Simultaneous Localization and Mapping using ZigBee Protocol

Project Proposal

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Outline

- Warehouses
- Cleaning systems
- Robotic concierge
- Large office mail systems
- Mining
- Research and education

Problem Statement

Design and implementation of a low-cost localization and mapping system using off-the-shelf hardware components.

Background Study

Literature

- Most systems in research environments utilize RFID
- Directional antennas with wireless sensor beacons
- Using a parabolic reflector to estimate angle-of-arrival
- Research literature showing proof of concept and not a real world implementation
- Implemented on custom, purpose-built mobile robots

- Accuracy of measurements, mapping, and localization
- Improve signal-to-noise ratio (SNR)
- Balancing cost and accuracy in the number of wireless beacons

Terminology

- Pose: $\mathbf{q} = [x, y, \theta]^T$
- Root Mean Square Error: RMSE $= \sqrt{\frac{1}{t_f} \int_0^{t_f} [e(t)]^2 dt}$
- Robot error: $e_P(t) = \sqrt{(\hat{x}(t) - x^d(t))^2 + (\hat{y}(t) - y^d(t))^2}$
- $e_B(t) = \Sigma_{i=1}^{n} e_i(t)$ where
  $e_i(t) = \sqrt{(\hat{x}_i(t) - x_i^d(t))^2 + (\hat{y}_i(t) - y_i^d(t))^2}$

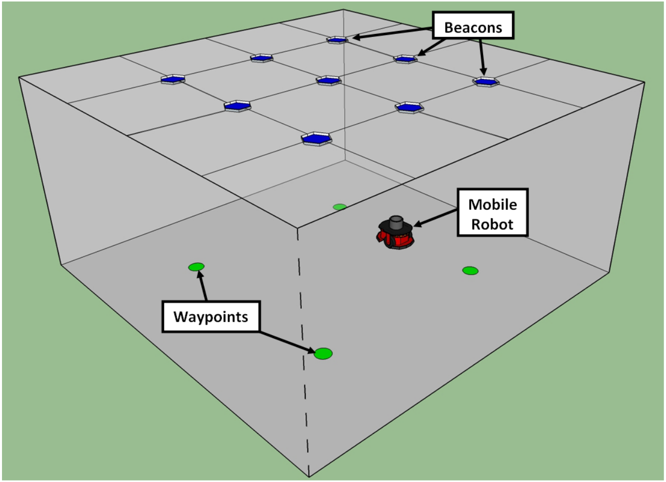
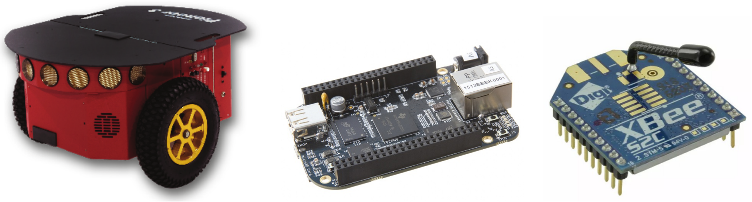


Figure: System Architecture

Functional Requirements

System Architecture



(a) (b) (c)

- Mobile robot (Pioneer 3-DX)
- Interfaced using BeagleBone Black running Robot Operating System (ROS indigo[1])
- Ceiling mounted beacons (XBee modules)
- Predefined waypoints (implemented in algorithm)

[1] www.ros.org

System Block Diagram

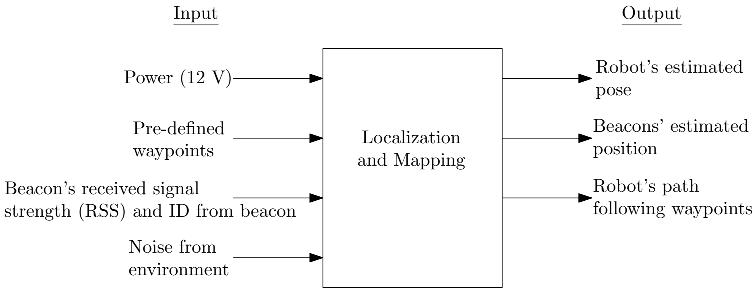


Figure: System block diagram

Functional Requirements

Subsystem Block Diagram

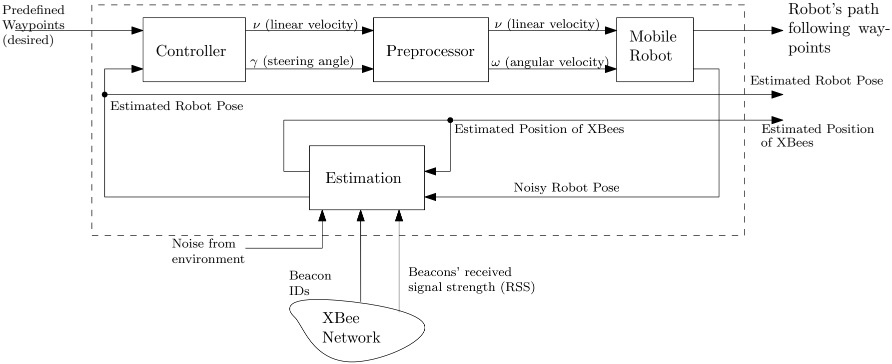


Figure: Subsystem block diagram

- Four subsystems
  - Controller
  - Preprocessor
  - Mobile Robot
  - Estimation
- Outputs are for debugging, used internally for implementing EKF-SLAM algorithm

Outline

Functional Requirements

Specifications

- Cost under \$500
- Localize mobile robot with RMSE $\leq 30\,\text{cm}$
- Estimate beacon positions with RMSE $\leq 30\,\text{cm}$
- Use ROS

Outline

- Real-time robot simulator
- Advantages
    - Simulates all dynamics of the robot (driving kinematics, object physics, sensors)
    - Easy to use through a variety of programming languages
    - Provides real-time simulation data for use in algorithm

Preliminary Results

Simulation Setup

- Time step, $T = 0.25\,\mathrm{s}$
- Linear velocity standard deviation, $\sigma_\nu = 8.8858 \times 10^{-4}$
- Angular velocity standard deviation, $\sigma_\omega = 0.0012$
- Observation range standard deviation, $\sigma_R = 1$
- Observation bearing standard deviation, $\sigma_B = 5^\circ$
- Maximum Pioneer linear velocity is $1.2\,\mathrm{m\,s^{-1}}$
- Maximum Pioneer angular velocity is $300\,^\circ\,\mathrm{s^{-1}}$
- Other parameters: 9 beacons, 2000 iterations, observations every 8 iterations

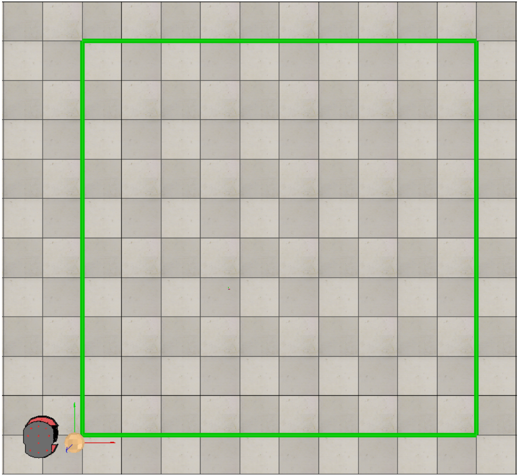


Figure: Starting configuration of the V-REP simulation

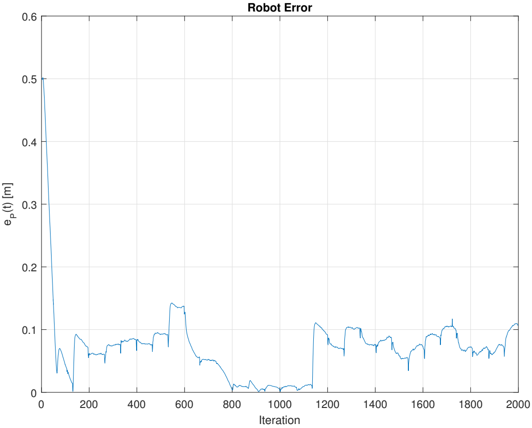


Figure: Robot error from simulation over 2000 iterations with an RMSE of 0.0928

Preliminary Results
Simulation

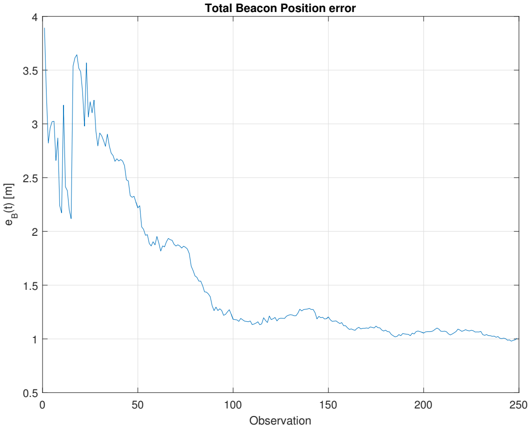


Figure: Total beacon error from simulation over 250 observations with an RMSE of 1.7254

Outline

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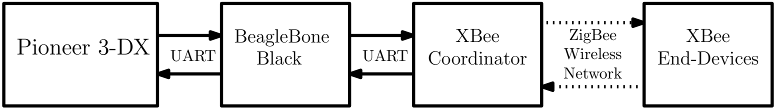


Figure: System interfaces

Preliminary Results

Design

- Basic wireless communication between two XBees in X-CTU, XBee configuration software, running on a PC.
- C program running on BeagleBone Black which interfaces with XBee via UART for basic communication between two XBees.
- Expanded C program with the help of open source library *libxbee*[2] to packet-based communication.
- Current functionality to obtain RSSI from beacons:
  - Robot mounted XBee (Coordinator) transmits ping signal to beacons. Beacons will register the RSSI.
  - Coordinator then requests beacons (End-Devices) to return individual IDs and registered RSSI.

[2] `https://github.com/attie/libxbee3`

Outline

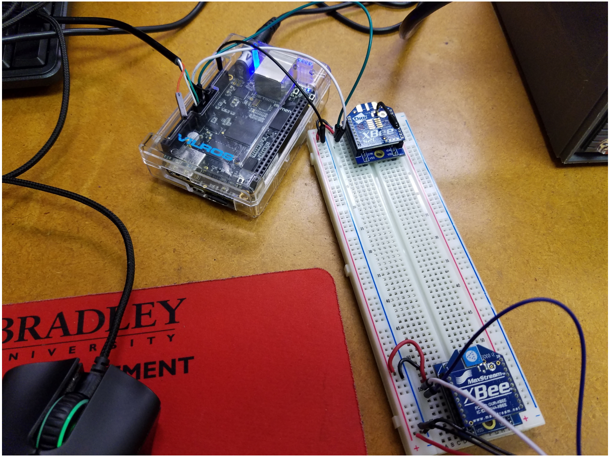


Figure: Lab set up for experiments

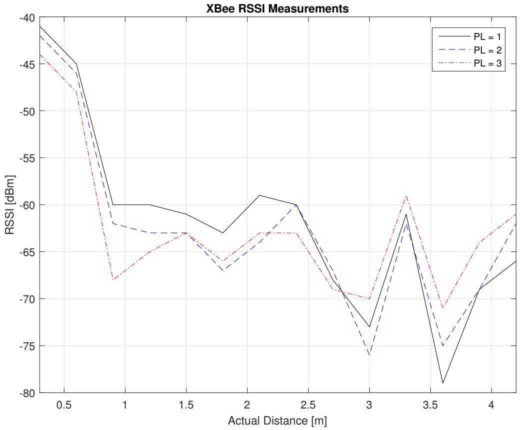


Figure: RSSI vs. Actual Distance

$$d = f(\mathrm{RSSI})$$

$$d = 10^{\frac{-\mathrm{RSSI} - P_{\mathrm{ref}}}{10\eta}}$$

where d is the calculated distance, RSSI is the measured RSSI, P_{ref} is the power level at a reference distance of 1 m, and η is the propagation constant

Preliminary Results

Experimental Activities

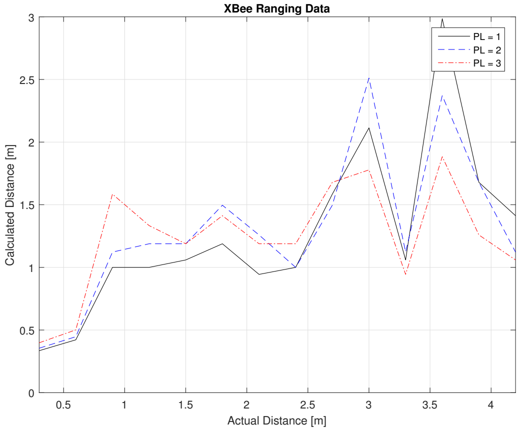


Figure: Calculated Distance vs. Actual Distance

Parts List

This list does not include parts already in the lab such as the Pioneer 3-DX, wire, capacitors, or resistors. We were also fortunate enough to have access to a BeagleBone Black and some XBee modules for experimentation without having to place a parts request.

Part	Price	Quantity
XBee S2C w/ whip antenna	$18.19	6
XBee Interface Board	$5.31	6
Perforated Circuit Board	$2.84	4
Stepper Motor	$14.95	1
Motor Controller	$19.95	1
3.3 V Regulator	$0.79	10
9 V Battery Clip	$0.39	10

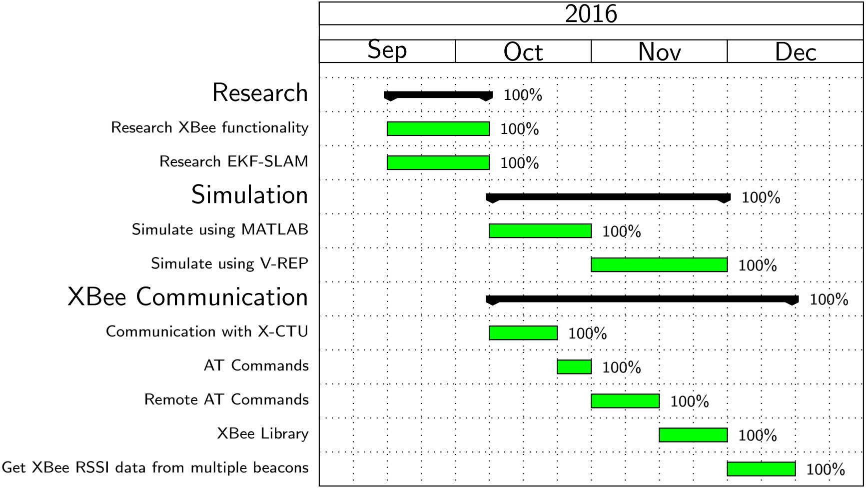
Table: List of ordered parts

Deliverables

- Experimental results
- Report
- Complete Documentation

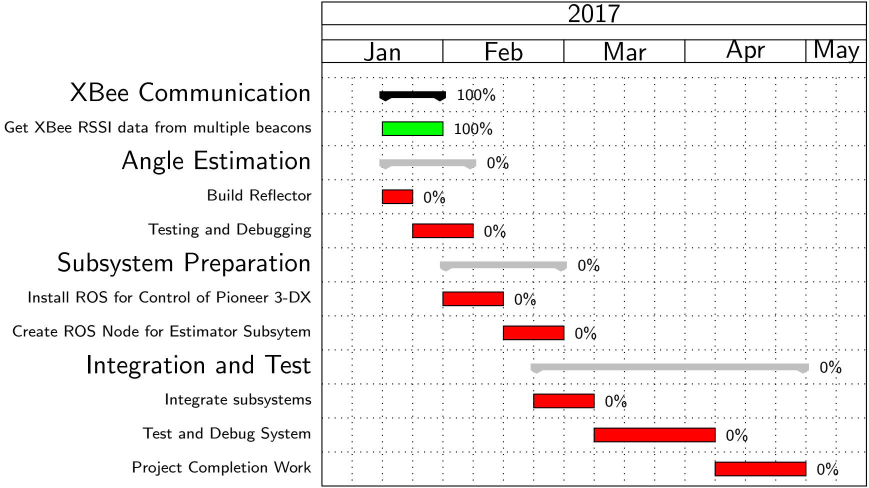
Timeline and Milestones

Fall Semester



Timeline and Milestones

Spring Semester



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Future Directions

- Estimate angle-of-arrival from wireless beacons
- Complete subsystems
- Integrate subsystems
- Demonstrate completed system

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