Continuous 3D Environment Sensing for Autonomous Robot Navigation and Mapping

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Abstract: Presented here is a novel approach for continuously sensing dynamic indoor environments in 3D. Based on this procedure virtual 2D maps are introduced that allow for computationally efficient navigation algorithms. Additionally, a methodology is proposed to interpret the gathered information in a way applicable for prevailing 2D and 3D mapping algorithms.

1 Introduction and Motivation

Current applications for autonomous mobile robots, like for instance in the field of service robotics, face, amongst others, the challenging task of reliably navigating in dynamic indoor environments. In order to achieve this capability it is decisive to employ robust modeling techniques that maintain internal world representations [Thr02]. Nature and complexity of these representations highly depend on the robot’s task and application space. While the creation of consistent world models requires highly accurate spatial information the focus for navigational purposes mainly lies on fast reaction times.

One of the currently most sophisticated approaches that aims at automatic model construction is applied by Surmann et. al. [SNH03]. They have extended a standard SICK LMS 200 2D laser range-finder with a horizontal opening angle of 180° (rotating mirror device) by attaching it to a rotatable axis. This allows to pitch the scanner vertically over an angular range of 120°. Taking one horizontal 2D scan at each vertical position yields a 3D model (or 3D scan) of the current scene. To construct a precise model of the environment Surmann et. al. collect such 3D scans at various locations and integrate or *register* them into a common coordinate system by applying an elaborated 6D Simultaneous Localization and Mapping (SLAM) algorithm [SNLH05]. Navigation between the scan locations is accomplished by means of 2D pose tracking and 2D obstacle avoidance, i. e. holding the scanner in a static horizontal position. The emerging course of actions results in *stop-scan-move* cycles and is thus interrupted each time a 3D scan is being acquired. Nevertheless,

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the major drawback of this procedure lies in the fact that obstacles are only perceived in the two-dimensional scan plane while moving from one location to another. While this strategy may be appropriate for the task of automatic model construction it is less suitable when facing the aforementioned dynamic everyday environments.

In the following means for overcoming this limitation are being proposed by introducing a novel procedure that allows for continuously scanning the environment in 3D – even while the robot is moving. The gathered data is used both for 3D obstacle avoidance as well as for 2D and 3D mapping purposes.

2 Continuous 3D Environment Sensing

To continuously perceive spatial information about the robot's environment the laser-scanner is pitched in a nodding-like fashion. Hereby, an *area of interest* (AOI) is defined extending the idea of virtual roadways [LNHS05] to the third dimension, i.e. with respect to the robot's boundaries and thus possible areas of collision. The height of the AOI as well as the pitch rate depend on the robot's current speed and are adjusted by applying a closed loop controller with proportional and integral gain (*PI-controller*).

Furthermore *virtual 2D maps* are introduced as a computationally efficient representation of three-dimensional data – inspired by the approach introduced in [WACW04] by Wulf et.al. who, nevertheless, did not update their model continuously while moving. Hereby, the perceived data is being projected into a two-dimensional plane allowing for two modes of operation:

Virtual obstacle map - The minimal distance from the robot to the projected points is stored for each scan angle resulting in a representation that stores the information of the closest obstacles in each direction. In contrast to the previous approaches obstacles are perceived regardless of their height as long as they intersect with the virtual roadway.

Virtual structure map - Taking the maximal distances instead of the minimal results in obtaining a map that reflects the environmental boundaries like e.g. walls. Hereby small or dynamic items are implicitly filtered out.

The maps are egocentric and updated according to the robot's movement. Since the robot is meant to operate in indoor environments the floor can be assumed to be flat. Thus perceived floor points can easily be filtered out. This kind of egocentric representation is organized in a format equivalent to that of an ordinary 2D laser scan (distances ordered with the discretized angles used as indices). This allows to apply the same set of feature extraction mechanisms and behavioral navigation procedures for both representations. To deal with environment dynamics and imprecise pose estimates, points stored in a virtual map are removed after a certain transformation count is reached (e.g. after 500 transformations per point which corresponds to five complete nodding movements on average) to avoid erroneous information.

3 Navigation by means of Virtual 2D Obstacle Maps

Virtual 2D obstacle maps bare all the information necessary for performing reactive behavior-based robot control [Bro86, Ark98]. Based on this representation the robot can determine the distance and direction to nearby obstacles and react appropriately by adjusting its driving direction and speed [Lör06]. Figure 1 depicts (left) the resulting robot trajectory with the laserscanner in a fixed horizontal position and (right) the resulting trajectory with a continuously pitching scanner. In the first case the robot was not able to perceive the obstacles while in the second they were integrated in the virtual obstacle map and thus the robot was able to avoid them successfully.

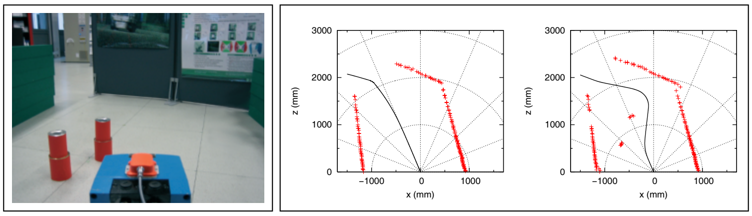

Figure 1: Obstacle avoidance in an exemplary scenario.

4 Construction of 2D and 3D Environment Maps

To construct a metric environment model based on the continuously acquired data the gathered information has to be merged into a common coordinate system. Due to the normally imprecise estimation of the robot's pose this registration is usually achieved by applying matching algorithms like the *Iterative Closest Point* (ICP) algorithm [BM92] or one of its derivatives.

Here the goal is to make the continuously acquired spatial information applicable for the usage of existing 2D and 3D matching algorithms. Regarding the case of 2D map construction the introduced virtual 2D structure maps are especially adequate for the matching process as dynamic and small obstacles are implicitly filtered out. However, to build a 3D map the continuously gathered information has to be integrated into uniform 3D point clouds as they are normally used for registration e.g. by Surmann et. al. [SNH03]. A point cloud representing one 3D laserscan is generated by transforming the continuously gathered consecutive 2D laserscans of one nodding motion by the meanwhile accumulated robot's pose shift and the scanner's pitch angle. These point clouds can afterwards be matched against each other to obtain a 3D model as shown in Figure 2.

Figure 2: Two views on a generated 3D model being constructed by matching the generated point clouds. The height of the built model corresponds to the height of the robot and thus to that of the area of interest.

By applying the presented procedures an autonomous mobile robot was able to safely navigate in dynamic indoor environments and to construct two-dimensional and three-dimensional models of the thereby visited environmental structures.

For a more detailed description of the presented approach refer to [Hol06].

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