THE DETECTION OF OBSTACLES BY
THE HORIZON VIEW CAMERA

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We propose a new camera system called the Horizon View Camera (HVC), which can
be installed in a small size robot. The HVC is a system in which the optical axis of
the camera is directed to the horizon using a mirror. The obtained image consists only
of objects without the ground. Therefore, by using the HVC system, distinguishing the
object from the ground becomes very easy. We demonstrate the effectiveness of the HVC
with experiments on the detection of the distance to the object by using features of the
HVC.

Keywords: Horizon View Camera; Obstacle Detection; Distance Measurement; Log-Polar
Transform.

1. Introduction

Many studies of autonomous robots have been proposed. According to them, the vi-
sual information from a camera is useful for an autonomous robot.1 The autonomous
robot has to recognize the surrounding environment using visual information. For
example, when the robot moves, the robot has to recognize the obstacles that limit
the action.

In the method of detecting the object, 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 cameras or more are needed, which increases the cost.2,3
On the other hand, in the case of using the single camera, the cost is lower, but
it is necessary to keep the camera at a higher position in order to acquire higher
accuracy.4 Therefore, the height of the system can become impractically big. Hence,
we proposed a new camera system called the Horizon View Camera (HVC) which
enables the construction of a small size robot.5
2. 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, and this strategy has the problem that the system becomes impractical. To solve this, our new method keeps the camera at a low position, that is, the camera is put near the ground. With this method, the image obtained contains only surrounding objects without the ground because the system position is low. The camera is put near the ground, and the system made so that the optical axis of a camera is directed to the horizon, giving the system its name. Since the image obtained by this system contains only objects without the ground, this system has the advantage that distinction of the object from the ground becomes very easy, and the calculation time can be reduced. By moving forward, the system can measure the distance easily.

In attempting to make the HVC system, we had to bury half of the cameras in the ground to make the optical axis of the camera direct to the horizon. But this is impossible in actual applications. Therefore, the optical axis of a camera was directed to the horizon by using a mirror. The HVC system is shown in Fig. 1. The height of the HVC system is decided according to the size of camera and mirror. Here, the size of the mirror used is 17 cm × 11.9 cm. The range of vision of this camera is about 46 degrees in the vertical direction, and about 60 degrees in the horizontal direction. The image obtained with this system is separated horizontally into two parts; the upper half of the image is the reflected image from the mirror, and the lower half of the image is the direct image in front of the system. The image obtained by the HVC is shown in Fig. 2, and Fig. 3 shows a sequence of the animation taken by the HVC — a person walking in front of the HVC.

3. Features of the HVC System

In this system, every object in the image is considered an obstacle because the ground is not included in the image of the upper part of the horizon. Therefore, the distance to the object is measured with the reflected image only by moving the HVC, without detection of the object.
The Detection of Obstacles by the Horizon View Camera

The images obtained by the HVC system have a feature in the emission point of the optical flow. When the HVC system moves some distance, the emission point is located on the horizon of the image. The optical flow of a stationary object flows radially from the emission point to the 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 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.

Moreover, when the image from the HVC was transformed to log–polar coordinates, the transformed image has an interesting feature; when the HVC system moves forward, the optical flow flows in an upward direction. Also, if the optical flow does not flow in the upward direction, the object of that image can be recognized as a moving object like the optical flow of the original image.

Generally, when the image by the HVC is transformed to log–polar coordinates, we have to fix the origin to the same position exactly in every image. This is a serious problem in applications using the log–polar coordinate transform. But in the case of the HVC system, the origin is always fixed at the center of the horizon.
Therefore, we can transform the image to log-polar coordinate easily. The details of the log-polar image are described in Chap. 4. Here, we define the image obtained by the HVC as an X-Y image, and the log-polar transformed image as the log-polar image.

4. Method of Measuring the Distance to the Object

4.1. Method of measuring the distance from an X-Y image

We used the optical flow for detecting the distance to the object. When the camera is moved forward, the object close to the camera moves a great amount in the image, while objects further from the camera do not move so much. Moreover, the distance of the movement also differs depending on 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 a great deal. If the object is located near the center of the optical axis, it moves a little. 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 be measured by the direction and the size of each movement vector to the object.

In this paper, we used template matching to detect the optical flow. Accordingly, the distance to the object is measured by the optical flow. The distance to the object is calculated by triangulation because the angle from the camera to each pixel of the image is constant, and the distance of the camera movement is already 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 following. The camera was located 23 cm from a wall, and we got an image about 9.8 cm high and 26.4 cm wide. Figure 5 shows the camera parameters. The value of $\theta$, which is the angle of each pixel from the camera, is decided using these values.
In the case of the resolution of $320 \times 240$ pixels, $(x, y)$ is calculated using Eq. (1) to give $(I, J)$, since the center of the horizon is at the origin:

$$I, J = (x - 160) \times \frac{13.2}{160}, (120 - y) \times \frac{9.8}{120} \quad (x = 0 - 320, y = 0 - 120). \quad (1)$$

$(I, J)$ is an actual position 23 cm from the camera. Figure 6 shows how the angle of each pixel in the image is calculated. The angle of each pixel from the camera is thus calculated using Eq. (2):

$$\theta = \tan^{-1} \frac{\sqrt{I^2 + J^2}}{23}. \quad (2)$$

Using the values of $\theta_1$ and $\theta_2$ calculated for each pixel, the distance to the object is calculated using Eq. (3), where $d$ is the movement distance of the camera, and $D$
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**Fig. 7.** Measurement of the distance to the object.

**Fig. 8.** Transform to log-polar coordinates.

is the distance to the object. Figure 7 shows the method of calculating the distance. The values of \( \theta_1 \) and \( \theta_2 \) for each pixel and \( d \) are already known:

\[
D = d \times \frac{\tan \theta_1}{\tan \theta_2 - \tan \theta_1}.
\] (3)

**4.2. Method of measuring the distance using the log-polar transform**

In order to improve processing speed and accuracy, a new idea was introduced. The upper half of the image obtained by the HVC is easy to transform to the log-polar coordinate image as shown in Fig. 8. This log-polar image has useful properties. The \( X-Y \) image is transformed to the log-polar image using Eq. (4). By using a general equation to transform to log-polar coordinates, objects distant from the center of the horizon are transformed to small sizes. Therefore, when we detect the optical flow, the accuracy of the distance measuring becomes low because the size of each vector is small. Therefore, we used Eq. (4), in which the increasing rate of “log” is regulated by using the value of \( k \) to detect the optical flow in order to be able to measure the distance with sufficient accuracy. Figure 9 shows the \( X-Y \) image and the log-polar image:

\[
r = \log_a (k \times \sqrt{x^2 + y^2} + 1),
\]

\[
\theta = \tan^{-1} \frac{y}{x}.
\] (4)
In the log-polar image, the optical flow of standing objects flows in an upward direction constantly, as shown in Fig. 10. By using this property, the 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. Moreover, by using the log-polar image, we think that the optical flow can be detected more correctly and the accuracy of the measuring distance can be improved. In addition, because the feature of an object with straight lines or textures which may cause failure in the template matching is changed into a complex feature, the template matching becomes easier. In the X–Y image, the objects move to the
outside from the center of the horizon. In the log–polar image, the objects move in an upward direction as shown in Fig. 9.

In order to find the distance, we substituted Eq. (4) into Eq. (1) to obtain \((I, J)\), and we calculated \(\theta\) by the substitution of \((I, J)\) into Eq. (2). We obtained the distance to the object \(D\) by substituting the angle of each pixel \(\theta\) into Eq. (3). We can also measure the distance to the object in the log–polar image using Eq. (5). In Eq. (5), \((r_1, \theta_1)\) and \((r_2, \theta_2)\) are coordinate values of the object in the log–polar image before and after movement. In the log–polar image, \(\theta_1\) and \(\theta_2\) do not change if the HVC moves forward, because the optical flow flows in an upward direction constantly. Therefore, \(\theta_1\) and \(\theta_2\) are not included in Eq. (5). \(d\), the movement distance of the HVC, is a known value:

\[
D = d \times \frac{a^{r_1} - 1}{a^{r_2} - a^{r_1}}. \tag{5}
\]

5. Experiments

Experiments were conducted to compare the accuracy of measuring the distance to the object using the \(X–Y\) image and log–polar image of the HVC. In these experiments, we detected only a stationary object. Therefore, the calculated optical flow flows from the center of the horizon to the outside in the \(X–Y\) image. The calculated optical flow flows in an upward direction in the log–polar image. If an unexpected movement vector is obtained, it was considered to be a mistake in the template matching and this movement vector was not used to measure the distance.

Templates were made on the feature points in the image, and then the camera was moved forward. The template matching was then executed for the image after moving. The optical flow in the image of the object was calculated from the difference in positions of the templates.

In the case of the single background, we used two objects with the flat surface at the same distance. The camera was moved forward each time by a constant

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{images}
\caption{Experimental image.}
\end{figure}
distance, and the image was taken at every step. The distance between the camera and objects was changed from 55 cm to 15 cm in 1 cm steps. Using the image obtained, we measured the distance in the $X-Y$ image and the log-polar image, and we obtained the measurement accuracy for each image.

Figure 11(a) shows the $X-Y$ image, and Fig. 11(b) shows the log-polar image used in the experiment. Figures 12(a) and (b) show the results of detecting the optical flow in Figs. 11 (a) and (b). Figure 13(a) shows one of the results of detecting the distance using the $X-Y$ image, and Fig. 13(b) shows one of the results of detecting the distance using the log-polar image. In the images of Figs. 11, 12 and 13, the actual distance to objects from the camera is 30 cm.

The average error for the $X-Y$ image was 2.99 cm, while the average error for the log-polar image was 1.65 cm. The reason for this difference is that the template matching was easier for the log-polar image, and the errors in the matching were reduced. Therefore, using the log-polar image, we obtained the measured distance to a higher accuracy.
6. Conclusion

In this paper, we have presented the effectiveness of the HVC, which was constructed using a mirror and a camera for a small robot system. By using the log-polar property of the HVC, the HVC can measure the distance to objects to a higher accuracy, and we consider that the HVC is very useful for a small robot system.

At present, we used only the upper half of the image captured by the HVC. However, the image obtained has another half, and we think that using two parts of the images gives us more varied information. For example, the accuracy of measuring the distance becomes better, and objects are detected by different methods.

In the future, we are going to install the HVC in a cleaning robot. By using the lower half of the image, the HVC will be able to see the conditions in front of it while by using the upper half of the image, the HVC will be able to detect the environment around it. Hence, the robot will easily find garbage and avoid obstacles by using the images obtained.

References

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