MiniMappers
Charting Hazardous Indoor Spaces using Robot Swarms

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Overview

Problem Statement / Definition

To design and development the simulation and implementation of a multi-robot system, based on the swarm heuristic, as a precise, robust and flexible solution to Simultaneous Localization And Mapping (SLAM) within a bounded (indoor) region, and to study its suitability and efficacy at the task at hand.

Introduction

Target Environments

What indoor regions need to be mapped?
Automated mapping is required in either vast, hard to reach or hazardous indoor environments. Such regions of interest need to be mapped before personnel or specialized equipment are deployed.

Applications

- Surveillance, e.g., search and rescue ops, urban counter-offensives.
- Exploration, e.g., mining, archeology.

Robots for Mapping

Why use Robots?
Tasks performed by automated robots strive to minimize human risk, and optimize efficiency in cost and effort.

Essential Characteristics

- **Precision**, the degree of detail in the data collected,
- **Robustness**, the ability of the system to operate in the face of hazards,
- **Scalability**, the ability of the system to increase its capacity to deal with larger areas of interest.

Issues with Traditional Multi-Robot Systems

- System may not be able to cope with the failure of critical robots.
- Costs of adding additional robots increases with the complexity of its design, limiting scalability.

Moving toward Robot Swarms

What is Swarm Robotics?
Organization and operation of large groups of relatively simple robots through the use of local rules. Characterized by decentralized control, lack of synchronization, simple and (quasi) identical members.

Why Swarm Robotics?

- **Scalable**, interaction is local, individuals can join or quit the task at any time,
- **Stable**, can continue to function when a section of the swarm quits due to failure,
- **Parallel**, can deal with multiple targets/locations simultaneously,
- **Economic**, the cost of the whole system is significantly lower than a complex single robot.

Literature Survey

Literature Survey 1

Mapping Using Vision: Trinocular stereo system mounted on a bot to generate Scale Invariant Feature Transform (SIFT) features for each image. Stereo matching matched each image with relative real world coordinates. Least Squares was used on the SIFT features to compute egomotion.

[Se, et al., 2001]

Multi-Robot SLAM without Prior Information: Successfully aggregated local maps without knowledge of robot poses and identifiable landmarks. Map representation allows constant time updates with a linear memory requirement. Algorithm features incremental and local updates.

[Thrun and Liu, 2005]

Literature Survey 2

Heterogenous Robot System: Surveillance performed using three robot classes. Mapping robots explore the environment, build an occupancy grid and identify the object of interest. The object is monitored through strategic deployment of Sensor robots coordinated by Leader robots.

[Howard, et al., (2006)]

Mapping with Robot Swarms: Localization performed by collecting data relative to weighted landmarks. Task allocation determined through the robot's ability to move based on constraints and information quality, and the robot's desire to move based on gathered local data.

[Rothermich, et al., (2004)]

Literature Survey 3

Introductory Texts to Swarm Robotics: These texts are compilations of recent advances in the field. They highlight the key features, review the tasks, and talk about the characteristics of Swarm Robotics with emphasis on their advantages over traditional multi-robot systems.

[Navarro and Matía (2012)]
[Tan and Zheng (2013)]
[Bayındır (2016)]

Methodology

Methodology: Outline

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

Stage 1: Design and Simulation of the Swarm Structure
Phase 2: Data Collection and Communication Modules
Phase 3: Translation to Hardware

Methodology: Phase 1

Design and Simulation of the Swarm

Goals

- Designing the architecture of the Robot Swarm.
- Develop algorithms for high level coordination.
- Pick suitable protocols for implementing communication.
- Simulate and verify the selected algorithms on a software testbed.

Status

- Each robot is modeled with four fixed wheels, a SONAR and a wireless transceiver.
- The robot is only allowed to turn on the spot and move either forward or back.
- The SONAR is mounted on a 360° motor allowing it to operate in any direction.

Design and Simulation of the Swarm

Status

- Although robots are homogeneous, tasks within the swarm are not identical.
  - A Marching Band algorithm is proposed where robots form a cubic lattice and follow a wall.
  - The first row is responsible for detecting objects in front of the lattice.
  - The row adjacent to the wall is responsible for ensuring a fixed distance from the wall.
  - Each robot aligns itself with the wall-adjacent column and the front row.
- Direct communication for any robot in the swarm is only possible with the outermost robot at the first row of the non wall-adjacent column.

Design and Simulation of the Swarm

Status

- Framework used to create lattices is called Physicomimetics.
- The system is set up to act as a molecular dynamics simulation ($\mathbf{F} = ma$).
- Each robot estimates a force applied on it by each neighboring robot given by, $F = Gm_i m_j / r^p$, where $F < F_{\max}$.
- The force is repulsive if $r < R$ and attractive if $r > R$.
- For cubic lattices, each robot is assigned one of two colors. Like colors have a separation of $R\sqrt{2}$ and unlike colors have a separation of R.

Design and Simulation of the Swarm

Status

- An interior region can be described to be compartmentalized into nested indoor regions.
- Each indoor region is characterized by one or more entrances.
- Entrances can be used to tag whether a region has been visited or not.
- While following a wall if the swarm detects and passes through an entrance, it remembers the location of the entrance.
- If it revisits the entrance without passing through any other entrance, the region can be assumed to be completely swept.
- If it revisits the entrance after passing another (that is hasn't cycled back to), the swarm knows it has a road not taken and goes back to cover it.

Methodology: Phase 2

Data Collection and Communication Modules

Goals

- Determine the protocols governing sensor control.
- Determine the protocols governing communication.
- Develop the internal representation of the data.
- Develop the algorithm to aggregate local maps into the complete representation.

Methodology: Phase 2

Data Collection and Communication Modules

Status

- Two primary sensors will be boarded onto each robot, an Ultrasonic Module for Ranging and an Inertial Measurement Unit for Localization.
- Reading the ranging data occurs synchronously with normal operation. Every operation cycle, the robot performs a sweep of its environment and constructs a partial map.
- The SONAR can detect objects at 5–400cm.
- The IMU records the changes in the objects position asynchronously to ensure minimal error. Once the change in position and orientation is determined, the object determines its position and direction with relation to a global frame.
- The global frame will have its origin at the first entrance the swarm visits.

Methodology: Phase 2

Data Collection and Communication Modules

Status

- Communication will be carried out over a WiFi connection.
- The head of the swarm is the robot at the leading row on the far side of the wall-adjacent column.
- The swarm head sets up an Access Point which is then connected to by the other robots in the swarm.

Methodology: Phase 3

Translation to Hardware

Goals

- Implement the robots in hardware and load the software modules.
- Test the robot swarm in an actual environment.

Status

- The following sensors have been considered,
  - HCSR04 Ultrasonic Module.
  - MPU6050 IMU.
- ESP8266 WiFi module will be used for communication.
- The Ultrasonic Sensor works by echolocation. The voltages at its ECHO pin vary by the distance measured.
- The Ultrasonic Sensor is mounted on a servomotor that operates on increments of 2°.

Translation to Hardware

Status

- The MPU 6050 is a 6 Degrees of Freedom (DoF) IMU sensor with an embedded accelerometer and gyroscope based on the Microelectromechanical systems (MEMS) technology.
- The Accelerometer works on the principle of the Piezoelectric Effect and Gyroscope on Coriolis Acceleration.

Attempts with Gazebo

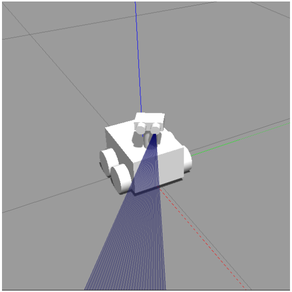
Status

- Initial plan was to simulate with Gazebo. Gazebo provides an Open Source solution to simulating single and multi-robot systems.
- Gazebo lacks basic support for several key functionality. SONAR sensors fail and wireless communication allows only intensity detection.
- Uses Google's Protobuf for data communication adding unnecessary overhead.

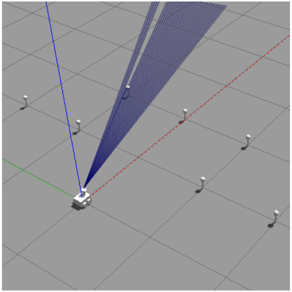
Experiment Setup and Implementation

Attempts with Gazebo

The early models for the system.



(a) MiniMapper Model



(b) SONAR Ranging

Figure: Simulating the Robot

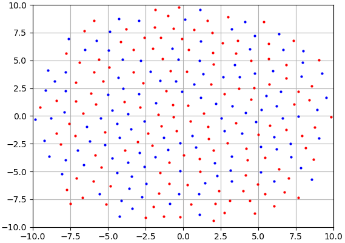
Experiment Setup and Implementation

Simulating with Matplotlib

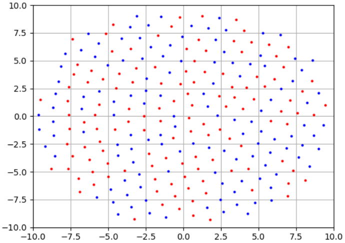
Status

- Wrote our own simple simulator using NumPy and Matplotlib.
- Allows us to tweak the system to meet our needs.
- The system is modeled as a class `Environment` which keeps track of the orientation and position of all objects with respect to a global frame of reference which is used when plotting.
- Each robot modeled as the class `MiniMapper` also keeps track of it's position relative to it's own frame of reference.
- Sensor inputs are given as calls to `Environment` that estimates the SONAR value and returns it after translating the values to the robot's frame of reference.

Simulating with Matplotlib



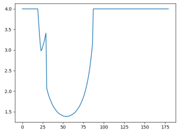
(a) Cube Lattice



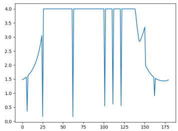
(b) Hexagonal Lattice

Experiment Setup and Implementation

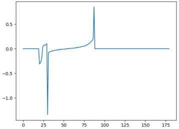
Simulating with Matplotlib



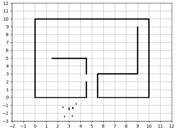
(a) Detecting Walls



(b) Wall with other Robots



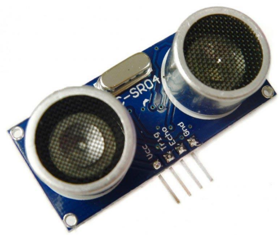
(c) Detecting Entrances



(d) Simulation

Figure: Sensors

Hardware Setup: Sensors



(a) HCSR04 Ultrasonic

(b) MPU 6050 (IMU)

Figure: Sensors

Hardware Setup: Reading points with SONAR

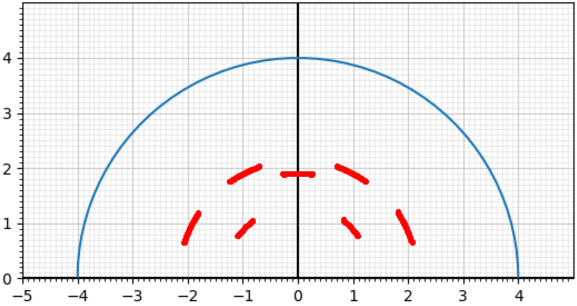


Figure: SONAR Plot

Hardware Setup: Hardware Setup: Robot Implementation

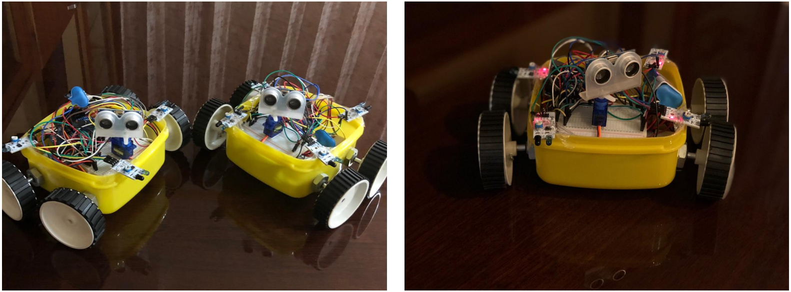
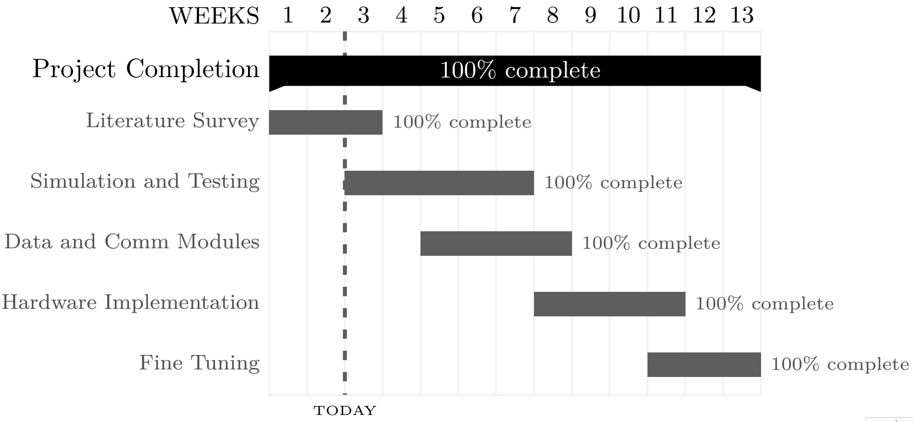


Figure: The MiniMapper

Timeline for Project Completion (Gantt Chart) Nov 2017–10th April 2018



Expected Outcome/ Results

1. Simulation of Swarm Behaviour

To develop an understanding of the emergent behaviour of a robot swarm in a simulated environment.

2. Test and Verify Swarm Algorithms

A set of implemented, tested and verified algorithms for coordinating robot swarms. These algorithms will target dispersion, localization, task allocation and aggregation of local data.

3. Implementation in Hardware

A functional robot swarm solution to SLAM.

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