A System for Mid-Air Images that Follow Real Objects

Ryo Sugawara
Graduate School of Informatics and Engineering
University of Electro-Communications
Chofu, Tokyo, Japan
Email: sugawara.ryo@media.lab.uec.ac.jp

Naoya Koizumi
Graduate School of Informatics and Engineering
University of Electro-Communications
Chofu, Tokyo, Japan
Email: koizumi.naoya@uec.ac.jp

***Abstract*—We present a novel interaction paradigm enabling the intuitive manipulation of mid-air images within a three-dimensional spatial environment. Leveraging the integration of an optical element, an actuator system, and an optical motion capture, our approach allows for the seamless movement of mid-air images across the spatial dimensions, including depth. Unlike tangible objects, mid-air images lack physical substance, rendering manual manipulation unfeasible. To address this challenge, we propose a method to synchronize the manipulation of physical entities with the control of mid-air images. By optimizing the actuator's control mechanism, we achieve real-time synchronization between the movement of physical objects and corresponding adjustments in the mid-air image position. Our experimental evaluation, particularly focusing on Motion-to-photon Latency, reveals a minimal delay of approximately 25 to 30 milliseconds between the display of an image and the actuation response. This latency measurement underscores the feasibility and efficacy of our proposed interaction framework, demonstrating its potential for seamless and responsive manipulation of mid-air imagery within three-dimensional space.**

Fig. 1. By a linking between the positions of the mid-air images and the physical objects, humans are able to manipulate the mid-air images freely. This photograph shows discretely overlays movements over a very short duration. On the left side, a card is displayed with computer graphics (CG) shown on top of it. The mid-air image gradually moving towards the back is depicted.

I. Introduction

What we aspire to is an experience where individuals can seamlessly control both information and the physical environment while retaining their natural appearance. One approach to realize this experience is through Mixed Reality systems employing head-mounted displays, which offer the advantage of versatility in usage location. However, such devices are uniform in design, bulky, and pose challenges such as concealing facial expressions and requiring power sources like batteries and Wi-Fi. On the other hand, employing mid-air images formed by converging light rays onto another point as a stationary system offers a useful means of presenting information without the need for wearable devices, albeit with spatial limitations, enabling the ideal coexistence of information and the physical world.

To fully integrate physical elements with information using mid-air images, it is essential to manipulate them freely in three-dimensional space, akin to how we manipulate physical objects. Previous research has proposed methods utilizing linear actuators to move light sources for shifting mid-air images in the depth direction [1], or moving physical objects integrated with the light source [2]. However, the former only achieves interactions where mid-air images gradually approach stationary physical objects, lacking tracking of moving physical objects. The latter faces the challenge of mid-air images being unable to move vertically. Therefore, in this study, we tackled this technical challenge by redesigning the control system, aiming to provide an experience where mid-air images move naturally and seamlessly, akin to physical objects, thus eliminating any sense of peculiarity as shown in Fig. 1. [1]

II. Related work

An optical system utilized to generate mid-air images involves the application of Micro Mirror Array Plates (MMAP). MMAP establishes mid-air images in symmetrical positions relative to the light source, allowing for manipulation of these images by moving the light source. In this study, an optical system employing MMAP was adopted. Placing the display horizontally with respect to the ground and tilting MMAP at a 45-degree angle results in mid-air images being formed directly in front of the user's viewpoint. By adjusting the display position within the apparatus, mid-air images can be moved horizontally and vertically, while manipulating the display with actuators enables depth-wise movement of the mid-air images. Kim et al. developed the MARIO system, wherein mid-air image characters traverse through space [1], employing linear actuators to facilitate movement in horizontal, vertical, and depth directions. In this research, we utilize the MARIO optical system capable of three-dimensional mid-air image

[1]Demo video: https://www.youtube.com/watch?v=zfVKG4ykaAU

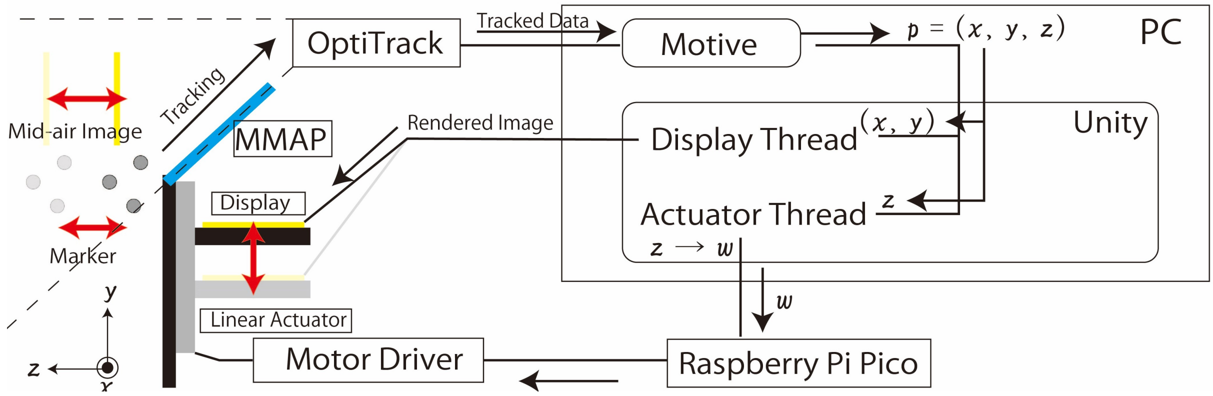

Fig. 2. System Diagram. The coordinates of markers are captured using OptiTrack, and base on this, the content displayed on the light source display and the movement of actuators are controlled. The update cycle for this sensing and display refresh is maintained at a rate exceeding 120Hz.

manipulation, enhancing the control of actuators. By tracking the position of physical objects and synchronizing actuator movements accordingly, mid-air images can accurately track and follow three-dimensional moving objects.

III. System

We update the optical system of MARIO capable of three-dimensional mid-air image manipulation, while additionally focusing on enhancing actuator control speed. By tracking the position of physical objects and adjusting actuators accordingly, mid-air images can accurately follow three-dimensional moving objects.

The system overview, depicted in Fig. 2, involves optical motion capture tracking physical objects, and transmitting coordinates to Unity. The processing diverges into two paths: one for horizontal and vertical image movement (display subsystem) and another for depth-wise movement (actuator subsystem). OptiTrack V120:Trio and Unity were used for motion capture and game engine, respectively. The coordinates were sent to Unity at 120 fps via UDP. Unity operated at 360 fps, rendering images on a 240 Hz, 17.3-inch display via Thunderbolt 4 USB. Raspberry Pi Pico controlled the linear actuator, driven by pulse waves computed in Unity and transmitted via serial communication. Incremental adjustments of 1 ms were made for acceleration and deceleration during periods without object tracking.

IV. Demonstration

Motion-to-photon Latency was measured to investigate the latency of the implemented system. Motion-to-photon Latency is commonly used for latency assessment in devices such as HMDs and VR controllers. The measurement method and conditions are described as follows. A marked board was placed on a slider and given an initial velocity with a hammer. The movement of the board was captured using a high-speed camera, and the number of frames was counted. The latency at the beginning and end of the board's movement was measured twenty times each for both the display subsystem and the actuator subsystem. The results of the Motion-to-photon Latency measurements are presented in Fig 3. The average latency of the display subsystem at the start of movement was 25.6 ms, and at the end of movement, it was 30.0 ms. For the actuator subsystem, the average latency at the start of movement was 26.0 ms, and at the end of movement, it was 27.5 ms.

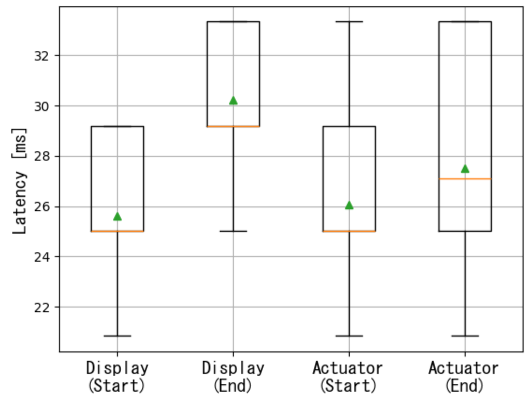

Fig. 3. Measurement results of Motion-to-photon Latency. As demonstrated in the box-and-whisker plots, there is no significant difference in the response times at the start or end of tracking, whether for the display or the actuators.

V. Conclusion

We achieved interaction wherein mid-air images follow the movement of physical objects by a system that updates the position and velocity of mid-air images with each tracking iteration, enabling them to track the movements of physical objects. Measurement of the system's latency revealed that it is kept within an average range of approximately 25 ms to 30 ms for both display rendering and actuator driving.

Acknowledgment

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References

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[2] H. Kajita *et al.*, "SkyAnchor: Optical Design for Anchoring Mid-air Images onto Physical Objects," in *Proceedings of the 29th Annual Symposium on User Interface Software and Technology*, 2016, pp. 415–423.