Navigating with Ranging Radios: Five datasets with groundtruth

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Abstract

Here we present five large datasets with range-only measurements between a mobile robot and stationary nodes. Each dataset consists of range measurements, surveyed locations of the stationary radio nodes, dead-reckoned trajectory of the robot, and groundtruth from a sophisticated INS/GPS system mounted on a robot traveling several kilometers at a time. Range measurements are made with two radio-based ranging systems: a RFID tag-based ranging system and a UWB ranging system. All the data are accurately timestamped and presented in standard formats (ie. text files). In addition to the raw data, we present some noise characteristics of the two different ranging systems to offer insight into the quality of the range data from each system.

1 Introduction

In this paper we present detailed description of range-only data intended for use in position estimation research. This data will be of particular use researchers interested in both tracking and localization in applications where GPS doesn’t provide sufficient accuracy or is not reliable. A key advantage of using radio based navigation is that the data association problem is solved trivially—each range measurement is easily tagged with the identity of nodes in between which the measurement is made. On the other hand, the working with such data is challenging because the probability distributions due to measurements are annuli and thus highly non-linear. Since such data can also be noisy, simple linearization around an operating point often causes filters to diverge.

The five data sets presented here are noteworthy for several reasons. First, we believe that they are the largest publicly available collection of range data to fixed nodes taken from a moving node. Second, these data have highly accurate groundtruth associated with them. The data are gathered in outdoor fields, free of obstacles and other occlusions. Using instrumented autonomous robots with highly accurate (2cm)
positioning for ground truth using RTK GPS receivers as well as a fiber optic gyro and wheel encoders. Ground truth position is updated at $100\,\text{Hz}$.

The data presented here were taken with two distinctly different radio-based ranging systems. The first is an radio frequency (RF) based system that measures the time delay of a message sent between low-cost, low-power, RFID tags placed in the environment and a moving transponder to compute the range. All datasets that use this system are referred to as the Gesling datasets because they were collected at the Gesling stadium at Carnegie Mellon University. The second system is also a radio based system that utilizes ultra-wide band signals and measures the range between two homogeneous nodes. These datasets are labeled as the Plaza datasets and were collected at a large flat grassy site close to the campus of Carnegie Mellon. While both systems use radio signals to measure range, the noise characteristics of the two vary significantly. In both cases the locations of the stationary radio nodes were manually surveyed to $2\,\text{cm}$ accuracy using the available GPS. Additionally, each dataset has synchronized timestamps between the range, odometry and groundtruth data streams.

All the data presented here are available at the dataset website: [http://www.frc.ri.cmu.edu/projects/emergencyresponse/RangeData](http://www.frc.ri.cmu.edu/projects/emergencyresponse/RangeData).

The remainder of the paper is organized as follows. Section 2 provides a detailed description of different data that is logged in each of the datasets. An analysis of the noise characteristics of each of the two ranging systems is presented in Section 3. Finally, Section 4 provides a summary of the data access and the log file parsing technicalities.

## 2 Data Description

For each of the datasets, we collected three kinds of data: the groundtruth path of the robot from GPS and inertial sensors, the path from dead reckoning, and the range measurements to the stationary radio nodes. The path from dead reckoning is computed by integrating over time incremental measurements of change in the robot’s heading from a fiber-optic gyro (with a drift rate of $30\,\text{deg/hr}$) and incremental distance traveled measurements from the wheel encoders.

The different datasets were designed to create a variety of robot paths, each with a distinct dead reckoning drift. Dataset $A1$ and $B2$ in which the paths chosen cause a monotonic increase in heading error due to repeatedly turning in the same direction. In contrast dataset $A2$ and $B1$ present paths that minimize the
effect of heading error by balancing the number of left turns with an equal number of right turns. Finally, dataset A3 highlights a much longer trial where the robot was driven in a random manner. Table 1 presents a comparative view of the different datasets. Datasets A1-3 were collected using the RFID-based ranging system, while datasets B1-2 were collected using the ultra-wide band ranging system.

<table>
<thead>
<tr>
<th>Groundtruth Path</th>
<th>Dead Reckoned Path</th>
<th>Dataset Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Groundtruth Path" /></td>
<td><img src="image2" alt="Dead Reckoned Path" /></td>
<td><strong>Dataset A1</strong></td>
<td>RFID-based Ranging</td>
</tr>
<tr>
<td><img src="image3" alt="Groundtruth Path" /></td>
<td><img src="image4" alt="Dead Reckoned Path" /></td>
<td><strong>Dataset A2</strong></td>
<td>RFID-based Ranging</td>
</tr>
<tr>
<td><img src="image5" alt="Groundtruth Path" /></td>
<td><img src="image6" alt="Dead Reckoned Path" /></td>
<td><strong>Dataset A3</strong></td>
<td>RFID-based Ranging</td>
</tr>
<tr>
<td><img src="image7" alt="Groundtruth Path" /></td>
<td><img src="image8" alt="Dead Reckoned Path" /></td>
<td><strong>Dataset B1</strong></td>
<td>UWB-based Ranging</td>
</tr>
<tr>
<td><img src="image9" alt="Groundtruth Path" /></td>
<td><img src="image10" alt="Dead Reckoned Path" /></td>
<td><strong>Dataset B2</strong></td>
<td>UWB-based Ranging</td>
</tr>
</tbody>
</table>

Table 1: Plot and description of the different datasets. The numbers next to each node in the groundtruth figure presents the number of measurements received by the robot to the node.
2.1 System Setup

In this section, the system setup for the two different ranging systems are described.

2.1.1 Dataset A: The Golfcart

In our first system, we use a radio tag system (Pinpoint) [Werb and Lanzl, 1998] to measure range between stationary RF tags (see Figure 1(a)) and a moving transponder equipped on an autonomous golfcart. The radio transponder with its 4 antennae are mounted on the four corners of the robot. The transponders send a “chirp”, and any tag that receives that signal responds with its unique ID. The range from the transponder to the tag is then estimated based on the elapsed time between the transmitted “chirp” and the received response.

The radio transponder electronics are mounted on the robot with its 4 antennae mounted on the four corners of the robot (see Figure 1) and pointing in four directions. The robot was also equipped with a computer that controlled the tag queries and processes their responses. For each tag response, the system produces a time-stamped distance estimate to the responding tag, along with the unique ID number of that tag and the ID of the antenna that received the response. The distance is an estimate of the distance between the specific receiving antenna on the robot and the beacon. Since the antennae are not co-located at the center of the robot, it becomes critical to know the robot’s heading angle in order to determine it’s position. During data collection, the RF tags are placed atop traffic cones approximately 45.7 cm above the ground. A total of seven RF beacons were distributed throughout the area, and then the robot retraced the path among the beacons guided by RTK GPS.

2.1.2 Dataset B: The Lawn Mower

Our second system utilizes ultra-wide band radio nodes from Multispectral Solutions to provide range measurements [MSSI, 2008]. The ranging radios are equipped with an omni-directional antenna, thus enabling a 360° ranging capability. These sensors use time-of-arrival of ultra-wide band signals to provide inter-node ranging measurements through walls. Once again the system produces a time-stamped distance estimate to the responding node, along with the unique ID number of that node and the ID of the node that received the response. While this system is capable of measuring range between any pair of nodes, in our experiments only measurements between the mobile robot and the stationary nodes are computed. During data collection, the radio nodes are placed atop traffic cones approximately 138 cm above the ground.
Figure 1: (a) Depicts the scale of the RF beacon used in our work. (b) The autonomous golfcart along side traffic cones holding the beacons. (c) and (d) reveal the antenna setup on the golfcart which is critical to computation of the corrected range measurement to the robot’s coordinate frame from the range reported by the antenna.

Four of these radio nodes were placed around the environment, and one was placed on the robot. The node that is placed on the robot is placed directly on top of the center of the robot’s coordinate frame.

Figure 2: (a) Shows the UWB radio nodes used in our work. (b) The autonomous lawn mower.
Additionally, the stationary nodes were also placed on top of traffic cones at the same height as the node on the robot, thus removing the need to perform any coordinate transforms to align the odometry with the range measurements. Figure 2 shows the lawn mower robot used in our setup along with the ultra-wide band ranging radio.

3 Range Data Characterization

3.1 Range Data

3.1.1 Dataset A: RFID System

Each time the robot logs a range measurement during one of our experiments, we can determine the error in that range, since we know the true location of the robot (to within 2cm) and of the stationary tags (from surveying with GPS). Figure 3 shows plots from an example dataset of the measurements against true ranges using these RF tags and their associated variances. The solid line in Figure 3(a) corresponds to the $y = x$ line, when the measured range measurements are equal to the true measurements. Figure 3(b) shows that the variance of observed range measurements varies significantly based on range, thus making the range data challenging to model and use.

![Figure 3](image)

Figure 3: RFID Ranging System: (a) A set of measured ranges plotted against the true measurements. The solid line represents the ideal case when the measured range equals the true range. (b) the variance associated with various measured ranges. The particular characteristics of the sensor and the non-uniform variance (uncertainty) in the range measurements can be observed.

**Antenna Specific Characteristics**: Directional information obtained from the robot’s ground truth system allows us to observe the noise characteristics of the range measurements in relation to the incidence
direction of the beacon to the antenna surface. Figure 4 presents the polar plot of the range error observed for measurements received from various directions for one of the four antennae on the robot. Each of the four antennae mounted on the robot, although rated as a directional antenna, displays a wide angle characteristic. Due to their near omni-directional range characteristics, we find that it might be beneficial to model each antenna as fully omni-directional ranging sensors.

![Polar plot of relative angle and absolute range error](image1)

**Figure 4:** Polar plot showing the absolute range error and the beacon’s relative angle to the antenna (computed from ground truth), for one of the four antennae on the golfcart. As can be observed, the antenna has an almost 360° field of view, making any angle of incidence based noise modeling unnecessary.

![Polar plot of relative angle and absolute range error](image2)

**Figure 5:** Polar plot showing the range error and the beacon’s relative angle to the antenna (computed from ground truth), for the omni-directional antenna on the ultra wide-band radios. As can be observed, the antenna has an almost 360° field of view, making any angle of incidence based noise modeling unnecessary.

### 3.1.2 Dataset B: UWB System

Once again for the second ranging system we can use the GPS groundtruth data to compute the error in the range data. Figure 6 shows plots from an example dataset of the measurements against true ranges using the UWB ranging radios and their associated variances. The solid line in Figure 6(a) corresponds to the $y = x$ line, when the measured range measurements are equal to the true measurements. Figure 6(b) shows that the variance of observed range measurements is more or less constant.

**Antenna Specific Characteristics** : Directional information obtained from the robot’s ground truth system allows us to once again characterize the error in the range measurements in relation to the incidence direction of the beacon to the antenna. Figure 5 presents the polar plot of the range error observed for
measurements received from various directions for the omni-directional antennae on the radio. As can be expected error is uncorrelated to direction of incidence, thus there is no need for incorporating angle based noise characterization.

Figure 6: UWB Ranging System: (a) A set of measured ranges plotted against the true measurements. The solid line represents the ideal case when the measured range equals the true range. (b) the variance associated with various measured ranges. The particular characteristics of the sensor and the non-uniform variance (uncertainty) in the range measurements can be observed.

4 Data Access and Interpretation

The data are available for download from http://www.frc.ri.cmu.edu/projects/emergencyresponse/RangeData. To ease the use of the dataset, we have also supplied a Matlab readable *.mat file for each dataset consisting all the data parsed into individual array structures. The website also links to additional technical articles (such as [Djugash and Singh, 2008] and [Djugash et al., 2005]) that have utilized these datasets to demonstrate the utility of various localization, tracking, and mapping methods.

Acknowledgments

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References


