# Sub-GHz Propagation Measurements using Drones

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***Abstract*—In order to improve localisation of wireless devices, wireless networks have to be optimised. This is attained by creating a wave propagation model of the environment. This survey paper focuses on the techniques that are available to map complete three-dimensional indoor environments using a quadcopter. In order to create such a map, mapping approaches that use an octree data structure appear to be most suitable. Several SLAM algorithms that implement this structure are applicable.**

**The three-dimensional model has to be as complete as possible in order to be representative for the environment. Therefore, executing an efficient exploration algorithm and completing the occupancy grid map is of the essence. Since a propagation model requires measurements at specific locations, accurate drone navigation has to be carried out as well.**

## I. Introduction

Over the past few years, few research topics have generated as much interest as the Internet of Things (IoT). IoT is the idea of connecting all kinds of ordinary objects, such as refrigerators, thermostats, cars or even clothing, to the internet.

Although IoT opens up a wide range of possibilities, numerous challenges arise when implementing this idea [1]. Because of the increasing popularity of location-based services, localisation of wireless devices based on received signal strength has become a significant research topic [2]. The received signal strength is an indication for the magnitude of the electric field at the receivers' location. A wave propagation model can predict the attenuation of signal strength as it propagates through space. Such a model can then be used to diagnose and optimise network configurations [3], thus improving localisation accuracy and precision. In order to create a propagation model, three dependencies have to be taken into account: hardware configuration, location and environment. The receiver has to gather information about its location in the current environment.

Many different types of propagation models have been defined [4]. Previous research focussed on the validation of an indoor ray launching propagation model for sub-GHz frequencies [5]–[8]. It is important to gather precise information about the environment in order to implement this type of model. In [5], the researchers used a sub-GHz measurement device that was programmed with an LPWAN protocol, such as DASH7, SigFox, LoRa, ZigBee, IEEE 802.11ah, etc. A robot was used to gather radio measurements, laser range measurements, and the odometry of a traveled trajectory. The robot drove around in a room that is equipped with multiple radio transmitters, which periodically transmit data. The collected measurements were inserted in a SLAM (Simultaneous Localisation and Mapping) algorithm in order to model a map of the environment and the trajectory of the robot. SLAM made an estimation of the trajectory while creating an occupancy grid map. AMCL (Adaptive Monte Carlo Localisation) provided a solution for the global localisation problem by calculating the location probability using particle filters [9]. Consequently, a fluent trajectory was calculated. The resulting map and trajectory were then stored into a quadtree data structure.

In order to extend the validation to a three-dimensional space, a drone can be utilised. When using a drone instead of a robot, some important differences have to be taken into account. In contrast to a driving robot, navigating a drone to a precise and accurate location has proved to be challenging. Due to the drift of a drone's inertial sensors, it is difficult to accurately determine its exact position [10].

Furthermore, the data structure for a three-dimensional map has to support a complete volumetric representation of the environment in order to generate a correct propagation model. Hence, a variety of 3D data structures has been developed, all of which have their pros and cons.

This paper is structured in the following way: section II is devoted to mapping algorithms. Section III provides information about the completion of 3D data. In section IV, we discuss drone navigation. Finally, section V concludes the paper.

## II. Mapping Algorithms

The SLAM problem is considered to be one of the main issues in robotic autonomy. A robot that is placed in an unknown environment has to be able to map this enviroment while determining its own location on the map [11]. This is done by gathering data from sensors attached to the robot, and information about the robot's odometry. In order to accurately keep track of the trajectory, AMCL can be combined with SLAM. When the SLAM algorithm detects that the robot is in an area that is already mapped, the trajectory can be finished because the environment has already been mapped.

The resulting occupancy grid map has to be stored in a data structure that supports volumetric representation, numerous structures qualify to do so. Figure 1 [14] compares the most common mapping approaches with OctoMap. Clearly, OctoMap models the most realistic result.

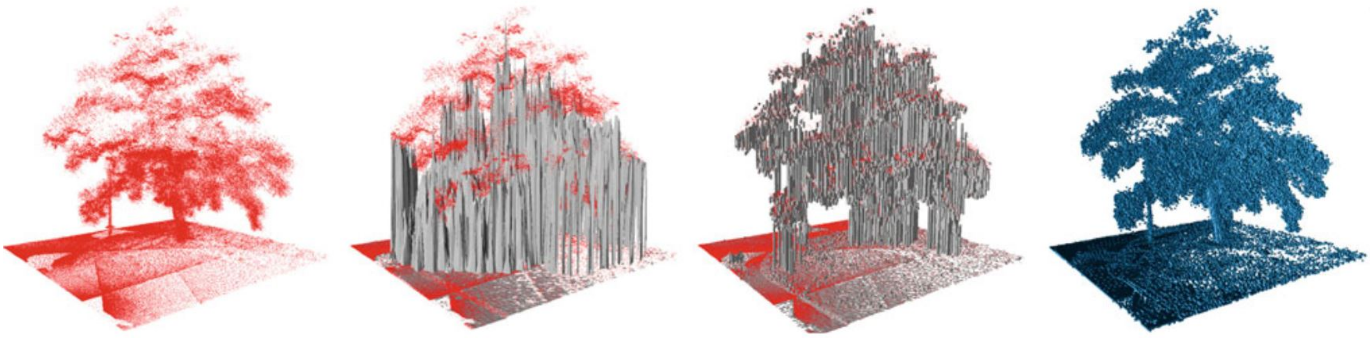

Fig. 1. 3D mapping approaches from left to right: point cloud, elevation map, multi-level surface map and OctoMap

A point cloud can represent a three-dimensional model of the environment, but has some weaknesses. To increase the resolution of the model, more measurements have to be executed. This causes the approach to be memory inefficient. Also, point clouds only model the occupied space.

Another approach is the elevation map, where a two-dimensional grid is vertically extracted to indicate the height of one pixel. Although this technique has proven its value in terrain mapping [12], it is not useful for mapping complete environments. A multi-level surface map is an improved version of the elevation map. Every cell on the map has multiple so-called surface patches [13], but there is no distinction between free space and occupied space.

Mapping approaches based on an octree data structure, such as OctoMap [14], have numerous advantages over other methods when it comes to mapping arbitrary 3D environments.

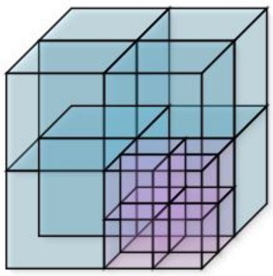

Fig. 2. Octree structure.

Firstly, an octree is highly memory efficient. It consists of an octnode which can be divided in octants. Subsequently, these octants can be seen as new octnodes, which in their turn can be divided in octants again. The desired resolution of the 3D model is determined by the depth of the octree, large adjacent volumes can be represented by a single leaf node to save memory. See figure 2 [15] for a visual representation of the structure.

Secondly, faulty measurements due to noise or reflections are cancelled out by calculating a probabilistic estimate of the correct environment based on multiple measurements. Furthermore, the map can be extended at any time when the robot explores new unknown areas.

Finally, OctoMap does not only store free space and occupied space, but also the unmapped space. With this information, the robot knows which areas he has to avoid for safety reasons, or which areas are yet to explore.

Since octree data structures are most suitable for mapping an environment, a SLAM algorithm should be chosen correspondingly. Several 3D SLAM algorithms use octrees in their mapping approach [16]–[18].

## III. 3D Completion

In order to gather as much information about the environment as possible, an exploration strategy has to be implemented. Quin et al [19] present the Nearest Neighbour Next Best View (NN_NBV) approach, which calculates the robot's next pose based on estimated effort gain and required effort. The algorithm is terminated when there are no more poses with an information gain that exceeds a fixed threshold.

Nevertheless, certain areas are difficult to map (e.g. the ceiling of a room) when using a fixed sensor. Consequently, the three-dimensional model will be distorted or incomplete in these areas. This does not benefit the validation of a propagation model, as it is important to have a complete overview.

In order to counteract this problem, the missing parts of the environment have to be reconstructed. Recent research proposes a method that combines a vertically extruded floor 2.5D plan with a 3D OctoMap [20].

Both parts of this approach use the same data as input, so no additional measurements are required. When desired, this method can even extract the objects from a room, so that only a map of the empty environment is created.

## IV. Navigation

As mentioned earlier, accurate navigation of a drone has proved to be challenging. When exploring the environment, the drone has to navigate as efficient and accurate as possible. The trajectory that the drone will follow should be planned efficiently in order to reduce battery consumption and the time it takes to gather all measurements. An efficient trajectory can be provided by the exploration algorithm [19].

On the other hand, moving the drone to the next target has to be done accurately in order to acquire information about the signal strength in a specific location. Since GPS is not practicable for indoor navigation at a small resolution, Yu et al propose the DroneSense platform [21]. The researchers used an Extended Kalman Filter (EKF) combined with reference markers placed on the floor to estimate the drone's current position. For stability, a Proportional-Integral Derivative Controller (PID) is utilised.

## V. Conclusion

Recently, 3D robotic mapping has become a popular research topic. This survey paper focussed on techniques to map complete three-dimensional indoor environments with a quadcopter. Combined with RF measurements, such a map can be used to create a wave propagation model. Section II discussed mapping algorithms and data structures. Octree data structures appear to be most suitable for mapping. Thus, a SLAM algorithm should be chosen accordingly to create a volumetric occupancy grid map. Section III considered the completion of the grid map in order to achieve a realistic representation of the environment. On the one hand, efficient exploration has to be implemented. On the other hand, the grid map can be merged with a vertically extruded floor plan. Finally, section IV briefly discussed accurate and efficient drone navigation.

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