Contextual Computing: Tracking Healthcare Providers in the Emergency Department via Bluetooth Beacons

by

Joshua Frisby

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Graduate Supervisory Committee:

Brian C. Nelson, Co-Chair
Vimla L. Patel, Co-Chair
Vernon Smith
David R. Kaufman

ARIZONA STATE UNIVERSITY

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ABSTRACT

Hospital Emergency Departments (EDs) are frequently crowded. The Center for Medicare and Medicaid Services (CMS) collects performance measurements from EDs such as that of the door to clinician time. The door to clinician time is the time at which a patient is first seen by a clinician. Current methods for documenting the door to clinician time are in written form and may contain inaccuracies. The goal of this thesis is to provide a method for automatic and accurate retrieval and documentation of the door to clinician time. To automatically collect door to clinician times, single board computers were installed in patient rooms that logged the time whenever they saw a specific Bluetooth emission from a device that the clinician carried. The Bluetooth signal is used to calculate the distance of the clinician from the single board computer. The logged time and distance calculation is then sent to the server where it is determined if the clinician was in the room seeing the patient at the time logged. The times automatically collected were compared with the handwritten times recorded by clinicians and have shown that they are justifiably accurate to the minute.

DEDICATION

To my family and friends.

ACKNOWLEDGMENTS

Special thanks to Vernon D. Smith, MD and Mayo Clinic for providing the materials and the emergency clinical environment necessary to conduct the research for this thesis. Special thanks to the advisors and committee members of this thesis for meeting regularly, suggesting improvements to the project and/or thesis and improving the overall quality of this work. Special thanks to Maria Adela Grando, Ph.D. for reviewing literature for this thesis and contributing to written ideas toward the thesis.

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CHAPTER 1

INTRODUCTION

The Center for Medicare and Medicaid Services (CMS) requires that Emergency Departments (EDs) log and report certain performance measurements including the door to healthcare provider time for the patients. CMS is a federal agency that operates within the United States Department of Health and Human Services (DHHS) to administer the Medicare and Medicaid programs. An ED is a healthcare facility that provides emergency medical attention to patients without a scheduled appointment regardless of the medical attention they seek.

The need for the CMS performance measures is due to ED Crowding (“Agency for Healthcare Research and Quality,” 2014). ED crowding reduces patient privacy, results in less hospital revenue from the ED, and lesser patient care quality (“Agency for Healthcare Research and Quality,” 2014). ED crowding compromises the trust of the community. If the community expects long wait times and a lack of immediate medical care from the ED, then it can effect whether the community seeks out medical care in time of need. Efforts have been made to improve the workflow of the ED (“Agency for Healthcare Research and Quality,” 2014), including the documentation of ED time performance measures, but the current data collection methods for those measures are not automatic in nature and require extra work for the provider to document the time a patient is seen.

The door to clinician time is one of the performance measures that hospitals report to CMS. The door to clinician time consists of two collected times. The door time is collected at the time of patient data registration. The clinician time is the time at which a clinician sees a patient. The time from the door to the clinician time is determined by subtracting the door time from the clinician time which provides the total patient wait time. The patient time can potentially be used for analysis purposes for improving the healthcare system including the workflow and/or appropriate staff scheduling. The door to clinician time is the focus of this research which seeks to provide an automatic method of provider time documentation, while not interfering negatively with the ED workflow.

1.1 Objective

The objective of this thesis is to provide a method for determining the door to clinician time that is automatic, reliable, does not hinder the Emergency Department workflow and accurately calculates the door to clinician time.

1.2 Clinical Environment

What is an ED in a hospital and what is its role in the healthcare system? A hospital ED provides initial treatment of patients in time of emergent need. The ED environment is complex and linear methods of data capture are not sufficient. Each ED staff member provides an important role in the execution of tasks in the clinical workflow, which is the systematic execution of tasks in the clinical environment. Physicians oversee residents, determine diagnoses and provide prognosis and prescription to the patient. Nurses observe patients, perform diagnostic tests, administer treatments and consult with other medical staff. These are a couple of examples of staff and how they contribute to the clinical workflow.

The clinical workflow is influenced by the conditions of patients and the particular treatments that patients require. The door to clinician time is integral to the clinical workflow since it is the time that a patient must wait to receive care from a clinician. If a reduction in that time is able to be achieved through analysis of said time, then it is beneficial to the patient as well as the healthcare system.

For the purpose of this research a tertiary care teaching hospital ED was utilized. The ED has 24 rooms with a capacity of up to 9 hallway stretchers when ED volume is reaching its limits, stretchers are available and not in use and the necessary nursing staff is available. Board-certified emergency physicians staff the ED 24 hours a day. The hospital is a teaching hospital, but it does not have an emergency medicine residency training program. However, residents from other services rotate through the department and assist in the evaluation of ED patients.

1.3 Challenges

Several challenges are expected to fulfill the objective and these are discussed below.

- There are no tracking methods in place in the ED.
- Current method of recording door to clinician time is not automatic.
    - Times are not reliable
    - Collection inaccuracies of the door to clinician time are possible

1.4 Contributions

Use of a sensor-based tracking method for collecting the "door to clinician" time automatically, reliably, accurately, all while being considerate of the ED workflow, is the main contribution of this thesis.

1.5 Solution Approach

As the research objective states, the intent is to provide a method to determine the door to clinician time that is automatic, accurate and reliable. A 24 Bed ED in an urban setting is where the research for this thesis was conducted and the solution applied. This ED was selected for testing of this approach because this ED did not already have a Bluetooth based clinician tracking system implemented. Figure 1.1 below provides a visual of the components and how they are related to one another in the tracking system. A system of single-board computers individually named "Raspberry Pi" (Raspberry Pi Foundation, 2015) were used to detect the position of clinicians in an ED in a tertiary care teaching hospital in Phoenix, Arizona. Raspberry Pi computers offer a good platform for the system due to their inexpensive cost of $35 each. Clinicians carry Estimote (Estimote, 2015) Bluetooth beacons that signal their location to the Raspberry Pi machines. In essence, the beacons act like a miniaturized lighthouse for the machines to see.

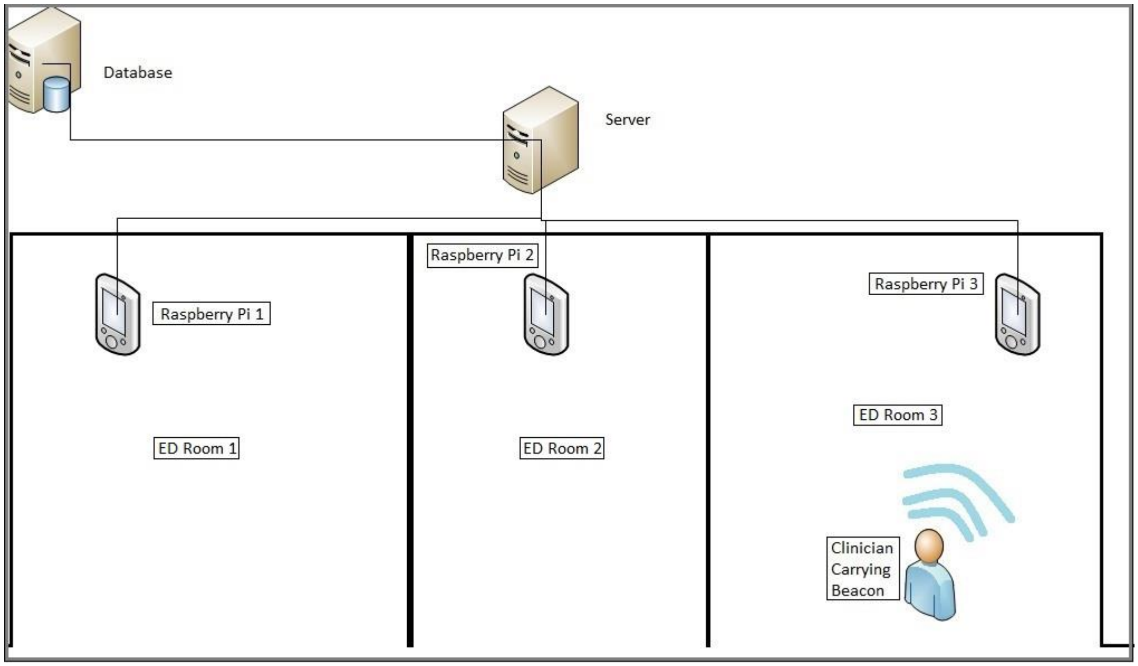

Figure 1.1: System of Raspberry Pi's, Clinicians, Beacons and Server Interactions

Bluetooth Low Energy (BLE) technologies were chosen for use as opposed to other technologies for several reasons. Table 1.1 provides a quick reference summary of the reasons, but the following sentences provide more thorough explanations. A technology that can see an entire room was needed because clinicians may travel freely around the ED and within its rooms. Near field communication (NFC) was not utilized because it requires that the receiving device and transmitting device be within four inches of each other. ZigBee is a local area network technology and its coverage area is similar to that of Wi-Fi, but Bluetooth was chosen over ZigBee because Estimote's Application Programming Interface (API) was fairly straightforward and the ease of implementation was convenient for experimentation. Also, Bluetooth Low Energy beacons are much more readily available on the market than ZigBee beacons making them easier to procure. Wi-Fi technology was not used to avoid potential interference with the hospital's internal network. Global Positioning System (GPS) technology was not used because it is not good for indoor use. Indoor room location accuracy is needed for this situation and GPS cannot provide that. Radio-frequency identification (RFID) technologies are not as dynamic as Bluetooth. A RFID tag operates within a specific frequency band. "The reading range can vary from a few centimeters to a couple of meters depending on the size of the transponders and the reader being used" (Moroz, 2004). The frequency band determines its detection range. The RFID detection ranges are up to 10 cm, between 10 cm and 1 m and 1 m to 100 m (Khan, Sharma and Prabhu, 2009). There are situations where a clinician is within one meter of the Raspberry Pi and then there are cases where the clinician is more than one meter from the Raspberry Pi. Bluetooth is capable, but RFID would not be able to switch between the two ranges. A great perk of passive RFID tags is that they do not require a battery to operate. While the Estimote beacons currently require a battery to function, other Bluetooth Low Energy beacons do not require a battery or have features to maintain battery charge. These features may include a built-in solar panel, a mechanism for harvesting energy from electromagnetic waves in the environment, and/or a transducer that converts ambient vibration energy into electrical energy. Estimote's BLE beacons are roughly $30 each, but their new BLE beacons called, "Stickers" are $10 each and Bluetooth beacons in general have been steadily decreasing in price. While the beacons may cost more than RFID tags, which run at around $5 each, the price difference is steadily becoming more equal. If the other benefits of the Bluetooth beacons are included, then the price difference seems negligible. Hypothetically, a combination of Bluetooth beacons and devices with Bluetooth receivers can accurately detect and document clinician locations.

Table 1.1: Radio Frequency and Ranges Comparison

Radio Frequency	Ranges			Remark
NFC	< 10 cm (4 in)			Range is too short
Bluetooth	0 m to 70 m			Range is good; Estimote Beacons and API are convenient; ~$30 with $10 Stickers on the way
Zigbee	0 m to 70 m			Similar to Bluetooth; Bluetooth is more commonly used
RFID	0 cm to 10 cm	10 cm to 1 m	1 m to 100 m	~$5; no battery in some cases; not as dynamic in ranges
Wi-Fi	0 m to 32 m			Used for hospital intranet; could cause interference
GPS	All over planet earth			Outdoor use; need indoor capability

CHAPTER 2

RELATED WORK

In this chapter, methods for tracking the door to clinician time are discussed in the context of general sensor-based tracking methods use in the hospital setting. The ED workflow as well as ED performance measures and their importance to the problem statement are discussed. Background on radio frequency identification (RFID) tracking methods and their use in the hospital setting are discussed. Another radio frequency technology is Bluetooth. It has been used for transferring files wirelessly, connecting to other devices, etc. and is available in many short range electronic devices. It is used for tracking purposes in this study.

2.1 Emergency Department

EDs provide initial emergency health care and can encounter a wide range of acute illnesses and injuries, some of which may be life threatening. Because the ED is often the initial point of access for patients the health care facilities, often suffer from crowding. Crowding is due to many factors such as long wait times, restrictions on the number of rooms available for patients and shortness of staff, which occurs from the irregularities of patient attendance. To improve the performance of the ED, CMS has enacted performance measures to take effect in and/or after 2012 (“Agency for Healthcare Research and Quality,” 2014). These performance measures are listed in the following table along with their effective date. The performance measures are meant to provide additional data that can be analyzed to potentially lead to refinements in the ED that can improve the performance and quality care of the ED.

Table 2.1: Performance Measures and Effective Date

Performance Measure	**Effective Date**
Use of Brain Computed Tomography (CT) in the Emergency Department (ED) for Atraumatic Headache	2012
Head CT Scan Results for Acute Ischemic Stroke or Hemorrhagic Stroke Patients Who Received Head CT Scan Interpretation Within 45 minutes of Arrival	2013
Troponin Results for ED Acute Myocardial Infarction (AMI) Patients or Chest Pain Patients (with Probable Cardiac Chest Pain) Received Within 60 minutes of Arrival	2013
Median Time to Pain Management for Long Bone Fracture	2013
Patient Left Before Being Seen	2013
Median Time from ED Arrival to ED Departure for Discharged ED Patients	2013

Door to Diagnostic Evaluation by a Qualified Medical Professional	2013
Median Time from ED Arrival to ED Departure for Admitted ED Patients	2014
Admit Decision Time to ED Departure Time for Admitted Patients	2014

The challenge of dealing with time from the door to the clinician is due to the complexity of the ED workflow (Thomas et al., 2011), including the nature of multitasking the work in the ED demands (Archana Laxmisan et al., 2007). It may be possible to decrease the overall time of the patient's stay in the ED by analyzing the door to clinician times that are collected periodically by looking at strategies for time reduction. There is a direct correlation between time and cost. If the time is greater, then the cost is also greater. It is beneficial to everyone if the cost is low.

Many hospitals have been penalized for not adequately implementing performance measures for time assessment, while other hospitals have hired more clinicians to be ready and waiting when a patient enters the ED. This makes the door to clinician time zero, but it also skyrockets the cost of healthcare. If a tracking technology was utilized for time collection purposes, then it would not be necessary to have an abundance of clinicians and a more appropriate staff to patient ratio could be applied. Tracking technologies and their use in the hospital environment are discussed in more detail in section 2.2 below.

2.2 Tracking Technologies

Tracking equipment is already available and in use in some areas of industry. There have been studies involving tracking technologies as well. In the year 2010, Elnahrawy and Martin pondered the impact of tracking systems on improving the healthcare workflow. “To identify workflow bottlenecks and efficiencies currently requires costly, labor intensive time-and-motion studies.” (Elnahrawy and Martin, 2010). Tracking equipment could potentially improve the workflow, but do so in a less expensive manner than manually studying and recording performance during work shifts. Instead, the tracking software can record the data and analyze it in an automatic fashion.

Radio-frequency identification (RFID) technologies are widely used for tracking purposes. There are three power sources available for RFID tags: Passive, Semi-Passive and Active. Passive RFID does not require a battery to operate as it pulls energy from the signal sent from the reader, but Semi-Passive and Active RFID do require an on-board power source. The ranges vary between the tags as they are based on the frequency band that the tag operates within. This is important because it determines the environment that RFID is most useful in (Impinj, Inc, 2014).

Parlak et al introduced RFID into the dynamic and time-critical medical setting (Parlak et al., 2012). They reviewed trauma resuscitation tasks, photographs of medical tools and videos of simulated resuscitations to understand resuscitation procedures. Based on the observations, they determined optimal placements of RFID tags on medical equipment. Although, their results were preliminary, they showed that deployment of tracking tools for recognizing trauma team activities is feasible.

Automated workflow analysis was researched by Vankipuram et al (2011). Clinicians can sometimes lose confidence in their own knowledge and ability and this effects the patient's safety, but an improvement in the workflow could alleviate this issue. Traditional methods for analyzing workflow stem from observation, which can be time consuming. The proposed method of Vankipuram et al involved giving clinicians RFID tags and recording the locations detected. The data was then utilized to create models of the activities in the critical care environments. Previously, data was observed and recorded, but their method enhanced workflow analysis and data collection methods by collecting the data automatically via the RFID tags.

All of the tracking technologies, with the exception of GPS, are possible because of the Received Signal Strength Indicator (RSSI) that these technologies utilize to deduce the approximate distance the mobile device/tag is from the detection device. While the tracking technologies may use RSSI, RSSI is not known to be reliable on its own. Qian Dong and Waltenegus Dargie evaluated the reliability of RSSI for indoor localization (Dong, 2012). They found that the noise from the environment caused the RSSI readings to be narrow, but haphazard. Due to the noise problem a filter algorithm needs to be applied to smooth out the distance calculations. The Kalman Filter is a commonly used filter algorithm for RSSI smoothing (Kalman, 1960). It also happens to be the most commonly used nonproprietary filter algorithm for Bluetooth beacons.

2.3 Existing Works

As previously mentioned, the study by Eiman Elnahrawy and Richard P. Martin was conducted to track systems to improve healthcare workflow (2010). General purpose, Real-time Adaptable Indoor Localization (GRAIL) Real Time Location System (RTLS) is an open source project from Rutgers University that was utilized in the study. GRAIL has the ability to use RSSI for Bluetooth, ZigBee, Wi-Fi and RFID. Through simulation, they showed that the utility of RTLS could model and manage workflow in hospitals and that tracking data could be converted into workflow processes. This study also shows that radio frequencies can be used to track objects, which is a good step toward automatic data collection.

Other RFID tracking technologies are available for hospital use such as ActiveWave's RFID system (ActiveWave, 2014). These systems can be quite costly to put into productive use, which is a huge downside to consider. Though the price is high, these systems do provide tracking of equipment, patients, employees, etc. as long as the item or individual being tracked is tagged.

CHAPTER 3

PRELIMINARIES

The sections following provide important information to consider when implementing a tracking system for an ED environment.

3.1 Emergency Department Workflow for Clinician Time Purposes

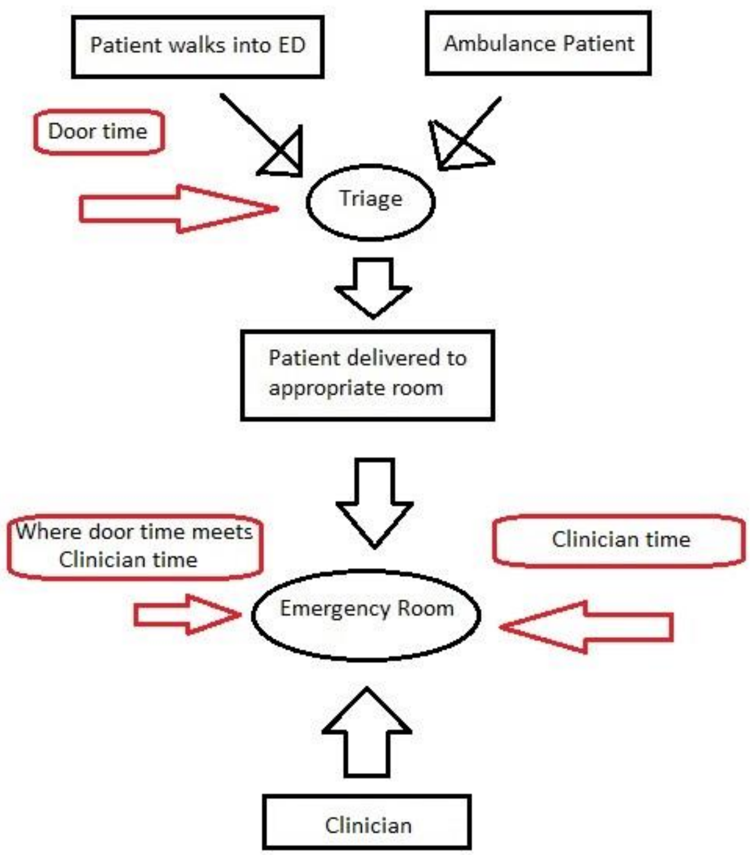

Figure 3.1: ED Workflow Concerned with Door to Clinician Time

In order to understand the door to healthcare provider time problem, one must understand the workflow of the ED. The ED workflow for the door to clinician time is a layout of the process of determining, upon arrival, a patient's degree of urgency in Triage to the Emergency Room (ER) where the patient is seen by a clinician. As can be seen in Figure 3.1, the workflow begins with a patient entering the ED via walk-in or ambulance. Triage determines which room the patient is sent to, based on the patient's condition. The door time is also recorded in Triage. When a patient is in an ER and a clinician visits him or her, the "healthcare provider time" is recorded. On occasion, a clinician will see a patient in Triage. This may occur when every ER contains a patient and/or if Triage does not think the patient needs a room, but should still be visited by a clinician. This is the extent of what is required to know about the ED workflow to understand the door to healthcare problem.

3.2 Raspberry Pi's Bluetooth Beacon Detection Radius

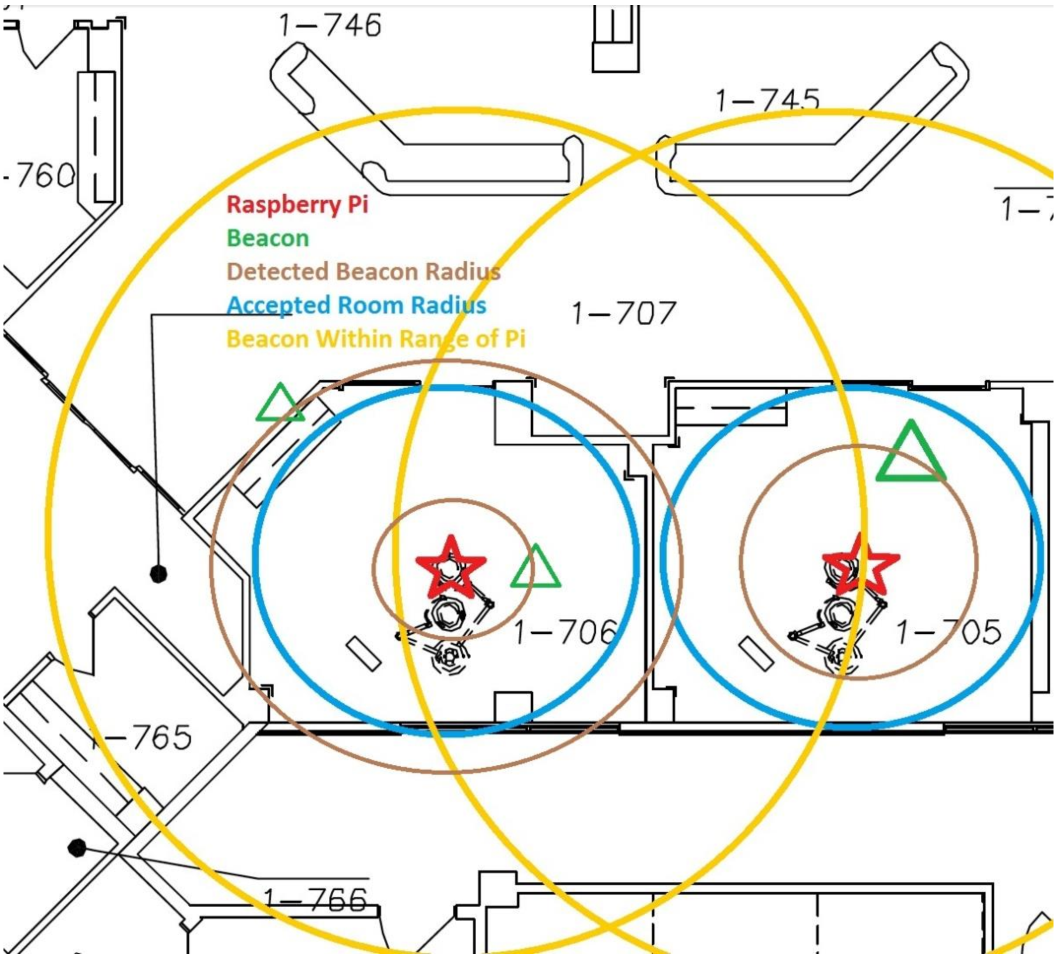

Figure 3.2: Raspberry Pi's Beacon Detection Radius

Figure 3.2 above shows an example floor plan of the ED. It also demonstrates how the distances from the beacons to the Raspberry Pi computers are seen via the green triangle representing a beacon, the red star representing the Raspberry Pi and the brown circle to show all the possible locations of the beacon at the distance it was seen. The yellow circles show that a beacon can be detected from far, while the blue circle provides the accepted distance of the beacon. The accepted distance is where it is safe to assume that the beacon is inside the ER.

While Figure 3.2 above is the layout that was ultimately set in place, other layouts were considered before they were ruled out. Figure 3.3 with the Raspberry Pi at the entrance to the room details a position for the Pi that allows it to see when a clinician is in the doorway to the ER, but it cannot determine whether the clinician is inside or outside of the ER based on distance. Figure 3.4 with the Pi located on the back wall has issues too. If a beacon is in the adjacent ER, then it might look like it is in the room with the Pi if a distance measurement is utilized for determining location.

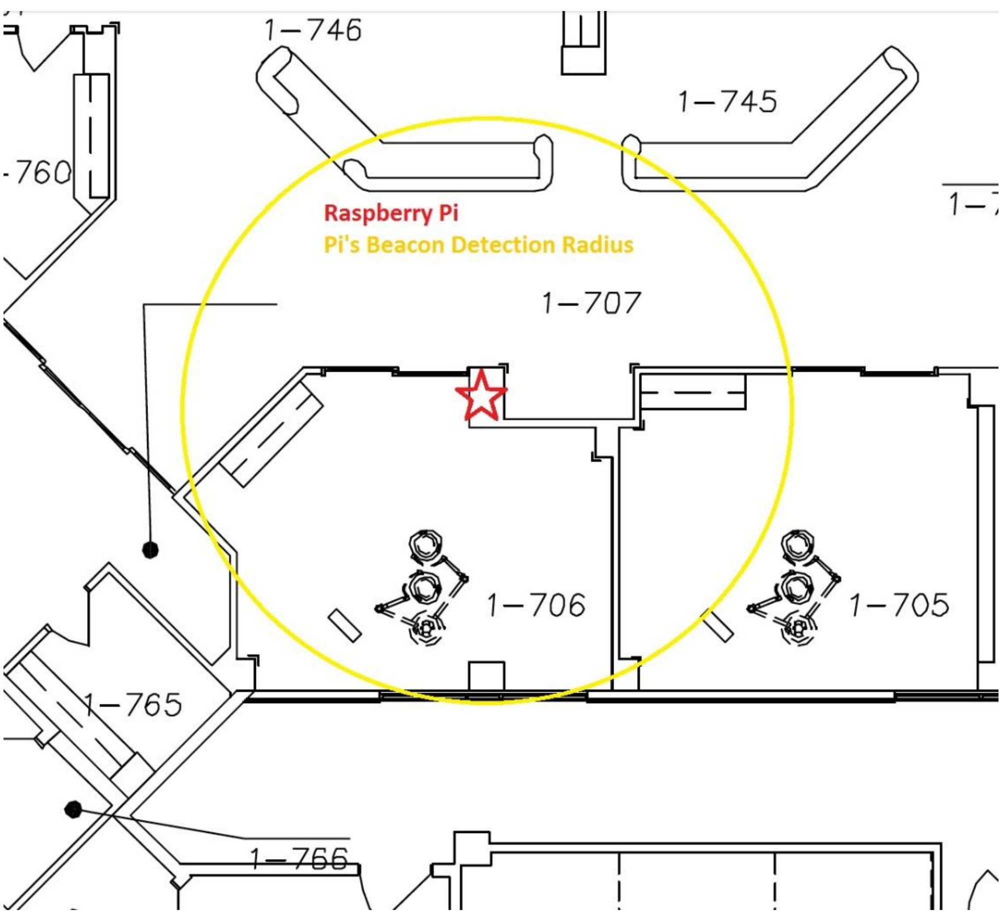

Figure 3.3: Pi at Entrance to ER 1-706

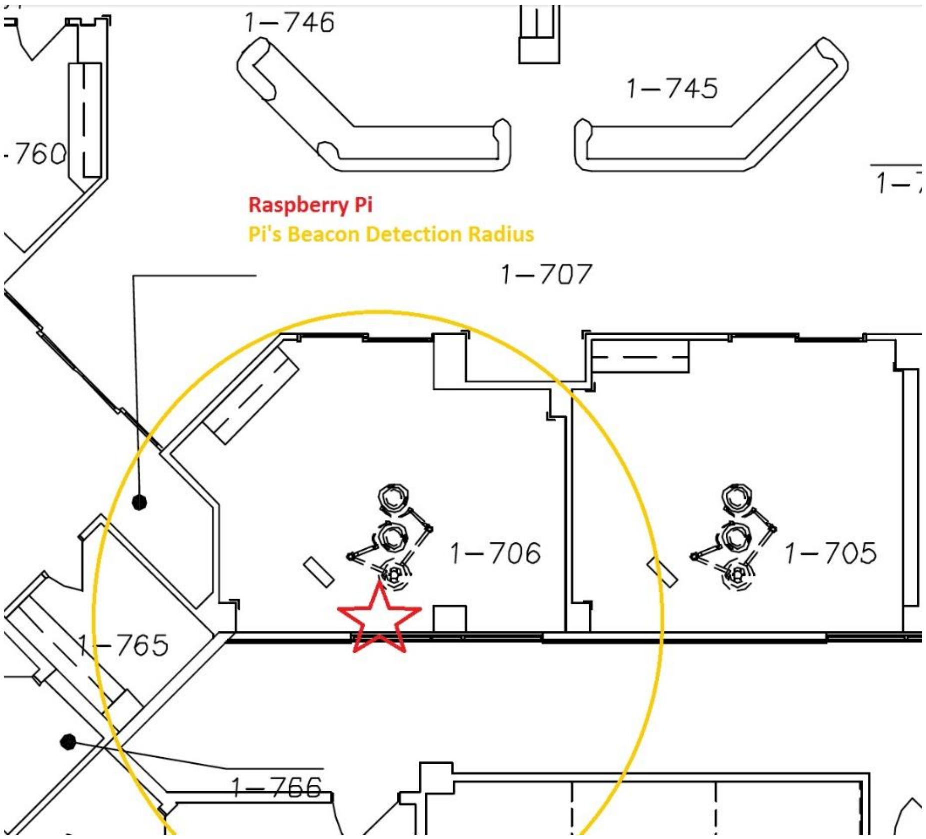

Figure 3.4: Pi on Rear Wall of ER 1-706

3.3 Point of Reference

To calculate the approximate location to install a sensor to detect beacons and/or its accepted clinician time radius, one must bear in mind the reference point of the beacon in a 3-dimensional space. It is simple enough to illustrate with a 2-dimensional plane. Start by determining the vertical distance between the sensor and the patient bed. Next, determine the horizontal distance between the center of the bed i.e. directly below the sensor and the first acceptable clinician time position of the clinician. To calculate an estimated accuracy value for the accepted radius value, use the Pythagorean Theorem. Note that this only works for distances that are in meters.

$$\textbf{(Line of sight)}^2 = \textbf{(vertical distance)}^2 + \textbf{(horizontal distance)}^2$$

See Figure 3.5 below for a visual representation of the reference point.

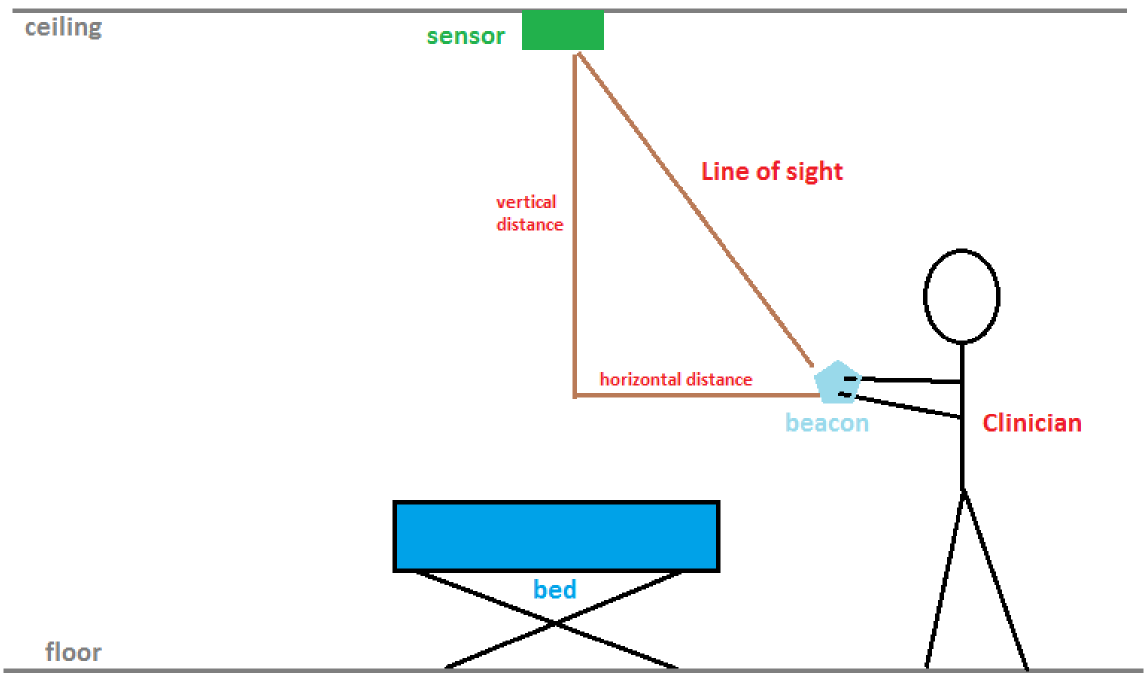

Figure 3.5: Bluetooth Beacon Point of Reference

3.4 Calculating Distance Based on RSSI

The distance is calculated using the RSSI value. The RSSI cannot be greater than or equal to 0. The RSSI divided by transmitted power ratio must be greater than 0 otherwise there was an error in the received signal. The RSSIOverPower ratio determines which formula to use. If the ratio is less than 1.0, then raise the ratio to the tenth power and that becomes the accuracy. This is because the RSSI was closer to 0 than the transmitted power signal and this only occurs when the beacon is roughly (consider environment interference) within 1 meter of the sensor.

$$\textbf{RSSIOverPower = RSSI/power}$$

$$\textbf{accuracy} = \textbf{RSSIOverPower}^{10}$$

If the RSSIOverPower ratio is greater than or equal to 1.0, then the ratio is raised to the 7.7095 power, multiplied by a constant of .89976 and summed with .111 to generate a rough estimate of the distance from the beacon to the sensor. The formula comes from the Android Beacon Library (2015).

$$\textbf{accuracy} = .89976\,\textbf{RSSIOverPower}^{7.7095} + .111$$

Accuracy is a term that Apple uses to describe the distance in meters that the Bluetooth beacon is from a device. “Apple called it accuracy, probably in an effort to discourage its use as a raw distance indicator” (Young, Radius Networks). The calculated accuracy is not perfect, but it does provide a fairly accurate measurement of the distance (Young, Stack Exchange).

3.5 Performing the Reverse 2’s Complement

An example is given below. Bluetooth packets are sent in Hexadecimal format. A two digit hexadecimal value holds the RSSI, but it has to be decoded using the reverse of the 2’s complement.

Convert hexadecimal value to numerical base ten:

$B6_{HEX} \rightarrow 182_{10}$

Subtract 2^8 from numerical base ten value to retrieve RSSI value:

182 – 256 = -74

3.6 Potential Causes of Wireless Interference

Wireless interference can cause the loss of wireless data and connection between devices. Some devices such as microwave ovens can cause interference, but luckily people don’t cook food in the ERs. Any wireless devices that operate in the industrial, scientific and medical (ISM) band from 2.4 to 2.485 GHz can potentially interfere with Bluetooth beacons. A properly configured WiFi network should not interfere with Bluetooth (Estimote, 2014).

Table 3.1: Potential Interference Sources

Potential Interference Level	**Sources**		
Low	Wood	Synthetic Materials	Glass
Medium	Bricks	Marble	
High	Plaster	Concrete	Ballistic Glass
Very High	Metal	Water	

To avoid unnecessary interference, it is best to place the beacons and beacon sensing device in an area that has a clear line of sight between the beacon and device.

CHAPTER 4

TRACKING HEALTHCARE PROVIDERS USING BLUETOOTH BEACONS

This chapter presents the bulk of this research. It provides detailed explanations of how to set up a cheap cost effective tracking system for automatically collecting the door to clinician time in an ED setting. The technical components are broken down in a manner such that they should be reproducible.

4.1 Setting up the Raspberry Pi

"If you just want that Raspberry Pi to work without hours of programming and struggles you will be happy to learn about the new NOOBS installation program" (Raspberry Pi Foundation, 2015). As such, plug in the New Out Of the Box Software (NOOBS) SD card (or a SD card with NOOBS on it), the keyboard, the Ethernet cable, the High-Definition Multimedia Interface (HDMI) monitor, a Universal Serial Bus (USB) power source and a BLE USB dongle to the Raspberry Pi Model B+ device. Boot up the Pi and wait until the NOOBS menu shows. Choose to install **Rasbian**, a Debian Wheezy port, optimized for the Raspberry Pi. After successful installation, click OK and then choose **<Finish>** when the raspi-config menu displays.

The default username is **pi** and the default password is **raspberry**. Use both for the initial login to the OS.

Install BlueZ using the necessary permissions and the following command:

sudo apt-get install bluez

When asked to continue type **'y'** and afterward use the following command:

sudo apt-get install bluez-hcidump

When the installation successfully terminates create a directory to hold the Java program using the command, **"mkdir beacons_scan"** and then add the necessary Java source files to the newly created directory, **beacons_scan**. After adding the files use the command **"javac Driverfile.java"** and when the compilation completes use **"java Driverfile"** to run the program and test that it is functioning correctly. Note that the program can be written in C and/or Python, but Java was used for this research implementation.

4.2 Run BlueZ in Background

The Java software executes two command line tools so it can detect the beacons. hcitool is used to configure the Bluetooth scan to look for Bluetooth Low Energy devices as well as to list a device each time it sees it even if the device has already been seen. It is important to include duplicate devices in the scan because the beacons repeatedly send their signal and it is how a change in beacon location can be determined. hcidump provides the raw data it sees in hexadecimal form. Note that hcitool and hcidump can be implemented directly using C or Python without having to execute a background process of the command line tools. The commands utilized in the Java software are as follows:

sudo hcitool lescan –duplicates

sudo hcidump –raw

4.3 Decode HEX Data

The Estimote default beacon UUID **is** B9407F30-F5F8-466E-AFF9-25556B57FE6D. Compare it to B9 40 7F 30 F5 F8 46 6E AF F9 25 55 6B 57 FE 6D picked up by hcidump and one can see that there is no need to convert the HEX value as it is identical. To decode the major and minor simply take the hexadecimal string and convert it to a base ten numerical value i.e. 3039 (HEX) converts to 12345 (numerical base 10). Take the HEX value representing the TxPower and convert it to a base 10 value. Then, subtract 256 from that to get the TxPower value. Essentially, this is the 2's Complement method in reverse. Use the same method to find the TxPower for finding the RSSI. The unused HEX data contains more information related to the beacon that can be decoded, but it is not needed for this research ("What is the iBeacon Bluetooth Profile", 2013). To better understand how to decode the data, see an example of the command line tools' output below with key elements of data color coded.

Key for example below:

Turquoise is the Estimote UUID

Bright Green is the Major

Yellow is the Minor

Gray is the txpower

Pink is the RSSI

An example of the command line tools output:

4E:BB:7B:99:0B:9E (unknown)

04 3E 2A 02 01 00 01 58 3C 1C 1B AA FC 1E 02 01 06 1A FF 4C 00 02 15 B9 40 7F 30 F5 F8 46 6E AF F9 25 55 6B 57 FE 6D 30 39 30 39 B6 C5 E1 DD D8 C4 C5

4.4 Compute Accuracy

Accuracy is the term that iOS uses to describe a numerical value representation of the distance of the beacon from the device in meters. If the RSSI is 0, then this means that the signal was lost and a -1 is returned by the computation to signify this. If the division of the RSSI by the TxPower is greater than or equal to 1, then the result of the division is raised to the 7.7095 power. The decimal number .89976 is divided by the result of the previous division and summed with .111 to get the accuracy for when the RSSI is less than the TxPower. If the TxPower is greater than the RSSI, then the result of the division of the RSSI by the TxPower is raised to the 10^{th} power and is given as the accuracy. This result should always be less than 1.0. These measurements are based on the Android iBeacon Library algorithm ("Understanding ibeacon distancing", 2013). The Java implementation of the accuracy computation is provided in Appendix A under the section titled, "Java Standard File."

4.5 Apply Kalman Filter

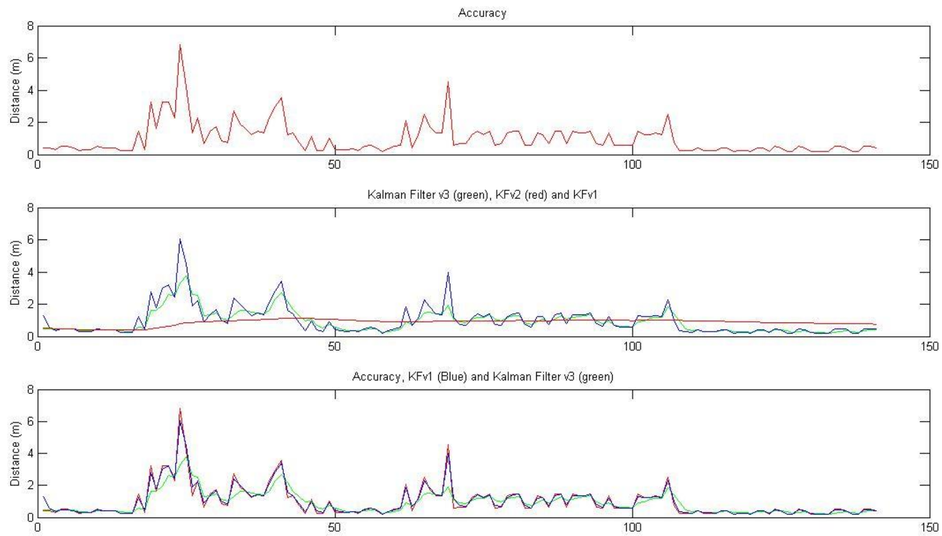

Figure 4.1: Accuracy, Kalman Filter (v3 is good, v2 is bad) and Combined Plots

A Kalman Filter is not necessary to accurately determine the door to clinician time, but after the accuracy is collected it is a good idea to apply a filter to reduce the interference of the environment on the RSSI values. Depending on the software implementation it may be beneficial to rely on the filter's results rather than the raw accuracy values - hallway beds come to mind for this case as they frequently have passers by.

Table 4.1: Sample Accuracy Values and Corresponding Kalman Filter Values

Timestep (ms)	Accuracy	Kalman Filter
n*950	0.429310914434837	0.426978874345768
(n+1) *950	0.234143735378922	0.344610622042835

(n+2) *950	0.273411242878504	0.324154470868935
(n+3) *950	0.273411242878504	0.294209928894592
(n+4) *950	1.4611688320646	0.576270578052205
(n+5) *950	0.318509329699946	0.493671066363976
(n+6) *950	3.24434645017012	1.63976798337855
(n+7) *950	1.60050100016887	1.62538610507163
(n+8) *950	3.24434645017012	1.96195835815103
(n+9) *950	3.24434645017012	2.62252058146592
(n+10) *950	2.29080323131803	2.49714371609851
(n+11) *950	6.80375319387659	3.29606155923787

To improve the accuracy calculation, a Kalman Filter was applied. The Kalman Filter is an algorithm used to stabilize the distance calculations by tracking previous accuracy values, their differences observed over time, predicting the next accuracy value and then comparing it with the current accuracy to provide a more precise accuracy value. Table 4.1 shows 12 sample timesteps from Figure 4.1. The 950 milliseconds is multiplied by the timestep because the Bluetooth Beacons were set to emit a signal every 950 ms. From the table it can be seen that the Kalman Filter is attempting to correct and stabilize the accuracy value. Figure 4.1 above shows the accuracy value, a good Kalman Filter application (v3) and a bad Kalman Filter application (v2). In the middle plot the red v2 Kalman Filter is bad because it is not dynamic enough to accurately determine when the distance of the beacon from the sensor has dramatically increased (such as when a clinician leaves the room) and it tries to converge to a specific value (Welch and Bishop, 2001), but the beacon distances should be changing regularly. Kalman Filter v3 can be seen in the bottom plot. It is a good application of the filter because it is dynamic enough to detect when a clinician quickly leaves the room. One last important consideration is that the door to clinician time is a one dimensional problem as we only need to track the distance. Many Kalman Filters track both x and y coordinates to determine a location, but in this case tracking both x and y is not needed so any implementation of the Kalman Filter will have to be adjusted accordingly.

4.6 Convert Data to XML and Send to Server

Converting the data to XML is trivial and involves putting the values between markup tags. See the example Figure 4.2 below.

```
<BEACON>
    <RUUID>RPiHallF</RUUID>
    <MAJOR>38990</MAJOR>
    <MINOR>62600</MINOR>
    <SUUID>B9 40 7F 30 F5 F8 46 6E AF F9 25 55 6B 57 FE 6D</SUUID>
    <ACCURACY>0.8727933003304253</ACCURACY>
    <TIME>Mon Feb 02 17:52:26 MST 2015</TIME>
</BEACON>
```

\

Figure 4.2: Example XML Received by Server

4.7 Implement Start-up Script

Use **“cd /etc/”** and **“sudo su”** to change to the etc directory on the Pi and get super user permissions for the next step. Use **“vi rc.local”** or **“nano rc.local”** to edit the rc.local file. Add the following lines to the rc.local and then save and exit the editor.

echo "Scanning for beacons"

cd /home/pi/beacons_scan/src/

java Driverfile

If the time a beacon was seen is reported to the server and the time has not been configured to the correct timezone and date, then it is useless. Thus, the correct time and date need to be configured. Note that the directory shown is an example and may differ between implementations of software. It should also be noted that the Driverfile can be replaced with a C or Python script if either of those languages were used for an implementation of the software.

4.8 Implement Time and Ensure Correctness with NTP

Enter **"sudo dpkg-reconfigure tzdata"** to configure the correct date and time. Select **"US"** and then select the appropriate state if the device is to be set up in the United States. Use the command line command **"date"** to verify that the correct date and time has been set in the system. However, having the correct timezone, date and time is not enough to ensure that times are reported and recorded accurately. Slowly, overtime, the system clock can desync from the actual time and this needs to be corrected. As such, the Network Time Protocol (NTP) needs to be implemented to monitor and make corrections to the system time as needed.

The GNU's Not Unix (GNU) nano text editor will be used for explaining the NTP implementation, but the vi text editor should also work if vi is preferred over nano. Use the following command in the command line to begin the implementation process.

sudo nano /etc/ntp.conf

Two lines need to be added below "You need to talk" in the ntp.conf file. These two lines are needed to guarantee that NTP can compare the clock against multiple server times, make corrections when appropriate and learn the desync tendencies of the Raspberry Pi machine's clock. Add at least the two lines listed below. If other servers are preferred to the ones listed below use those instead or if more servers are preferred than just two, add more servers.

server wwv.nist.gov

server ntp-nist.ldsbc.edu

Thereafter, edit the rc.conf file using **"sudo nano /etc/rc.conf"** and include the single line **"DAEMONS=(!hwclock ntpd ntpdate)"** without the quotes. After saving the file and exiting the editor restart NTP.

sudo service ntp stop

sudo service ntp start

4.9 Send XML to Server and Determine Door to Clinician Time

The server receives the XML and then parses out the date, time, beacon major, beacon minor, SUUID of beacon, RUUID of device sending beacon data to server and the accuracy that was detected. The parsed data is sent to the database where it is stored for future use.

The arrival time of the patient is already known in the ED database and the beacon data is recorded in the database each time it is seen. A script takes the first seen doctor time for that patient, and subtracts the arrival time of that patient to get the door to clinician time. As an example, a patient arrived at 6:00 a.m. on February 7, 2015 and was seen by a clinician at 6:01 a.m. on February 7, 2015. The door to clinician time is therefore 1 minute and was found by subtracting 6:00 a.m. from 6:01 a.m.

4.10 Useful Tools

Once a Raspberry Pi has been installed in a room for detecting and recording beacons it may be inconvenient to update the Pi directly such as when the Pi is installed on a ceiling. The Secure Shell (SSH) Telnet and Putty applications are particularly useful for remotely accessing a Pi ("PuTTY Download Page", 2015). The IP Address is needed to remote into the Pi and the Pi's IP Address can be found (depending on the database configuration) in the recorded XML logs stored in the database.

When a process becomes troublesome or needs to be stopped, use **"sudo kill -9 PROCESS_ID"** to end the process, where the PROCESS_ID is the value shown in the results of the command line command **"ps -aux"** for the process that needs to be stopped. Another useful command line command is **"sudo shutdown –r 0"** and is needed occasionally after updating the software. The command serves to immediately restart the device.

CHAPTER 5

SYSTEM VERIFICATION AND VALIDATION

In order to ensure that the system could accurately determine when a clinician was seeing a patient in the 24 bed ED many aspects of the system had to be tested. Location context such as room size and potential environment interference, patient interests i.e. “will the patient try to take the sensor if it looks valuable?”, and ED workflow i.e. clinician dwell time are all important factors to include in the design of the system. The goal of this system is that it collects the door to clinician time automatically and accurately. This chapter will discuss the tests performed and analysis conducted to create a robust system as well as the results that verify the system has achieved its goal.

5.1 Verification

Specification:

Software must automatically detect beacons without user input, and accurately detect and document the time that a clinician sees a patient.

Experiments:

An Android app and an iOS app were created. These apps were meant to run on a mobile device while the clinician went about his or her work day. The original intent was to have the beacon on the ceiling instead of the sensing device. Thus, the mobile app would detect the beacon and notify the server when it was located in the ER. The server would then determine if a patient was in the ER as well and document the door to clinician time if so. This method of data collection was scrapped when it was realized that the method was not cost effective.

In an effort to avoid rewriting software for detecting Bluetooth beacons, Android OS was installed on a laptop. The Android app functioned properly outside of any functions that required Bluetooth. This was due to Android OS not having the correct driver for the hardware. A Bluetooth USB receiver did not enable Bluetooth either. Further attempts to use Android OS were made and involved setting up virtual machines of Android OS on a Windows 8.1 machine, Mac Mini and Ubuntu machine as well as setting up a hack in Ubuntu OS to run Android apps in the Chrome web browser. Android OS could not enable Bluetooth in any of the methods mentioned, which led to the development of the current system implementation.

The programming language Java and the hcitool Bluetooth configuration tool were utilized to detect beacons and send the results wirelessly to the server via a Transmission Control Protocol (TCP) socket. The newly written software was tested on a Linux Ubuntu laptop. Error checks were implemented to ensure that the software could detect Estimote beacons (Estimote's BLE beacon product) and compute the correct accuracy associated with its distance from the device. The distance from the laptop (along the back wall of the ER) to a beacon at the doorway of the ER (roughly 4.5 meters) was tested to see if the software could compute the correct accuracy.

Estimote beacons allow the user to adjust the signal strength of its signal using Estimote's mobile app. Initially, it was thought that the signal interference could be mitigated by increasing the signal strength. The broadcasting power levels of the beacons were set to 4 decibel-milliwatts (dBm), which shortens the battery lifespan, but makes it less likely that the signal is lost in transmission. The RSSI-esque representation of the power level is -60. The beacons are no longer set to 4 dBm because the accuracy measurement becomes inaccurate within 1 meter of the sensing device. This is due to the RSSI value rarely going above -60, with the occasional -59 coming through. A RSSI value of -60 means that it will calculate 1 meter and often -61 or -62 was received, which calculates at above 1 meter. When the beacon is a centimeter from the device, it is well under one meter and the calculation should have represented this, but it did not. -30 dBm has similar issues, but with the opposite end of the spectrum. The distance calculation is far more accurate within 1 meter, but the beacon only sends it signal about 1.5 meters at most and is often lost sight of at 1.1 meters. The ED needs to be able to see beacons from 5 meters away. The beacons were set to -12 dBm or about a RSSI-esque power level of -74. This mitigates signal loss enough to not drain the battery life as fast as the strongest setting, but it also allows the beacons to be seen farther than 1 meter (up to 15 meters).

Once it was deemed that the software could perform its necessary functions correctly, Raspberry Pi machines were set up with the software and installed on the ceilings of select ERs. Wi-Fi was not an interference issue, but metal, people (who are water based) and ballistic glass doors caused interference for the laptop as it was surrounded by metal and was at waist level. To improve the received RSSI values, the Pi machines were mounted to the ceiling where a much clearer line of sight could be maintained.

The Pi machines were mounted, but how was the software executed? The software can technically be executed remotely via SSH, but to make installation of the machines more robust a startup script was set up that executes the software upon machine boot. As necessary, software was upgraded remotely via SSH. It is rather difficult to find an opportunity to unplug and replug the power to the machines when they are mounted to the ceiling of an ER occupied by a patient. The difficulty stems from patients frequently occupying an ER for hours. When a patient is moved from an ER, another patient fills the room shortly after.

For this software to be useful and reliable to hospitals it must be as precise in its time documentation as is possible. Not only were the timestamps reviewed during the development phase of the software, but during the data collection process clinicians were viewed entering ERs and the time seen from the Pi machine was compared against that shown on time.gov's website ("Right now, the official U.S. time is," 2015). The time documented by the Pi was accurate to the second. Internal clocks of mechanical and electronic devices are known for slowly desyncing from the current time so to alleviate this issue the default Network Time Protocol (NTP) of the Pi machine was upgraded to ping multiple time servers and keep track and correct its own desyncing tendencies.

Table 5.1 below shows example tests performed on the system to ensure its correct function. The Action column includes "Entered Room," "Exited Room," "Standing at bed in room," "Standing outside room," and "Standing in doorway." There are five actions that a clinician may perform. The most common actions involve the clinician walking into the room and stopping at the bed where the patient is located, performing the patient examination and then walking out of the room. It is also possible that a clinician may stand in the doorway or outside of the patient's room. Three rooms were used for testing. Rooms 1 and 2 are the same size, while room 3 is slightly smaller. Note that it is recommended that the room size be stored in a database and the server script references the database to avoid hardcoding room sizes. The accuracy is an estimate of the distance in meters of the beacon's distance from the Raspberry Pi computer. Lastly, the determined location of the beacon is either in the room or out of the room.

Table 5.1: An Example of Beacon/Device Testing Factors

Action	Room Number	Beacon from Device (meters)	Accuracy Value Detected (meters)	Accepted Room Size accuracy value (meters)	Room Size (meters)	Determined Beacon Location
Entered Room	1	1.3	1.29323	2	4.5x4.5	In room
Exited Room	1	3.7	3.72350	2	4.5x4.5	Out of room

Standing at bed in room	1	1.1	1.07616	2	4.5x4.5	In room
Standing outside room	1	6.3	6.28469	2	4.5x4.5	Out of room
Standing in doorway	1	2.3	2.29080	2	4.5x4.5	Bounces between in and out of room
Entered room	2	1.2	1.27284	2	4.5x4.5	In room
Exited room	2	4.4	4.36121	2	4.5x4.5	Out of room
Standing at bed in room	2	1.4	0.93460	2	4.5x4.5	In room
Standing outside room	2	4.5	4.50475	2	4.5x4.5	Out of room

Standing in doorway	2	2.3	2.096330	2	4.5x4.5	Bounces between in and out of room
Entered room	3	1.0	0.963656	1.2	3.5x3.5	In room
Exited room	3	3.6	3.688140	1.2	3.5x3.5	Out of room
Standing at bed in room	3	.9	0.908421	1.2	3.5x3.5	In room
Standing outside room	3	3.9	3.917750	1.2	3.5x3.5	Out of room
Standing in doorway	3	1.2	1.27284	1.2	3.5x3.5	Bounces between in and out of room

Testing was conducted with multiple non-Estimote Bluetooth devices running Bluetooth to see if Bluetooth interference could occur and interfere with the detection capabilities of the software. The software handled the alternate Bluetooth signals appropriately and maintained constant detection of the Bluetooth beacons.

5.2 Validation

CMS Requirement:

CMS requires that the door to diagnostic evaluation by a qualified medical professional performance measurement is reported and that the reported times are precise.

Validation of Automated Times:

Validation of automated times requires that these be compared against non-automated times. Clinicians documented patient visit times by hand. The hand-written patient visit times were compared against the automatically collected visit times by the software to ensure that times matched for the accuracy in their measures. The automatically collected times were accurate within seconds of the clinician-patient encounter, but the hand-written times were recorded in terms of minutes. Thus, it can be justified to say that the clinician times collected are accurate to the minute.

CHAPTER 6

DISCUSSION

This chapter discusses aspects that should be considered when designing a system to maintain accuracy while automatically collecting the times of clinicians in specific locations and determining if there is a patient-clinician encounter. The reliability of the system and its effect on the ED workflow are an important matter in its design. Trade-offs of this method compared to the traditional approach of hand-written door to clinician times are discussed as well.

6.1 Considerations

The most prominent factor to consider is the location of the patient-clinician encounter. Where will the clinician first meet the patient? Depending on how crowded the ED is the clinician may meet the patient in an ER, in an ED hallway or in the ED waiting room. Each location has its own set of considerations that include the context of the location and what kind of equipment is reasonable to place in the location. The cost and likelihood of theft of the equipment should be thought about too.

Equipment cannot be placed in a room if it presents itself as something valuable to a patient outside the hospital and/or easy to steal. A hospital bed is not valuable to a patient outside of the hospital so a patient is not likely to steal the bed nor is the patient likely to remove a bed inconspicuously from the hospital. Laptops should not be used to track the beacons in the ED. Patients can find value in a laptop easily because of its cost and may be able to play it off as their own laptop. Patients may find value in a mobile device, but patients are not likely to take a small electronic box from the ER ceiling during their stay. In addition, a patient may not recognize the box as a computer due to its obscurity.

The system must maintain the confidentiality of patient information. The Health Insurance Portability and Accountability Act (HIPAA), Federal Trade Commission (FTC) Red Flags Rule, and individual state laws provide regulations that hospitals uphold to ensure the security of patient data ("Security and Privacy of Electronic Medical Records"). In addition, the hospital may have a set of policies of its own that it strives to uphold. All statutes and internal policies must be considered when designing the software. The software can be considered faulty if it does not protect the confidentiality of patients.

Bluetooth Beacons propose a security risk and as such certain conditions should be handled by the software. The Beacons should not receive any data back from the server or Pi's as their only function is to broadcast their location. Keeping the beacon-Pi communication to a unidirectional format prevents hacking attempts where a device acts like a Beacon and pings the server until a valid response is received. The server should ignore any Bluetooth signals that it receives that are not from the approved brand(s) of Beacons and/or approved Bluetooth products in use by the hospital. It is recommended that the Raspberry Pi computers be connected to the hospital intranet via Ethernet cables rather than Wi-Fi to prevent Wi-Fi sniffer tools from collecting data. It is okay to use Wi-

Fi if the type of data sent is similar to the type of data seen in the XML examples in this thesis.

If other aspects of the ED, such as the five level triage system, are considered for using Beacons, then it may be beneficial to have patients wear Beacons. The five level Emergency Severity Index (ESI) assigns patients a level of severity to determine how long it is that the patient can wait (“Agency for Healthcare Research and Quality,” 2014). The severity levels are 1-resuscitation (immediately), 2-emergent (1-14 minutes), 3-urgent (15-60 minutes), 4-less urgent (1-2 hours) and 5-nonurgent (2-24 hours). The Beacons system can adapt to the ESI by monitoring patient wait time. If the system sees that the patient is still waiting and the patient is approaching the limit of the safe wait time that triage assigned, then the system could send a notification to the appropriate hospital staff of such. Tracking patients can be beneficial to hospitals in general, especially in situations where it is common for in-patients to wander away from their rooms. The key aspect to be aware of when applying this system to other areas of the medical field is that the system is built to provide context of location and/or proximity and any other context has to be inferred by supplementing data.

Location context is key to the design of an efficient system for collecting the door to clinician time. The size of the room in terms of its radius is the first aspect to consider. The size is the determining factor of whether or not a clinician is positioned in the room. Size alone can be used for determining a patient-clinician visit in a standard ER or in the ED waiting room, but for the hallway beds size alone is not enough. The accepted size should be less for a hallway bed, but a dwell time supplementing the accepted size is necessary. All types of staff frequently pass through the ED hallways including clinicians. If a clinician enters the accepted radius, which is highly likely to occur, then the system will interpret it as an acceptable patient-clinician time if the length of stay of the clinician is not also considered. This is the dwell time and it is reasonable to assume that the clinician would be with the patient for more than a few seconds.

Clinicians were given Bluetooth beacons and instructed to follow their typical workflow. The tracking software documented each instance of the Bluetooth signal that it saw. The documented times that the system collected were compared with the server to determine if and when a patient and clinician were in the same room and if it was the first patient-clinician encounter. If it was the first patient-clinician encounter, then it was logged as the door to clinician time. Physicians that can prescribe medication to patients are considered to be a clinician and thus were given a beacon with the exception of resident trainees who were not given beacons.

6.2 Results

Table 6.1: Sample Clinician-Patient Encounter Data

Room ID	*Clinician ID*	*RPi Door To Clinician Time*	*ED Arrival Time*	*Clinician Handwritten Exam Time*	*Handwritten Door to Clinician Time*	*Difference between Handwritten and RPi*
3	A1	15	0900	0916	16	1
1	A1	1	0851	0858	7	6
2	A1	11	0817	0828	11	0

3	B2	14	0319	0327	8	-6
2	C3	52	2159	2239	40	-12
3	D4	14	2031	2032	1	-13
1	F6	21	1052	1113	21	0
3	B2	16	0323	0338	15	-1
3	C3	180	2033	2104	31	-149

A total of 17 out of the 500+ clinician–patient encounters (to this date) have been reviewed, of which six sets of data were excluded because the care provided was by resident trainees, who were not given the beacons. Table 6.1 above shows sample data collected. Although, the detected beacon times are accurate to the second, the times recorded are described in minutes to maintain consistency with the handwritten times. The registration time is the time that the patient was entered in the system while the ED arrival time is the time that the patient arrived at the ED. Clinician ID refers to the beacon that a clinician carried and was detected by a specific room i.e. Room ID. The RPi Door to Clinician Time is the time calculated from the registration time to the detected beacon in room time. The detected beacon in room time is the time that the beacon is first detected within the accepted radius of the room. The handwritten clinician exam time and the ED arrival time are used to determine the handwritten door to clinician time. The final column is the difference between the handwritten door to clinician time and the RPi door to clinician time.

The overall results show that the recorded door to clinician times were accurate in detecting the beacons and recording the time in seconds. Technically, the time is accurate within seconds, but the times for the hand-written notes and our times were compared in minutes, providing the justification of accuracy of the results in terms of minutes. The data corresponding to the registration time of “2/11/15 9:02” shows that the handwritten time and the Raspberry Pi time are close, but there may be some inaccuracies in writing a time of a clinician-patient encounter before or after it happens. The registration time of “2/9/15 20:35” shows one of the documented results where a resident trainee (someone who didn’t have a beacon) visited a patient, satisfied the door to clinician time and effected the results of the system because the clinician did not enter that room for the first time until much later. Some of the results with a larger difference between Handwritten and RPi times are the result of not having a Raspberry Pi in Triage. Sometimes the patient will be assigned an ER, but then the clinician will visit the patient in Triage and document the time of the clinician-patient encounter. Later, the clinician will enter the room that the patient had been assigned and the system would log that time as the door to clinician time. This signifies the need to have Raspberry Pi computers in Triage.

CHAPTER 7

CONCLUSION AND FUTURE WORK

7.1 Conclusion

Bluetooth Low Energy beacons are a viable solution for automatically collecting accurate times of contextual occurrence. The cost of Bluetooth beacons are low (at around 10 for $100 currently; the price is steadily decreasing) in comparison to tablet/smartphone devices, which run anywhere from $100 to $400 on average. The Bluetooth receiver implementation is simpler than other radio frequency receiver implementations. The combination of the beacons and software are extensible as they can adapt to the increasing and changing needs of the hospital environment. Specialized hardware is not needed and current operating systems support Bluetooth, Java, Python and C. The implementation is unobtrusive to users. Users simply go about their day as normal and not think about the portable beacon attached to his or her badge. Prototypes are easy to make since the beacons are small and the software functions are already implemented to detect the beacons, be it in this research's software or Estimote's API. As such, the beacons and software are a viable solution to automatically recording the door to clinician time as well as improving the workflow and efficiency of the hospital working environment.

7.2 Future Work

It is hoped that this research can be extended to provide a solution for detecting if and when clinicians wash their hands and/or use hand sanitizer. Currently, hospital staff are required to wash hands and use hand sanitizer periodically as well as before and after certain events. Hospital staff are required to wash hands in general because it is a preventative measure of infections in the hospital. An extension of the study can include assessment of team interactions, given the installation of additional sensors in areas such as over the hallway patient beds and the Triage area. The beacons have such potential as to provide direct delivery of hospital items to clinicians and staff via drones, open doors automatically by walking toward them instead of waving an RFID card near a scanner, provide immediate and up-to-date information on a tablet/smartphone/wearable device to the clinician as he or she sees a patient and/or auto login a user into his or her workstation just by walking up to it. It is hoped that this can become a reality.

Beacons do not have to be solely purposed for hospital staff. It is possible to know where patients are when they wander away from their rooms. This is a problem with in-patients and the inconveniences it causes for hospital staff to track down the patient are costly. Wasted time could be reduced if a nurse can pull up an application to see where the patient is located. Then, the nurse can retrieve and return the patient to the proper room. If a patient is wearing a wireless vitals monitoring device, it can be paired with the beacon to identify and provide the server continuous patient vitals. Patients could feel more comfortable without wires attached to their body allowing them more freedom of movement.

Beacons have uses in other non-medical fields. Smart homes and amusement parks quickly come to mind. Imagine walking around a home or office with a Beacon. Computers can detect which room the Beacon is in and then based on the major and minor of the Beacon link it to the preferences, such as room temperature, of the person carrying the Beacon. Vents could automatically open and close as needed to only cool/heat the room that the beacon is present in rather than the whole building. All other rooms could have a default temperature to be kept at when someone is not present. Amusement park haunted houses could create location specific scares, projections, puffs of air on the legs, etc. that seem to follow someone regardless of where they travel in the house. Beacons can be used to track inventory in any industry setting. It would be great to have doors predict someone's path of travel and open upon approach rather than having to wave a badge at a reader or slide a key card. A similar idea applies to bicyclists travelling toward an intersection. If the traffic controller at the intersection could predict a bicyclist traveling north and no cars were traveling east or west, then the traffic controller could change the intersection lights to let northbound traffic through as the bicyclist nears the intersection. If one were to attach a Beacon to a pet collar, then a food dispenser could be programmed to dispense a specific portion of food for a pet when the pet approaches the dispenser. The dispenser should have a wait period before dispensing more food to prevent overfeeding the pet. Another sensor should be implemented to check that the bowl is not full in case the pet does not eat previously dispensed food. It is good to know that the future holds many possibilities for beacons.

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APPENDIX A

JAVA STANDARD FILE

```java
// Accuracy.java
public class Accuracy {
	// computes the beacon Accuracy a.k.a the distance in meters
	public double computeAccuracy(double power, double rssi) {
		double rOverP;

		if (rssi == 0) {
			return -1.0;
		}

		rOverP = rssi/power;

		if (rOverP >= 1.0)
			return .89976*Math.pow(rOverP, 7.7095) + .111;
		else
			return Math.pow(rOverP, 10);
	}
}
```