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An Obstacle Extraction Method Using Virtual Disparity Image

N.Suganuma, N.Fujiwara

Abstract— The driving support system is one of most important research field in intelligent transport system (ITS). In this paper, we address an obstacle extraction method for driving support system. The stereovision system is one of most suit sensor to recognize details of environment. On the other hand, a disparity image obtained by stereovision system has quite a lot of information. Therefore an efficient algorithm to analyze obtained disparity image is strongly demanded. If the road surface is extracted, obstacles can be easily extracted by evaluating whether one object touch on a road or not. In this paper, we propose a novel method to estimate three-dimensional road surface position by using virtual disparity image. Moreover, an obstacle extraction method is expressed.

I. INTRODUCTION

RECENTLY, a number of researches related to Intelligent Transport System (ITS) have been done. The ITS is one of available way in order to solve some problems about traffic accident, traffic jam, environment pollution and so on [1]. There are many research field related to ITS, the driving support system is one of most important field. Some systems, which are mainly used at expressway, are developed currently, such as the lane-keep support system, adaptive cruise control system, and so on.

At the moment, the aged society becomes a serious problem in Japan. It is, therefore, considered that a driving supports system for short range driving rather than long range driving like expressway will become to play an important roll in such an aged society. So, we have focused on a driving support system for general road from now on, such as obstacle extraction method, lane marker extraction method, traffic sign and signal detection system, and so on [2] [3] [4]. This paper addresses an obstacle extraction method using in-vehicle sensor.

In case of general road, it is necessary to obtain details of three-dimensional information of circumstance around vehicle because recognition of complicated environment is strongly demanded. A stereovision system is one of suitable

range sensor for such application. In this paper we propose novel method to extract obstacles from stereovision system.

II. STEREOVISION SYSTEM

Figure 1(a) shows our experimental vehicle. The stereovision system, in our vehicle, is mounted in front of room mirror as shown in figure 1(b).

Stereovision is a system that analyzes the images taken from two or more viewpoints, and recognizes three-dimensional form from obtained images [5]. In our system, two cameras are installed in parallel each other. The disparities, in parallel stereovision system, are appeared only on the horizontal line called epipolar line.

When the disparity is computed with a stereo camera that baseline length is b and focal length is f as shown in figure 2, three-dimensional position of target object is obtained by

$$\begin{cases} x = b(u - c_u)/d \\ y = b(v - c_v)/d \\ z = bf/d \end{cases} \quad (1)$$

where (c_u, c_v) and f are principal point and focal length of the camera, respectively. (u, v) are image coordinate on the right side camera, and d denotes the disparity. Thus we can simply obtain three-dimensional form from this equation.

The images that the disparities are arranged on each pixel are called disparity image. Figure 3 shows an example of this disparity image. In our algorithm, obstacles are extracted by using this disparity image.



Fig. 1. (a) Overview of our experimental vehicle (Left-side picture). Various measurement sensors are installed in the vehicle such as RTK-GPS, Fiber Optic Gyro, Laser radar, stereovision system, and so on. Furthermore, some actuators are also installed to drive automatically without human. (b) Installation of stereovision system (right-side picture). The stereovision system is installed in front of room mirror.

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N. Suganuma is with Kanazawa University, Kakuma-machi, Kanazawa, JAPAN (e-mail: suganuma@puma.ms.t.kanazawa-u.ac.jp).

N. Fujiwara is with Kanazawa University, Kakuma-machi, Kanazawa, JAPAN (e-mail: fujiwara@t.kanazawa-u.ac.jp).

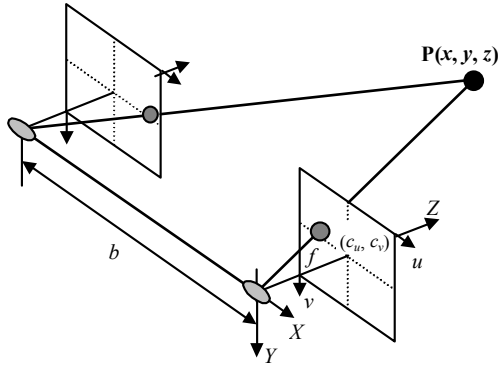


Fig.2 Geometry of stereovision system.



Fig.3. Example of disparity image. Left-side image is a original image and right-side image denoted a disparity image corresponding to left-side image. In this disparity image, brightness shows distance from camera, it is shown that the brighter, the shorter the distance is.

III. ROAD SURFACE EXTRACTION

A. Road surface extraction by means of linear projection

It is important and useful to extract road surface from disparity image, because we can find whether an object is touch on the road surface. If u -axis of image coordinate is in parallel with road surface, the road surface can be easily extracted by simple image projection [2], [6].

Now we consider about road surface on disparity image space, which is defined as the three-dimensional orthogonal coordinate system that has image coordinate u, v and disparity d as each axis. Figure 4 depicts the road surface on the disparity image space. The road surface can be approximated as a flat plane, so the projection on to the v - d plane of disparity image result in a simple line. The road surface, therefore, can be easily extracted by detecting this line on v - d plane. If this line is approximated as

$$v = Ad + B \quad (2),$$

geometrical relation between road surface and stereo camera as shown in figure 5 can be solved by

$$\theta = \tan^{-1} \left(\frac{c_v - B}{f} \right) \quad (3),$$

$$h = bA \cos \theta \quad (4),$$

where b is baseline length of stereovision system, c_v and f are the v -coordinate of principal point and focal length of the

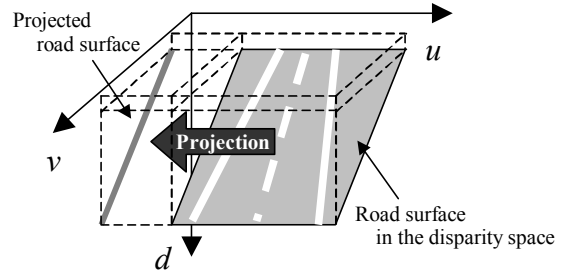


Fig.4 Road surface on disparity image space. If u -axis of image coordinate system is in parallel with road surface, the projection onto the u - d plane will result in a line, because road surface is nearly a flat plane.

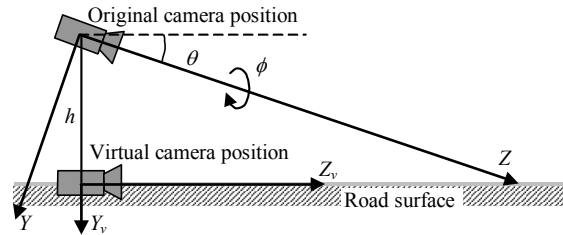


Figure 5 Original and virtual camera position, which is put on a road surface virtually. The geometrical relation between original and virtual position can be defined by roll angle ϕ , pitch angle θ , and its height h . In this paper, we call disparity image on virtual camera position virtual disparity image.

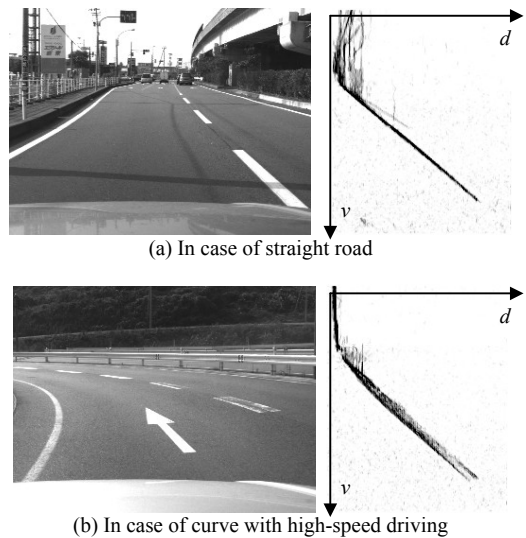


Figure 6 Linearly projected image onto v - d plane of disparity image space

image, respectively. Figure 6 shows examples of projected image. We can find a line, which denotes the road surface, is clearly appeared on projected image.

B. Road surface extraction using virtual disparity image

We were considered that the stereo camera was installed in parallel with road surface so far. It is rational assumption when the vehicle is drove on a straight road. Though, the vehicle accompany the roll movement when the vehicle is drove on a curve with high-speed, e.g. in case of expressway interchange, junction and so on. It is, therefore, inadequate to

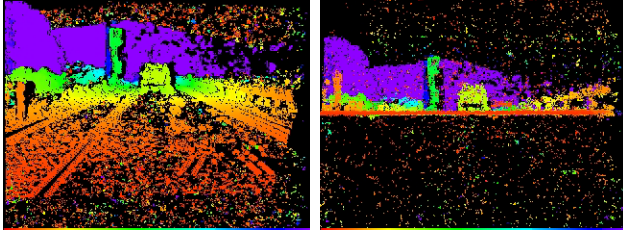


Fig.7 Example of virtual disparity image. Upper image is the original image. Left-side image and right-side image of bottom denote original and virtual disparity image, respectively. In virtual disparity image, you can see a disparity image taking from road surface.

consider only height h and pitch angle θ analyzed by linear projection described on previous section. Figure 6(b) is an example of projected image onto v - d plane when the vehicle was drove on a curve with high-speed. In such case, the roll angle becomes significant value, therefore the line on v - d plane, which denotes road surface, becomes thicker than figure 6(a). In this section, we propose a novel method to estimate the full pose between road surface and stereo camera including roll angle ϕ .

The problem of estimating three parameters ϕ , θ , and h can be solved by Generalized Hough Transform, because we can consider such problem as an extraction of a flat plane from three-dimensional space. This solution is similar to the algorithm described in above section because the problem is simple expansion of dimension from line extraction to plane extraction. But it is necessary, in such approach, to arrange huge voting space. It is, therefore, inappropriate to vehicle equipment because of computing cost, memory size and so on. Therefore, more rational approach approximately estimating these three parameters ϕ , θ , and h is adopted in this paper.

1) Virtual disparity image

At first, we explain about a virtual disparity image, which is used for estimating geometrical relation between road surface and stereo camera in the next sub-section. Now, we define a virtual disparity image as a disparity image transformed from original to virtual observed point. Especially, in this paper, a virtual disparity image is defined as a disparity image taken from road surface virtually as described on figure 5.

The geometrical transformation of disparity image space can be achieved by homogeneous transformation without approximation, because disparity image has three-dimensional information. In our approach, a three-dimensional point $\mathbf{U} = [u/d, v/d, 1/d]^T$ is defined as a point of disparity image. Note that a vector \mathbf{U} contains no

stereovision parameters. In this case, three-dimensional position $\mathbf{M} = [X, Y, Z]^T$ of real space is given by

$$\tilde{\mathbf{M}} = \mathbf{S}\tilde{\mathbf{U}} \quad (5),$$

where a symbol ' $\tilde{\cdot}$ ' denote the augmented vector by adding 1 as the last element. \mathbf{S} is coefficient matrix containing stereovision system parameter, is given by

$$\mathbf{S} = \begin{bmatrix} b & 0 & -bc_u & 0 \\ 0 & b & -bc_v & 0 \\ 0 & 0 & bf & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (6),$$

where (c_u, c_v) are principal point of image, b and f are baseline length and focal length of stereovision system, respectively. If the geometrical relation between road surface and stereo camera is given, virtual disparity image is computed by

$$\tilde{\mathbf{U}}_v = \mathbf{S}^{-1}\mathbf{D}\tilde{\mathbf{S}}\tilde{\mathbf{U}} \quad (7),$$

where a vector \mathbf{U}_v denotes a point of virtual disparity image. A matrix \mathbf{D} denotes the homogeneous transformation matrix defined by using three parameters ϕ , θ , and h , and given by

$$\mathbf{D} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & -h \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & \sin\theta & 0 \\ 0 & -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos\phi & \sin\phi & 0 & 0 \\ -\sin\phi & \cos\phi & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (8).$$

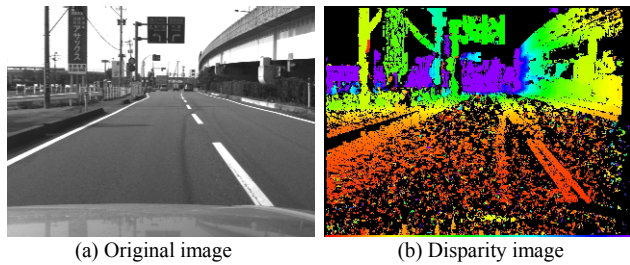
Figure 7 shows an example of virtual disparity image. From this figure, you can see that a road surface is clearly appeared as a line.

2) Road surface extraction using virtual disparity image

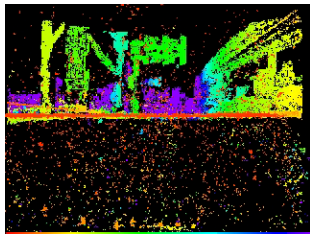
In this section, we propose a road surface extraction method using virtual disparity image. Our approach is very simple but powerful estimating ability. A concrete method is as follows.

At first, a disparity image in each frame t is transformed to a virtual disparity image using three parameters ϕ_{t-1} , θ_{t-1} , and h_{t-1} estimated on previous frame $t-1$. Hereby, a disparity image generated from vehicle mounted stereo camera installed in front of room mirror is approximately transformed to a virtual disparity image observed from road surface as described in previous sub-section. But generated virtual disparity image does not become a virtual disparity image observed from road surface rigorously, because this transformation is achieved using previously estimated parameters. Therefore, geometrical differences from generated virtual disparity image to rigorous road surface are estimated using virtual disparity image.

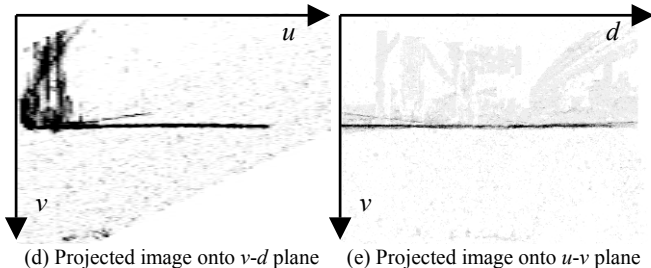
After generating the virtual disparity image, two projected images are generated from virtual disparity image. One is the projection on to the v - d plane of virtual disparity image space. From this projection image, we can know the pitch angle $\Delta\theta$ and height Δh from observed point of virtual disparity image to true road surface. In the projection images, a line, which



(a) Original image (b) Disparity image



(c) Virtual disparity image



(d) Projected image onto v - d plane (e) Projected image onto u - v plane

Fig.8 Example projection images.

denotes the road surface, is clearly appeared as described in figure 8 (d), and pitch angle and height from virtual disparity image to true road surface is estimated using equation (1)~(3) in similar way.

The other image is the projection onto the u - v plane of virtual disparity image space. From this projection, we can know the roll angle $\Delta\phi$ between observed point of virtual disparity image and true road surface. In this projection image, a line, which denotes the road surface, is also clearly appeared as described in figure 8(e). This line is approximated by equation (1), and the roll angle $\Delta\phi$ is given by

$$\Delta\phi = \tan^{-1} A \quad (8)$$

It is, actually, demanded to estimate three parameters simultaneously rather than estimate each parameter separately, but separable consideration result in an efficient solution. To do so, our approach becomes very simple solution.

Once modification parameters $\Delta\phi_t$, $\Delta\theta_t$, and Δh_t are estimated using two projected images, then the true parameters ϕ_t , θ_t , and h_t are calculated by decomposition of

$$\mathbf{D}_t = \hat{\mathbf{D}}_t \mathbf{D}_{t-1} \quad (9)$$

where $\hat{\mathbf{D}}_t$ is homogeneous transformation matrix defined by using three parameters $\Delta\phi_t$, $\Delta\theta_t$, and Δh_t .

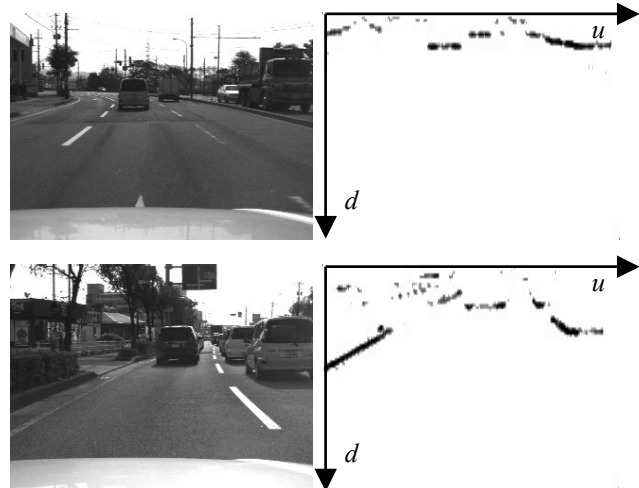


Fig.9 Examples of projected image onto u - d plane.

An initial value of ϕ_0 , θ_0 , and h_0 at frame 0 can be given by manually as design parameters of stereo camera installation. As another method, you may also consider that the parameter ϕ_0 is simply set to zero, and parameter θ_0 and h_0 is estimated by linear projection of disparity image as described by section 3.A. when the system is starting up. Once an initial value of three parameter ϕ_0 , θ_0 , and h_0 are given, a disparity image, which is generated by vehicle mounted stereo camera installed in front of room mirror, can be transformed to a virtual disparity image observed from road surface view as described by figure 8(c).

IV. OBSTACLE EXTRACTION USING VIRTUAL DISPARITY IMAGE

Finally, we consider about obstacle extraction method. In the previous chapter, we consider about simple two kinds of linear image projection onto v - d plane and u - v plane from virtual disparity image space. In addition to these two linear image projections, you may also consider about linear image projection onto u - d plane from virtual disparity image space.

The projected image onto u - d plane has information about maps of obstacles, and we can find that three-dimensional position of obstacle can be analyzed by this image. But simply projected image includes not only obstacles touch on the road surface but also some objects in the sky such as bridge, traffic sign, signal, and so on. In our method, the projection onto u - d plane is limited within a predefined region.

A height in virtual disparity image space h_v is given by

$$h_v = \frac{d_v}{b} H_v \quad (10)$$

where b is baseline length of stereovision system, d_v denotes disparity in virtual disparity image space, and H_v is the height in real three-dimensional space. A height from road surface ΔH_v , therefore, can be easily expressed by

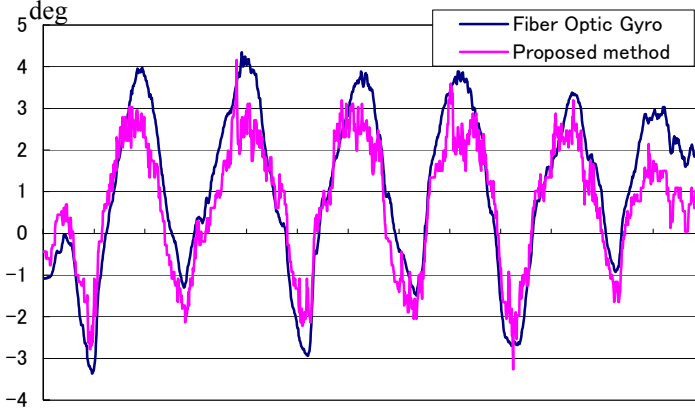


Fig.10 Measurement accuracy of roll angle

$$\Delta H_v = b \frac{v_v - \rho(d_v)}{d_v} \quad (11),$$

where v_v and d_v are the v -coordinate and disparity of target point in virtual disparity image space, respectively. $\rho(d_v)$ is road surface position corresponding to d_v , and this is calculated from a line formula estimated from v - d plane. Note that the road surface position is actually defined by not only v - d plane but also u - v plane. Though, the modification parameter on u - v plane is very small in most cases compared with that of v - d plane. Therefore, we use only v - d plane information for simplifying a problem.

A valid region in real three-dimensional space is defined beforehand, and virtual disparity image space points within this region are selected by $H_v^{\min} < \Delta H_v < H_v^{\max}$, where H_v^{\min} , and H_v^{\max} is the predefined minimum and maximum height from road surface in real three-dimensional space. Then, the validated points are projected onto u - d plane. In our algorithm H_v^{\min} , and H_v^{\max} is set to $-0.5[m]$ and $2.5[m]$, respectively.

V. EXPERIMENT

In this section, we consider about experimental result of proposed method. In this experiment, a stereovision system was used, which the baseline length is 120[mm], focal length is 6[mm], and image size is VGA (640x480 pixel). Moreover, the proposed method was implemented on Intel Pentium-4 3.06GHz processor, and computed maximum disparity was 32 [pixel]. An average processing time was about 258 [ms].

At first, we investigate about the measurement accuracy of estimating roll angle using virtual disparity image. Figure 10 shows a result of roll angle estimation. In this figure, roll angle estimated by our method is compared with fiber optic gyro system. The fiber optic gyro system used in this experiment can measure not only angular rate but also acceleration, and the roll angle is estimated by integrating these values by means of kalman filter. Note that our algorithm can measure geometrical relation between road surface and camera but fiber optic gyro system is measuring

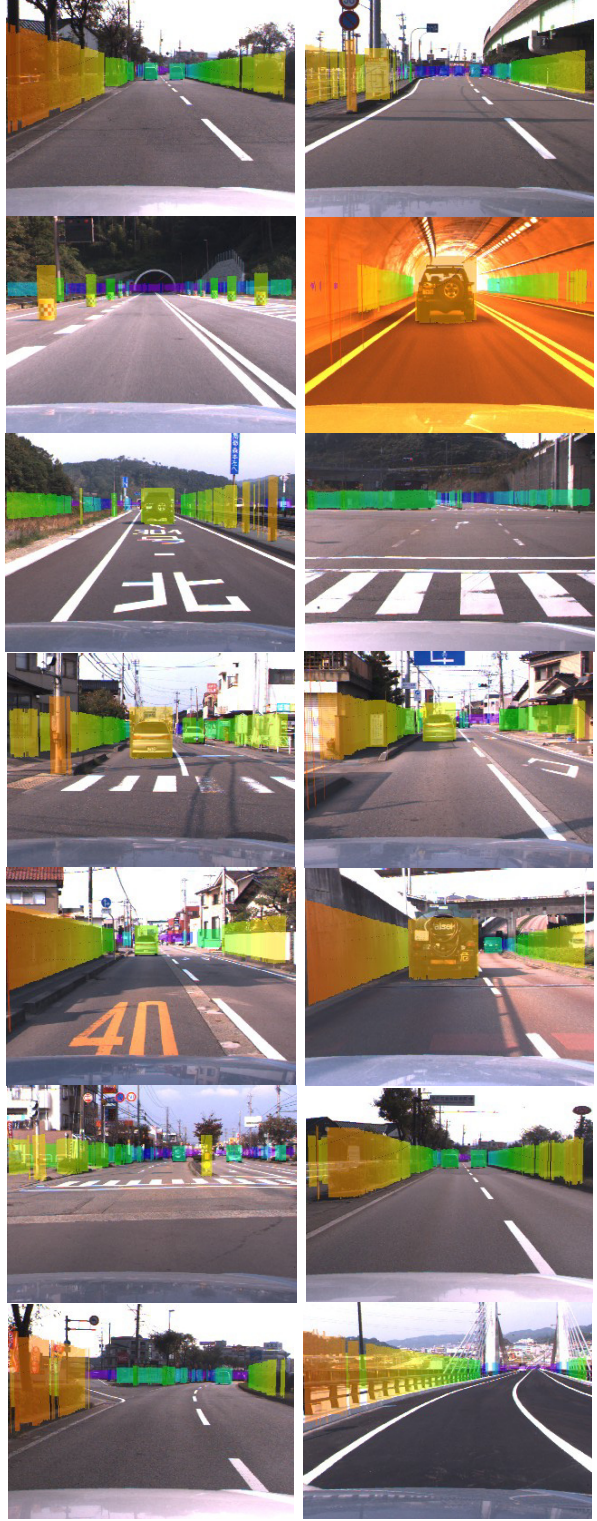


Fig.11 Examples of obstacle extraction on various scenes.

geometrical relation from geocentric direction. Therefore the measurement by fiber optic gyro can be only compared when the road is horizontal.

From figure 10, we can find that the estimated roll angle by our method is similar to that of fiber optic gyro systems, and

the difference between these values are within about 1 degree. Therefore we can find that our algorithm worked properly and has high measurement ability.

Next, we investigate about the obstacle extraction algorithm. Figure 11 shows results of obstacle extraction on various scenes. In this figure, obstacles are marked out by color, and its color shows corresponding distance. From these results, we can find that almost all of obstacles are extracted and our algorithm works properly at general road scene.

On the other hand, our algorithm has some problem on some scene. One scene is in case of missing generation of road surface disparity as described on figure 12. In such cases, the position of extracted obstacles will become away from road surface because road surface cannot be extracted. This case occurs when a texture on road surface is lacking, but most cases on arterial road, this situation will rarely happen because lane marker is drawn on road. In this problem, we are now planning to use Kalman filter to integrate vehicle movement data and image measurement data.

Another scene of problem is night scene. At night, the image taken from stereo camera becomes dark and noisy. Therefore, it is difficult to generate disparity compared with daytime. In this problem, now we are planning to illuminate in front of vehicle by infrared light.

VI. CONCLUSION

In this paper, we propose a novel method to extract obstacles using virtual disparity image. This method has high abilities to extract obstacles by extracting road surface, is summarized as follows:

- 1) A disparity image, which is generated from stereovision system installed in front of room mirror of experimental vehicle, can be transformed to virtual disparity image that is virtually observed from road surface without

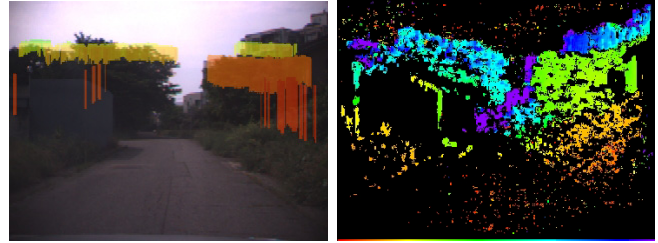


Fig.12 In case of missing generation of road surface disparity. Left-side image denotes obstacle extraction result and right-side image shows its corresponding disparity image.

approximation.

- 2) The geometrical relation between road surface and vehicle mounted stereo camera can be estimated using virtual disparity image robustly and efficiently.
- 3) Almost all of obstacles can be extracted on general road scene.

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