Radar Based Through-Wall Mapping

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Abstract. Autonomous robots have been in use to construct maps of unknown areas, offering indispensable help for various emergency situations, including but not limited to hostage rescue and fire accidents. In these situations, time and safety are paramount requiring prompt and accurate action. Through-wall mapping capability, allowing robots to create a map without physically visiting all the space of interest, provides both a faster and safer way to create a map. In this paper, we show that an off-the-shelf automotive radar can be used to detect obstacles placed behind walls, and hence create a proper map for various configurations.

1. Introduction

Autonomous robots are frequently used to construct maps of unknown areas in an effective manner, These maps can later be used in search and rescue missions. Traditional mapping approaches depend on line of sight sensors, like cameras, sonar and lidar, and they require the visit of the robot to all the spaces of the environment. This requirement may not be easily met in a hostage situation, where some passages are blocked and hence the robot is not able to traverse the whole space. Additionally, the bare appearance of a robot may annoy hostage-takers endangering the hostages' life. These concerns support the research in through wall imaging, which utilizes the fact that electromagnetic waves of proper frequency can pass through building materials. However, this pass-through capability is not uniform, and depends both on the frequency of the wave and the building's material, being able to easily pass through materials like wood, plasterboard wall etc. but being considerably attenuated by reinforced concrete, which has a mesh of iron bars [1-3]. This has led researchers to try various methods to study through-wall imaging capabilities, with varying quality of results. Narayanan et al. [4], and Amin and Ahmad [5] were able to coarsely detect large objects behind walls. Aftanas and Drutarovsky [6] were able to roughly reconstruct the interiors of a wooden building, whereas Tan et al. [7] were able to roughly reconstruct a second wall behind a plasterboard wall. The best results reported in the literature up to now are constrained to simulations reported by Le and Dogaru [8], who

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reconstruct a 2-story building. In this work, we investigate the feasibility of using an off-the-shelf Short Range Radar (SRR) working at 24GHz frequency, like the ones used in cars, for through-wall mapping of walls made of wood or plaster.

2. Method

An accurate map needs multiple measurements, collected from different positions. This can only be achieved with the aid of a proper localization system, which is able to accurately estimate the position of the measuring device. For this purpose, in this work, a mobile robot equipped with odometry, lidar and radar was used. The lidar data was fused with odometry and an improved estimation was achieved. Then the radar measurements obtained as the robot traveled through the environment were tagged with the corresponding robot positions obtained from the localization system. These tagged measurements were then used to construct an occupancy grid map by merging the measurements using a probabilistic sensor model for the detections.

The short range radar returns range and bearing information for a fixed number of obstacles in its field of view, similar to a lidar in terms of the reported data. However, in lidar mapping, all the space up to a detection is assumed to be empty, which is not a valid assumption in a through-wall mapping system. Additionally, the radar's probability of detection depends on various factors like the orientation of the target surface, its reflectivity, as well as existence of stronger reflectors in the environment. These issues require both scanning the testing area using a range of radar bearing angles and a sensor model that does not update empty space, but instead just updates detections, similar to [10], who update free space only conditionally.

The occupancy probability of a map m is calculated using all the radar measurements z and the corresponding robot positions x obtained up to time t. In order to simplify, the occupancy probability of each cell is assumed to be independent, and hence the following approximation is used

$$p(m|x_{1:t},z_{1:t})=\prod_i p(m_i|x_{1:t},z_{1:t}) \tag{1}$$

where m_i represents each cell i. The probability $p(m_i|x_{1:t},z_{1:t})$ is updated recursively using a binary Bayes filter. In order to avoid numerical issues the probability is represented in log odds form as

$$l_{t,i}=\log\left(\frac{p(m_i|z_{1:t},x_{1:t})}{1-p(m_i|z_{1:t},x_{1:t})}\right) \tag{2}$$

and the following formula is used to update it recursively [9].

$$l_{t,i}=l_{t-1,i}+\log\left(\frac{p(m_i|z_t,x_t)}{1-p(m_i|z_t,x_t)}-l_{0,i}\right) \tag{3}$$

The final occupancy probability of the map is later obtained by inverting the log odds ratio given in equation (2).

3. Experimental Setup

Figure 1. The differential drive robot used in the experiments. The radar can be seen on the top of the robot.

Figure 2. The testing arena in one of the mapping configurations.

In this work, a short range radar from Cobham ltd was utilized. The radar, reporting various information like range, bearing and signal to noise ratio of up to 10 detections in a 30 m range, was put on top of an indoor mobile robot, a Nomad Super Scout II (Figure 1), using a servo motor, which allowed changing bearing of the radar as the robot moved in the testing arena . The experiments were run in an indoor environment built out of portable wall segments, forming an enclosed arena of 4m x 4m (Figure 2). A set of obstacles were put inside the arena in various configurations, and the robot was moved around, probing the arena with its radar.

4. Results & Discussion

In the first setup (Figure 3), just an outer wall was built and two circular hollow obstacles were put inside the arena. The robot was driven around the arena, following the trajectory shown in red in figure 4. This figure shows that the robot is able to properly detect the two circular obstacles behind the wall. Fully reconstructing the fourth side of the obstacles would require scanning from the fourth side of the arena as well. The second setup (Figure 5), consisting of two layers of walls and a hollow circular obstacle was also properly reconstructed by the robot (Figure 6). In both cases, constructed maps can be seen to contain some ghost images, which are randomly distributed however with a lighter intensity and hence they can be easily filtered out for use in a mission.

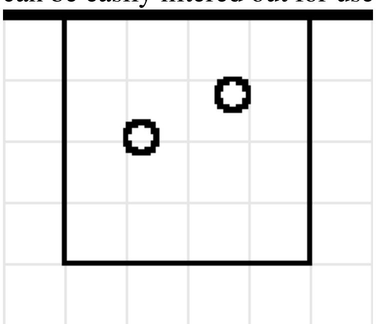

Figure 3. Setup showing two round obstacles inside a closed area.

Figure 4. The map constructed for the setup of figure 3.

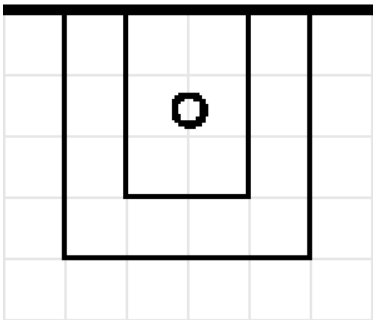

Figure 5. Setup showing one obstacle behind two layers of walls.

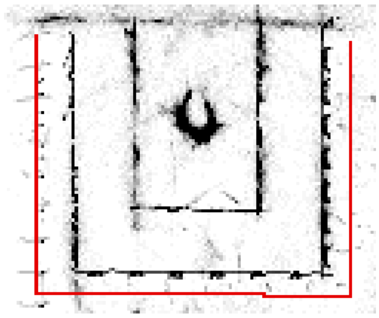

Figure 6. The map constructed for the setup of figure 5.

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