Floagent: Interaction with Mid-Air Image via Hidden Sensors

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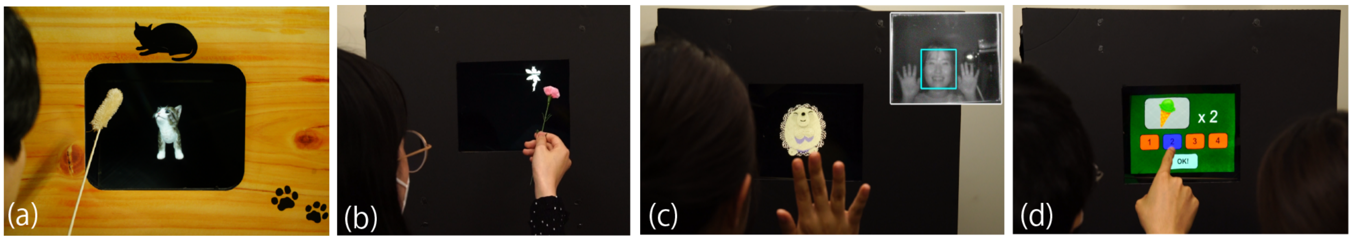

Figure 1: (a)(b) Interaction with a character displayed as a mid-air image with an object without any sensors (c) Peek-a-boo game with a character displayed in mid-air played via a hidden IR camera (d) Mid-air touch interaction by a user's finger

ABSTRACT

This paper proposes Floagent as a human-computer interaction system that displays images in mid-air using infrared light reflected by a hot mirror. Floagent is an interaction system that allows users to focus on mid-air images without being aware of the sensors. By combining a hot mirror and a retroreflective transmissive optical element, Floagent conceals the camera from the user without affecting the mid-air image. We investigated the touch input interactions accuracy with mid-air images to evaluate the proposed system. The results show that the proposed system can effectively measure user input. Floagent enables an interaction design with a hidden sensor in which mid-air images appear to respond spontaneously to a wide variety of interaction events.

CCS CONCEPTS

• **Hardware** → **Display and imagers**; • **Human-centerd computing** → Display and imagers.

KEYWORDS

mid-air interaction, augmented reality, mid-air image

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1 INTRODUCTION

In this study, we aim to realize communication with characters and images displayed in mid-air, as popularized in science fiction and fantasy. In particular, we aim to provide an interaction mechanism that users perceive as "magical" to create a dramatically novel human-computer interaction experience. Although methods to display computer graphics (CG) images floating in mid-air images have been developed, the equipment comprising these systems, such as sensors, is typically visible to users, which considerably detracts from the special experiences commonly shown in fictional media. We propose Floagent as a system that allows users to interact with mid-air images as if no sensors were present, which uses a micro-mirror array plate (MMAP) device to display mid-air images in real space. The MMAP comprises two orthogonal mirror arrays. The light emitted from the source is reflected by the MMAP to form a real image in the air. The mid-air images thus formed can be observed with the naked eye without wearing a device such as an HMD, and can be observed by multiple people simultaneously.

Because mid-air images are formed at some distance from the hardware, research interest in developing non-contact interface methods to prevent the spread of COVID-19 has increased. However, because such mid-air images lack any physical substance to touch beyond the light reflected in the air, user touch must be detected using non-contact sensors, such as cameras. MARIO[Kim et al. 2014] used a depth camera to measure the position of objects and enabled interaction with mid-air images through objects. Similarly, Chan *et al.*[Chan et al. 2010] used an IR camera to measure the positions of the user's finger and projected a shadow to aid interaction. Additionally, Hunter*et al.*[Hunter et al. 2017] solved the occlusion problem when interacting with mid-air images using sensing fingers.

In such mid-air image interaction systems, the quality of the user experience with mid-air images may decrease if the user discovers the sensors. Alternatively, the equipment comprising the system should be invisible for the user to enjoy the experience with mid-air images as a magician hides tricks. Hence, sensors, such as cameras, should be positioned in unrecognizable positions to enable a "magical" experience.

The proposed system shields the sensors from users using infrared light reflected by a hot mirror. A hot mirror is an optical

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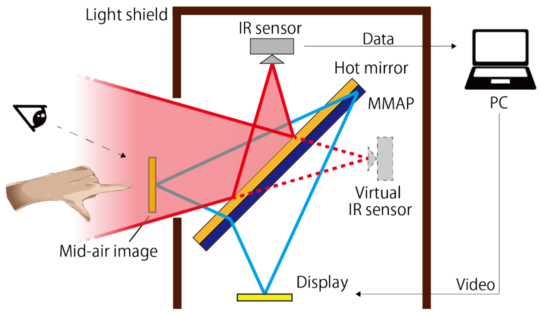

Figure 2: Optical design and system flow

element that transmits visible light and reflects only infrared light. The combined system, comprising a hot mirror and an MMAP unit, hides the camera in the visible light region and creates an experience that enables interaction with a magical mid-air images.

2 SYSTEM DESIGN

Floagent consists of an IR sensor, a display, an MMAP, a hot mirror, and a light shield, as shown in Fig. 2. The light emitted from the display is reflected by the MMAP, which is tilted at a 45° angle and forms mid-air images at a position that is plane-symmetrical to the MMAP. The light that forms the mid-air images is unaffected by the hot mirror because the visible light is transmitted through the hot mirror. In contrast, infrared light is reflected by the hot mirror; therefore, the hot mirror behaves as a mirror in the infrared band. Thus, the IR sensor measures the user from the position of the virtual IR sensor, as shown in Fig. 2. Moreover, the light shield prevents the user from observing the sensors or the display. We sent images from the IR sensor to a workstation computer that used the information to control the images displayed by the system.

3 IMPLEMENTATION

The implementation of Floagent is shown in Fig. 3. An iPad (2048 × 1536 px) device was used for the display, the MMAP unit was an ASKA3D-488 display (488 mm × 488 mm, pitch width 0.5 mm) manufactured by ASUKANET, and the hot mirror was a 250 mm × 250 mm (5 mm thick) unit from Keihin Optical Co. Because the hot mirror used was smaller than MMAP, its position was adjusted by fitting it to an acrylic plate. A time-of-flight (ToF) camera from Vzense was used as the IR sensor. Additionally, the enclosure was covered with blackout curtains and styrene boards to conceal the equipment comprising the system from the user. In this setup, the infrared light emitted from the ToF camera is reflected by the blackout curtains and interferes with the image captured by the ToF camera. Therefore, we placed light-absorbing materials inside the blackout curtains to prevent unwanted infrared light reflection.

We evaluated the accuracy of finger touch input to the mid-air image display using the implemented device. The distance error (cm) between the real space and measured coordinates was calculated, and the results are shown in Fig. 4. Measurements were recorded at 20 points, and the vertical axis shows the average distance error in cm between the coordinates detected by the touch input system and the true real-space coordinates. The results show that the maximum median distance error of the coordinates detected by the ToF camera

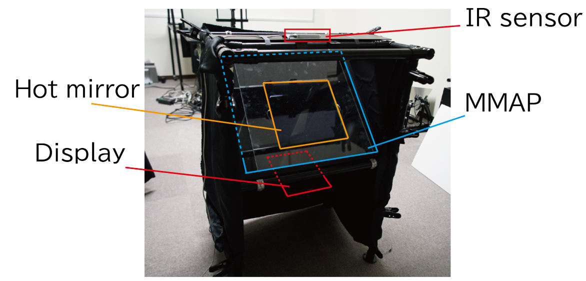

Figure 3: Implementation

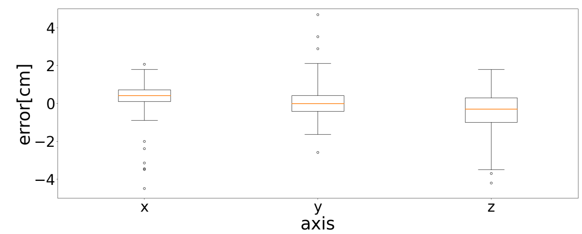

Figure 4: Results of accuracy evaluation

was approximately 2 cm; that is, the error was approximately the width of the fingertip.

4 EXPERIENCE

Floagent enables the interaction with CG characters using an ordinary object with no sensors, face-to-face communication with mid-air CG characters through face detection by an IR camera, and finger input to interact with interface components, such as touch panels, as shown in Fig 1. As shown in (a) and (b), the ToF camera was used to detect the position of the tool held by the user, and the animation of the CG character changed according to its position. Because depth estimation was performed with a ToF camera, the tools need not include sensors, and users can use their fingers as well as objects such as pencils or flowers. As shown in (c), the CG character reacted when the user's face was detected by the IR camera, realizing a so-called "peek-a-boo" game. As shown in (d), the ToF camera detects the position of the user's finger, allowing the user to operate a mid-air touch panel. In all of these cases, users can perceive magical images floating in the air without being distracted by special equipment comprising the optical system.

ACKNOWLEDGMENTS

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