An Approach for Mapping Unknown Environments using Frontier-Led Swarms

Kumara Ritvik Oruganti
A James Clark School of Engineering
University of Maryland
College Park, Maryland 20742
Email: okritvik@umd.edu

***Abstract*—Robots have become increasingly important in many aspects of life, from manufacturing to health care, logistics to entertainment. The basic building blocks for the robot or agent to function in an environment are Perception, Navigation and Control. To navigate in an environment, it is necessary for the robot to require a map in which they operate. This project proposes an implementation of a novel swarm-based algorithm for the exploration and coverage of unknown environments while maintaining the formation of the swarm and a frontier-based search for effective exploration of the unknown environment.**

***Index Terms*: Navigation, Control, Perception, Swarm, Frontier-Based Search**

1. Introduction

A common assumption for robotics applications is that the robot has prior information about the environment. The state-of-the-art planning algorithms like Dijkstra [10], A*, Randomly Exploring Rapid Trees (RRT) [11] and different flavors of RRT assume that the obstacle space is well known to the agent. Exploration is the process of selecting a location that maximizes the search area coverage. Conventional coverage algorithms like the Voronoi-based [9] approach, and the graph-based approach assumes independent agents. To tackle this problem of priori information of environment to the robot, this project proposes to implement a frontier-based exploration strategy using multiple robots motivated by the biological and physicomimetic emergent behaviours in bird flocks [12], ants [13], and repulsion between likely charged particles.

Frontiers are the boundary regions between known and unknown space. To gain knowledge of unknown space, the agents or robots should move near the frontiers and explore again [1]. This process should be repeated until there are no frontiers left for the robot to explore which completes the exploration of the environment. There are several approaches for the frontier-based search algorithm namely Wavefront Frontier Detection [7], Fast Frontier Detection etc. This project utilizes the concept of Reynolds' boids [8] to implement the search strategy. There are many other conventional algorithms for Simultaneous Localization and Mapping (SLAM) that updates the environment information while exploring and avoiding the obstacles simultaneously on platforms like TurtleBot and Robot Operating System (ROS).

2. Related Work

Titus Cieslewski et al. [2] proposed a novel approach of using a version control system to look up and update the map of an agent and reduce the bandwidth of inter-robot communication for the distributed networks. Alejandro Puente-Castro et al. [3] has proposed a swarm path planning using the reinforcement learning technique for the application of field prospecting regardless of the size of the field. Syed Irfan Ali Meerza et al. [14] proposed a dynamic obstacle avoidance and coverage technique using particle swarm optimization. Area coverage can be divided into two types, namely, static coverage [4] and dynamic coverage. Static coverage corresponds to the formation of a swarm in such a way that the sensors cover the whole environment. Practically, in many applications, this is not possible and hence, due to the limitations in the range of the sensors and communication bandwidth, the robots move and sample the environment at a reasonable resolution to cover the entire environment [5]. Collaborative exploration and coverage is another field where dynamic obstacle avoidance and situational awareness are required. Cheng et al. [6] proposed a dynamic coverage algorithm using a leader-follower that uses a flocking technique for the formation of the swarm.

3. Approach

3.1. Swarm Rule

3.1.1. Cohesion. The agent moves towards the average position of the nearby neighbours.

3.1.2. Alignment. The direction of the agent is towards the average heading of its neighbours.

3.1.3. Separation. The agents move away from the obstacles or other agents to avoid collision as in the repulsion in the likely charged particles.

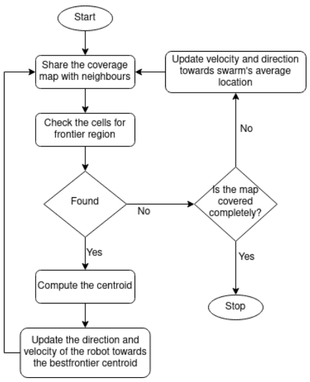

Figure 1. An overview of the implementation

3.2. Coverage

The coverage problem is dealt with frontiers in an unknown environment by specifying the boundary conditions of the environment. This approach uses a distributed solution that has a coverage matrix in each agent that gets shared with its neighbours. The map is decomposed into cells with a resolution and those cells are initially set as unexplored. When the agent passes through that cell, the cell is set as explored and when there is an obstacle, the value of the cell is set with a value that denotes an obstacle. A Breadth-First-Search algorithm is then used to detect the frontier regions and use them in a queue that has a minimum Euclidean distance from the robot's present position. Then the robot is headed towards the direction of the frontier centroid which has a minimum distance. The flowchart is given in figure 1

3.3. Obstacle Avoidance

The obstacle avoidance is achieved using repulsion force between the robots by utilizing the LIDAR sensors on the robots.

4. Goals

The goal of this project is to implement the above-proposed approach on a swarm of TurtleBot3 using ROS 2 framework in a Gazebo environment. Due to the development stage of ROS 2 and issues related to the ROBOTIS TurtleBot3 packages with ROS 2 Foxy and Humble versions, there can be a switch between using TurtleBot3 with ROS Noetic or ROS 2 Foxy and Humble.

5. Fall back Goals

- The implementation of obstacle avoidance can be more complex using the LIDAR data from the robots in Gazebo simulation environment. Hence, the assumption is that the robots will not be colliding with each other and there are no obstacles in the workspace.
- Another fallback goal is to implement the above methodology using a 2D visualization using OpenCV functions instead of simulating them in Gazebo.
- Since there is a need to develop the algorithms, world map and visualization from scratch, due to time constraints and commitments, an implementation of boids algorithm on a map that has no obstacles using a swarm of TurtleBot3 is proposed.

Acknowledgments

The author would like to thank Dr. Michael W. Otte and Dr. George P. Kontoudis for their insights and constant support throughout the project selection and course of study.

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