論 文 の 内 容 の 要 旨

論文題目　Optical Design of Geometrically Superimposing Layered Mid-air Images onto Physical Objects for Glasses-Free Mixed Reality Interactions
（裸眼複合現実感インタラクションのための
多層空中像の幾何学的重畳を可能にする光学系の設計）

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Mixed reality (MR) concept has been proposed to extend the features of everyday objects with the visual images. The goal of MR interactions is to provide high sense of reality from a seamless connection between visual images and physical objects. Despite the progress of display technologies, however, in current MR interactions, it is still a big challenge to realize glass-free systems for multiple users that allows users to manipulate physical objects superimposed with visual images. Therefore, this thesis focuses on visual presentation in the 3D space and implementation of MR interactions in the real world space.

From the property of MR interactions, this thesis gives importance to manipulation for physical objects and the number of viewing zones of visual images as two criteria for designing MR interactions. Based on these two criteria, a 2×2 matrix for MR interactions is proposed with providing four kinds of MR interactions: MR showcases for a single user, MR showcases for surrounding users, MR interface for a single user, and MR interface for surrounding users. The goal of this thesis is to design and implement optical systems that form layered mid-air images in 3D space and superimpose them directly onto physical objects. The proposed optical designs are applied to three glasses-free MR interactions to complete the matrix. The main contribution of this thesis is to implement and validate the optical designs through three glasses-free MR interactions.

In Chapter 3, MRsionCase is proposed as an MR showcase for surrounding users, which can superimpose two layered mid-air images onto a physical exhibit. The use of DCRA solves the limitations of virtual images by forming a real mid-air image immediately next to the physical object. Its symmetric optical design can provide visual images with four separate viewing zones so that users can see the image from different directions, front, back, left, and right. In each direction, two layers of mid-air images are formed and sandwich the physical object to express correct occlusion between the images and the physical object.

In Chapter 4, MARIO is implemented as an MR interface for a single user, which enables a direct interaction between physical objects and a mid-air image. From the combination of a real imaging optics and linear actuator, the optical design of MARIO can form a mid-air image in the range of 350 (W) × 300 (D) × 250 (H) mm. The position of mid-air image can be moved back and forth along the depth direction. An artificial shadow is cast below the mid-air image and provides a high sense of reality. Thus, users can see and interact with the mid-air character in this 3D space without any interruption.

In Chapter 5, HoVerTable is developed as MR interface for surrounding users, which combines horizontal image projection and dual-sided vertical images. Two layers of vertical mid-air images are formed on the tabletop surface and superimposed onto physical objects as MRsionCase. Each vertical image layer provides view-dependent images to two facing users. The optical design combines real imaging optics with diffusion control film to provide vertical and horizontal images with a compact design. With vertical mid-air images and horizontal image projection, HoVerTable extends the display area of conventional tabletop displays to vertical direction.

The optical designs proposed in this thesis can overcome the limitations in display area of current displays with superimposing mid-air images onto physical objects for glasses-free systems. Such glasses-free MR interactions will enable people to more intuitively access visual information and finally enrich our information usage in everyday life.