The Detection of Obstacles Using Features by the Horizon View Camera

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Abstract

In this paper, we propose a new camera system called Horizon View Camera (HVC). The HVC is a system in which the optical axis of a camera is directed at the horizon with a mirror so that obtained image contains objects on the ground without including the ground itself. Therefore, by using the HVC system, separating objects from the ground becomes very easy. In this paper, we measured the distance to the object by using the obtained image actually and easily. Moreover, there are many other useful features in the HVC system. In order to improve the processing cost and accuracy, we propose a new idea whereby the detection of objects becomes easier and the results are more accurate by the experiment.

1 Introduction

Nowadays, many researches of autonomous robots has been proposed. According to researchers, the visual information from a camera is useful for an autonomous robot because the autonomous robot has to recognize surrounding scenery using the visual information [1]. For example, when the robot moves, the robot has to recognize objects such as obstacles that limit action.

In methods of detecting objects, a single camera or a stereo camera is usually used. However, these methods have some problems. In the case of using the stereo camera, two or more cameras are needed which increases the cost. Also the processing tends to complexify [2][3]. On the other hand, in the case of using the single camera, while cost becomes low because only one camera is needed, it 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. So, we propose a new camera system called the Horizon View Camera (HVC) for constructing a small size robot [5].

2 HVC System

2.1 Outline of the HVC System

In the case of using a single camera, it is necessary to keep the camera at a higher position in order to acquire higher accuracy, but this strategy has the problem that the system becomes tall. To remedy this, we came across a different viewpoint to this method. Our new idea is to keeping the camera at a low position, i.e., the camera is put on the ground. By this method, the obtained image contains only surrounding objects without the ground because the system position is too low. For this paper, therefore, the camera was put on the ground, and the system was made so that the optical axis of the camera was directed to the horizon. This system is named the Horizon View Camera (HVC). 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, and the calculation time for that can be reduced. By moving forward, the HVC system can easily measure the distance to an object.

We tried to make the HVC system, but we have to bury half of the camera in the ground to make the optical axis of the camera direct to the horizon, an impossibility in actual

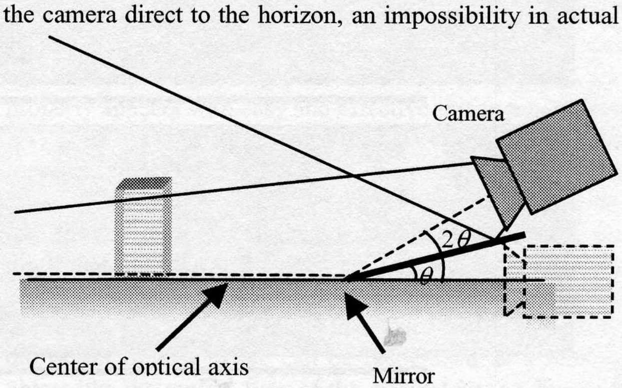


Figure 1: *HVC system*

applications. Therefore, the optical axis of a camera was directed to the horizon by using a mirror. The HVC system is shown in figure 1. 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 2, and figure 3 shows a sequence of a person walking front of the HVC of an animation which was recorded by the HVC.

2.2 Feature of the HVC System

In this system, every object in the image is considered an obstacle, because the ground is not included in the upper half of the image. Therefore, the distance to the object is measured with the reflected image only by moving the HVC, without detection of the object.

The images obtained by the HVC system have a feature that its emission point of the optical flow which is formed by the movement of the system is located on the horizon of the image. Moreover, when the HVC system moves forward, the emission point exists at the center of the horizon. The optical flow of a standstill object flows radially from the emission point to outside. Figure 4 shows the optical flow of the HVC system. If the optical flow does not flow from the emission point, that part of the image can be recognized as a moving object.

The general systems of the single camera with a mirror are proposed. These systems are intended to obtain stereo images by the single camera exclusively [6]. But in the case of the HVC system using the mirror, this system is not intended to obtain stereo images by the single camera as usual although two kinds of the obtained image. The HVC system is intended to be able to detect objects of the front of this system easily based on the new idea. Moreover, when the HVC system moves forward, this system can measure the distance to objects using one kind of the obtained image.

The HVC also has a feature that the image of the object in the center of the optical axis does not move when the HVC moves forward.

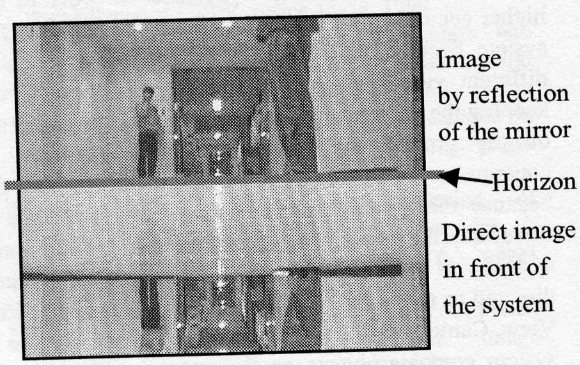


Figure 2: *Obtained image of the HVC*
(320×240 pixels)

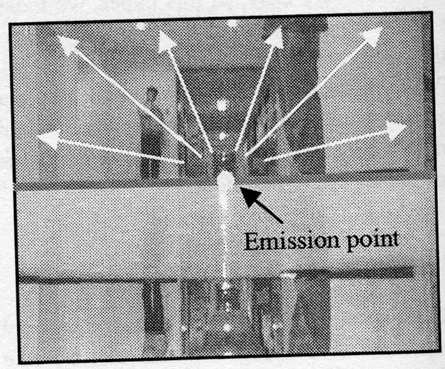


Figure 4: *Optical flow of the HVC*

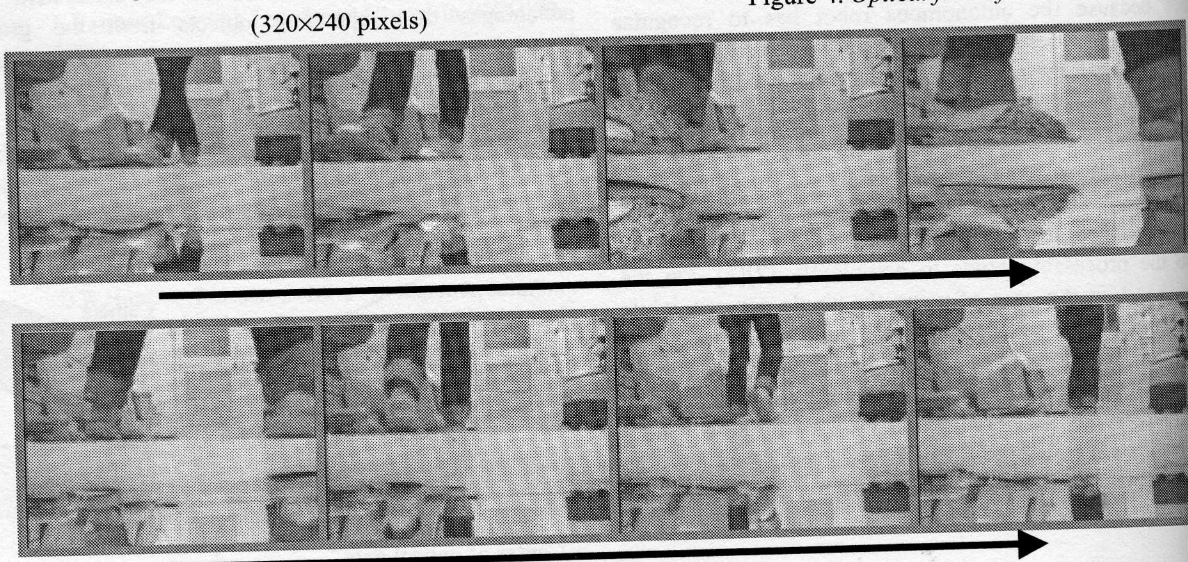


Figure 3: *The animation from the HVC*

3 Measuring the Distance to Objects

We used the optical flow for measuring the distance to an object in the image [7]. When the camera is moved forward, objects close to the camera move more than those farther away in the image. Moreover, the distance of the movement also differs by the distance between the object and the center of the optical axis. If the object is located far from the center of the optical axis, it moves more than if the object is located near the center of the optical axis. By using this difference, the movement vector of the object in the image before and after the camera's movement can be calculated. The distance can then be measured by the direction and the size of each movement vector to the object.

For this paper, we used template matching to detect the optical flow [8]. So, the distance to the object is measured by the optical flow. The distance to the object is calculated by the triangulation, because the angle from the camera to each pixel of the image is constant, and the distance of the camera movement is known.

To measure the distance from the camera to the object, we have to know the camera parameter, the angle corresponding to each pixel. The calculation for the camera used here is presented. In the place of locating S from the camera, the image was h high by w wide as shown in figure 5. The value of θ that is the angle of each pixel from the camera is decided by using these values.

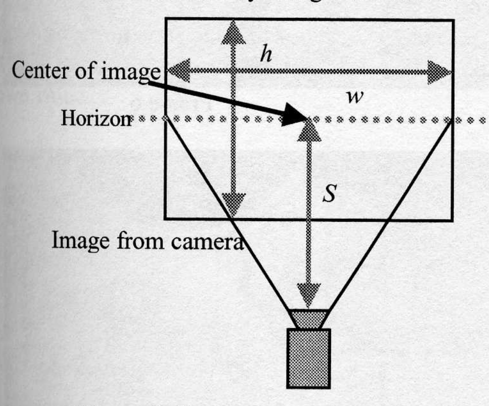


Figure 5: *Camera parameters*

In the case of a resolution of $W \times H$ pixels, $p(x, y)$ is calculated by eq.(1) to give $P(I, J)$, since the center of the horizon is at the origin,

$$P(I,J) = p((x - \frac{W}{2}) \times \frac{w}{W}, (\frac{H}{2} - y) \times \frac{h}{H}) \quad (1)$$

$(x=0\sim W, y=0\sim H/2)$

The obtained $P(I, J)$ is an actual position S from the camera. Figure 6 shows how to calculate the angle of each pixel in the image. Therefore, the angle of each pixel from the camera is calculated by eq.(2).

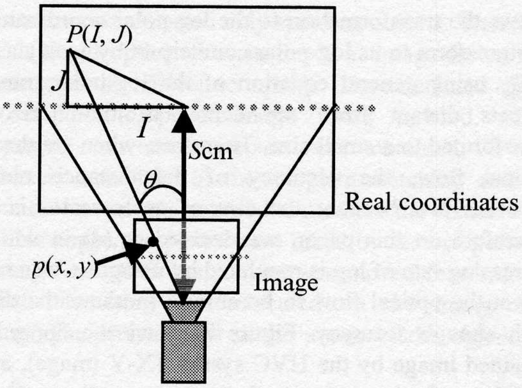


Figure 6: The angle of each pixel

$$\tan\theta = \frac{\sqrt{I^2 + J^2}}{S} \quad (2)$$

Figure 7 shows the method of calculating the distance. The value of θ_1, θ_2 for each pixel and d are known. Using the value of θ_1, θ_2 calculated for each pixel, the distance to the object is calculated by eq.(3), where d is the distance the camera moved, and D is the distance to the object.

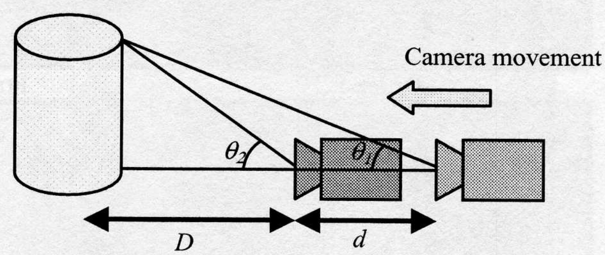


Figure 7: *Measurement of the distance to the*

$$D = \frac{d \times \tan\theta_1}{\tan\theta_2 - \tan\theta_1} \quad (3)$$

4 Improvement of the Distance Measuring

In order to improve the computation cost and accuracy, a new idea was introduced using the property of HVC system. When an upper image from the HVC was transformed to the log-polar coordinates [9][10], the property appears with easy and effective image procession. As noted previously, when the HVC system moves forward, the optical flow flows from the center of the horizon. So transformed image to the log-polar coordinates, the optical flow flows upward. Using this property, we think that the optical flow can be detected more correctly and the accuracy of the distance calculation can be improved. Also, if the optical flow does not flow upward, the object of that image can be recognized as a moving object like the optical flow of the original image. Figure 8 shows the transformation to the log-polar coordinate. Also we transform to its log-polar counterpart by eq.(4).

By using general equation of the log-polar transform, objects distant from the center of the horizon are transformed to a small size. Therefore, when we detect the optical flow, the accuracy of the distance measured becomes low because the size of each vector is small. Therefore, in this paper, we decided eq.(4) in which the increasing rate of log is regulated by using the value of k to detect the optical flow to be able to measure the distance with enough accuracy. Figure 9 shows the upper of the obtained image by the HVC system (X-Y image), and the transformed image to the corresponding log-polar coordinate (log-polar image).

In the log-polar image, the optical flow of standing objects constantly flows upward. By using this property, a process of detecting the optical flow becomes very easy, because the searching area for the template matching is limited to a small area, and the computation cost is reduced. Figure 10 shows the optical flow of the X-Y image and the log-polar image. Also in the X-Y image as shown figure 9 (a), objects are moving to the outside from the center of the horizon. In the log-polar image as shown figure 9 (b), objects are moving to upward.

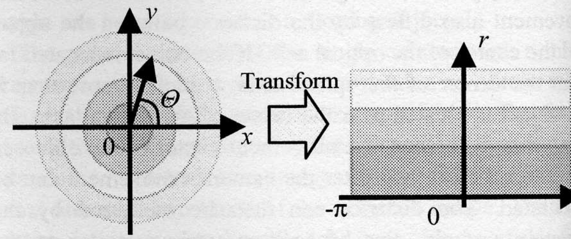
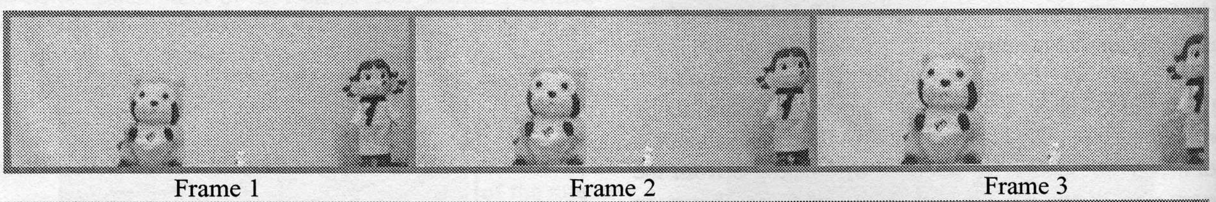
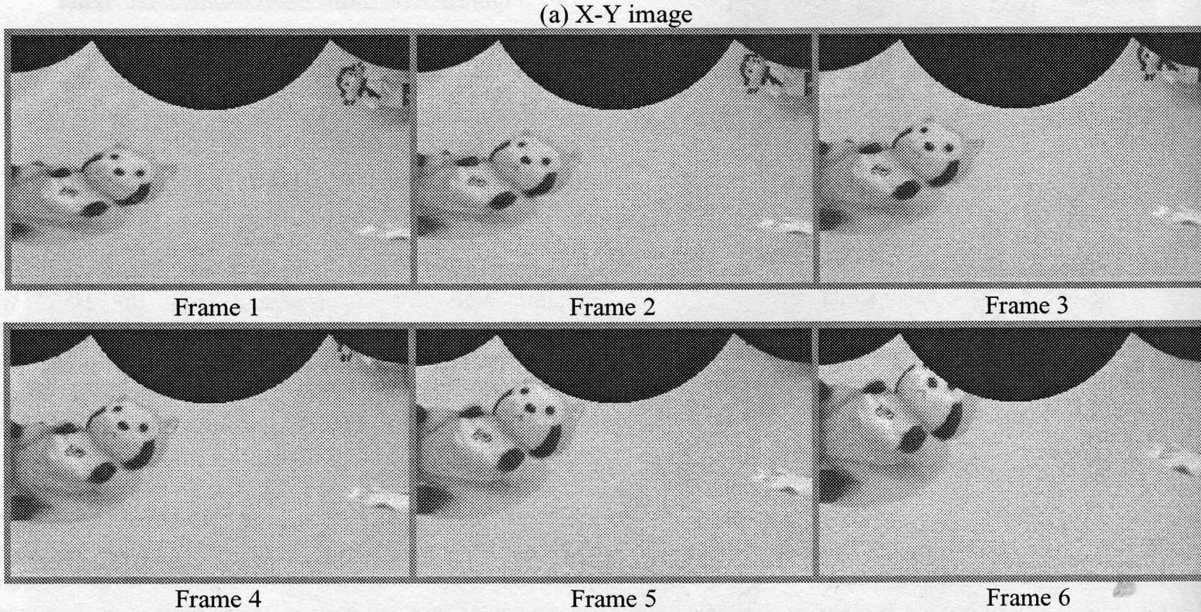


Figure 8: *Transform to the log-polar coordinate*

$$r = \log_e \left\{ k \times \sqrt{x^2 + y^2} + 1 \right\}$$
$$\Theta = \tan^{-1} \frac{y}{x} \qquad (4)$$



(a) X-Y image



(b) log-polar image

Figure 9: *Transform to the log-polar image*

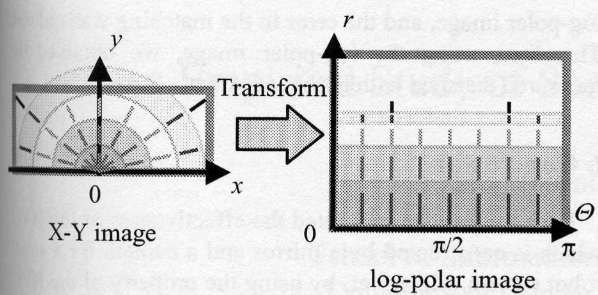


Figure 10: *Optical flow of X-Y image and log-polar image*

Moreover, by using the log-polar image, we think that optical flow can be detected more correctly and the accuracy of the distance calculation can be improved. Because the feature of an object with straight lines or textures which may cause failure in the template matching is changed into complex feature, the template matching becomes easier.

In order to decide the distance, we substituted eq.(4) into eq.(1) to obtain $P(I, J)$, and we calculated Θ by substituting the obtained $P(I, J)$ in eq.(2). We obtained the distance to the object D by substituting the angle of each pixel Θ in eq.(3). We can also measure the distance to the object in the log-polar image by eq.(5). In eq.(5), $q(r_1, \Theta_1)$ and $q'(r_2, \Theta_2)$ are coordinate values of the object in the log-polar image before and after movement respectively as shown in figure 11. In the log-polar image, Θ_1 and Θ_2 are constant if the HVC moves forward, because the optical flow flows upward direction constantly. Therefore, Θ_1 and Θ_2 are not included in eq.(5). The distance the HVC moved, d is a known value.

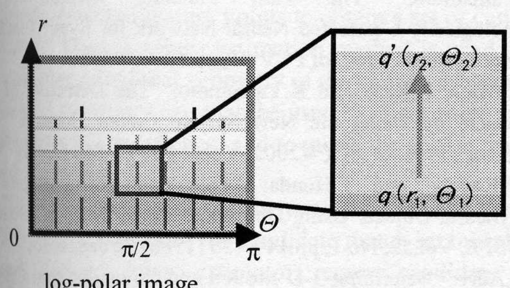


Figure11: *Optical flow of log-polar image*

$$D = d \times \frac{e^{r_1} - 1}{e^{r_2} - e^{r_1}} \qquad (5)$$

5 Experiment

We constructed experiments to compare of the accuracy of measuring the distance to an object using the X-Y image and log-polar image obtained by the HVC. In these experiments, we detected only standing objects. Therefore, the calculated optical flow in the X-Y image flows from the center of the horizon to outside. The calculated optical flow in the log-polar image flows upward. If an unexpected movement vector was obtained, it was considered a mistake of the template matching and that movement vector was not used to measure the distance.

In this paper, templates were made by feature points in the image, and then the camera was moved forward. The template matching was executed on the image after moving. The optical flow in the image of the object was

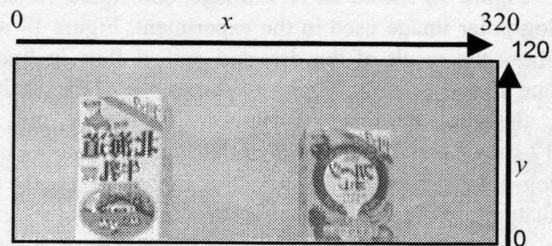


Figure 12: *Experimental image (X-Y image)*

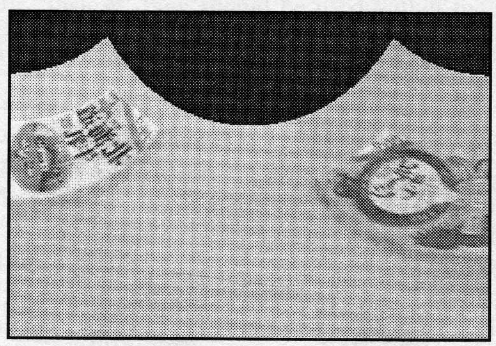


Figure 13: *Experimental image (log-polar image)*

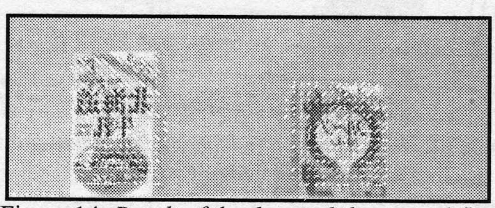


Figure 14: *Result of the detected the optical flow (X-Y image)*

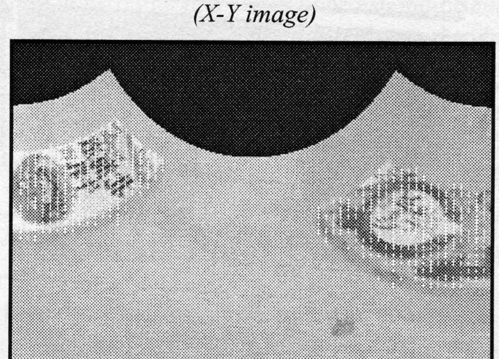


Figure 15: *Result of the detected the optical flow (log-polar image)*

calculated by the difference in the position of the templates.

In the situation of a single background, we put two objects with the flat surface at the same distance. 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 55cm to 15cm by a 1cm step. Using the obtained images, we measured the distance in the X-Y image and the log-polar image, and we obtained the accuracy of the measuring the distance in each image type.

Figure 12 shows an X-Y image, and figure 13 shows a log-polar image used in the experiment. Figure 14 and 15 show the result of the detected optical flow in figure 12 and 13 respectively. Figure 16 shows one of the results of detecting the distance using an X-Y image, and figure 17 shows one of the results of detected the distance using a log-polar image. In the images of figures 11-16, the actual distance to objects from the camera is 30 cm.

By the experimental result, the average error in the X-Y image was 2.93 cm, while the average error by the log-polar image was 1.64 cm. The reason of this result is that the template matching became easier by using the log-polar image, and the error in the matching was reduced. Therefore, using the log-polar image, we obtained the measured distance with higher accuracy.

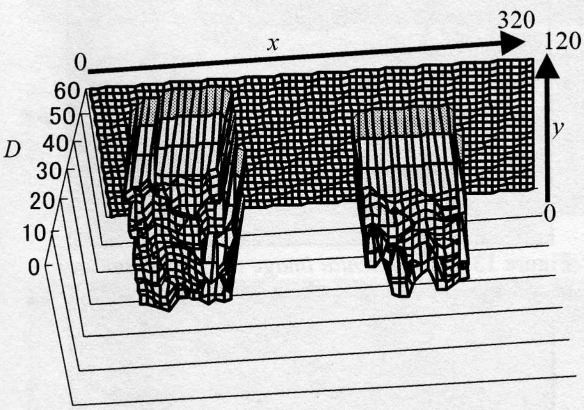


Figure 16: *Result of the detected the distance (X-Y image)*

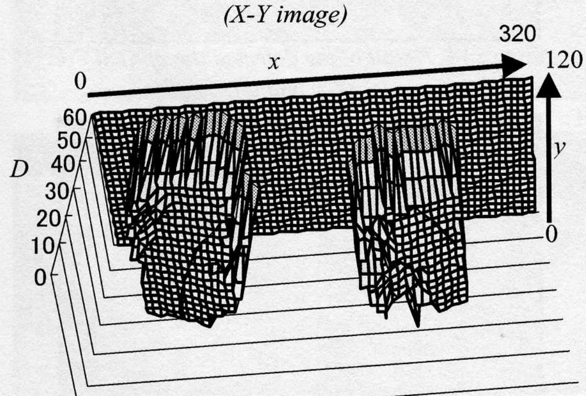


Figure 17: *Result of the detected the distance (log-polar image)*

6 Conclusion

In this paper, we presented the effectiveness of the HVC, which is constructed by a mirror and a camera for a small robot system. Moreover, by using the property of the HVC like the log-polar image, the HVC can measure the distance to the object with higher accuracy, and we consider that the HVC is very useful for the small robot system.

In the future, we have a plan to install the HVC in a cleaning robot. By using the lower half of the image, the HVC can see the ground in front of it. By using the upper half of the image, the HVC can know the obstacles around it. Therefore, the robot can easily find garbage and obstacles by using the obtained image.

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