Intermediate Image Temple Optical System with Small Diameter for Super-Light Smart Glasses Using Thin Plastic Light Guide Plates

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ABSTRACT

We have developed super-light smart glasses using thin plastic light guide plates. Using a non-rotationally symmetric optical element on the intermediate image temple optical system, we succeeded in reducing the diameter of the optical system to approximately half, which is suitable for the light guide plate.

1 INTRODUCTION

In recent years, Microsoft and Magic Leap have launched smart glasses (also called see-through head-mounted displays and AR glasses), with high-performance AR functions. We can anticipate new user experiences in the near future.

In many smart glasses, the light emitted from the image display element passes through the optical system, reflects multiple times in the light guide plate, and then reaches the eye. Various configurations of light guide plates have been proposed [1–7]. There are mirror types and hologram types of configurations for emitting light from inside the light guide plate. The mirror types have higher light utilization efficiency than the hologram types, making it easy to keep the image display device small, leading to small optical systems. In our opinion, the two major weaknesses of the mirror types are thickness and weight. Therefore, we emphasized thickness, weight, and light utilization efficiency when developing our light guide plate featuring a multi-stage micro-mirror structure [8].

Fig. 1 shows a perspective view (a) and side view (b) of the light guide plate. The 2.5-mm-thick plastic light guide plate can display an image with an FOV of 40° and can be mass-manufactured at low cost using injection molding.

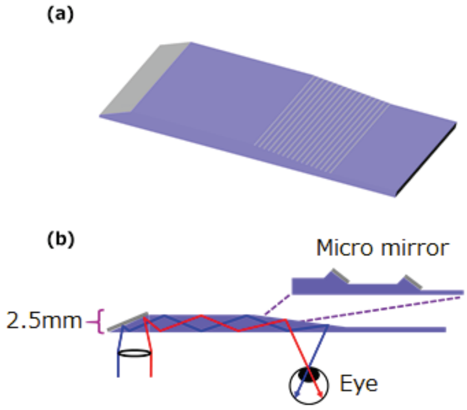


Fig. 1 Plastic light guide plate

Fig. 2 shows a prototype of the smart glass using the developed light guide plate. The prototype has a design similar to that of regular glasses. The total weight is 49.2 g, and the front weight is 27.2 g. The prototype is lighter than conventional smart glasses. The burden on the nose from the prototype is small, and a user can wear the smart glass throughout the day.

Fig. 2 Developed prototype

Fig. 3 shows an actual image produced by the smart glasses. We placed a blackboard behind the prototype and shot it with a camera.

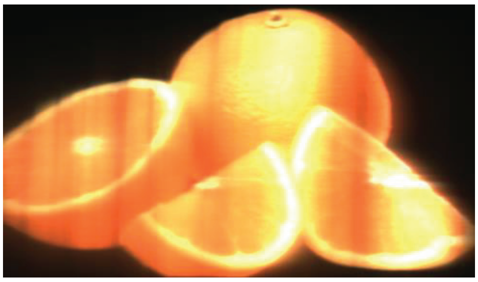


Fig. 3 An actual image produced by the prototype

In this report, we describe an optical system (intermediate image temple optical system) with a small diameter, which can effectively make the light incident on the light guide plate.

2 Problem

First, we explain the intermediate image temple optical system that we developed.

Fig. 4 shows a schematic of the conventional incident optical system for smart glasses and the developed intermediate image temple optical system. The conventional incident optical system consists of a display unit containing an image display element, collimator optical system, and light guide plate, making the front of the system heavier and larger. Therefore, we placed a relay optical system between the display unit and the collimator optical system to separate the display unit and light guide plate by a certain distance.

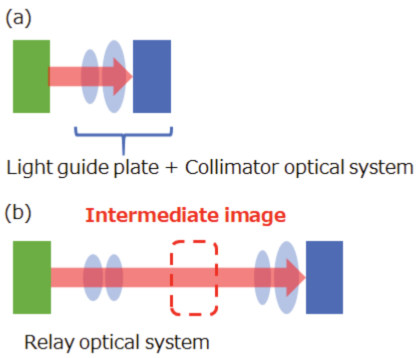


Fig. 4 Schematic (a) Conventional optical systems (b) Intermediate image temple optical system

Next, we explain the incidence of light on the developed light guide plate and explain the problems.

As shown in Fig. 5, which is in the section [Horizontal] of the side view of the light guide plate, the light incident on the light guide plate gets reflected by the mirror, totally reflected multiple times inside the light guide plate, and reflected by the multi-stage micromirror structure, before reaching the eye.

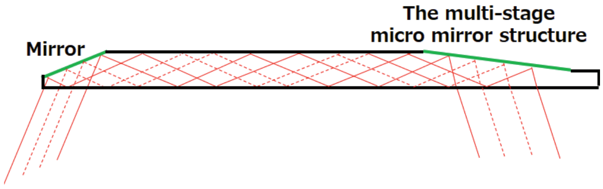


Fig. 5 optical path in the light guide plate

Fig. 6 shows the outline of the optical path when the light guide plate is replaced by a parallel plate. In the section [Vertical] that is orthogonal to the horizontal section, it is necessary to design such that the pupil of the collimator optical system matches the eye position. In the horizontal cross-section, it is necessary to design the pupil of the collimator optical system near the incident position of the light guide plate to narrow the incident range of the light guide plate. Furthermore, in the horizontal cross-section, the light must be properly incident on the light guide plate so that the light can reach the eyes.

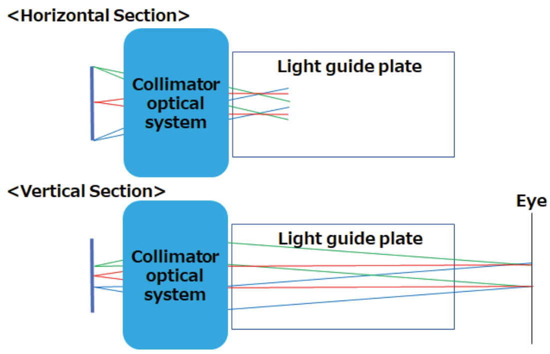


Fig. 6 Outline of the optical path

In the case of the developed light guide plate and conventional incident optical system, there is no problem. However, in the case of the developed light guide plate and intermediate image temple optical system, the problem that occurs is that the relay optical system becomes large (see Fig. 7).

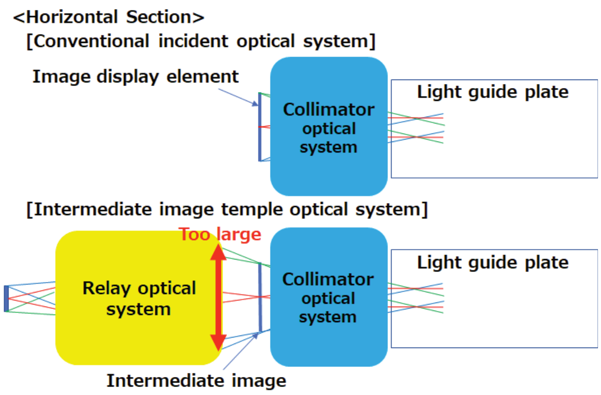


Fig. 7 Problem of large relay optical system

3 Intermediate Image Temple Optical System using the non-rotationally symmetric optical element

Parameters listed in Table 1 show that the developed optical system is lightweight and has a wide field of view.

Table 1. Specification of intermediate image temple optical system

	Specifications
Image Display Element Size	0.23type
FOV(Diagonal)	40°
Weight	5.64 g
Volume	8647 mm^3

Fig. 8 shows a cross-sectional view of the optical system of the developed smart glasses, as seen from above. The intermediate image temple optical system is composed of a display unit, relay optical system, non-rotationally symmetric optical element, and the collimator optical system from the image display element side. In this prototype, the non-rotationally symmetric optical element is a cylindrical lens.

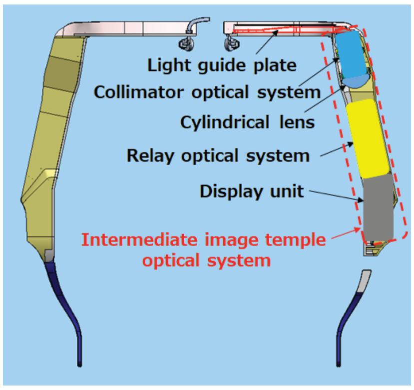


Fig. 8 Developed optical system

Fig. 9 shows the optical path diagram of the intermediate image temple optical system. Using a cylindrical lens, the pupil of the intermediate image temple optical system is aligned at the eye position in the vertical section, and the pupil of the intermediate image temple optical system is aligned near the incident position of the light guide plate in the horizontal section.

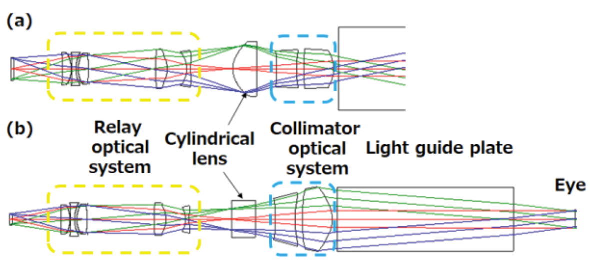


Fig. 9 Intermediate image temple optical system (a)Horizontal section (b)Vertical section

Designing an optical system without a cylindrical lens would approximately double the diameter of the relay optical system. (See Fig. 10)

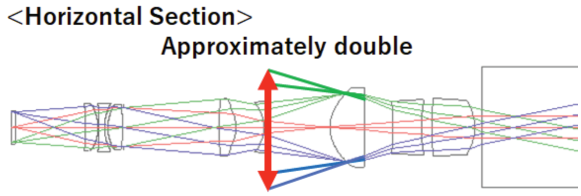


Fig. 10 Without using cylindrical lens

In the developed optical system, it was necessary to minimize the non-rotationally symmetric aberrations generated on that surface of the cylindrical lens. Therefore, the cylindrical surface was placed near the intermediate image.

Fig. 11 shows the modulation transfer function (MTF) of the optical system. The horizontal axis is the object height, and the vertical axis is MTF[6LP/deg]. The dotted line is the vertical resolution, and the solid line is the horizontal resolution. The MTF is calculated under the condition that an image is formed with an ideal lens. The intermediate image temple optical system can secure a high MTF.

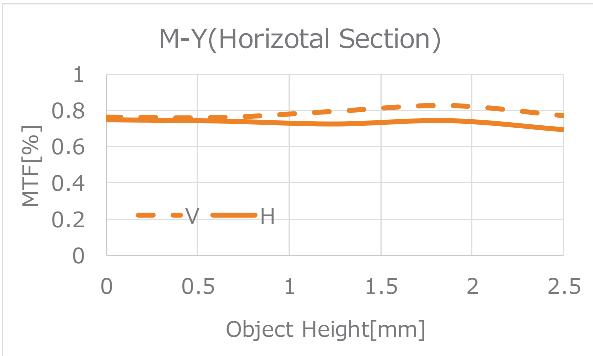


Fig. 11 MTF[6lp/deg] of intermediate image temple optical system

Next, we explain how light should be incident in the horizontal direction so that more light can reach the eyes. Fig. 12 shows the result of inverse ray tracing from the eye to the incident position of the light guide plate in the horizontal section. The horizontal axis represents the ray height at the incident position of the light guide plate, and the vertical axis represents the field of view. The light gray area is the light flux that passes through the incident position of the light guide plate when inverse ray tracing is performed from the eye at each field of view. More light can reach the eye if light is incident to cover the range of the red line (i.e., the required range).

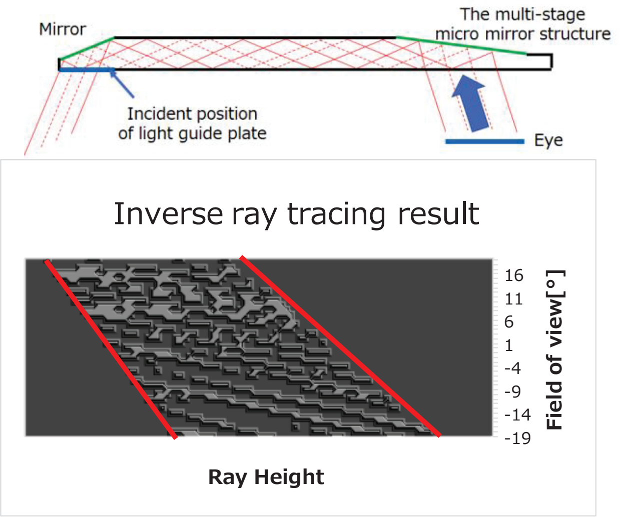
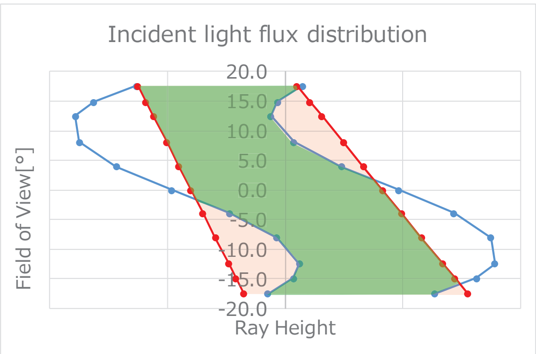
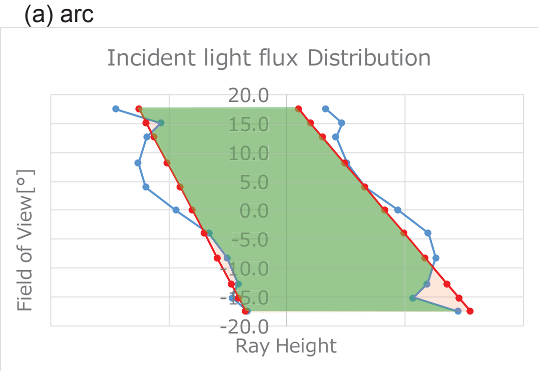


Fig. 12 Inverse ray tracing from the eye

We solved it by making the cylindrical surface non-arc. Fig. 13 shows the incident light flux distribution on the incident position of the light guide plate when the cylindrical surface is designed with an arc and a non-arc. The horizontal axis represents the ray height at the incident position of the light guide plate and the vertical axis represents the field of view. The range of the red line is the required range, the blue line is the incident light from the intermediate image temple optical system, and the green range is the range where the required range matches the incident light.



(a) arc



(b) non-arc

Fig. 13 Incident light flux distribution

If light can be incident along the required range, a lot of light can reach the eyes without requiring a larger optical system.
When the cylindrical surface is designed as an arc, the distribution of the incident light flux becomes S-shaped at the incident position of the light guide plate, and the effective light efficiency is 80%. Effective light efficiency is the ratio of the range in which incident light and required range match to the required range. When the cylindrical surface is designed as a non-arc, the effective light efficiency is greatly improved to 96%.

4 CONCLUSIONS

We have developed an intermediate image temple optical system using a non-rotationally symmetric optical element. The intermediate image temple optical system has a high MTF, brings more light to the eye, and has a small diameter.
In the future, we plan to develop various AR applications using this lightweight smart glass to provide users with a new experience.

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