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A detection cell using multiple points of a rotating triangle to find local planar regions from stereo depth data

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ABSTRACT

This paper presents a method to recognize plane regions for unobstructed motion of mobile robots. When an autonomous agency, using a stereo camera or a laser scanning sensor, is in an unknown 3D environment, the mobile agency must detect the plane regions so that it can independently decide its direction of movement in order to perform assigned tasks. In this paper, a fast method of plane detection is proposed, wherein the normal vector of a triangle is inscribed in a small circular region such that the normal vector passes through the circumcenter area of the triangle. To reduce the effects of noise and outliers, the triangle is rotationally sampled with respect to the center position of the circular region, and a series of inscribed triangles having different normal vectors is generated. The direction vectors of these generated triangles are normalized and the median direction of the normal vectors is then used to test the planarity of the circular region. A pose finding procedure is introduced from range data of a surface to decide the scale and rotation angle of the circular region superimposed on range image data. The method of plane detection is very fast as computation of local information about the plane typically requires sub-ms duration, and the performance of the algorithm for real range data obtained from a stereo camera system has been verified.

1. Introduction

A robot operating in an unknown 3D space must identify its surroundings before the agency conducts the tasks given to it. Biped or wheel-based robots should be able to recognize obstacles within their area of motion and avoid the detected obstacles or drive over them if they are not high. In the presence of a staircase, a robot should be able to recognize the planes of the steps and walk on them. In order to operate without falling in an unknown 3D space, it must be able to use the available information about 3D depth, to recognize planar regions without obstacles in the direction of movement.

Planar space recognition has many fields of application. A robot moving around indoors should be able to recognize the planar floor region on which it will drive. Also this plane must not have too greater inclination against the direction of gravity so that the robot will not fall while moving. Planar space recognition can be used in recognizing an obstacle, such as a wall, a table on which things are located, or the plane of a table. It can also be used to find the centerline of the road on which an agency could drive. Recognition of the planes of steps is an important application for the movement of humanoid biped robots (Okada et al., 2001).

With the rapid development of small and low-cost computers, sensor devices for measuring 3D spaces are being widely studied. Many sensing systems are also being developed to produce information about 3D depth in real-time, some of which are available commercially. Active sensing is done by laser scanners or structured lighting pattern investigation (Sick company page, http://www.sick.com; Katz et al., 2005; Guivant et al., 2000). Passive sensing is done by two or more cameras (PointGray company page, http://www.pointgray.com; VidereDesign company page, http://www.videredesign.com; Se et al., 2001; Gutmann et al., 2005) for the measurement of information about 3D distance. The active methods offer relatively accurate range data, but the real-time acquisition of information about distance remains difficult. As such, it cannot be directly applied to mobile agencies such as walking robots. With the increase of computer processing capacity and speed, and the development of a practical stereo camera system, an image processing system offering high-speed 3D data about depth has recently been commercialized (PointGray company page, http://www.pointgray.com; VidereDesign company page, http://www.videredesign.com). Although the quality of its range data is lower than that of the widely used methods such as laser scanning system, it has been applied to moving robots that are capable of

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high-speed delivery of information about distance (Se et al., 2001; Gutmann et al., 2005; Kim and Suga, 2007). With the development of 3D measurement sensors, methods involving the use of these data measurements for driving in an unknown space are indispensable, and should thus be studied along with the sensor development.

Past studies have focused on the segmentation of range data through parametric methods. Range data are classified as planes, spheres, cylinders, and cones. The data measurements are fitted to these basic geometric types to find the corresponding parameters and to segment the related area (Besl and Jain, 1988; Fan et al., 1987; Hoover et al., 1996). These methods can segment exact geometric shapes based on range data, but they require excessive performance time and accurate data measurements. As such, they are not suited for moving agencies such as robots, for which real-time processing is important.

Recently, a method was proposed which detects regions in real-time for the driving of mobile robots. Based on the Hough Transform (HT), the method was applied to biped robots such as ASIMO of Honda, which walked on steps and avoided obstacles successfully (Okada et al., 2001). Using the HT, X–Y–Z data in 3D space is transformed into another parameter space, with ρ–θ–ϕ, representing the vertical distance from the origin and the rotation angle on the plane for voting. The corresponding planes are detected by the peaks in the voting space.

Even though the method produces segmentation results for range data with some noise and complex planes for an indoor environment, it requires many impractical procedures such as excessive memory for voting, decisions about optimal voting size, difficulties in fixing the peak locations in the voting space, and many additional processes which need high computer processing speed (Okada et al., 2001; Illingworth and Kittler, 1988; Nixon and Aguado, 2002). Many variants to solve these problems in HT have been proposed during decades (Xu et al., 1990; Kyryati et al., 1991; Lu and Tan, 2008).

One disadvantageous aspect of a Hough transform is the requirement for the existence of global planar regions in the tested 3D range data. For example, applying a HT to detect the planes in an outdoor terrain such as an unpaved road or an unstructured environment could result in unreliable results because of the absence of a global planar region.

In this paper, a method is proposed to avoid the aforementioned problems, using normal vector detection of a triangular region inscribed in a local circular region. A circular region is defined around the point of interest in a plane in space to verify the planarity of data about 3D distance. Three points on the circumference of the circular region are identified and used to build an inscribed triangular region such that the circumcenter lies within the triangle. The normal vector of the triangle passing through the circumcenter area allows us to determine a measure of the planarity. As the triangular plane is rotationally sampled on the circular region, the normal vector is re-computed thereby detecting the plane in the region with non-uniform data for different heights. Although the coarse range data has noise and non-uniform information about 3D depth, the method can extract the local planes and evaluate the degree of confidence about planarity.

Because the method uses range image data to find planar regions, the circular region should be superimposed on the range image, so that the pose angle and the scale of the circular region can be determined by the change of the relative direction and distance between the sensor and a plane. This paper proposes a pose decision procedure to calculate the scale and transformation angle of the circular region superimposed on range image data.

The proposed method also uses a lookup table to create a triangular region for the purposes of detection and verification of the plane region with great speed. As such, it is suitable for the real-time driving of a mobile agency or for its performance for a given task. This method can accurately and quickly detect the planar regions using the information about 3D depth from a stereo vision camera. The proposed algorithm is verified herein by examples of a plane detection using real range data.

2. Detection of a planar region

2.1. Plane recognition cell

Fig. 1 shows the 3D distance data from a stereo camera sensor. The original left and right images obtained from a corrected stereo camera of Fig. 1a are shown in Fig. 1b and c, respectively. The range data shown in Fig. 1d is the information about horizontal disparity between the two images. The data has the relative 3D coordinates with respect to the origin of the right-hand camera axis which is the 3D information about distance.

In Fig. 1d, the region close to the camera is dark, and the bright region is distant from the camera. The 3D range information is very useful for driving robots, but these do not ensure the recognition of the 3D space itself.

The range data should be processed so that the information needed by robots to drive could be detected or recognized by them. Although the quality of the range data obtained from the stereo range sensor (PointGray company page, http://www.pointgray.com) is lower than that of the range data obtained by the active sensor, the data can be obtained from a desktop PC practically in real-time. The moving robot is able to distinguish the floor region (with no obstacles) from the collision region (with obstacles, indicated by the wall objects as seen on both sides of the image), and is able to decide its direction of movement on the planar floor.

When the stereo sensor on a mobile robot measures the range data of 3D space, the robot is interested in the normal directions of various surface regions in the space. A small detection cell is randomly placed on the range image region or regularly located on fixed grid positions of the image region. The purpose of the detection cell is to obtain the surface normal and offset distance from the sensor origin for the 3D surface that the local data on the 3D range image describes. The cell generation is dependent only on the requirements of the moving robot.

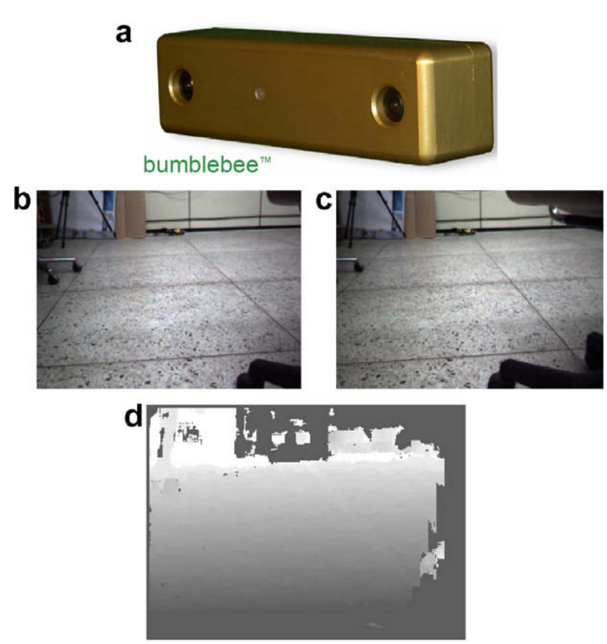

Fig. 1. An example of stereo camera and range image.