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Evaluation of Effectivity of Omnidirectional Image Sensor COPIS in a Real Environment

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Abstract

We designed a new omnidirectional image sensor COPIS (COnic Projection Image Sensor) to guide the navigation of a mobile robot. Under the assumption of the known motion of the robot (COPIS), an environmental map of an indoor scene is generated by monitoring azimuth change in the image. We did several experiments in the simple indoor environment to examine the potential of COPIS against effects of observational errors in real-time navigation. The precision of obtained environmental maps was sufficient for robot navigation in such environment. In this paper, we improve the image processing method for extracting and tracking vertical edges, and also evaluate the effectivity of omnidirectional image sensor COPIS in a real indoor and outdoor environment.

1.Introduction

While there has been much work on mobile robots with vision systems [1][2][3], most robots view things only in front of them and avoid static obstacles and as a result, they may collide against objects moving from the side or from behind. To overcome these drawbacks, a sensor is needed to view the environment around the robot so that it may navigate safely.

We have proposed an omnidirectional image sensor COPIS (COnic Projection Image Sensor) for guiding navigation of a mobile robot [4][5]. The key feature of COPIS is passive sensing of the omnidirectional environment in real-time (at the frame rate of a TV camera), using a conic mirror. Mapping of the scene onto the image by COPIS involves a conic projection and vertical edges in the environment appear as lines radiating from the image center. The main field viewed by COPIS is a side view and the resolution along a radial direction of conic mirror is sufficient to extract vertical edges.

We also reported a method of map generation, which is based on azimuth information in the image sequence [6][7]. Under the assumption of known motion of the robot, locations of objects around the robot can be estimated by detecting their azimuth changes in the omnidirectional image. One can recognize the surface of objects and estimate the free space for a mobile robot from the geometrical relation between object points in the image. Using this method, the robot generates an environmental map of an indoor scene while it is moving in the environment. The method used properties common to many indoor environments. The floor is almost flat and many visible vertical edges are present about the room. Therefore, the method can be used for mobile robots working in most buildings or plants. Using this method, we did several experiments in the simple indoor environment. The obtained precision of environmental maps was sufficient for robot navigation in such environment. However, in this experiment, we simplified the image processing method and the experimental environment to examine the potential of COPIS against effects of observational errors in real-time navigation.

In this paper, we improve the image processing method for extracting and tracking vertical edges to discriminate these edges and evaluate the effectivity of omnidirectional image sensor COPIS in a real indoor and outdoor environment. Experiments done in an actual environment support the validity of our method.

2.Conic Projection Image Sensor (COPIS)

COPIS mounted on a robot consists of a conic mirror and a TV camera, with its optical axis aligned with the cone's axis, in a cylindrical glass tube. A prototype of the COPIS system is shown in Fig.1. COPIS maps the scene onto the image plane through a conic mirror and a lens. We call this mapping " conic projection ". We describe here how features of the scene appear in the image.

Let us use the three dimensional coordinate system O-XYZ, aligned with the image coordinate system o-xy and the Z-axis pointed toward the cone's vertex (see Fig.2). We fix origin O at the camera center, thus the image plane is on a level of f, where f is the focal length of the camera. A conic mirror yields the image of a point in space on a vertical plane through the point and its axis. Thus, the point P at (X,Y,Z) is projected onto the image point p at (x,y) such that

$$\tan\theta = \frac{Y}{X} = \frac{y}{x}. \qquad (1)$$

If a line is vertical, it appears radially in the image plane, as shown in Fig.2. Thus, COPIS can easily find and track the vertical edges by searching consecutive images for radial edges. For further details, we refer to reader to our preceding report [5].

3.Assumptions

The following properties of the environment and the mobile robot are assumed for image analysis.

The floor is almost flat and horizontal while walls and static objects such as desks or shelves have vertical planes. The robot moves in a man-made environment such as a room or a corridor. Its motion parameters are two translational components (U,V) and one rotational component φ (pan angle).

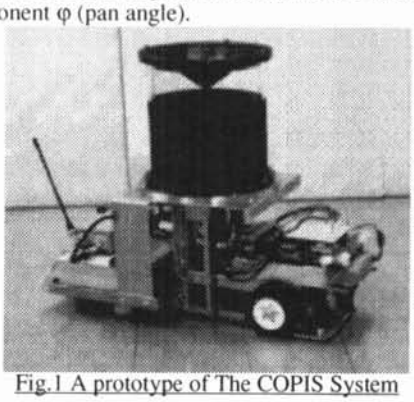


Fig.1 A prototype of The COPIS System

4.Generation of an Environmental Map

Let us denote the robot motion by (u(t),v(t)) and $\varphi(t)$. $\varphi(t)$ is the pan angle at time t. Defining the position of P at time t=0 by $P_1(X(0),Y(0),Z(0))$, the relative velocity of the point P in the environment at time t is represented by (-u(t), -v(t), 0). We get the location of point P at time t as

$$X(t) = \int_{\tau=0}^{t} -u(\tau)\, d\tau + X(0)$$

$$Y(t) = \int_{\tau=0}^{t} -v(\tau)\, d\tau + Y(0) \qquad (2)$$

$$Z(t) = Z(0)$$

Thus, from (1) and (2), the relation between an azimuth angle of an object and time t is obtained as follows,

$$\tan(\theta(t) - \varphi(t)) = \frac{\int_{\tau=0}^{t} -v(\tau)\, d\tau + Y(0)}{\int_{\tau=0}^{t} -u(\tau)\, d\tau + X(0)} \qquad (3)$$

The locus of the azimuth angle in consecutive image is represented by (3). Thus, if the azimuth angle θ is observed at two points, the relative location between the robot and the object point is calculated by triangulation .

The azimuth angle has an observational error due to the swaying motion of the robot. This swaying motion may change the pan, tilt and roll angles of the camera. While the tilt and roll angles have little influence on the observed azimuth angle, the pan angle has a strong effect on the angle. Therefore, as shown in Fig.3, we estimate the more precise location using consecutive measurements, by the least squares method. For further details, see our proceeding report [7].

5.Extracting & Tracking Vertical Edges in Omnidirectional Image Sequence

To evaluate the effectivity of COPIS in a real indoor and outdoor environment, we improve the method for extracting vertical edges, as shown in Fig.4.

The robot begins to move and takes an image sequence. First, each input image is transformed into 2-D polar coordinates(r,θ) ($r = \sqrt{x^2 + y^2}$). Next, we apply the differential operator to each polar coordinates image for finding only vertical edge points, then apply thresholding to each edge picture. To find the vertical edges, each edge picture is projected onto the θ-axis to get the 1-D projection. In this projection, the data are segmented into regions of each edge and the azimuth of the edges is estimated by calculating the average angle of each region.

In the previous method, it is difficult to distinguish the projection data of all edges in the area where there are dense vertical edges. Dense areas often appear in the real environment.

Using edge signs, edges from black to white (plus edge) and edges from white to black (minus edge) are projected separately. Then, edges can be discriminated in the area where there are dense vertical edges. Therefore, we use edge sign to precisely define the vertical edges in the improved method.

To estimate the loci of azimuths of vertical edges, the correspondence between edges with the same edge sign in the 1-D projection of consecutive images is established by using a correlation method in the restricted search field. As consecutive images are sampled densely, one can consider that the azimuth angle of the vertical edge in next frame is in the neighborhood of the azimuth angle in the current frame. Therefore, a certain margin of search field in the next frame is set around the current azimuth angle of the obtained vertical edge. After matching a few frames, the search region can be limited to a narrowed one by calculating the locus of each edge from equation (4). We then evaluate the conformation of neighboring relations. For instance, if there is some difference in matching score by correlation, the order of azimuths of edges becomes a prior consideration. As shown in Fig.5, the edge 1(2) matches with edge 1'(2').

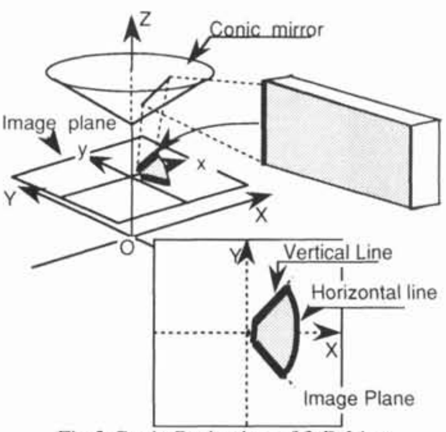


Fig.2 Conic Projection of 3-D Line

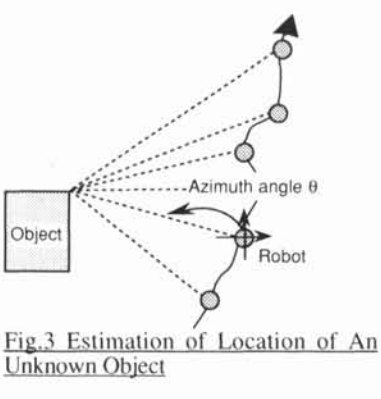


Fig.3 Estimation of Location of An Unknown Object

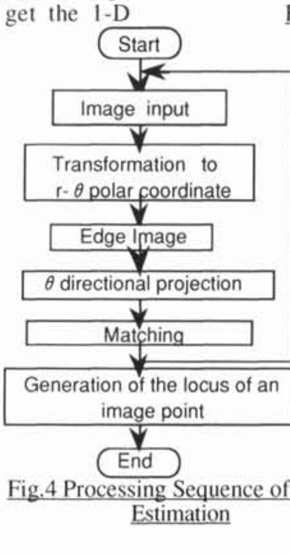


Fig.4 Processing Sequence of Locus Estimation

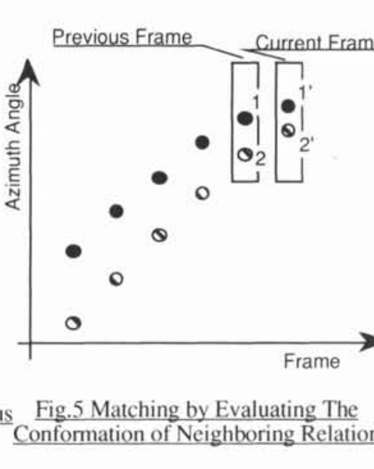


Fig.5 Matching by Evaluating The Conformation of Neighboring Relation

In a real environment, there are objects with vertical edges and also curved objects. As the method is based on vertical edges that often appear indoors, it cannot estimate locations of curved objects with no vertical edges such as cubes. However, such objects rarely appear indoors. Many curved objects, which often appear in a man-made environment, are cylindrical ones such as pipes and extinguishers. Apparent vertical edges appear on both sides of the cylindrical object. We call the apparent edge as extremal boundary. When the cylindrical object is viewed from two different camera positions, the location of its extremal boundaries can be estimated by triangulation. The estimated location has measurement error because the intersecting point of two lines of sight is not actually on the extremal boundary. However, this gap between the intersecting point and the boundary is small and the obtained precision of location of cylindrical objects can be considered to be sufficient for robot navigation.

6.Experimental Results

Using the COPIS system, we did several experiments. In section 6.1, we show the COPIS system configuration. In section 6.2, we show results for generating maps in a real room and a corridor and evaluating effectivity in a real environment.

6.1System Components

Wireless modems are used for serial communication between the robot and the image processing subsystem. The image is transmitted by UHF video transmitter and receiver. The speed of the robot is about 6 cm/sec and size is approximately 25 cm (W) x 45 cm (L) x 42 cm (H). Each omnidirectional image is converted into a 512x480 8 bit digital image. The total processing cycle is about 2 sec/frame.

6.2 Results of Extracting and Tracking Vertical Edges

Results were obtained with the robot moving in a corridor, in a computer room and in an outdoor road. Fig.6 is results in a computer room. As shown in Fig.6(b), each input image(Fig.6(a)) is transformed into 2-D polar coordinates(r,θ). Fig.6(c)),(d) show the edge image and results of estimated loci of vertical edges.

Vertical edges sometimes disappear and reappear due to occlusion by other obstacles. In case of the short interval of occlusion, it can continue to match the vertical edges in consecutive images because the azimuth angle at the next frame is predicted from the locus of azimuth angle of the vertical edge in consecutive images. However, when the occlusion becomes longer, the error between the predicted and the real observed azimuth angle will increase, therefore, it is difficult to find the corresponding one. In this case, we estimate the location separately, before and after occlusion. Usually, both estimated locations are close. In this case, we connect them and reestimate the location. If the distance of both estimated locations is longer than a certain length, we consider that each locus of azimuth angles occurred from different vertical edges.

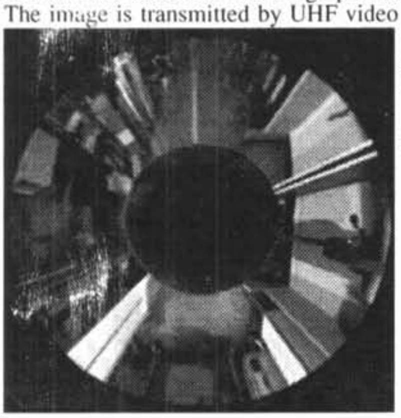


Fig.6 (a) COPIS Input Image (Computer Room)

Fig.6 (b) Transformed to Polar Coordinate

Fig.6 (c) Edge Image of Fig.9(c)

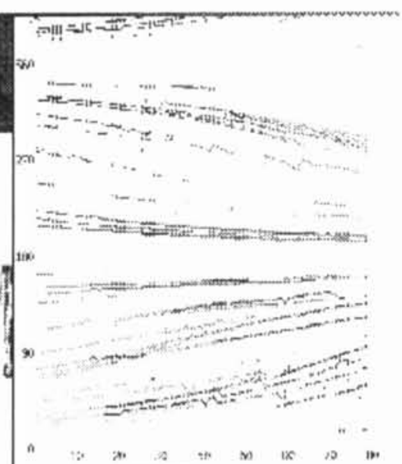


Fig.6(d) loci of azimuths of vertical edges

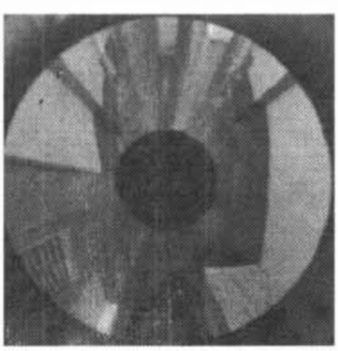


Fig.7(a) Omnidirectional input image (Corridor)

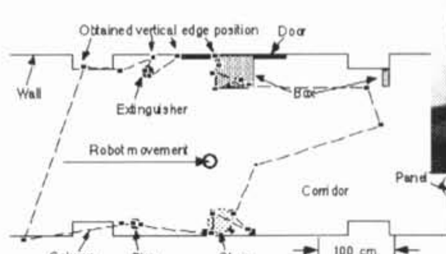
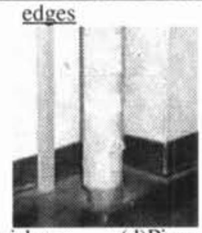
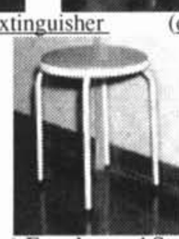


Fig.7(b) The Result of Map Generation (Corridor)

(c)Extinguisher



(d)Pipe



(e) Four Legged Stool

Fig.7 Ojects in the Corridor

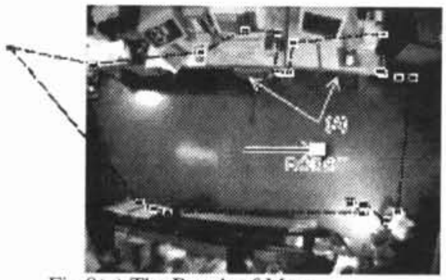


Fig.8(a) The Result of Map Generation (Computer Room)

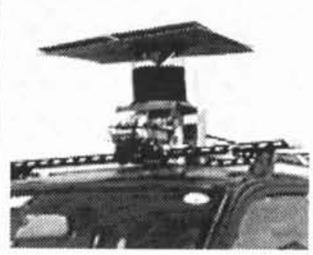


Fig.9(a) COPIS Mounted on The Car

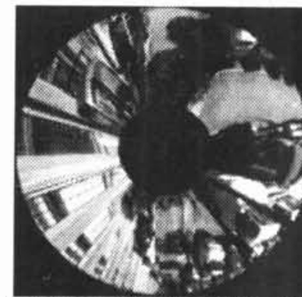


Fig.9(b) Omnidirectional input image (Outdoor Road)

Fig.9(c) Transformed to Polar Coordinate

Fig.9(d) Result of Map Generation (Outdoor Road)

6.3 Evaluation of Effectivity in a Real Environment

In the corridor, the robot moves straight during 40 frames. Fig.7(a) and (b) are examples of input image and the result of estimated locations of vertical edges, at the final frame, respectively. The estimated locations of vertical edges were plotted by black squares and the estimated surfaces were drawn by a solid line between the estimated vertical edges. The large error in front of the robot occurred because azimuth angles of edges in front of the robot did not change significantly and the movement of the robot was short. By changing the direction of movement or moving continuously straight, precision can be increased. In case of cylindrical objects such as an extinguisher or a pipe, as shown in Fig.7(c) and (d), estimated locations were adequate for navigation. In case of a four legged stool, as shown in Fig.7(e), regions between legs are estimated as for a candidate surface because we assume the surface by using only a simple geometrical relation. However, the false surfaces could be removed by using an acoustic sensor as described. For details, see our report [7].

Next, we show the result in the computer room with several objects. Fig.8(a) is the result of estimated locations of vertical edges at the final frame from the top view of the environment. The estimated locations of vertical edges were plotted by black points and the estimated surfaces were drawn by a dashed line between the estimated vertical edges. In this case, the height of the object (desk) is higher than that of COPIS. COPIS observed the lower part the desk and estimated the desk configuration to be a concave object as label (A). Therefore, one can estimate both convex and concave ones.

The final experiment was done in the outdoor road. We mounted COPIS on a loof of a car as shown in Fig.9(a). Fig.9(b) and (c) show the input image and the polar trasformed image, respectively. The top view of the environment and the result of estimated locations of vertical edges are shown in Fig.9(d). The central dark car with COPIS moved at the speed of 20 cm/sec. The Wall of the building and three trees by the right side of COPIS could extract. However, it was difficult for the previous method to extract the vertical edges on the white car beside COPIS because of low 1-D projection value of its vertical edges. In the right side region of the figure, there are a few vertical edges because of the large parking space.

7. Conclusions

In this paper, We improved the image processing method for extracting and tracking vertical edges and evaluated the effectivity of omnidirectional image sensor COPIS in a real indoor and outdoor environment.

The obtained precision of environmental maps is sufficient for robot navigation in a man-made environment. The method uses properties common to many indoor environments. The floor is almost flat and many visible vertical edges are present about the environment. Therefore, the method can be used for mobile robots working in most buildings or plants.

References

1. Waxman, A.M., J.J. LeMoigne, and B. Scinvasan, *A visual navigation system for autonomous land vehicles*. IEEE Journal of Robotics and Automation, 1987. **3**(2): p. 124-141.

2. Turk, M., *et al.*, *VITS-A vision system for autonomous land vehicle navigation*. IEEE Trans. PAMI, 1988. **10**(3): p. 342-360.

3. Thrope, C., *et al.*, *Vision and navigation for the Carnegie-Mellon Navilab*. IEEE Trans. PAMI, 1988. **10**(3): p. 362-373.

4. Yagi, Y. and S. Kawato. *Panorama scene analysis with conic projection*. in *Int. Workshop Intell. Robots and Sys.* 1990. IEEE.

5. Yagi, Y., S. Kawato, and S. Tsuji, *Real-Time Omnidirectional Image Sensor (COPIS) for Vision-Guided Navigation*. IEEE Trans. Robotics and Automation, 1994. **10**(1): p. 11-23.

6. Yagi, Y. and M. Yachida. *Real-time generation of environmental map and obstacle avoidance using omni-directional image sensor with conic mirror*. in *CVPR* 1991. IEEE.

7 Yagi, Y., Y. Nishizawa, and M. Yachida, *Map-Based Navigation for A Mobile Robot with Omnidirectional Image Sensor COPIS*. Trans. IEEE Robotics and Auto. (Accept).