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VISUAL NAVIGATION SYSTEM ON WINDSHIELD HEAD-UP DISPLAY

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ABSTRACT

We introduce a unique visual navigation system for car drivers in which important information is projected onto a windshield head-up display (WHUD). The display area of the WHUD is actually the whole windshield. We installed a prototype WHUD on a real vehicle and realized a new navigation system that can display direction and distance to a destination as visual cues. The primary advantage of the system is that the driver needs little eye movement to see them. The cues are easy for drivers to recognize because the sign position for the destination on the WHUD directly indicates the orientation toward it. A GPS and a geomagnetic sensor are used to estimate the vehicle's location and orientation, and data from these are used to move the navigation signs on the WHUD according to the vehicle's movements.

KEYWORDS
driver assistance, WHUD, navigation, visual support

INTRODUCTION

Drivers can obtain many kinds of information from their vehicle about its status, such as speed or fuel level. Furthermore, there are many kinds of driving support systems that provide drivers with live information like navigation information or live views from a rear-view camera mounted on the back of the vehicle.

Among the range of information given to drivers, visual information is useful because it is easy to understand, thus it can be recognized in a short time. In addition, it can convey detailed information to drivers. However, drivers have to move their eyes from the outside road scene to the inside monitor or meters in order to obtain this visual information, but such eye movement is sometimes unsafe especially when they are maneuvering.

A head-up display (HUD) is a useful device for providing visual information to a driver. A HUD is usually set just in front of the driver's seat near the windshield, making it possible for the driver to see the information displayed on it with little eye movement and with little refocusing. HUDs enable drivers to keep their eyes on the outside scene in front of their vehicle even when they need some critical driving information. Since the display area of conventional HUDs is small, advanced HUDs that feature wider display area have been developed [2] that are designed to use the whole windshield area as the display. We call this a windshield head-up display (WHUD).

In this paper, we describe our preliminary implementation of a WHUD on a real vehicle and introduce a new visual navigation system that displays information on the direction and distance to a destination on the WHUD.

IMPLEMENTATION OF THE WINDSHIELD HEAD-UP DISPLAY

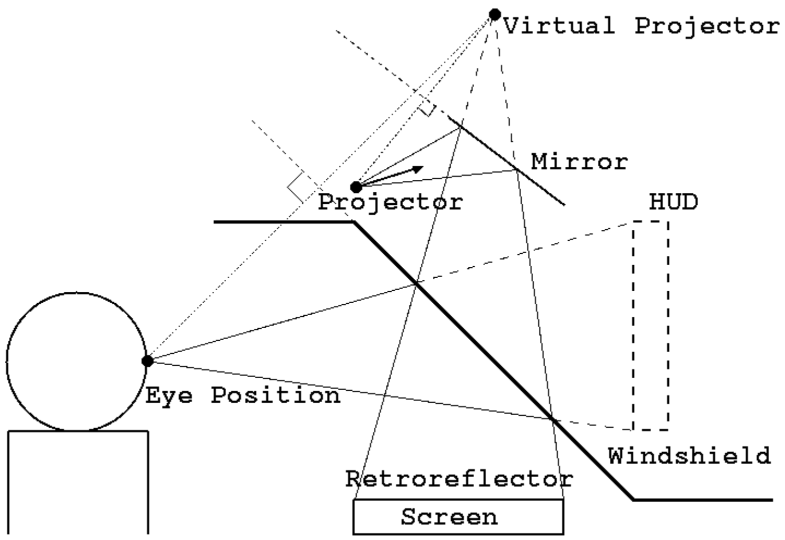

Figure 1 – Schematic design of the WHUD system. The light from the projector converges at the driver's eye position.

HUDs should be highly luminous and have a broad display area. In daytime, drivers should be able to see the displayed information on the HUD against strong light coming from outside.

Currently, most HUD applications are for nighttime use. To realize a brighter HUD, we designed the WHUD system shown in Fig. 1. In our system, the light from the projector converges at the driver's eye position. As the figure illustrates, a retroreflective material is spread on the dashboard. The projector is set on the roof of the vehicle and the light from it is projected in front of the vehicle and then reflected by a mirror so that it goes through the windshield. The retroreflector on the dashboard returns the light to the direction from which it came. On its way back to the projector, some of the light is reflected by the windshield. The reflected light will converge on a single point that is in an optically symmetric position to the projector. By arranging the position close to the driver's eye position, the driver can see a bright image from the screen together with the outside scene.

Our implementation makes installation and adjustment relatively easy, though a rather large structure has to be installed on the top of the vehicle. It also enables the HUD to have a wide display area. Fig. 2 shows photographs of the WHUD mounted on a vehicle.

Figure 2 – External view of the WHUD system. The right picture shows the high luminance and wide display area of the WHUD.

WHUD SETUP

Distortion correction

As seen in Fig. 2, an image projected onto the windshield is distorted because the windshield is not flat. To present an image with no distortion, we need an image-warping process. First, we assume that distortion caused by the windshield can be modeled by warping transformation function W. If an image I is projected, the driver observes an image $W(I)$, where W is a nonlinear function. It consists of a set of parameters, each of which defines the correspondence between a pixel in an original image given to the projector and a pixel observed by a camera at the driver's eye position. The transformation of the inner area of the correspondence points is interpolated by affine transformation. The procedure of distortion collection is as follows.

1. Project a grid pattern image on the WHUD.
2. Capture an image using a camera set at the driver's eye position.

3. Estimate parameters of W by recording the correspondence between the crossing points of the original grid image and that of the observed grid image. The parameters express the warping function W.
4. Calculate the inverse warping function W^{-1}.
5. Prepare an original image I, which should be observed linearly by the driver.
6. Make an image of $W^{-1}(I)$ that is going to be projected.
7. When the image $W^{-1}(I)$ is projected on the WHUD, the image is distorted at the windshield by the warping function W. Then the distorted image is warped as $W(W^{-1}(I)) = I$. As a result, driver can see the original image I on the WHUD.

Fig. 3 shows images of each stage of distortion correction when a grid image is to be projected.

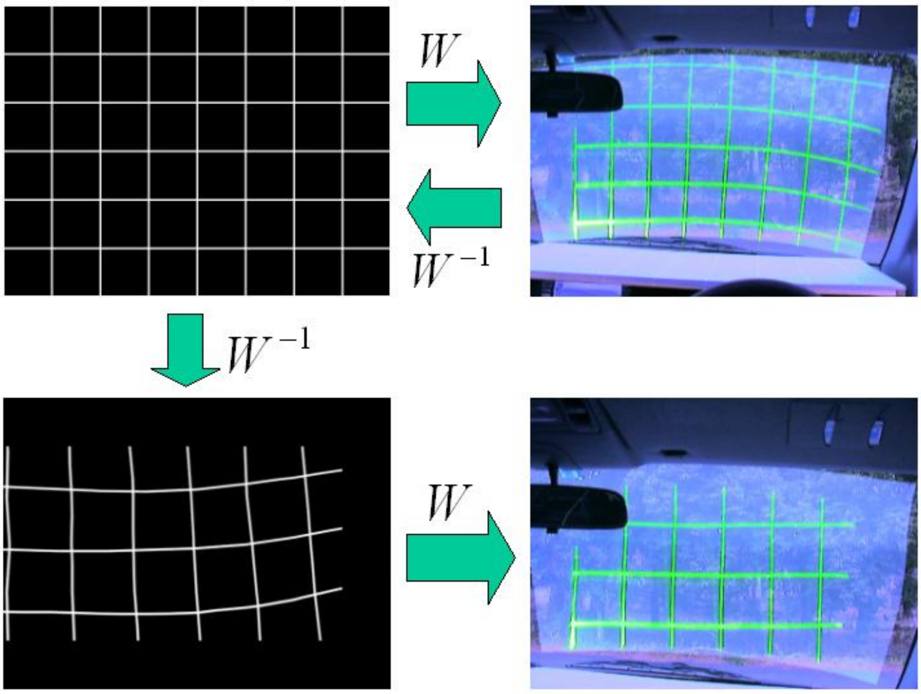

Figure 3 – Distortion correction process. Transforming an original image I (top left) with W^{-1} enables the driver to observe the original image I from the driver's position.

Direction control

Another important aspect is how to display an image at an arbitrary position. As the screen can be recognized as a simple planner image from the eye point of drivers due to the image-distortion correction, it is relatively easy to calculate the location x given the orientation to be shown to the driver. Suppose the width of the screen is w_{im} and the orientation angle is O when it is parallel to the vehicle's center axis. θ_{cam} denotes a field of view of the screen against the eye position. Then, given the orientation θ, x can be calculated using

$$x = \frac{\frac{w_{im}}{2}\tan\theta}{\tan\frac{\theta_{cam}}{2}}.$$

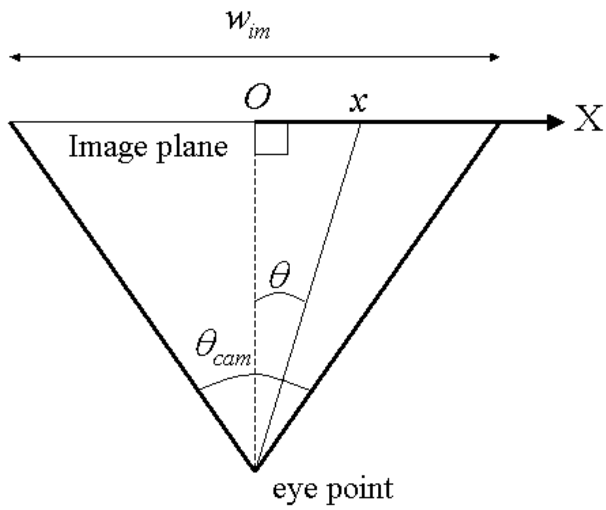

Figure 4 – Orientation from the eye point of a driver

VISUAL NAVIGATION ON WHUD

System overview

Here we introduce a visual navigation system as an application that uses the WHUD system. Drivers can see two types of visual information, “navigation flags” and “direction signs,” on the WHUD. Navigation flags show the name of a destination and the distance to it. The position of the navigation flag directly indicates the orientation to the destination, making it easy for drivers to recognize the direction in which to head. The position of visual information shifts as appropriate on the WHUD as the vehicle moves and makes turns because the orientation is calculated online. The direction signs show the directions of north, south, east, and west. Fig. 5 presents two snapshots of driving scenes with the visual navigation system running on the WHUD. The driver can see the displayed information clearly even in daytime.

The navigation flags have to be carefully placed on the WHUD to avoid their hiding an important portion of driver’s view of the road. To prevent distraction of the driver, navigation flags will not be placed on the road area in front of the driver’s vehicle; instead, they will be projected onto the upper or lower regions of the WHUD.

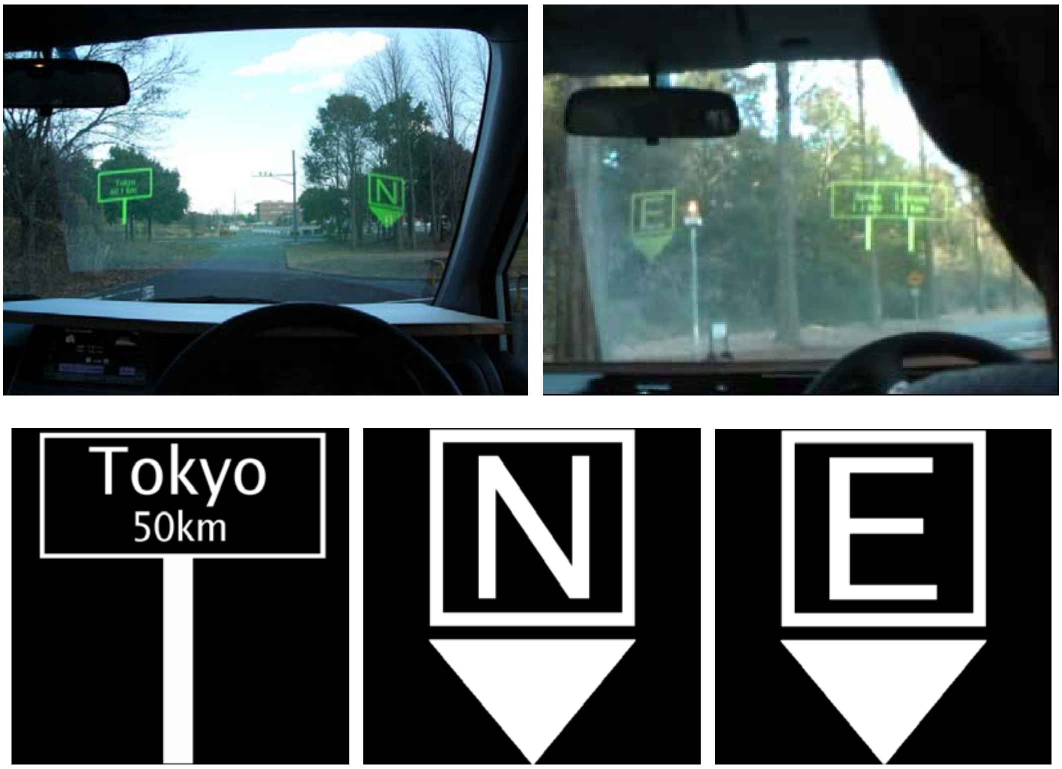

Figure 5 – Navigation flags and direction signs superimposed on a road scene show the orientation and the distance to a destination. The bottom three images are of the navigation flag and the direction signs.

System components

Our visual navigation system requires the WHUD, GPS, and a geomagnetic sensor. The vehicle's location is determined by the GPS, and its direction is estimated by the geomagnetic sensor. When the longitude and latitude of a destination are set, the system calculates the orientation θ and the direct distance L for the destination:

$$\begin{aligned}
\Delta x &= (\lambda_d - \lambda_{gps}) R \cos\phi_{gps} \\
\Delta y &= (\phi_d - \phi_{gps}) R \\
\theta &= \tan^{-1}\frac{\Delta x}{\Delta y} - \theta_{compass} \\
L &= \sqrt{\Delta x^2 + \Delta y^2}
\end{aligned} \quad ,$$

where $\theta_{compass}$ is the direction of the vehicle obtained by the geomagnetic sensor, λ_{gps} and ϕ_{gps} are the longitude and latitude obtained by the GPS sensor, λ_d and ϕ_d are that of the destination, and R is the radius of the earth. The formula above is a simple model but it can be used if the destination is not far from the vehicle's current position.

System performance

In this system, performance is important because if the frame rate is slow, navigation flags on the WHUD do not move smoothly. This causes a problem especially when the vehicle is making turns. Our system can update the images at the video frame rate of the graphics card of the PC that feeds images to the projector. The PC used has an Intel Pentium D 3.2-GHz processor and an ATI RADEON X300SE, enabling the system to achieve smooth movement of the navigation flags.

FUTURE WORK

Future work will involve conducting some experiments to evaluate the system's effectiveness and usability. Other work will include developing applications that use the WHUD. Since we have proposed mixed-reality navigation such Virtual Mirror [3] and Virtual Slope [4], they will be candidates to be realized on this system. Systems that emphasize hazardous objects could also be implemented if a driver-viewpoint camera is installed and images are accurately and quickly processed.

The accuracy of sensors in the navigation system, especially those for orientation estimation, is crucial because their precision directly affects the estimation of the navigation flags' orientation. Using a high-accuracy GPS, such as an RTK-GPS, the direction of the vehicle can be calculated by differentiating the position. We expect the accuracy to improve by combining an RTK-GPS and a geomagnetic sensor.

As for colors of images projected onto the WHUD, green can be observed well but other colors are faint. This is because of the material comprising the windshield, which cuts certain wavelengths of light. However, if we correct the projected colors, this problem can be avoided to allow many colors to be displayed.

Figure 6 – Experiment to show colors on the WHUD. Colors except for green are faint due to the material comprising the windshield.

CONCLUSION

In this paper, we have introduced a new visual navigation system that displays visual signs on a windshield head-up display, WHUD. The WHUD we have developed has a wide display area and high luminance, hence it can be used even during daytime. The distortion correction can cancel the distortion effect caused by a curved windshield. The navigation system we proposed projects visual signs (navigation flags) onto the WHUD, with which the driver can easily recognize information regarding the direction and the distance to a destination.

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