Real reproducing of 3D appearance with multi-projectors and cameras

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Abstract

Rapid proto-typing of product is important technology that the computer science can contribute. Especially, the evaluation of realistic appearance decides the quality of the product in a final process. As the industrial design application, we have been developing the Appearance-based Display System by using the radiance control of projector and technique of mixed-reality. In this paper, we proposed a novel reproduction system of three-dimensional appearance with glossiness, which is controlled by two or more projection images. R. Raskar et al. proposed 2-pass rendering method to consider the 3D geometry. However, view-dependent shading, such as specular highlights is not considered in this method. Because the shading view is assumed to be the same as rendering view or user's viewpoint, the view-dependent shading could not ensure consistency. Therefore, in this paper, we divide 3D geometry into object shape, virtual light direction (shading direction), user's viewpoint (view-dependent rendering view) and projector position(view-independent rendering view). 3D geometry of the viewpoint and the object can be calibrated by the space encoding method with projector-camera system. According to the geometry calibration, the partial responsibility and compensation of the intensities errors such as occlusions, overlaps and attenuation for each projection is automatically decided. As the result, this system can generate the real appearance of gloss, color and shade on the mock object's surface.

Introduction

Accurate reproduction of real objects is an important technique that has been researched in the field of a digital imaging and the computer graphics. Recently, this reproduction has achieved the remarkable progress that is improved by using BRDF (Bi-Reflectance Distribution Function) and ray tracing technique. As a similar approach with this description of appearance, several researchers have investigated the possibility of using projectors for mixed-reality reproduction [1, 2] . Such projector display systems can project images onto any object, and the image can be recognized as a reflection of the object.

As the industrial application with mixed-reality, we constructed a projection based display system. In this system, photometric appearance is corrected for color matching between a real mock object and a mixed-reality mock object [3, 4]. The projected image is reproduced by each observer's position, the mixed-reality mock surface is perceived as the real object material. As the other applications, image-based rendering technique is introduced to reproduce intricate glossiness accurately. However, these reproduction is considered only the projection image, not 3D (three-dimensional) geometry.

R. Raskar et al. proposed 2-pass rendering method to consider the 3D geometry[5], which is able to controll two or more projection images. However, view-dependent shading, such as specular highlights is not considered in this method. Because the shading view is assumed to be the same as rendering view or user's viewpoint, the view-dependent shading could not ensure consistency. As well known, in view-dependent shading, the specular highlight as seen by the observer, which moves compared with the moving of diffuse color in view-independent shading. Therefore, in this paper, we divide 3D geometry into object shape, virtual light direction (shading direction), user's viewpoint (view-dependent rendering view) and projector position(view-independent rendering view). In this system, 3D geometry of the viewpoint and the object can be measured by the space encoding method with projector-camera system. According to the measured geometry, the partial responsibility and compensated image of each projection is automatically decided. As the result, this system can generate the real appearance of gloss, color and shade on the mock object's surface.

The proposed work is introduced in this paper as follows. Section 2 describes the concept and improvement of our Appearance-based Display which we have ever constructed. Section 3 explains our improvement for reproducing of 3D appearance with multi-projector and camera, and shows experimental system and results. Section 4 discusses the advantage and disadvantage of this achievement, we concludes our work and future work.

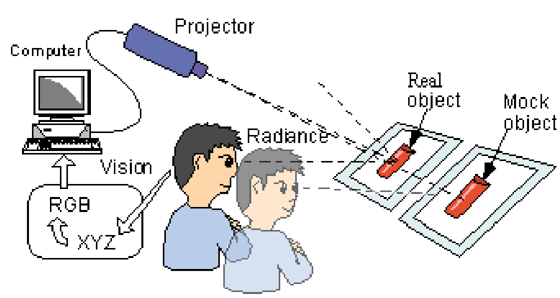


Figure. 1. Schematic illustration of the Appearance-based Display system

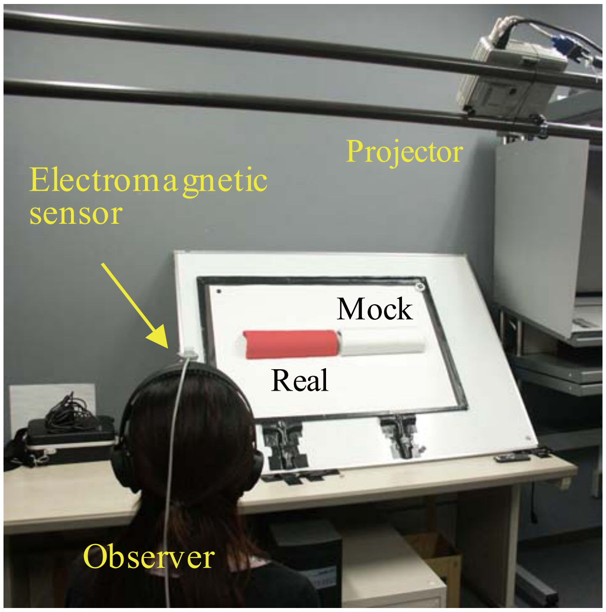


Figure. 2. Experimental system using the projector and head tracking system

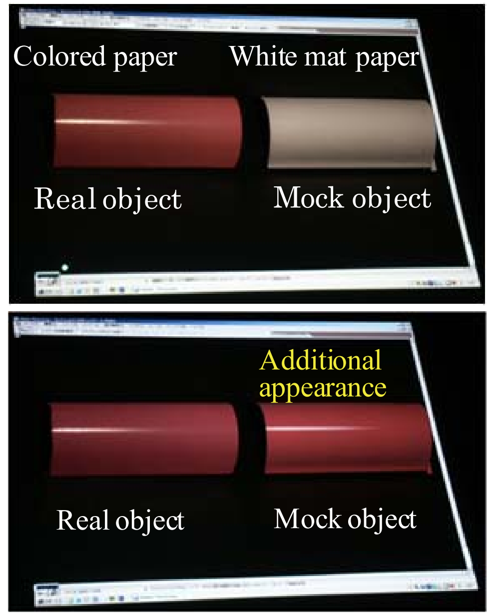


Figure. 3. Experimental images of reproduction for gloss appearance

Relation to previous work

In our previous development, the basically idea was the radiance matching between the real and mixed-reality mock objects. The projected luminance was controlled to match the reflected radiance on tristimulus value XYZ between both objects . Accurate reproduction was possible by photometric correction and ray tracing techniques as shown in Figure 1.

The luminance distribution on the mock object can be calculated by its BRDF and the position of observer. In order to perform real-time reproduction of gloss appearance with the movement of the observer's position, the proposed system uses graphics hardware to accelerate the calculation. Figure 2 shows an experimental system using the head tracking system, and Figure 3 show the results of reproduction for gloss appearance at the Appearance-based Display System.

In this experiment, these appearances were the reproduction based only on the projection image, not 3D geometry. Therefore, we proposed a novel reproduction system with three-dimensional appearance with glossiness, which is controlled by two or more projection images.

Approach

As shown in Figure 4, a projector-camera pair forms the basic constituent of the proposed display system. The camera is rigidly attached to the projector and its field of view is wider than that of the projector, making it possible to capture the entire area illumined by the projector. The display system consists of multiple such projector-camera unit connected to a computing platform (e.g. a PC). Inter-system communication is accomplished through networking.

In our research, we focus on multi projection system with observer's view-dependent virtual shading such as specular highlights. As well known, in view-dependent shading, the specular highlight as seen by the observer moves compared with the moving of diffuse color in view-independent shading. To reproduce the specular highlight with the observer's position, the specular highlight is 2pass-rendered the same as texture of view-independent shading.

Figure 5 illustrates the main modules of our display system.

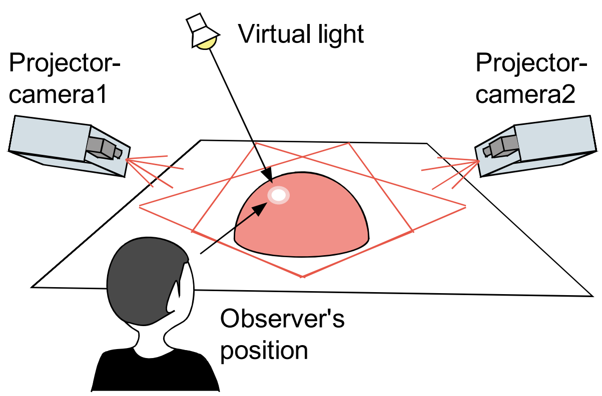


Figure. 4. Illustration of 3D reproduction and shape measurement

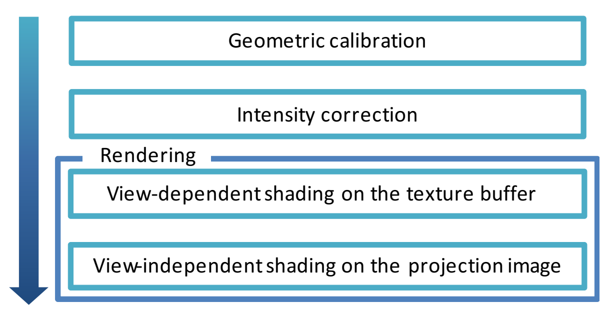
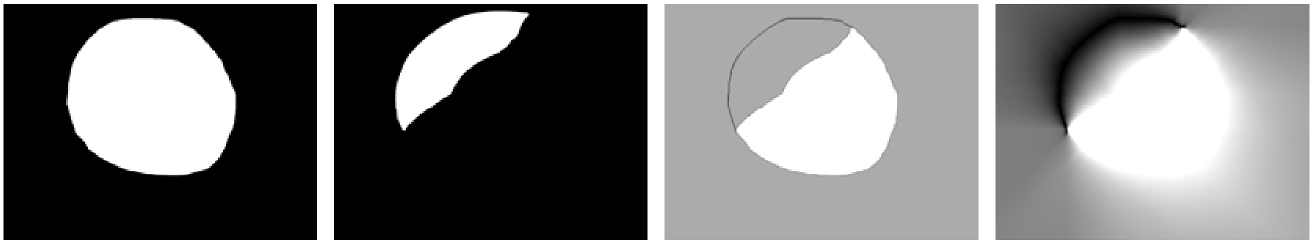


Figure. 5. Flowchart of the projection display system



(a) D2 viewed from P2 (b) D1 viewed from P2 (c) Shadow and borderline (d) Alpha blending filter

Figure. 7. *Measurement result of shadow information and compensation image of its shade*

The geometric calibration module estimates the intrinsic and extrinsic parameters of the projector and camera, as well as their relative pose. And the shape of the object's surface is acquired for which each projector-camera pair obtains its own surface description (e.g. a mesh). The next module is to compute the alpha blending filter for correction of projection intensities errors. In the rendering, the view-dependent module monitors the display configuration and renders only specular highlight on the texture buffer for each projector-camera pair. Once the specular highlight is rendered, texture of the specular highlight is mapped on the shape of the object's surface and rendered on projection image automatically. During rendering, the intensities errors such as occlusions, overlaps and attenuation are modified using alpha-blending available in the graphics hardware.

Geometric calibration

3D geometry of each projector-camera are calibrated due to acquire both intrinsically and extrinsically. Camera can be calibrated using the techniques proposed by Z. Zhang et al. [6]. Projector can be also calibrated easily using the techniques proposed by S. Zhang et al. [7] with paired camera. All extrinsic parameters are calibrated to capture the checker board pattern that is overlooked from all devices. According to the camera-projector calibration, each optical axis can be almost approximated with the same. The paired projector-camera's intrinsic and extrinsic parameters used to reconstruct the shape of the object's surface. In addition, the projector's intrinsic and extrinsic parameters matches a perspective projection matrix that is used to render the scene from the projector's view.

To acquire the partial responsibility and compensation of the intensities errors such as occlusions, overlaps and attenuation for each projection, each projector-camera pair obtains its own surface description as geometric calibration. In calibrated setting, the structure encoding pattern is projected to mock object from each projector as shown in Figure 6 (left, center). Due to capture several pattern each projector-camera system, the shape of object is calculated by using linear triangulation method[8]. According to acquire the shape of the object's surface, each projector-camera pair obtains its own surface description (e.g. a mesh Figure 6 (right)).

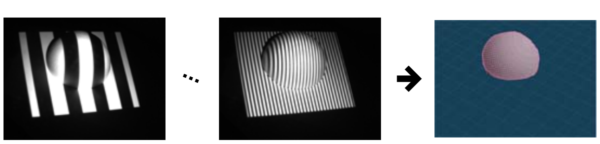


Figure. 6. *Illustration of shape measurement*

Intensity Correction

For compensation of the intensities errors, the alpha blending filter is computed. For illustrative purposes, Each projector-camera pair denoted as P_i, C_i, forms an active stereo pair S_i in our system. The shape of the object's surface is denoted as D_i that is acquired from S_i. the alpha blending filter is denoted as α_i

For example, each shape of the object's surface D_1 and D_2 are calculated by using perspective projection from a projector's view P_1 as shown in Figure7 (a, b). D_1 and D_2 are defined in the 2D local coordinate frame $D_{2D,1}$ and $D_{2D,2}$, which is shape and position of intensities errors such as occlusions, overlaps and attenuation. In the Figure 7 (c), the part of white color is shadow region by other than P_1. The part of black color is borderline between multi-projected region by including P_1 and single projected region by excluding P_1. Shadow region is equal to only P_1's projection on $D_{2D,1}$. The alpha blending filter α_1 able to be computed by using [1, 9, 10] for compensation of the intensities errors such as occlusions and overlaps (Figure 7 (d)). And, the alpha blending filter α_1 is divided by inner product between projection surface's normal and projector direction P_1 and multiplied by squared distance between projection surface and projector for the attenuation's correction.

In this system, we try to compensate the projection image of the intensity uniform illuminant area as shown in Figure 8. Since the shadow region that is equal to only one projection is already known from previous measurement, each projection image is reduced its intensity to make the reflected radiance seamlessly. As the same case of appearance rendering process, the blending process operates by computed blending filter for the intensities correction.

The rendering process

For reproduction of three-dimensional appearance with glossiness, which is controlled by two or more projection images. R. Raskar et al. proposed 2-pass rendering method to consider the 3D geometry[1, 9]. However, view-dependent shading, such as specular highlights is not considered in this method. Because the shading view is assumed to be the same as rendering view or user's viewpoint, the view-dependent shading could not ensure consistency. As well known, in view-dependent shading, the specular highlight as seen by the observer, which moves compared with the moving of diffuse color in view-independent shading. Therefore, in this paper, we divide 3D geometry into object shape, virtual light direction (shading direction), user's viewpoint (view-dependent rendering view) and projector position(view-independent rendering view) as shown in Figure 9. Phong shading

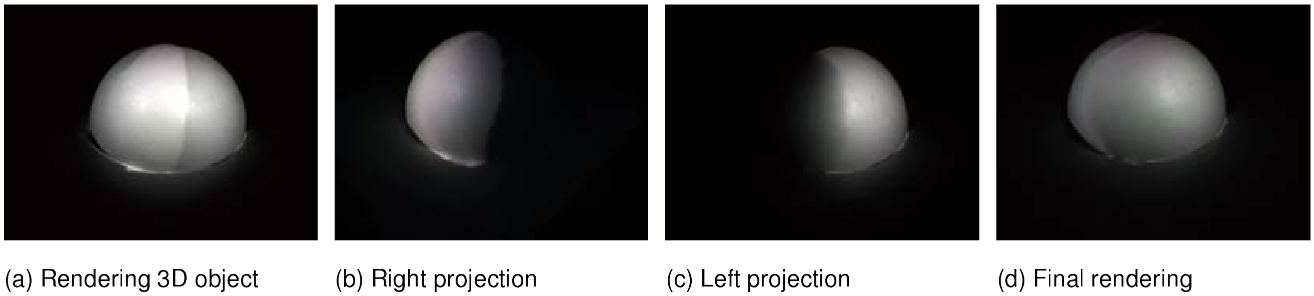


Figure. 8. *Explanatory figure of rendering process of 3D object and compensation of its shade*

is used for rendering 3D model as shown in the following equation [11].

$$I = L(k_d cos\theta + k_s cos^n \varphi) \quad (1)$$

View-independent shading such as specular highlight is denoted by first term. View-dependent shading such as diffuse color is denoted by second term. L is incident light and I is reflected light as the observer's view. To reproduce the specular highlight with the observer's position, the only specular highlight is rendered in the first pass. This image is then served as a projective texture and projected from the viewer's point of view onto a 3D model of the object's surface. The textured 3D model is rendered by using perspective projection from each projector's view in the second pass. According to the specular highlight is 2pass-rendered on texture of view-independent rendering, this second rendered projection will appear as the desired specular highlight to the viewer. In addition the diffuse color is multiply rendered in the second pass. Finally, the rendered image I is alpha blended as projection image I_{P_i} by computed blending filter for the intensities correction as shown in the following equation.

$$I(\mathbf{x}) = \sum_{i=1}^{n} \alpha_i I_{P_i}(\mathbf{x}) \quad (2)$$

Coodinate of projection image is denoted as **x**. n is pair unit uses.

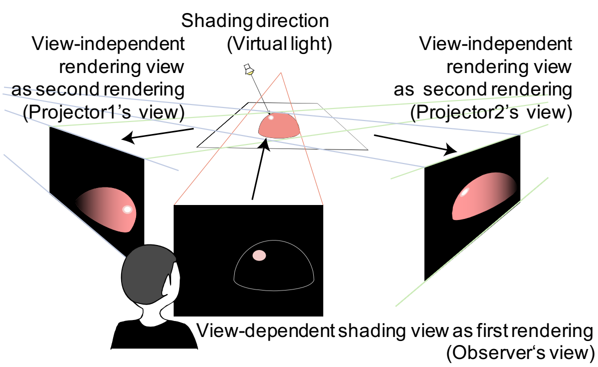


Figure. 9. *Two-pass rendering algorithm*

Implementation

Implementation of system

Figure.10 shows the experimental proto-type system which is minimum setup to examine the rendering of 3D appearance. In this system, we use two projectors (Panasonic PT0LB51NT, 1024x768) and two cameras (IMI Tech IMC-17FT, 1280x960). Each projector-camera system is set against each other. The intrinsic and extrinsic parameters of projector-camera system are initially measured by using the check pattern which size is already known. The 3D mock object is half sphere material which has diffuse reflection, and set to the center on the desk covered by projection and capture area.

The object shape and projection pixels on the object surface are measured by projecting structured light patterns. Since projector has 1024x768 and camera has 1280x960 resolutions, the dynamic range of the structured encode measurement has 9 bit resolutions. Therefore, theoretical accuracy of position is 0.68mm at 650mm x 700 mm measurement region.

Instead of observer's eye, we use another monitor camera which is installed upon 5 degrees in the vertical direction on the desk. This camera is used to evaluate the compensation of registration, overlapping and shadow.

Experiment for gloss appearance on 3D object

For the first evaluation of our system, we reproduce the red appearance on 3D object. Figure 11(a, b, c) shows the appearance of diffuse reflection, and Figure 11(d, e, f) shows the gloss appearance on the same object. In the diffuse reproduction, it succeeds in the alignment of projected position and division to the responsible area of each projector. In the gloss reproduction, it is confirmed that the position of specular is also accurate. Another examination of reproducing appearance is shown in Figure 12(a). Figure 12(a) shows the reproduction of plaster appearance, and Figure 12(b) shows the reproduction of metal appearance. It is known that these texture appearances depend on variation of its histogram [12, 13, 14]. Our 3D reproducing system is suitable for these cases like augmented object's appearance gives the important visual perception. If our tracing system for eye position is added, it seems that augmented object's reality is more increased.

Conclusion and future work

In this paper, we proposed a novel reproduction system with three-dimensional appearance with glossiness, which is controlled by two or more projection images. From the experimental results, reproduction of diffuse object and gloss object show that it succeeds by using perspective projection from each projector's view. As the other examination of reproducing appearance, we examine the plaster appearance and metal appearance. It is clear

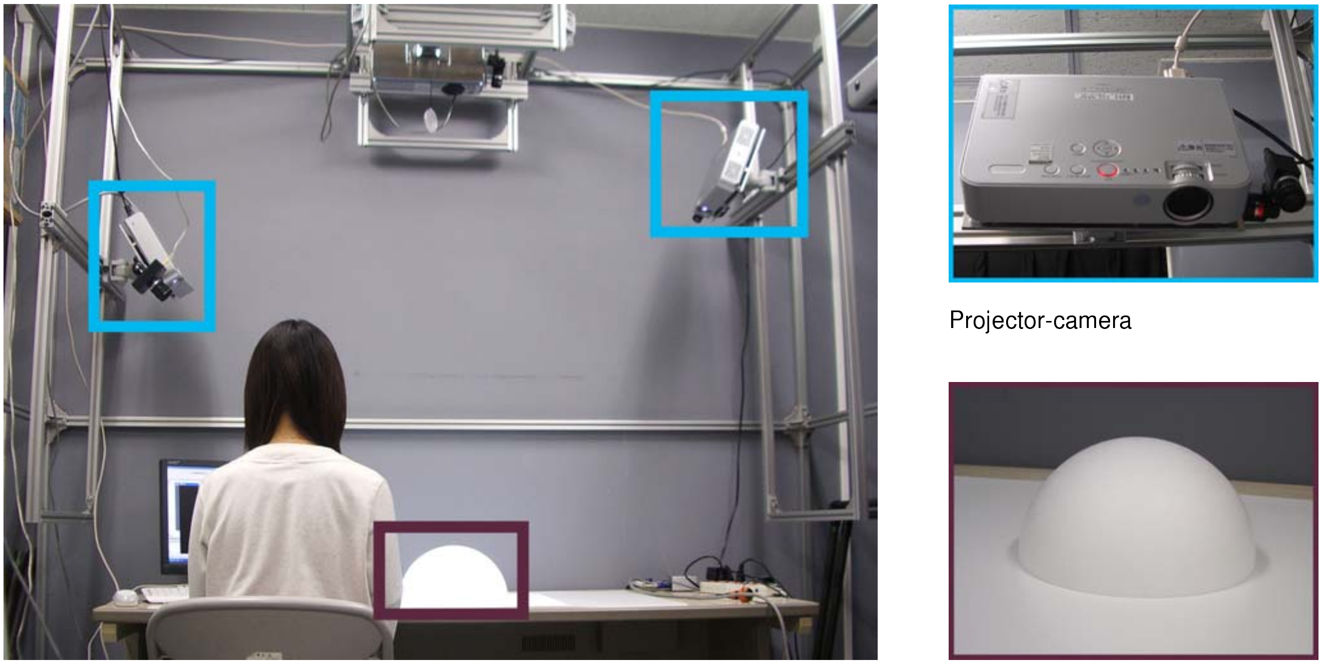


Figure. 10. *Experimental proto-type system to reproduce the real appearance on 3D mock object*

that our 3D reproducing system is suitable for these cases where the augmented object's appearance gives the important visual perception. For the future work, we are planning to implement the gloss texture manipulate system based on image statistics for surface reflectance perception. Additionally, if our tracing system for eye position is added, it seems that augmented object's reality is more increased.

Acknowledgments

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Author Biography

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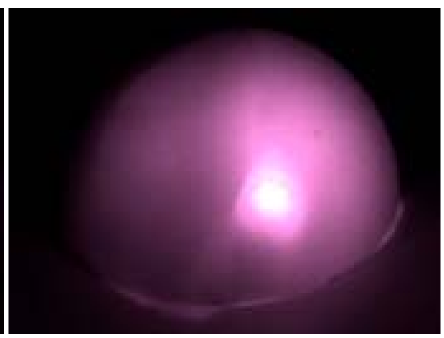
(a)Diffuce color (left)

(b)Diffuce color(center)

(c)Diffuce color(center)

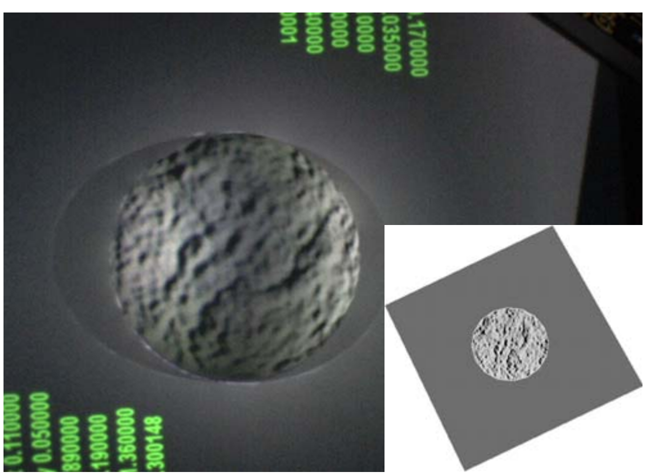
(d)Added specular highlight (left)



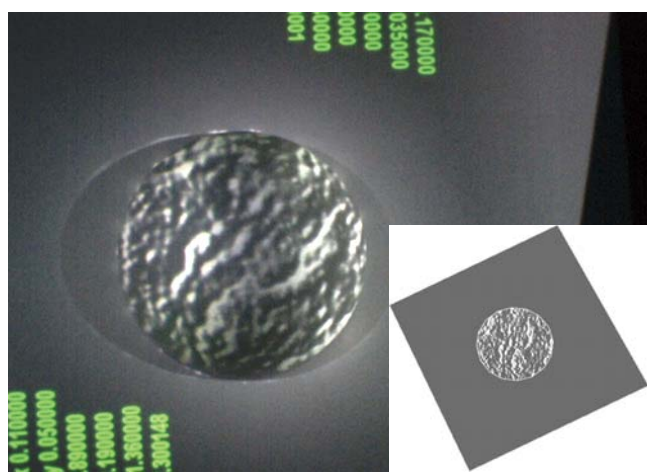
(e)Added specular highlight (center)

(f)Added specular highlight (right)

Figure. 11. *Elementary examination of reproduction for 3D appearance*



(a)reproducing result of plaster appearance



(b)reproducing result of metal appearance

Figure. 12. *Another examination of reproduction for 3D appearance*