Charting hazardous indoor spaces using robot swarms.

Abhijit J. Theophilus Surya Prakash M
Vijayalaxmi Hullatti Vinay Kumar Adiga G

Project Guide: Dr. T.S.B. Sudarshan

1 Problem Definition

Indoor regions, like mines, collapsed structures and archaeological ruins, that are either inaccessible or hazardous, often need to be mapped with minimal cost to personnel and equipment. Tasks such as these are most efficiently performed autonomously by robots. However, to construct robust single or traditional multi-robot systems requires investing in the durability of individual robots. These costs, amplified by the complexities arising in extending such specialized multi-robot teams leads to expensive solutions. Swarm Robotics presents a novel solution to such problems that require robust and scalable solutions at low costs. Multitudes of robots with simple architectures replace a few specialized robots to perform highly parallel tasks. This lends robot swarms their flexibility and robustness. This project aims to explore these properties to judge the suitability and efficacy of robot swarms specifically in mapping indoor regions.

Keywords: robotics, robot swarms, collective mapping, indoor mapping.

2 Introduction

In several professions, there arise situations that involve accessing indoor locations that are either hard to reach, or pose a certain level of risk to human wellbeing. These locations could occur underground, or under extreme circumstances on the surface. Archeology and Mining are examples of professions where such locations are places of exploratory interest, while public services like the Fire department or the Police force would require surveying regions like collapsed structures for search and rescue, or terrorist occupied buildings for counter offensives. Ideally, such regions of interest would need to be mapped and studied before personnel and specialized equipment are deployed. By mapping such hazardous and inaccessible regions, robots not only minimize human risk, but also ensure that each operation carried out is efficient in cost and effort. Robots designated for such tasks would need to be precise, robust and scalable. Precision is the degree of detail in the data collected so as to render a map with a feasible resolution and scale ratio, robustness is the ability of the system to operate in the face of hazards and scalability deals with the ability of the system to increase it's size or capacity to deal with larger areas of interest.

The precision of the data collected by robots, either single or multi-robot, is primarily dictated by the sensors and equipment that they carry. However, the resilience of single or traditional multi-robot systems rests entirely on the durability of individual robots. In a single robot system, if the only agent fails, the system is dead. For traditional multi-robot systems, where each robot has a specific function, if any of the critical robots fail the system is left inoperable. When it comes to scalability, a single robot has an inherent limitation to its reach. Multi-robot systems however can be extended to include more robots. The disadvantage this holds for traditional systems is that the cost of adding an additional robot increases with the complexity of its design. Therefore, for systems with specialized robots, this limits the extent to which the multi-robot system can scale.

Swarm Robotics is a multi-robot paradigm that capitalizes on the advantages that come with using multiple robots while doing away with the complexities involved in them being specialized. Swarm Robotics deals with the organization and operation of a large number of homogeneous autonomous robots with simple functionality and, limited communication and sensing capabilities. The interaction of these robots among themselves and with the environment leads to emergent behavior targeted towards a common goal. Robot swarms are both highly robust and can scale to significant proportions. With large numbers of robots performing repetitive tasks in parallel, the system can still function if a subset of the total robots is damaged during operation. Further, owing to the simplicity and extreme modularity of a swarm design, it becomes significantly easier to add or drop large numbers of robots from the swarm. These qualities make robot swarms especially suitable for mapping hazardous indoor regions.

3 Literature Survey

Single robot mapping of indoor regions was carried about by Stephen Se, et. al., using a vision based approach [1]. Their robot was equipped with a trinocular stereo system which generated Scale Invariant Feature Transform (SIFT) features for each image capture. Stereo matching allowed them to match each image with real world coordinates relative to the robot. Once the SIFT features were matched, they used a least squares procedure to compute better camera ego-motion and thereby more accurate localization.

Thrun and Liu proposed an algorithm for multi-robot Simultaneous Localization And Mapping (SLAM) when the initial positions of the robots are unknown and the environment landmarks are ambiguous [2]. Their algorithm, called Sparse Extended Information Filer (SEIF) represents robot maps using a sparse Gaussian Markov random field which allows constant time updates and linear memory requirement. The key features of SEIF are additivity, which allows robots to contribute incrementally, and locality, which ensures that updates performed by a robot are confined to its own pose and detected landmarks. Their algorithm was the first to successfully merge local maps into a single global map without knowledge of robot poses and identifiable landmarks. Howard, et. al., presented another approach to indoor mapping for large scale heterogeneous robot teams [3]. Their approach involved three distinct classes of robots, mapping robots, leader robots and sensor robots, to explore the environment, build an occupancy grid, identify the object of interest and monitor it through strategic deployment.

Navarro and Matía [4], as well as Tan and Zheng [5] highlight the key features and characteristics of Swarm Robotics along with advantages of using large number of simple homogeneous robots over a few specialized ones. Their papers are compilations of recent advances in the field.

Rothermich, et. al., described and studied the behavior of robot swarms in distributed mapping using both simulations and physical robots [6]. Localization was performed by collecting data relative to multiple landmarks with weights assigned to the reliability of landmarks. Task allocation to each robot was dynamically determined by two components. The first component is determined by whether the robot is allowed to move based on the constraints and quality of localization information. The second component calculates a robot's desire to move through gathered local data. Collaborative mapping was performed by superimposing individual maps generated by these robots to construct a complete representation of the environment.

4 Objective

To design, simulate and implement a swarm of wheel-based robots to be deployed in a bounded unknown environment with obstacles in order to survey the region autonomously. The gathered data would then be used to render a human-readable two-dimensional map for the surveyed region.

5 Methodology

The project time line will comprise of three major phases, where each phase acts as a milestone, as well as the completion of one aspect of the problem statement.

Phase I
The first phase will involve designing the architecture of the Robot Swarm, along with the simulation of the experiment and the verification of the selected algorithms on a software testbed. The first step in this phase is deciding the type and design of algorithms to be used for higher level coordination mechanisms like dispersion and task allocation as well as the underlying protocols implementing these communication methods. The next step will involve implementing these algorithms and validating them. Once the software for coordinating the swarm is ready, it will be loaded onto the simulator and verified.

Phase II
The next phase involves building the data collection modules of the robot and the rendering software used to generate the final processed map. This phase includes deciding the type and quantity of sensors and data transmitters required, along with the protocol for transferring the data to the external processing unit. The libraries used for the rendering software will be chosen

and implemented upon in this phase. If feasible, these modules will be loaded onto the simulation built in the first phase and tested on a procedurally generated environment.

Phase III
The last phase is the translation to hardware. Here, the robots will be implemented in hardware and the software modules will be loaded into each robot. Relocatable objects will be used to build a dynamically organized environment. The robots will have an established connection to the external processing unit and will operate autonomously over the environment. The robots may need to be tweaked in order to ensure consistent performance.

6 High Level Design

(To be done later.)

7 Proposed Metrics

(To be done later.)

8 Model

(To be done later.)

9 Assumptions

(To be done later.)

10 Outcomes

(To be done later.)

References

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