BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LVII (LXI), Fasc. 6, 2011
Secţia
ELECTROTEHNICĂ. ENERGETICĂ. ELECTRONICĂ

3-D MEASUREMENT TECHNIQUES: AN OVERVIEW

BY

LEVENTE TAMAŞ* **and GHEORGHE LAZEA**

Technical University of Cluj-Napoca

Received, May 31, 2011
Accepted for publication: July 6, 2011

Abstract. This paper deals about the promising 3-D technology for mobile robots, automation industry or manufacturing. The first part of the paper describes the design details of 3-D a time of flight measurement system based on 2-D laser range finder, while in the second part there are shown the laser scan data assembler with experimental results as well. Finally, the stereo camera based approach is summarized.

Key words: 3-D perception; laser range finder; 3-D mapping.

1. Introduction

There are more possibilities to acquire 3-D information from the surrounding environment. The measurement methods can be divided into three major categories based on applied sensor and sensing technology: stereo vision (with two or more cameras) (Mallet *et al.*, 2002), active triangulation (Perceptron, 2003) and time of flight measurements. One of the most precise time of flight measurement systems is based on the laser scanners. The paper further on is focused on this type of 3-D sensor.

The 3-D laser range finder (LRF) is a relatively new active remote sensing system which has been applied also in the mobile robotics domain in the last years. The application domain of these sensors is extending from the underground mine measurement to the architectural city planning and to aerial 3-D image acquisition.

*Corresponding author: *e-mail*: Levente.Tamas@aut.utcluj.ro

The laser time of flight measurement sensor usually is based on a transmitter–receiver laser diode pair which can give distance information from a few centimeters till hundreds of meters with a relative accuracy of less than 1%. Commercial laser range finders like Sick, Leica, Riegl or Velodyne make use of a rotary mirror system through which the laser beam is swept along a surface to gain 2-D or 3-D information (Grüner *et al*., 2004).

In order to gain information also for the third dimension, often standard 2-D laser scanners are used with an auxiliary rotary mechanical system on which the 2-D laser is mounted, thus getting the third degree of freedom for the measurements. Such an approach based on a servo actuator system is proposed by Lingemann *et al*. (2001).

The main motivation for developing a custom 3-D laser scanning system is the fact that the available commercial 3-D laser measurement systems either are not suitable for mobile robotics applications (they are too heavy or they need too much power or acquisition time) or they are too expensive compared to a standard 2-D LRF (Dröschel *et al*., 2009).

The designed 3-D LRF meets the requirements of the state of the art 3-D laser sensors used in the mobile robotics community (Wagner & Wulf, 2003), and the cost of it is less than 10% of a commercial version.

2. 3-D Laser Device Design Principles

The key component of the 3-D sensor is the 2-D LRF for which the rotary platform was designed. There are more possibilities to rotate the LRF, *i.e.* around the yaw, pitch and roll axes, thus achieving a yawing, pitching or rolling 3-D sensor (Wagner & Wulf, 2003). Each of these setups has its own advantage and disadvantage.

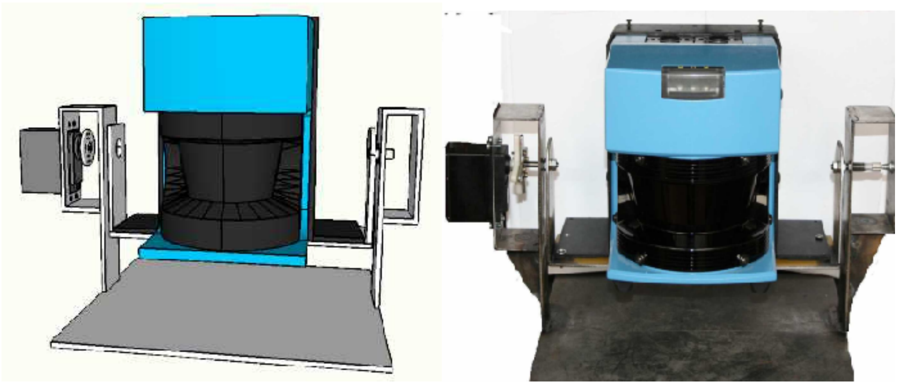

Fig. 1 – The design and the prototype of the 3-D laser sensor.

As for the mobile robots the most common approach is the pitching scan, this solution was adopted for the current design. The mechanical design shown in Fig. 1 has two parts: one fixed part containing the driving motor (left) and the rotation encoder (right). On this mobile rotary part was placed the Sick LMS200 laser scanner device.

For the driving motor a Hitachi 12 V servomotor was chosen with a minimum rotation of 0.45°, while for the rotation sensor a potentiometer was considered. The motor control and the serial interface to the PC were solved using an AVR microcontroller based Cerebot2 type board. This type of board as well as the other mechanical and electrical components of the prototype are low cost products and available at the market.

The Sick LMS200 has a depth resolution of 2 cm and an angular resolution of 0.25°, 0.5° or 1°, depending on the configuration. The scanning cone of the device can be set either to 100° or 180°, depending on the actual needs, while the maximum range of readings is up to 80 m. The scanning time is around 15 ms, and additional time is required to send the data to the PC at 9,600, 19,200, 38,400 or 500,000 kb/s. Thus a complete 3-D scan may require a few seconds.

2.2. Measurement Model and Data Acquisition

For a pitching type of scanner the third information about a point is from the pitch angle information. The coordinates of a 3-D point result from the distance to the surface, the yaw measurement angle of the beam and the pitch angle moving of the mechanical part. Thus a scan point can be represented as a tuple of the form $(\rho_i;\theta_i,\gamma_i)$, where ρ represents the depth information from the LMS and θ,γ are, respectively, the yaw and pitch measurement angles from the reading. The Cartesian coordinates of a point hence can be computed by means of

$$p=\begin{pmatrix}x\\y\\z\end{pmatrix}=\begin{pmatrix}\cos\gamma & 0 & \sin\gamma\\0 & 1 & 0\\-\sin\gamma & 0 & \cos\gamma\end{pmatrix}\begin{pmatrix}\rho\cos\theta\\\rho\sin\theta\\0\end{pmatrix}, \tag{1}$$

In eq. (1) there was not taken into account the displacement between the center of the robot and the 3-D sensor. This could be introduced into the mathematical model by means of an additional translation term.

Also there is not discussed the error induced by the misalignment between the rotation axes of the laser mirror and the pitching axes. This misalignment introduces a systematic error which can be detected by tests and eliminated by considering an additional constant term in eq. (1). A more detailed discussion regarding the error budget can be found was performed by Hu and Zhang (2008).

A typical indoor scan for an area of interest (AOI) between –30° and +60 pitch angle is presented in Fig 2. As it can be seen in this figure, the objects being closer to the right and left edges of the AOI are represented with a higher density of 3-D points, while in the center the density is lower. This is due to the distribution properties of the pitching scan acquisition mode. In case that the AOI would be the central region, then the yawing or rolling scan method should be chosen.

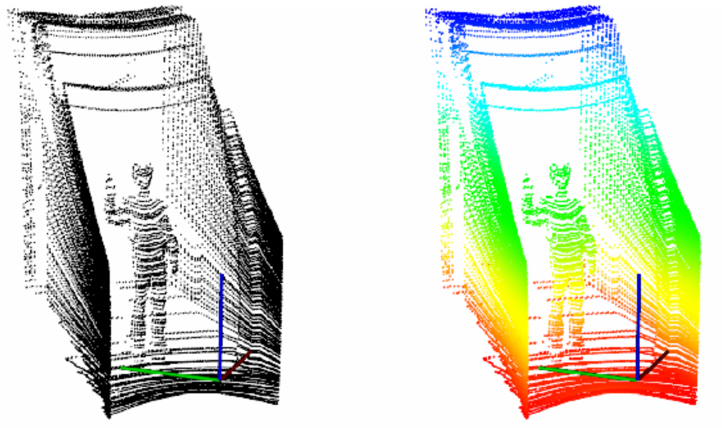

Fig. 2 – A typical indoor 3-D laser scan.

3. Stereo Vision Based 3-D Sensing

Another popular way for 3-D sensing is related to the multiple camera systems. These 3-D measurement sensors are based on the depth estimation from the disparity between two or more figures.

3.1. Stereo Vision Depth Estimation

This section focuses on the recovering of the 3-D information from 2-D images in order to estimate distances in the navigation application. The reconstruction of the third dimension from multiple images can be expressed in several ways. The stereo sensor geometry and a method regarding how it is possible to calculate disparities form stereo images are presented.

A simple representation of a stereo camera system is given on Fig. 3, where C_1 and C_2 are the centers of the lens for the right and left camera, f is the focal length, Z – the depth in the coordinate system, and x_1, x_2 represent the image coordinates in the right and left camera; B is the baseline. By simple geometrical deduction the depth information, Z, can be obtained with relation

$$Z = \frac{fB}{d}, \tag{2}$$

where d represents the disparity; this one disparity can be defined as the difference between the coordinates x_1 and x_2 of the same feature in the left and right image.

The correspondence between images can be established in several ways. One of the fastest methods to compute disparities form stereo images is based on correlation analyses. Using this method the depth is computed at each pixel, a grey level around the pixel in the left image is correlated with the corresponding pixel in the right image. The disparity of the best match from the correspondence is determined using the sum of absolute differences (SAD) (Rojas *et al*., 2077), for a given square mask, *m*, and is given by

$$\min_{d=d_{\min}}^{d_{\max}} \sum_{i=-m/2}^{m/2} \sum_{j=-m/2}^{m/2} \left| R(x+i, y+j) - L(x+i+d, y+j) \right|, \tag{3}$$

where $d_{\min}$ and $d_{\max}$ are, respectively, the minimum and maximum disparities, m is the mask size in which the search is done and R and L – the right and left images (row and column pixels). Once the disparity is determined the depth Z can be computed using relation (2) and knowing the camera constants (baseline, focal length).

Also the sum of squared differences (SSD) can be used which has a similar form, but the computational time for this is greater compared with the SAD. The disparity space is a projective one, and the noise in the disparity space is isotropic (Rojas *et al*., 2077).

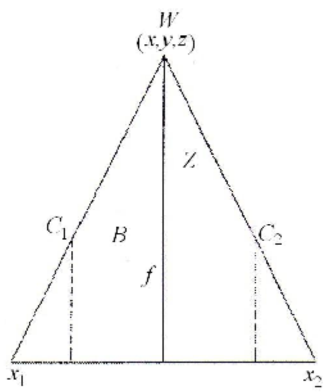

Fig. 3 – Stereo geometry.

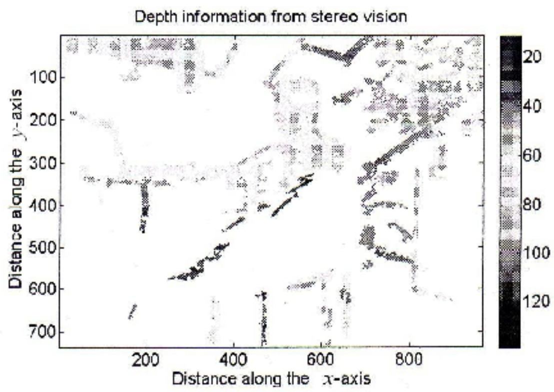

Fig. 4 – Typical stereo camera image in indoor environment.

Acknowledgment. This paper was supported by the project "Development and Support of Multidisciplinary Postdoctoral Programmes in Major Technical Areas of National Strategy of Research – Development – Innovation" 4D-POSTDOC, contract no. POSDRU/89/1.5/S/52603, project co-funded by the European Social Fund through Sectoral Operational Programme Human Resources Development 2007-2013.

REFERENCES

Brugard W., Thrun S., Hähnel D., *Learning Compact 3-D Models of Indoor and Outdoor Environments*. Robot. a. Autonom. Syst., **44**, *1*, 15-27 (2003).
Dröschel F., Wisspeintner D., May T., Surmann S., Maurelli H., *A 3-D Laser Scanner System for Autonomous Vehicle Navigation*. Proc. of the 14th Internat. Conf. on Adv. Robot., München, 2009, 1-6.
Grüner J., Siegwart G., Weingarten R., *A State-of-the-Art 3-D Sensor for Robot Navigation*. Proc. of the IEEE/RSJ Internat. Conf. on Intell. Robots a., Sendai, Japan, **3**, 2004, 2155-2160.
Hu S., Zhang A., *Fast Continuous 360 Degree Color 3-D Laser Scanner*. The Internat. Arch. of the Photogr., Rem. Sens. a. Spat. Inform. Sci., Beijing, 2008, 409-415.
Kristensen S., Jensfelt P., *Active Global Localization for a Mobile Robot Using Multiple Hypothesis Tracking*. IEEE Trans. on RA, **17**, 748-760 (2001).
Lingemann H.K., Nüchter A., Surmann J., *A 3-D Laser Range Finder for Autonomous Mobile Robots*. Proc. of the Internat. Symp. on Robotics, Zürich, 2001.
Mallet S.A., Bonnafous D., Bauzil G., Lacroix S., *Autonomous Rover Navigation on Uneven Terrains: Functions*. Internat. J. of Robot., **21**, 917-942 (2002).
Rojas J.R. *et al.*, *An Autonomous Car for the Darpa Urban Challenge*. Techn. Report, Freie Univ. Berlin, Fraunhofer Gesellschaft, June 2007.
Wagner O., Wulf B., *Fast 3-D-Scanning Methods for Laser Measurement Systems*. Proc. of the Internat. Conf. on Control Syst. a. Comp. Sci., section **2**, Bucharest, 2003, 3-8.
* * * *Perceptron*. ScanWorks 3D product Brochure. Online. www.perceptron.com, 2003.

MĂSURĂRI ÎN 3-D: O PREZENTARE GENERALĂ

(Rezumat)

Se prezintă pe scurt metodele cele mai frecvent întâlnite pentru crearea imaginilor 3-D în robotică şi anume metodele bazate pe camere stereo şi cele de tip laser. Pe lângă caracteristicile acestor echipamente, sunt prezentate şi baza teoretică pentru funcţionarea acestora, respectiv exemple de măsurători.