Probabilistic Approaches and Algorithms for Indoor Robot Mapping in Structured Environments

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Introduction

Robots have come a long way since the beginning of the industrial age. Traditionally, robots were meant to be bulky, with huge arms and fixed to a certain place away from human interaction. Early industrial robots brought a revolution into the manufacturing and production industries with rapid product development and round the clock use of robots in industries. At present, multiple robots are being employed in military, manufacturing, hospitals, and disaster mitigation and for entertainment. The most significant change has been brought up by the advancement of artificial intelligence and machine learning techniques in robotics. This has made possible for robots to become completely autonomous in unstructured environments by utilizing sensors. Today there are robots operating in hazardous areas in applications such as search and rescue, mapping of collapsed mines, disaster site surveying, disposing dangerous chemicals and bombs and numerous other examples. Autonomous robots have become crucial for our quest to outer space explorations.

More and more ground robots are now employed into services and industries. These robots rely heavily on sensor information for obstacle avoidance and navigation. A critical requirement of higher-level navigation applications is that the robot has some reasonable knowledge of its current position with respect to a fixed reference frame. For example, in navigation applications that entail motion to a target position, the robot needs an accurate estimate of its current position to plan a path to the goal and to confirm success. This thesis aims at such kinds of autonomous robots in indoor environments with emphasis on accurate navigation and mapping of indoor structures for complex tasks through sensor fusion, computer vision and artificial intelligence algorithms.

Summary

The work in this thesis addresses an important problem in mobile robot navigation called as the Simultaneous Localization and Mapping (SLAM) problem. Just like we humans perceive the world using our senses and make judgment as how to navigate in the real environment, robots need high level of intelligence and computation to make such judgment using onboard sensors. They also need to consistently update their belief about its position and uncertainty. There are three main problems in mobile robotics. The first problem can be described as a "Localization" problem or by a simple question of "Where am I?" in the world. This problem refers to the correct pose of the robot in the global coordinate frame of reference and is commonly termed as a "Localization problem". The process of position estimation with respect to a fixed reference frame is defined as the localization of the robot. The second problem for the mobile robot to autonomously operate in any structured or unstructured environment will be described by the question "How do I go from point A to point B?" and is commonly referred to as a "path planning problem". This will require the robot to accurately know its position or "localization" and to have some information of the environment to go from start to goal position. The third problem can be described in a simple question as to "How does the world look like?" This is referred to as the "Mapping problem" or in simple terms the correct information of the environment the robot is moving in by means of data collected by sensors. Clearly, all the three problems are critical and are very much co-related to each other because, when an accurate description (map) of the environment exists then the robot can "localize" itself by matching its observations using the sensors to the world reference model; also, if the robot knows its pose with high accuracy, then it can seamlessly navigate from point A to B using the observed features, its pose and map. This process of trying to solve the above problems is termed as "Simultaneous Localization and Mapping (SLAM)" or "Concurrent Localization and Mapping (CLM)".

SLAM is such a fascinating field that it gives any mobile robot intelligence to interact with the environment it’s operating in and make intelligent decisions on how to navigate inside such environments. To do so, they require an accurate map of the environment (2D or 3D), and autonomously navigate in structured environments.

The applications of such kind of robots are many, mainly autonomous navigation, obstacle avoidance, as service robots, search and rescue operation, teleoperation and many more. This thesis aims to find solutions to construct accurate 2D and 3D maps of indoor environments for successful autonomous behavior of a wheeled mobile robot.

The thesis addresses three major solutions to the SLAM problem:

1. Localization using state of the art filters: Localization using existing solutions for estimation like the Extended Kalman Filter (EKF), particle filters, and graph theory is presented. The work briefly describes techniques for building maps using Laser Range Finders (LRF) for 2D mapping and localization. 2D features such as corner points and 2D lines are used as features for building robust maps. These are then
incrementally built using the probabilistic methods. Since the robot is assumed to be starting with no map, the map is built as the robot moves around inside the environment.

2.) Clustering approach to build maps: This work proposes many solutions to make accurate maps by utilizing clustering algorithms for effective noise removal, data segmentation, data extraction and building memory efficient maps for long time mapping of large environments. A novel line extraction methods using clustering of LRF data is briefly presented which is computationally faster and robust to noise produced from cluttered areas.

3.) 3D mapping using low cost RGBD sensors: Finally, 3D mapping solution is presented that uses low cost depth or RGB-D sensors. Vision algorithms are used for fast feature extraction from depth images for constructing accurate maps providing rich information for safe navigation in cluttered areas. The image feature extraction method is combined with 2D localization method to make accurate 3D maps of large areas.

All the above algorithms are presented with results in real environment. The methods can easily be integrated to all kinds of wheeled robots for accurate navigation in indoor environments.