PREDICTED POLAR MAPPING FOR MOVING OBSTACLE DETECTION

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Abstract: This paper presents the predicted polar mapping that is to improve the efficiency of an unexpected moving obstacle detecting system in a single vision-based robot. The polar mapping is used to simplify the segmentation of moving objects from the background and is performed with the focus of expansion (FOE) as the center. When the movement of the robot per a step becomes a bit large, then static objects or background are detected as moving objects. Thus, the velocity of the robot becomes so slow. Therefore, to enlarge the movement of the robot and to improve this system, we propose the predicted polar mapping that predicts the polar mapped image after robot moves to be admissible. In order to verify experimentally our proposed procedure, we make several comparative tests in the corridor.

1 INTRODUCTION

Vision systems are used more and more for the navigation of mobile robot because visual sensing can provide the robot with an incredible amount of information about its environment. One of the central problems of vision-based navigation is moving obstacle avoidance. Many approaches have been taken to solve the problems of moving obstacle avoidance and a wide variety of approaches and algorithms were researched in this field (Bhaunu, 1988), (Thompson, 1988). One of the key issues is differentiating nonstationary objects from the stationary background in a moving platform, since both the background and the object appear to be moving (Frazier, 1992), (Nair, 1994), (Nair, 1998).

The algorithms for detecting moving objects from a moving platform compute the global optical flow (Enkelmann, 1996). Other algorithms use image transformations and qualitative analysis of the motion of points to detect and segment the moving objects (Bhaunu, 1988), (Nair, 1994), (Nair, 1998). These methods are typically more effective in the purpose to get information about the detected motion of a robot. In these methods, the camera provides the global information on the working environment, so that it can separate the moving and static objects without changing its pose by finding the difference of two consecutive images. A more sophisticated method is to find the optical flow using two consecutive polar mapping images (Nair, 1994), (Nair, 1998), (Enkelmann, 1996).

In this paper, we present a procedure using the predicted polar mapping and the segmentation to detect unexpected moving objects that appear in the path of a navigating robot and to estimate the relative motion of the object with respect to the robot. After qualitative detection of the moving obstacles, relative motion information of the object is obtained by computing the time-to-impact between the robot and the obstacles (Tistarelli, 1991), (Tistarelli, 1993). Since this method requires the determination of correspondences between all pixels in the image, the computational cost and error rate are very high. Therefore, by the help of the method in (Nair, 1994), (Nair, 1998), moving objects are segmented from image for effective use of this method or less computation. But, it has the terrible limitation as follows. If the movement of robot increase, then the static objects or background is detected as moving objects. Thus, we use the image that is acquired after very small movement. As a consequence, the velocity of robot becomes slow. Therefore, to improve the efficiency of this method, we proposed the predicted polar mapping that predicts the polar mapped image after robot moves to be admissible.

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2 PREDICTED POLAR MAPPING

To segment moving object from the background, each image acquired by the robot is transformed from Cartesian coordinates to polar coordinates, using a polar mapping that transforms the image to a polar coordinate system with the focus of expansion (FOE) as the center. The image is transformed to polar coordinates using the following equations.

$$\rho = \sqrt{(x - x_{FOE})^2 + (y - y_{FOE})^2} \quad (1)$$

$$\eta = \tan^{-1} \frac{(x - x_{FOE})}{(y - y_{FOE})} \quad (2)$$

In the above equations, ρ is the radial distance from the FOE to the Cartesian image coordinate (x, y), and η represents the angle $0 \sim \pi$ subtended by the Cartesian image coordinates (x, y), the FOE, and the Cartesian image coordinates $(1, 0)$. The advantages of using the polar and the log-polar or complex logarithmic mapping (CLM) have been shown in (Bishay, 1994), (Tistarelli, 1993). Two successive images

(a) (b)

Figure 1: (a) The first image with moving forward of a robot = 0. (b) The second image with moving forward of a robot = 3cm.

from a typical sequence in a corridor are shown in Fig.1. When this transformed image is represented with radial, ρ, and angular, η, axis as the Cartesian coordinates, the motion of the stationary objects will be in the horizontal direction. Objects that are moving with respect to the observer will have motion in an angular direction in this transformed space. To perform the polar mapping, the FOE must be located accurately. For the experiments presented in this paper the FOE is determined using the vision-based algorithm described in (Frazier, 1992).

For the system that detects unexpected moving objects that appear in the path of a navigating robot, the difference image between the first image and the second image after robot moves is used. In this detecting system, if the movement of robot per step become a bit large, then the static objects or background is detected as moving object. Thus, we use the difference image after robot moves very small. As a consequence, the velocity of robot becomes so slow. Therefore, for more large movement of robot, we predict the polar mapping image after robot moves to be admissible. The followings are the procedure of the predicted polar mapping.

Procedure 1: The predicted polar mapping

A. Acquire an image from camera.

B. Execute polar mapping of the image.

C. Compute the optical flow with respect to movement of robot.

D. Compute the zooming rate.

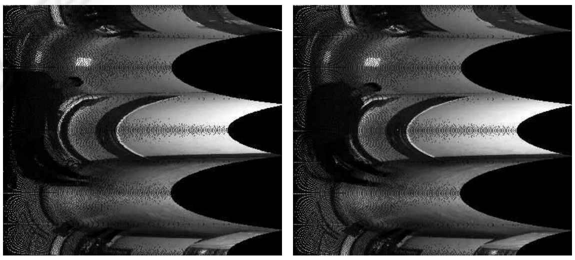
E. Enlarge the polar mapping image with zooming rate horizontally. (i.e., Enlarge the radial axis of the polar mapping image with zooming rate.)

F. Cut off the end part of radial axis of the polar mapping image with zooming rate. (i.e., Cut off the right end part of the polar mapping image.)

The zooming rate used in procedure 1 is defined as follows:

$$\alpha = \frac{W_\rho}{H} \quad (3)$$

where α is a zooming rate, W_ρ is a radial component of the optical flow, which is described in (Tistarelli, 1991), (Tistarelli, 1993) and H is the size of horizontal axis (i.e., radial, ρ, axis). The (a) in Fig.2 is the resultant image from procedure 1 that is the predicted polar mapping of the first image, and the (b) in Fig.2 is general polar mapping of the second image that is acquired after robot moves forward at 3cm.

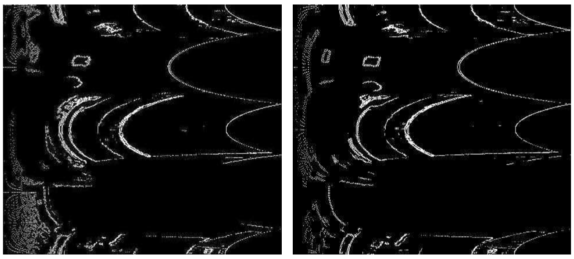


(a) (b)

Figure 2: (a) The predicted polar mapping of (a) in Fig.1. (b) The polar mapping of (b) in Fig.1.

3 DETECTING VERTICAL MOTION

After transforming the image into the predicted polar mapping, the problem of detecting a moving obstacle is to find vertical motion along an angular axis in sequence of transformed images. If a horizontal edge in an image moves horizontally, then the overlap between the edge from one image to the next image is very large. On the other hand, if a horizontal edge moves vertically, then there is very little overlap. Hence, the qualitative measure of the motion is obtained by detecting the vertical motion of edges present in the transformed image. In this paper, we use the Sobel operator presented in (Gonzalez, 1992), (Forsyth, 2003) to detect edges from each image. The (a) in Fig.3 shows the edge detected images of the predicted polar mapping (i.e., (a) in Fig.2), and the (b) in Fig.3 shows the edge detected images of the general polar mapping (i.e., (b) in Fig.2). A qualitative es-



(a) (b)

Figure 3: (a) The edges detected image of (a) in Fig.2. (b) The edges detected image of (b) in Fig.2.

timate (reported in (Nair, 1994), (Nair, 1998)) of the motion of the object in these images is obtained as follows. First, horizontal and angular edges in the transformed images are enhanced. Let $I_{sobel}^{(p)}$ and $I_{sobel}^{(n)}$ represent the edge images of predicted polar mapping and second polar mapping obtained by Sobel operator, respectively. Then, the resultant image I_{det} that detects moving objects is obtained as following equation.

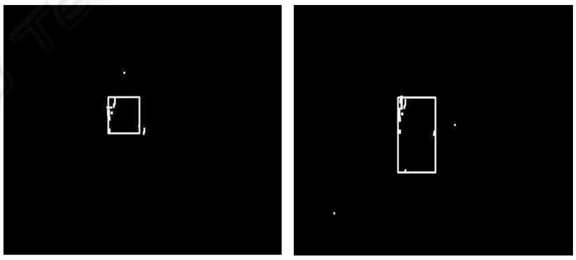
$$I_{det} = I_{sobel}^{(p)} \cdot I_{sobel}^{(p)} - I_{sobel}^{(p)} \cdot I_{sobel}^{(n)} \quad (4)$$

In above equation, we can enlarge the positive values along horizontal edge components of each image using multiplication. Edges that move vertically produce little overlap, so they are eliminated. Hence, (4) is a map of all horizontal and angular edges that have moved vertically. Some edges that have moved horizontally may be present in this resultant image, but they are usually small pieces. Actually, this map contains small pieces of horizontally moving edges that did not completely cancel out. In practice, however, these small pieces are very weak, and are filtered out by a thresholding process (Gonzalez, 1992), (Forsyth, 2003). As a consequence, this map, I_{det}, contains the detected motion. Next, this map is transformed back into the rectangular frame. In order to compute the optical flow, rather than use the qualitative motion detected entire image, the segmentation can be used to find the region where the moving object may be located (i.e., the region of interest) in consecutive images.

In this paper, we use a region using a rectangular area as the base template. A rectangular was chosen as the shape that best represents the area occupied by the moving object because in most cases, the moving objects in a man-made environment are in the forms of people or opening doors (Nair, 1994), (Nair, 1998). To obtain the regions that enclose the detected motion pixels, general rectangular clustering method (Gonzalez, 1992), (Forsyth, 2003) is used. In using this method, to reduce errors or disturbance, we discard the detected pixels that are the most outer of each side as Fig.5. The (a) in Fig.4 shows the resultant image that is transformation of the motion detected image using the predicted polar mapping back into rectangular coordinates, and the (b) in Fig.4 is the restored motion detected image using the general polar mapping. Fig.5 is segmentation of Fig.4, respectively.

(a) (b)

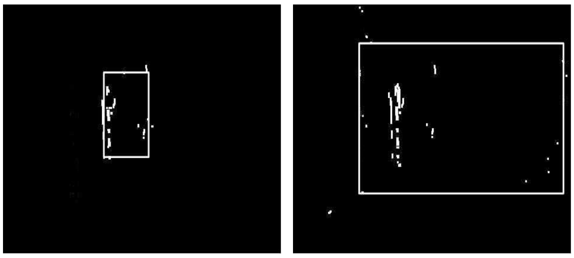
Figure 4: (a) The restored motion detected image of the predicted polar mapping. (b) The restored motion detected image of the general polar mapping.



(a) (b)

Figure 5: (a) The segmented image of (a) in Fig.4. (b) The segmented image of (b) in Fig.4.

To verify our proposed method that is predicted polar mapping, we make the simple comparative test. In this test, we make a robot move at 9cm for comparison of the predicted polar mapping with the general polar mapping. The results of this test are shown in Fig.6, and we see that the result of the polar mapping has great noise as compared with the predicted polar mapping. It is obvious that the general polar mapping is not suitable to the system that needs a little more movement of robot. As a consequence, our proposed method can be of help to detect a moving object. In addition, The optical flow can be obtained by the help of (Tistarelli, 1991), (Tistarelli, 1993).



(a) (b)

Figure 6: (a) The segmented image using the predicted polar mapping with moving forward of a robot = 9cm. (b) The the segmented image using the polar mapping with moving forward of a robot = 9cm.

4 EXPERIMENTAL RESULTS

The moving object detecting system using the proposed method was implemented on the Pioneer 2–AT mobile robot of ActivMedia. The main control processor of this robot is a Simens 88C166(20MHz) microprocessor. For image processing and control of the robot, a industrial computer with Intel Pentium III(850MHz) and Windows 98, a Panasonic CCD camera, and frame grabber (DataTranslation DT3132) are mounted on the robot. The images have been acquired at a resolution of 480×360 pixels. The optical axis of the camera is almost parallel to the ground. In order to verify experimentally the proposed method outlined in procedures 1, we make several comparative tests in the corridor. We make a robot move at 3cm to 15cm for comparison of the predicted polar mapping with the general polar mapping. The results are shown in Fig.7, and we see that the polar mapping has great noise as compared with the predicted polar mapping. Hence, the predicted polar mapping is robustly admissible to the system that needs a little more movement of robot.

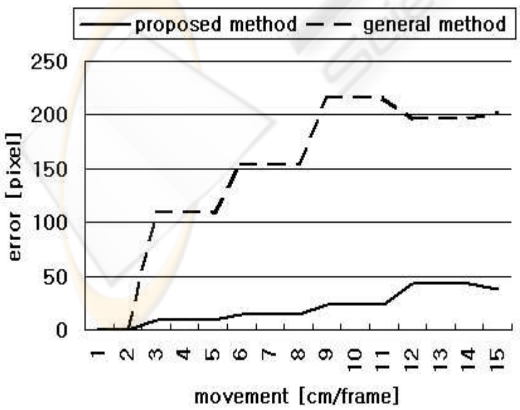


Figure 7: Errors of the optical flow in comparative test

5 CONCLUSION

In this paper, the procedure using the predicted polar mapping and the segmentation to detect unexpected moving objects has been presented, and has been implemented with a Pioneer 2–AT mobile robot. In order to enlarge movement of robot per a step and improve the effective use of polar mapping, we have proposed the procedure that predicts the polar mapping image after robot moves to be admissible. To verify experimentally our proposed procedure, we make several comparative tests in the corridor. It is obvious the predicted polar mapping has a little noise as compared with the polar mapping.

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