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Optical 3D laser measurement system for navigation of autonomous mobile robot

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ABSTRACT

In our current research, we are developing a practical autonomous mobile robot navigation system which is capable of performing obstacle avoiding task on an unknown environment. Therefore, in this paper, we propose a robot navigation system which works using a high accuracy localization scheme by dynamic triangulation. Our two main ideas are (1) integration of two principal systems, 3D laser scanning technical vision system (TVS) and mobile robot (MR) navigation system. (2) Novel MR navigation scheme, which allows benefiting from all advantages of precise triangulation localization of the obstacles, mostly over known camera oriented vision systems. For practical use, mobile robots are required to continue their tasks with safety and high accuracy on temporary occlusion condition. Presented in this work, prototype II of TVS is significantly improved over prototype I of our previous publications in the aspects of laser rays alignment, parasitic torque decrease and friction reduction of moving parts. The kinematic model of the MR used in this work is designed considering the optimal data acquisition from the TVS with the main goal of obtaining in real time, the necessary values for the kinematic model of the MR immediately during the calculation of obstacles based on the TVS data.

1. Introduction

Autonomous robot navigation and collision prevention tasks are becoming very important not only in the automotive industry but also in scientific research such as planet exploration e.g., the Mars Rover by NASA [1], exploration of unknown or dangerous terrain such as DEPTHX project by Carnegie Mellon University in Mexico [2], autonomous vehicles like Stanley in the DARPA Grand Challenge by Stanford University [3], among others.

Optical methods seem to be a very attractive option for such solution. However, its application is still of great demand due to its main weak point, which supposes that most of optical methods are for probabilistic estimation, not for measurement of real obstacle spatial position. Or those methods that can measure, they are still very sensitive to vibrations or any other kinds of mechanical noise. This paper is aiming to propose a robust and precise way to obtain a digitized map of robot's surrounding with metrological quality by means of optical measurements.

Autonomous vehicles such as Stanley from Stanford University (see Fig. 1) and most of the vehicles that have participated in the DARPA Grand or Urban Challenge [4] like Boss by Carnegie Mellon University [5], Odin by Virginia Tech [6], Talos from MIT [7], among others, use a combination or fusion of sensors to acquire the necessary information to detect obstacles and roads, required for safe traveling such as Light Detection and Raging (LIDAR), RADAR, Stereo Vision, GPS, Inertial navigation system. This is very important and a great advantage in comparison with autonomous

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Fig. 1. Stanley—the Stanford Autonomous Vehicle that won the DARPA Grand Challenge.

vehicles using a single sensor to detect obstacles. However, the more sensors are included the higher the cost of the autonomous vehicle, this can be considered a great disadvantage if the available processing resources are not enough for full sensor fusion.

Nonetheless, the evident high cost of such systems is not its worst disadvantage; it still undermines another one. Such a versatility of the devices in use remains due to an uncertain situation in regards to which one of the multiple sensory system provides in a present moment the most proper information about the surrounding of the mobile robot.

In other words, such complex multisensory system always provides redundant information about the current situation on the robot's trajectory, and the most important task in this case is to properly filter this information and to correctly detect which one of the multisensory components is the most correct (less error) in a current moment. Such task is the main problem in dead reckoning and it consumes a huge capacity of computational resource.

Accordingly, as it is shown in all the mentioned publications about the autonomous vehicles that participated in the DARPA challenges [4], mobile robots equipped with such complex multisensory system still cannot achieve sufficient velocity, which is caused, first of all, by the necessity to solve in real time the difficult task of optimal data search.

Most of the relevant research, present autonomous robots using 2D laser range finders and servo motors for rotation [8,9]. Others propose stereo vision systems that utilizes two cameras to obtain two images of the same object from different points of view and reconstruct a 3D scene, such approach does not give true Cartesian coordinates of the object or obstacle, it just permits an evaluation of the shape and size of the obstacle, based on complex probabilistic algorithms of image processing [10–14]. Finally, it is very time consuming for a processor, it lacks precision, present solutions does not yet allow for a full 3D-reconstruction of the scene and it does not guarantee for errors or image misunderstanding.

Systems that use structured light methods for 3D shape measurement such as [37] present great advantages over stereo vision systems e.g., faster measurement performance and simpler processing algorithms but they also present a few disadvantages such as higher cost equipment, greater dimensions of the overall 3D system and the need of being connected to an AC power supply; these characteristics may limit this system to static applications as the author states in the conclusions of [37], such as computer graphics, medical diagnostics, plastic surgery, industrial inspection and reverse engineering instead of mobile applications such as robot navigation, mine exploration, rescue operations, among others. Although it is worth mentioning that this type of system may be modified to be applied in mobile applications but with some trade-offs.

Therefore, in this paper we present an autonomous mobile robot navigation system that utilizes a low cost high precision vision system with sufficient reliability of information about the surrounding of the mobile robot to allow the mobile robot's navigation system to make decisions regarding the path or trajectory it should follow to achieve its goal.

Our navigation system consists of a new method of motion planning and the mathematical model of a four wheel, four motor skid-steer mobile robot used to successfully navigate without collisions in an (indoor and outdoor) environment with obstacles.

This navigation system obtains the surrounding environment information by means of a 3D laser scanning vision system which is briefly explained in Section 2. The mechanical characteristics and specifications of the mobile robot are explained in Section 3. The mobile robot kinematics model is found in Section 4. In Section 5 our navigation system is presented. Section 6 presents the simulation results of our work with the TVS and the navigation system; followed by the statistical analysis of the data obtained through experimentation in Section 7; and at the end, the conclusions of this work are presented.

2. Technical vision system (TVS)

As mentioned before, the presented navigation system will obtain the environment information from our TVS. This system has been partially presented before in [15,16,35]; therefore the explanation will only contain the most important aspects of the TVS.

2.1. Dynamic triangulation method

The TVS is based on a method we developed which is called dynamic triangulation, it is called dynamic due to the rotation ability of the positioning laser and the scanning aperture, allowing us to have moving angles that can form laser light triangles with different shapes for a very short period of time and when a triangle is formed thanks to the reflected light of an obstacle surface, we obtain all the necessary information to calculate the 3D coordinates.

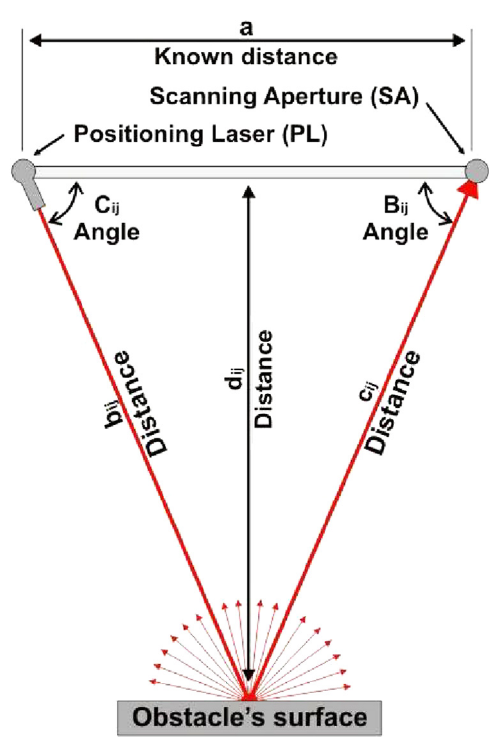

Fig. 2. Dynamic triangulation method.