Transparent Cockpit: Visual Assistance System for Vehicle Using Retro-reflective Projection Technology

Takumi Yoshida * Kensei Jo † Kouta Minamizawa ‡ Hideaki Nii § Naoki Kawakami ¶ Susumu Tachi ‖

The University of Tokyo

Abstract

For safety and operability of drivers while operating a vehicle, it is very important to obtain a wide field of vision. However, the space available for setting up windows is limited. Therefore, we propose a "transparent cockpit," in which the image of a blind spot is displayed on the inner wall of the vehicle using a retro-reflective projection technology. In this system, the internal components of the vehicle, such as the doors and floor, are virtually transparent, and the blind spot is clearly visible, as observed from a window. In this paper, we describe the implementation of a prototype of the proposed system and demonstrate its effectiveness by an evaluation experiment.

Keywords: Augmented reality, display technology

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities

1 Introduction

Supporting technologies for vehicle operators have gained increasing importance with the technological progress of vehicles such as cars, airplanes, and helicopters. In particular, many studies have been conducted on visual assistance systems using cameras and image processing techniques, such as the traffic sign detection system[1, 2], blind spot monitor[5, 11], night view system[13], and HIR(Human-Oriented Information Restructuring) system[8, 14]. Moreover, the design and realization of augmented-reality-based vehicular assistance systems are proposed in recent years [7, 12].

The purpose of this study is to develop a visual assistance system that improves the safety and operability of vehicles. While operating a vehicle, it is very important to obtain a wide field of vision. However, the space available for setting up more windows is limited. Therefore, the vehicle has certain blind spots that may lead to accidents. Some studies have reported techniques for capturing these blind spots with cameras. In these techniques, images of blind spots are displayed on an in-vehicle display. However, in these techniques, some problems are encountered: first, the operator cannot pay attention to the surroundings when observing the display; secondly, it is difficult to display complete information about the surrounding environment due to size limitations of the in-vehicle display.

Therefore, we propose a "transparent cockpit", wherein the image of a blind spot is displayed on the inner wall of the vehicle using a retro-reflective projection technology (RPT) [3, 10]. Figure 1 shows the concept of our proposed system. In this system, the internal components of the vehicles such as the doors and seat, are virtually transparent as shown in Figure 2. Therefore, the blind spot is clearly visible, as observed from a window. RPT has been researched as a visual display method for augmented reality. Furthermore, a technique for optical camouflage using the RPT has been proposed [4]. We aim to realize our proposed system by applying the RPT to the vehicle cockpit.

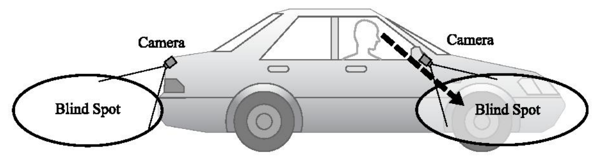

Figure 1: Conceptual drawing of our proposed transparent cockpit.

Figure 2: Implementation on a car:the door seems transparent.

A considerable number of projector-based augmented reality systems have been proposed[6, 15]. In such systems, the projection would have to take occur on a complex-shaped surface. Therefore, geometric compensation is necessary. On the other hand, a nondistorted image can be displayed on a complex-shaped screen by using the RPT. In addition, there is an advantage of not obstructing the usual view because the image is not presented on parts other than the retro-reflector.

In the conventional method of optical camouflage using the RPT, it is necessary to estimate the camera-to-subject distance. The scale and position of the subject are incorrectly displayed if the assumed camera-to-subject distance is different from the actual distance. However, blind spots at various distances comprise various types of subjects such as a walker, a guardrail, and buildings. Therefore, this is a critical problem for our proposed system. To overcome it, we propose a method to correct the image by measuring the camera-to-subject distance.

In this paper, we describe the features and principle of the transparent cockpit system. Then, we describe the implementation of the prototype system. Finally, we demonstrate the effectiveness of

*e-mail:takumi_yoshida@ipc.i.u-tokyo.ac.jp
†e-mail:kensei_jo@ipc.i.u-tokyo.ac.jp
‡e-mail:kouta_minamizawa@ipc.i.u-tokyo.ac.jp
§e-mail:hideaki_nii@ipc.i.u-tokyo.ac.jp
¶e-mail:kawakami@star.t.u-tokyo.ac.jp
‖e-mail:tachi@star.t.u-tokyo.ac.jp

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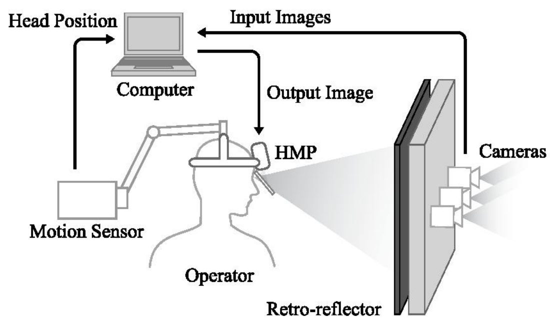

Figure 3: System configuration of transparent cockpit.

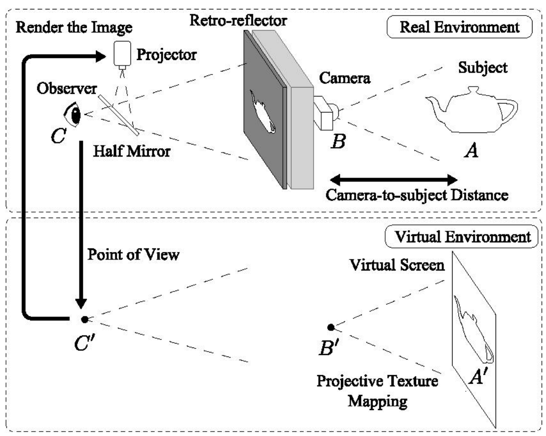

Figure 4: Concept of algorithm for rendering the image seen from the operator's view. A, B, and C correspond to A', B', and C', respectively.

our proposed system by the evaluation experiment.

2 Proposed System

Figure 3 shows the configuration of our proposed system. We positioned cameras outside the vehicle to capture the blind spots. The internal components of the vehicle, such as the doors and floor are covered with the retro-reflector. The operator switches on the head-mounted projector (HMP). The process flow of this system is as follows.

1. Cameras capture images of the blind spots.
2. They are loaded into a computer.
3. The operator's point of view and line of sight are measured using a motion sensor.
4. The camera-to-subject distance is measured by stereo matching.
5. The image as seen from the operator's point of view is rendered by the computer in realtime.
6. The image is projected onto the retro-reflector from the HMP.

Then, the image of the blind spot is displayed on the interior internal components of the vehicle. Therefore, these components are virtually transparent, and the operator can intuitively identify the surroundings. Thus, the safety and operability of the vehicle can be improved.

3 Principle

3.1 Rendering Algorithm

The algorithm for rendering the image seen from the operator's point of view is described below. First, we create a virtual environment on the computer as shown in Figure 4. The scale of the virtual environment is same as that of the real environment. Then, a virtual screen A' is set up in the virtual world. Next, the image captured by camera B is projected onto the screen from point B' using projective texture mapping [9]. The distance between B' and A' is equal to the camera-to-subject distance in the real environment. This process is repeated for each camera. Then, we measure the position of the operator's point of view (C). Finally, the image seen from C' is rendered.

Thus, we convert the images captured by the cameras into an image as seen from the operator.

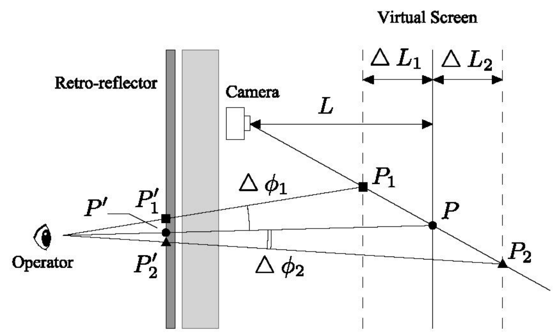

Figure 5: Gap($\triangle\phi_1$, $\triangle\phi_2$) between the subject(P_1, P_2) and the displayed image(P_1', P_2') caused by the position of the virtual screen.

3.2 Image Correction Algorithm Based on Camera-to-subject Distance

As described in section 1, it is necessary to estimate the camera-to-subject distance in the conventional method of optical camouflage using the RPT. Figure 5 shows the gap between the subject and the displayed image caused by the position of the virtual screen. When the subject is at P, P' is the correct point that should be displayed. However, if the virtual screen is shifted $\triangle L_1$ forward, the subject is displayed at P_1'. It should be noted that $\triangle\phi_1$ increases with $\triangle L_1$. This is also applicable to the case of $\triangle L_2$.

Therefore, we propose a method for correcting the image by measuring the camera-to-subject distance. We use the basic stereo matching algorithm to measure the distance.

In order to display information about the blind spot, we must reconstruct the 3D environment of the surroundings. However, in general, it is still very difficult to achieve such a reconstruction in real-time. Therefore, we only measure a distance in the direction of the operator's line of sight.

The algorithm of our proposed method is as follows. We select two cameras that capture the direction of the operator's line of sight. Then, feature points in the left camera image are detected. The epipolar lines in the right camera image are calculated. Next, we locate the corresponding points on these lines by pattern matching. The points closer to the direction of the operator's line of sight are selected. Subsequently, we measure the distances to the points by triangulation. Finally, the virtual screen is set up at the average distance, as mentioned in the previous section.

4 Implementation

We have developed a cockpit model and implemented the prototype system for the evaluation experiment (Figure 6). The shape of the cockpit is cylindrical, and its radius is 1 m in length. The wall and floor in the cockpit are covered with a retro-reflector (Reflite, 8318). There are 4 IEEE-1394 cameras (Point Grey Research, FireflyMV) outside the cockpit. Further, we use a 6 DOF motion sensor (Shooting Star Technology, ADL-1) for sensing the operator's point of view. We have developed a HMP by using a LED

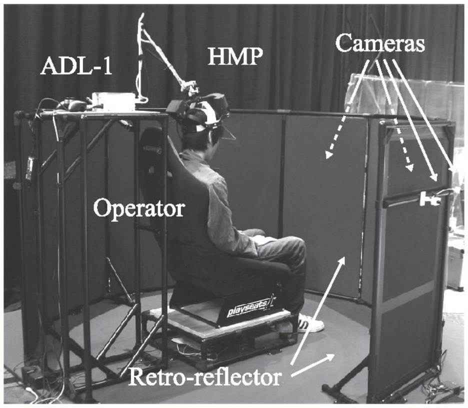

Figure 6: Prototype system of transparent cockpit.

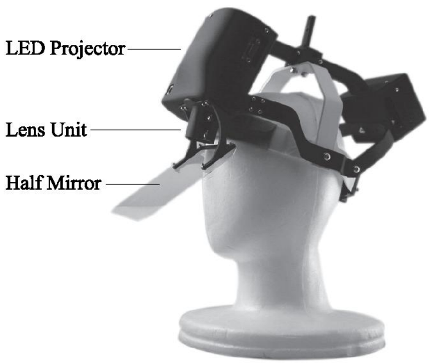

Figure 7: HMP:Head-mounted Projector.

projector (TOSHIBA, TDP-FF1)(Figure 7). It displays information only for the left eye. Table 1 lists the specifications of the prototype system.

Table 1: Specifications of the prototype system

Camera frame rate [fps]	30
Camera horizontal angle of view [deg]	80
Camera resolution [pixel]	640×480
HMP frame rate [fps]	60
HMP horizontal angle of view [deg]	60
HMP resolution [pixel]	800×600

5 Evaluation Experiment of Image Correction

5.1 Experiment Description

In section 3.2, we proposed the method for image correction based on the camera-to-subject distance. To show the effects of this method, we conducted the evaluation experiment using the prototype system. In this experiment, we measured the gap between the subject and the displayed image with and without correction.

As shown in Figure 8, we set a marker before the two cameras. The camera-to-subject distance was varied from 1 to 3 m. The distance between the HMP and the retro-reflector was 1 m. Then, we compared the results obtained with and without correction:

1. Without correction: The virtual screen is fixed at 2 m from the cameras.
2. With correction: The virtual screen and marker were shifted by the same distance using our proposed method.

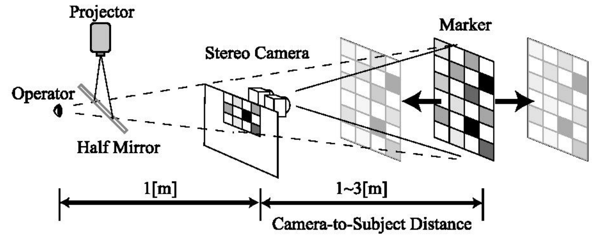

Figure 8: Experimental arrangement for evaluating image correction.

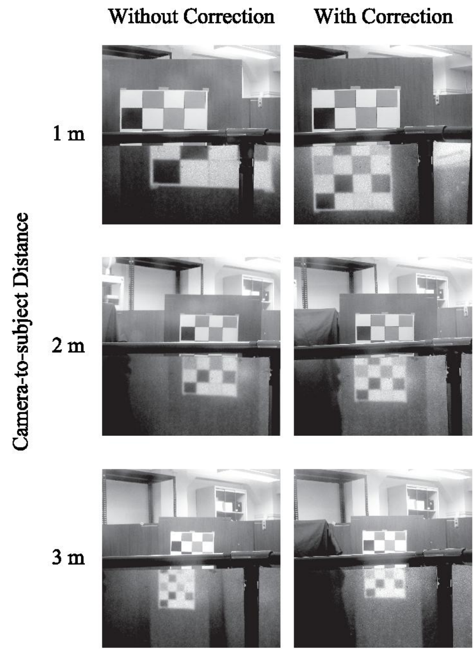

Figure 9: Comparison of the operator's view between without correction and with correction in the evaluation experiment.

The criteria for evaluation were (a) scale ratio, (b) horizontal angle error, and (c) vertical angle error of the marker and displayed image.

5.2 Experimental Results

Figure 9 shows the comparison of the operator's view between without correction and with correction in the evaluation experiment. In each image, the upper and lower halves show the real environment and retro-reflector on which the image is displayed, respectively. The result shows that when the marker is at a distances of 1 m and 3 m, there is a large gap between the marker and the displayed image without the correction. On the other hand, when the correction is applied, the displayed image comparatively fits the marker at any distance.

Figure 10 shows the data of the criteria for evaluation. The near 1 is superior at graph (a). The near 0 is superior at graph (b) and graph (c). The data of our proposed method with correction is superior in every graph. These experimental results further demonstrate the effectiveness of our proposed method.

5.3 Discussion

The gap in the image was improved by the proposed technique. However, the error margin still remains. As a cause of the error margin, it is thought that the coordinates of the virtual environment do not accurately correspond to those of the real environment. To

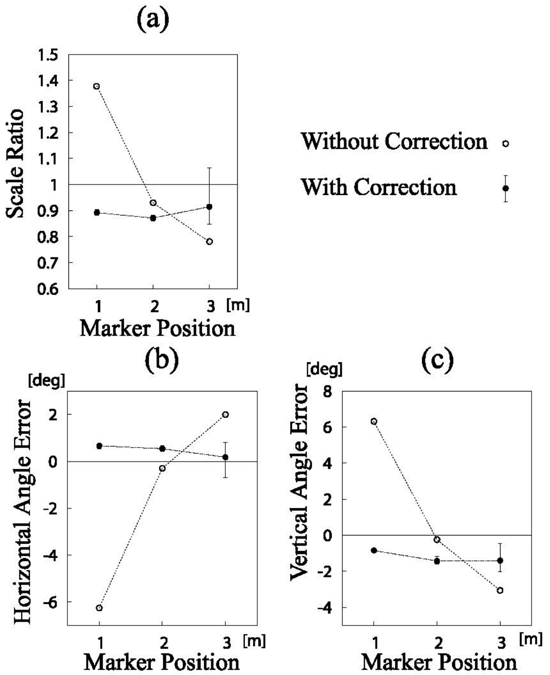

Figure 10: Results of the evaluation experiment.

Figure 11: Implementation of our proposed system on an actual car. The lower part of a person(left) and traffic signs on the road(right) are clearly visible, as seen from a window.

decrease the error margin, it is necessary to develop a calibration method and improve the accuracy of the stereo matching.

One of the problems encountered in the proposed system is that the displayed image is distorted when the subject is close to the cameras because the distance of subject is at distance too close for recognition. The area where the distance information can be acquired depends on the arrangement of the cameras. It is necessary to decide the arrangement of the cameras according to the application such as to cars, airplanes, or helicopters.

6 Test Run

We carried out a test run in order to demonstrate the effectiveness of our proposed sustem. We implemented the basic system on an actual car. We applied the retro-reflector to the passenger's door and dashboard. In this experiment, we used only one camera, and did not perform the image correction based on the camera-to-subject distance. The position of the HMP was fixed; and it was not worn by the operator.

Figure 11 shows the experimental result. As shown in Figure 11, the internal components of the car are virtually transparent, and the location of the blind spot is clearly visible. This result qualitatively demonstrates the effectiveness of our proposed system. The displayed image was bright enough in the daytime. But if it is dark outside, the displayed image darkens. So it is neccesary to adjust the brightness and the contrast of the image according to the situation.

7 Conclusion

In this paper, we proposed the visual assistance system for vehicle using RPT, named "transparent cockpit". This system enables the operator to observe the surroundings in the blind spot through the internal components of the vehicle. We developed the prototype system applying the image correction method based on the camera-to-subject distance. The result showed that the gap between the displayed image and real environment was improved by the proposal method. Finally, we implemented the limited system on an actual car and carried out a test run. Then we confirmed the effectiveness of our proposed sustem.

There still exist some gaps between the subject in the real environment and the displayed image. It is neccesary to improve the measurement accuracy of the camera-to-subject distance. In the future, we will implement the complete system in a vehicle to determine the improvement in the safety and operability of the vehicle.

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