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Computing an unevenness field from 3D laser range data to obtain traversable region around a mobile robot

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ABSTRACT

We introduce a novel measure of terrain unevenness, which is computed in terms of ranges of neighbouring laser beams of a 3D laser scanner mounted on a mobile robot. The unevenness so computed over all sampled points forms an unevenness field around the robot. We explore the nature of this measure of unevenness through analysis, and arrive at a reasonable policy for setting thresholds on unevenness in order to detect obstacles, and in the process mark out the traversable region around the mobile robot. The traversable region is obtained as a connectivity graph over 180 × 32 cells in about 30 ms time on an Intel i3 processor. This connectivity graph can be potentially used for path planning of the mobile robot. Conceptually and computationally the measure is simple and efficient. It has an added advantage of being robust against small tilts of the sensor during locomotion. It also works well on slopes. Although there are numerous ways of detecting traversable regions in the literature, it is the novelty of the measure and its analysis, which we believe is our contribution through this paper. We demonstrate its usefulness through experimental results and compare its performance with a standard method that uses both height and slope between neighbouring range points to detect obstacles.

1. Introduction

Autonomous capabilities of mobile robots allow them to be deployed in applications where they can be operated with minimum or no human intervention. Applications for autonomous outdoor robots include driverless vehicles, planetary rovers, agricultural robots, survey and rescue robots, etc. It is often a basic requirement for such a robot to identify the traversable region around it, so that it can plan a path to the desired location avoiding obstacles. Autonomous navigation in outdoor environments is complex because of varying navigability of different parts of the terrain, irregular shapes and dynamic nature of obstacles. In addition to detecting regular obstacles like trees, buildings, people and vehicles in order to avoid colliding with them, it is important to detect smaller obstacles such as road boundaries or pavement edges. Detection of stones or kerbs is also essential, as otherwise the robot may try to drive over them and hurt or destabilize itself. All these make detection of traversable region a primary task for robot navigation.

The unstructured nature of outdoor environments requires a robot to perceive its surroundings in three dimensions (3D). In recent years, multi beam 3D laser scanners (e.g., Velodyne) have commonly been used for this purpose because of their high speed and accuracy in acquiring range data. Alternatively, 2D laser scanners are turned around using an external motor to obtain 3D scans [1]. Such a scan results in a structured range data having information on neighbouring points and angles at which the lasers are fired. Traditional approach towards obstacle detection using 3D laser range data is by representing the environment using occupancy grids [2] where the environment is discretized into a grid of cells. Data points are projected vertically onto a grid where its cells may either be occupied or free. The cells are then checked individually for presence of obstacles. It is common to identify a cell as obstacle cell using height difference between the points contained in a cell; this approach is followed by most teams in the DARPA challenge [3]. But the height difference method is very much susceptible to noise, especially at longer ranges. Non uniform distribution of range data from a single scan, for example with Velodyne, makes it difficult to set meaningful height thresholds or cell sizes in grids for detecting obstacles. It is also difficult to take care of discrepancies caused by presence of terrain slopes or the roll and pitch of sensor using this method. In occupancy grid

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based methods, some non obstacles points are labelled as obstacles due to their association with cells that contains obstacles. It is particularly difficult to separate smaller obstacles such as footpath or road edges from the neighbouring ground points.

An alternative approach suggests detection of obstacles along the radial directions of a scan [4]. Processing proceeds with the acquisition of scan at each azimuth angle of sensor rotation, instead of waiting to populate the entire grid. This improves the performance of the methods, making them close to real time. Here the obstacle detection criterion is applied starting from the range of the innermost laser beam and progressing in steps to the outermost. A range point is classified as belonging to an obstacle when it is found to be higher than its preceding point by a certain height or angle threshold. Since the distance between successive points increases with distance from sensor, the corresponding height between points so sampled also increases. This results in most of the traversable regions far from the sensor to be detected as obstacle regions even for moderate slopes that are otherwise easily traversable. This is shown in Fig. 1. On the other hand slopes between points are high near the sensor and decrease with distance for a given height difference.

Instead of identifying obstacles using explicitly the height of the intercepting point, there is merit in using the range difference between consecutive laser beams of a 3D Laser scanner to detect unevenness of the terrain. As we shall see, this approach can be made relatively insensitive to small slopes or sensor tilts [5]. In Fig. 1, the method using height difference between successive points detects most of the traversable slope away from the sensor as obstacle region which is not desirable. Setting a higher threshold will not detect smaller obstacles like foot path edges. The proposed unevenness based method on the other hand detects most of the slope as traversable region, even while detecting boxes and footpath edges as obstacles.

In this paper, the expected range difference between neighbouring laser beams for a flat ground is computed and compared with measured range difference. Departure from unity of their ratio measures the unevenness at the sampled point. We introduce the notion of an unevenness field which intuitively represents the terrain surrounding a robot. Through detailed modelling and analysis, we decide on the criteria to set threshold on this unevenness field for detection of obstacles. Although range difference between neighbouring laser beams is used earlier in DARPA challenge by Stanford's Junior [5], the unevenness based method presented in this paper is novel and original. Our contribution lies in defining this new measure of unevenness, and working out a simple mathematical model for characterizing it. We have shown how the defined unevenness varies with range and how a suitable single threshold can be set for detection of obstacles. The proposed method is verified through experimental results. Even though we describe the method using a Velodyne HDL-32 Laser scanner, we also show that the method works with a rotating Sick 2D scanner.

The rest of the paper is organized as follows. The next section details the approaches used by different researchers in the areas of traversability and obstacle detection. In Section 3, we present the details of Laser scanners and then present the method for detection of obstacles using unevenness. In Section 4, we detail a working method for building traversability map. In the end, experimental results are reported in Section 5 before concluding the paper in Section 6.

2. Related work

Obstacle detection and traversability are active areas of research in robot navigation. Papadakis [6] classifies methods employed for classifying terrain as a stage preceding motion planning. Primary classification is into Proprioceptive and Exteroceptive sensory data processing methods. Proprioceptive sensors like vibration sensors gauge the nature of surface when the vehicle moves over the terrain. Exteroceptive sensors including Cameras, Time-of-Flight cameras [7], Stereo cameras [8,9] and Laser scanners perceive the environment before the actual vehicle movement. Exteroceptive sensing is hence essential for safe navigation of autonomous vehicles. In some approaches multiple sensors are used [10,7,11]. Because of high accuracy, field-of-view and direct range reading, most methods including ours primarily use Laser scanners.

Data representation is primarily in the form of point clouds, but Occupancy grids [2] are commonly used for spatial representation of the environment. Occupancy grids can be in 2D, or in 3D called voxels [12,13,9]. But 2.5D representation is commonly used as a trade off between completeness of 3D and the simplicity of 2D representation. 2.5D representation was used successfully [3] in DARPA challenge. Height difference or elevation map is most common approach in determining obstacles [14,5,15,16]. The height of point from perceived ground gives elevation of the region. This approach faces difficulty in dealing with overhanging objects like tree branches, which may prevent the regions under them to be seen as traversable. Overhanging obstacles are dealt with by employing a safe height [5,17] or by using extended elevation maps [18] where the obstacles above a free space are safely discarded. Points in a grid cell are discretized into different levels based on heights called Multi Level Surface Maps [19] allowing vehicles to traverse on multiple surfaces like over and under the same bridge.

Unlike regular grids, polar grids overcome the problem of non uniform data distribution. They provide natural distribution of 3D laser scan with discretization along the rotation angle and returned ranges. Several implementations [20,21,17] use polar grids for detecting obstacles. Korchev et al. [22] perform real time segmentation using min-map, max-map and difference-map to remove even non flat ground and then does the 8 connected component analysis and compares the performance using both the rectangular and the polar grids. Himmelsbach et al. [21] bin polar segments in radial direction. Each bin has a single representative point reducing the number of data points. Piece wise line fitting is done to segment ground and obstacle points. Points are classified as ground given the line segment has slope and height difference smaller than a threshold. Non ground points are then segmented by 2D connected component labelling.

Our method performs obstacle detection at point level where each point is classified as either belonging to ground or an obstacle. Point level detection leads to real time processing of the data points along a sensor rotation angle starting from the inner most point and proceeding outwards. This overcomes the problem of under-segmentation. Chang et al. [4] primarily use slope between last classified ground and the next point for detection of obstacles. For detecting large objects faraway, a height difference threshold of 1 m is set. This does not detect smaller obstacles, something that our method does. Shneier et al. [11] learn the near regions by using sensors like stereo, Lidars using similar approach and then predict the regions beyond the stereo or Lidar range to predict the traversable regions imaged by the cameras. Steinhauser et al. [23] identify points belonging to road surface by fitting lines to points beginning from the innermost point. Points fitting into the line segment are considered traversable and that do not as obstacle points. Lines are also fit beyond the obstacle points to bring drivable regions behind the objects. Wulf et al. [24] detect obstacles by finding edges on scans both in the horizontal direction based on range discontinuity and in the vertical direction by locating a point vertically above the ground point as an obstacle. This method is only suited for flat regions. Slopes at times are traversable if they