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Optimization of 3D laser scanning speed by use of combined variable step

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ABSTRACT

The problem of 3D TVS slow functioning caused by constant small scanning step becomes its solution in the presented research. It can be achieved by combined scanning step application for the fast search of n obstacles in unknown surroundings. Such a problem is of keynote importance in automatic robot navigation. To maintain a reasonable speed robots must detect dangerous obstacles as soon as possible, but all known scanners able to measure distances with sufficient accuracy are unable to do it in real time. So, the related technical task of the scanning with variable speed and precise digital mapping only for selected spatial sectors is under consideration. A wide range of simulations in MATLAB 7.12.0 of several variants of hypothetic scenes with variable n obstacles in each scene (including variation of shapes and sizes) and scanning with incremented angle value (0.6° up to 15°) is provided. The aim of such simulation was to detect which angular values of interval still permit getting the maximal information about obstacles without undesired time losses. Three of such local maximums were obtained in simulations and then rectified by application of neuronal network formalism (Levenberg–Marquradt Algorithm). The obtained results in its turn were applied to MET (Micro-Electro-mechanical Transmission) design for practical realization of variable combined step scanning on an experimental prototype of our previously known laser scanner.

1. Introduction

The task of 3D-coordinates spatial data acquisition is an important task for many practical applications, such as structural health and integrity monitoring, robot vision, micro-relief inspection, biometrics, shape recognition in security applications, physical monitoring of internal structures in complete darkness (mines, caves, underground pipelines), etc. Optical scanning, especially laser based scanning, is a very attractive approach to this solution due to its advantages over other recognized solutions. Laser scanning has direct information acquisition, relatively small quantity of data to be processed, high coherence of laser bandwidth to help noise filtering in optic channel, predictable accuracy with well-studied uncertainty distribution laws, ability to work in complete darkness (even works better this way), etc. But the most attractive advantage is fast growth in the last decade of optical sensors reliability and data stability. Nowadays, there has been a clear trend for the contactless sensors based on optical technologies [1]. Contactless can quickly acquire a large number of points (about 10,000 points per second). However, laser sensors currently on the market do not have the accuracy of the classical dynamic contact sensors. In general, the accuracy provided by the manufacturer of these devices presents a factor of 10 compared to the contact sensors. For example, with the sensor METRIS LC50 used in [1], the expanded measurement uncertainty of a sphere with 15 mm diameter is in the order of 50 $\mu m +/- 3\sigma$. Furthermore, this accuracy depends on different parameters such as materials properties, surface texture, product color, etc. Therefore, in order to use this technique in the context, it is necessary to have a good control of their metrological properties. In recent years various optical methodologies [2] have been implemented in tracking general-purpose systems. Although, optical tracking systems have been used in several contexts, its application to align 3D point clouds generated by full field techniques has been poorly evidenced in technical literature. Moreover, some commercial solutions have been proposed (naviSCAN^{3D}, Leica T-Scan, MetraSCAN [2], and Vitus Smart 3D Laser Scanning [22]). Neither technical literature nor commercial

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solutions fully provide scientific and technical evidences about performances, reliability and applicative fields of the optical tracking approaches. For example, industrial applications may involve the reconstruction of complex shapes by aligning several 3D views captured on the basis of a scanning strategy that should be settled during the measurement process [20]. In these cases, robustness and flexibility are the fundamental attributes of a multi-view methodology, but for example in robot navigation or any other dynamic application there is no way for its practical use. In [3] two-dimensional x–y laser scanning was demonstrated using a computer controlled and rotating reflective cube. This particular application was the digitizing of transparent foils and they achieved milliradian resolutions. This concept may be easily adapted to other industrial vision applications such as scanning products on an assembly line or two-dimensional extensions of bar codes. The reflective cube method described in [3] is less expensive, simpler and more durable than other techniques such as use of planar mirrors mounted on galvanometer rotors, as shown in [3] in 1992. Due to the same reason now we will not explain the lack of galvanometer rotors, but will advance the simple/durable optic scanning method (more or less based on the same idea as in [3]) which is able to give still more open angle-of-view than those of any other known techniques, except the omnidirectional vision (fish-eye lens) [16]. However, fish-eye lens gives very curvy and distorted image, which needs a time consuming post-processing. Application depth map by an efficient epipolar plane analysis method [17,18] was analyzed in [19] for omnidirectional stereo vision [15]; meanwhile our solution is able to find and digitize objects in real time, without any post-processing. Why it is important?

For robot application in an environment where many obstacles exist [4], it needs to avoid obstacles and detect gateways in order to select a valid pathway to traverse in the shortest time possible. Avoiding obstacles according to their shape will demand a lot of environment knowledge, so this method will demand high computational power. The laser scanner developed in [4] does not provide 3D shape information of the detected obstacles because of the absence of enough computational power for 3D shape reconstruction. The avoidance strategy proposed in [4] is to avoid obstacles regardless of their shape; in other words, the height information of the obstacle and the width information of the gateway are key parameters for making a judgment. For a single image, it takes 0.2 s to detect the obstacles in front of the scanner. Therefore, as the scanner scans obstacles at 10 different bending angles, it takes 2 s to scan fully. Because the scanning speed is not fast enough to deal with moving objects, currently the developed laser scanner cannot work in a changing environment; in other words, the detected obstacles must be stationary. A good review of 3D model acquisition techniques can be found in [13,14]. The main features of the proposed 3D laser scanning system in this paper compared with other kinds of 3D sensing systems for mobile robots are as follows:

compared with passive binocular or trinocular vision sensors, the proposed laser scanner can maintain more robust 3D sensing under illumination variations;

compared with time-of-flight or phase shifting laser scanners, the proposed laser scanner has less power consumption, and is cheaper;

compared with the multi-line pattern projector in a structured-lighting scanner, the proposed laser scanner has a more simple and robust mechanical construction, and reduced power consumption.

This paper addresses the design and implementation of an active 3D triangulation laser scanner. The contribution of this paper and the scientific field of the proposed system are in using a low-cost and simple method to construct a laser and wide-angle sensor system which is used for navigation of mobile robots in unknown environments [5]. The most crucial point in this case is time of scanning. In other words, the obstacle must be detected in the shortest possible time interval, but precise coordinate measurements are not necessary for all obstacle shapes, but only for its edge nearest to the robot's desired safe trajectory (see [5,7,10]). It is evident that this is possible only under the condition that the laser can scan robot's field-of-view with variable speed. In this study, we concentrate on modeling several scenes with regular obstacles, establishing a simulation tool for the analysis to find the best angles (optimal angles) for combined-step scanning, and designing stepper-motors in laser positioning system, as well as development and demonstration of an automated micro-gearbox for such tasks.

This paper is organized as follows. In Section 2 the problem formulation of slow functioning of 3D TVS caused by constant small scanning step is presented. The solution by application of combined scanning step consisting of several specific values is introduced in Section 3. The simulation of variable scanning step and data post-processing techniques are presented in Section 4. Design of Micro-Electro-mechanical Transmission for steps combination performance is proposed in Section 5. Finally, conclusions and prospects for future work are reported in Section 6.

2. Problem formulation

According to our previous research [5–12], the TVS allows us an insight into spatial coordinates measurements, with sufficient accuracy in the field of view; it also has the ability to detect obstacles inside any given scene during navigation of the autonomous robot. It can make a digital map of the obstacles within the field of view in high resolution. The current TVS uses constant scanning pitch which is not optimally efficient for robot navigation. The goal of a reliable navigation in exploration of unknown scenes is the scanning variable (combined) scanning step, which will minimize scanning time, with guaranteed detection of critical obstacles within the field of view. It must detect any obstacle as soon as possible, but having a high resolution only of the most critical obstacles (dangerous for the robot safety). It is intended that the simulations performed in the present work must answer this question by our simulation results. Based on these results, we can provide a tentative construction of electromechanical transmission. Its application can optimize the TVS function by the minimum time criterion under the condition of maintaining the maximal resolution on the nearest edge of scanned objects.

For a better understanding of the problem we have to present here the basic principle of Dynamic Triangulation and corresponding laser scanning system forming jointly with passive aperture the completed 3D Technical Vision System (TVS), firstly introduced in our previous publications [5–12], and which is the object of further development and complication in the present paper. TVS works on Dynamic Triangulation theory in order to obtain 3D coordinates of objects or obstacles on mobile robot vision; as shown in Fig. 1 [7], a laser beam is projected by a mechanism transmitter (which will be called Positioning Laser (PL)) onto the obstacle surface, reflecting back the laser beam into a revolving sensor inside, which will be called Scanning Aperture (SA) [21].

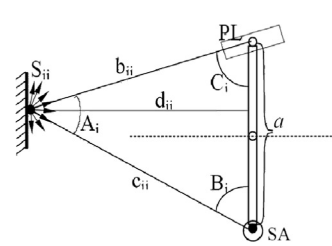

Fig. 1. Dynamic Triangulation [7].