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Acquiring Omnidirectional Range Information

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SUMMARY

This paper describes a method of obtaining a precise omnidirectional view and coarse ranges to objects by rotating a single camera. The omnidirectional view is obtained by arranging image data taken through a vertical slit on the image plane while the camera rotates around the vertical axis. The omnidirectional view contains precise azimuth information determined by the resolution of the camera rotation. The range is obtained from two omnidirectional images taken through two slits when the camera moves along a circular path. This range estimate contains errors due to a finite resolution of the camera rotation system, while a conventional binocular stereo method contains errors due to quantization of images. The representation of an environment, "panoramic representation," by the omnidirectional view and range information is useful for a vision sensor of a mobile robot.

1. Introduction

A camera used for a vision sensor of a conventional mobile robot is mounted on the robot. To recognize an environment more flexibly, it is necessary to design a camera to have more active functions. To achieve this requirement, a camera should be able to sense the whole environment and its specific part.

Fixation of gaze upon the interesting object is used in the paradigm of "Active Vision" [1, 2] which is a current topic in Computer Vision. In the Active Vision, a camera gazes upon a particular feature point in an environment while moving,and generates an environmental description with respect to the point.

Viewing the whole environment from an observation point is also important for a robot. It is necessary to build an accurate map when a robot works in an unknown environment. For this purpose, it is more efficient to use a wide view than integrating partial views ofthe whole environment by using a camera with a limited visual field. Since the conventional camera has a limited visual field, it is necessary to add extra facility to the camera to obtain an omnidirectional view field.

Yagi and Kawato [3] obtained an omnidirectional image by using a conic mirror which yields the image of the environment from the entire direction and by taking this image by a camera viewing from the top of the cone. Their method takes an omnidirectional image in real time and can analyze the image using a property whereby the optical flow of a point for a linear camera motion forms a curve. However, the angular resolution of their method is rather limited (the minimum resolution is about 0.2° in an image of 512 × 512 pixels), the resolution being coarse near the vertex of the cone, since the image of the entire environment is projected onto a single image plane.

Morita et al. [4] obtained a wideview image by using a camera with a fisheye lens. The angular resolution of their method is also not very high, although they reconstruct a three-dimensional (3-D) structure using the vanishing point of straight lines in its environment and not directly using omnidirectional information.

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Sarachik [5] has devised a method to obtain an omnidirectional image and the distance to a ceiling edge (a horizontal edge between a ceiling and a wall) by using two rotatable cameras on a robot. Her method can locate the robot in a room and estimate the camera direction.

By contrast to these passive methods, there have been active methods which project an optical pattern onto objects to measure their distances. Blais et al. [12] have constructed a compact stereo-based distance-measurement system by projecting a light onto the environment. By rotating their system, omnidirectional range information can be obtained. A disadvantage of the active method is that its environment is restricted by physical conditions, especially those of illumination.

The method proposed in this paper is a passive one without projecting a light pattern and uses a camera rotating around a fixed vertical axis, similar to Sarachik's system, to obtain an omnidirectional image. However, unlike her method which uses two cameras to obtain the distance information, the proposed method uses a single camera and can obtain both the view and range information with a high angular accuracy over 360°. Let us call this camera-centered 2.5-D representation containing both the visual information and the range information "panoramic representation." The method of Blais et al. [12] also can obtain both the omnidirectional view and range information. The difference of the proposed method from their method, other than the light projection, is the cause of errors in azimuth measurements. The error in their method depends on the resolution of its image sensor, and that in the proposed method depends on the angular accuracy of rotation of the camera around its axis (see section 2).

Advantages of the panoramic representation are as follows:

(A) Omnidirectional visual information has the following features:

(1) When an omnidirectional image is taken in a rectangular room, four vanishing points appear every 90°.

(2) When a camera moves on a straight line on a plane perpendicular to the rotation axis of the camera, two "foci of expansion" (FOE) of the optical flow of objects in its environment appear at an interval of 180° in the omnidirectional image.

(3) The environmental structure is obtained by a set of two omnidirectional images.

By using feature (1) as a constraint, the vanishing points in an omnidirectional image can be determined more precisely; and this is useful in obtaining the rotation angle of a mobile robot. By using feature (2), the rotation angle and the direction of the robot motion can be obtained from the projection of the features onto a Gaussian sphere [6]. Feature (3) can be used for stereovision by using two omnidirectional images taken at different locations in an environment. The correspondence of the two images can be obtained by using "circular dynamic programming" [7] based on the structure of the omnidirectional image.

(B) Precise angular information

An image obtained by the proposed method has a resolution equal to that of the camera rotation; i.e., by using a precise camera rotation control system, the resolution of the angular information could be higher than that of a conventional method. This is an excellent feature of the proposed method. For example, the stereovision using a pair of two omnidirectional images (feature (3) in (A)) is useful for determining both the structure of the wide environment and positions of objects in it.

(C) Omnidirectional range information

The proposed method can obtain an omnidirectional view and at the same time the range information. The latter is useful in finding free regions in its environment, establishing the correspondence of a pair of two omnidirectional images, and determination of motion parameters of a robot.

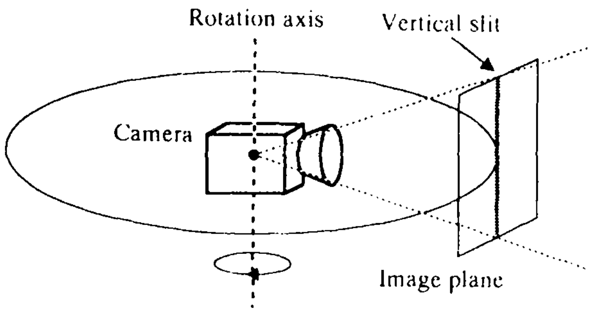

Fig. 1. Imaging method (omnidirectional view).

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