Revised version

NaviView: Visual Assistance by Virtual Mirrors at Blind Intersection

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***Abstract*— We propose a vision support system "NaviView" as visual assistance for safe driving based on Augmented Reality technique. "NaviView" is a system to realize visual assistance for drivers by utilizing images obtained from roadside surveillance cameras. In this paper, we propose virtual mirrors that display geometrically reshaped images taken from the surveillance cameras to support safe driving at a blind intersection. We proved the usefulness of the proposed method by comparing virtual mirrors with normal mirrors at a blind intersection under CG simulation environment.**

I. INTRODUCTION

The idea of visual assistance for drivers is to provide drivers an enhanced vision so that they can detect and recognize hazardous objects earlier than the objects actually come up to them. As the visual assistance does not take over the role of object recognition process, it does not suffer from faulty recognition results that are inevitable even in advanced researches[1][2].

We have been proposing a system "NaviView" that visually assists drivers to recognize objects in dead zones by providing images of them. The images of dead zones can be obtained by surveillance cameras that have been increasingly installed on roadsides these days. Drivers can recognize the objects in the dead zone by watching the images. The images are shown on a display device in their vehicle.

When images of surveillance cameras are provided to drivers, how to present the images to be recognized easier is an important problem. We have been working on visual assistance systems for various situations [3][4]. HIR system[5] has also been proposed as a visual assistance system.

In this paper, we propose a new method that shows images of surveillance cameras as a form of virtual traffic mirrors. Traffic mirrors are widely used at blind intersections. Imitating the form of traffic mirrors will lead to less mental burden of drivers. Consequently, drivers can easily recognize objects coming from dead zones by finding the objects in a virtual mirror. In order to realize the virtual mirror, video images from surveillance cameras are geometrically reshaped based on Augmented Reality techniques.

In the rest of this paper, we first discuss visual assistance methods at blind intersections and then describe the method to generate images. After that, we show the experimental results of our method.

II. VISUAL ASSISTANCE AT BLIND INTERSECTION

A. Normal Traffic Mirror

In ordinary traffic environment, traffic mirrors are installed at blind intersections. They indirectly cover dead zones hidden by walls or buildings. By traffic mirrors, detection delay of objects in dead zones can be shortened. Since the detection delay is a main factor of traffic accidents, traffic mirrors are considered to be useful in many situations. However, traffic mirrors still have dead zones, and some traffic accidents are caused by the dead zones.

B. Form of Geometric Transformation

To avoid traffic accidents, it is necessary to let drivers detect and recognize objects in dead zones as early as possible. In order to speed up the detection and recognition, we propose a vision support system by which images of surveillance cameras are reshaped and shown to drivers.

The images shown to drivers are reshaped by geometric transformation. We examine three reasonable forms of geometric transformation and discuss their merits and demerits. Geometric transformation can be classified into three forms.

1) No transformation (original images)
2) Transformation for driver's viewpoint
3) Transformation for fixed viewpoint

Form 1) directly uses the original images obtained by surveillance cameras. This is the simplest method and whole area in the image can be used. However, since the locations of surveillance cameras are generally different in each intersection, it is sometimes difficult for drivers to understand the spatial relationship between the location of the camera and their current viewpoint in the intersection. It may cause the detection delay.

Form 2) is a method to display images as if they were taken from the viewpoint which moves with the driver's motion. An example is a virtual camera that is always located several meters ahead of the vehicle and is directed right or left. This virtual camera is really useful to check crossing streets at blind intersections and it can shorten the detection delay. However, it is usually difficult to prepare roadside surveillance cameras that can provide sufficient image materials to synthesize the images of such virtual camera because the virtual camera changes its location as the vehicle runs.

Form 3) is a method to display images as if they were taken at a certain fixed viewpoint at intersections, regardless of the actual location of the surveillance cameras. In this method, it is not necessary to measure the eye position of the driver because the virtual viewpoint is fixed against intersections. It is important to determine the appropriate position of the virtual viewpoint in intersections so as to shorten the detection delay. For example, the virtual viewpoint should provide wider view at the roads of the intersection. Providing the image materials for synthesizing the images from the virtual viewpoint of Form 3) is relatively easy by using Augmented Reality techniques because the virtual viewpoint and the real surveillance cameras are all fixed.

C. Display Device

The most important issue in selecting a display device for visual support is whether drivers can confirm the images safely in a short time or not. The device should satisfy the requirements shown below.

a) Less eye movement
b) Less burden of using/wearing the device
c) Wider viewing angle so that drivers can see any direction

A Windshield Display (WSD) is a device that can show images on a windshield. It satisfies all the requirements from a) to c).

III. VIRTUAL MIRRORS

In this paper, we propose three types of virtual mirrors; VM1, VM2, and VM3. The first one corresponds to Form 1) while VM2 and its improved version VM3 correspond to the idea of Form 3). Since the idea of Form 2) requires a number of image sources as the user's vehicle runs, we do not think it is practical and we do not deal with it.

A. VM1: Monitor Mirror

This is a method based on Form 1). Original images obtained by a surveillance camera are displayed on the mirror area of a virtual mirror. This is the simplest method. Drivers will see the mirrors as if they saw surveillance camera monitors on roads. To realize this, we set assumptions shown below.

I) When a 3D point X of a virtual object is mapped to x on the image plane of the display device by projection matrix P_D, drivers see the virtual object as if it were in the real world. P_D is defined by the eye position of a driver.
II) Surveillance camera i takes images of the intersection by using a perspective projection matrix P_i.

When assumptions I) and II) are both true, a point X is mapped to x_i on the image plane of a surveillance camera i by:

$$x_i = P_i X$$

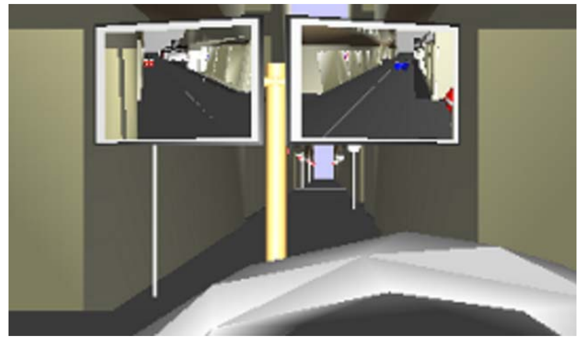

Fig. 1. Virtual Mirror VM1

Then the relation between x and X can be expressed by x_i and a homography matrix H_{VM1}.

$$x = H_{VM1} x_i = H_{VM1} P_i X$$

H_{VM1} is defined by both P_D and the location of the virtual mirror in the real world. P_i is determined uniquely by the location of the surveillance camera i in the intersection. In order to estimate H_{VM1}, four corners of the mirror on the image plane of the display device should be specified when the eye position of the driver is given.

Fig.1 is an example of VM1. The advantage of VM1 is that the whole area of the video surveillance image is visualized. Dead zones caused by VM1 depend on the location of the surveillance camera in an intersection.

B. VM2: Virtual Mirror based on Virtually Fixed Camera

This is a method based on Form 3). This method generates images that do not depend on the location of real surveillance cameras. Drivers can see images as if surveillance cameras were always at a same location in every intersection. To realize this method, we set assumptions III) and IV) in addition to I) and II).

III) Objects in the real world exists on a flat road surface.
IV) Virtual surveillance camera V takes images of the intersection by using a perspective projection matrix P_V.

When the assumptions are all true, a point x on the display device is computed as follows.

$$x = H_{VM2} x_i = H_{VM2} P_i X$$

H_{VM2} is a homography matrix defined by P_D, P_V, and the location of the virtual mirror. If the location of the virtual surveillance camera is given, P_V is determined uniquely. H_{VM2} is estimated by locating four points, which are on a plane (e.g. road surface) in the real world, on the image plane of the display device.

One problem of this method is that the visible regions may become smaller depending on the relation between P_i and P_V. Another problem is that target X needs to exist on a flat surface.

Fig.2 is an example of generating VM2. The 3D location of this virtual surveillance camera (◎ in Fig.3) is just above

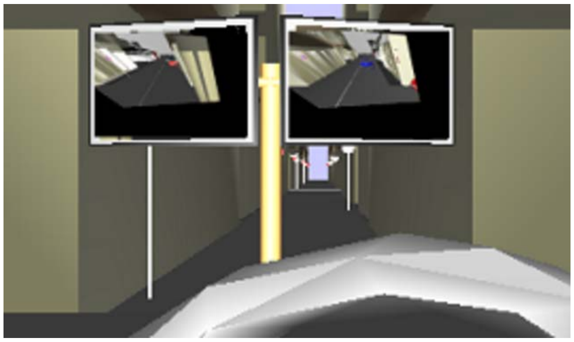

Fig. 2. Virtual Mirror VM2

Fig. 3. Location Of Surveillance Cameras

the center of the lane. It is directed to face the lane and it can take images of the intersection on which drivers can see coming vehicles. Note that the vanishing point of the lane will always be found at the same position in the virtual mirror of VM2.

As mentioned before, the advantage of VM2 is that it can provide fixed unique view of intersections because the image is synthesized as if it were taken at a virtual fixed viewpoint. Drivers do not need to imagine the actual locations of real surveillance cameras. On the contrary, VM2 has a disadvantage that it may include black-out regions due to the possible lack of image source for the regions. Fig.2 is the case that the image of a surveillance camera located at ① in Fig.3 is reshaped to the image of a virtual surveillance camera located at ◎ in Fig.3. The black-out regions indicate the space that the surveillance camera ① can not cover.

C. VM3: Virtual Mirror based on Virtually Relocated Camera

This is an improved method based on VM2. This method can eliminate the disadvantage of VM2 and it can reduce the black-out regions. The size of black-out regions depends on the spatial relationship between a virtual surveillance camera and a real surveillance camera. This method sets a virtual surveillance camera at a location that is above the center of the lane and is the nearest location to a real surveillance camera. Fig.4 is an example of generating VM3. % is the location of the virtual surveillance camera corresponding to ②④. # and $ correspond to ①③ and ⑤⑥ respectively.

As Fig.4 shows, VM3 can provide wider visible regions in

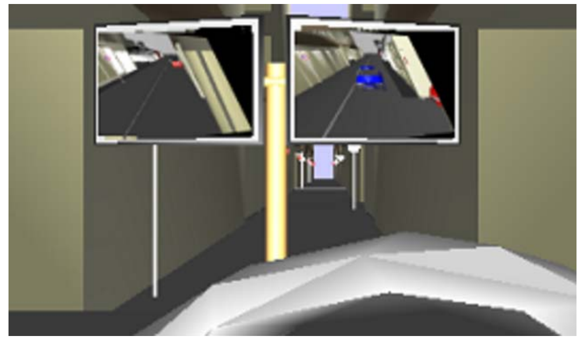

Fig. 4. Virtual Mirror VM3

the virtual mirror because the virtual viewpoint is relatively close to the corresponding real surveillance camera. On the contrary, the driver may need extra time to recognize spatial relationship against the images in the virtual mirror since the virtual viewpoint is not fixed at intersections (there are three possible virtual viewpoints in the case of Fig.4), though the direction of the virtual viewpoint can be set parallel.

IV. EXPERIMENTS

We conducted experiments to examine the validity of our method. We changed the parameters of virtual mirrors and measured the response time for confirming the safety of proceeding into a blind intersection.

We implemented a driving simulator shown in Fig.5 and Fig.6. The system is composed of a WSD part by which virtual mirrors are displayed to the driver and a simulator part by which blind intersections are rendered by CG.

We set the situation of a blind intersection that a vehicle is coming from the right without noticing the vehicle of the subject at all. Subjects, as drivers, do not know when the vehicle from right reaches the intersection. The arriving time of the vehicle from right is denoted as T_i.

The vehicle of subject runs automatically to a stop line and stops there. The task of subject is to judge the safety of proceeding into the intersection by confirming the coming vehicle visually as soon as possible after the vehicle of the subject stops at the stop line. Subjects can move their vehicle forward and can look around the intersection by pressing some keys on keyboard. The confirmation is notified by pressing a key, and the response time is measured. The response time is counted from the time when the vehicle stops at the stop line.

The experiments were conducted by ten subjects between the ages of 22 and 26. All of the subjects have the driver license. At first, they are told the concept and operation of the experiment while they receive training. Then, the data collection is executed.

A. Usefulness of Virtual Mirrors

We measured the response time by using virtual mirrors, and collected the data by changing T_i. In the training phase, T_i was set randomly from 0.0 seconds to 5.5 seconds. The training phase ends when the subject claims the training is

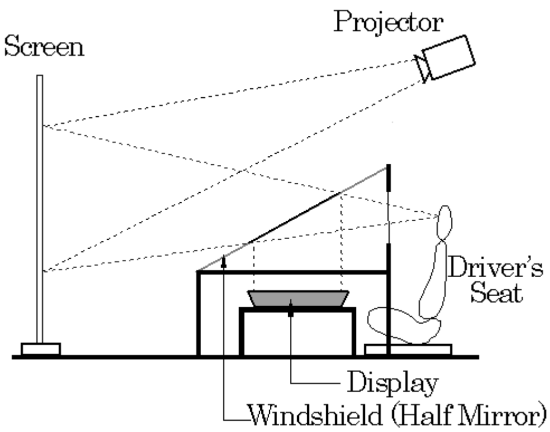

Fig. 5. Driving Simulator

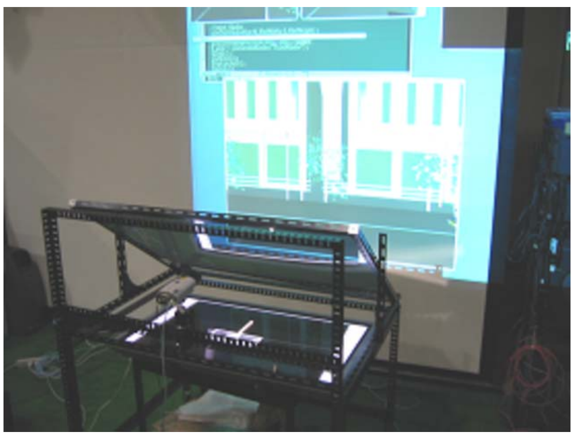

Fig. 6. Snapshot Of Driving Simulator

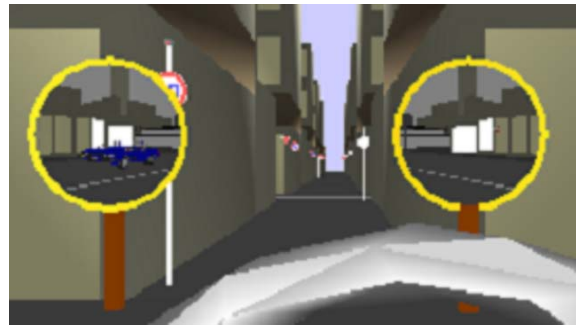

Fig. 7. CG Traffic Mirror

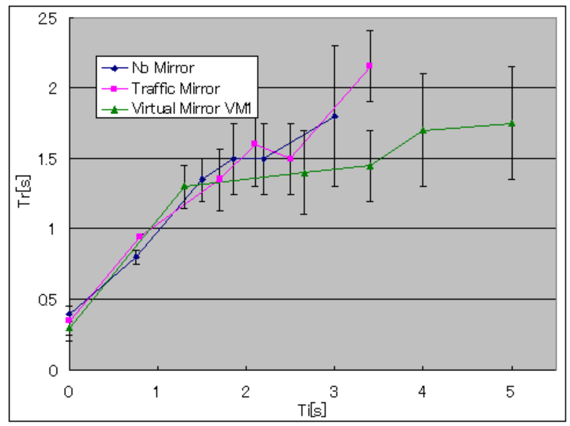

Fig. 8. Response Time By Virtual Mirror

sufficient. In the data collecting phase, T_i was pre-determined for each intersection. However, the subjects were told that T_i would be set randomly.

In this experiment, we collected the data for "No Mirror", "CG Traffic Mirror", and "VM1". "No Mirror" means there is no mirror in the intersection. "CG Traffic Mirror" means there is a normal traffic mirror as shown in Fig.7. It optically simulates a real traffic mirror by CG. "VM1" means there is a virtual mirror of VM1. The procedure of the experiment is as follows.

- Collect data after training with no mirrors
- Collect data after training with CG traffic mirrors
- Collect data after training with VM1

Fig.8 shows the average response time (T_r) of three mirrors. The horizontal axis indicates T_i, and the vertical axis indicates T_r. The error bars stand for the standard deviation.

T_r of VM1 does not become longer compared to T_i. This is because subjects could recognize the coming vehicle at far location by VM1. This means that the virtual mirror is useful to find vehicles far from the intersection.

B. Location of Surveillance Cameras

Generally, the locations of surveillance cameras are different at intersections. If the original images taken by the real cameras are directly shown to drivers as a virtual mirror, it is sometimes difficult for them to understand the spatial relationship. We installed surveillance cameras at different locations in an intersection and measured the response time. In training phase, the locations of surveillance cameras were set randomly among ① to ⑥ in Fig.3. In the data collecting phase, the order of the locations was ①②③④⑤⑥①. The subjects were told the locations would be randomly selected.

In this experiment, we collected the data for VM1, VM3, and VM3'. As for VM3', a real surveillance camera is set at the location where the virtual surveillance camera would be set in VM3. The procedure of the experiment is as follows.

- Collect data after training with VM1
- Collect data after training with VM3
- Collect data after training with VM3'

Fig.9 shows the average response time (T_r) of the three methods. From the result, we can say:

(1) The average response time of VM3 is always longer than that of VM3'.
(2) The average response times of VM1, VM3, and VM3' do not highly depend on the location of surveillance cameras.

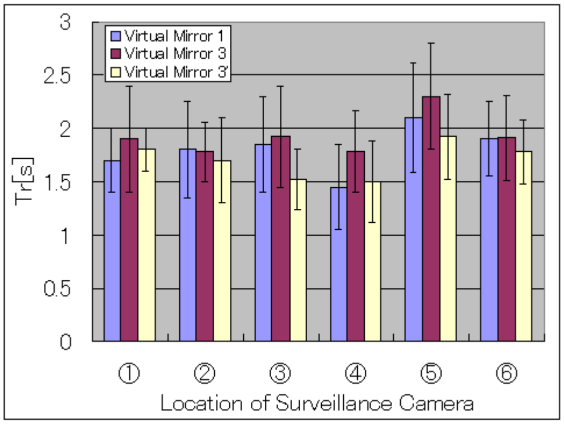

Fig. 9. Response Time By Location Of Surveillance Cameras

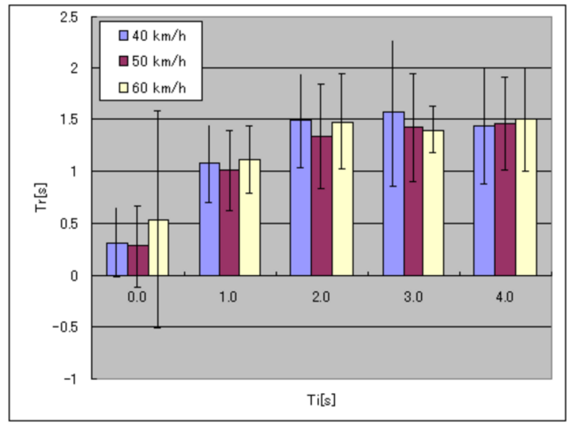

Fig. 11. Response Time By Changing Speed Of Coming Vehicle

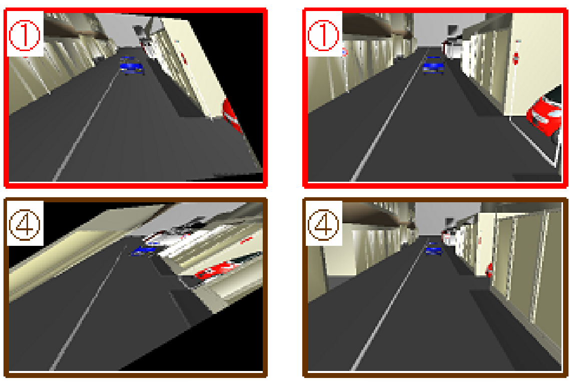

Fig. 10. VM3 And VM3'

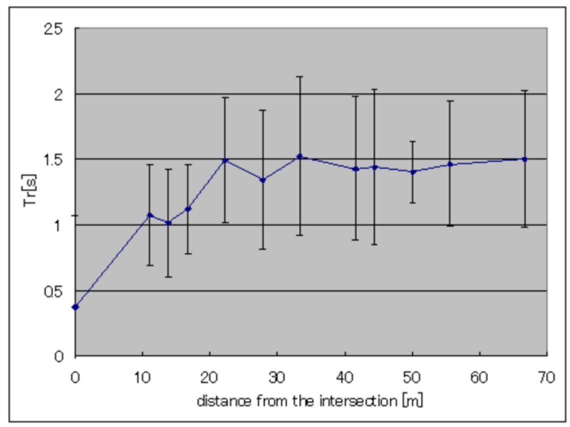

Fig. 12. Response Time Against Distance Of Coming Vehicle

We think two reasons for (1). One is that VM3 has black-out regions in the mirror while VM3' does not. Fig.10 shows the example. The two left images are VM3 and the two right images are VM3'. The other is that since the real world does not satisfy assumption III), distortion makes it hard to recognize the objects in virtual mirrors.

As for (2), the difference among response times was smaller than the standard deviation. It means that response time is independent of the location of surveillance cameras.

C. Speed of Coming Vehicle

We examined the relation between the response time and the speed of the coming vehicle. We collected data for different speeds of coming vehicle of 40km/h, 50km/h, and 60km/h. A virtual mirror of VM1 was set in the center of the road in front of the driver, and it was displayed for all the time. Fig.11 shows the response time for each speed of the coming vehicle. Though a little difference can be seen, the differences are not significant. Thus, we can say that the speed of coming vehicles does not make significant effect on the response time.

Fig.12 shows the relation between the distance of the coming vehicle and the response time. The horizontal axis indicates the distance of the coming vehicle at the time measurement begins. Error bars stand for the standard deviation. When the distance is longer than a certain distance, the response time is around 1.5 seconds.

D. Timing to Display Virtual Mirrors

Virtual mirrors can be displayed at an arbitrary time. We measured the response time by changing the timing of displaying virtual mirrors. Although virtual mirrors are useful, they might hide their background area in the real world. Furthermore, if virtual mirrors show up too early, they may draw driver's attention too much and disturb their safe driving. For these reasons, the timing to show virtual mirrors should be examined. We collected the data for four timings:

- Just when the vehicle of subjects stops (0 second)
- 1.2 seconds before the vehicle stops (10m before the intersection)
- 2.4 seconds before the vehicle stops (20m before the intersection)
- Always

We used VM1 for this experiment.

Fig.13 shows the response time of each timing. Compared to the timing to display virtual mirrors when the vehicle stops, other timings show shorter response time. It is because drivers can recognize the virtual mirrors before the vehicle

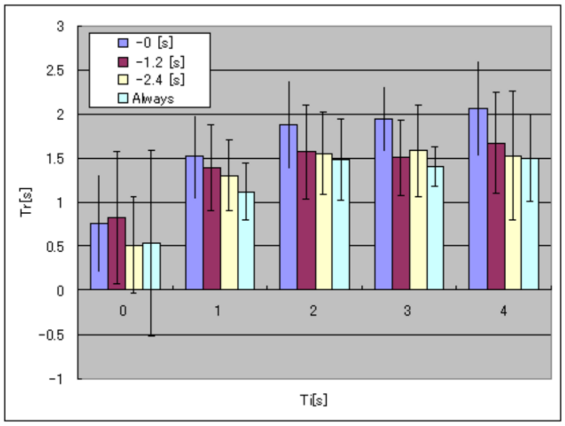

Fig. 13. Response Time By Changing Timing Of Display Virtual Mirrors

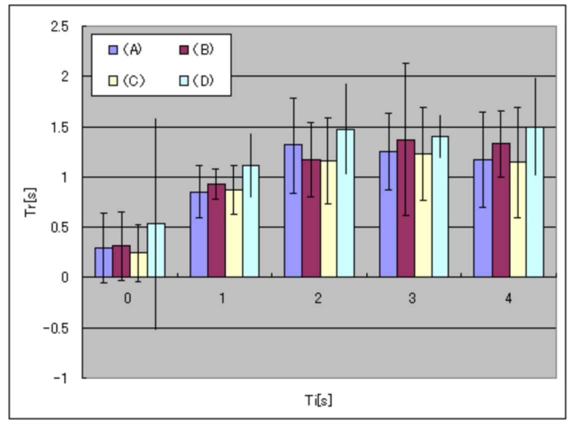

Fig. 15. Response Time By Changing Location Of Virtual Mirrors

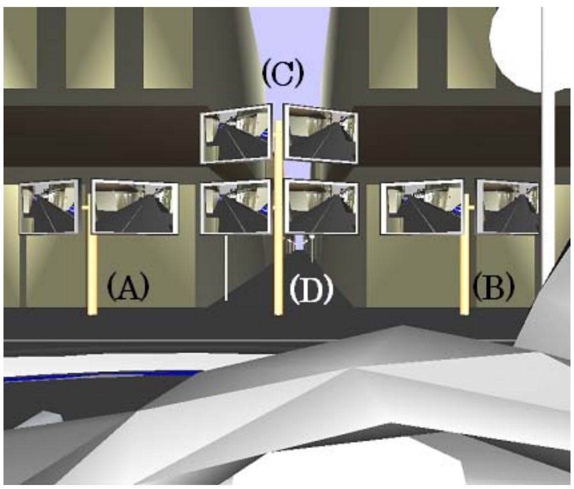

Fig. 14. Location Of Virtual Mirrors

reaches the intersection. We can say that virtual mirrors should be displayed as early as possible.

E. Location of Virtual Mirror

Virtual mirrors can be set at arbitrary location even if it is physically impossible in the real world. We examined the response time by changing the location of virtual mirrors. We set virtual mirror of VM1 at four locations of (A), (B), (C), and (D) shown in Fig.14.

Fig.15 shows the result. Elements of the graph from the left corresponds to (A), (B), (C) and (D) respectively in Fig.14.

The response time of (D) marks longer compared to others. It is because (D) is an impossible location in the real world, while (A) and (B) are possible. (C) is also an impossible location, but it does not disturb drivers to see the direction in front of their vehicle. Thus, we think (C) marked shorter response time compared to (D).

V. CONCLUSION

In this paper, we proposed a system in which virtual mirrors help drivers to see blind intersections by using surveillance cameras. To verify the proposed method, we implemented a driving simulator and conducted five experiments. They showed that users could shorten the delay for detection of coming vehicles in dead zones by virtual mirrors. As a result, we can say that they are useful for reducing traffic accidents at blind intersections.

However, it might not be true in real driving situations because the vehicle of subjects is automatically driven to the stop line in the experiments. As a future work, we should conduct further experiments in which drivers have to drive their vehicle all the time.

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