Development of Photo-Realistic and Interactive Driving View Generaor by Synthesizing Real Image and Artificial Geometry Model

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In this paper, we propose an efficient and effective driving-view generation system as a module of "Mixed-Reality Traffic Experiment Space", an enhanced driving/traffic simulation framework which we and our colleagues have been developing for Sustainable ITS project at the University of Tokyo. Conventional driving simulators represent their view by a set of polygon-based objects, which leads to less photo-reality and huge human cost for data construction. We introduce our image/geometry-based hybrid method to realize more photo-reality with less human cost at the same time. Images for datasets are captured from real world along a public road by video cameras mounted on our data acquisition vehicle. And the view for the system is created by synthesizing the image dataset in real-time. The paper mainly describes details on data acquisition and view rendering.

Keywords: *Image-based rendering (IBR), Driving simulator, Omni-directional image, Arbitrary viewpoint image*

1. Introduction

An endeavor to reconstruct three-dimensional urban models on a virtual space in a computer has become highly interested research topics in the field of computer vision and graphics, virtual- and mixed- reality, remote sensing, architectonics, etc. Such models are expected to benefit various kinds of applications such as city planning, disaster prevention, intelligent transport systems, etc.

Since April 2003, we have been developing a novel mixed-reality simulation system called "Mixed-Reality Traffic Experiment Space " as one part of Sustainable ITS Project[16], a collaborative research project established in Center for Collaborative Research, The University of Tokyo. This simulator is an extended framework of a conventional driving simulator and a traffic simulator. Macroscopic changes of traffic flow and microscopic behaviors of each vehicle based on vehicle dynamics are integrated and aimed to recreate realistic driving situation. Moreover, the view the user sees is produced by synthesizing real video images in real time with high photo-reality.

The view which should be provided to the user in this simulator is nothing less than a view of virtual urban model from ground level. Generally, approaches to reconstruct or represent such spatial model are divided into two types: One is *geometry-(polygon-) based* approach, where the view is created with three-dimensional geometric information and surface reflectance attribute of objects. The other is *image-based* approach, where the view is created only by processing and synthesizing real video images acquired and accumulated in advance.

Conventional driving simulators often seen in driving schools or railway companies provide the view for users by geometry-based rendering, as shown in Fig. 1 . Geometry-based models have relatively small data size, however, have poor photo-reality. Additionally, development of geometry models such as buildings and traffic signals requires a great deal of human work, leading to one of the main cause of vast development cost.

Image-based model, on the other hand, is able to produce highly photo-realistic view. Quality of a view is essential for our future attempt to collect acknowledgment

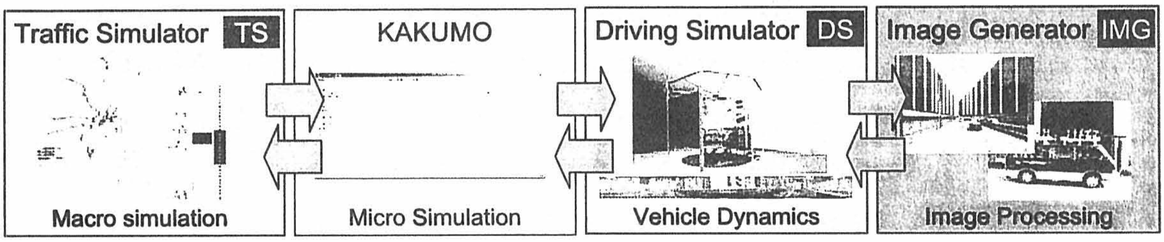


Figure 2: Mixed-Reality Traffic Experiment Space

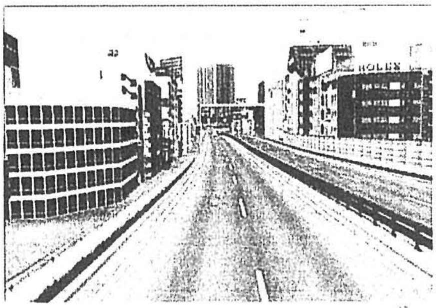


Figure 1: Geometry-based view of driving environment

and decision parameters in human driving operation by using this simulation system. However, image-based approach is not appropriate for interactive and versatile use such as dynamically superposing other objects as other vehicles and pedestrians.

In this paper, we propose a novel method to offer useful and valuable view to users in real-time. We use both geometry-based model and image-based model, giving them different roles and synthesizing them into a single view that emphasizes the merit of each and compensates for the defects of each. To be concrete, *near-view* including roads, guardrails, other vehicles etc. is represented by geometry-based model and *far-view* including buildings and sky is represented by image-based model.

2. System overview

2.1. Whole system

Mixed-Reality Traffic Experiment Space is composed by extending conventional framework of traffic/driving simulators and by integrating several modules as listed below and shown in Fig.2.

- TS: Macroscopic traffic simulator [2]
- KAKUMO: Microscopic traffic simulator [2, 3]
- DS: Driving Simulator [3]
- IMG: Image Generator

TS is a module to simulate macroscopic traffic flows with traffic volume parameters and road network model composed of node/link-based graph structure.

DS is a module to recreate microscopic behavior of self vehicle according to the user's handling, acceleration, braking operation and vehicle-dynamics model. The behavior of the vehicle is transmitted to the user through the seat.

KAKUMO is a module to simulate microscopic position of each vehicle on a road using macroscopic traffic flow information provided from TS. Each vehicle changes its position, heading and velocity according to relative position/velocity between self vehicle and surrounding vehicles.

IMG is a module to produce driver's surrounding view in real-time using position and pose informations of self/surrounding vehicles. The detail is described in the following.

With this system configuration, user can experience a driving situation inside the network of TS.

This Mixed-Reality Traffic Experiment Space can virtually deal with existing public roads as a simulation scene. Our current prototype system targets a part of Metropolitan Expressway[17] No.3 and Loop Line No.1, from Shibuya to Miyakezaka, about seven kilometers long. There already exists a commercial driving simulator which implements only geometric models of this region.

2.2. IMG: Image generating module

This section describes the details of IMG module. A view generated by IMG for user is nothing less than a view of virtual urban model from ground level. Approaches to represent such models are classified into geometry-based one and image-base one as described in the first section.

Considering aptitude of each method in the whole system, geometry-based rendering is superior from the perspective of computing cost, versatility and interactions with other objects such as other vehicles, and image-based rendering is superior from the perspective of photo-reality provided to users. Therefore we propose a novel approach: use both rendering method according to each objective, and synthesize each view at displaying stage. In concrete, each approach handles near part and far part of view respectively as listed below and shown in Fig.3.

- Near-view part: Geometry-based
- Far-view part : Image-based

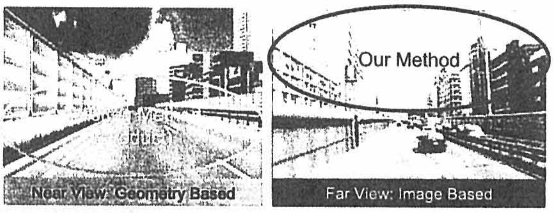


Figure 3: Hybrid model expression: Near-view is represented by geometry-based model, and far-view is represented by image-based model.

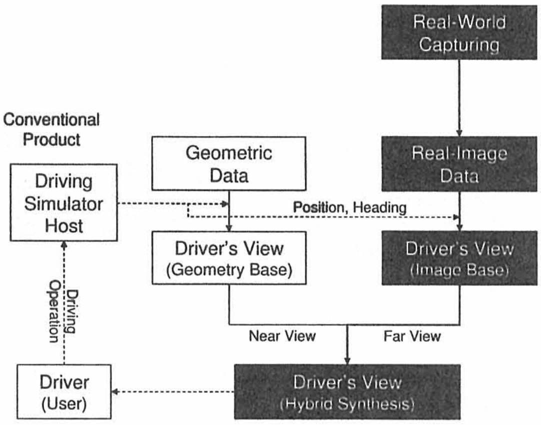


Figure 4: System chart of IMG module

Near-view part includes roads, guardrails, soundproof walls, traffic signs, signals, other vehicles, pedestrians, etc. This part is rendered by using conventional techniques implemented on DS module, a product of Mitsubishi Precision Co. Ltd.[18] This module can represent behaviors of each vehicle at the rate of 60Hz.

Far-view part includes surrounding buildings and a sky. This part is rendered by processing an video image database, which is constructed by running along the model course by capturing vehicle in advance. By capturing video images in an omni-directional format, a view from outside the trajectory of capturing vehicle can be virtually reconstructed by image processing. This virtual view reconstruction is dynamically carried out in real-time according to the position and the heading of self vehicle given from DS module.

Fig. 4 represents the system chart of the IMG module. Our main works described in this paper are filled in black in the chart, for far view. And we partly use the conventional product, filled in gray in the chart, for near view.

By the proposed hybrid method, the view can be created exploiting each advantage. Additionally, construction process of geometric model usually with huge manpower is required only in near-view part, leading to less developing cost.

Though our system currently targets a region where buildings densely stand by side, it is applicable to general scenes in theory, except special effects such as fluctuation of trees or pedestrians.

3. Related works

There are several fields of related works in our research. The most remarkable feature of our work is that the *driving simulator* is realized both by *geometry-based modeling* and by *image-based modeling* of urban scene. In this section, we describe related works from the viewpoint of these items.

3.1. Modeling of urban scene

Modeling of urbane scene is actively researched not only in the field of ITS but also computer vision/graphics, virtual reality, remote sensing, architecture etc.

Frueh et.al[6], Zhao et.al[7] reconstructed urban 3D model by using ground-based laser range. These models are mainly created by laser range scanners equipped on vehicles or other moving platforms. Teller et.al[9] reconstructed geometric urban 3D model by processing photo images taken by still camera. These models are represented in geometry-base. Kotake et.al[8] developed image-based urban scene modeling system with high photo-reality using multiple video cameras. However, none of these systems are designed for driving simulation.

3.2. Driving simulator

Driving simulators are actively developed mainly by private enterprises[18, 20, 21]. In addition to manufacturing corporations, entry by a game vendor can be seen recently[19]. In academic fields, in addition to the development of driving simulators, lots of experimental study have been researched by using conventional driving simulators[12, 14, 13, 15]. However, driving simulators developed or used in these researches are all rendered by geometry base.

There exists a research using driving simulator with real video image. Katakura and Ohta et.al [10, 11] developed an experiment system whose real view captured in advance can be changed slowly or quickly according to the acceleration of the user. In these research, however, viewpoint changing is limited to a path just same as capturing path, and lane changing effect can not be realized. As far as we know, there exists no research treating a driving simulator with image-based and free viewpoint. Moreover, neither exists the one with image base and geometry base combined.

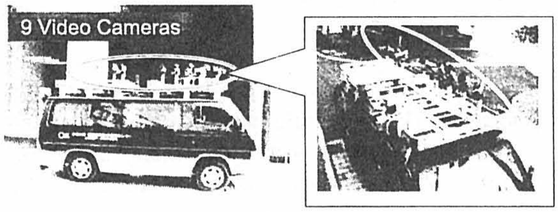


Figure 5: Data acquisition vehicle

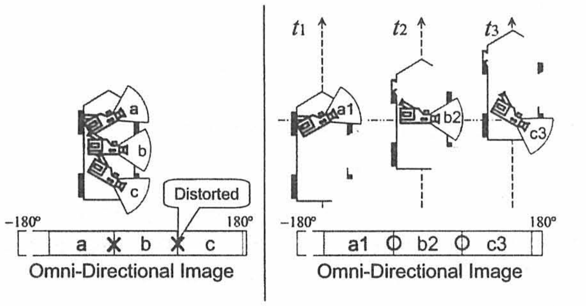
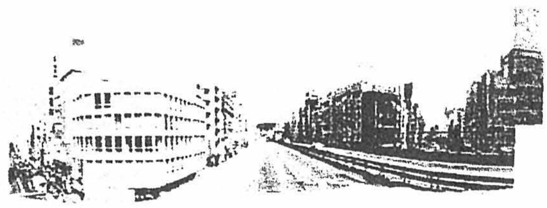


Figure 6: Spatio-temporal agreement of optical centers

(a) Before mosaicing



(b) After mosaicing

Figure 7: Omni-directional image (Half-directional in this case)

4. Real-world capturing for view source

4.1. Creation of omni-directional video image along the model course

Surrounding view for the user is produced by processing real video images captured by data acquisition vehicle, running along the targeting road, Metropolitan Expressway in the prototype system. Fig.5 shows our data acquisition vehicle. Nine video cameras are equipped on the roof and omni-directional video image is created by mosaicing each image captured by the camera. As following part will describe in detail, once omni-directional images viewed from running path is accumulated, a view from outside the path can be virtually created by image processing. Therefore capturing travel is carried out only once.

It is generally known that mosaiced image synthesized from multiple camera images will include distortions at joint parts if optical centers of each camera are not coincided in one point as this case (Fig.6 left). We use Kawasaki's spatio-temporal optical synchronization method[4] for solving this problem. By arranging each camera parallel to moving direction, optical centers are coincided into one point at different timing each (Fig.6 right): as for camera n, at time t_n. Fig.7 shows an example of omni-directional image created by mosaicing multiple video camera images.

4.2. Swinging removal

It is ideal that the data acquisition vehicle runs just horizontally parallel to the road surface. In our case, we assume that relative camera poses and positions between nine video cameras in each single capturing frame are constant. However, change of absolute camera poses against the road surface can not be ignored in reality due to the swinging of the vehicle. In our rendering algorithm, as described in 5.1., even a single virtual view requires some parts of image data which are captured at various moments, if a viewpoint is apart from capturing path. Therefore it will affect undulant deflection to the rendering result.

Swinging is removed through software approach by using block matching of each frame of omni-directional image. The procedure is as follows:

1. Divide omni-image into parts: front, left, rear, right.
2. Calculate pitch, yaw and z (vertical movement) by matching two consecutive frames in front part and rear part.
3. Create {pitch, yaw, z}-free image according to the calculation result.
4. Calculate roll by matching two consecutive frames in right part and left part of semi-corrected image.
5. Create roll-free image according to the calculation result.

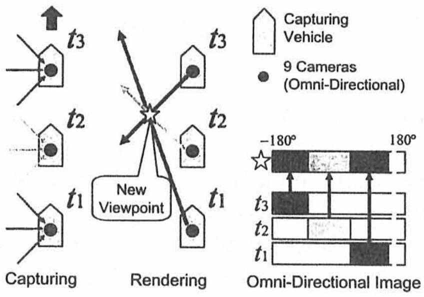


Figure 8: View synthesis from new viewpoint by using omni-directional image

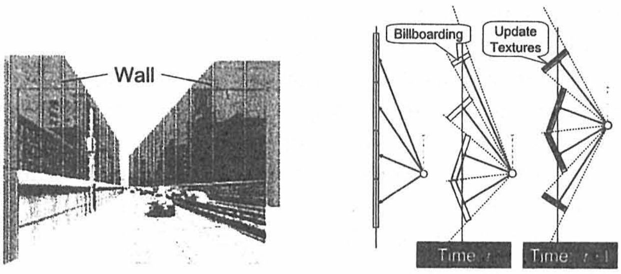


Figure 9: Virtual walls along roadside. Textures on wall slits are updated according to the position of viewpoint. Slits are rotated to visual line direction of the user.

5. Reconstruction of view from user viewpoint

5.1. Basic concept

A set of omni-directional images captured along running path of data acquisition vehicle enables to create a view from outside the path by stitching parts of omni-directional images[5]. In Fig.8 for example, a left-part view from a star signed point is composed of forward-left, left, and backward-left part of omni-directional image captured at time t_1, t_2, t_3 respectively. Also, right-part view can be created by copying and stitching right-directional rays(counter direction of three arrows in Fig. 8–Rendering) captured at each time.

Since the road can not be regarded as straight in practice, we divide the road into a series of line segment and copied the nearest ray from omni-directional image captured on the segment.

This process is actually implemented as a kind of texture mapping onto virtual walls assumed along the roadside, a boundary zone of near-view and far-view part. The face of wall is divided into some vertical slits and a part of omni-directional images captured from appropriate points are mapped per each slit. Textures are dynamically updated according the position of self vehicle given from DS module. The slits are rotated to the visual line direction of the user (Fig.9).

The method to synthesize arbitrary-viewpoint image proposed in [5] can not deal with front view. As shown

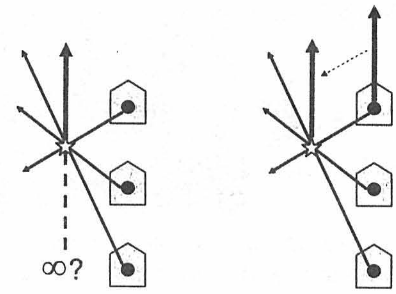


Figure 10: Exception process for front view

in Fig.10 left, the front-directional ray can be copied from nowhere, i.e., ray parallel to the required ray have never been captured. In such case, we just compensate front-directional ray from the nearest capturing point. In our case practically, we applied this way not only for completely front-directional ray but also the ray whose directional difference is within $\pm 30°$ from front.

This compensation process inevitably brings error compared with appropriate view. This error is just same as a parallax in the field of stereo vision, i.e., farther part will include smaller error though, nearer part will include larger error in rendering phase. However, as described in Sec. 2., such nearer part is not rendered by image base but by geometry base. This will lead the view more natural even in the case of front view.

5.2. Quality improvement

Textures are to be updated every time the position of self vehicle changes inside DS module. The refreshment rate of vehicle position is 60Hz at DS of conventional geometry-based rendering and 20Hz at KAKUMO output, a simulation result of surrounding vehicles. Since it is impossible to load all datasets to a graphic memory along targeting road, texture generation task is allocated to multiple machines per some short running regions. A machine which finished rendering its allocated region is allocated a new region and fetches the dataset of new region.

Texture datasets can be obtained only discretely because of finite frame rate of video camera and therefore positions of omni-directional images exist discretely on the capturing path. When an appearance from direction between two directions is required, each texture is complemented by alpha-blending and the quality of rendering is improved.

5.3. Synthesis of image-based part and geometry-based part

As a pre-processing of synthesizing image-based part and geometry-based part, correspondence of each part must be clarified. In concrete terms, look-up table between each frame of omni-directional video image and

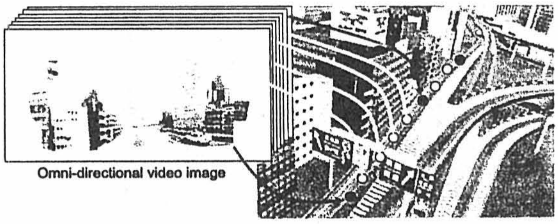


Figure 11: Indexing of sampling points of omni-directional images and coordinates in geometric model.

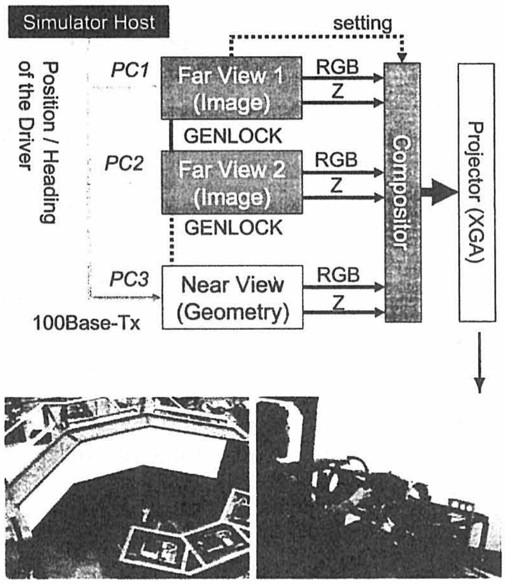


Figure 12: Hardware configuration of IMG module

the position where it is captured in the coordinate of geometry-based model is required. It is possible to get correspondence of capturing points to the real world in some measure, however, geometry model in ready-made product of driving simulator does not strictly reflect the real world. Therefore, we first created a series of geometry-based view with the same FOV as omni-directional image, and manually indexed two views at several characteristic points. And then we interpolated residual points by using cubic spline interpolation (Fig. 11).

Image-based part and geometry-based parts are synthesized into one view by using special hardware device. The hardware configuration of IMG module is shown in Fig.12. Far-part (image-base) rendering machines and a near-part (geometry-base) rendering machine output both view from same viewpoints with color values (R, G, B) and depth value (Z). These outputs are integrated by a hardware called Compositor (VizCluster), a product of Mitsubishi Precision Co. Ltd., and color values per each pixel are determined according to the depth value of each output. And finally, it is projected to a screen in front of the user through multiple projectors.

6. Result and discussion

Fig. 13(a) shows an example of rendering result of image-based part. The viewpoint is approximately same as Fig. 1, fully geometry-based one. It can offer relatively high photo-reality to the user. We confirmed that the update of frame worked well in 60Hz.

Fig. 13(b)(c) are examples of viewpoint changing effect. Since the part near from front direction in each figures are rendered by copying irregular rays as described in Sec. 5., positions of white lines on the road for example are not appropriate. However, the change of depth to side buildings are effectively expressed.

Fig. 14 shows a synthesizing result of image-based part and geometry-based part through the compositor. Sky, buildings, advertising displays on buildings are rendered in image-base, and roads, soundproof walls, other vehicles, traffic signs, which are located in front of a virtual wall of image-based rendering, are rendered in geometry-base. By such way of right-method-in-the-right-place rendering, we can offer highly photo-realistic view for users, and can simultaneously realize interactive and versatile use such as changing behaviors of other vehicles or changing the contents of traffic signs.

Some frame include distortions as seen in Fig. 14(c). These are caused by several conditions; One is a projection to just two flat walls, which becomes especially unrealistic when objects like an elevated bridge intrude. We are planning to add one more virtual wall above the road for projection as shown in Fig. 15 to avoid the problem.

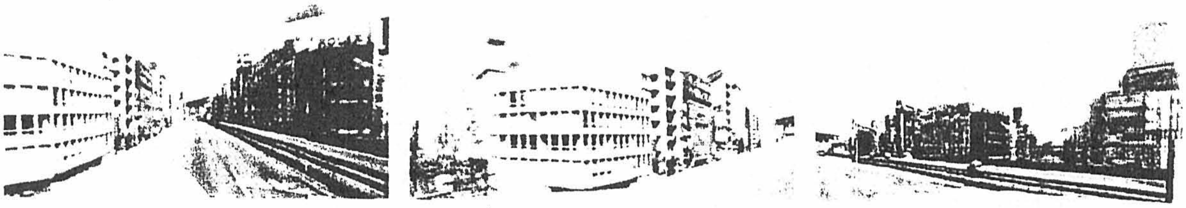
Another is image dataset itself is not complete, i.e. it does not contain "hidden" textures behind objects located in near part such as signboards, columns, and elevated bridges. We are planning to interpolate hidden areas by referring both spatially and temporally nearby textures.

7. Conclusion

In this paper, we introduced an interactive driving-view generation system, a module of Mixed-Reality Traffic Experiment Space , which we have been developing as one sphere of "Sustainable ITS Project". Our system synthesize both geometry-based view and image-based view according to their own aptitudes and can offer photo-realistic and utilizable view.

In the image-based part, an arbitrary view can be rendered by processing omni-directional video image which are obtained by capturing and running on the model course in the real world only once. Geometry-based part is composed by existing product which required huge human cost for model construction hitherto, however, in this case, the model construction process is needed only in roadway part. Our future works are listed as follows.

- **Improvement of projection:** By adding another virtual wall above the road, we expect we can improve

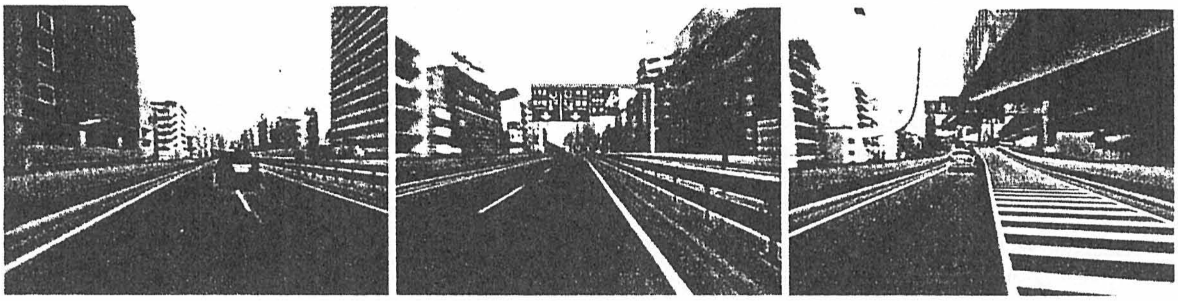


(a) A view from capturing lane, gazing at front

(b) A view from right side of capturing lane, gazing at left

(c) A view from left side of capturing lane, gazing at right

Figure 13: Rendering result of image-based part and lane-changing effect



(a)

(b)

(c)

Figure 14: Synthesized rendering result of image-based part and geometry-based part

rendering distortions of elevated objects.

- **Interpolation of hidden textures:** By referring spatially and temporally nearby textures, textures hidden by near objects can be interpolated.
- **Automatic extraction of near objects:** To realize above-cited interpolation, we are planning to automatically extract near objects by analyzing omnidirectional video or by using laser range sensor.
- **Sag zone simulation in Tomei Expressway:** A sag zone is composed of a series of subtle gradient changes and is said to psychologically causes traffic congestion. Our photo-realistic system will just be suited for realizing such subtle situation. Currently we are targeting a region of Tomei Expressway, from Yokohama-Aoba I.C. to Atsugi I.C. (Fig. 16), and going to analyze human parameters around driving behavior or judgment, and verify effectiveness of sag-zone traffic signs depending on its contents, dimension, and location.

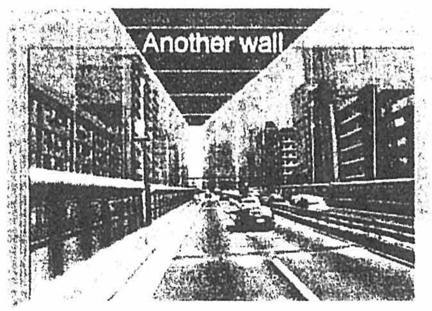


Figure 15: Another virtual wall above the road

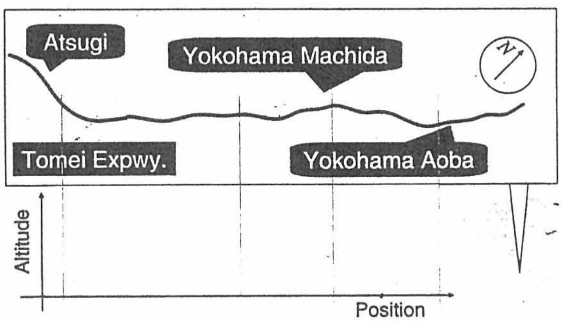


Figure 16: Sag zone in Tomei Expressway

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