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# New 3-D display that can display 3-D images at long distances and that can control their 3-D positions using changing size as a cue to depth perception

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ABSTRACT

This paper presents a new three-dimensional (3-D) display that can display 3-D images at long distances of tens or hundreds of meters in the depth direction and that can control their 3-D positions to meet new requirements for outdoor use. The proposed display uses changing size as a cue to depth perception, i.e., the smoothly expanding motion of virtual images formed with optical systems according to the forward movements of the users to display 3-D images at more distant positions in the depth direction than positions where virtual images are formed with optical systems because conventional 3-D displays that use binocular disparity are only able to display 3-D images at short distances in the depth direction. The feasibility of the proposed display was evaluated by subjective tests using a moving minivan in which observers viewed a test pattern that overlapped the real view ahead of the automobile observed through the windshield. The results obtained from the subjective tests revealed that the test pattern was observed at long distances over tens and hundreds of meters in the depth direction and that the position in the depth direction of the test pattern could be controlled by changing the rate at which the motion of the test pattern smoothly expanded. These results demonstrated that the proposed display was feasible.


## 1. Introduction

Three-dimensional displays have recently become widely distributed among consumers, and they are mostly used indoors. For example, consumers watch 3-D TV programs and play 3-D games in their homes and watch 3-D films in movie theaters. In addition to these indoor applications, outdoor applications have been increasing [1–5]; one of the most attractive of these applications is in automobile navigation systems, in which navigation information is displayed in the space in front of the windshield that overlaps the real scene [6–9]. Such navigation systems help drivers to intuitively and intelligibly obtain navigation information, whereas conventional systems, which use small displays and voice guidance, often confuse them. The most intuitive and intelligible way of displaying navigation information is to display 3-D images at the same positions in real space, such as intersections that are tens or hundreds of meters ahead. Therefore, 3-D displays for automobile navigation systems are required to display 3-D images in such wide spaces and to control their 3-D positions to avoid displaying them at different positions from the positions that are targets of navigation information.

There are two possibilities toward displaying 3-D images in wide spaces and controlling their 3-D positions. The first possibility is to use lenses with long focal distances to form virtual images at long distances in the depth direction. However, optical systems containing lenses with long focal distances are too large and are not suitable as on-vehicle navigation systems because large areas are necessary to accommodate them. The second possibility is to use 3-D displays because they can display 3-D images by controlling their positions in the depth direction. However, the conventional 3-D displays developed thus far cannot control the position at long distances over tens or hundreds of meters because those in practical use currently utilize binocular disparity as a cue for depth perception (see Appendix A). Therefore, the displays do not meet the requirements for automobile navigation systems.

This paper presents a new 3-D display that can display 3-D images at long distances in the depth direction and that can control their 3-D positions. First, we describe the principles underlying the proposed display that utilizes the smooth expanding motion of virtual images formed with optical systems according to the forward movements of users to display 3-D images at the farther position in the depth direction than the position where the virtual images are

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formed with optical systems. We then describe the results of experiments performed to evaluate whether the proposed display was feasible.

## 2. Three-dimensional display using changing size as a cue to depth perception

Changing size, which is in the basis of this study, is the smooth motion of retinal images caused by observer motion. For example, when observers move toward real objects, the retinal images of real objects are smoothly expanded. According to previous studies on human visual perception, changing size strongly affects the perception of distances in the depth direction [10,11].

Fig. 1 outlines the basic concept behind the proposed display. The automobile is moving toward an intersection. The distance in the depth direction from the user to the image that is formed with the optical system, which is denoted "*D*" in Panels A and B, is constant, i.e., "*D*" at Time 1 and "*D*" at Time 2 are equal. When the image that is formed with the optical system is smoothly expanded according to the forward movement by the automobile, i.e., when the image that is formed with the optical system at Time 2 becomes smoothly larger than that at Time 1, this smooth expansion produces the same smooth motion in the retinal image of the image that is formed with an optical system as the changing size of a real object at the intersection. We assumed that this smooth motion in the retinal image of the image that was formed with an optical system had the same effect as the changing size of the real object on the perception of the distance in the depth direction. That is, when the size of the retinal image of the image that was formed with the optical system was smoothly expanded at the same rate as the size of the image on the moving user's retina for the real object at the intersection, the image that the user observed was at the intersection (see Panel C).

Fig. 2 shows an example of the changing size of an image at a velocity of 60 km/h as a function of the distance to objects from observers. The changing size is calculated as

$$\theta_1 = 2 \times arctan \frac{W}{2 \times D}, \tag{1}$$

$$\theta_2 = 2 \times arctan \frac{W}{2 \times (D - V \times T)}, \tag{2}$$

and

$$CS = \theta_2 - \theta_1, \tag{3}$$

where *W* is the width of objects, *D* is the distance to objects from observers, and *V* is the velocity of observers. Here, *T* is the time for motion, and *CS* is the changing size. We defined the width as 2 m in our calculations, the velocity as 60 km/h, and the time as

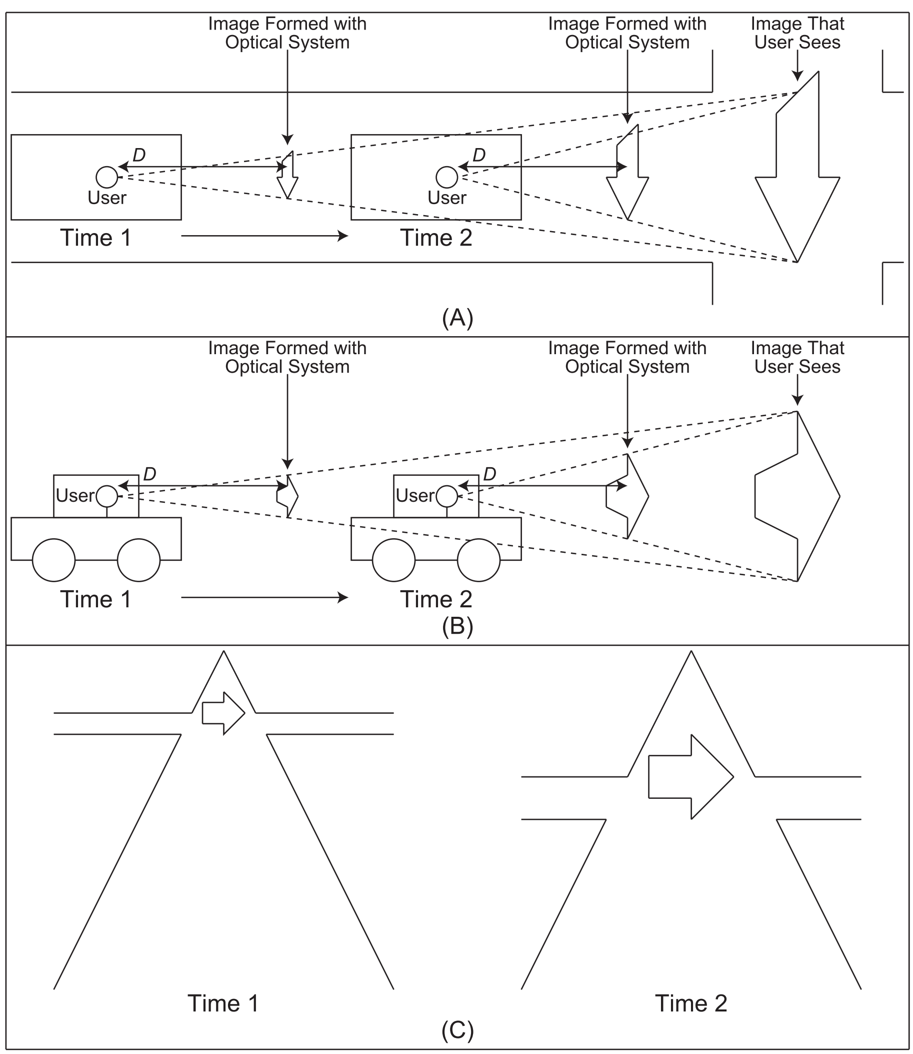


**Fig. 1.** Illustration of the basic concept of the proposed display. (A) Top view. (B) Side view. (C) User's visual perception.