GoThro: Optical Transfer of Camera Viewpoint Using Retro-transmissive Optical System

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Figure 1: a,b: set-up at time of capturing. c,d: Images being taken by virtual camera. Image c is taken from front of plant leaves and image d is taken through small gap (yellow circle) in leaves.

ABSTRACT

Recent advances in computational photography have enabled the creation of images that contain additional attributes. However, capturing images of objects concealed behind obstructions or out of a camera's field of view is a challenge. We designed an optical transformation system that utilizes a conventional camera, a concave lens, and Micro-Mirror Array Plates (MMAPs) to enable images to be captured through small holes in walls or other obstructions. Our experimental prototype demonstrated that it was possible to capture images of the area on the other side of a wall through a 3-mm hole. Our system could be used to capture images from places difficult to position a camera, such in rubble in disaster areas.

CCS CONCEPTS

• **Human-centered computing** → *Human computer interaction (HCI)*; Graphics input devices;

KEYWORDS

mid-air camera, optical system, optically transformation

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1 INTRODUCTION

Computational photography has enabled cameras to exceed the limitations of those that use conventional methods[Nayar 2006]. Recent advances in the computational photography research field have enabled the creation of images that include additional attributes such as those with all objects in full focus, those with depth, those with a high-dynamic range, those with giga-pixel resolutions, those in full wavelength, and those taken from a viewpoint around a corner. With such novel camera capabilities, images that could not have been seen before are now possible. However, it is difficult to capture an image if the target objects are hidden from the camera ' s view. Figure 2 shows an example of the problem to be addressed related to non-line-of-sight (NLOS) imaging [O'Toole et al. 2018]. Previous research reconstructed the shape and albedo of hidden objects from multiple scattered lights. However, it is difficult to capture RGB colors. A color sensor similar to a camera is required to capture RGB data, but a small hole in a physical barrier like a wall makes it difficult to see what is on the other side of the wall even if the camera is brought close to the limit. If it is possible to position a camera through the hole, we can capture what is on the other side of the wall with a wider angle of view. In this paper, we propose a novel optical system that can work as a mid-air camera positioned through a small hole in a wall. In this study, we designed an optical transformation system by combining a camera and an optical system (a concave lens and a an aerial imaging plate (AIP). With this system, people can capture images in places where obstacles prevent them from entering or where they cannot physically place a camera, such as in rubble in disaster areas, etc.

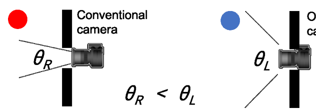

Figure 2: Conventional camera (left) and our camera (right).

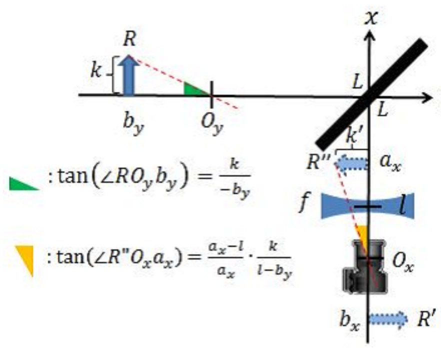

Figure 3: Transformation of focal plane($a_x \rightarrow b_x \rightarrow b_y$) and real object(R→R'→R"). k is size of real object (R). k' is that of real image after being completely transformed (R").

2 OPTICAL DESIGN

For the mid-air camera, it is necessary to set the focus range, perspective, and angle of view.

2.1 Focus range

First, we describe the focus range. Captured images blur only when a camera and AIP are combined. This is because the focus range of the camera is for the side opposite to a subject by the AIP. By using a concave lens, it is possible to set the focus range to the side of the subject. As shown in Figure 3, when the position of the focal plane is transformed by a concave lens and the AIP such that $a_x \rightarrow b_x \rightarrow b_y$, the following expression is established for a_x, b_y.

$$b_y = l - f + f^2/f - (a_x - l) \tag{1}$$

When $a_x > l + f$, a_x corresponds one by one to b_y.

2.2 Perspective

Next, we describe the perspective. Since a concave lens has a nonlinear nature, a mismatch in perspective occurs. When the size of a subject viewed from the mid-air camera is the same as that taken by the camera, the following expression is satisfied.

$$\tan(\angle R''O_x a_x) = tan(\angle RO_y b_y) \tag{2}$$

Solving this,

$$l = 0 \tag{3}$$

In other words, it is necessary to always control the concave lens to align it with the position of the camera lens. Therefore, we tried to get distortion-free images by attaching the concave lens to the camera and synchronously moving them.

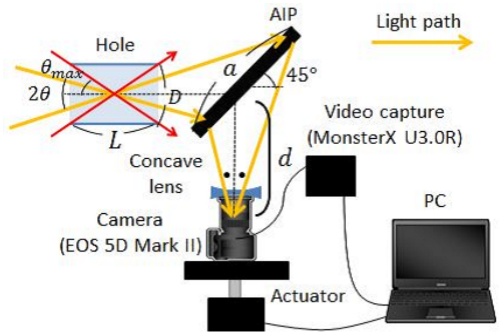

Figure 4: System structure.

2.3 Angle of view

Finally, we describe the angle of view of the mid-air camera. There is a limit to the hole diameter that the mid-air camera can penetrate. The distance between AIP cameras, size of the AIP, thickness of obstacles, and hole diameter of obstacles are mainly related to the design. As shown in the Figure 4, the angle of view θ of the mid-air camera can be expressed as follows using the distance d between the AIP and the camera and the length a of one side of the AIP (square).

$$\tan 2\theta = a/\sqrt{2}d \tag{4}$$

Further, using the thickness L of the obstacle and the hole diameter D, the maximum angle of view θ_{max} of the camera can be calculated as follows.

$$\tan \theta_{max} = D/L \tag{5}$$

We confirmed the limit in the hole size through thin obstacles by building a prototype (Figure 4). When the aperture of the camera was set to its narrowest, it was possible to capture images of the area on the other side of a wall through a 3-mm hole. Also, even if the aperture was opened to its maximum, it was possible to capture images of the area through a 5-mm hole. Figure 1 shows images being captured through a 5-mm hole in the leaves of a plant.

3 APPLICATIONS AND CONCLUSION

With this method, it is possible to capture images through gaps in debris in disaster sites or through animal cages without disturbing their natural behavior. In this paper, we realized a system that works as a mid-air camera positioned through a small hole with a wider angle of view.

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