School of Mechanical and Manufacturing Engineering

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Out-patient tracking to reduce transmission of infections

by

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Abstract

There is an estimated 200,000 hospital acquired infections (HAI) each year in Australia [**ausHAI**]. This is a major cause for concern Cystic Fibrosis (CF) patients who are highly susceptible to cross infection. Therefore, this thesis aims to tackle the issue of HAIs among CF patients receiving out-patient care by developing an indoor real time locating system (RTLS). The collected mobility data on CF patients will be utilised to determine risk areas for cross infection by social network analysis (SNA).

This document presents a progress report. A literature review of the current state of indoor RTLS technology and SNA techniques was performed. Using this research, preliminary steps were taken to design the RTLS software along with experiments. The experiments were designed to aid in the creation of a robust and accurate indoor positioning system. Finally, this document concludes with an outline consisting of planned activities.

Acknowledgements

This work has been inspired by the labours of numerous academics in the Faculty of Engineering at UNSW who have endeavoured, over the years, to encourage students to present beautiful concepts using beautiful typography.

Further inspiration has come from Donald Knuth who designed TEX, for typesetting technical (and non-technical) material with elegance and clarity; and from Leslie Lamport who contributed LATEX, which makes TEX usable by mortal engineers.

John Zaitseff, an honours student in CSE at the time, created the first version of the UNSW Thesis LATEX class and the author of the current version is indebted to his work.

Abbreviations

HAI Hospital Acquired Infection

CF Cystic Fibrosis

RTLS Real-Time Locating Systems

SNA Social Network Analysis

GPS Global Positioning System

NLoS Non-Line-of-Sight

PDR Pedestrian Dead Reckoning

SHS Step-and-Heading System

IR Infrared

LoS Line of Sight

RFID Radio Frequency Identifier Description

USID Ultrasound identification

WPAN Wireless Personal Area Network

ISM Industrial, Scientific and Medical

RSS Received Signal Strength

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Chapter 1

Introduction

1.1 Background

There is an estimated 200,000 hospital acquired infections (HAI) each year in Australia [**ausHAI**]. The major causes of transmission of HAIs are believed to be direct or indirect contact "between the patient, the staff and the environment" [**airTrans**]. To minimise the occurrence of HAIs, hospitals and governments have put in place various policies and guidelines. These include practices such as: routine hand hygiene, patient flow management, quarantine procedures [**WHOHAI**]. These practices have been successful for inpatient treatment, where there is strict monitoring and control of the patients' environment. However, these policies are more difficult to uphold during out-patient treatment where the individuals are free to move about in the hospital environment and interact with other people.

Cystic Fibrosis (CF) is the most common lethal genetic disease in Caucasian populations [**OSullivan20091891**]. CF patients experience chronic respiratory infections and inflammation [**flume2007cystic**]. Cross infection amongst CF patients is a high occurrence and multiple cases of the spread of *Pseudomonas aeruginosa* strains by social contact and proximity has been well documented in [**govan1993evidence**, **cheng1996spread**]. Furthermore, the delivery of health care for CF patients has shifted from inpatient to outpatient clinics and the home so as to provide chronic suppressive treatments and reduce days of hospitalization [**infectionCF**]. Hence, there is an emerging need to reduce cross infection among CF patients receiving outpatient health care.

1.2 Research Overview

There is speculation that the patient flow within the hospital out-patient environment allows for opportunities for close contact among CF patients. Our hypothesis is that patient encounters can be tracked using lightweight indoor localisation technologies allowing for interventions to improve patient flow, reduce patient contact, and reduce HAIs.

The aim of this thesis is to identify areas of potential cross infection in the hospital out-patient environment. The project will accomplish this by utilising Real-Time Locating Systems (RTLS) to track CF patients movements and dwell times. Social network analysis (SNA) will make use of the gathered mobility data into identifying high risk areas for cross infection.

1.2.1 Objectives

To successfully complete this thesis, the following objectives must be met:

1. Investigation into an accurate and scalable indoor RTLS approach for tracking patient movements.
2. Development of a smart-phone application to accurately track the position of the CF patient indoors.
3. Development of algorithms to identify high risk areas for CF patients in the hospital out-patient environment.

4. Implementation and testing of the software system to identify areas of improvement and practicality of system.

1.2.2 Scope

The scope of this thesis is limited to the development of the RTLS using smart-phone software on the Android operating system, and its user interface on the desktop browser. The system will solely be developed for use in solving cross infection amongst CF patients. Experimentation is limited to the Randwick hospital environment in Sydney, Australia. The subjects used for testing will be CF patients.

The RTLS implementation will involve the Android environment due to following factors:

- presence of low cost embedded sensors in smart-phones
- ubiquity and support available for android development
- ease and simplicity involved in implementation

1.3 Thesis Outline

Chapter 2 is the study of current literature relevant to this thesis. The topics include an analysis of the current state of RTLS specific to hospital environments, and the android smart-phone environment. There is also further study into the use of SNA with the aim of reducing the spread of infections.

Chapter 3 presents the the design of the software system. It outlines the experiments conducted, and the algorithms utilised in the software.

Chapter 5 details a summary of the current work completed for Thesis A. It outlines the planned activities for Thesis B.

Chapter 2

Literature Review

The following literature review comprises of a systematic study of the current state of technology and systems in place that are relevant to the thesis. The two main components required to successful achieve the aim are:

1. Develop a real time indoor positioning system to track the patient in the hospital out-patient environment.

2. Determine areas which have a high risk of cross infection based on SNA of the mobility data collected from the RTLS.

A systematic and structured method, inspired by the guidelines of **webster2002analyzing** [**webster2002analyzing**], was followed to perform this review.

Firstly, we will look into current RTLS implementations used in hospital environments. Secondly, we will review indoor positioning technologies making use of smart-phones presented in literature. This analysis will serve as a basis for the design of the real time patient positioning system. Finally, research will be conducted on the used of SNA in infection control.

2.1 RTLS in Health Care

It is apparent from **orwat2008towards** [**orwat2008towards**] that technology has become an integral component of the health care industry, stating that computing has "entered health care in almost every setting". In specific, RTLS in health care is used for multiple applications as demonstrated by **boulos2012real** [**boulos2012real**]. The common technologies used in RTLS consists of specialised fixed receivers or readers (location sensors) receiving wireless signals from small ID badges or tags attached to objects of interest and/or persons, to determine where the tagged entities are located within a building or some other confined indoor or outdoor space [**boulos2012real**]. This is shown in Figure 2.1.

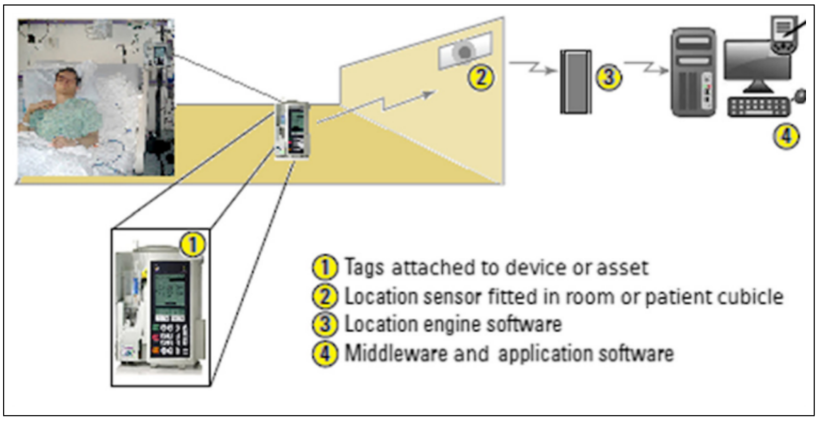

Figure 2.1: RTLS components in health care [**boulos2012real**]

RTLS are currently deployed to help protect patients and staff by monitoring movement of patients, staff, visitors and equipment in real time to detect instantly their whereabouts and analyse historical movement [**cobbley2011easing**]. The applications also extend to improving work flow. Tracking patient flows for throughput management can help diagnose bottlenecks and tailor appropriate solutions for problems such as extended waiting times, overcrowding and boarding in outpatient clinics, emergency departments/rooms (ED/ER); bumped and late surgeries; and the lack of available routine inpatient and intensive care unit (ICU) beds [**boulos2012real**, **stahl2011measuring**, **drazen2011using**, **malik2009rtls**].

The impact of RTLS systems have been significant in the health care industry. **laskowski2012rtls** [**laskowski2012rtls**] and **boulos2012real** in [**boulos2012real**] report impressive RTLS-enabled workflow efficiencies, including quantifiable significant cuttings in ED wait times, length of stay (LOS) and 'left without being seen' (LWBS) rates. The value of the intelligence gleaned from RTLS patient flow data can be maximised by combining it with 'lean production system principles' (pioneered by Toyota Motor Corporation) to optimise patient flows [**boulos2012real**]. Other benefits of patient flow tracking and optimisation include fewer ambulance diversions and higher patient satisfaction ratings [**drazen2011using**], which can translate into improving the care facilitys perception and reputation.

Although there are significant benefits, the choice of RTLS technology must be very carefully made. A given technology or hardware may not work well despite all its merits, if not properly matched to the intended application or the hospital environment, budget and future expansion plans (the latter will require an adequately scalable RTLS solution) [**boulos2012real**]. For example, radio signals are susceptible to interference via signal propagation, metals, water, people, and radio. Not every environment is suited for RF (radio frequency) systems.

One can conclude that RTLS systems are an emerging standard in hospital environments. However, their use is largely focused to locating and/or analysing the flow of the various 'players' (patients, doctors, nurses, equipment) in the hospital environment. There has been no establishment of a clear link between RTLS systems in controlling the transmission of infections within the hospital environment. Furthermore, the use of RF technologies for localisations poses issues with accuracy and scalability (as discussed in Section 2.2).

2.2 Indoor Positioning Technologies

In outdoor localization contexts, the most well-known and widely spread technology is the Global Positioning System (GPS). It is able to guarantee excellent performance in outdoor scenarios but experiences issues in indoor environments due to poor satellite coverage and signal degradation. Thus, the use of indoor localization techniques is increasingly becoming an essential component for a large number of applications and contexts such as "healthcare, home-care, monitoring, tracking, etc" [**mainetti2014Indoorlit**]. Currently, indoor localisation lacks a ubiquitous system comparative to GPS. This is due to: errors by multipath and Non-Line-of-Sight (NLoS) conditions, presence of moving people that modify the indoor propagation channel, greater density of obstacles that cause a high attenuation and signal scattering, demand of a higher precision and accuracy [**mainetti2014Indoorlit**].

fallah2013indoor [**fallah2013indoor**] have grouped indoor localisation methods into four different techniques:(a) dead-reckoning, (b) direct sensing, (c) triangulation, and (d) pattern-recognition. These methods are discussed in the sections below.

2.2.1 Pedestrian Dead Reckoning

These systems use sensors on the user to estimate relative rather than absolute location i.e. the change in position since the last update. The sensors utilised can be can be a combination of sensors such as accelerometers, magnetometers, compasses, and gyroscopes [**fallah2013indoor**] or using a users specific walking pattern (such as the users average walking speed) [**wu2007pathplan**]. They require little or no infrastructure to be pre-installed in buildings, but without an external reference, errors quickly accrue [**harle2013PIndoor**]. This accrued error can be corrected by synchronizing direct sensing localisation techniques however the drawbacks of the direct sensing mechanism (for example blue-tooth beacons) are also applied to the system [**fallah2013indoor**].

Dead-reckoning for walking users and hybrid systems using such techniques are called Pedestrian Dead-Reckoning (PDR) systems. These systems are of particular importance because they retain the low deployment costs associated with dead-reckoning whilst successfully addressing many of the shortcomings [**harle2013PIndoor**]. Furthermore, a Step-and-Heading Systems (SHS) is specific to pedestrians, estimating position by accruing distance and heading vectors representing steps [**harle2013PIndoor**]. The fundamental cycle for an SHS is:

1. identify subsets of the data corresponding to individual step;
2. estimate the length of the step; and
3. estimate the step heading or change in heading.

Step Detection

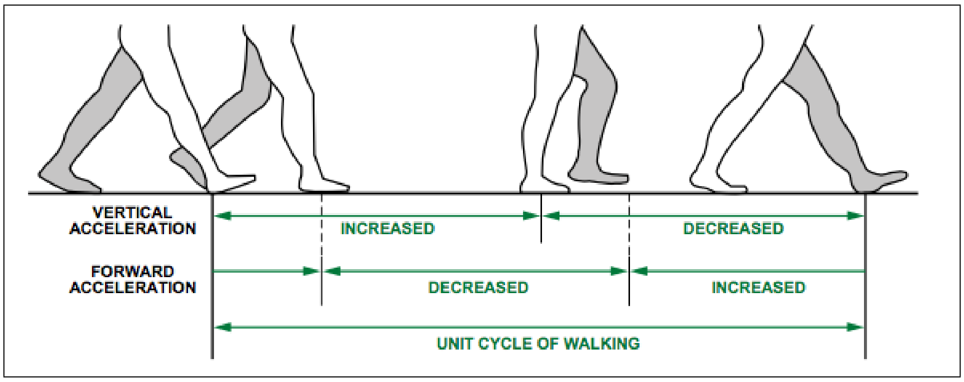

Figure 2.2: Walking Stages and Acceleration Pattern [**zhao2010full**]

Various techniques using accelerometer and gyroscope sensor data have been developed to detect the step motion. Figure 2.2 depicts a single step, defined as a unit cycle of walking behaviour, showing the relationship between each stage of the walking cycle and the change in vertical and forward acceleration. **harle2013PIndoor** has identified the following algorithms [**harle2013PIndoor**]:

1. **Peak Detection** - the heel strike is associated with sharp changes to the vertical acceleration. Standard peak detection algorithms can be used to highlight potential strikes. Note that each foot impact may generate multiple local peaks the nearer to the foot it is sited, due to the higher forces resulting in sensor bounce [**ying2007automatic**]. This can significantly increase the algorithm complexity.
2. **Zero Crossings** - is a method by which accelerometer readings are monitored for zero crossings [**goyal2011strap**].
3. **Spectral analysis** - this involves computing the frequency spectrum of the cyclic data and identifying strong peaks at typical stepping frequencies. Subsets of the

data (of a size that includes at least two cycles) are converted to the frequency domain and the dominant frequency taken as the walking frequency [**levi1996dead**].

Step Length Calculation

The simplest approach to estimating step length is to assign a constant value [**harle2013PIndoor**]. However this approach can be too simplistic as **weinberg2002using** reported that the step length can vary by as much as 40% between pedestrians walking at the same speed, and up to 50% across the range of walking speeds of an individual [**weinberg2002using**].

weinberg2002using also described a dynamic step length estimation procedure based on the maximum vertical displacement of the hip (bounce). The stride length was shown to be a function of the bounce and the vertical angle between the highest and lowest point of the hip during a single stride [**weinberg2002using**]. This angle is taken as constant although it is actually related to the leg length of the user. Nonetheless the step lengths are reported to be within 8% of their true values.

Heading Estimation

Single integration of gyroscope signals provides estimates of heading change. Because SHSs can avoid using subsequent integration for the step length, the overall drift does at least grow linearly rather than cubically. In addition, some systems use only a single gyroscope mounted parallel to the torso, making the assumption that it remains (near) vertical during walking. Magnetometers may also be used directly or fused with the gyroscope outputs to estimate heading [**harle2013PIndoor**].

2.2.2 Direct Sensing

Direct sensing based localisation utilise the identifiers or tags to localise to a coordinate. Two approaches can be applied in the direct sensing method: (a) location information and information on the users environment is stored in the tag itself; or (b) this information is retrieved from a database using the tags unique identifier [**fallah2013indoor**]. The users orientation can be determined from relative changes in location from subsequent reads of tags [**willis2005rfid**].

fallah2013indoor have identified these common direct sensing technologies:

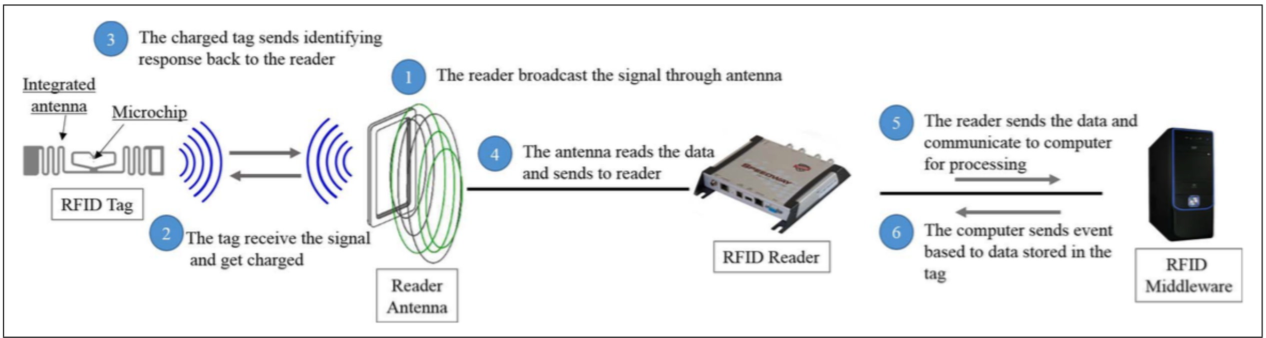

Figure 2.3: A generalised RFID System[**mainetti2014Indoorlit**]

1. **Infrared (IR)**: is one on the most common wireless technology used to localize objects or people through infrared emitters and receivers [**mainetti2014Indoorlit**]. This technology can provide several advantages. First, IR beam does not penetrate through walls then it is possible to obtain a confinement of the signals inside the room [**mainetti2014Indoorlit**]. Moreover, IR technology is characterized by the absence of radio electromagnetic interference and the power of transmitted IR signal can be easily adjusted to cover only the area of interest. Nevertheless, there are also several drawbacks. The multipath errors reduces drastically the localization accuracy and IR based indoor systems have expensive system hardware and maintenance costs. Furthermore, IR technology requires a Line of Sight (LoS) between transmitter and receiver to function properly [**mainetti2014Indoorlit**].

2. **Radio Frequency Identifier Description (RFID)** : The RFID technology is based on the use of an RFID reader equipped with one or more reader antenna and active or passive transceivers (i.e., tags). The general system components are shows in Figure 2.3. The RFID technology works without direct LoS since the radio waves have the ability to penetrate solid materials, but strength of the signal depends upon the density of the objects in the building, and then accuracy is often limited [**mainetti2014Indoorlit**]. In addition to the possibility to work in NLoS environment, other advantages of the RFID technology are high data rate, high security, cost effectiveness, and compactness. Main limitations of low frequency (125-134 kHz) and high frequency (13.56 MHz) RFID technology are related to a short reading range and to the ability to read only a few tags at the same time.

3. **Ultrasound identification (USID)** : use ultrasonic waves to measure distance between fixed-point station and the mobile target to localize. In order to implement such a localization system, multiple ultrasonic receivers are needed and they must be synchronized. The synchronization among receivers is done via IR or radio waves, because of the greater speed of the radio waves than the ultrasound ones. The transmitter sends a radio signal and an ultrasonic wave at the same time. Radio signal reaches receivers almost instantaneously, providing them with the synchronization signal. Receivers start to measure the time between the synchronization signal and the detection of ultrasonic waves, and then each of them calculates the distance between transmitter and itself. Advantages of this localization technique are the relative low cost and the capability to reflect most of the indoor obstructions. Disadvantages of an ultrasonic localization system arise from the multipath reception that could disturb measurements of the distance between emitter and receivers, and the complexity of a large-scale implementation.

4. **Bluetooth beacons** : Bluetooth is a wireless standard for Wireless Personal Area Networks (WPANs) and operates in the 2.4 GHz Industrial, Scientific and Medical (ISM) band. Since Bluetooth is a low-cost and low-power technology, it is

efficient in order to design indoor localization systems. In addition, Bluetooth tags are small size transceivers. As any other Bluetooth device, each tag has a unique ID, which can be used for locate the Bluetooth tag [**mainetti2014Indoorlit**]. One of the drawbacks of using Bluetooth technology in localization is that it can only provide accuracy about from 2 m to 3 m with a delay of about 20s [**mainetti2014Indoorlit**]. Furthermore, the Bluetooth localization systems suffer from the drawbacks of the RF localization technique in the complex and changing indoor situations [**fallah2013indoor**].

RTLS in hospitals make use of direct sensing methods to localise the patient or object. Figure 2.4 highlights the direct sensing technologies that can be applied to the hospital environment and the precision levels of these technologies.

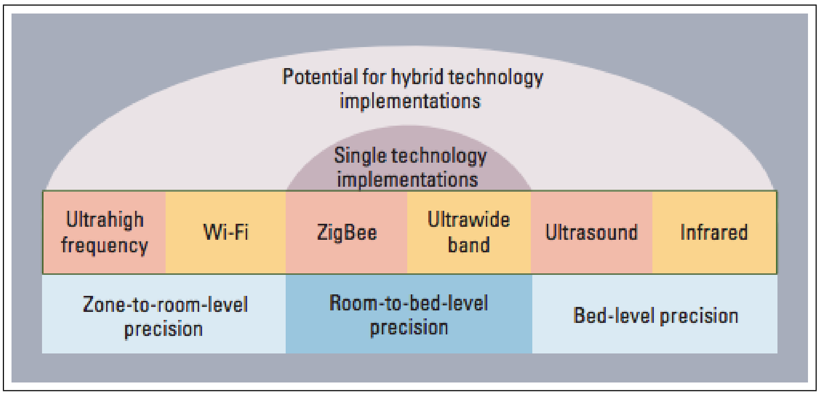

Figure 2.4: A comparison of commonly used RTLS technologies used in hospitals [**Dsouza2011emergency**]

2.2.3 Triangulation

A number of systems employ multiple identifiers and triangulation to locate the user. These methods locate the user by triangulating the tags installed in known locations. The tags that have been used for indoor or outdoor localization include RFID, IR, and USID [**fallah2013indoor**]. As shown in Figure 2.5 where A and B represent reference nodes, after obtaining the angles θ_1 , and θ_2 , the physical position of T (representing the target to be located) could then be calculated based on the predetermined coordinates of the reference nodes.

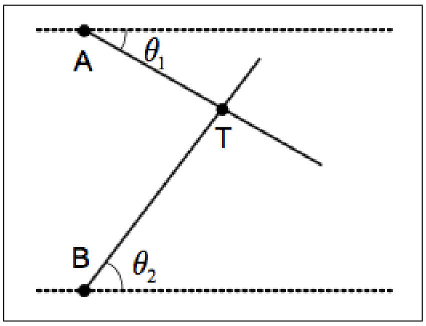

Figure 2.5: Triangulation-based positioning

Triangulation based localization methods use the location of at least three known points to determine the users location [**zheng2010smart**]. Lateration uses the distance between the user and at least three known points, whereas angulation uses the angular measurements from at least three known points to the user to determine the users location [**zheng2010smart**]. In the context of indoor areas, where GPS signals are significantly degraded, the received signal strength (RSS) of either a cell towers or wireless local area network (WLAN) nodes are used to triangulate the position. The precision of the process is generally degraded due to multi-path reflections [**fallah2013indoor**].

2.2.4 Pattern-Recognition

Pattern recognition based localization methods use data from one or more sensors carried or worn by the user and compare this perceived data with set of prior collected raw sensor data that has been coupled with an environment map. This map of sensor data can be created by sampling at different locations or by creating it manually [**fallah2013indoor**]. Most human navigation systems use a combination of different sensing techniques:

1. **Computer Vision** : While users navigate in an environment, a camera captures images of the environment, and then by matching the images against a database

of images with known location, users position and orientation can be determined. The camera captures images while the user navigates [**fallah2013indoor**]. Using image matching the users position and orientation can be determined [**fallah2013indoor**].

The accuracy of camera-based indoor localization systems has reached appreciable levels [**mautz2011survey**] (i.e., between 10-6 m and 10-1 for high precision systems). Moreover, the increase in both data transmission rate and computational capabilities, as well as the development of high performance image processing algorithm make this technology very efficient.

A drawback of this technology is that costs are still a bit high but, thanks to the new technologies, low-cost solutions are spreading and recently attention is increasingly directed towards localization systems that use camera-equipped mobile phones [**mautz2011survey**]. A disadvantage of this technique is the high storage capacity required for storing the images that are coupled with the environment map. Significant computing power may be required to perform the image matching [**mautz2011survey**], which may be challenging to implement on a handheld device. Users are often required to carry supporting computing equipment [**mautz2011survey**], which may impede their mobility.

2. **Fingerprinting** : is the most viable solution for RSS-based indoor localization and works by mapping the observed signal strength of fixed routers placed in the indoor environment into a database (i.e., the radio map) [**mainetti2014Indoorlit**]. The basic design of the fingerprinting method can be divided in offline stage and online stage. During the offline stage, RSS is collected at sampling locations to build the radio map for the specific environment. During the online stage, the physical location of the client can be estimated by comparing the measured RSS with the stored RSS values [**mainetti2014Indoorlit**].

2.2.5 Comparison among technologies

In order to choose the most suitable technology (or a combination of them) for the design and implementation of an indoor localization system, a comparison among the alternative technologies is very useful.

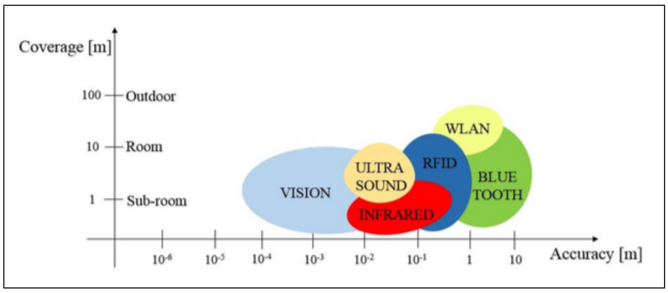

Figure 2.6: Comparison between indoor localisation technologies [**mainetti2014Indoorlit**]

In Table 2.1, some parameters have been selected for the comparison, i.e., accuracy, coverage, cost, complexity, and typical applicative environment. The values of these parameters have a purely indicative meaning as the real values, which depend on many factors, should be evaluated case by case. A graphical overview of all these technologies in dependence of accuracy and coverage is given in Figure 2.6. The scalability that many system approaches offer has not been taken into account.

		Parameters				
		Accuracy[m]	*Coverage [m]*	*Cost*	*Complexity*	*Typical Environment*
Technologies	*Vision*	$10^{-3}\div10^{-1}$	1-10	High	High	Indoor
	Infrared	$10^{-2}\div1$	1-5	Medium/High	Low	Indoor
	Ultrasound	10^{-2}	2-10	Medium	Low	Indoor
	Wi-Fi	$1\div10$	20-50	Medium/Low	Low	Indoor/Outdoor
	RFID	$10^{-1}\div1$	1-10	Low	Low	Indoor
	Bluetooth	$1\div10$	1-30	Low	Low	Indoor/Outdoor

Table 2.1: Comparison between indoor localisation technologies [**mainetti2014Indoorlit**]

2.3 Social Network Analysis (SNA)

A social network is defined as a social structure of individuals, who are related (directly or indirectly to each other) based on a common relation of interest [**sri2008SocialNEt**]. SNA is the study of social networks to understand their structure and behavior. Social network analysis has gained prominence due to its use in different applications - from product marketing (e.g. viral marketing) to search engines and organizational dynamics (e.g. management).

With the aim to identify high risk areas, SNA can play a pivotal role in making use of the mobility data of CF patients. Parameters such as 'dwell times', distance between each patient collected from the indoor positioning system can be used to determine high risk areas from cross infection. Specific to infection control, SNA has been applied to the study of infectious disease, including HIV and syphilis in human populations and *Mycobacterium bovis* in captive possums [**christley2005infection**].

Chapter 3

Methodology

3.1 PDR Implementation

As defined in Section 1, the design of the indoor positioning system is constrained to the android smart-phone environment. As identified in the literature review a PDR system consists of a simple cycle:

1. identify subsets of the data corresponding to individual step;
2. estimate the length of the step; and
3. estimate the step heading or change in heading.

For the android environment, the PDR design is described in Figure 3.1.

3.2 Experimental Methods

Experiments conducted so far have revolved around identifying an accurate PDR system. Hence, the experiments described below verify the PDR cycle.

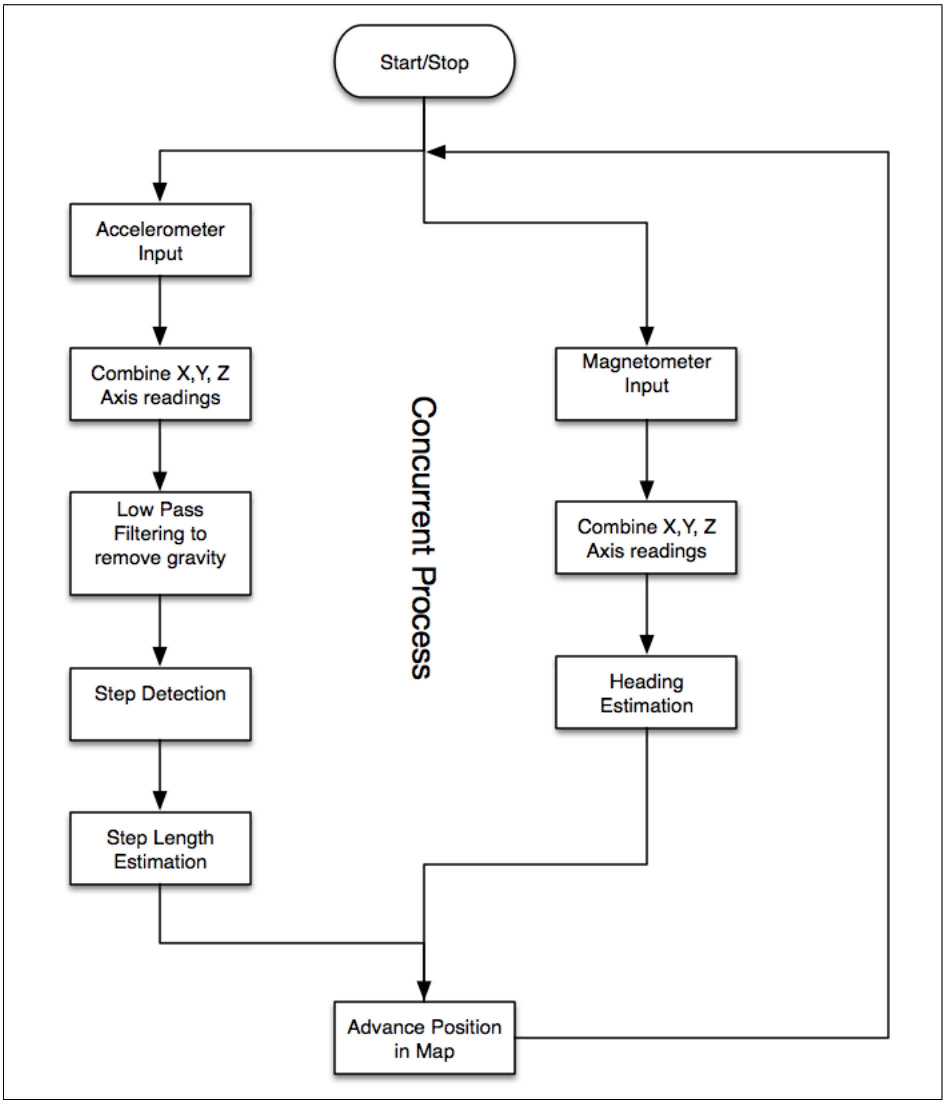

Figure 3.1: PDR Implementation

3.2.1 Step Detection Experiment

The step detection experiment will be conducted to verify that the algorithm implemented correctly detects a step. The user will walk a pre-defined number of steps with the smart-phone. The accelerometer data readings will be saved and the algorithm will be applied to the data. A correct system will be one that correctly identifies the number of steps taken. Appendix A showcases preliminary results of the conducted experiment.

3.2.2 Step Length Experiment

The step length experiment will be conducted to verify the correct distance walked by the user. The user will walk in a straight line for a pre-defined distance in metres. The accelerometer data readings will be saved and the algorithm will be applied to the data. A correct system will be one that correctly calculates the distance walked.

3.2.3 Map Matching Experiment

To test the complete PDR cycle,i.e., step detection, step length, heading estimation and experiment will be conducted where the user walks in a pre-defined path in the environment. The PDR algorithms will then be applied to the saved sensor readings and a historical path will be formed. The accuracy of the PDR system can be quantified by comparing the PDR path to the correct path. Appendix A showcases preliminary results of the conducted experiment.

Chapter 4

Results

Chapter 5

Conclusion

There is great motivation to combat HAIs not only for the patient's well being but also from fiscal perspective for the hospital. Estimates of the cost of these infections, suggest that the annual economic costs are $6.7 billion per year in the United States [**martone1992incidence**] and £1.06 billion (approximately US $1.7 billion) in the United Kingdom [**plowman2001rate**].

The literature review demonstrates that the area of indoor positioning is a highly promising field. Its use in the health care industry has been focused around positioning and process flows. However, this mobility data has the potential to be used in new and innovative ways such as the aim for this thesis.

The preliminary software design of the PDR system has shown promising results. More experiments need to be conducted in order to come to a definite conclusion on the accuracy of the PDR algorithms used.

5.1 Future Work

This progress report lays the foundation for the successful completion of the following areas of work. Figure 5.1 graphically outlines the planned future activities.

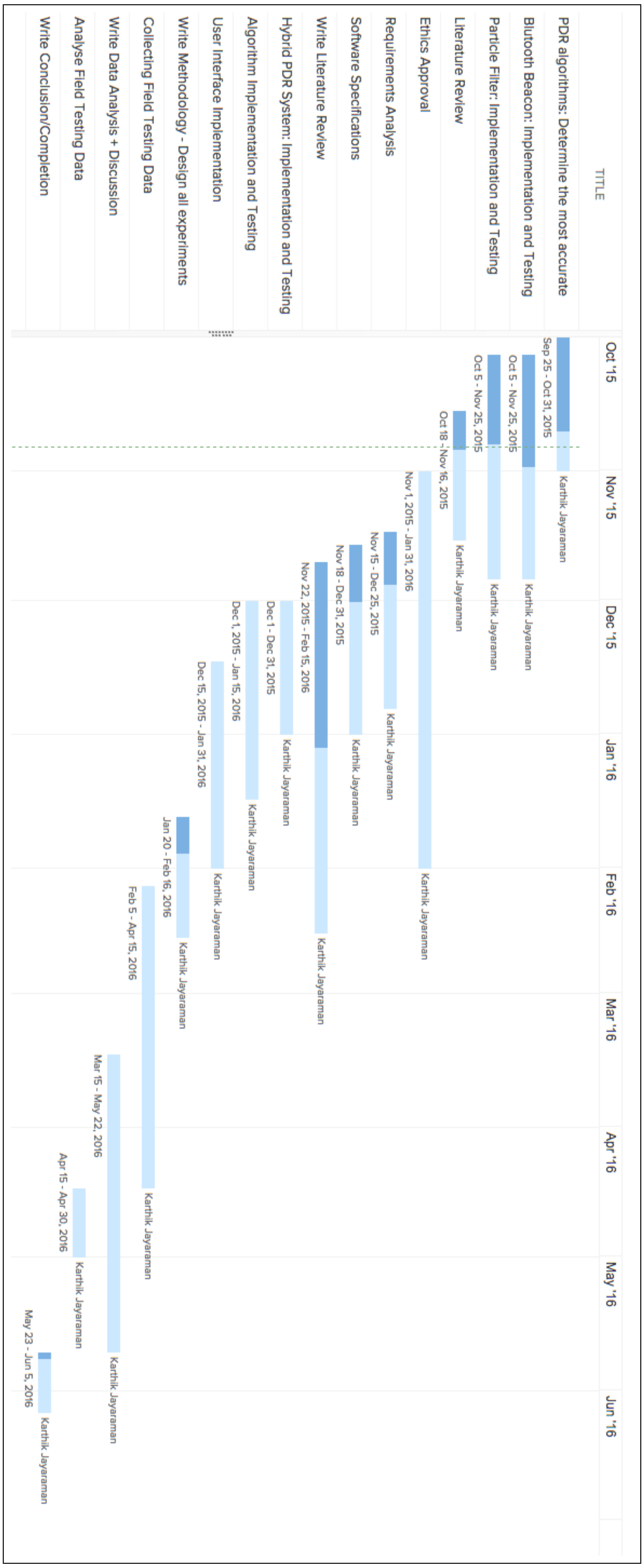

Figure 5.1: Thesis Plan

5.1.1 PDR Design

The PDR system requires further analysis and testing to determine an accurate result. This involves further experimentation using various algorithms for step detection, step length calculation and heading estimation.

As with any PDR, drift is inevitable hence direct sensing technologies such as bluetooth beacons along with bayesian filters such as particle filters need to be incorporated to create a hybrid PDR system. This hybrid system will require further analysis and testing for verification and validation.

5.1.2 SNA

SNA implementation has not been conducted for Thesis A, hence it will form a core part of Thesis B activities. The main task include:

1. Further study of literature on SNA, specific to disease control and transmission
2. Identifying algorithms that can be used to determine high risk areas
3. Software implementation of the said algorithms
4. Experimentation and testing to verify and validate the correctness of these algorithms

5.1.3 Software Design

The final outcome for this thesis is to create a software package that incorporates both the PDR and SNA. A simple waterfall model approach was taken for the design of the PDR system. For future work, a more rigorous approach will be taken (possibly using the Agile Method) to identify and create the key components of the software system.

5.1.4 Field Testing

After successfully verifying and validating the software system, more specifically the PDR system. It is planned that these components be implemented in the hospital environment. The data collected from these tests can be used to verify the robustness of the software system as well as experimentations on SNA.

Appendices

Preliminary Results

This section outlines preliminary results collected during experimentation. Repeated testing is planned to improve the experimentation process.

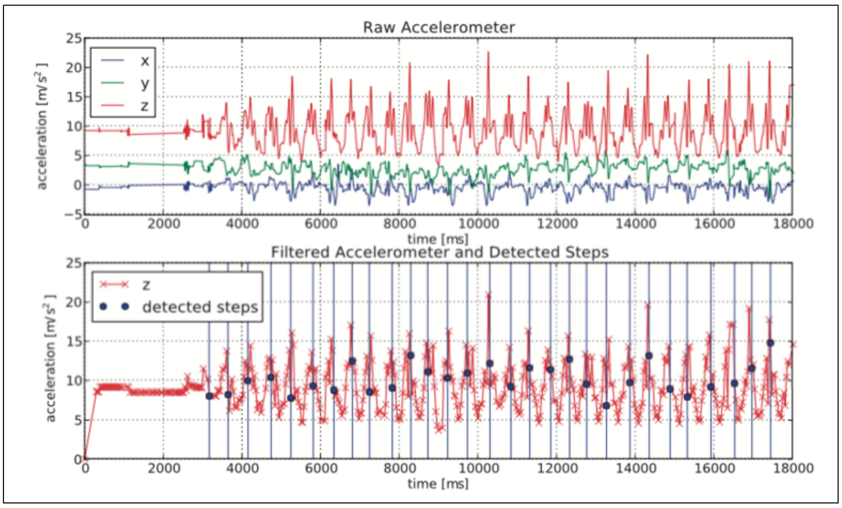

Figure A.1: Preliminary step detection with peak detection algorithm

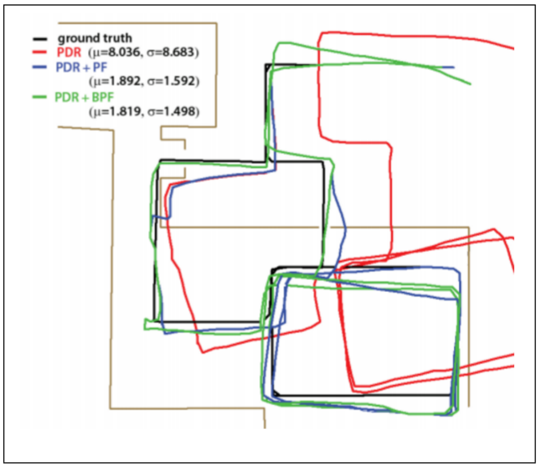

Figure A.2: Preliminary map matching of the PDR and hybrid PDR systems

Screen Shots

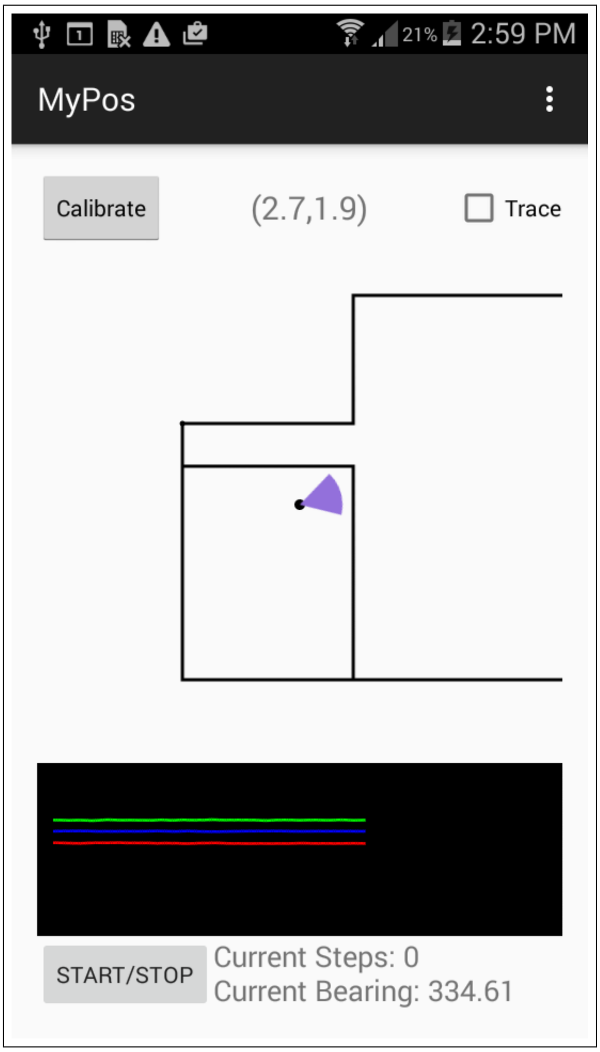

Figure B.1: Calibration stage of the RTLS android app

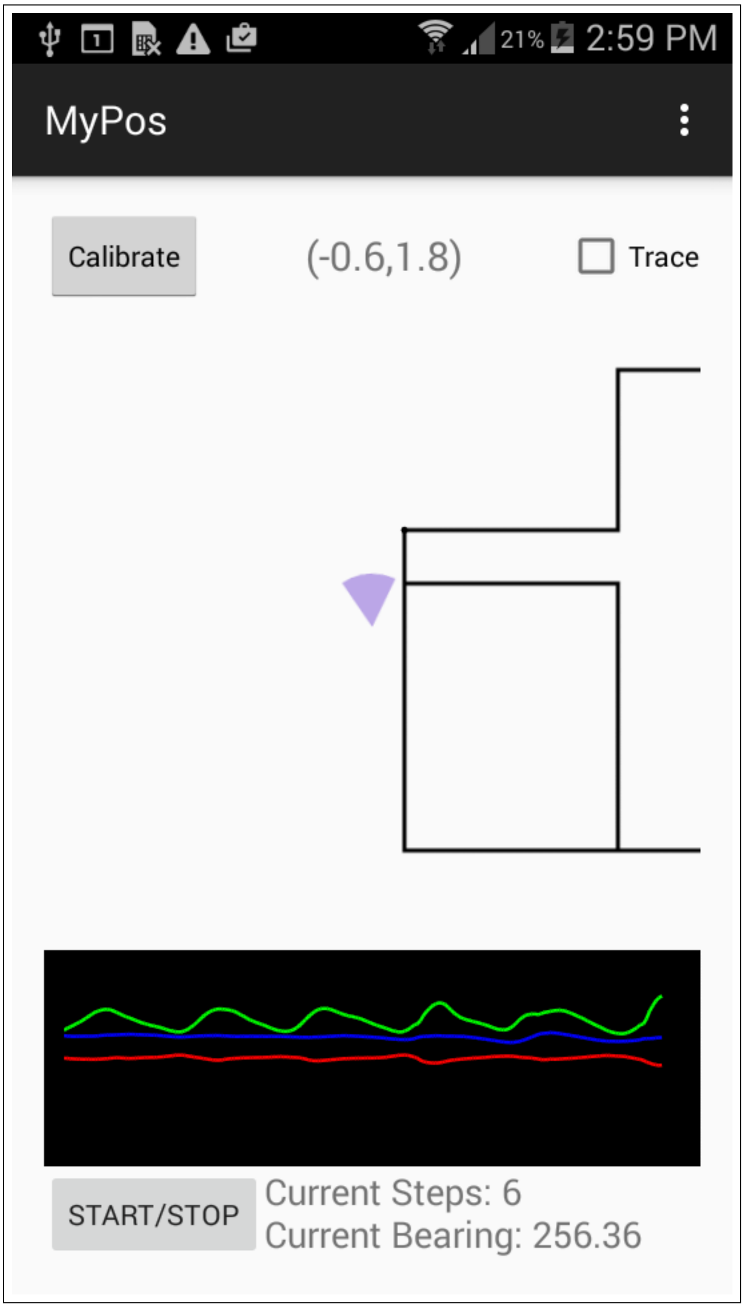

Figure B.2: Run stage of the RTLS android app