AN ABSTRACT OF THE THESIS OF

Sean Robert Connell for the degree of Honors Bachelor of Science in Electrical and Computer Engineering presented on May 31.

Title: A Personal Dead Reckoning RFID Waypoint Updated System for Footstep Level Resolution Path Tracking to Enable Research Into Early Diagnosis of Alzheimer's

Abstract approved: ____

Dr. Chiang

The problem of footstep level resolution indoor path tracking and gait velocity lacks a good solution. The current solutions are either prohibitively expensive [4], extremely invasive to deploy [1], or too inaccurate to achieve the sub meter level resolution required to track foot paths. By combining existing pedestrian dead reckoning (PDR) using an inertial measurement unit (IMU) techniques with radio frequency identification (RFID) location updates, one can solve the problem of indoor path tracking. RFID tags placed in the building act as waypoints to correct the error that accumulates over time with PDR, thus yielding a system that can be used for arbitrary amounts of time with a resolution high enough to track individual footsteps.

Key Words: Dead Reckoning, Location Tracking, In Home Monitoring, Alzhiemer's

Corresponding e-mail address: seanrobertconnell@gmail.com

A Personal Dead Reckoning RFID Waypoint Updated System for Footstep Level Resolution Path Tracking to Enable Research Into Early Diagnosis of Alzheimer's

by

Sean Robert Connell

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APPROVED:

Mentor, representing Electrical and Computer Engineering

Committee Member, representing Electrical and Computer Engineering

Committee Member, representing Electrical and Computer Engineering

Dean, University Honors College

I understand that my project will become part of the permanent collection of Oregon State University, University Honors College. My signature below authorizes release of my project to any reader upon request

Sean Robert Connell, Author

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DEDICATION

To all those who work tirelessly to advance human knowledge and ability.

PREFACE

This project was originally created as a research collaboration between OSU and OSHU. It has since become my senior design project as well as my honors thesis. I worked primarily to design, build, and program the system that this data was collected with. The post processing of the data uses recently developed filtering techniques. These are however, not novel to the project and were not my part of the project. As such, I leave them out of the discussion and focus mainly on the abilities and potential applications of the device.

Chapter 1 – Introduction

By 2030, it is estimated that there will be 72.1 million US citizens over 65+ years of age, based on information from the Administration on Aging. As a large portion of the population ages, it is important to ramp up health-care systems to meet this growing need. One method is early diagnosis and prevention of common diseases. Alzheimers will effect roughly 10% of the population over 65 and thus is a primary candidate for early diagnosis. [8] Researchers at OHSU in the Point of Care Laboratory (POCL) are attempting to correlate certain walking patterns and developing Alzheimer's as well as other similar neurological diseases. There has been research that shows this is a promising method for the early detection of Alzheimer's. [6] This provides a clear need for footstep level resolution indoor path tracking solutions. These devices will enable research into how long term foot path patterns and gait velocity correlate to Alzheimer's onset. [3]

Chapter 2 – Thesis Statement

Medical research into walking pattern based diagnoses has thus far been restricted by the lack of sensors capable of gathering the resolution of data required; A foot mounted IMU fused with an RFID reader and passive RFID tags is one possible solution for long term position tracking.

Chapter 3 – Design Goals

This device was created for research purposes, and because of this had somewhat vague requirements. However, we knew that we needed to achieve a battery life on the order of days to make the system feasible for long term use, and resolution high enough to track individual footsteps in a path. Further more, the cost was to be lower than a similar time of flight system we had considered developing, which was a few thousand dollars, as well as other purely dead reckoning IMUs, which range from hundreds to thousands of dollars. From these considerations, we developed three design goals.

- Battery life greater than one day, preferably a week.
- Resolution high enough to track footsteps.
- Cost lower than $ 400.

Chapter 4 – System Overview

4.1 Physical Device

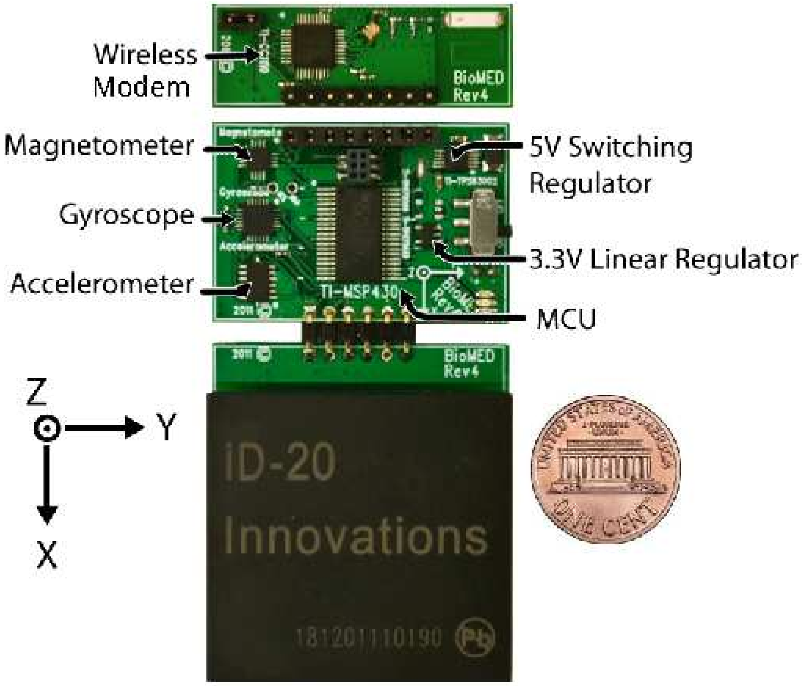

Figure 4.1: IMU/RFID prototype device.

4.2 Block Diagram

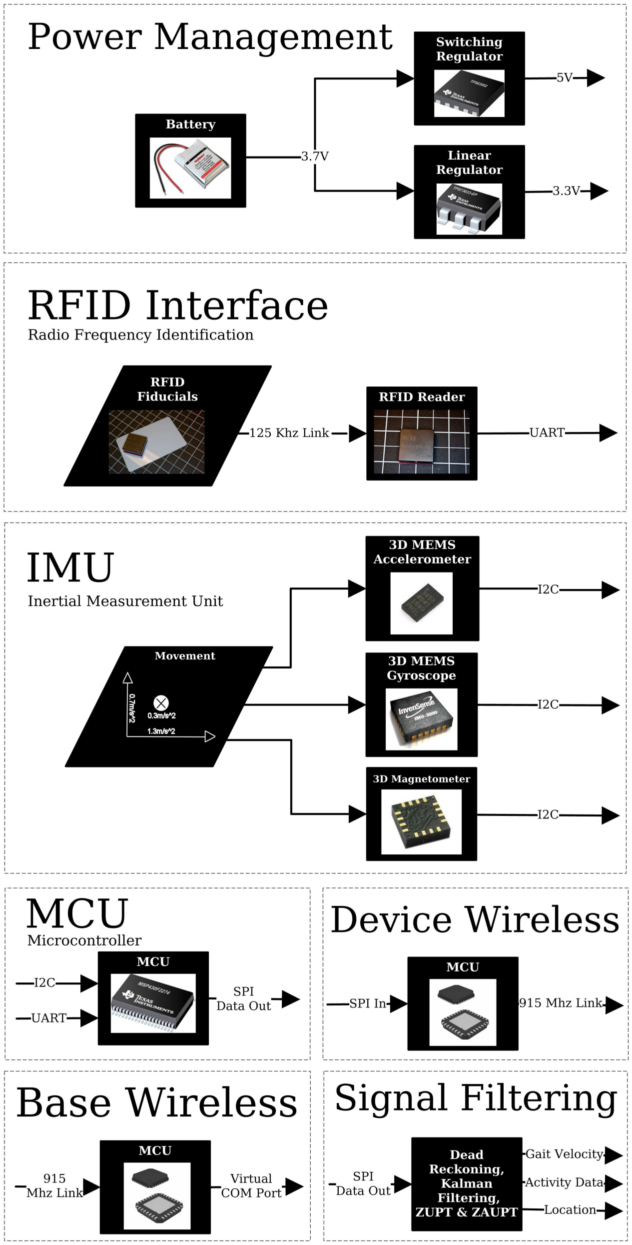

Figure 4.2: System Block Diagram.

The protoype IMU/RFID device is shown in Fig. 4.1. The size of the device (without battery) is 8cm by 4cm by 1cm at the tallest point.

4.2.1 IMU & Role of Sensors

The IMU consists of a three inertial sensors: A tri-axial accelerometer, gyroscope, and magnetometer. Together, these sensors provide information about the orientation and forces experienced by the device.

The accelerometer provides accelerations, the gyroscope provides rotational velocity, and the magnetometer provides magnetic field strength. The gyroscope and magnetometer act to detect the orientation of the device. Integrating the gyroscope data gives change in oreintation, and ideally the magnetometer gives an absolute reference of the device against the Earth's magnetic field. The accelerometer gives acceleration from movement as well as gravity.

The accerlation data is combined with the known platform oreintation to remove the effects of gravity from the sensor readings. This is then double integrated vs. time to produce location data.

4.2.2 MCU

The microcontroller coordinates sensor readings and sends them to the wireless modem to be relayed back to the base station at a computer for processing. It was chosen with low power requirements in mind, as well as for the hardware interfaces it needed to have.

4.2.3 Wireless Modem

The wireless portion of the device allows unobtrusive constant data monitoring. It consists of a device side wireless modem and computer side base modem. These operate on the 915 MHz ISM band. This band was chosen to help alleviate propogation problems with the more common 2.4Ghz band near human bodies. [2]

4.2.4 RFID Interface

The RFID reader reads tags in the enviroment to provide waypoint updates to the device. It operates on the standard RFID 125Khz range for passive tags.

4.2.5 Power Management

The device uses a switching regulator to generate the neccesary 5 volts for the RFID reader from a 3.7V lithium ion cell. It also includes a linear regulator to provide the 3.3V required by the main MCU, the wireless, and the IMU sensors.

4.3 Sensor Axis & Orientation

Ignoring the relatively small distance between the sensors, they can be assumed to be on the origin of a coordinate system with the positive X direction below the device, the positive Y direction to the right of the device, and the positve Z direction out of the page above the device. In reality, they are truly coaxial only along the X axis.

4.4 Battery Life

The device consumes a nominal 70mA. Coupled with a reasonably sized li-ion cell of 2.2Ah, it can be expected to last around 32 hours. This is about two days of active use, as the device is not worn at night.

4.5 Cost

This device uses consumer grade commercially available parts; this results in a low total system cost in the sub $ 100 range. Again, because the magnetometer ended up being unreliable, future revisions of the device will not incorporate it. Thus it is not included in the table. See table below for system costs.

Table 4.1: Device Components

Analog Devices ADXL345	
Description	Three-axis Accelerometer
Cost	6.16 USD
Detection Range	± 16 g
Power Consumption	35 μw

Invensense IMU3000	
Description	Three-axis Gyroscope
Cost	15.00 USD
Detection Range	± 1000 dps
Power Consumption	13 mw

ID Innovations ID-20	
Description	125 kHz RFID Reader
Cost	34.95 USD
Detection Range	≈ 10 cm
Power Consumption	<150 mw

Texas Instruments MSP430	
Description	Micro-controller
Cost	7.35 USD
Power Consumption	590 μw

Texas Instruments CC1110	
Description	Wireless Interface
Cost	2.75 USD
Power Consumption	45 mw active

Chapter 5 – Device Testing Methedology

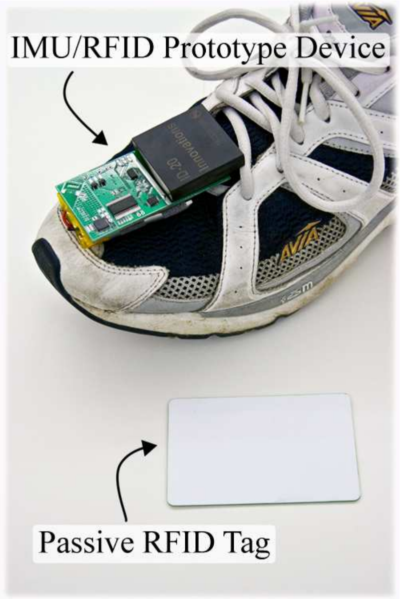

Figure 5.1: Equipped device next to an RFID tag waypoint.

5.1 Path Accuracy

In order to characterize the device, multiple runs were done in known configurations then processed with and without RFID waypoints. The paths were simple to allow accurate error estimations, and were straight lines that turned at set points. It is very difficult to accurately record a path if it doesn't consist of simple elements like lines. Because of this, these types of paths were omitted in the interest of lucid results. Closed loops were chosen to make drift at the closed end of the path easy to measure and detect.

The path tests consisted of a subject walking normally with the device attached to the top of their right foot in a predefined path. During this path, inertial data was collected from the device. It was then later processed to calculate path data. There is no accepted standard or absolute measure for activity level, so this was not included in the post processing.

The error was calculated by subtracting the calculated path from the closest real path. This gives a much rougher idea of the error, becuase if the path drifts to the other side of the circular path, the error seemingly drops. Therefore, I include these plots as a comparison of with and without waypoint updates, and less as an absolute measure of error. This method of error calculation was required because of the lack of another more accurate device to compare our data against.

5.1.1 Rectangular Path

This path consisted of a rectangular circuit with sides of 5 by 5 meters. RFID tags were placed at the corners.

5.1.2 Hourglass Path

This path consisted of a more complicated path with the same RFID tag locations as Path 1. The path consisted of diagonal cuts across the center followed by a side of the rectangle, making somewhat of an hourglass shape.

Chapter 6 – Results

The following plots show the reconstructed paths both with and without RFID waypoint updates. Note that the scale is in meters.

6.1 Path 1: Rectangular Path in Kelley Engineering Center

6.1.1 Plots of Runs

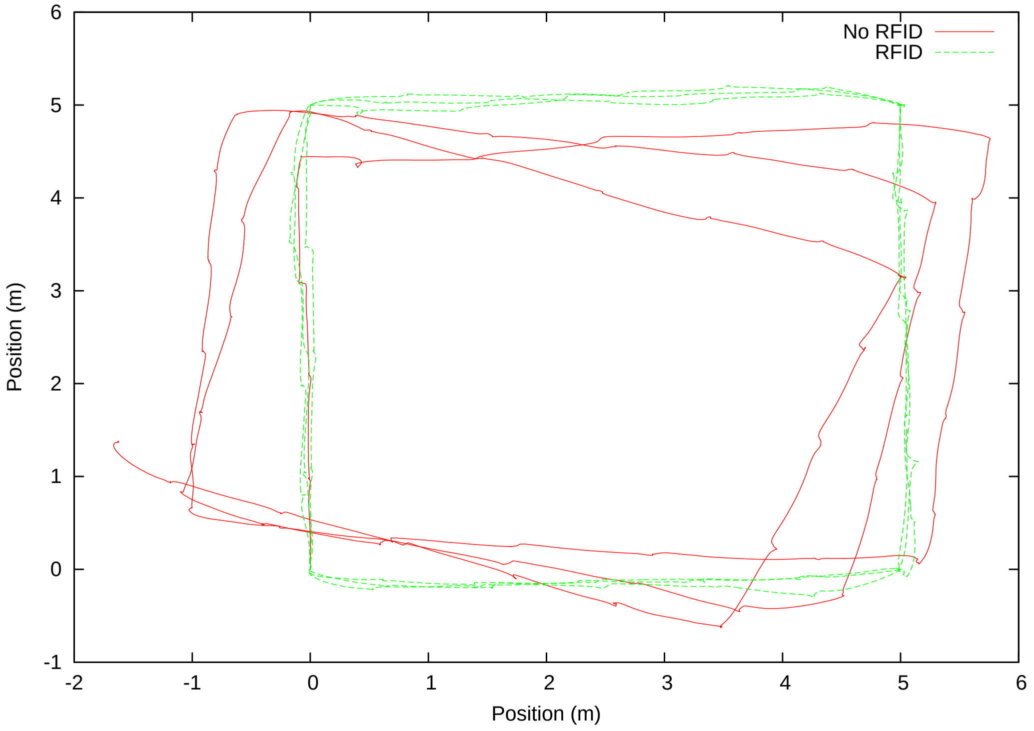

Figure 6.1: Rectangular path run 1 with & without waypoint updates.

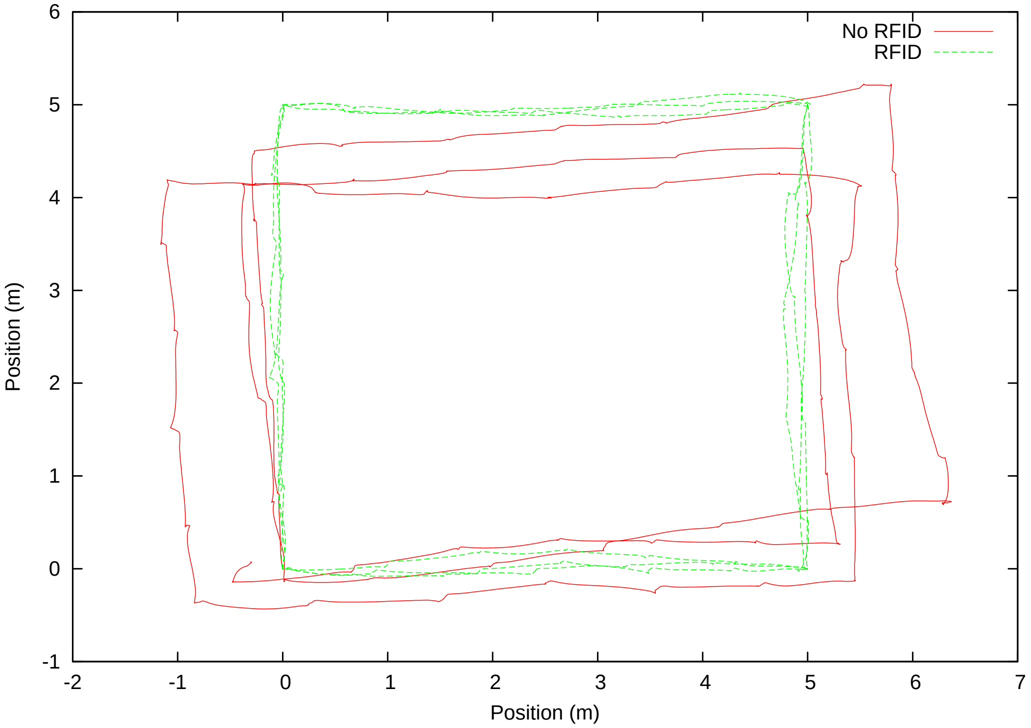

Figure 6.2: Rectangular path run 2 with & without waypoint updates.

6.1.2 Error Over Time of Rectangular Path Run 1

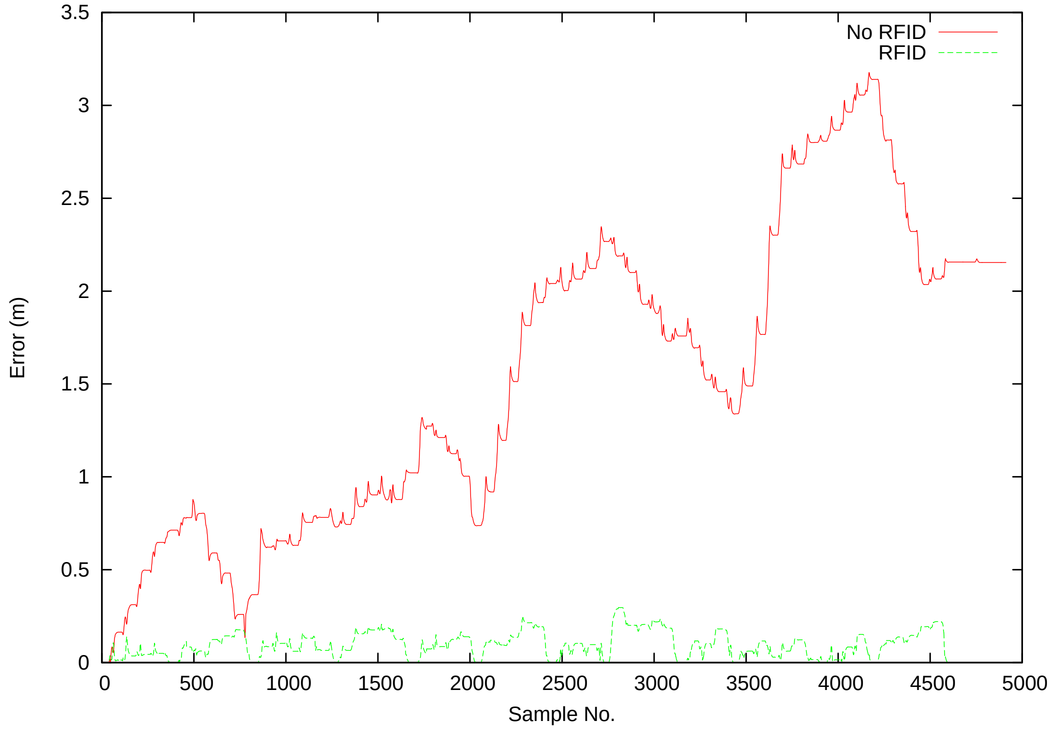

Figure 6.3: Error over time.

Average error without waypoints: 1.525 meters

Average error with waypoints: 9.011e-2 meters

6.1.3 Error Over Time of Rectangular Path Run 2

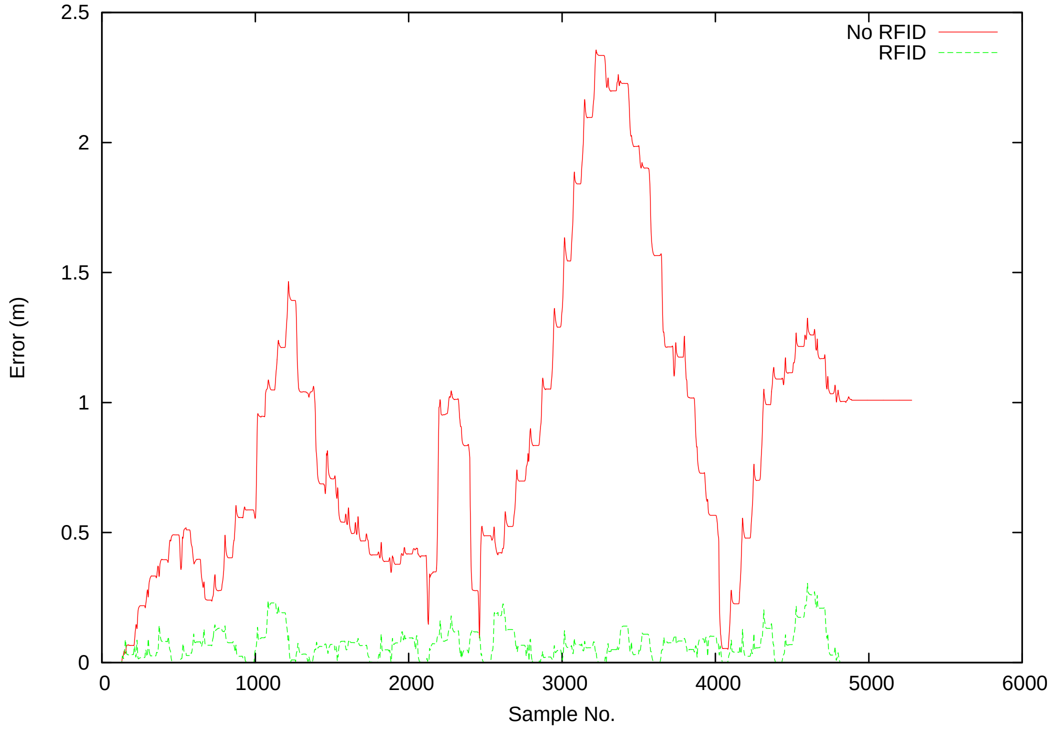

Figure 6.4: Error over time.

Average error without waypoints: 0.861 meters

Average error with waypoints: 6.294 e-2 meters

6.2 Path 2: Hourglass Path in Kelley Engineering Center

6.2.1 Plots of Runs

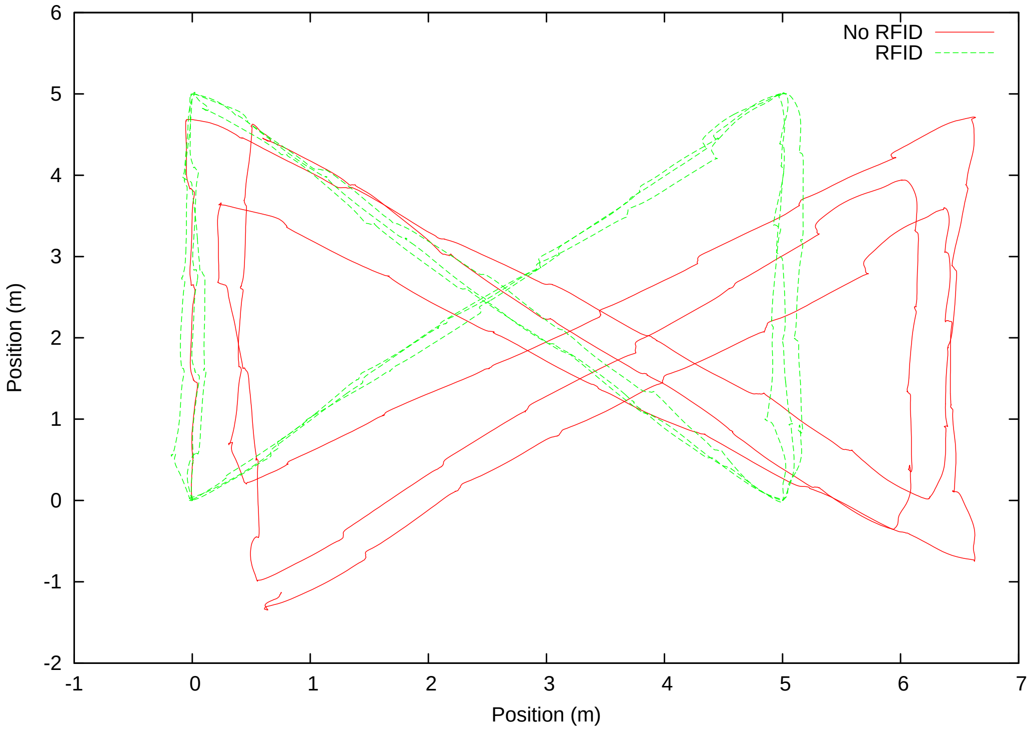

Figure 6.5: Hourglass path run 1 with & without waypoint updates.

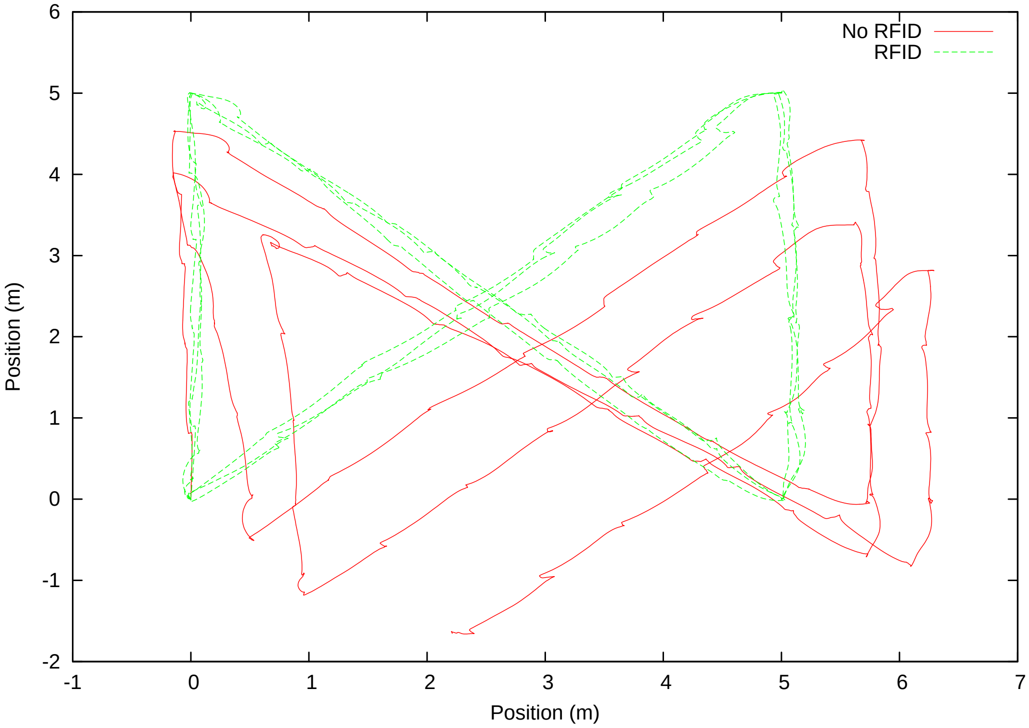

Figure 6.6: Hourglass path run 2 with & without waypoint updates.

6.2.2 Error Over Time of Hourglass Path Run 1

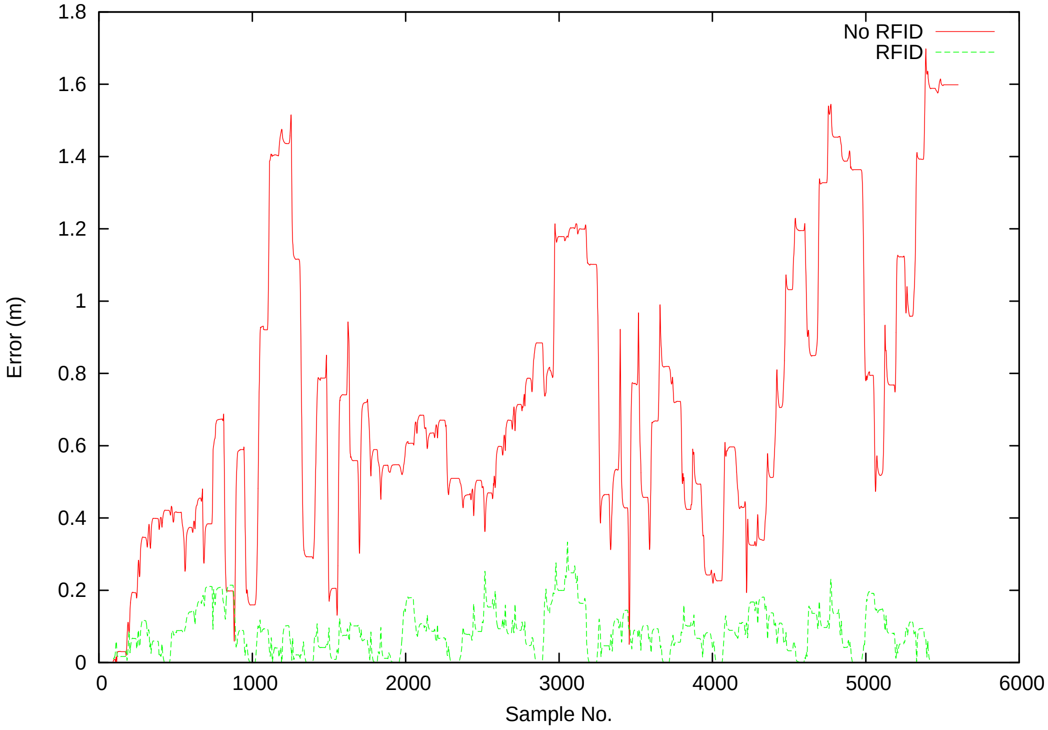

Figure 6.7: Error over time.

Average error without waypoints: 0.705 meters

Average Error with waypoints: 8.060 e-2 meters

6.2.3 Error Over Time of Hourglass Path Run 2

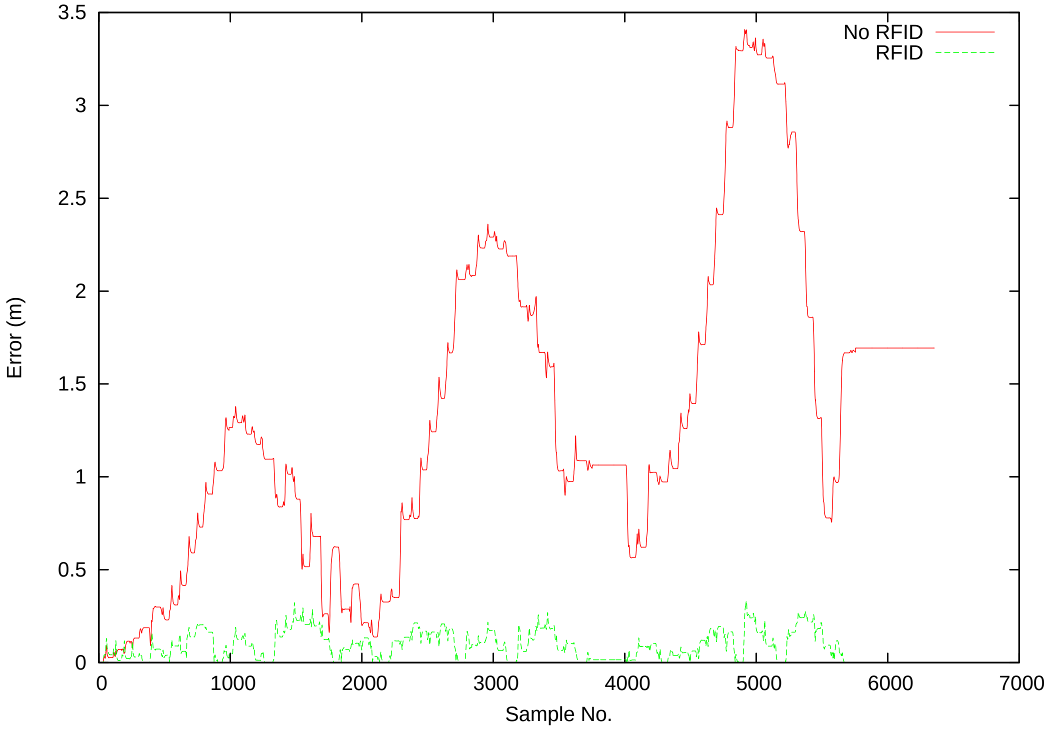

Figure 6.8: Error over time.

Average error without waypoints: 1.302 meters

Average Error with waypoints: 8.710 e-2 meters

Chapter 7 – Design Implementation

The original design goals were all met.

- Battery life of 2 days.
- Footstep level resolution.
- Cost in the sub $ 100 range.

Chapter 8 – Discussion

8.1 Data

As the data shows, the position data tends to drift over time. This is a well known problem with dead reckoning because of the relative nature of the process. [5] The MEMS gyro also exhibits a greater zero rate output drift than more expensive and larger sensors. This problem with the device is however fixed by RFID waypoint updates, as can be seen in both the path plots and the error plots. Without RFID waypoint updates, the path and error diverge from the real path. With updates however, they remain within a bound determined by the frequency of updates.

Another problem that we experienced was noise in the magnetic fields measured by the magnetometer. In many cases, it was difficult to pick out the Earth's magnetic field, making the magnetometer useless for the task of orientation tracking. Because of this, it was not included in the filtering algorithms.

8.2 Device Applications

This project has enabled new research into gait velocity related illnesses. The low cost and high accuracy of the data are unlike anything currently in existence, and present exciting new possibilities. Where other sensors provide at best a room level delineation, or very imprecise location estimates, this device provides on the order of a meter of accuracy for the path, and with low jitter. Where other devices cost multiple thousands of dollars, this device uses inexpensive sensors and achieves a sub $ 100 cost, making it ultra low cost in terms of medical sensors. This device can simultaneously provide three dimensional location and activity levels, all through a wireless link with a data rate of 50Hz for two days before requiring recharging. As the device is foot mounted the resulting path information also represents gait velocity data, because the device is accurate over short periods of time from step to step. The applications that are currently being investigated are clinical trials, and long term research.

There is great potential for this device in clinical trial settings. Clinical trials attempt to collect as much data as often as possible about anything that could be correlated to changes based on the treatment or drug trial. Usually this consists of invasive monitoring as with an EEG, or infrequent sampling, like with blood samples. Very few trials have the luxury of continuous data. This device allows for such data, and activity data is generally applicable to most drug trials. The added benefit of location permits tracking of where those activity levels took place, which is also helpful for categorizing the activity data.

Another potential use of this device is in long term trend monitoring. Because of the ease of use and relatively low impact the device has, it is feasible that it could be used for longer term studies of not just weeks as in clinical trials, but also months or perhaps even years. The device could be built into a house slipper that charged on an inductive mat. This would be almost transparent to the user and could provide data over long trials looking for shifts in patterns of behavior or walking patterns. This has applications to dementia research, and could lead to better early detection and diagnosis of Alzheimer's.

As discussed, this device has applications to research in health-care and health-care solutions. As such, it is a universally useful tool of study, and presents great opportunity to the health-care industry as a whole.

Chapter 9 – Future Work

The current revision of the device implements the set specifications, but could be improved in a number of ways:

- Changing from the pre-built RFID reader to a more controllable IC based solution to further lower power consumption and increase battery life.
- Addition of a bluetooth modem to allow tethering to smartphones for data relay and display.
- Inclusion of this system into a larger body area network of sensors to create a monolithic biosignals collection system.
- Field testing for the optimal number of RFID tags to achieve the desired path accuracy needs to be done to characterize the difficulty of deploying the device.

Chapter 10 – Concluding Remarks

This project has shown me not only the way that research and the topic selection therof occurs, but also the state of the medical device community. Currently, there is an unsettling large divide between the engineers who create devices and the medical practitioners who use them. If future devices are to be succesfull, they will require a cross disciplinary approach with tight feedback and excplicit requirements.

I believe this project has met its specified goals by offering footstep level tracking resolution, acceptable battery life, and a low unit cost. It has a lot to offer the medical community it was tailored to. I hope that future engineers who venture into the burgeoning field of biomedical engineering realize and focus upon the importance of good communication with the medical community. I know I will.

APPENDICES

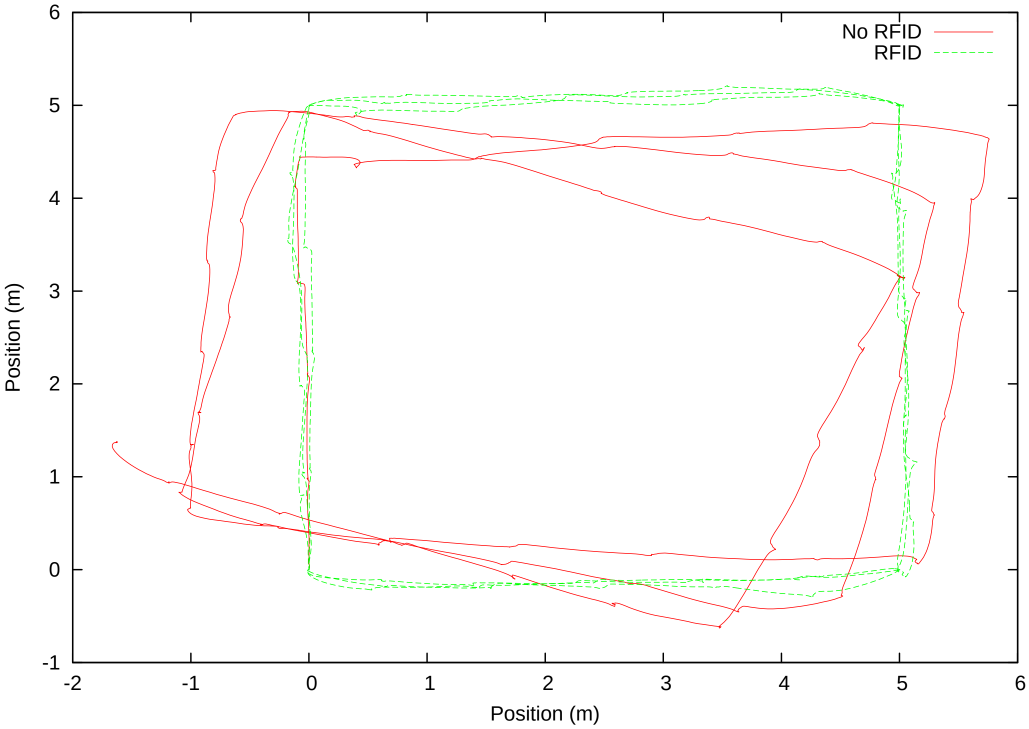

Figure 1: Rectangular path run 1 with & without waypoint updates.

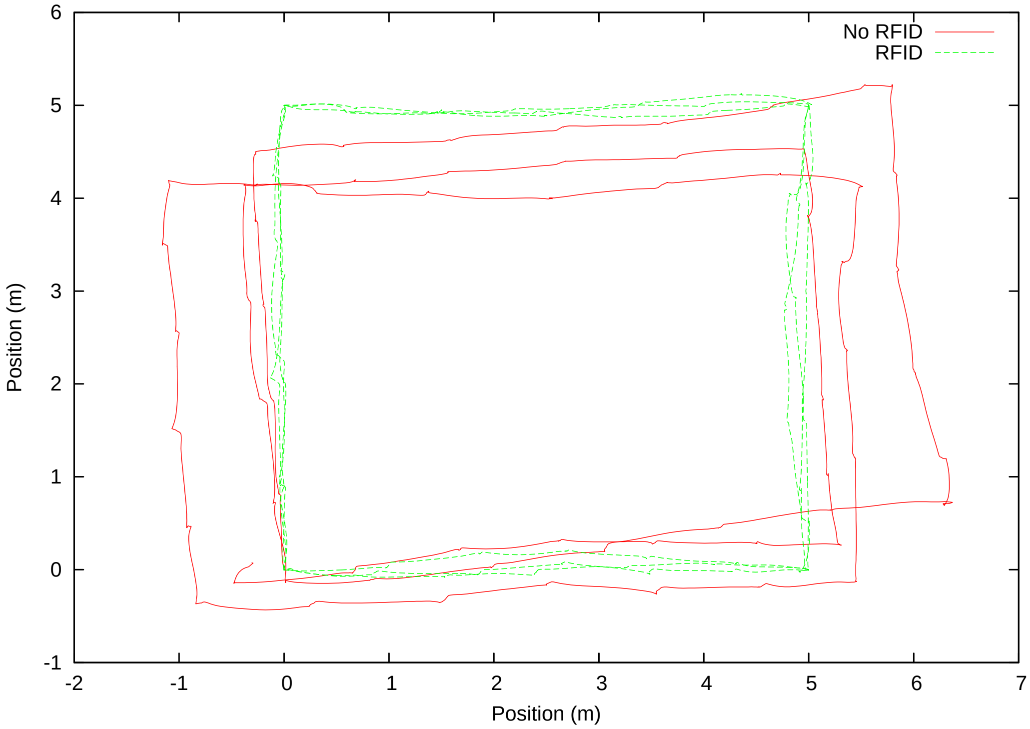

Figure 2: Rectangular path run 2 with & without waypoint updates.

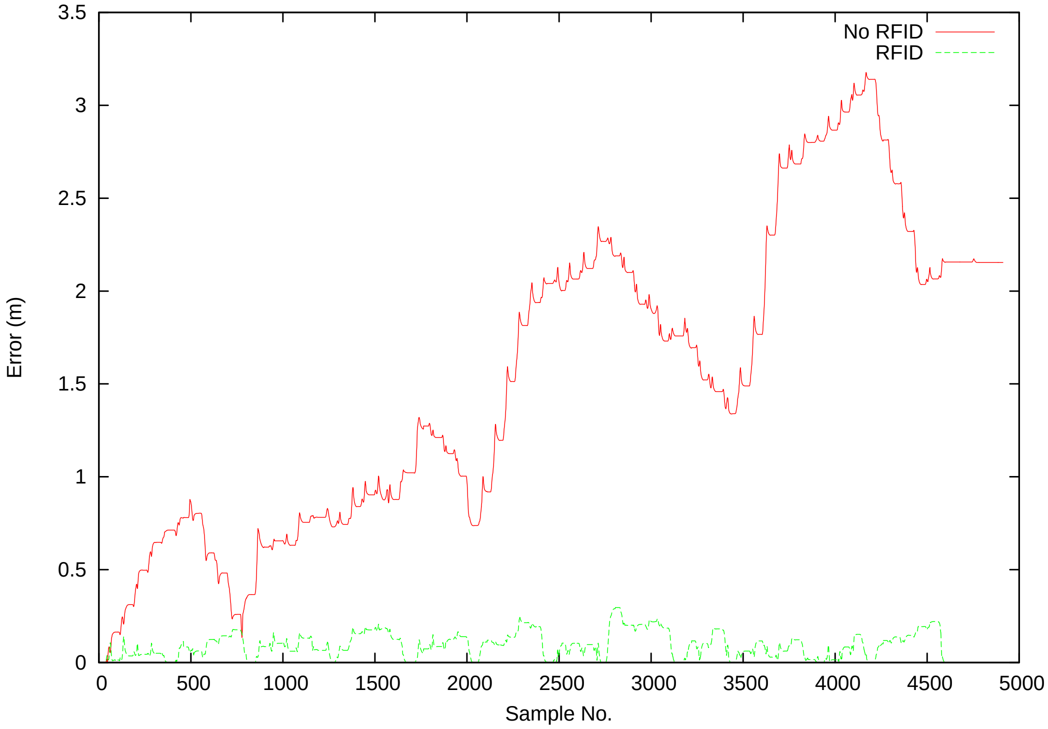

Figure 3: Error over time.

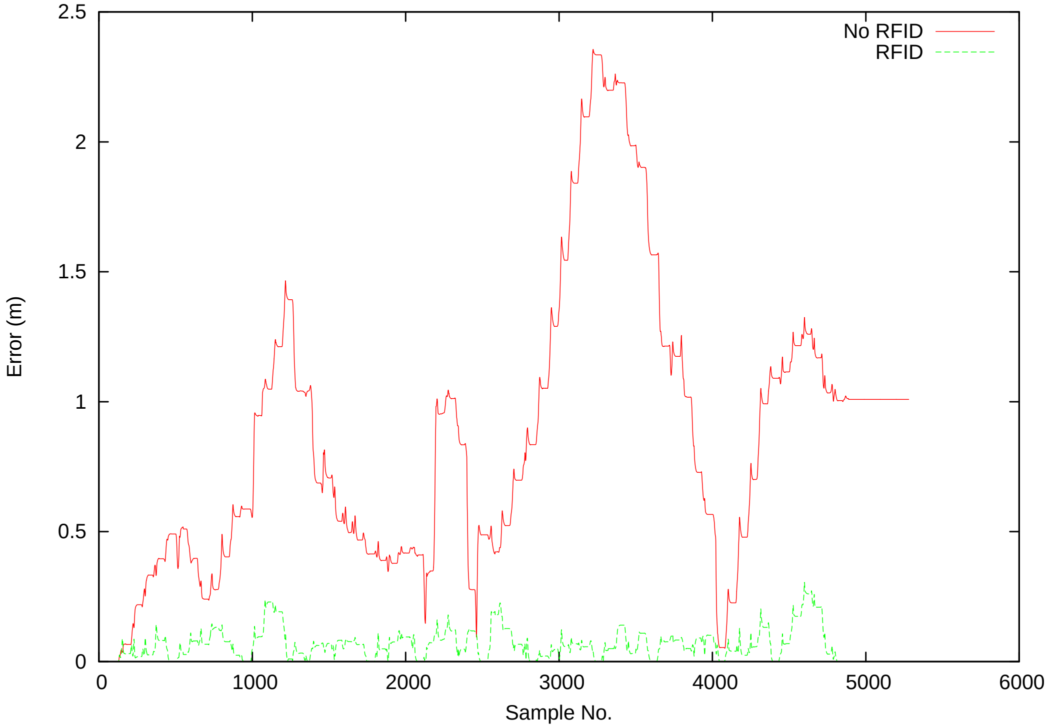

Figure 4: Error over time.

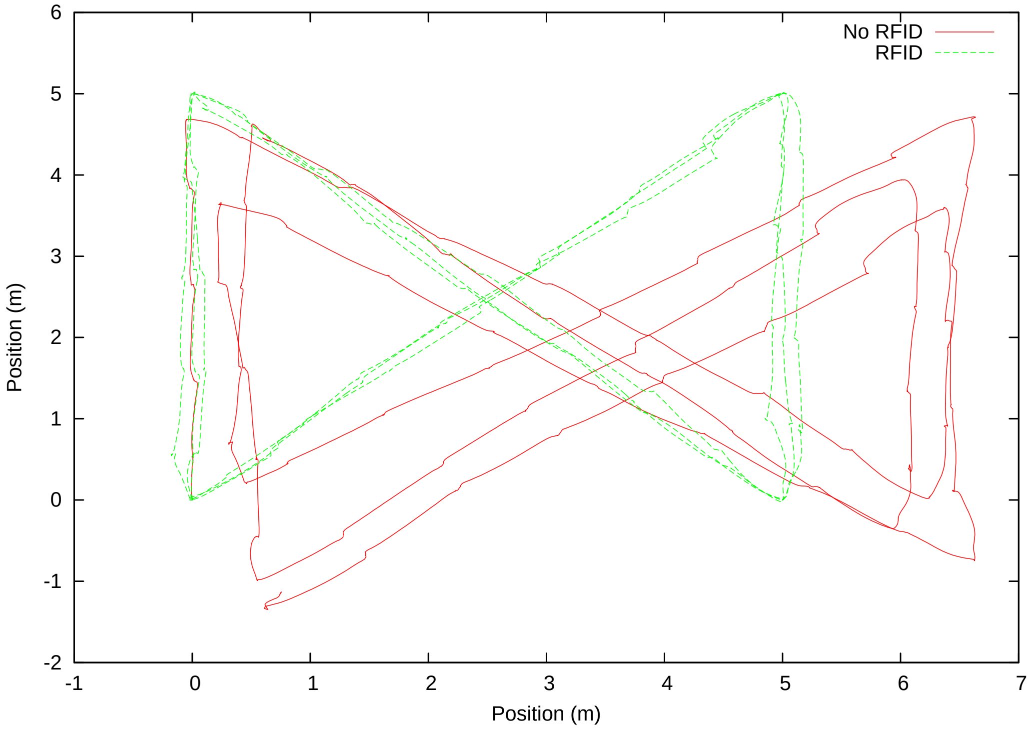

Figure 5: Hourglass path run 1 with & without waypoint updates.

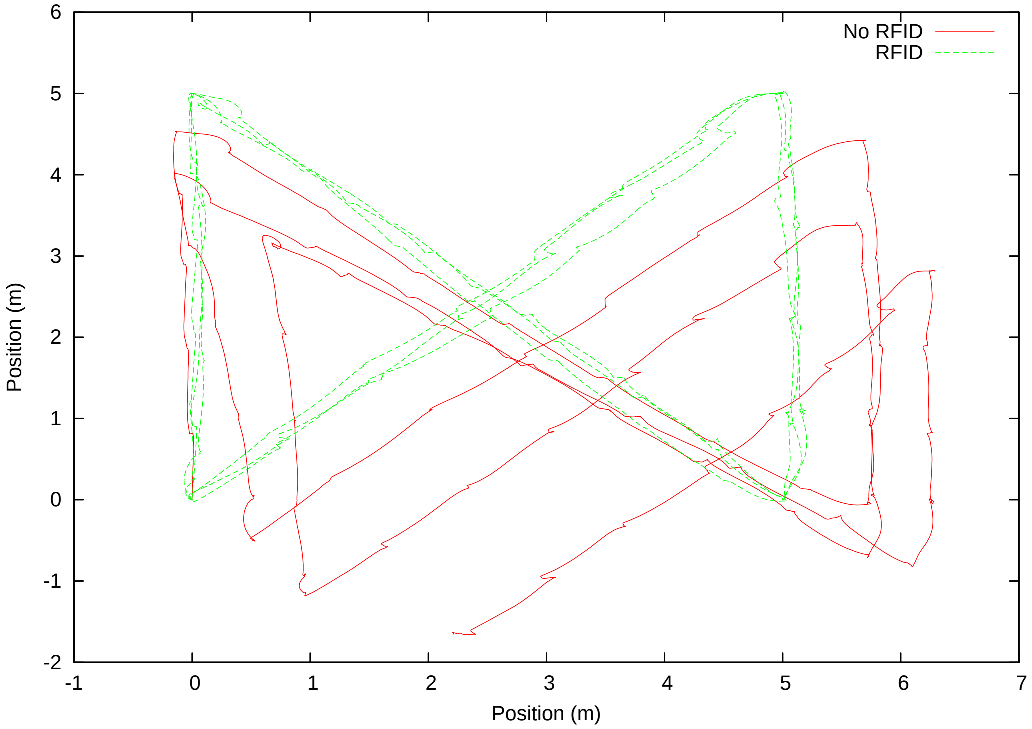

Figure 6: Hourglass path run 2 with & without waypoint updates.

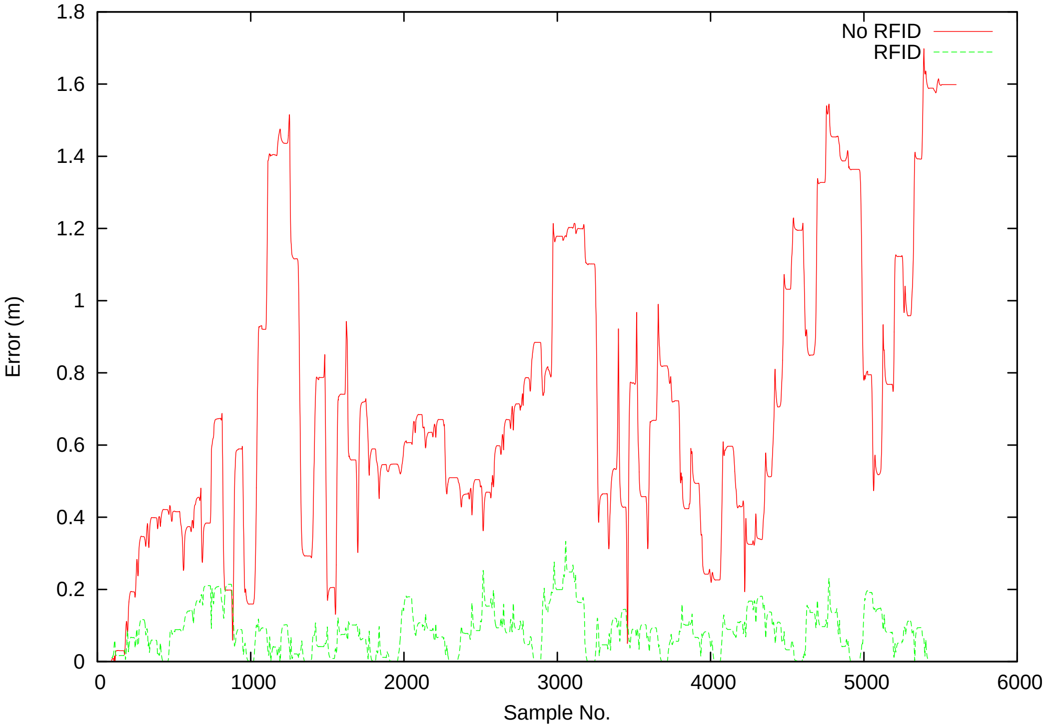

Figure 7: Error over time.

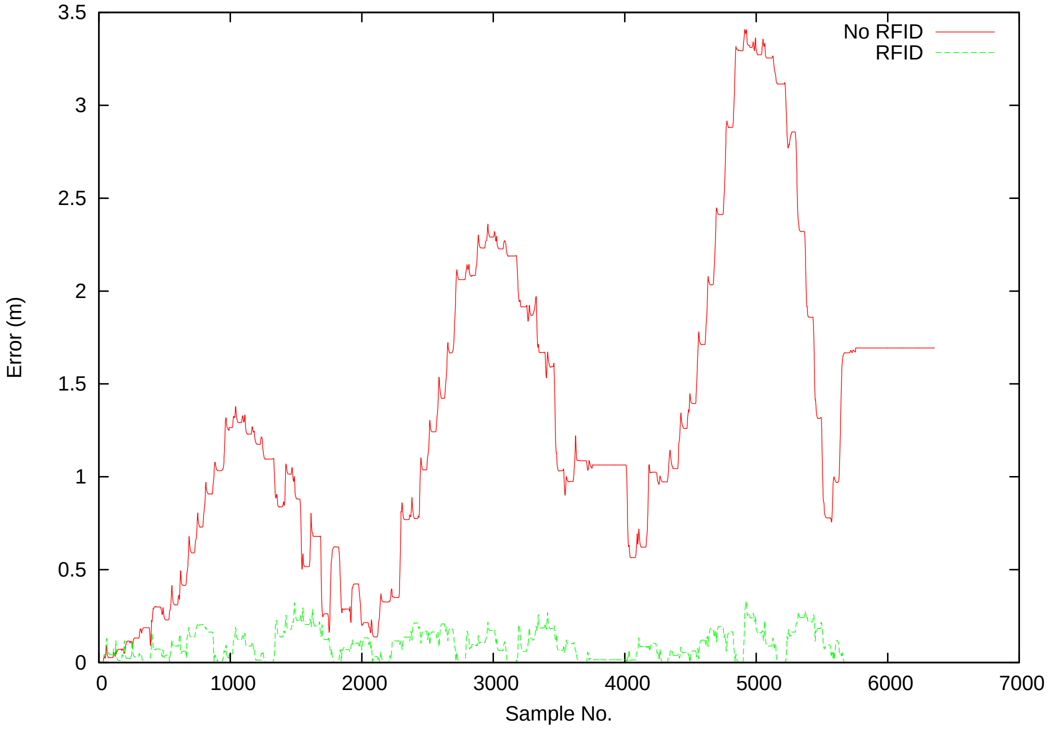

Figure 8: Error over time.

Appendix A – Bibliography

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