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Floating Virtual Mirrors: Visualization of the Scene Behind a Vehicle

Toru Miyamoto, Itaru Kitahara, Yoshinari Kameda and Yuichi Ohta

Graduate School of Systems and Information Engineering, University of Tsukuba
1-1-1, Tennoudai, Tsukuba, Ibaraki, Japan.
miyamoto@image.esys.tsukuba.ac.jp, {kitahara, kameda, ohta}@iit.tsukuba.ac.jp
http://www.image.esys.tsukuba.ac.jp

Abstract. In this paper, we propose a visual assistance system that shows the scene behind a vehicle to its driver in the form of a virtual mirror by utilizing a surveillance camera. The virtual mirror will be displayed on a windshield display as if it were floating in the air in front of the vehicle. The driver entering an intersection can confirm the safety around the vehicle by checking the image in the virtual mirror while facing forward, because it shows the image of the scene behind the vehicle in an optically correct manner. We utilize a surveillance camera set up on a signal pole. The image in the virtual mirror was formed by applying geometric its transformation to the image taken by the camera so that it satisfy the optical constraints of a mirror.

1 INTRODUCTION

It is very important for drivers to confirm safety around and behind their vehicle when driving a car. To support drivers with new equipment by enhancing their vision, two conditions outlined below are important.

- There should be no or little blind area in images shown to drivers.
- Drivers should be able to instantly understand their spatial relationships relative to other objects by watching the images.

Rearview mirrors and door mirrors are usually used as visual assistance devices to allow the driver to see into blind areas. As people are familiar with such mirrors, they can easily recognize the spatial relationships relative to other vehicles and objects in the blind areas. However, use of these mirrors requires the driver to look aside, and the extent of eye movement can be quite large. In addition, there are some blind areas that the mirrors cannot show. Therefore, drivers require a new visual assistance device capable of showing the scene behind the vehicle without looking aside, so that it is possible to instantly understand the spatial relationships of the vehicle with other objects. In addition, such a visual assistance device should have no or little blind area.

We propose a new method to show the scene around and behind the vehicle in the form of a mirror by utilizing a windshield display device. The image of the scene is shown in a virtual mirror, which is displayed as if it were floating in front of the vehicle. The image on the virtual mirror is formed by applying geometric transformation to the image taken by a surveillance camera installed on a signal pole. The transformed image in the virtual mirror can be considered to be the same as that seen with a real mirror in the same position. Therefore, it is easy for the driver to recognize the spatial relationships of the vehicle to other objects.

In section 2, we discuss related works, section 3 presents an outline of the proposed system, and section 4 presents geometric transformation of an image to realize the virtual mirror. The results obtained with our preliminary imaging system in a real road environment are shown in section 5, along with a discussion of the benefits of the system. In section 6, we conclude the paper with a discussion of future work.

2 RELATED WORKS

In this paper, we report the development of a visual assistance system capable to show the driver the images of their vehicle with the surrounding scene. We assume that the image will be presented on a windshield display. The image is made from an image taken by a surveillance camera installed at intersections.

In this paper, we discuss the safety around intersections. There are a number of systems for displaying signs to drivers at intersections[7][8]. However, they present only symbolic information, such as road signs and signal status, without informing drivers of the dynamic status of the intersection. A report described research in which the whole traffic scene is displayed from the viewpoint of the air[11]. However, it is not easy to perceive the locations of objects in map-view relative to objects around the vehicle when driving. It is easy for drivers to recognize the spatial relationships of objects in our method that shows the blind area in the form of a mirror. An HUD (Head up Display) is an ideal display device for visual assistance on a vehicle as it can display information in conjunction with the driver's viewpoint. Among the HUDs available, we feel that a windshield display is a promising device for such a purpose. Such displays have already been used in real vehicle to show vehicle status, such as speedometer and gasoline gage readings. Dynamic visual information can also be displayed on the windshield[10]. An advanced research has been proposed for visualizing the area hidden by other vehicles on a windshield display by making a virtual slope based on images from a surveillance camera[9][12].

There have been a number of studies regarding different forms of virtual mirrors. For example, the blind area can be eliminated by extending side mirrors[5][6], and blind areas can be reduced at blind corners by utilizing a virtual mirror, where there are no real mirrors[1]. In the systems[5][6], an in-vehicle camera must be installed to obtain an image of the virtual mirror. Two cameras are needed to realize the virtual mirrors on both sides. Our method, however, does not require any in-vehicle cameras.

3 SYSTEM OVERVIEW

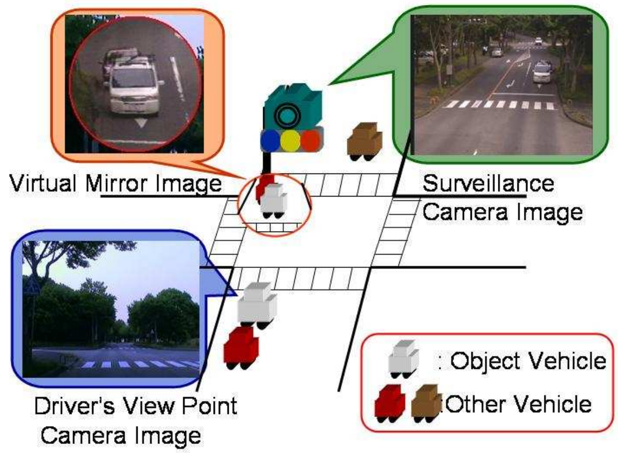

Fig. 1. Virtual mirror implementation

In this paper, we propose a new visual assistance system that can visualize the whole area around the vehicle near an intersection. The image of the area is shown in the form of a mirror, and is designed to present the virtual mirror on a windshield display. We call this "floating virtual mirror". The mirror image is made by processing images taken by a surveillance camera.

We assume that a surveillance camera is installed at an intersection, looking down on the road, and that it can send images of the area surrounding the driver's vehicle. This system can be realized by installing the surveillance camera on the signal pole at the intersection. The images taken by the surveillance camera are transmitted to the driver ' s vehicle over a wireless network around the intersection.

The image of the floating virtual mirror is presented on a windshield display, and therefore makes use of the driver's viewpoint for verification. Assessment of the floating virtual mirror is made using the driver ' s viewpoint camera image. This paper describes a visual assistance system in which the image seen by the driver ' s viewpoint camera is displayed on the windshield.

An outline of making the floating virtual mirror image is shown in Fig. 1.

Suppose the driver is in a white car and is approaching the intersection. Note that vehicles run on the left side of the road in Japan. The driver ' s view is as shown in the lower left sub-image in Fig. 1. Let us place a blue vehicle in the blind area around the driver ' s vehicle. The driver will usually attempt to confirm the safety of the area surrounding and behind the vehicle utilizing side mirrors, but may not be able to see the blue vehicle. A surveillance camera is installed alongside a signal device and looks down on the road as shown in the top right sub-image. Note that both the blue vehicle and the driver ' s (white) vehicle are captured in the same image taken by the surveillance camera. The image is transmitted, and warped to satisfy the conditions to allow recognition as a mirror. Finally, in the warped image, the corresponding image region that includes both the driver ' s vehicle and the surrounding area where the blue vehicle is located is trimmed and presented on the driver ' s viewpoint image. The top left sub-image in figure 1 shows a magnified view of the virtual mirror. The presented region may be perceived as a floating virtual mirror because it is placed in the air overlapping the surveillance camera in the driver ' s viewpoint image. The size of the virtual mirror can be changed arbitrarily.

If the synthesized image is shown on a windshield display, the driver will not need to move their eyes to see the virtual mirror. This is because the virtual mirror is placed just above the intersection to which the driver pays attention. In addition, the position of the virtual mirror depends on that of the driver ' s vehicle. For example, the virtual mirror moves upward as the driver approaches the intersection, and is rotated to face the vehicle consistently.

4 FLOATING VIRTUAL MIRROR

The virtual mirror shows the driver the scene around and behind their vehicle. As people are familiar with mirrors, e.g., the curvature of the mirror, they can instantly understand the spatial relationships between their vehicle and other objects in the blind area. A curved mirror cannot show some blind areas, but there are less blind areas that cannot be shown by the virtual mirror.

It is important to make the image of the virtual mirror so that it satisfies the conditions necessary to allow drivers to recognize it as a mirror. In this section, we first discuss the mirror conditions. Then, we describe the image processing to make an image of the virtual mirror and its position for display.

4.1 Mirror Conditions

To visualize the area around the driver ' s vehicle by the virtual mirror, we transform an image taken by a surveillance camera into an image like that projected through a mirror. To this end, two conditions should be satisfied between the driver ' s viewpoint and the surveillance camera. One is that both the driver ' s line of sight and the optical axis of the surveillance camera should share the same line. The optical axis of the surveillance camera should pass the driver ' s viewpoint because the eye level is not changed even if the eyes are rotated. The other is that the center of the virtual mirror should be located in the midpoint between the driver ' s viewpoint and that of the surveillance camera, and the virtual mirror should be orthogonal to this line. We call the two conditions " mirror conditions. " Fig. 2 shows these two conditions. Here, let $\boldsymbol{C}$ be a surveillance camera, and $\boldsymbol{C'}$ be a surveillance camera that satisfies the mirror conditions for the driver. $\boldsymbol{D}$ indicates the driver ' s viewpoint and $\boldsymbol{M}$ indicates the virtual

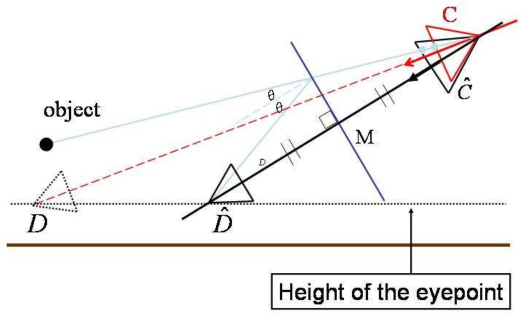

Fig. 2. Satisfying the mirror conditions, and projecting onto the plane.

mirror. 3D positions of the surveillance cameras are denoted as $\boldsymbol{P}_C$ and $\boldsymbol{P}_{C'}$, respectively, and that of the driver ’ s viewpoint is $\boldsymbol{P}_D$. The center of the virtual mirror is located at $\boldsymbol{P}_M$.

According to the mirror conditions, The center position of the virtual mirror $\boldsymbol{P}_M$ depends on both the surveillance camera position $\boldsymbol{P}_C$ and the driver ’ s viewpoint position $\boldsymbol{P}_D$.

$$\boldsymbol{P}_M = \frac{\boldsymbol{P}_C + \boldsymbol{P}_D}{2} \tag{1}$$

Let us define a point on the virtual mirror $\boldsymbol{P}_O$. The location of the virtual mirror can be defined as equation (1) and (2). The virtual mirror is displayed in a direction perpendicular to the midpoint of the segment between the driver ’ s viewpoint and the surveillance camera.

$$(\boldsymbol{P}_O - \boldsymbol{P}_M) \cdot (\boldsymbol{P}_C - \boldsymbol{P}_D) = 0 \tag{2}$$

Our proposed virtual mirror meets the mirror conditions between the driver ’ s viewpoint and the surveillance camera if we can prepare the camera $\boldsymbol{C'}$ in Fig. 2 and 3. Here, we call the driver ’ s viewpoint that meets the mirror conditions the ideal driver ’ s viewpoint. Let this point be $\hat{\boldsymbol{D}}$. In addition, the driver ’ s viewpoint exists on the optical axis of the surveillance camera. Thus, the driver can visually confirm the safety of the situation around and behind the vehicle while facing forward, as shown in Fig. 3.

As shown in Fig. 3, drivers can see the image as a mirror only if the image from the surveillance camera is inverted appropriately, because it satisfies the mirror conditions. However, as a surveillance camera $\boldsymbol{C}$ is usually fixed and the eye level is fixed, there is only one point $\hat{\boldsymbol{D}}$ where the inverted image of the surveillance camera can be used directly as a mirror image according to the mirror condition-1 (shown in Fig. 3). If the driver ’ s viewpoint is not on $\hat{\boldsymbol{D}}$, the mirror condition-1 cannot be satisfied (shown in Fig. 4). As shown in Fig. 4, the driver cannot instantly understand the spatial relationships between the vehicle

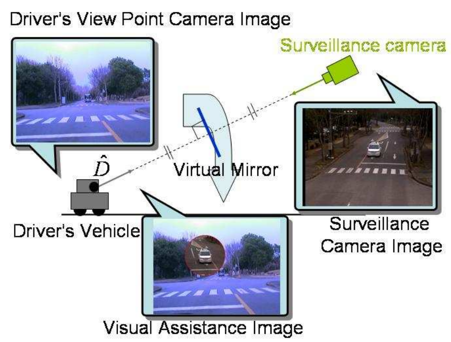

Fig. 3. Positional relationship between the driver's viewpoint and the surveillance camera when "mirror conditions" are met

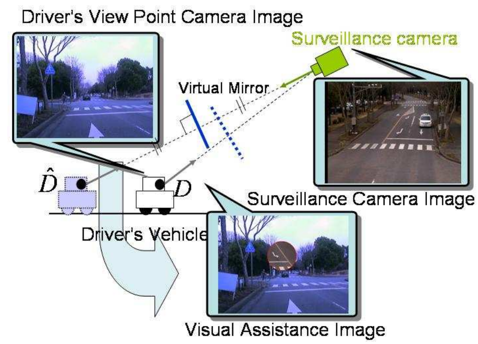

Fig. 4. Positional relationship between the driver's viewpoint and the surveillance camera when "mirror conditions" are not met

and other objects when watching the image of a virtual mirror that does not satisfy the mirror condition.

4.2 Generation of Virtual Mirror Image

To meet the mirror conditions for any viewpoint $\boldsymbol{D}$ at a given height, we transform the surveillance camera image into an image in which the driver's viewpoint is projected in the center. In Fig. 2 as the optical axis of $\boldsymbol{C}$ does not pass $\boldsymbol{P}_D$, the image cannot be used as the image in the virtual mirror. Hence, we introduce a new camera position, $\boldsymbol{C'}$, which is obtained by rotating $\boldsymbol{C}$ to allow its optical axis to pass $\boldsymbol{D}$.

It is well known from the literature regarding computer vision that if the camera is modeled by perspective projection, the image warping effect of camera rotation around its focal point can be described by two-dimensional projective transformation[3]. Suppose $\boldsymbol{u}$ is a point on the image plane $\boldsymbol{C}$, $\boldsymbol{u'}$ represents a point on that of $\boldsymbol{C'}$. Let us denote their homogeneous coordinates as $\hat{\boldsymbol{u}}$ and $\hat{\boldsymbol{u'}}$, respectively. The two-dimensional projective transformation can project one image plane onto another, and can be described as:

$$\lambda \tilde{\boldsymbol{u'}} = \boldsymbol{H}\tilde{\boldsymbol{u}} \tag{3}$$

where λ is a scale factor and $\boldsymbol{H}$ is the two-dimensional projective transformation matrix.

In this study, we generated an image that satisfies the mirror conditions only by rotating the camera virtually. $\boldsymbol{H}$ is determined if it can compute a rotating angle from $\boldsymbol{C}$ to $\boldsymbol{C'}$, as shown in Fig. 2. That is, $\boldsymbol{H}$ can be computed if the driver's viewpoint $\boldsymbol{D}$ is determined. The 3D position of $\boldsymbol{D}$ is estimated by utilizing RTK-GPS. Standard deviation of measurement by RTK-GPS could be less than 10 cm.

First, we computed the 2D position of $\boldsymbol{D}$ in an image using the 3D position of $\boldsymbol{D}$ estimated by RTK-GPS. Let the position in the image be $\boldsymbol{I}_D$. Although $\boldsymbol{H}$ has 9 elements, $\boldsymbol{H}$ has 8 degrees of freedom because there is an undetermined scale factor λ in equation (3). Therefore, four pairs of corresponding image points on camera $\boldsymbol{C'}$ are needed to determine the two-dimensional projective transformation.

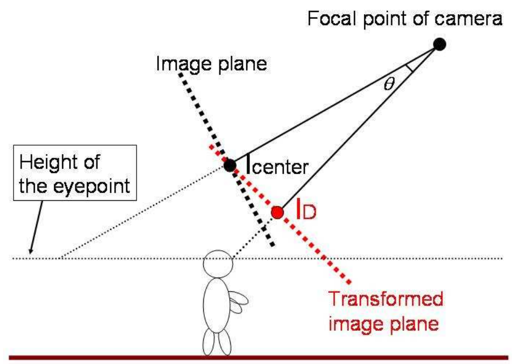

Fig. 5. Outline of calculating the two-dimensional transformation

However, in our approach, only one pair of image points is needed to find a correspondence on the image plane of $\boldsymbol{C}$ and $\boldsymbol{C'}$ because the focal length f of the camera is known. We use the pair $\boldsymbol{I}_D$ on $\boldsymbol{C}$ and the image center of $\boldsymbol{C'}$.

Examples of image processed by the two-dimensional projective transformation are shown in Fig. 6 to Fig. 8. In Figs. 7 and 8, the output image is successfully eliminated utilizing the two-dimensional projective transformation.

4.3 Location of Virtual Mirror

As $\boldsymbol{P}_C$ is fixed, $\boldsymbol{P}_M$ is moved in conjunction with the movement of the driver's viewpoint $\boldsymbol{P}_D$ (See Equation (1)). From the driver's viewpoint, $\boldsymbol{P}_M$ is placed to hide the position of the surveillance camera $\boldsymbol{P}_C$ and the mirror is moving back at half speed as the driver approaches the camera. As a result, the virtual mirror appears as if it is floating in the air. Note that the optical features of a mirror are completely preserved on the floating virtual mirror so that the driver does not have any difficulty in recognizing the spatial relationships of the objects in the mirror.

Fig. 6. Input image.

Fig. 7. Output image when the camera is rotated virtually using the two-dimensional projective transformation.

Fig. 8. Output image when the camera is actually rotated.

5 EXPERIMENT

5.1 Experimental Environment

We set up a surveillance camera C and a wireless Local Area Network in an intersection in the campus of University of Tsukuba. We set the driver's vehicle going into the intersection. The surveillance camera was installed at 5 meter high on the pole, which is almost the same height of traffic signals in Japan. The surveillance camera was directed to look down the lane in which the driver's vehicle was approaching. The 3D position and orientation of the surveillance camera $\boldsymbol{P}_C$ had been calibrated in advance.

Inside the vehicle, we set up a driver's viewpoint camera at driver's eye point for verification.

On conducting the experiment, both the surveillance camera and driver's viewpoint camera are used to record images. In addition, the position of the driver's vehicle $\boldsymbol{P}_D$ is recorded by utilizing RTK-GPS.

5.2 Image Acquisition and Visual Assistance Image

Fig. 9. Surveillance camera image.

Fig. 10. Driver's viewpoint camera image.

Fig. 11. Source of virtual mirror image.

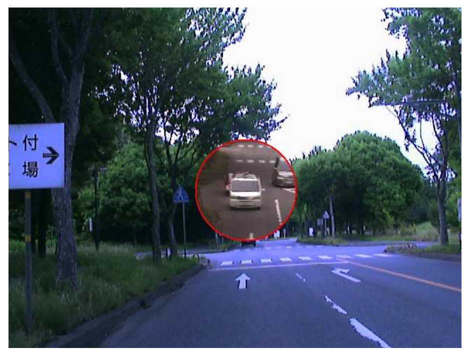

Fig. 12. Virtual mirror imposed to driver's viewpoint camera imae.

Fig. 9 is an image recorded by the surveillance camera. The white vehicle in Fig. 9 is the driver's vehicle in this experiment. As shown in Fig. 9, the driver's vehicle does not exist on the optical axis (image center) of the surveillance camera $\boldsymbol{C}$. In other word, it cannot be used as an image in the virtual mirror directly.

Fig. 10 shows the image from driver's viewpoint camera. The driver sees the road in this manner. In the middle of the image, there are the pole and the surveillance camera.

We conducted two-dimensional projective transformation to Fig. 9 to meet the mirror conditions. The warped image is shown in Fig. 11. In Fig. 11, the driver's vehicle is reprojected at the center of the image plane of the camera $\boldsymbol{C'}$. In other word, it meets the mirror conditions because the driver's vehicle exists on the optical axis of the surveillance camera.

Then, finally, a region around the driver's vehicle is trimmed and it is superimposed in the driver's viewpoint camera image. The result is shown in Fig.

12. A position of the virtual mirror is determined by equation(1)). The size of the floating virtual mirror can be changed arbitrary. Note that the driver can easily check the area around his/her vehicle, including both the side area and the rear area simultaneously by watching the floating virtual mirror. In addition, the driver can instantly recognize where the objects are if they exist because it surely works as if it were a normal mirror. Therefore, the driver can confirm the safety of the surrounding area of the driver's vehicle when he/she drives. The other results are shown in Fig. 13. The images are made for the different locations along the lane.

In our current implementation, there might be a possibility of hiding some objects behind the virtual mirror in a traffic scene, which can be seen under normal circumstance (shown in Fig.12). For example, the virtual mirror may hide the traffic signal if it is set close to the signal device. Therefore, we consider showing additional information with the virtual mirror, i.e. a virtual mirror with visual signal sign display.

6 CONCLUSION

In this paper, we proposed a new visual assistance system that can visualize the whole area surrounding a driver ' s vehicle in the form of a mirror by utilizing images taken by a surveillance camera. The virtual mirror is very effective for recognizing the scene around the vehicle because the virtual mirror acts as if it were a real mirror.

We clarified the mirror conditions that must be satisfied in making an image in the virtual mirror, and presented an image processing algorithm to realize the virtual mirror. The results of this experiment indicated that our approach is promising as a visual assistance system for drivers.

In future works, it will be necessary to combine the virtual mirror and the information hidden by the virtual mirror. It is also very important to implement this scheme on a vehicle and to conduct on-line tests for subject evaluations.

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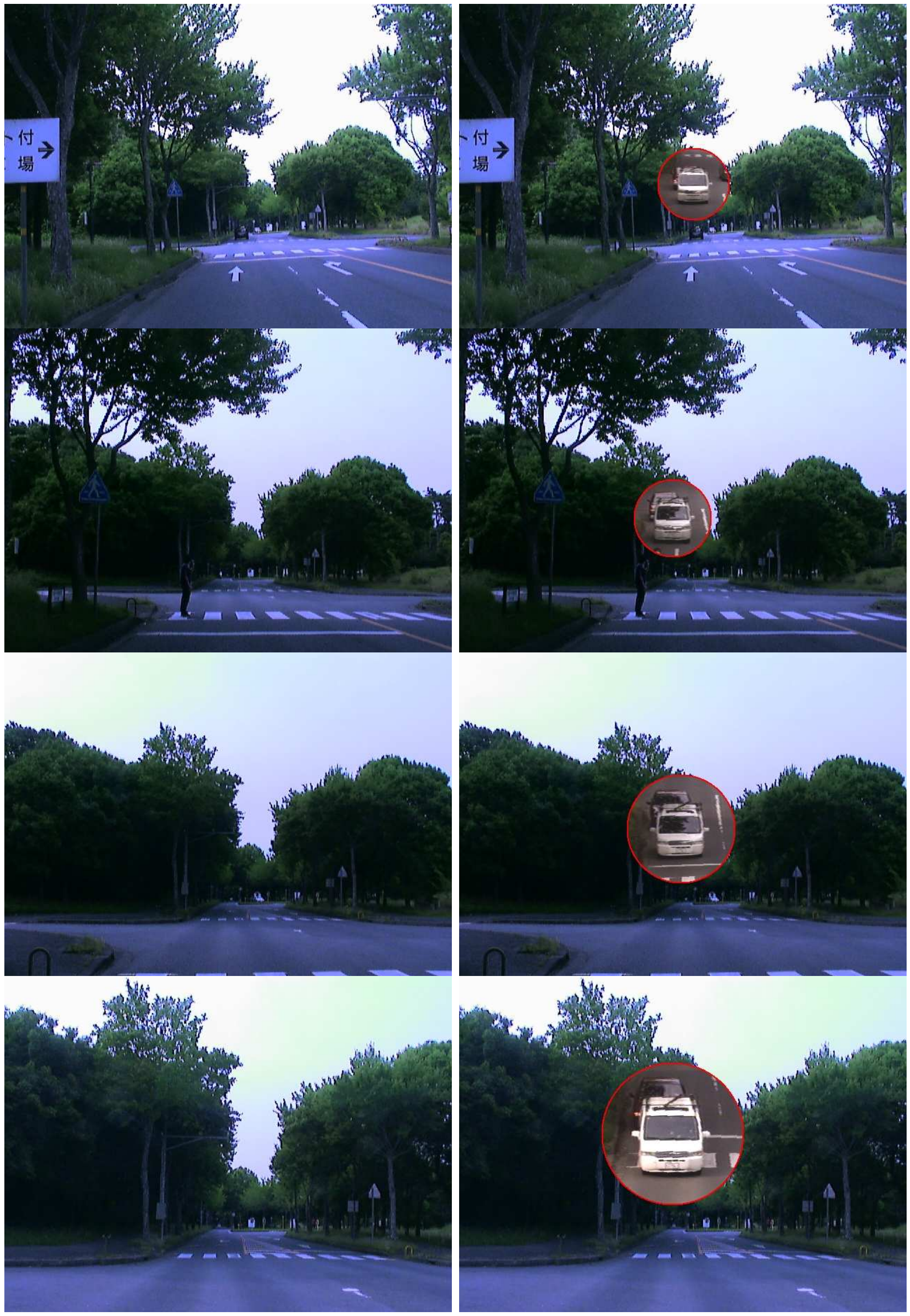

Fig. 13. Example of the visual assistance system. Driver's viewpoint images (left), and visual assistance images (right). The radius of the mirror was seto to 1.5m. The driver's vehicle was approaching to the intersection.