# Floagent: Interaction with Mid-Air Image via Hidden Sensors


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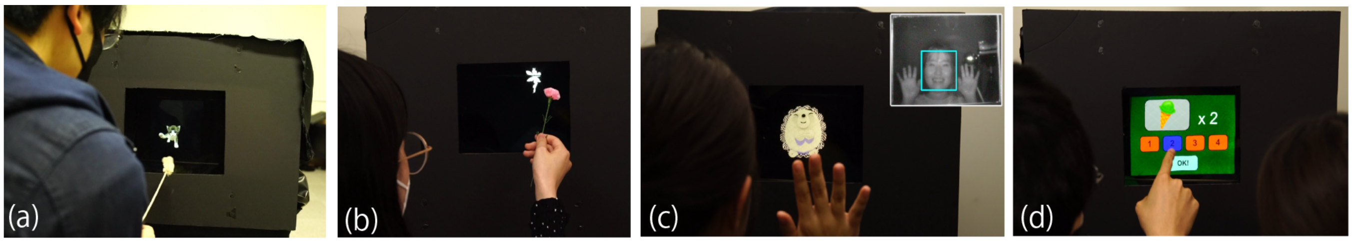


**Figure 1: (a)(b) Interaction with a character displayed as a mid-air image with an object without any sensors (c) A peek-a-boo game with a character displayed in mid-air played via a hidden IR camera (d) Mid-air touch interaction by a user's finger**


## ABSTRACT

In this study, we propose 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 a mid-air image without being aware of 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. To evaluate the proposed system, we investigated the accuracy of touch input interactions with mid-air images. The results show that the proposed system was able to measure user input well. 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

**ACM Reference Format:**
Shohei Ando and Naoya Koizumi. 2022. Floagent: Interaction with Mid-Air Image via Hidden Sensors. In *Proceedings of Make sure to enter the correct conference title from your rights confirmation emai (Conference acronym 'XX).* ACM, New York, NY, USA, 3 pages. https://doi.org/XXXXXXX.XXXXXXX



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*Conference acronym 'XX, June 03–05, 2018, Woodstock, NY*


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ACM ISBN 978-1-4503-XXXX-X/18/06…$15.00
https://doi.org/XXXXXXX.XXXXXXX


## 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 media. 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 the users, which considerably detracts from the special experiences commonly shown in fictional media. We propose Floagent as a system designed to allow 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. Light emitted from a 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 the mid-air image is formed at some distance from the hardware, research interest in the development of non-contact interface methods to prevent the spread of COVID-19 infection has increased. However, because such mid-air images lack any physical substance to touch beyond light reflected in air, user touch must be detected with 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 position of the user's finger and project 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 the mid-air image may decrease if the user notices 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

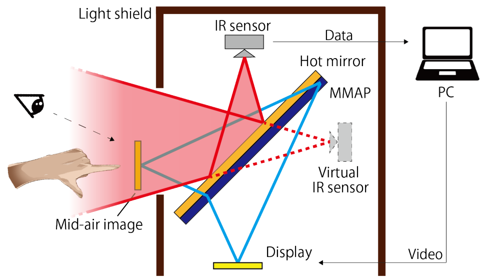


**Figure 2: Optical design and system flow**

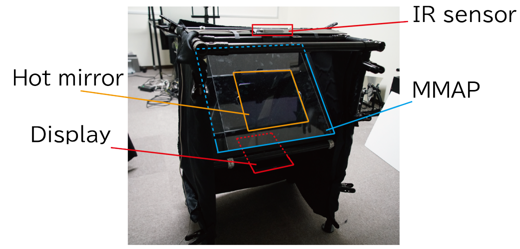


**Figure 3: Implementation**

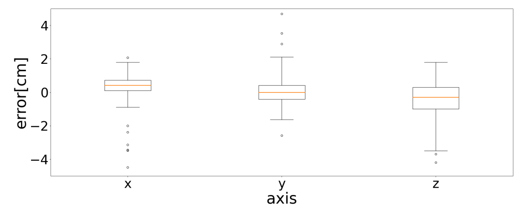


**Figure 4: Results of accuracy evaluation**

cameras should be positioned such that users cannot recognize them to enable a "magical" experience.

In the proposed system, the sensors are shielded from the user using infrared light reflected by a hot mirror. A hot mirror is an optical element that transmits visible light and reflects only infrared light. The combined system comprising a hot mirror and a MMAP unit hides the camera in the visible light region and creates an experience that enables interaction with an apparently magical image displayed in mid-air.

## 2 SYSTEM DESIGN

Floagent consists of an IR sensor, a display, an MMAP, a hot mirror, and a light shield 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. This light that forms the mid-air images is not affected by the hot mirror because visible light is transmitted through the hot mirror. In contrast, infrared light is reflected by the hot mirror, so the hot mirror behaves as a mirror in the infrared band. Thus, the IR sensor can measure 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. Images from the IR sensor are sent to a workstation computer, which uses the information to control the images displayed by the system.

## 3 IMPLEMENTATION

An 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 the MMAP, its position was adjusted by fitting it into an acrylic plate. A time-of-flight (ToF) camera from Vzense was used as the IR sensor. In addition, 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 could be reflected by the blackout curtains and interfere with the image captured by the ToF camera. Therefore, light-absorbing materials were placed inside the blackout curtains to prevent unwanted reflection of infrared light.

Using the implemented device, we evaluated the accuracy of finger-touch input to the mid-air image display. The distance error (cm) between the real-space coordinates and the 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 median distance error of the coordinates detected by the ToF camera was about 2 cm at maximum; i.e., the error was approximately the width of a fingertip.

## 4 EXPERIENCE

Floagent enables interaction with CG characters using an ordinary object without any 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 was changed according to its position. Because depth estimation was performed with a ToF camera, the tools need not include sensors and users can also 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 detected 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 apparently magical images floating in the air without being distracted by the special equipment comprising the optical system.

## ACKNOWLEDGMENTS

This research was supported by JSPS Grant-in-Aid JP21K19821 and the Canon Foundation.

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