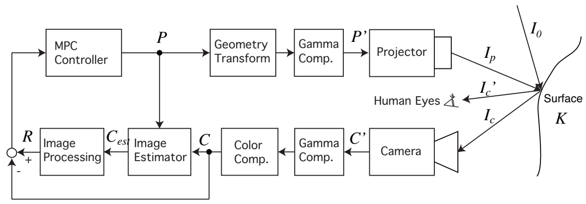


Figure 1. Appearance Control with MPC

the appearance alternation capability of a textured real-world object. However, a successive projection has not yet been considered.

Unlike the above display technique, we aim to obtain a successive material appearance manipulation of the object in the real world without physical modeling. This successive manipulation is important for many augmented reality applications such as visual simulation, display, and intelligent lighting techniques. Its application field is not limited to entertainment and it includes a psychological experiment, scientific simulation, design tool, human vision support, etc. In our solution, the appearance control technique is employed for dynamic reflection estimation, and image-based material appearance manipulation is used.

3. Material Perception Manipulation

We employed the projector camera feedback that was proposed in [2]. This framework enables a desired appearance manipulation with model prediction control by the illumination projection. The abovementioned two algorithms are implemented as the image processing that converts C_{est} to R in the appearance control framework shown by figure 1.

3.1 Translucent Perception

Recently, studies about human material perception have attracted attention. Motoyoshi studied the human discrimination capability of translucent materials and showed the idea that the contrast and sharpness of the non-specular image component have a strong impact on the judgment of translucency [9]. His study showed an image reconstruction that used an inverse tone mapping of the low spatial frequency component that can make the appearance of the opaque object look transparent. Our study inherits this idea, and we implemented a translucent control, as shown by figure 2. Then, C_{est} is processed by this algorithm and its output yields a reference image R of figure 1.

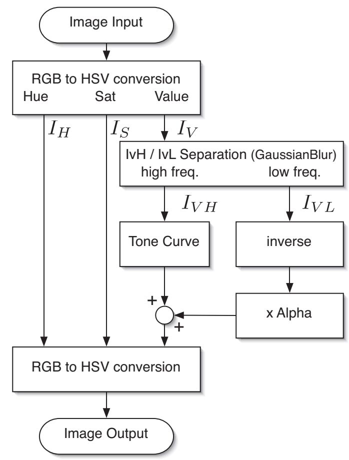


Figure 2. Transparentize Flow

3.2 Gloss Perception

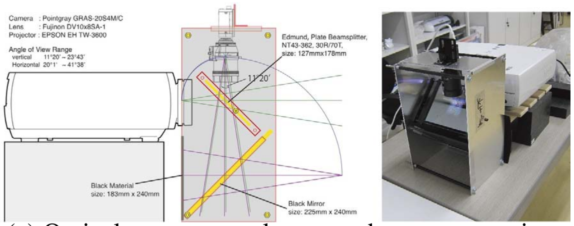
Motoyoshi et al. have shown that the skewness of both the luminance histogram and the sub-band filter output are correlated with a glossy surface and inversely correlated with diffuse reflectance [10]. We also implement this idea as another material perception manipulation. After the HSV separation, we applied the following process, as shown in figure 2.

First, we apply histogram equalization to I_V. Then, we apply a tone curve to obtain a manipulated image histogram having a negative slope. Lastly, we apply Gaussian blur operation for noise reduction. This processing output is merged with other components and is converted to an RGB color image.

4. Experimental Results

4.1 Projector Camera System

Figure 3(a) shows our system configuration. In our system, a 1600×1200 resolution IEEE1394 camera and a 1920×1080 resolution projector were used. The system has a beam splitter to optically place both entrance pupils in the same place, and it separates outgoing and incoming rays. Its co-placed entrance pupils optics ensure an invariant pixel map and enable the projector camera feedback on the arbitrary shape object without any individualized calibration. The major concern for this optical layout is that the direct coming scattered projection light forms an artificial image that later causes an image quality drop. As a solution, our system employed a light absorbing blackout material with a black mirror reflection.



(a) Optical components layout and system overview

(b) Target Scene (c) Projection (d) Manipulated

Figure 3. Projector Camera System

(a) Color Removal (b) Phase Shift+ (c) Phase Shift-

(d) Brightness EQ (e) Contrast Boost (f) Optical Hiding

Figure 4. Various Appearance Control

Because the entrance pupils are co-aligned, we obtained a projection pattern (c) with the same aspect as (b). With the overlay projection using this pattern, we can enhance the scene color saturation, as shown by (d). Other appearance control results shown in figure 4 were obtained with the image processing algorithms of (a) grayscale conversion, (b-c) color-phase rotation, (d) brightness equalization, (e) gamma function operation, and (f) paint over with solid gray color image.

The appearance control framework gets an appearance under white light illumination. Hence, it allows us an easy and successive application of conventional image processing in the real world.

4.2 Translucent Perception Manipulation

The "Translucency" in figure 5 shows the manipulation results of several types of objects including crazy dolls, vases, a fabric flower, a soft toy, and a plastic model. In this experiment, we used the algorithm shown in 3.1. For the I_{VH} and I_{VL} separation, we used Gaussian Blur with $sigma = 10$ pixel and the tone curve function

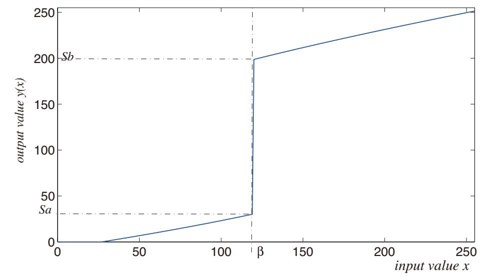


Figure 6. Tonemap Function

$$y(x) = \begin{cases} x, & x \leq 0 \\ k(x/k)^g, & otherwise \end{cases} \quad (1)$$

with the parameters $k = 255/2$ (because we employed an 8-bit image format $I_{VH} \in [0, 255]$), $g = 2.0$, and $\alpha = 0.6$. A processing speed of 4 fps was attained using a Linux PC (Core2Quad at 2.66 GHz with OpenMP).

Different from figure 4d, the contour parts became bright and its optical feature cannot be explained without light emission from our physical experience. Thus, we can suppose that these objects have subsurface scattering because they are transparent objects. However, because of scene spatial frequency, its algorithm was not effective for fabrics, flowers, and soft toys. In addition, because of the shading gradient, we could not get translucency from a necktie.

4.3 Gloss Perception Manipulation

The "Glossiness" in figure 5 shows the gloss perception manipulation results. Its behavior is similar to a contrast boost that was shown in figure 4e. However, we can see the narrow directional reflection on these targets and it reminds us of strong gloss reflections such as metallic surfaces (see bear, cat, necktie, and plastic in the figure).

Figure 6 shows our tone curve for this gloss perception manipulation. Unlike a naive power function, the tone curve has a discontinuity to switch its response depending on whether the area in the scene is considered to be specular. Its threshold and gap are defined by the user parameter $x = \beta$, s_a, and s_b. The s_a and s_b are decided by the contrast of our desired control result. In general, we cannot decide β uniquely because of scene illumination change; however, we have applied histogram equalization before tone mapping. Thus, we can easily decide these parameters using an area ratio of the specular region in relation to the entire scene.

Figure 5. Perception Manipulation

5. Conclusion

We proposed a new concept of human material perception manipulation using projector camera feedback. Although it is our subjective view, the experimental results showed its potential for manipulation of translucent and glossy surfaces. Further evaluation and quality improvement through a users' study will be done in our future work. We believe that this innovative concept is not only important for a new display technique but also supports human vision in many applications.

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