# Leaked Light Field from Everyday Material: Designing Material Property Remained Light-field Display

Kazuki Takazawa[1]* Kenta Suzuki[1] Shinji Sakamoto[1] Ryuichiro Sasaki [2] Yoshikuni Hashimoto[2]
Yoichi Ochiai[1]

[1]University of Tsukuba [2]AISIN SEIKI Co.,Ltd

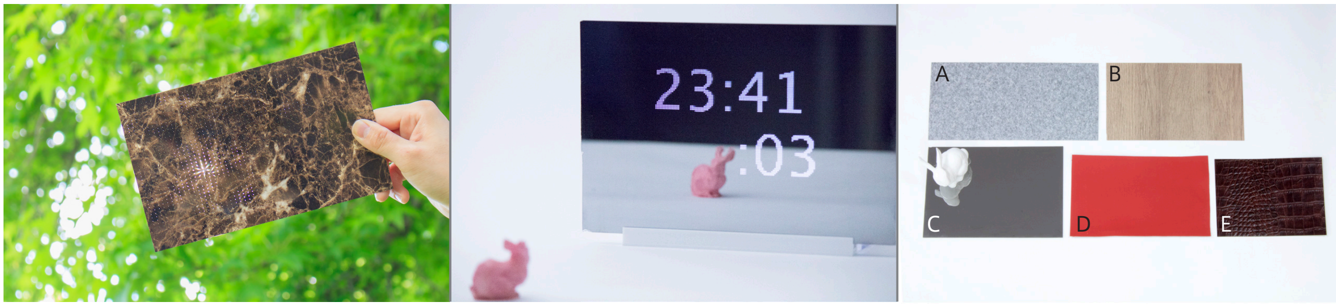


**Figure 1:** *Left: Our novel method make the everyday materials such as wood or stone to display surface. Center: Mirror based pinhole-display that is indicating the time. Right: The material properties are shown in table 1.*

**Keywords:** Display, Design, Fablication

**Concepts:** •**Computing methodologies** → **Image manipulation;** *Computational photography;*

## 1 Introduction

Conventional LCD displays do not use opaque materials, such as wood or mirrors, as a surface. The surface materials for most displays are limited to transparent, smooth materials, because the surfaces need to transmit the backlight through the LCD and color filter. However, these displays do not allow for the expression of surface texture; therefore, they cannot be built into an object without damaging its natural surface. We propose a new method that changes the display surface to allow for not only glass or plastic surfaces, but also a wide variety of materials such as wood, stone, or mirrors, in order to overcome this weakness of conventional displays.

In this paper, we develop a new display device called a pinhole-display that uses everyday materials such as wood, stone, or mirrors. The surface materials used in our method are processed into plates and drilled 19,200 pinholes with 100 $\mu$m diameter. Rays from backlighting can be seen through the surface as an indication of the presence of the holes. The user is only able to see the original material, because the holes are small enough to be invisible to the human eye. The plates work as a display only when exposed to the backlight. We can embed the display in a floor, wall, or mirror without damaging their natural surfaces.

*e-mail:1220kazu1412@gmail.com

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It is possible to generate different rays depending on the viewing angle, based on the ray selectivity of the pinhole. It is thus made possible to provide different information to multiple viewers. We can create a stereoscopic 3D view based on a parallax barrier [Ives 1903] to present different images to the right and left eye. Also, the image can be changed with the distance of the viewer from the display. Therefore, we are able to achieve various user interactions from the pinhole-display.

**Table 1:** *Material Properties*

| Material | Number of pinhole | Diameter | Processing method |
|---|---|---|---|
| Wood (B) | 520(26 × 20) | 200$\mu$m | Drilled |
| Stone (A) | 520 | 200$\mu$m | Drilled |
| Genuine leather (D) | 19,200(160 × 120) | 200$\mu$m | CO2 Laser |
| Synthetic leather (E) | 520 | 200$\mu$m | CO2 Laser |
| Mirror (C) | 19,200 | 100$\mu$m | Femtosecond Laser |

## 2 Design Method

The pinhole is a small hole, which is drilled into the object. It has been used in conventional methods such as the Coded Lens [Sekikawa et al. 2014] and the Pinlight Display [Maimone et al. 2014].The F-number of light passing through an ideal pinhole is infinite. In our display, we focus on the effect of the pinhole, which can block out light. A pinhole of about 100 $\mu$m is difficult to observe with the naked eye, and as such one cannot identify pinholes in the display plate. By adding this feature to surface materials, even those not typically used as displays, it is possible to cause the surface to act as a display only when the power is turned on.

We make three types of pinhole arrays for our display: One is made from a mirror, one is made from a wood-style plate, and one is made from a stone-style plate. To make the mirror pinhole array, we use femtoseconds lasers to cut the pinholes. To make the stone-style pinhole array, we use a typical laser cutter and drill. In accordance with the machine's limit, the pinhole size is 200 $\mu$m.

When we observed through the microscope both pinhole processing with femtosecond laser and one machining with drill and normal laser, we found out difference in precision. Pinhole processing

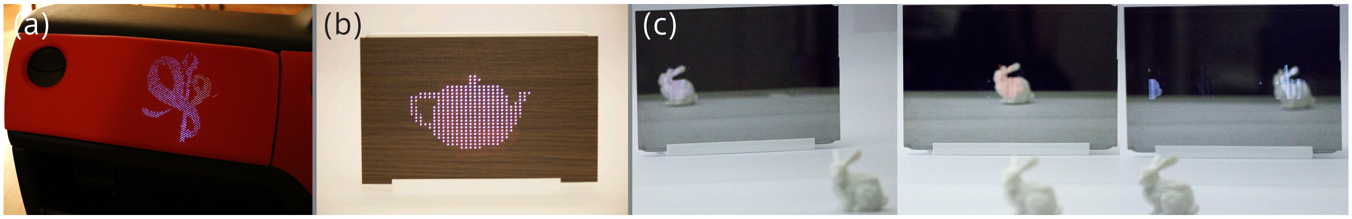


**Figure 2:** *The design example that using pinhole array. The Dash board display(a). It's possible to indicate for the wood style board or furniture without damaging to surface materials Utah teapot is shown on wooden board (b). These applications are using Multi-viewpoints Display. The application example of mirror pinhole array (Infinite AR)(c).*

with femtosecond laser is shapely and its edge is smoothly. On the other hand, we learned that pinhole machining with drill and normal laser is distorted its shape by machine and its edge become fluffed. Additionally, depending on the material to be used, the result is different. Using a laser beam machine in a normal wood sear around the hole. This looks bad because leave a working mark. We use woodgrain and stone style pinhole and veneer made of melamine board. Then when we process a mirror with normal laser beam, processed part has thermal denaturation. So we use a femtosecond laser. It can process without thermal denaturation [Chowdhury and Xu 2003]. List of material is shown in table1.

## 3 Application

In the case of a conventional mirror, it is impossible to indicate highlighting on a mirror with two or more viewpoints. We consider the case of several people looking at a mirror at the same time. When one user looks at the highlighted mirror from angle A, while another user looks at the same mirror from angle B, the highlights is shift from the reflected image on a conventional mirror. This phenomenon happens because the highlighting of the mirror is performed in the same way regardless of the viewing angle. In the case of a mirror pinhole-display, it is possible to change the information indicated depending on the viewing angle. We can thus highlight the same thing when many users look at the same mirror by indicating different information depending on the viewing angle of the user.

We assume that a mirror display with pinholes is used in a situation such as the rearview mirror of a car. When one user looks at the mirror from the driver's seat and another user looks at it from the passenger's seat, it is impossible to highlight the same reflected image, because the reflected image is different at the two viewpoints on the conventional mirror.

The pinhole mirror display can present a light-field that makes it possible to see the same thing from point of view of the driver and the passenger. In this way they are able to share information about dangerous situations or target items. We consider the case where the object is at a distance $l$ away from the mirror. In this case, we observe a mirror at a location a distance W away from the object and a distance $L$ away from the mirror. The location $x$ where the reflected image is seen can be expressed by the following formula.

$$x = W * \frac{l}{L + l} \tag{1}$$

When a light field is designed using this calculation, it can be assumed that the real light field and the imaginary light field exist across the pinhole mirror. The ray issued from the reflected image in the imaginary light field passes the mirror surface, and projects into the real light field. The light field of the ray from the pinhole is designed according to the projected ray in the real light field. This makes it possible to produce a light field that emphasizes the object from every angle at which it is seen. If we design according to the light field in this way, the only variable required for the calculation will the location of the object. If the location is measured correctly, the highlighting of a multi-aspect moving object becomes possible.

We develop a system using the single depth camera that measures the location of the object and shows the pattern on the LCD display in order to compose a light field. The location of the object acquired using the single depth camera is substituted for the abovementioned arithmetic expression. This is achieved by adjusting the patterns according to the movement of the object's calculated location for where the reflected image appears in the mirror. When the pinhole mirror device is fixed, we can highlight the object even if both it and the viewpoint are moving (Figure 2).

## 4 Conclusion and Future Work

In this study, we propose a novel method allowing the use of opaque materials such as wood, stone, or mirrors as display surfaces. The 100 $\mu$m diameter pinhole is invisible to human eyes, and as such appears only when the pinhole-display is switched on. Therefore, we are able to extend the list of potential display surfaces to include everyday materials such as wood or stone. In addition, we have realized glassless 3D and a display that depends on viewing angle, based on the ray selectivity of the pinhole. The Infinite AR mirror pinhole array can be used to highlight the same object from different points of view.

We may be able to use this novel display as a touch panel to embed capacitive sensors behind the surface material. We would like to further examine the application of this technology to locations such as furniture or car interiors.

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