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A PROPOSAL OF GENERALIZED HORIZON VIEW CAMERA

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Abstract

In this paper, we propose Generalized Horizon View Camera system. It can able to improve a degree of freedom of Horizon View Camera (HVC) while keeping characteristics of previous HVC by using a horizon that existed at a center of camera lens. In this paper, we measured a distance to the object by the obtained image actually. In this experiment, we confirmed that detecting object using the GHVC is effective.

1. Introduction

Recently, person and object detection methods using a single camera have been proposed in many fields [1][2]. However, there is a problem which detecting image includes objects and regions corresponding to the ground. Therefore, it is necessary to separate a target object from the ground [3][4]. In this way, various methods are proposed to detect them. However some methods don't have high accuracy. Moreover, system which uses single camera is necessary to keep the camera at a higher position in order to acquire higher accuracy [4]. Therefore, the height of the system becomes inevitability tall.

The Horizon View Camera (HVC) which can miniaturize had proposed as one of the solution to these problems [5][6][7], and it has shown the accuracy of the object detection by the HVC. However the HVC system has a problem that has a narrow view, and the degree of freedom of the camera settings is not large. Then, we improve the degree of freedom of camera settings of HVC by using the horizon line that exists at the center of camera lens, and propose Generalized Horizon View Camera (GHVC) that can observe wider view.

2. Outline of the HVC System

HVC camera system set the camera optical axis passing through on the horizon is proposed [5]. The obtained image by the HVC system contains objects on the ground without including the ground itself. Therefore the HVC system has advantages that separating objects from the ground becomes very easy, the object detection can be done by high precision. By moving forward, the HVC system can easily measure the distance to an object.

HVC have to bury half of the camera in the ground to make the optical axis of the camera direct to the horizon, this is impossibility in actual applications. Therefore the optical axis of a camera was directed to the horizon by using a mirror [5].

The HVC system is shown in figure 1(a). The image obtained by this system is separated horizontally into two parts; the upper half of the image is the image reflected by the mirror, and the lower half of the image is the direct image in front of the system. An example is shown in figure 1(b). The reflected image is reversed by the mirror.

3. Proposal of Generalized Horizon View Camera

3.1. Characteristic Of Horizon Line

HVC have to align the angle between the camera optical axis and the mirror [5], and uses only a half of image for object detection. Therefore the HVC system has a problem that has a narrow view. Then, we used characteristic of horizon line to improve the degree of freedom in camera settings and viewing angle of the previous HVC by a single camera.

If the center of camera lens on the horizon, even if the camera rotates, the horizon line always exists to center of camera lens.

HVC system is set the camera on the ground, and the optical axis of the camera is set direction of the horizon by a mirror. In our world coordinate system, Z-axis is defined as pointing towards front; X-axis is pointing to right; and Y-axis is pointing up. The center of camera lens is set on the origin of the world coordinate system. Based on this definition, when the camera is assumed to be an ideal pin-hole camera model and the camera doesn't translate, coordinates of image coordinate system and coordinates of a point in the world coordinate system be realized the relation of eq.(1).

$$m = PRM \tag{1}$$

Here,

$$m = \begin{pmatrix} x \\ y \end{pmatrix},\quad P = \begin{pmatrix} f & 0 & 0 \\ 0 & f & 0 \\ 0 & 0 & 1 \end{pmatrix},\quad M = \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

$$R = \begin{pmatrix} R_{11} & R_{12} & R_{13} \\ R_{21} & R_{22} & R_{23} \\ R_{31} & R_{32} & R_{33} \end{pmatrix}$$

$$R_{11} = \cos\beta\cos\gamma,\quad R_{12} = \cos\beta\sin\gamma,\quad R_{13} = -\sin\beta$$

$$R_{21} = \sin\alpha\sin\beta\cos\gamma - \cos\alpha\sin\gamma$$

$$R_{22} = \sin\alpha\sin\beta\sin\gamma + \cos\alpha\cos\gamma,\quad R_{23} = \sin\alpha\cos\beta$$

$$R_{31} = \cos\alpha\sin\beta\cos\gamma + \sin\alpha\sin\gamma$$

$$R_{32} = \cos\alpha\sin\beta\sin\gamma - \sin\alpha\cos\gamma,\quad R_{33} = \cos\alpha\cos\beta$$

Since, m is the coordinates of the image coordinate system, M is the coordinates of point in the world coordinate system, P is an intrinsic parameters of the pin-hole camera, and R is the rotation matrix of the camera. α, β, and γ are the rotation angles respectively around X, Y, and Z axis. Then, coordinates in the world coordinate that project coordinates on the image are obtained by eq.(2).

$$y = f\frac{XR_{21} + YR_{22} + ZR_{23}}{XR_{31} + YR_{32} + ZR_{33}} \qquad (2)$$

To take the extreme by Z-axis, vanishing line in the image coordinate system can be obtained from eq.(2) to eq.(3).

$$\lim_{Z\to\infty} y = f\frac{R_{23}}{R_{33}} = f\frac{\sin\alpha\cos\beta}{\cos\alpha\cos\beta} \qquad (3)$$

In the previous HVC system, rotation matrix of the camera R_{23} is 0, the vanishing line in the image is calculated as y=0 by eq.(3), The vanishing line is corresponding to horizon line. As shown in figure 2, when the camera rotates to $\alpha=\theta_d$ on X-axis, vanishing line is calculated $y=f\tan\theta_d$ by eq.(3), and we can see the vanishing line is also corresponding to horizon line. Therefore, if the center of camera lens is set on the horizon, the horizon line always exists to center of camera lens, and project to the image even if the camera rotates.

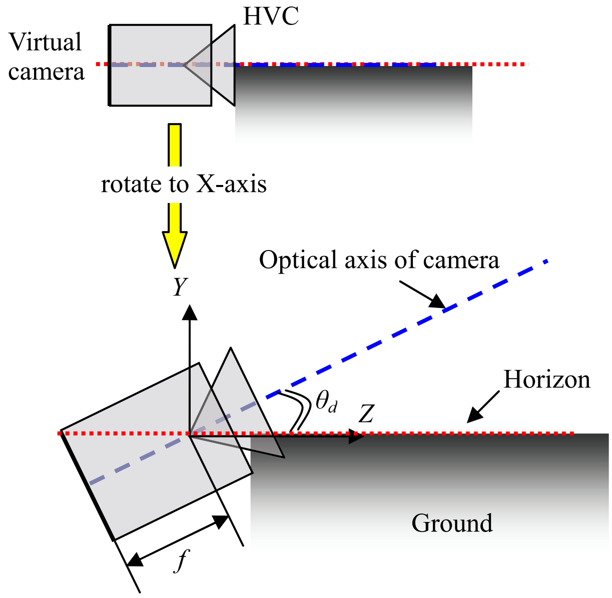
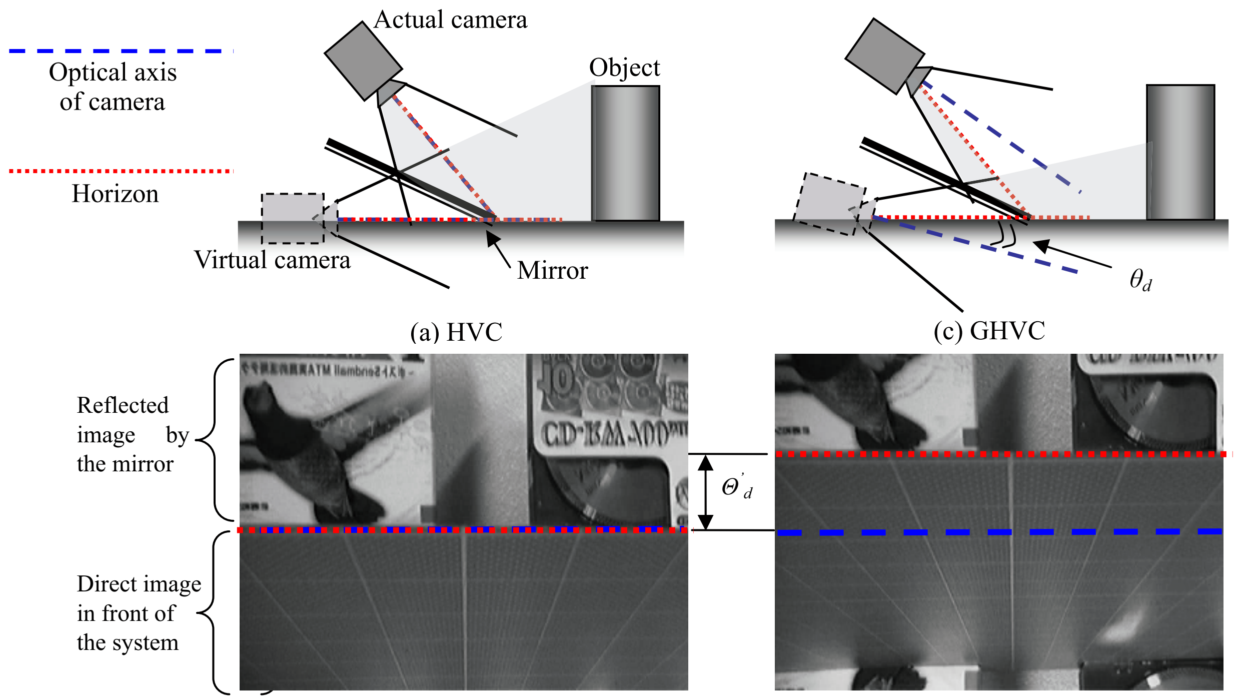


Figure 2. Position of horizon in image

3.2. GHVC Used Horizon Line

If not the camera optical axis but the center of camera lens is set on the ground by using a mirror, HVC which has large degree of freedom in camera settings can be obtained using the characteristics of horizon line. We call HVC which has large degree of freedom in camera settings is Generalized Horizon View Camera (GHVC).

We set the object on the ground, and took image by HVC and GHVC, figure 1 shows an example of the image obtained from HVC and GHVC, figure 1(a)(c) show a arrangement illustrations of HVC system and GHVC system. Figure 1(b)(d) are images obtained from HVC and GHVC. As show in figure 1, if set the center of camera lens on ground with a mirror, the horizon line changes only the $f\tan\theta_d$ gap in the image when the camera rotates, but the characteristics of reflected image by the mirror doesn't change. The reflected image by the GHVC system also contains objects on the ground without including the ground, and the object never leaves from the horizon line. Therefore, we can adjust the angle of the camera to obtain a GHVC with wider view. And it can also detect the object and measure the distance to the object.



(a) HVC (c) GHVC

(b) Image from the HVC (d) Image from the GHVC($\Theta'_d=f\tan\theta_d$)

Figure 1. HVC and GHVC

4. Object Detection by Generalization HVC

4.1. Method for Measuring Objects

When the GHVC system moves forward, the object never leaves from the horizon line in the image, and the emission point of the image is located on the center of horizon line in the image. In this time, distance between the camera and the object is short, the object moves greatly in the image. On the other hand, the distance is long, the object does not move very much. Moreover, the distance of the movement also differs by the distance between the object and the horizon line. If the object is located far from the horizon line, moves greatly, and if the object is located near the horizon line, it moves a little. By using these differences, we can calculate the movement vector of the object in the image before and after the camera's movement. We can measure the distance by the direction and the size of each movement vector to the object.

In this paper, we used the template matching to detect the optical flow [8]. Then, the distance to the object is measured by the optical flow. Because we used only reflection image for distance measurement, so we adjust the viewing angle of the GHVC to observe the broad outlook.

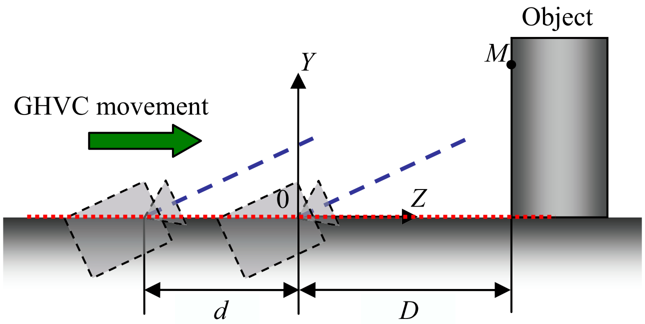


Figure 3. Calculation of the distance to objects

We make the center of virtual camera lens after moved is 0 as show in figure 3, and the camera is assumed to be an ideal pin-hole camera model, the distance to objects is obtained from eq.(1) and eq.(2).

$$m_r = PRTM \tag{4}$$
$$m'_r = PRM \tag{5}$$

Here,

$$m_r = \begin{pmatrix} x_r \\ y_r \\ w_r \end{pmatrix}, \quad P = \begin{pmatrix} f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

$$R = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta_d & \sin\theta_d & 0 \\ 0 & -\sin\theta_d & \cos\theta_d & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$m'_r = \begin{pmatrix} x'_r \\ y'_r \\ w'_r \end{pmatrix}, \quad T = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d \\ 0 & 0 & 0 & 1 \end{pmatrix}, \quad M = \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix}$$

In eq.(4) and eq.(5), m_r and m'_r are coordinate values of the object in the image before and after movement respectively. $m_r \rightarrow m'_r$ is optical flow. Moreover, P is an internal parameters of the pin-hole camera, R is angle θ_d of the camera optical axis and the horizon line, T is the movement distance d of the camera, and M is a point in the world coordinate system that is (X, Y, Z).

We can obtained coordinates on the image projects coordinates of point in the world coordinate system by eq.(4) and eq.(5) as eq.(6) and eq.(7).

$$Y = \frac{y_r\left(Z\cos\theta_d + d\cos\theta_d\right) - f\left(Z\sin\theta_d + d\sin\theta_d\right)}{f\cos\theta_d + y_r\sin\theta_d} \tag{6}$$

$$Y = \frac{y'_r Z\cos\theta_d - fZ\sin\theta_d}{f\cos\theta_d + y'_r\sin\theta_d} \tag{7}$$

When a vertical distance from GHVC to the object is assumed to be Z=D, the distance is detected is obtained from eq.(6) and eq.(7) to eq.(8).

$$D = d\frac{\left(f\cos\theta_d + y'_r\sin\theta_d\right)\left(y_r\cos\theta_d - f\sin\theta_d\right)}{f\left(y'_r - y_r\right)} \tag{8}$$

4.2. Experiments

We measured the actually distance to the object by using the GHVC system.

We set two objects with the flat surface at the same distance on ground in the situation of a single background. The camera was moved forward by a constant distance each time, and an image was taken at each distance. The distance between the camera and objects changed from 34cm to 26cm by a 2cm step. We calculated the distance of the object by eq.(8) by using the detected optical flow. θ_d is 15°, the resolution of the image is 320×240, we adjusted the size of the template to 9×9pixel, and internal parameter P is calculated previously.

(a) 28cm from camera

(b) 26cm from camera

Figure 4. Experimental image

We detect optical flow by using the block matching. We check the number of different brightness in the template, only detect optical flow there have a lot of number of different brightness in the template. Because the extension line of optical flow passes the center of horizon line. We only used the optical flow that the extension line of flow and the intersection of the horizon line are near the center of the horizon line for the distance measurement. Moreover, because the optical flow of *Y*-axis in the vicinity of the horizon line doesn't change very much. We are not using flow in the vicinity of the horizon line in this experiment.

Figure 4 shows the image used in this experiment. Figure 5 shows the result of the detected optical flow at the actual distance to objects from the camera is 26cm, figure 6 shows the result of detecting the distance using an X-Y image at the actual distance to objects from the camera is 26cm. The average error in the X-Y image in this experiment was show in table 1.

Figure 5. Result of the detected optical flow

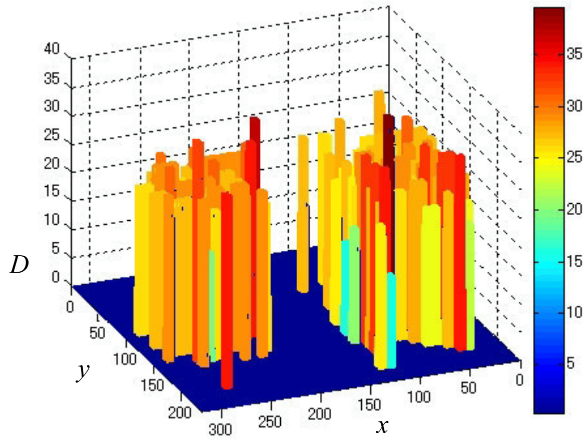


Figure 6. Result of the detected the distance

Table 1. Average error

Actual distance	Detected distance	Average error
34cm	33.14cm	3.06cm
32cm	31.61cm	2.64cm
30cm	30.77cm	3.27cm
28cm	28.10cm	2.69cm
26cm	27.66cm	2.33cm

By this experimental result, we obtained the measuring distance of the GHVC was detected correctly. However, some results of the measuring distance were detected with good accuracy but the others were inaccurate result. There are two reasons for this result. First reason is by the effect of the amount of movement. The measuring distance becomes low because it is including the error of the amount of movement. The other reason is the image quantization error. We have a plan to improve this in our future work.

5. Conclusion

In this paper, we proposed GHVC has large degree of freedom in camera settings and viewing angle of the previous HVC by using the horizon line that existed at the center of camera lens, and described the characteristics of it. If the center of camera lens on the horizon line, horizon line always pass the pin-hole of camera and project to the image even if the camera rotates. As this, we adjust the angle of the camera to obtain a GHVC with wider view. Then, the range of the measurement broadens more than HVC, and the object detection can be achieved easily.

Using the characteristic of GHVC, we measured the actually distance to the object. It is confirmed that the technique for designing it is effective by the experiment. In the future we have a plan to improve the accuracy of the measuring distance. For the example, we consider that by using the property of the GHVC as the log-polar image, the GHVC can measure the distance to the object with higher accuracy. And we are going to install this system in a small cleaning robot. Used the robot to apply to obstacle detection and target recognition. We think the robot can easily to find garbage and obstacles by using the obtained image.

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