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A smart phone based expert system for airport screening of infectious diseases: test case with the Ebola virus symptoms

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A Smart Phone Based Expert System for Airport Screening of Infectious Diseases: Test Case with the Ebola Virus Symptoms

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Declaration and Approval

Declaration

I declare that this work has not been previously submitted and approved for the award of a degree by this or any other University. To the best of my knowledge and belief, the dissertation contains no material previously published or written by another person except where due reference is made in the dissertation itself.

Dickson Odhiambo Owuor

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Approval

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Abstract

The outbreak of infectious diseases such as Severe Acute Respiratory Syndrome, Influenza and Ebola require that border screening measures be instituted especially at the airports in order to minimize the risk of spreading these infectious diseases by passengers from one country to another. In the case that there is a reported outbreak of an infectious disease in a certain region; people traveling from the affected areas should be screened for the infectious disease's symptoms before being allowed to mingle with any unaffected population. During the 2014/2015 Ebola outbreak in West Africa, health workers at the major airports of most countries were supposed to diagnose the travelers' symptoms for the Ebola virus disease in person, and decide if the traveler should be allowed into the country or if the traveler should be isolated in order to undergo further Ebola virus disease tests. This process puts the health worker at the risk of coming into contact with infected travelers and it is also inefficient especially when presented with a large group of travelers. This work presents a smart phone based screening expert system for the Ebola virus disease that can be used at the airports. The expert system uses a temperature sensor and a mobile application to capture the symptoms of the traveler. This inference symptoms are analyzed in relation to a knowledge base in the expert system and the generated results are sent to a health worker's smartphone device. The proposed system's execution is spread across the following technology platforms: the Web platform, the Android platform, and the Java platform.

Key words: *Infectious Disease, Ebola, Artificial Intelligence, Expert System, Border Screening, Airport, Smart Phone.*

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List of Abbreviations

3G	Third Generation
4G	Fourth Generation
AI	Artificial Intelligence
AODA	Automatic Outbreak Detection Algorithms
API	Application Programming Interface
bioMEMS	Biomedical Micro-electromechanical Systems
C	Celsius
CDC	Centers for Disease Control and Prevention
CEO	Chief Executive Officer
DFD	Data Flow Diagram
DRC	Democratic Republic of Congo
E-Mail	Electronic Mail
ERD	Entity Relationship Diagram
EVD	Ebola Virus Disease
F	Fahrenheit
GCM	Google Cloud Messaging
GSM	Global System for Mobile Communications
GSMA	GSM Association
HTML	Hypertext Markup Language
IC	Integrated-circuit
ID	Identification Number
IE	Inference Engine

IR	Infra-red
JKIA	Jomo Kenyatta International Airport
KAA	Kenya Airports Authority
KB	Knowledge Base
MEMS	Micro-electromechanical Systems
ms	Milliseconds
NCIT	Non-Contact Infrared Thermometer
OS	Operating System
PDA	Personal Digital Assistant
PHP	Hypertext Preprocessor
RNA	Ribonucleic Acid
SARS	Severe Acute Respiratory Syndrome
SQL	Structured Query Language
UML	Unified Modelling Language
URL	Uniform Resource Locator
USB	Universal System Bus
WHO	World Health Organization
WWW	World Wide Web

Definition of Terms

Android	A popular smart phone operating system that is developed by Google
Browser	A program installed on a computer or mobile device in order to allow it to access and display website pages.
Expert System	An artificially intelligent system
Hemorrhage	Bleeding or bruising
Inference Engine	A rule-based model in an expert system that performs automated reasoning
Knowledge Base	A collection of information in an expert system concerning a particular domain
Mobile phone	A hand held telephone device
Phone Application	A software that runs on top of a phone's operating system
Port Health	A division of the Ministry of Health of Kenya responsible for disease surveillance and public health control at all points of entry at the airport.
Precept	An Intelligent Agent's perceptual inputs at any given instant
Smart phone	A fully featured high-end mobile phone featuring PDA capabilities
Tablet	A large but portable device featuring smart phone capabilities
Virus	An infectious agent of small size and simple composition that can multiply only in living cells of humans, animals, plants or bacteria.
XAMPP	**X** (acronym for any Operating System), **A**pache web server, **M**ySQL Database, **P**HP Language and **P**erl
Web	a complex Internet system of interconnected elements
Website	An online page that can be accessed from the Internet

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I thank my supervisor Dr. Joseph Orero for guiding me through this research study. I thank Mrs. Harriet Koyoson and Dr. Almeida of the Strathmore Clinic for their professional assistance. I thank Strathmore University and all its staff. Finally, I give God Almighty all the honor and glory for this far that He has brought me.

Dedication

To my family, friends, classmates and everyone else that assisted me.

Chapter One: Introduction

1.1 Background

Infectious diseases that have no cure or vaccine always throw governments all over the World into panic; since, they can very easily be spread from one country to another and cause huge numbers of fatalities. In particular, the Ebola virus disease formerly known as Ebola hemorrhagic fever is a severe often fatal illness in humans. The virus is transmitted from wild animals and spreads in the human population through human-to-human transmission. The average EVD case fatality is around 50%. There are currently no licensed Ebola vaccines but 2 potential candidates are undergoing evaluation (WHO Media Center, 2014).

Following the 2014/2015 Ebola virus outbreak, World Health Organization recommended several precautionary measures that were to be implemented by airports all over the world. This Ebola virus outbreak caught most airports unprepared; hastened border screening systems were put in place in order to institute the recommended precautionary measures. Kenya Airways is among the airports that instituted additional precautionary measures following the 2014/2015 Ebola outbreak in parts of West Africa (Kenya Airways, 2014). The institution of the precautionary measures by JKIA saw that health workers were provided with hand-gun thermometers, gloves, hand sanitizers and other special equipment to enable them to screen passengers traveling from Ebola-hit countries.

Considering the current screening system that was employed at JKIA during the 2014 West Africa Ebola outbreak, health workers wore the gloves and used hand sanitizers in order to prevent the exchange of body fluids through contact with passengers. The hand-gun thermometers were used detect passengers with fever. However, the same health workers complained of the following: poor equipment especially the unreliability of the gun thermometers that were provided, lack of follow-up on passengers and low morale (Sylvie Briand et al., 2014).

This research work proposes a smart phone based EVD screening system that uses a different IR temperature sensor to automate the screening process at the airport. The proposed system uses the IR temperature sensor and a Mobile Web application to capture the symptoms of the passenger. The proposed system uses an AI expert system to analyze the symptoms presented by the passenger and generate a screening report.

The proposed system was tested on 32 people and they were asked to rate the performance of the proposed system in comparison with the current systems. 31% of the participants were extremely positive, while 69% of the participants were very positive that the proposed system is efficient.

1.2 Statement of the Problem

Infectious diseases that have no cure or vaccine require the implementation of outbreak containment measures to prevent them from spreading fast. According to WHO, Media Centre (WHO Media Center, 2014): "outbreak containment measures include: prompt and safe burial of the dead; identifying people who may have been in contact with someone infected with Ebola; monitoring the health of contacts for 21 days; the importance of separating the healthy from the sick to prevent further spread; the importance of good hygiene and maintaining a clean environment."

Considering the current screening process that was implemented during the 2014 Ebola outbreak in West Africa by airports in particular JKIA, health workers were equipped with at least one hand-gun thermometer in order to measure the body temperature of the passengers. Passengers with fever were isolated in order to undergo further Ebola checks. The contact details of the passengers were recorded in surveillance forms by the passengers themselves, and the responsible staff were supposed to use the details in these forms to make follow ups on the health of these passengers (Kenya Airways, 2014).

The current screening process requires that each passenger be personally screened and diagnosed for the Ebola symptoms by at least one health worker at a time, this makes the process slow in identifying travelers that show Ebola symptoms especially when presented with a large group of travelers (Kenya Airways, 2014). Since a paper record keeping system is used for managing the surveillance forms, it becomes cumbersome to retrieve the contact details that are to be used to make follow up on the health of screened travelers from Ebola-hit countries as required.

1.3 Research Objectives

i. To review the current challenges faced by health workers at the airport while screening for EVD symptoms.

ii. To explore how infectious disease detection can be automated by use of expert systems.

iii. To propose an efficient smart phone based border screening expert system for EVD.

iv. To test and implement the proposed border screening expert system for EVD.

1.4 Research Questions

i. What are the challenges faced by health workers at the airport while screening for Ebola virus disease symptoms?

ii. How can infectious disease detection be automated by use of expert systems?

iii. How can an efficient smart phone based border screening expert system for EVD be designed and developed?

iv. How can the proposed border screening expert system for EVD be tested and implemented?

1.5 Justification

The proposed system will only require the installation of a single IR temperature sensor which will be used to detect the body temperature of all the passengers. This will reduce significantly the cost of implementing the border screening system by the airport management board. The proposed system will automatically capture the temperature of the passenger and also enable the passenger or health worker to use his/her smart phone to enter the passenger's contact details together with the other Ebola related symptoms that they exhibit. This will eliminate the use of surveillance forms, which are pieces of papers that are used to collect the contact details of passengers.

The proposed system will automatically diagnose the symptoms presented by the passenger using an expert system and present the screening results to the health worker through a smart phone device. Therefore the health worker will only be required to decide if the passenger should be isolated for further Ebola tests or be allowed to proceed with his/her journey. This will make the screening process extremely fast relative to the current screening systems.

The proposed system will as well provide the airport management board with a web-based management system to enable them to monitor the records of screened passengers and screening equipment. The management system will replace the paper record keeping system which is cumbersome with an electronic database system which is flexible, dynamic and easy to use.

1.6 Scope of the Study

This research study focused on exploring and developing an expert system for detecting infectious diseases, in particular the Ebola virus disease, from the symptoms presented by the passenger. The other focus of the research study was to find a different IR temperature sensor that can be used to develop an automated screening system for infectious diseases at the airport.

1.7 Limitation of the Study

This research work only covered how EVD symptoms can be automatically detected by use of an automated smart phone based screening system. The system developed was limited to the diagnosis of EVD from the symptoms presented by a passenger at the airport. This research work did not cover diseases other than EVD. The research as well limited its research target area to JKIA, because it is the border point in Kenya that handled the largest number of travelers from other countries (Kenya Airports Authority, 2015).

1.8 Summary

In this chapter we have discussed how important it is to put in place outbreak containment measures in case there is a reported outbreak of an infectious disease that has no cure. In particular, we explored the Ebola virus disease; how deadly it is; and, how fast it can spread if there is slow response to its outbreak. It has also been seen that the current screening systems are not efficient enough when screening for the EVD symptoms at the airports and making follow ups on the health of travelers from Ebola-hit countries after 21 days as required.

Chapter Two: Literature Review

2.1 Introduction

This chapter reviews: the characteristics of infectious diseases especially the Ebola virus disease and what has been done currently to curb the spread of Ebola; the emergence of the mHealth field and how fast it has gained popularity; the enabling technologies for automatic disease detection; types of temperature sensors that can be used for EVD screening.

2.2 The Ebola Virus Disease

Four species of Ebola virus have been identified: Ivory Coast, Sudan, Zaire, and Reston (CDC, 2015). Ebola being an RNA virus like HIV and Influenza has a high rate of mutation. That makes the virus more able to adapt and raises the potential for it to become even more contagious (Hoenen. T et al., 2015). The Ebola virus strain that caused the 2014/2015 outbreak in West Africa belongs to the Zaire species (WHO Media Center, 2014). During the 2014/2015 outbreak more than 22,000 people were infected with Ebola and at least 8,795 people have died in Guinea, Sierra - Leone and Liberia. Figure 2.1 is an infographic of the EVD following the 2014/2015 outbreak in West Africa.

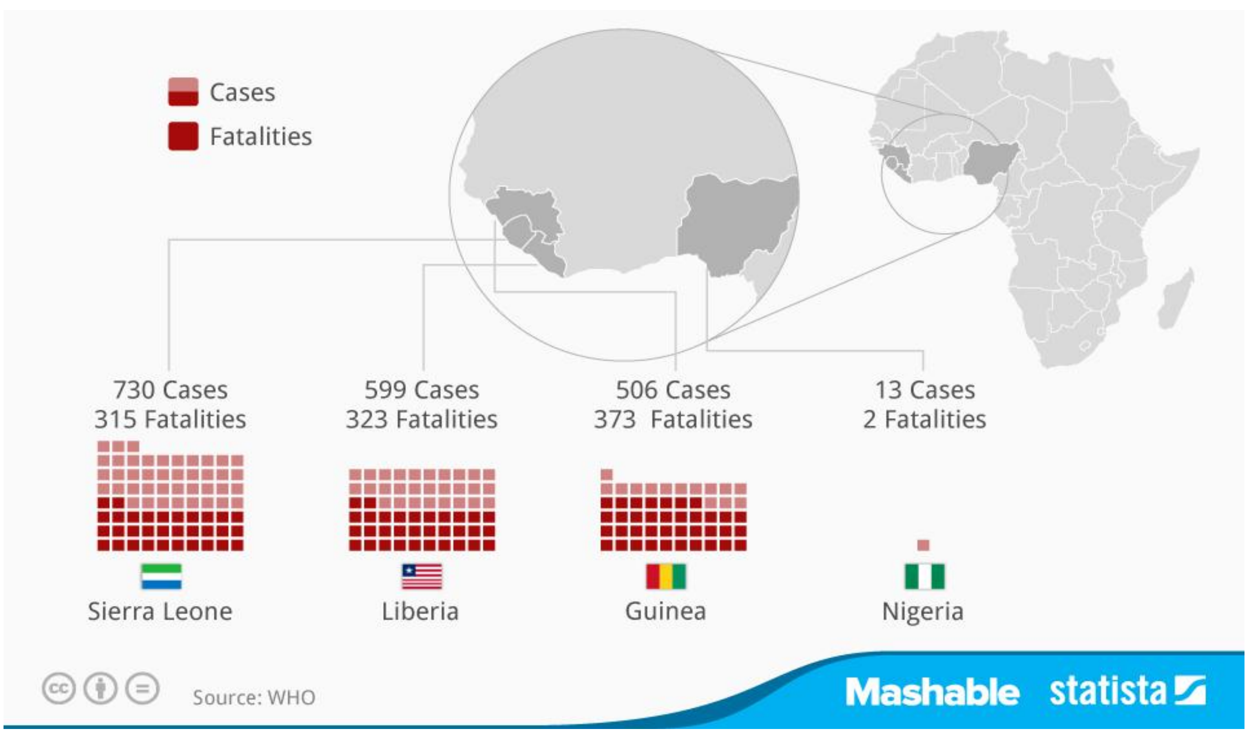

Figure 2.1: Infographic of 2014/2015 Ebola West Africa Outbreak (Statista, 2014)

2.2.1 Transmission, Symptoms and Diagnosis

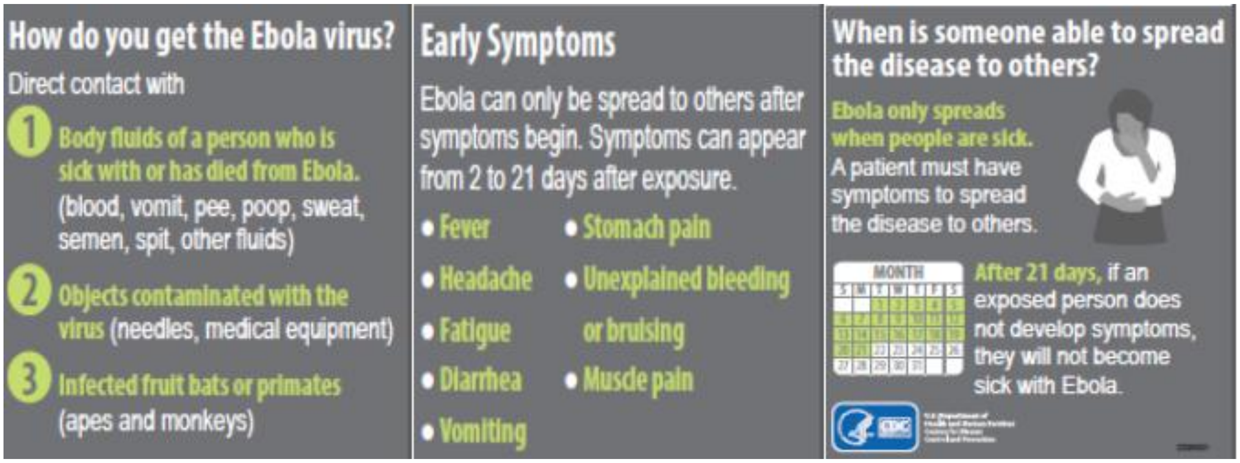

Figure 2.2: Ebola Virus Symptoms Summary
CDC (2014)

The infographic depicted in Figure 2.2 gives a summary of: the ways through which Ebola Virus can be transmitted; the early symptoms in case of an infection by the Ebola Virus; when can an infected person spread the virus and for how long should an exposed person be monitored in order to make sure that he/she does not become sick with Ebola.

2.3 Border Screening of Infectious Diseases

2.3.1 Border Screening Measures

According to Selvey et al., (2015) the border measures instituted by many countries in response to infectious disease outbreaks: such as the SARS of 2003, the influenza pandemic of 2009, the Ebola virus epidemic in 2014 are resource intensive: high opportunity costs, both financially and in terms of the use of scarce public health staff resources at a time of high need. Modeling and observation studies indicate that border screening is not effective at detecting infectious persons. Border measures usually consist of a combination of border entry/exit screening, quarantine, isolation and communications. Border measures are usually implemented to delay or prevent the entry of infected persons into a country/geographic area or to prevent global spread of a disease from a source country. Border screening measures according to Selvey et al., (2015) has the following benefits:

i. Detecting possibly infectious persons at the border, either on entry to or exit from a country, so that they can be placed in isolation or prevented from traveling and spreading the disease elsewhere.

ii. Increasing public awareness about and confidence in protection from the disease in question.

During infectious disease outbreaks, the World Health Organization usually recommends border screening of travelers from affected areas. Border screening can be undertaken through self-identification by means of health declaration cards; airline or transit agency notification to health authorities of sick passengers; visual inspection of travelers; fever screening of travelers which is implemented through the use of infrared thermal image scanners.

Selvey et al., (2015) conclude that border screening should not be used, and instead they recommend that: the less costly measure of providing information to arriving travelers should be used together with effective communication with local clinicians; and more effective disease control measures in the community. However, if border screening could be done automatically with less health staff intervention, then it would be less resource intensive and highly beneficial.

A research study conducted by Straetemans et al., (2008) whose aim was to determine the efficacy of automatic outbreak detection algorithms in Germany; suggested that the usefulness of automatic outbreak detection algorithms to detect local outbreaks was limited because local health departments generally detected outbreaks earlier an in more detail than those algorithms.

Straetemans et al., reviewed the electronic system called SurvNet that was implemented by Germany's federal institute in 2001 for notifiable infectious disease surveillance. The system allowed local health departments to send electronically reports of confirmed cases to the state health departments. On the other hand, Automatic outbreak detection algorithms ran weekly on those case-based data and generated signals when the observed number of cases per specific week was higher than a defined threshold value. The goal of the study was to access the probability that a signal generated by automatic outbreak detection algorithm reflected a real outbreak being reported by local health department.

The conclusion of the research study conducted by Straetemans et al., (2008) only re-enforce the recommendations made by Selvey et al., (2015); that their should be effective communication with the local clinicians and more effective disease control measures should be implemented at the community level. However, this is a preventive measure against infectious diseases; in the case that an outbreak of an infectious disease has occurred, curative measures should incorporate border screening measures which is usually recommended by the World Health Organization.

2.3.2 Border Screening Systems Used by Airports

a) Taiwan

Taiwan provided its airlines with an Ebola Declaration Form which was to be distributed to the passengers. The declaration form was used to obtain the travel history of the passengers and passengers were required to fill out the form truthfully (Press Releases CDC Taiwan, 2014).

b) Singapore

Singapore as well instituted additional screening measures against the Ebola virus following the 2014/2015 West Africa Ebola outbreak. One of the measures required that all passengers were to fill a Health Declaration Card, which included their contact details in Singapore (Press Releases, MOH Singapore, 2014).

c) Kenya

According to the letter from Kenya Airways (2014) all passengers traveling from Ebola-hit regions such as Free Town, Monrovia, Accra, Lagos and Abuja were to undergo temperature checks at the points of departure. All passengers were required to complete a surveillance form while still on board to supply adequate information for tracking them down. A division of the Ministry of Health responsible for disease surveillance and public health control at all points of entry, were supposed to regularly inform the various County Health teams of persons who have traveled to their county as per the surveillance forms.

Almost all the countries of the world required their major airlines to institute additional precautionary measures in order to minimize the chances of importing the Ebola virus into their countries through passengers. However, it should be noted that this did not completely eliminate the risk of spreading the Ebola virus from one country to another. For example, even though Kenya Airways had instituted these precautionary measure, Kenya was still ranked among the top countries who were at the risk of importing Ebola virus disease from affected countries. Figure 2.3 is an infographic of the probability of Ebola importation risk that was prepared by (Mobs Lab, 2014).

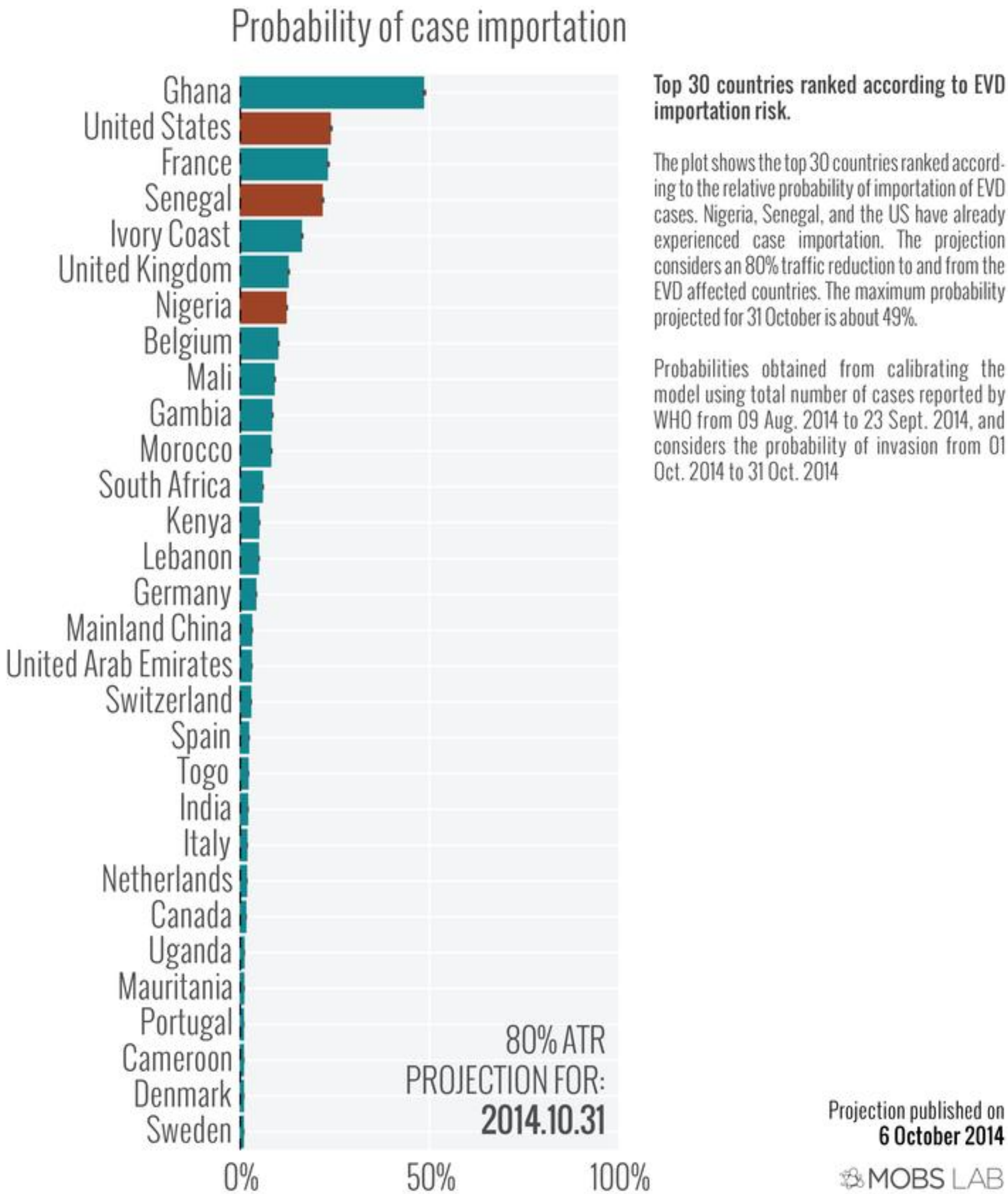

Figure 2.3: Infographic of Ebola Case Importation Risk
(Mobs Lab, 2014)

2.4 M-Health

E-Health is an emerging field in the intersection of medical informatics, public health and business; referring to health services and information delivered or enhanced through the Internet and related technologies. M-Health is also another field that has emerged as a sub segment of eHealth. M-Health is a term used for the practice of medicine and public health with the support of mobile devices Meier et al., (2013). Mobile devices include portable devices such as mobile phones, smartphones, tablets and PDAs.

Application of mHealth include the use of mobile devices in collecting community and clinical health data; delivering health-care information to practitioners, researchers and patients; monitoring patient vital signs in real time; and directly providing care via mobile telemedicine Meier et al., (2013). Apart from developed countries, the mHealth field is also emerging rapidly in developing countries because of the fast rise of mobile devices penetration in these countries. The exponential growth of the usage of mobile devices in developing countries provides a good platform for mHealth systems to be used to provide greater access to health-care services to larger segments of the population, as well as improving the provision capacity and quality of these health-care services. The extensive use of mHealth services is a deep assurance for this research for easy implementation of the proposed smart phone based screening system.

2.5 Expert Systems for Automatic Disease Detection

An expert system is an artificially intelligent system that analyzes and classifies a set of observed data, in order to draw conclusions from the pattern identified using prior knowledge (Russel and Norvig (2010). An expert system is an implementation of an AI agent program whose function is to map percepts to actions. Figure 2.4 shows an AI agent that can be used to implement a medical expert system.

The proposed border screening expert system is designed to infer an Ebola infection from the symptoms presented by a patient. The analysis and classification of the symptomatic data is challenging because it has to be done in the face of uncertainty; this is because datasets or precepts are usually noisy, incomplete, and prior knowledge may be inconsistent with the measurements (Sajda, 2006). However, if the expert system is able to learn from statistical patterns and prior knowledge, then the system can be used with a high degree of trust.

2.5.1 Parts of an Expert System

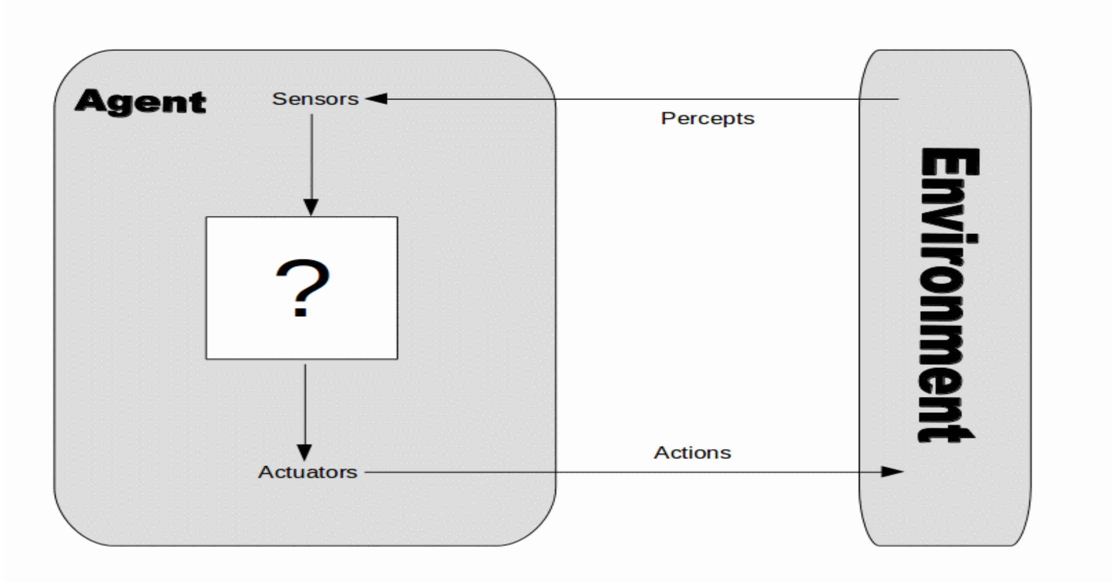

Figure 2.4: An Artificial Intelligent Agent
Russell and Norvig (2010)

The question mark image between the sensors and the actuators in Figure 2.4, represents the inferential framework and it performs automated reasoning for the expert system. This component uses information stored in the knowledge base to draw conclusions from the inference rules. Figure 2.5 illustrates in detail the parts of the proposed border screening expert system.

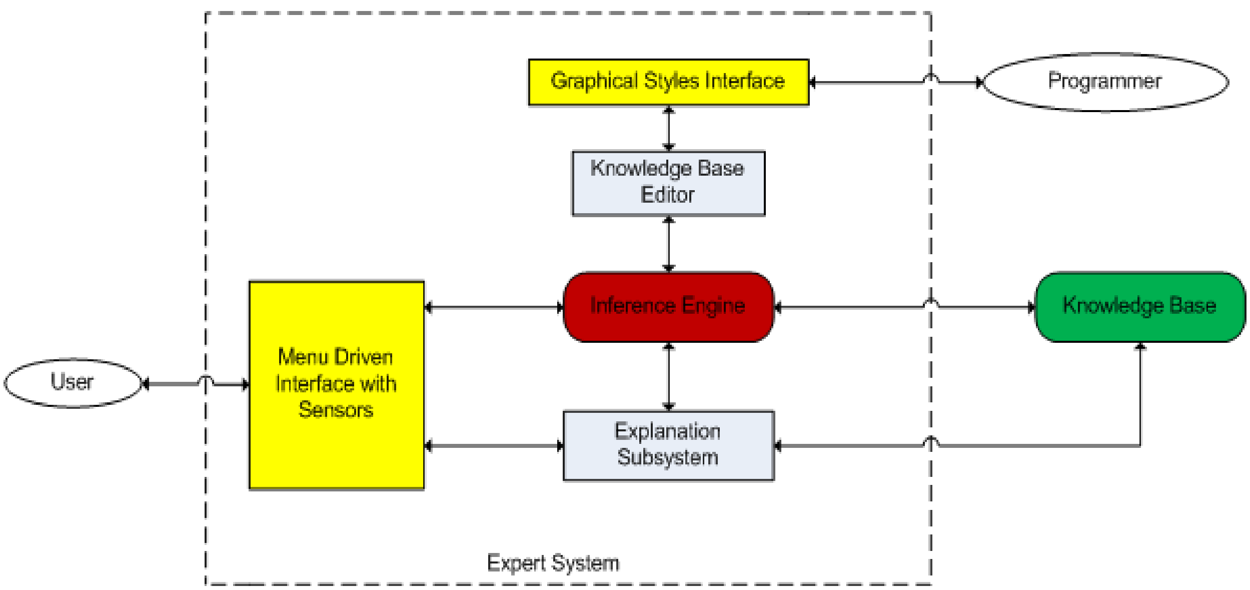

Figure 2.5: Parts of an Expert System
(Luger, 2005)

2.5.2 Expert Screening System for Ebola Virus Disease

The actual parts of the proposed border screening expert system were derived from the AI concepts discussed by Luger (2005). Figure 2.5 was design these parts.

a) User

The user in this case the traveler interacts with the expert system through a menu driven interface and a temperature sensor application to capture his/her symptoms. The menu driven interface is implemented using a mobile web application.

b) Knowledge Base

The knowledge base contains information of a particular domain. It contains both general information concerning fever detection and case specific information which is the Ebola virus symptoms. The EVD symptoms stored are: fever, headache, fatigue, stomach pain, vomiting, diarrhea, muscle pain and unexplained bleeding. The fever information stored is the temperature range for normal body temperature, fever and high fever. This two pieces of information are stored in web PHP file.

c) Inference Engine

The inference engine applies the knowledge in the knowledge base to the solutions of the actual problems. It performs the recognize-act control cycle. It determines if the traveler has fever from the temperature data presented by the sensor application; it does this by normalizing the temperature data received to an acceptable medical range before comparing it to the range in the knowledge base.

It also calculates the chances of a traveler being infected with the Ebola virus from the symptoms presented by him/her; the inference engine does this by selecting the weighted values of the symptoms matching those presented by the traveler and summing them up. Further calculations are done on this sum to obtain the chances of the traveler having EVD as a percentage. However, the medical logic used for weighting the symptoms needs to be approved by a medical expert so that the inference engine does not misdiagnose the travelers. For this research a personal interview was conducted on a medical expert to approve it. This component is executed using a backend PHP script program.

d) Explanation Subsystem

The explanation subsystem allows the expert system to explain its reasoning to the user by justifying the system's conclusions. It sends the traveler screening results to the health worker's smart phone device. This component is implemented using and Android application together with a backend PHP script.

e) Knowledge-Base Editor

The knowledge base editor enables the programmer to locate and correct bugs in the expert system performance. It as well enables the programmer to update the knowledge base with new information about the concerned domain.

In conclusion, expert systems require input sensors to allow them to automatically observe changes in the environment that they are monitoring. IC technology provides methods of developing extremely reliable micro-sensors that can be used by these expert systems.

Figure 2.6: An Arduino Micro-processor
Arduino (2015)

Micro-processors such as Arduino shown in Figure 2.6, Raspberry pie among others and bioMEMS can be integrated into a medical expert system so that it can automatically diagnose, detect and treat diseases. According to Polla et al., (2000) application of IC bioMEMS materials and processing technologies hold the promise of inexpensive health care devices, because they can be manufactured in batch quantities.

2.6 Infra-red Temperature Sensors

One of the most common symptoms exhibited by a person that has been infected by the Ebola Virus is high fever. Fever screening can easily help the health workers isolate passengers who might have contracted the Ebola Virus for further testing and confirmation (WHO Media Center, 2014). According to CDC (2014), the average normal body temperature is 98.6^{o}F or 37^{o}C. Fever is a measured body temperature above normal. For Ebola, a fever of 101.5^{o}F or 38.6^{o}C or higher is considered significant. The IR temperature sensor used for screening should be able to accurately and consistently measure temperatures within this range.

According to a research done by Department of Paediatrics, Kwong Wah Hospital (2005), the normal range of forehead temperature detected by most non-contact Infra-red thermometers is between 31.0 C degrees to 35.6 degrees C. Forehead temperature in excess of 35.6 degrees C is suggestive of fever. The research done by Department of Paediatrics also confirmed that Infra-red temperature measurements have reasonable accuracy in detecting fever. Since the normal medical body temperature is between 36^{o}C to 37^{o}C (CDC, 2014); the IR temperature body range needs to be normalized upwards to a reasonable medical range. The normalization should be done so that health workers using the IR temperature sensors are not misguided by the detected temperature values into misdiagnosing the passengers.

2.6.1 Non-Contact Infrared Thermometer

Figure 2.7: Nubee Temperature NCIT
CDC (2014)

NCITs are the thermometers recommended by CDC (2014), for use in port of entry screening. They allow the health worker to take the passenger's temperature without touching them. They are accurate and retail at approximately USD 17.21 apiece (Nubee, 2015).

The NCIT are usually held 1.2 and 6 inches or 3 to 15 cm from the body. Airports are advised to use NCIT that have been approved by one of the country's trusted body.

2.6.2 MLX90615

Figure 2.8: MLX90615 Infra-Red Thermometer
Melexis (2015)

This is an IR thermometer for non-contact temperature measurements. It is digitally calibrated with a resolution of 0.02^{o}C (Melexis, 2015). It retails approximately at USD 10.36 apiece.

MLX90615 is usually used with an Android IOIO board that retails at approximately USD 75. When used together temperature measurements can be sent directly to an Android smart phone.

2.6.3 Phidget 1045

Figure 2.9: Phidget IR Temperature Sensor
Phidgets (2015)

This is an intelligent non-contact temperature sensor with a 10^{o} field of view and a USB interface for easy connection to a computer. It outputs a continuous data flow after every 32ms with an active alarm running in the background (Phidgets, 2015). The sensor's software can be executed on top of most operating system environments. It retails approximately at USD 75.

2.6.4 Comparison of Temperature Sensors

Although NCIT, is the most commonly used thermometer at airports for screening passengers; it is costly to implement a screening system using them because each health worker will be required to have at least one NCIT. Since NCIT are not designed to communicate with a computer or a smart phone device; it makes it difficult to design a fully automated online system based on them.

The MLX90615 temperature sensor on its own cannot be used capture temperature data from a passenger. It has to be used in conjunction with an Android IOIO board in order to capture a passenger's temperature and send it to an Android device. The connection and the configuration of the MLX90615 temperature sensor with an Android IOIO board has to be done manually by the developer. This makes it complex to implement especially on a large scale basis.

The Phidget 1045_1 comes fully integrated on an Integrated-circuit board, which runs a program that can send temperature data to a connected computer after every 32 milliseconds. The board has a USB interface to connect it to a computer. It is also designed to send temperature data to a computer operating on either a Linux OS, Windows OS of Macintosh OS. The source code for operating this sensor is provided by the manufacturer in Java, C, C++, C# and many other programming languages. This research settled on the Java source code and modified it to meet the specific requirements of the proposed border screening system.

All the three temperature sensors reviewed meet the requirements for accurately measuring body temperature. However, Phidget 1045 is the recommended temperature sensor for this research work. Its outstanding ability to communicate with a computer can be leveraged to develop a smart phone based infectious disease screening system.

2.7 Related Works Concerning EVD

2.7.1 Related Efforts Put Forth to Eliminate EVD

There has been a lot of development by people towards reducing the number of fatalities caused by the EVD. As an example part of this research work is exploring the possibility of developing an automatic EVD screening system. Many other researchers in the world are also working to develop better equipment for laboratory testing; the quest for finding a cure for the Ebola virus is still strong; better containment methods are also being developed and adopted.

a) OpenMRS

According to an article posted by Ellen Ball (2014) OpenMRS started the Ebola Treatment Center project whose aim is to harness the community, and the power of the existing OpenMRS platform to optimize the care of patients with Ebola while maintaining infection control procedures to prevent transmission of the EVD.

b) New Ebola Treatment

University of Toronto through their Media Room, Michael Kennedy (2014) announced that it had combined forces with Chematria and IBM in the quest to find new treatments for the Ebola virus. This project leverages on a virtual research technology invented by Chematria, which is a drug discovery platform based on the science of deep learning neural networks, and IBM’s super-computers to find promising drug candidates.

c) HealthMap

HealthMap is another project that is being worked on by a team of researchers, epidemiologists and software developers at Boston Hospital. It utilizes online informal sources for disease outbreak monitoring and real-time surveillance of emerging public health threats. This platform can be used to detect the outbreak of EVD very fast, at its onset (Health Map, 2006).

2.7.2 Similar Mobile Phone Application

Smart phone application stores especially Google Play has a lot of smartphone applications that do something about EVD. Most of these applications are prank applications. However, there are also smart phone applications that have been developed with the genuine intention of trying to reduce the number of fatalities that Ebola Virus outbreaks claim.

a) HealthMap: Outbreaks Near me

HealthMap Android application was developed by HealthMap. It provides all the HealthMap's latest real-time disease outbreak information to the user. The application enables users to see all current outbreaks in their neighborhood, including news about H1N1 influenza or swine flu. Users are able to search and browse reports on an interactive map, set the application to alert him/her with a notice when an outbreak is occurring in his/her area (HealthMap, 2015).

b) Ebola Prevention App

Ebola Prevention Android application was developed by CloudWare Technologies. It enables users to view Ebola affected areas in a map, it gives users tips on preventive measures against the deadly Ebola Virus (CloudWare Technologies, 2015).

c) iTreat – Your Companion Doctor

I-Treat Android application was developed by Centroid Studio Medical. It has a huge database of medical information which is offline. It enables users to diagnose themselves through the application by entering their symptoms (Centroid Studio Medical, 2015).

2.7.3 Proposed Smart Phone Application

The distinguishing factor between the applications discussed and the one being proposed in this research work is that the proposed application incorporates the use of an external temperature sensor.

2.8 Summary

This review has discussed how the constant advancement in technology combined with the improvement in capability of smart phone devices has led to the emergence of the mHealth field, which enables medicine and public health services to be supported on a mobile platform. M-health has gained high popularity both in developed and developing countries because of the large penetration of mobile devices in these countries.

The literature review again has discussed how combining the Integrated-circuit technology with artificial intelligence, can provide an enabling platform for developing an automatic infectious disease detection systems.

The literature also reviewed the Ebola virus disease; its symptoms, transmission and diagnosis. The review also discussed the efficacy of border screening measures for infectious diseases; and concluded that even though it may not be the most effective method for controlling the spread of infectious diseases, it is still a recommended measure in the case of a fully blown outbreak of an infectious disease.

The literature has as well reviewed the current screening systems used at the airports for the EVD; a brief review of different projects done by different institutions but with the same intention of reducing the fatalities that the Ebola virus disease claims; a brief review of Android applications, which are already in the application stores, that are similar to the proposed application.

Finally, this literature review establishes that even though precautionary measures are established to prevent the spread of infectious diseases through a country's border, there is still a chance that EVD can be imported into that particular country.

Chapter Three: Research Methodology

3.1 Introduction

This chapter covers the research methodologies that are used to satisfy the research objectives and determine the system requirements of the proposed system. The main research objectives are: to determine how the current challenges faced at the airport by health workers while screening passengers for infectious diseases can be eliminated through automation of that screening process; to find an IR temperature sensor and an AI inferential engine that will determine the optimal design requirements for the proposed border expert screening system.

3.2 The Research Design

Action research design was adopted in this work. Action research design is an approach that is used for researches that aim at finding a solution for an immediate problem facing a society (Kothari, 2004). The problem identified in this context was the inefficiency and slowness in screening passengers for EVD symptoms using the systems. The other problem identified was the difficulty in making follow up on the health of screened passengers.

3.3 Software Development Process

Agile development methodology was used in this research work. Agile methodology is based on iterative and incremental system development. This methodology was chosen because this work required the user feedback to occur simultaneously with the proposed system development (Blankenship et al., 2011). Figure 3.1 illustrates the life cycle of the agile development method.

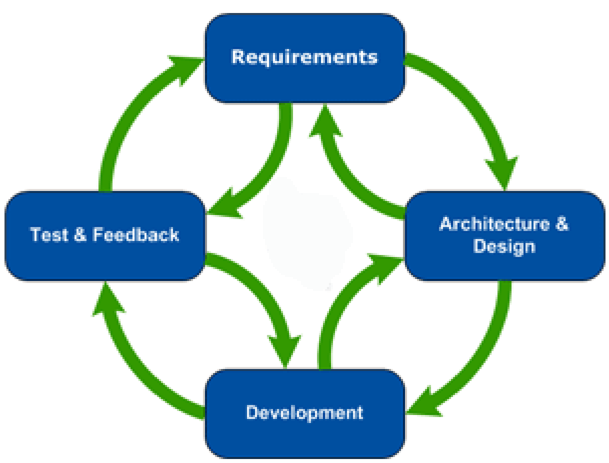

Figure 3.1: Agile Development Life Cycle
(P2C Infotech, 2013)

The four phases illustrated in Figure 3.1 were carried out as follows. The system requirements were derived from document reviews in Chapter Two together with the results obtained after conducting a pilot phase survey. The system architecture and design phase involved using the derived system requirements to produce the software specifications which were to be implemented in the development phase. The development phase involved building the actual proposed border screening expert system. In the final test and feedback phase a testing phase survey was conducted to test if the proposed system met the functional and nonfunctional system requirements. The four phases used different methodologies to achieve their task. This chapter also describes the methodologies chosen for each of the phases.

3.3.1 System Design and Architecture

System design and architecture were used to convert the determined system requirements into system specifications which were used to implement and test the proposed system. UML is a visual language for specifying, constructing and documenting the fragments of a system (Douglass, 2014). UML was used to represent the design of the proposed system because it provides graphical illustrations that are relatively easy to understand when compared to textual explanations.

The following UML diagrams were used to model the system: use case diagram, data flow diagrams, data class diagram and entity relationship diagram. Use case modelling was used to describe the relationship between use cases and actors within the system. Data flow diagrams were used to describe how data was captured and stored by the system. A design class diagram was used to illustrate the specifications of software classes and interfaces. An entity relationship diagram was used to illustrate the specifications of the system database. The system architecture was drawn using the derived system requirements to illustrate how the proposed border screening system is distributed across different technology platforms.

3.3.2 System Implementation

Extreme programming, which is one of the agile methods, is implementation methodology that focuses on small, feature-driven iterations that strive to solve specific project problems (Blankenship et al., 2011). This was used because the proposed system required a lot of feedback from stakeholders after the development of every functional component of the system.

3.3.3 System Testing

According to Watkins and Mills (2011), the V model is a software testing model that helps highlight the need to plan and prepare for testing early in the development process. The acceptance testing and system testing modules of the V model were used to test the nonfunctional and functional requirements of the proposed system respectively. The V model was used because the development of the proposed border screening expert system required a lot of user feedback.

3.4 Population and Sampling

3.4.1 Target Population

One target population was drawn from the general public because travelers using the airport are mostly ordinary people. The public stood the risk of being infected by an infectious disease and/or carry the risk of spreading an infectious disease. The other target population was drawn from the medical professionals at Strathmore University Clinic. The medical professionals helped in providing the medical requirements that the proposed system had to meet.

The final target population was drawn from the Port Health division at JKIA; Port Health is a division of the Ministry of Health of Kenya responsible for disease surveillance and public health control at all points of entry at the airport. Port Health staff are the ones responsible for screening passengers at airport terminals for symptoms of infectious diseases. According to the researcher's personal interview with a Port Health official at JKIA: JKIA has a total of at least 100 health workers, with each terminal having an average 20 health workers.

3.4.2 Sampling Design

The research used both random and purposive sampling technique to select the participants of the study. According to Tongco (2007), purposive sampling is a technique that allows the researcher to decide what needs to be known and sets out to find people who can and are willing to provide the information by virtue of knowledge and experience. Since the port health staff possess wide wealth of experience and knowledge in terms of the screening process at airport terminals; they were purposively selected make up this target sample.

Random sampling involves using probability distribution to select the research sample Tongco (2007). Random sampling was used to obtain the research respondents from the general public.

3.4.3 Sample Size

This research work used a formula that was adopted by Krejcie and Morgan (1970) to determine the sample size.

$$n = \frac{X^2 * N * P * (1 - P)}{(ME^2 * (N - 1) + (X^2 * P * (1 - P)}$$

Where:

n = Sample Size

X^2 = Chi-square for the specified confidence level at 1 degree of freedom

N = Population Size

P = Population Proportion

ME = desired margin of Error

The actual sample size was determined by applying the formula using the parameters recommended by Krejcie and Morgan (1970) for research studies. The results are displayed in Table 3.1.

Table 3.1: Determining the Research Sample Size

	N	***P***	***ME***	***X^2***	***n***
Health workers	*20*	*50%*	*5%*	*95%*	***19***
Medical professionals	*5*	*50%*	*5%*	*95%*	***5***

3.5 Data Collection Methods

3.5.1 Document Reviews

A review of documents that discussed the EVD and the significance border screening measures against infectious diseases was done. There was also a review of documents that explained how artificial intelligence when coupled with IC technology can be leveraged to develop automatic disease detection expert systems. Finally, a review of temperature sensors that could be used to develop a smart phone based infectious disease screening system was done.

3.5.2 Personal Interviews

Personal interviews were conducted by the researcher on several Port Health officials in order to get information about the screening process that was used by JKIA during the 2014 Ebola outbreak in West Africa. Another interview was conducted by the researcher on the medical staff at Strathmore University Clinic; in order to determine how to normalize the IR temperature range into a medical range and to approve the weighting used by the proposed expert system to analyze the symptoms of the passenger as described in Chapter Two.

3.5.3 Questionnaires

A pilot phase and a testing phase survey were conducted and questionnaires (Appendix B and Appendix C) were designed to collect functionality and performance data from respondents about the proposed screening system in relation to the screening system that was implemented by JKIA during the 2014 Ebola outbreak. The feedback collected from these surveys were used to improve on the functional components of the proposed system as required by the agile development methodology and the V model testing methodology.

3.6 Data Presentation and Analysis

Descriptive analysis together with simple graphical analysis was applied in this research in order to provide summaries of the data collected from the selected samples. This research is a form of quantitative research and descriptive analysis is recommended to simplify large amounts of data in a sensible way (Trochim, 2008). Frequency distribution and methods of central tendency were used to describe the data collected; the distribution was displayed using percentiles. The data collected from the questionnaires was tabulated in a Microsoft Office 2013 Excel Sheet in order to represent it in a digital format. Microsoft Office Excel 2013 was used to analyze the data; as well as to generate graphs and charts which give a clear presentation of the results and findings.

Chapter Four: System Architecture and Design

4.1 Introduction

This chapter documents how the proposed border screening system was designed and its architecture modelled. The design and architecture of the system were illustrated by models and diagrams derived from UML, so as to provide a blueprint for visualizing the system. The design and architecture of the proposed system were hugely influenced by the responses obtained from a pilot survey conducted by the researcher.

4.2 Presentation of Pilot Phase Findings

A mockup of the proposed smart phone based Ebola screening system was demonstrated during the pilot phase of this research, in front of 20 participants of the survey; in order for them to understand the concept of the proposed system. After the demo was performed, the participants were asked to respond to the questions presented in the research questionnaire (Appendix B). The mockup was developed using the requirements drawn from the document reviews in Chapter Two. The aim of this pilot survey was to help the researcher to accurately derive the system requirements that would be used in creating the design and architecture of the proposed border screening expert system.

4.2.1 General Demographic Data

The survey results of the respondents' gender, age, education level and occupation has been summarized in Appendix G (Table 10.8). This gender balance did not introduce any bias on the results of the research because infectious diseases affect both genders alike. The research had responses from across all age brackets in order to obtain the opinions of people from different ages concerning screening of infectious diseases.

4.2.2 General Ebola Virus Disease Data

All the participants deducing from Figure 4.1 indicated that: Ebola was an infectious virus disease; fever check was part of the Ebola screening procedure and follow up on the health of Ebola screened passengers was important. However, only 58% of the respondents had experienced or knew about the Ebola screening procedure. This shows that almost all the respondents were conversant with the general information about EVD.

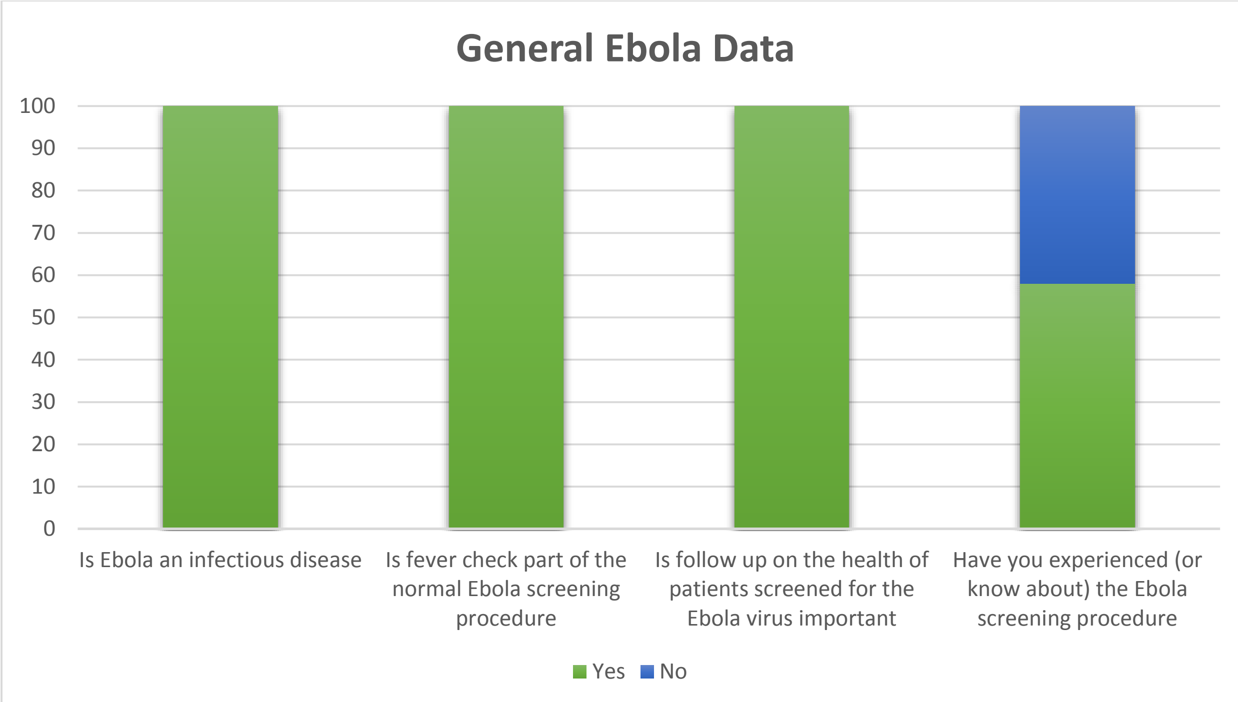

Figure 4.1: Respondents' Responses on Ebola

4.2.3 Respondents' Ratings on the Proposed Border Screening System

In the screening of passengers for the Ebola virus: 31% of the respondents were extremely positive, while 69% of the respondents were very positive that the proposed system would be efficient; 19% of the respondents were extremely positive, while 81% of the respondents were very positive that the proposed system would be effective; 19% of the respondents were extremely positive, 58% of the respondents were very positive, and 23% were positive that the proposed system would be accurate; 19% of the respondents were extremely positive, 62% of the respondents were very positive, and 19% of the respondents were positive that the proposed system would be reliable; 19% of the respondents were extremely positive, 65% of the respondents were very positive, and 16% of the respondents were positive that the proposed system would be inexpensive relative to the current screening systems.

Figure 4.2 shows the survey participants' ratings results on the cost of implementation, reliability, accuracy, effectiveness and efficiency of the proposed border screening system. These results show that none of the participants rated the system as extremely expensive, extremely unreliable, extremely inaccurate, extremely ineffective or extremely inefficient.

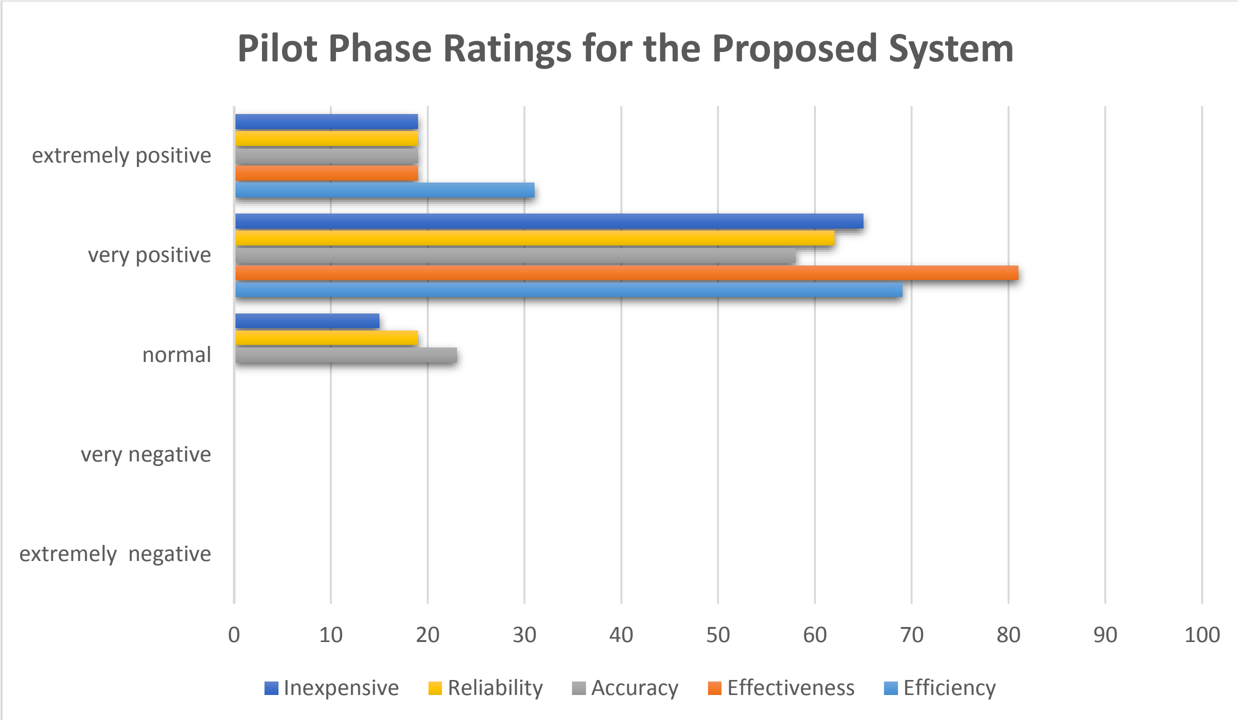

Figure 4.2: Participant's Ratings on the Proposed System

4.2.4 Respondents' Suggestions

5% of the respondents suggested that the system could be used to diagnose other diseases' symptoms other than the Ebola symptoms. 7% of the respondents suggested that the system could not detect if the passenger submitted dishonest symptoms. 9% of the respondents suggested that passenger photos should be added as part of the contact details of the passenger. 5% of the respondents suggested that the proposed system would not be accepted by the airport administration.

12% of the respondents suggested that the system would be convenient when used to screen passengers for the Ebola symptoms and also to follow up on the health of the passengers that had been screened. 23% of the respondents suggested that the system was easy to use. 32% of the respondents recommended the proposed system as a good system to be implemented in border entry/exit points, especially in airports.

Figure 4.3 shows the survey results for the participants' suggestions. These suggestions were used to determine the functional requirements that the proposed border screening system should meet.

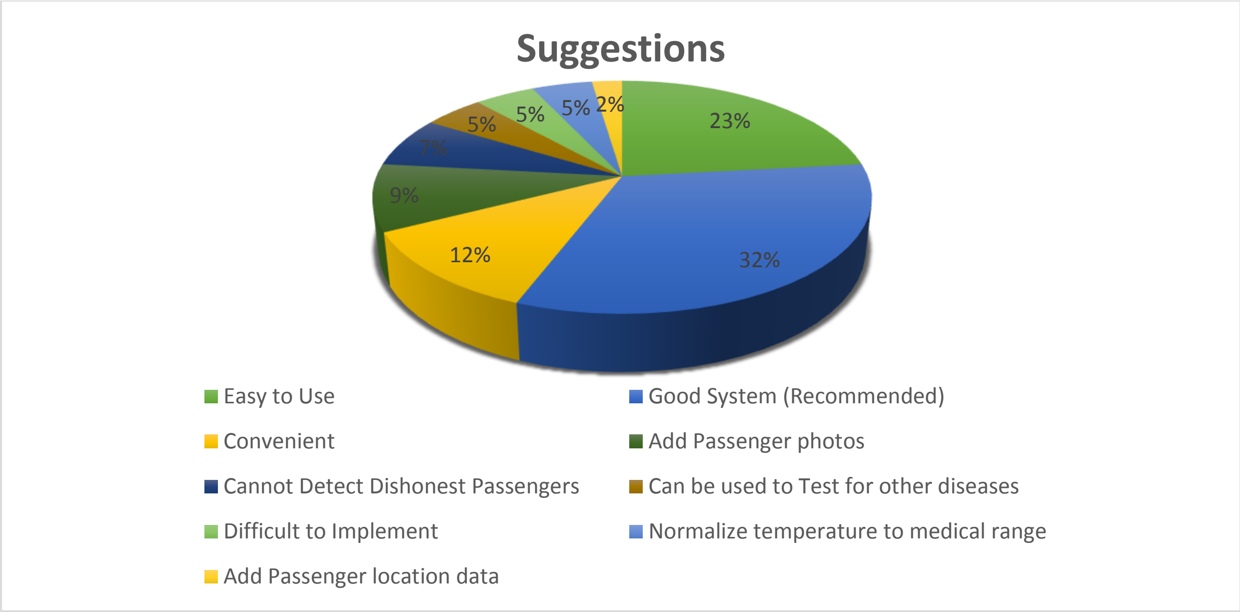

Figure 4.3: Participant's Suggestions on the Proposed System

4.3 System Requirements

The system requirements were derived from the knowledge gathered in the document reviews in Chapter Two together with the responses given by the participants in the pilot phase survey.

4.3.1 Functional Requirements

i. Automatically detect body temperature and send it over the Internet to the backend system.

ii. Automatically analyze the symptoms of the passenger and provide the screening results to the health worker.

iii. Enable health workers to conveniently make follow up on the health of screened passengers.

4.3.2 Nonfunctional Requirements

i. Accurately detect consistent temperature readings

ii. Accurately analyze the symptoms presented by the passenger

iii. Easy to use

4.4 System Architecture

Figure 4.4 illustrates how the system was distributed across different technology platforms derived from the system requirements.

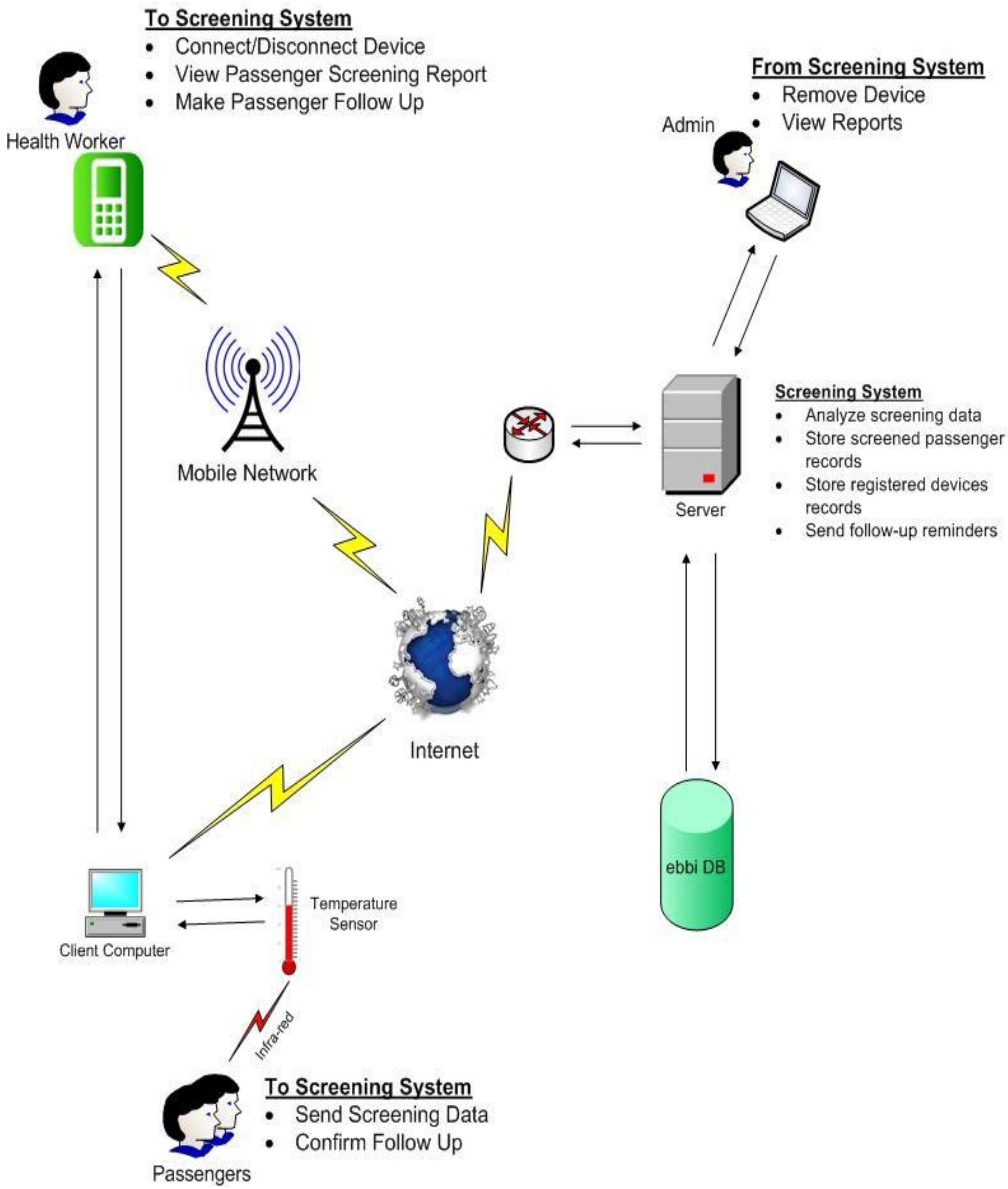

Figure 4.4: System Architecture

The smart phone based border screening system used a client-server architecture. The client side had three different applications: the temperature sensor application, the mobile web application and the mobile Android application. The server side had two applications: the backend application and the management system.

4.4.1 Client Side Architecture

a) Frontend Temperature Sensor Application

The frontend temperature sensor application consists of a computer program that allows the computer to retrieve body temperature data collected from the Phidget 1045_1 IR sensor and sends it to the server backend application via an Internet enabled connection.

Figure 4.5: Phidget IR Temperature Sensor
Phidget (2015)

The Phidget 1045_1 sensor is an intelligent non-contact temperature sensor with a 10^{o} field of view and a USB interface for easy connection to a computer. It outputs a continuous data flow after every 32ms with an active alarm running in the background (Phidgets, 2015). The sensor can measure temperature on objects that ranges from -70°C to 380°C. To get accurate readings, the object being measured should occupy the full field view of the sensor while not making physical contact with the sensor.

Since the Infra-red sensor measures temperature based on what object is emitting, there is theoretically no limit to the range of such a sensor; except that the further away from the sensor and the object is, the larger the area of detection that is required. Figure 4.6 shows the Phidget 1045_1 Mechanical Drawing.

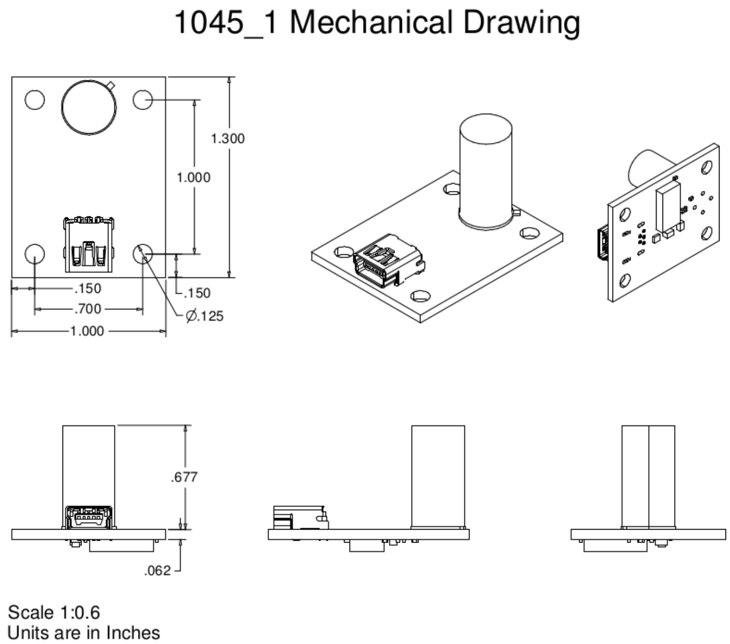

Figure 4.6: Phidget 1045_1 Mechanical Drawing
Phidget (2015)

b) Frontend Web Application

The frontend web application consists of a smart phone application that was used to capture Ebola virus screening information from a passenger. It allowed the passenger to enter his/her contact details, together with the symptoms he/she exhibited. This details were then sent to the server application for analysis in order to determine if the passenger had contracted the Ebola virus. The application was used in conjunction with the temperature application to capture the symptoms of the passenger. Since this application was a web application, it could be accessed by smart phones running on any phone platform for example Android, Blackberry, and Symbian among others.

c) Frontend Android Application

The frontend Android application consists of an Android application that was used to obtain screening results after the analysis of the symptoms presented by the passenger. The application was also used to remind the health worker to make health follow ups on specific passengers during/after three weeks. For the smart phone application to achieve all this functionalities; it had to exchange information with the server application via a GSM network.

4.4.2 Server Side Architecture

The server side architecture consists of a backend server application that analyses temperature data coming from the temperature application together with the passenger's symptoms captured from the mobile web application. After the analysis of the symptoms exhibited by the passenger, it sends the screening results to the mobile Android application.

Finally, it runs a web display application that was used to give instructions to the passenger whose temperature and symptoms had been captured. The server application also had a management system which is built on a Web platform and it enabled the administrator to manage records of passengers that had been screened through the system and devices registered in the system.

4.5 System Design

System designs are difficult to explain textually, Unified Modelling Language was used. UML is a visual language for specifying, constructing and documenting the fragments of a system and UML was approved by the Object Management Group as a standard in 1997 (Douglass, 2014). Modelling has the following merits:

i. Enables easy visualization of the system

ii. Reduces the complexity of the system

iii. Clear communication

This research work used the following UML diagrams to model the system: use case diagram, data flow diagrams, data class diagram and an entity relationship diagram.

4.5.1 Use Case Modelling

Use case modelling uses use case diagrams and use case forms to describe the relationship among actors and use cases within a system. An actor is a person, organization or external system that interact with the system. A use case represents the behavior of a system when an actor sends a certain stimulus to the system.

Figure 4.7 shows a use case diagram of the proposed border screening system. The major actors are health worker and administrator while the passenger is a minor actor because he/she does not interact with the system intensely.

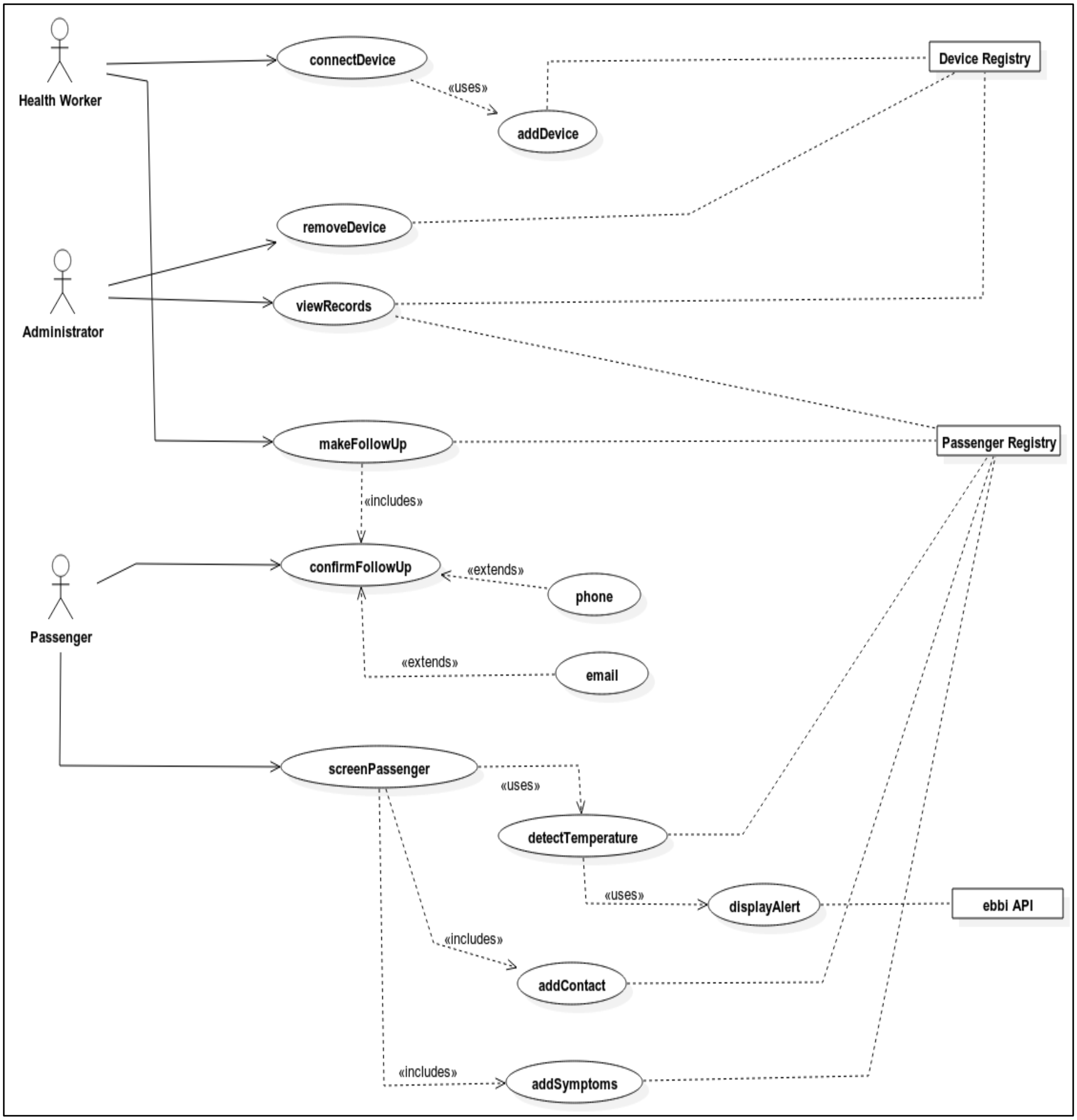

Figure 4.7: Use Case Diagram of the System

4.5.2 Use Case Descriptions

This research work documented only the most important use case forms under this chapter. The other use cases forms are attached at Appendix D.

a) Connect Device Use Case

The connect device use case illustrates in detail the process of connecting a client side Android device application to the server backend application. This use case uses the Add Device (Appendix D) use case if an unregistered device tries to connect to the system. The Add Device use case illustrates how the device is registered using the Google notification API and the unique registration ID is what is used to uniquely identify the device in the system. Once the device has been added or already exists; the device is connected to the server backend application and its connection status is changed. Only connected devices are able to communicate with the server backend application.

Table 4.1: Use Case Form for Connecting Device

System: Border Screening System	
Use Case Name: Connect Device	**Group ID:** A
Primary Actor: Health Worker	**Use Case ID:** UC-001
Stakeholders: Administrator	**Priority (H, M, L):** H
Goal: To connect device to the system, so that it can communicate with the server application.	
Trigger: Request from user/actor by pressing a button.	
Inputs: Device ID, Connection status	
Relationships: Includes: Add Device	
Preconditions: Device is already registered in the system.	
Basic Flow:	
<u>Actor</u>	<u>System</u>
1. Sends device ID	1. Searches for device 2. Alternate Flow 3. Connects to device and changes connection status to indicate active connection
Alternate Flow: 2a if device does not exist, add device 2b if device exists, skip	
Post Conditions on Success: Device is registered.	
Post Conditions on Failure: None	
Output: Device connected.	

b) Screen Passenger Use Case

The screen passenger use case illustrates how the health worker or the passengers themselves will use the mobile web application to record and store the symptoms presented by the passenger as well as the contact details of the passenger. This information is sent to the server application for storage and analysis.

Table 4.2: Use Case Form for Screening Passenger

System: Border Screening System	
Use Case Name: Screen Passenger	**Group ID:** A
Primary Actor: Passenger	**Use Case ID:** UC-002
Stakeholders: Health Worker	**Priority (H, M, L):** H
Goal: To add passenger Ebola virus symptoms and contacts into the system	
Trigger: Temperature data received from server application.	
Inputs: Temperature, Headache, Stomach Pain, Muscle Pain, Bleeding, email, phone number, country, city	
Relationships: Includes: Add Passenger Contact, Add Passenger Symptoms	
Preconditions: Passenger body temperature received by smart phone device	
Basic Flow:	
Actor	System
1. Enter symptoms: headache, stomach pain, muscle pain, bleeding 2. Enter contact details: email, phone number, country, city	1. Save passenger symptoms 2. Save passenger contact details 3. Analyze symptoms data 4. Calculate follow-up date and create reminder for that date. 5. Send screening results to health worker
Alternate Flow: None	
Post Conditions on Success: Follow up date saved	
Post Conditions on Failure: None	
Output: Passenger Screened	

c) Make Follow up Use Case

The make follow up use case illustrates how a health worker is reminded of making passenger health follow ups during/after three weeks using phone notifications sent from the server backend application. The health worker has the option of calling or sending an e-mail to the passenger. The passenger is expected to respond to the health worker's message. The health worker will then confirm the follow up in the system depending on the response received from the passenger.

Table 4.3: Use Case Form for Making Follow up

System: Border Screening System	
Use Case Name: Make Follow Up	**Group ID:** A
Primary Actor: Health Worker	**Use Case ID:** UC-003
Stakeholders: Passenger	**Priority (H, M, L):** H
Goal: Follow up on passenger health	
Trigger: Push notification sent to smart phone from the server application.	
Inputs: None	
Relationships: Includes: Add Follow Up Confirmations Extended by: Make Phone Call, Send E-Mail	
Preconditions: Passenger record must exist	
Basic Flow:	
<u>Actor</u>	<u>System</u>
1. Health worker gets follow up notification 2. Health worker calls passenger, to confirm health 3. Health worker confirms follow up	1. System sends follow up notification 2. System waits for confirmation 3. System records follow up
Alternate Flow: None	
Post Conditions on Success: No more follow up reminders for that passenger are scheduled.	
Post Conditions on Failure: More follow up reminders that passenger are scheduled.	
Output: Follow up completed	

4.5.3 Data Flow Diagrams

Data flow diagrams are used to describe how data is captured and stored by the system. This research work used a context diagram, a level 0 DFD, two level 1 and one Level 2 DFDs to describe the data flow in the system.

a) Context Diagram

Context diagram is used to describe in general the data flow in the system. Figure 4.8 shows the context diagram of the proposed border screening system.

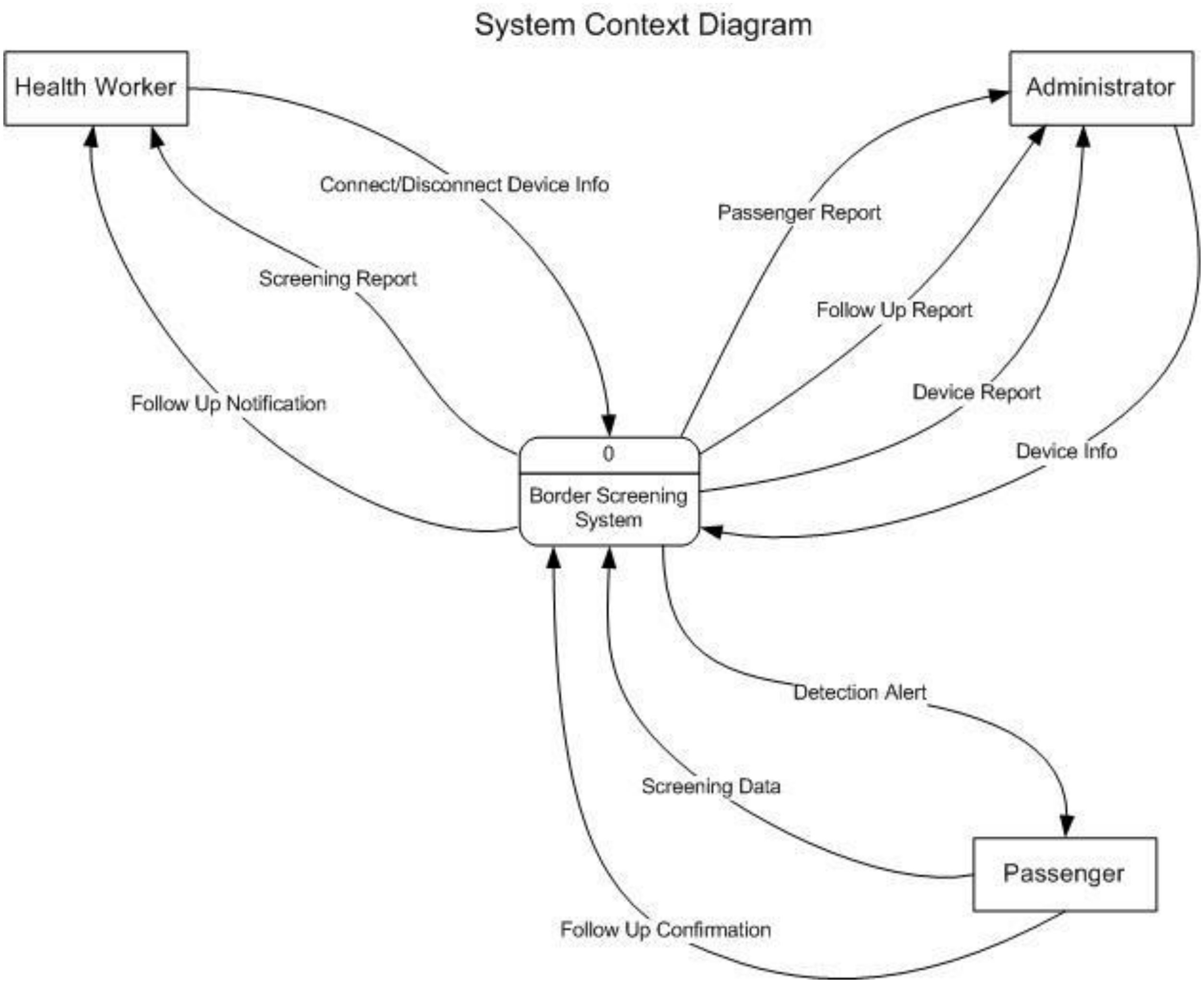

Figure 4.8: System Context Diagram

b) Level 0 Data Flow Diagram

A level 0 DFD is used to describe in detail the data flow in the system. It illustrates the order of performing tasks in the smart phone based border screening system.

Figure 4.9 shows the level 0 data flow diagram of the proposed border screening system.

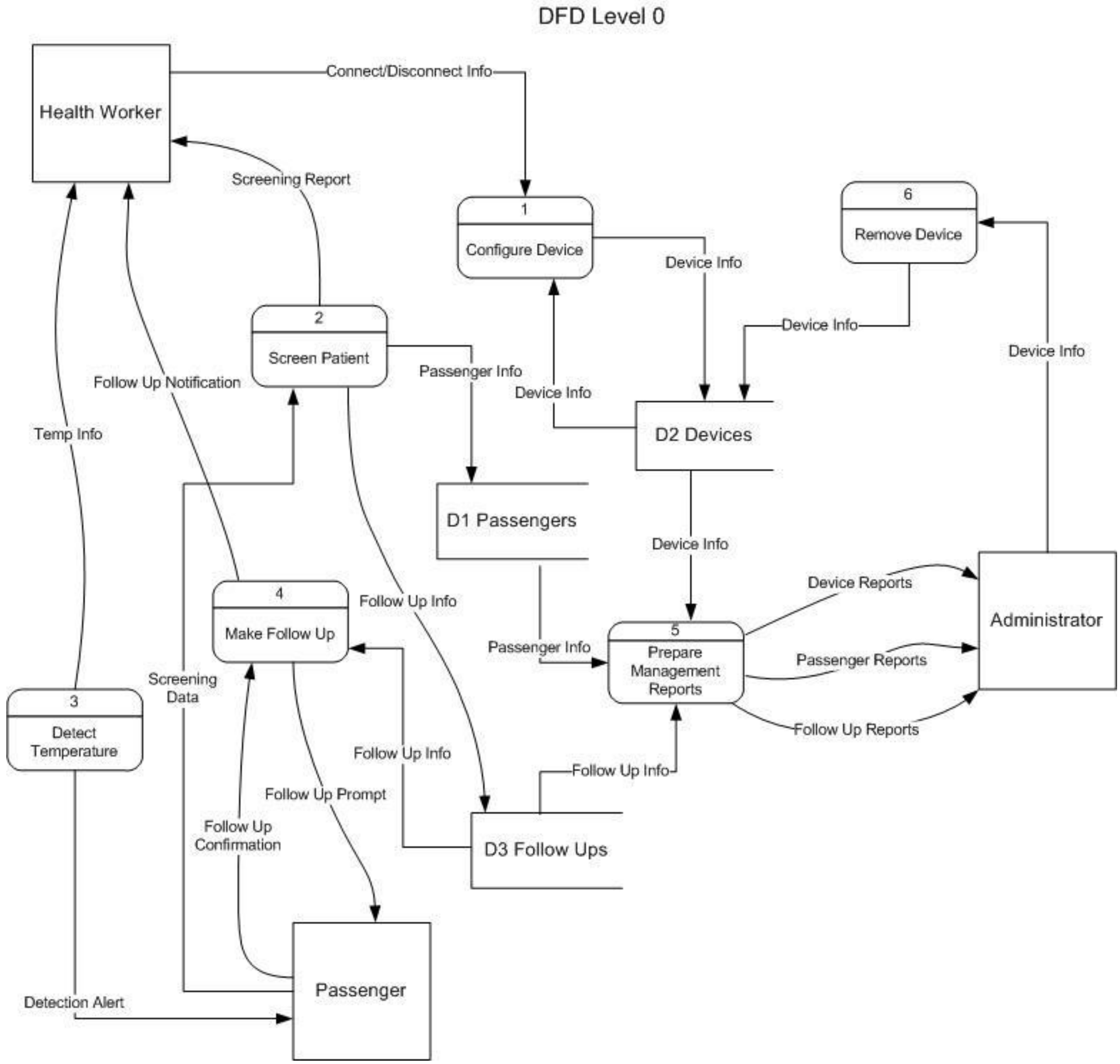

Figure 4.9: System Level 0 Data Flow Diagram

c) Level 1 Data Flow Diagram for Configuring a Device

Level 1 data flow diagram for configuring a device illustrates the steps taken to connect a smart phone device to the server backend application so that they can communicate. If the device does not exist in the system's records; then, the device is registered using the Google notification API before being added into the system.

Figure 4.10 shows the level 1 data flow diagram for configuring an Android device.

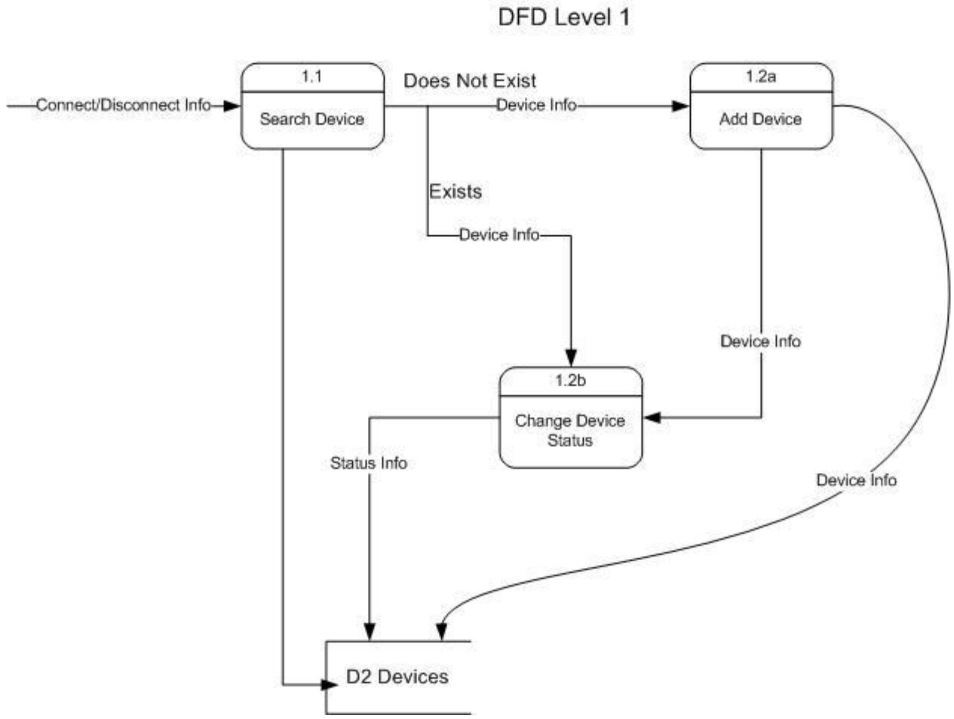

Figure 4.10: Configuring Device Level 1 DFD

d) Level 2 Data Flow Diagram for Adding Device

Figure 4.11 shows the level 2 data flow diagram for adding an Android device to the system.

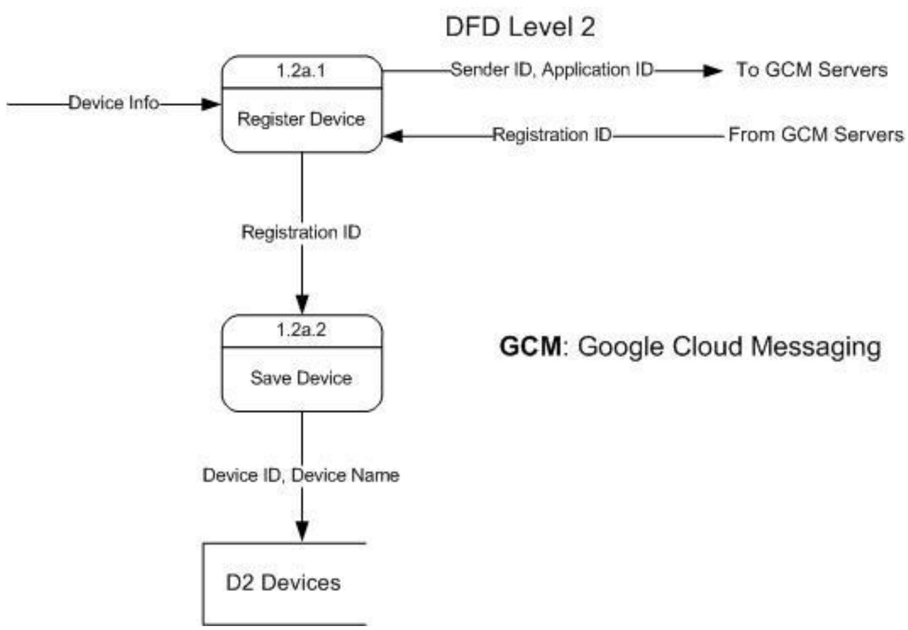

Figure 4.11: Adding Device Level 2 DFD

e) Level 1 Data Flow Diagram for Screening Passenger

Figure 4.12 illustrates the order of events that occur when recording and storing screening information from a passenger.

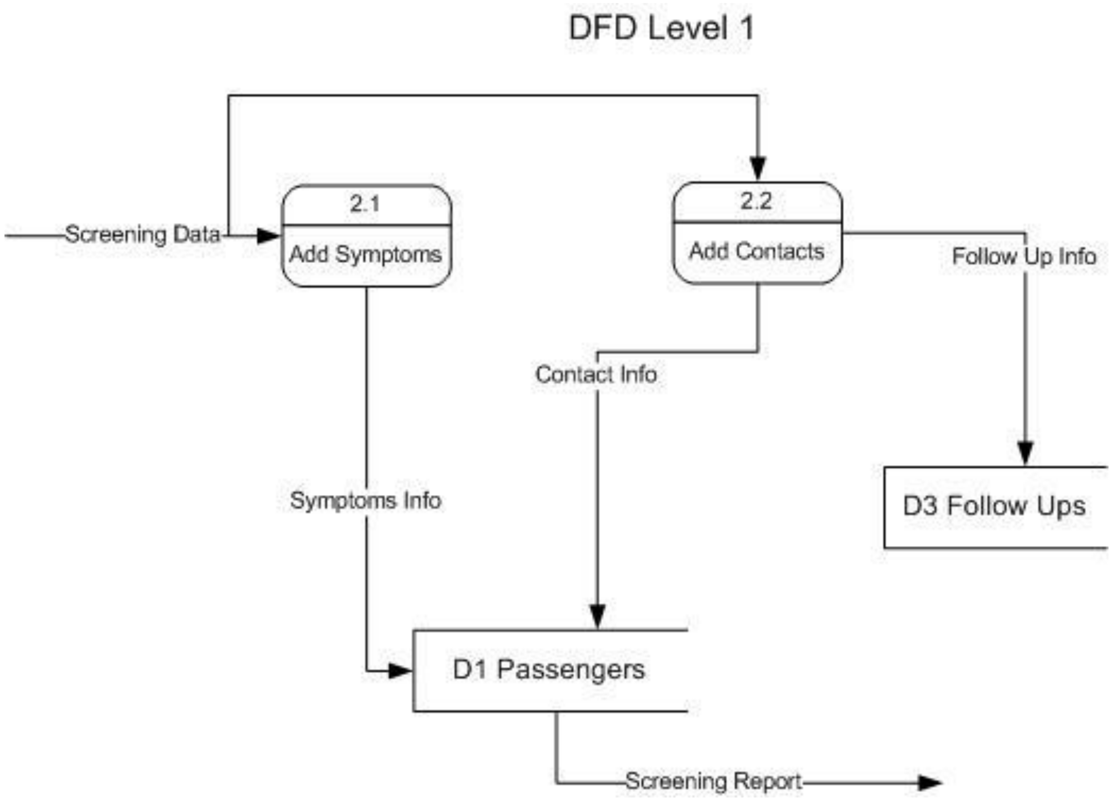

Figure 4.12: Screening Passenger Level 1 DFD

4.5.4 Design Model Class

A design class diagram was used to illustrate the specifications of software classes and interfaces. The design class diagram expresses for the software application developer, the definitions of classes he/she should use and the software components of the system. A domain class model provides information about:

i. Classes together with their attributes, methods and associations

ii. Navigability and dependencies of the classes to other classes

Figure 4.13 shows the design class diagram of the proposed border screening system.

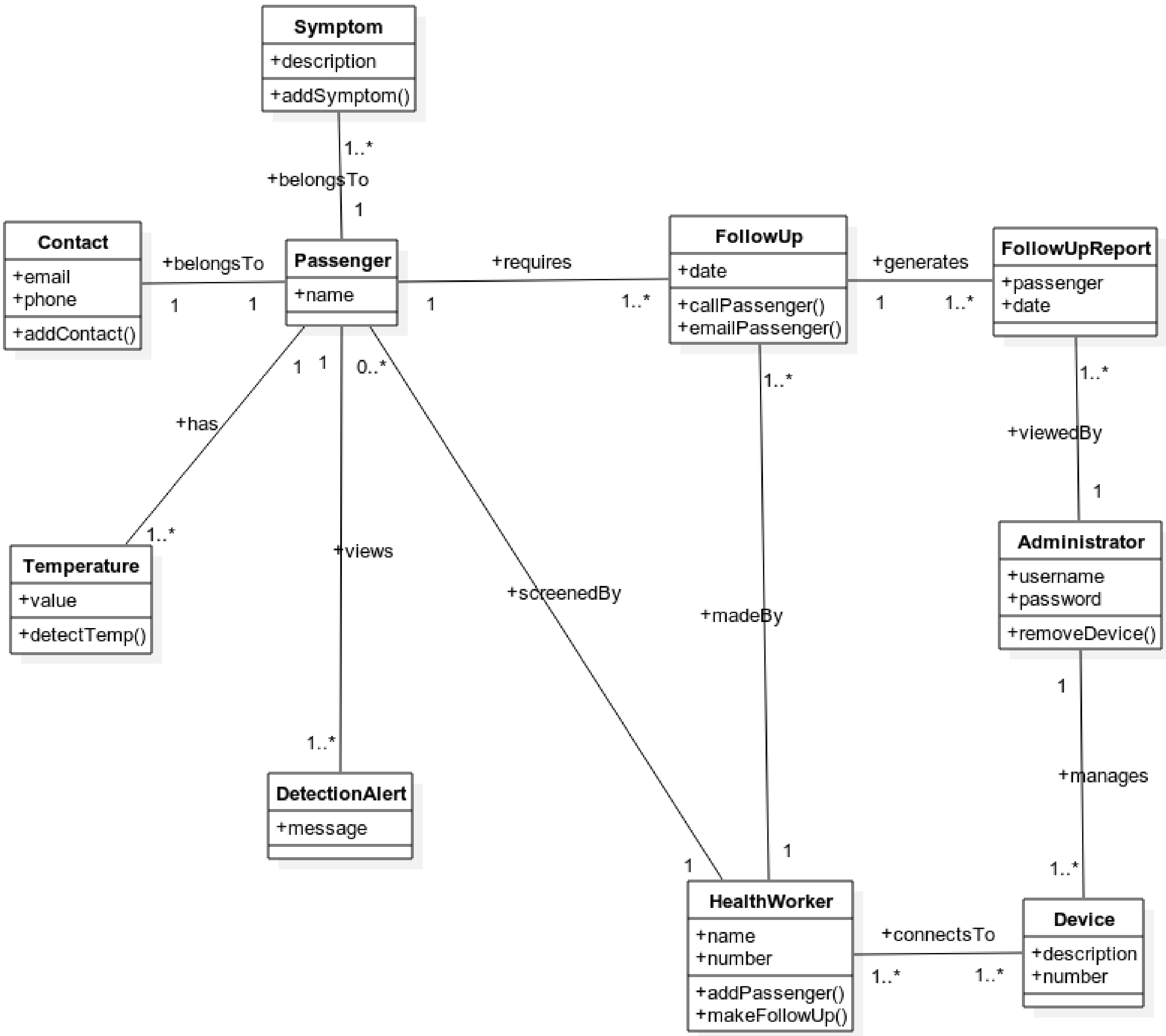

Figure 4.13: Design Class Diagram of the System

4.5.5 Entity Relationship Diagram

An entity relationship diagram is usually used to represent a conceptual data model of the system. It used to show how data is organized, therefore it is the best tool to illustrate the whole database of a system. In the implementation stage, this entity relationship diagram was translated into a real database which is used to store data gathered by the system.

Figure 4.14 shows the Entity Relationship diagram of the proposed border screening system.

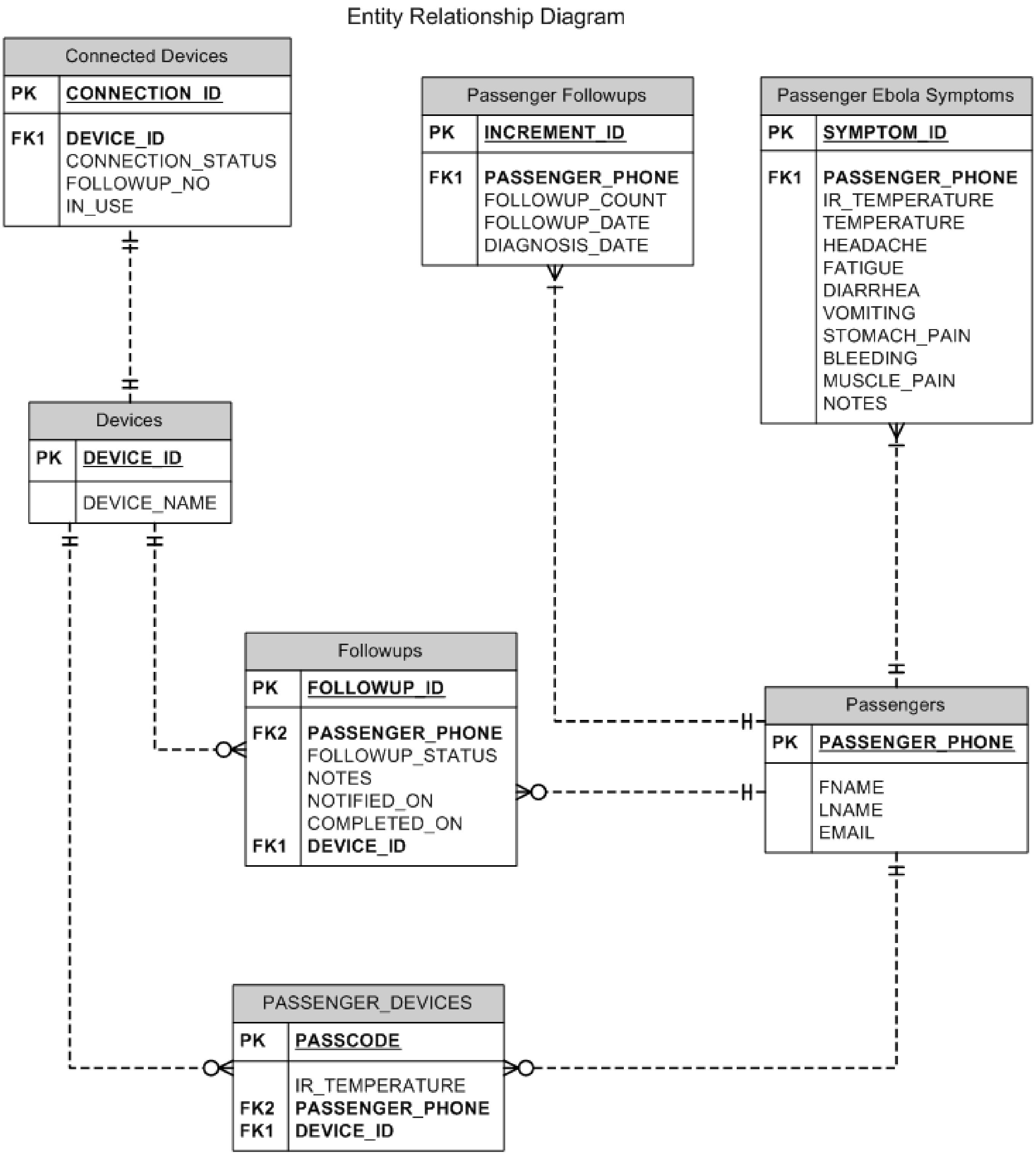

Figure 4.14: Entity Relationship Diagram of the System

4.5.6 Database Schema

Figure 4.15 shows the database schema of the proposed border screening system.

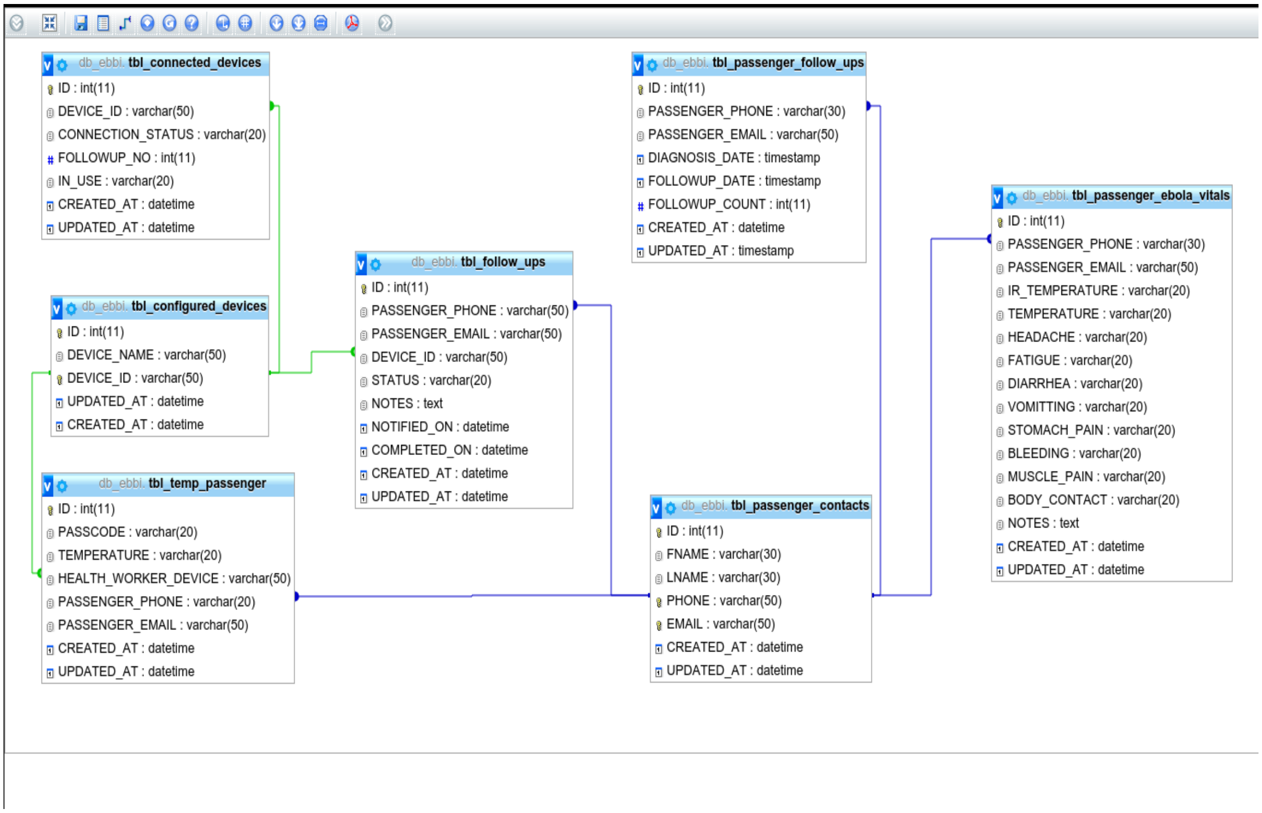

Figure 4.15: Database Schema of the System

4.6 Summary

In this chapter, the architecture of the system was illustrated by the use a diagram. The diagram showed how the whole border screening system would be distributed across different technology platforms. It also documented the main responsibilities of the major stakeholders to this system.

The chapter used the UML notation to illustrate the design of the proposed border screening system; because the language makes it easy to visualize the design of this system. UML diagrams used to document the design of the system include: a use case diagram; data flow diagrams; design class diagrams and an entity relationship diagram.

The design and architecture described by this chapter were used to specify the requirements of implementing the system. The implemented system was tested to make sure it met all the design and architecture requirements.

Chapter Five: System Implementation

5.1 Introduction

This chapter explains the functionalities and features of the proposed system. It also covers how the proposed system was implemented using the agile development methodology. The feedback received from the stakeholders of this system was used to improve the functionality and usability of the different system application modules. System implementation was subdivided into four application modules: frontend temperature application module, frontend mobile web application module, frontend mobile Android application module, and server backend application module.

5.2 Frontend Temperature Application

Frontend temperature application module is to retrieve the body temperature of a passenger that has been detected by the Phidget 1045_1 Infra-red temperature sensor; and send it to the backend server.

5.2.1 Development Tools

The temperature module was implemented using the Java programming language. The Java program enabled the Phidget 1045_1 Infra-red temperature sensor to send temperature values to the server backend application. The Java program source code was provided by the Phidget 1045_1 Infra-red temperature sensor manufacturer and it was modified accordingly so that it could meet the requirements of this system.

NetBeans version 8 which is a complete Integrated Development Environment was used to write, compile, debug, test and deploy the temperature sensor module. The client computer that executed this module, was on a Linux environment, Gnome version 3.10; however, other operating systems platforms could also be used to achieve the same results.

5.2.2 Application Components

a) Detect Temperature

The main function of the detect temperature component is to use the Phidget 1045_1 IR sensor to automatically detect the body temperature of a passenger and send it to the backend application.

Figure 5.1 shows a screenshot of the temperature sensor application module. This research settled on the Java source code over the C, C++ and C# languages because it came with a basic screenshot and it was as well relatively easy to integrate it with the other system application components.

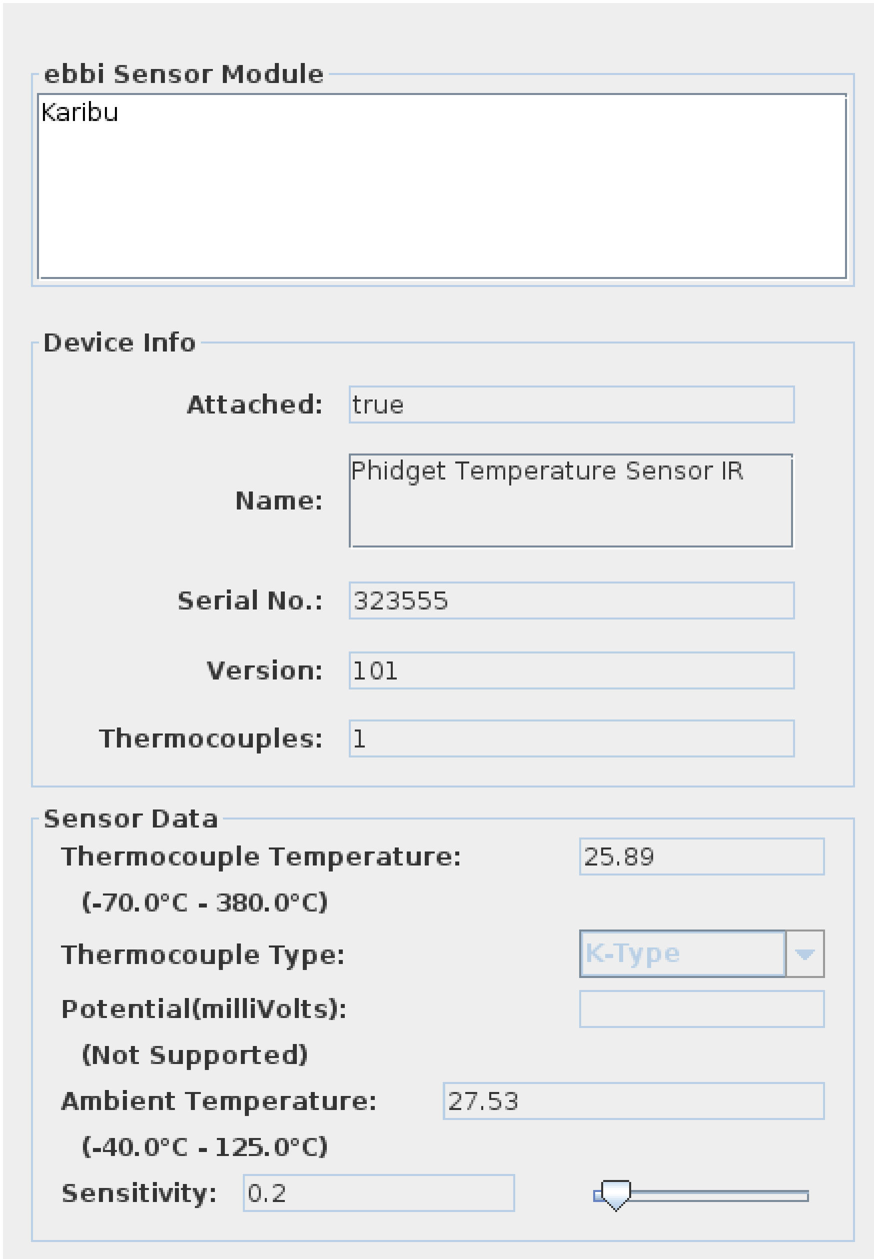

Figure 5.1: Temperature Sensor Application Screenshot

5.3 Frontend Mobile Web Application

The purpose of this module is to enable the system to capture the symptoms of the passenger. After the body temperature of the passenger have been detected and uploaded to the server backend application, this module is used to capture the other Ebola symptoms from the passenger as well as their contact information. Since this module is a web application, it can be accessed by all smart phones platforms like Android, Blackberry, and Windows mobile among others.

5.3.1 Development Tools

The frontend mobile web application module was developed using the following web programming languages: PHP, MySQL, HTML and JavaScript. Sublime version 3.0 text editor was used to write the source code. XAMPP software version 1.8 was used to develop the database and test the web application.

5.3.2 Application Components

a) Initiate Manual Screening

The initiate manual screening component is used to manually initiate the automatic screening process by manually feeding the temperature value into the system. This component is a backup module that is used in case the temperature sensor module fails to automatically initiate the screening process.

b) Add Contact

The add contact component is used to capture the contact details of the passenger. Before the passenger is allowed to add her/his contact details; his/her temperature has to have been captured and sent to the backend application. A passcode is provided by the server backend application to the passenger upon the reception of the temperature data. This passcode has to be sent together with the contact details of the passenger by this component. Figure 5.2 shows the screenshot of the web application that is used by the passenger to enter his/her contact details into the system.

c) Add Symptoms

The add symptoms application component prompts the passenger/health worker to enter the symptoms that the passenger exhibits, after the contact details have been saved in the system. This component uses radio buttons to enable the passenger/health worker to select the symptoms very fast. The symptoms captured by this component are sent to the backend application.

Figure 5.3 shows a screenshot of the add symptoms interface.

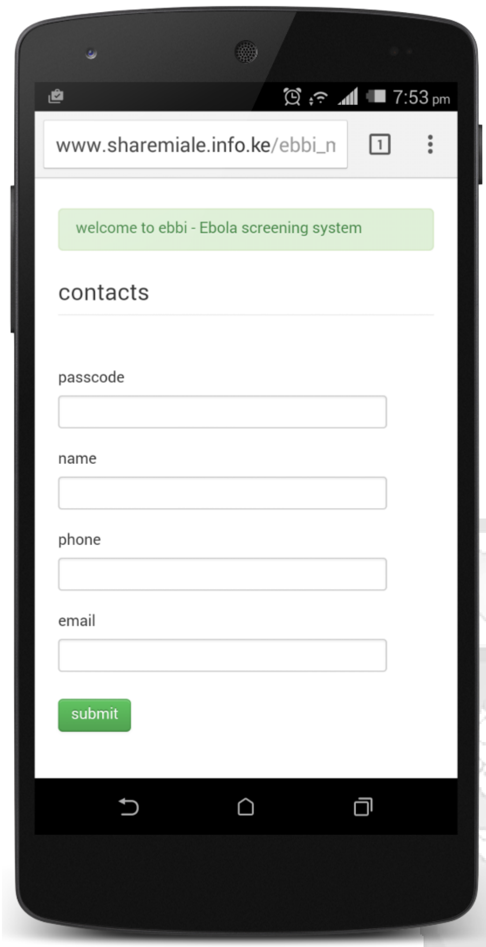

Figure 5.2: Add Contact Screenshot

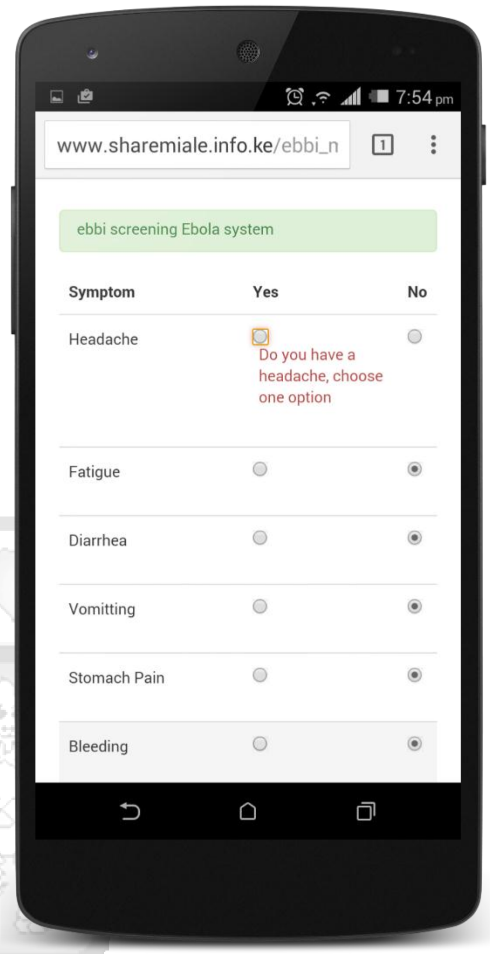

Figure 5.3: Add Symptoms Screenshot

5.4 Frontend Android Mobile Application

The main purpose of the frontend Android mobile application module is to enable health workers receive the screening results of passengers using smart phones. The smart phone device receives the screening results from the server backend application after the analysis of the symptoms presented by the passenger through the expert system. The other function of this module is to remind and enable the health worker to follow up on the health of specific passengers through an email or a phone call during/after three weeks after screening.

5.4.1 Development Tools

The Android mobile application was developed using the Android programming language which is based on the Java programming language. The smart phone application could run on any Android phone that supports the Android Operating System of version 2.2 upwards.

The application uses the Google Cloud Messaging push notification API in order to send follow up reminders to health workers. Intellij IDEA version 14 which is a Java Integrated Development Environment was used to write, compile, debug, test and deploy the Android application.

5.4.2 Application Components

The Android device has to be registered in the system, before any of the major functionalities are accessed. Figure 10.5 and Figure 10.4 in Appendix E shows screenshots that demonstrate how the device should be configured and connected to the whole system.

a) Display Screening Report

The display screening report application component allows the health worker to access the passenger screening reports that have been created by the server backend application. The server backend application receives the temperature and symptoms exhibited by the passenger through the mobile web application. It then analyzes this data using an AI inference engine and sends the screening report to the health worker through this module. The report tells the health worker the chances of the passenger having the Ebola virus as a percentage together with the positive symptoms captured during the analysis process. Depending on the nature of the results received, the health worker can decide to isolate the passenger for further Ebola tests or allow the passenger to proceed with his/her journey.

This module uses the GCM API to alert the health worker of any incoming screening report from the server backend application through push notifications. A screenshot of this component is shown in Figure 5.5.

b) Make Follow Up

The make follow up component enables the health worker to receive the phone number and email address of passengers that require health follow up during the three week period after screening. It also enables the health worker to either call or send an email to the passenger using the default smart phone call and email applications. Figure 5.4 shows this component’s screenshot.

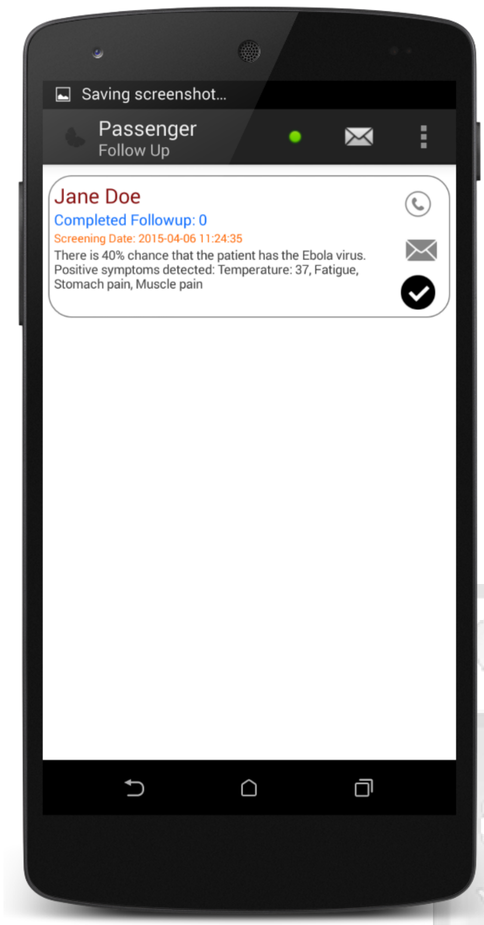

Figure 5.4: Make Follow Up Screenshot

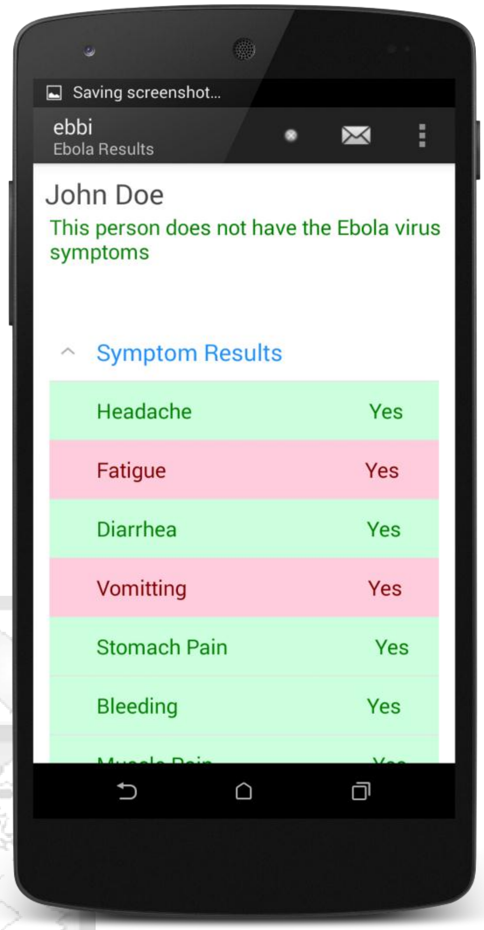

Figure 5.5: Screening Report Screenshot

5.5 Backend Server Web Application

The backend server web application module is the intelligent part of this proposed border screening system. It receives temperature data from the temperature sensor application module, the passenger Ebola symptoms and the passenger contact details from the mobile web application module. It analyzes these symptoms using an AI inference engine and sends the results to the mobile Android application.

It also runs a display alert interface that directs the passenger accordingly during the screening process. The display alert interface is shown in Figure 5.6. Finally, it sends follow up reminders to health workers and it as well provides the administrator with the system management interface which is shown in Figure 5.7. The system management system enables the administrator to manage the records of the passengers and screening devices.

5.5.1 Development Tools

The web application module was developed using the following web programming languages: PHP, MySQL, HTML and JavaScript. Sublime version 3.0 text editor combined with the Yii Framework version 2.0 was used to write this application’s source code.

5.5.2 Application Components

a) Analyze Symptoms

The analyze symptoms component does not have an interface or screenshot; however, it is the functionality that makes the backend application an expert system. It receives the temperature data and the symptoms of the passenger and analyzes them using an AI inference engine.

b) Display Alerts

The display alert component is used to relay information from the server application to the passenger during the screening process. It informs the passenger what his/her temperature is, what passcode to use when entering his/her contact details, and which health worker to approach for the further directions after the screening process is complete. Figure 5.6 shows a display alert interface screen that is used to instruct the passenger accordingly.

c) Send Notifications

The send notification component does not have an interface or screenshot. It runs a process that periodically searches the passenger records to find out if they require a health follow up. If they do, it sends a push notification alert to any health worker, requesting them to make a health follow up on the passenger. This component is also used by the server backend application to send push notification alerts to a health worker, requesting them to view the screening results of a passenger.

d) Manage Records

The manage records component provides an interface for the administrator to view and edit the records of devices and passengers. The administrator has to be registered in the system and be authenticated in order to have access to the passenger and device records. Figure 5.7 shows a screenshot of the manage records component.

All other users that access this application module are treated as guests and all the records are hidden from them. Figure 10.6 in Appendix E shows a screenshot for the guest account.

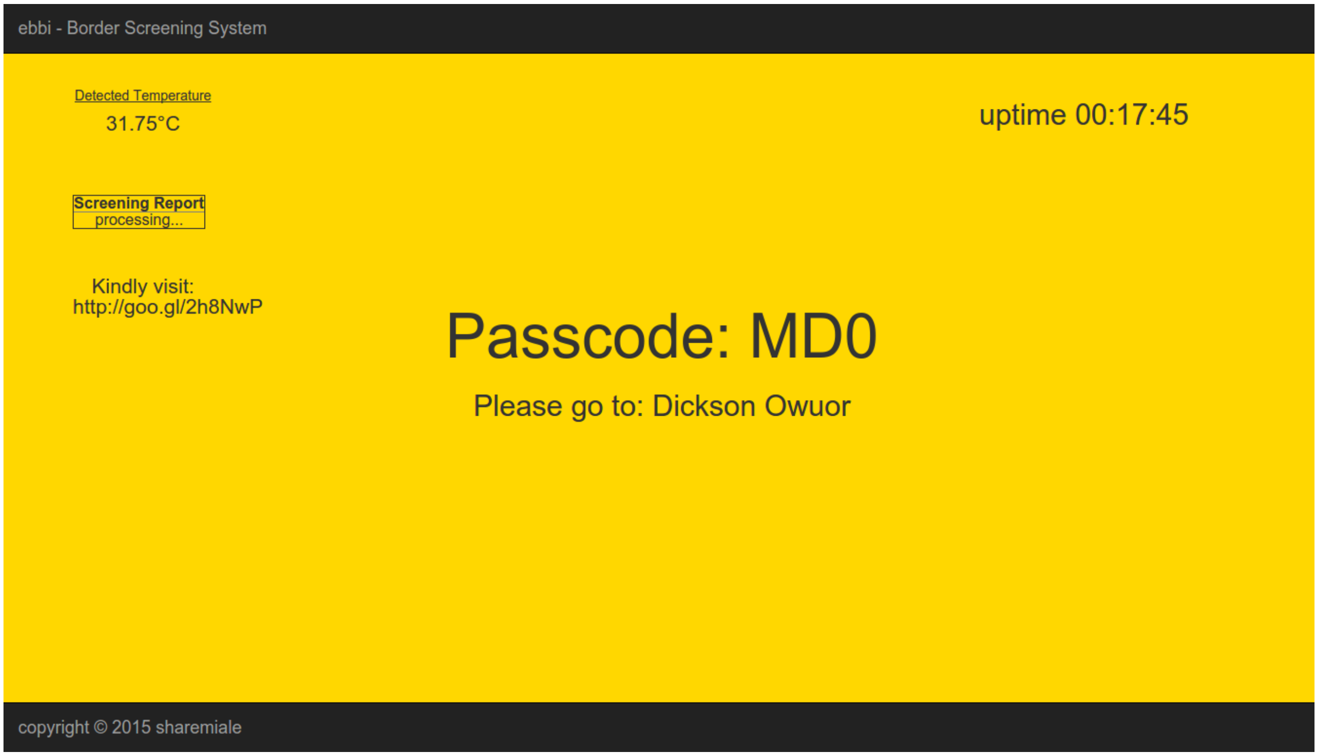

Figure 5.6: Display Alert Screenshot

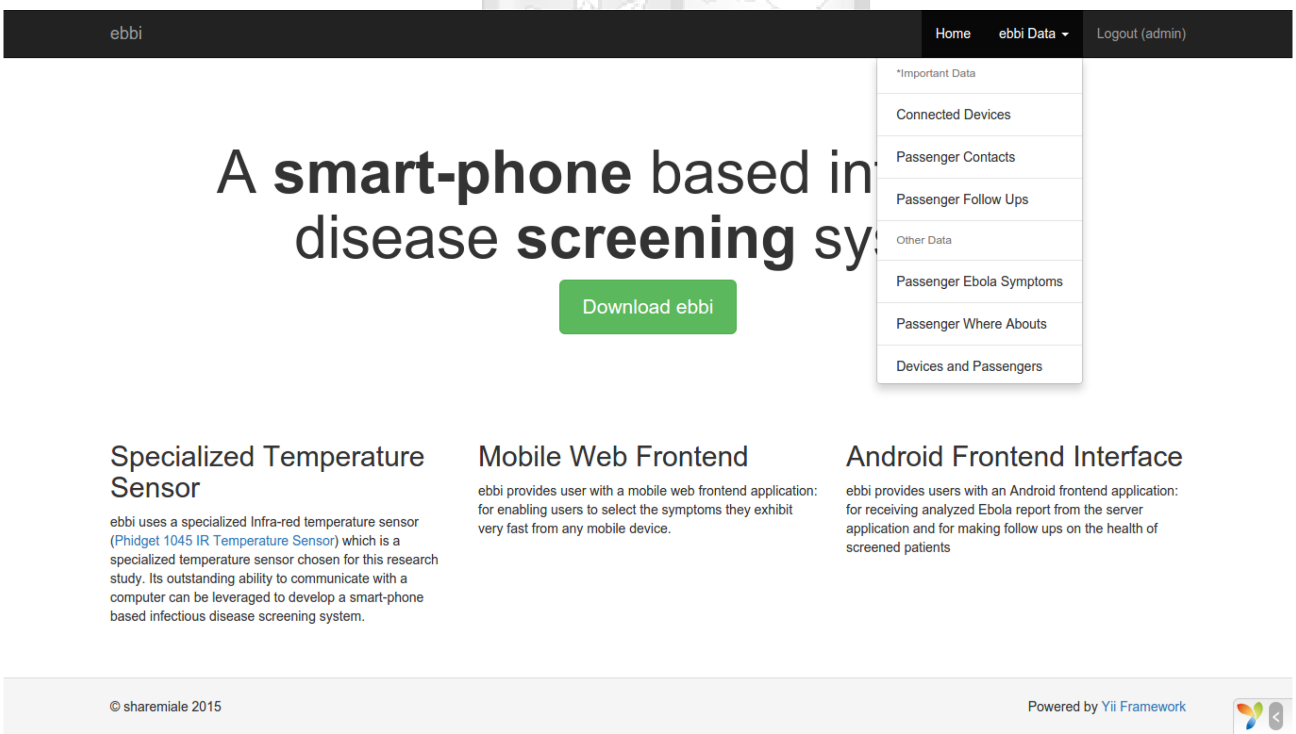

Figure 5.7: Report Management System Screenshot

Chapter Six: System Testing

The overall system testing process involved conducting a series of pilot executions of the whole system so as to inspect and improve all the system functionalities as required by the V model testing methodology in combination with the agile development methodology. The system testing of the proposed border screening system was broken down into: nonfunctional requirement testing and functional requirement testing.

6.1 Nonfunctional Requirement Testing

System testing, using the V model methodology, involved confirming that the functional requirements were met while the acceptance testing involved confirming that the nonfunctional requirements such as accuracy and usability were met. Table 6.1 summarizes the nonfunctional requirements to be met by the proposed system through the testing phase survey conducted using the questionnaire in Appendix C.

Table 6.1: Nonfunctional Requirements to be Met

Nonfunctional Requirements	**Method of Testing**	**Expected Results**
Temperature Detection Accuracy	System is executed in front of the users and afterwards they are asked to rate the system on a scale of 1 to 5.	An average rating of at least 3 of 5 and/or above by the users
Disease Prediction Accuracy		
Temperature Detection Consistency		
System Usability		

6.1.1 Presentation of Testing Phase Findings

A demonstration of the proposed smart phone based Ebola screening system was performed during the testing phase, in front of 12 participants of the survey; in order for them to understand how the proposed system works. After the demo was performed, the participants were asked to respond to the questions presented in the research questionnaire in Appendix C. A summary of the independent survey results on the participants' rating on the system is presented in the following figures: Figure 6.1, Figure 6.2, Figure 6.3 and Figure 6.4.

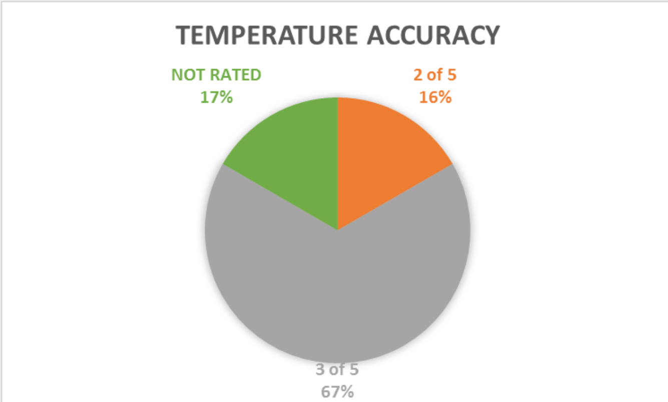

Figure 6.1: Temperature Accuracy Rating

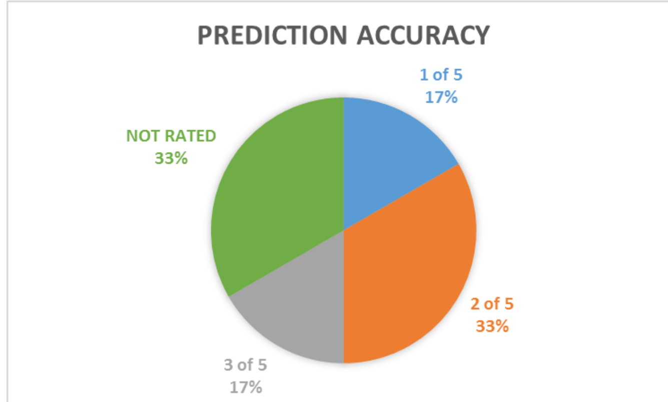

Figure 6.2: Prediction Accuracy Rating

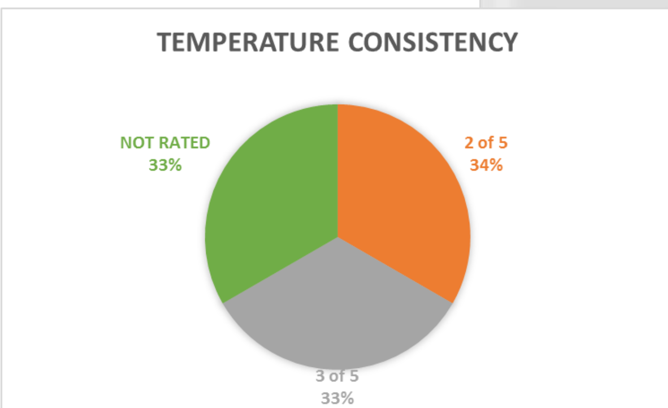

Figure 6.4: Temperature Consistency Rating

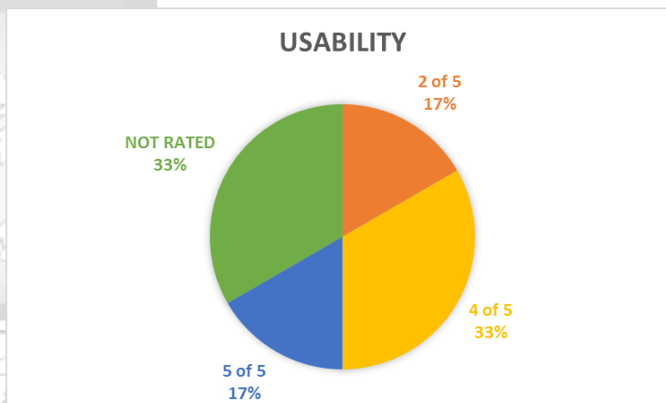

Figure 6.3: System Usability Rating

Figure 6.1, Figure 6.2, Figure 6.3 and Figure 6.4 show that some of respondents did not rate all the nonfunctional features of the proposed border screening system. However, the percentage of participants that avoided rating some nonfunctional features are less than half in all the cases.

Figure 6.5 shows the combined responses of the participants on the temperature accuracy, temperature consistency, disease prediction accuracy and usability of the proposed border screening system. The respondents rated the four aspects of the proposed border screening system each on a scale of 1 to 5.

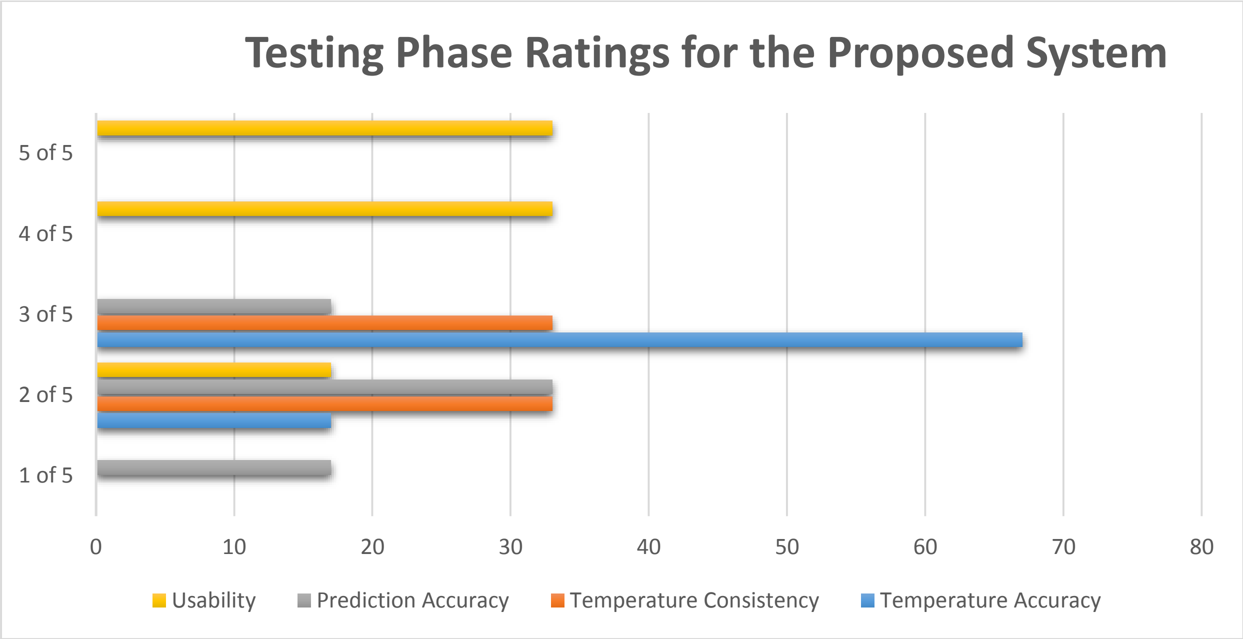

Figure 6.5: Ratings on the Accuracy, Consistency and Usability of the Proposed System

The calculation of mode which is a method of central tendency was used to analyze the results from the testing phase survey in Figure 6.5. A majority of the users rated the system 5 out of 5 and 4 out of 5 as usable, 3 out of 5 as consistent and accurate in the measurement of temperature and 2 out of 5 as accurate in predicting if a passenger has EVD.

6.2 Functional Requirement Testing

The functional system requirements to be met by the proposed border screening system were confirmed by breaking down the whole proposed border screening system into four parts and testing each part independently. The four testing parts were as follows: temperature application testing, mobile web application testing, mobile Android application testing and server application testing. Test case forms were used to document the actions performed during the testing; the expected responses; and if the system passed by giving the expected results.

6.2.1 Temperature Application Testing

The main functionalities of the temperature application were tested in order to make sure that it worked flawlessly to produce the expected results. The process of detecting the body temperature of a passenger and sending it to the server backend application was tested.

Table 6.2: Detect Temperature Test Case

Test Case Name	Detect Temperature	**Test Case Number**	1
Brief Description	Test the action of automatically detecting the body temperature of a user		
Pre-conditions	None		
Step	**Action**	**Expected Response**	**Pass/Fail**
1	User stands in front of the temperature sensor.	The body temperature is detected and printed on the display. A random passcode is generated and printed on the display.	Pass
Post-conditions	Temperature data is saved		

6.2.2 Mobile Web Application Testing

The main functionalities of the mobile web application were tested so as to make that this component was free from bugs and errors. This application was used after the temperature of the passenger had been detected and displayed on the screen together with a randomly generated passcode.

Table 6.3: Add Contact Test Case

Test Case Name	Add Contact	**Test Case Number**	2
Brief Description	Test the action of adding passenger contact details into the system.		
Pre-conditions	The user has navigated to the mobile web application in the browser		
Step	**Action**	**Expected Response**	**Pass/Fail**
1	User enters: passcode, name, phone number, email and presses the submit button.	A popup dialog appears with the submission message.	Pass
Post-conditions	Contact details are saved.		

Table 6.4 shows the test case form for adding passenger symptoms to the system.

Table 6.4: Add Symptoms Test Case

Test Case Name	Add Symptoms	Test Case Number	3
Brief Description	Test the action of adding the symptoms exhibited by the passenger into the system.		
Pre-conditions	The user has navigated to the mobile web application in the browser. The user has successfully added contact details through the mobile web application		
Step	**Action**	**Expected Response**	**Pass/Fail**
1	User checks off the symptoms that he/she exhibits and presses the submit button.	A popup dialog appears with the submission message.	Pass
Post-conditions	Symptoms exhibited are saved.		

6.2.3 Mobile Android Application Testing

The main functionalities of the Android smart phone application were tested in order to make sure that there were no errors or bugs during the execution of the application. The process of registering the device with the GCM servers and connecting the device with the server backend application was tested. This process enables the system to communicate with the device.

Table 6.5: Connect Device Test Case

Test Case Name	Connect Device	Test Case Number	4
Brief Description	Test the action of connecting a smart phone device to the system		
Pre-conditions	The user has installed the application and has launched it.		
Step	**Action**	**Expected Response**	**Pass/Fail**
1	User clicks on the connect button	Device registers with the GCM server and the Add Device Details page appears with the device's registration number	Pass
2	User enters the device name, the administrators passcode and clicks on the configure button.	Device connects with the online server and the Temperature Page appears.	Pass
Post-conditions	Device registration ID is saved and the device can receive notifications alerts from the online server application.		

Table 6.6 shows the test case form for making passenger follow ups.

Table 6.6: Make Follow Up Test Case

Test Case Name	Make Follow Up	**Test Case Number**	6
Brief Description	Test the action of making passenger follow ups within the three weeks after screening.		
Pre-conditions	The user has installed the application and launched it. The device has successfully connected to the server backend application.		
Step	**Action**	**Expected Response**	**Pass/Fail**
1	User clicks on the Follow Up button on the splash screen.	Follow up page appears with a list of all passengers that require follow up.	Pass
2	User clicks on the call icon.	A phone call is initiated using the passenger's phone number.	Pass
3	User clicks on the e-mail icon	All e-mail applications installed on the phone appear.	
4	User selects one of the e-mail applications and sends a message to the passenger	Application returns to the Follow up page.	
Post-conditions	Follow up is made on the passenger by the health worker.		

6.2.4 Server Application Testing

The main functionalities of the server backend application were tested in order to make sure that there were no errors or bugs during the execution of the application. The server application was tested to make sure it could receive temperature data from the temperature sensor application; analyze it and then display instructions for the passenger on what to do next. The process of testing these functionalities is illustrated in Appendix F: Table 10.6.

The process of sending follow up push notification reminders to Android devices was tested. This is illustrated in Appendix F: Table 10.7. The process of managing passenger and devices records by the administrator was tested and Table 6.7 shows the results of the test.

Table 6.7: Manage Records Test case

Test Case Name	Manage Records	**Test Case Number**	10
Brief Description	Test the action of managing records.		
Pre-conditions	The user has navigated to the server web application on the browser.		
Step	**Action**	**Expected Response**	**Pass/Fail**
1	The user clicks on the drop down menu at the top navigation bar.	A drop down list appears with the links to records that can be managed.	Pass
2	The user clicks on a link of a record.	A web page with a table of the records appear. The table has buttons for editing each record.	Pass
Post-conditions	Passenger and devices records can be viewed and edited.		

6.3 Summary

The chapter also described how these main functional features of the system were tested in order to make sure that the implemented system met all the design and architecture specifications without any major errors and bugs. The chapter also discussed the results of testing if the system met all the nonfunctional requirements.

Chapter Seven: Discussions of Results

7.1 Introduction

This chapter discusses the results of this research work from the previous chapters. It as well explains how the results achieved meet the research objectives of this research study. This chapter also discusses the results obtained from the survey that was conducted at the testing phase.

7.2 Discussion of Results and Objectives

The challenges faced by health workers at the airport while screening for EVD symptoms during the 2014 Ebola outbreak were identified from the article published by Sylvie Briand et al., (2014). Together with a review of border screening measures from the research done by Selvey et al., (2015); the first research objective was met. The results of the findings were that: the current screening process was slow, cost and resource intensive, and inefficient in making health follow ups on the passengers that had been screened for the Ebola virus.

The concepts for developing the proposed system artificially intelligent in order to automatically detect EVD from the symptoms presented were derived from the work of Russel and Norvig (2010), Sajda (2006) and Polla et al.,(2000) in Chapter Two. Using the concepts learnt from their work together with the results from the personal interview on the Strathmore medical staff mentioned in Chapter Three; it was possible to develop an AI inference engine that weighted the symptoms of EVD in order to calculate the chances of someone having the Ebola virus from the symptoms he/she presents as a percentage. In this way the second objective was fully met because it was confirmed that artificial intelligence coupled with IC technology can be used to develop medical expert systems that can automatically detect infectious diseases. The requirements recommended by CDC (2014) and WHO Media Center (2014) in Chapter Two enabled this research to meet the third objective and go on further to identify a different IR temperature sensor that could be used to automate the border screening process. From the personal interview on the Strathmore medical staff, this research was able to develop a model in the AI inference engine for normalizing the IR body temperature range detected to a medical body temperature range. The identified Phidget 1045_1 sensor together with the AI inference engine were used to develop the proposed border screening expert system. This enabled this research to fully meet the fourth objective.

7.3 Discussion of Testing Phase Survey Results

The calculation of mode which is a method of central tendency was used to analyze the results from the testing phase survey in Figure 6.5. A majority of the users rated the system 5 out of 5 and 4 out of 5 as usable, 3 out of 5 as consistent and accurate in the measurement of temperature and 2 out of 5 as accurate in predicting if a passenger has EVD. From these results, the system met the expected nonfunctional requirements as well as the functional requirements. The major achievement of this research was to develop an automated smart phone based EVD border screening system.

7.4 Summary

This results of this research work were used to meet all the objectives of the study. All the research questions were as well answered by this work. The results obtained from the pilot phase survey and testing phase survey show that the proposed system is more efficient, effective, cheap to implement, accurate and easy to used.

Chapter Eight: Conclusions, Recommendations and Further Work

8.1 Conclusions

The research determined that there are challenges that were faced in the process screening passengers for infectious diseases at the airport. Due to the inefficiency and ineffectiveness of the screening systems employed during the 2014 Ebola outbreak in West Africa, the following challenges were clearly identified: the current systems were slow and cumbersome, since the health worker had to personally measure and record temperature and other symptoms presented by the passenger; the current screening systems did not provide a good platform for making health follow ups on screened passengers by the responsible staff.

In addition to that the research also established that the border screening measures were cost and resource intensive, because the airport had to invest heavily on screening equipment and extra human resource within a very short time. In light of all these challenges, an Infra-Red temperature sensor was identified and it was used to develop a smart phone based border screening system. The developed expert system used an AI inference engine to automatically analyze the symptoms of the passengers and send the results to the health worker. The aim of the developed system was to mitigate the challenges presented by the current screening systems.

The evaluation of the feedback obtained after designing, implementing and testing the proposed system, showed that users were able to screen more passengers at a time as well as easily make follow ups on the health of screened passengers. The new system also is less cost effective than the current screening systems used during the 2014 Ebola outbreak because it requires fewer screening devices to operate.

The three major achievements drawn from this research work are: the identification of a better IR temperature sensor that was used to automate the border screening process; the normalization of the body temperature range detected by IR thermometers to a medically acceptable range; and the use of AI concepts to weight symptoms of an infectious disease. This makes it possible for any computerized machine to automatically diagnose patients for infectious diseases using the developed system. These achievements are the novelty of this research and the findings of this research may be beneficial to areas whose major interest is to automatically detect diseases from the symptoms presented by a patient without human intervention.

8.2 Recommendations

The proposed system was developed to meet the requirements of screening for the EVD symptoms. The functionalities and steps indicated by the system were chosen based on the known symptoms of EVD. However, the architecture of the system with a few modifications could still be reused to screen for other infectious diseases at the border entry/exit points. Apart from airports, this system could also be used at any other entry/exit point of a country. Therefore, it would be very practical for the proposed system to be implemented with a few modifications to screen for other infectious diseases at all entry/exit points of a country.

8.3 Further Work

The application of expert systems in detection of infectious has not yet been fully explored. As proof of concept the proposed system shows that it is possible to use artificial intelligent concepts to develop medical expert systems for disease detection that require no human intervention to operate.

The only symptom that the developed system could automatically detect was the high fever symptom. Other Ebola symptoms had to be entered by the passenger or the health worker; therefore, dishonest passengers could enter false data. As further work, the system could be improved to detect the following EVD major symptoms automatically: headache, fatigue, stomach pain, vomiting, diarrhea, muscle pain and unexplained bleeding.

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Appendices

Appendix A: Request Letter to Conduct Research

@iLab Africa
excellence in research

Our Ref.: iLab/PP/15/65

28 January 2015

TO WHOM IT MAY CONCERN

Dear Sir/Madam,

Re: Dickson Owuor - 079218

This is to certify that the above named is currently a student of Strathmore University undertaking a Masters degree Course – Master of Science in Mobile Telecommunications and Innovation (MSc.MTI) in the Faculty of Information Technology.

As part of his studies, he is required to undertake an information research project prior to completion of his master's degree.

Any assistance given to him will be highly appreciated.

Please contact us in case of any further clarifications.

Yours faithfully,

Dr Everlyne Makhanu
Academic Director, @iLabAfrica

Strathmore University

Figure 10.1: Request Letter to Conduct Research

Appendix B: Pilot Phase Questionnaire on the Ebola Screening Process

This questionnaire is for an academic research work for a dissertation titled: **"SMART PHONE BASED AIRPORT SCREENING SYSTEM FOR INFECTIOUS DISEASES"**. Your assistance will be highly appreciated.

Indicate your choices using [√ or ×]

A: GENERAL DEMOGRAPHIC DATA

Location							
Gender		**Age Bracket [years]**					
Male	Female	16 - 25	26-35	36 - 45	46 - 55	Over 56	
Education Level				**Job Position**			
Primary School	Secondary School	College	University	Student	Business Person	Health Worker	Professional (Employee)

B: GENERAL EBOLA VIRUS DISEASE DATA

Question	**Yes**	**No**
Is Ebola an Infectious virus disease?		
Is fever (or temperature) check part of the normal Ebola screening procedure?		
Is follow up on the health of patients screened for the Ebola virus important?		
Have you experienced (or know about) the Ebola screening procedure?		

Indicate your choices using [√ or ×]

C: PROPOSED SMART PHONE BASED EBOLA SCREENING PROCESS

Rate the proposed smart phone based Ebola screening system				
Extremely Inefficient	Very Inefficient	Efficient	Very Efficient	Extremely Efficient
Extremely Ineffective	Very Ineffective	Effective	Very Effective	Extremely Effective
Extremely Inaccurate	Very Inaccurate	Accurate	Very Accurate	Extremely Accurate
Extremely Unreliable	Very Unreliable	Reliable	Very Reliable	Extremely Reliable
Extremely Inexpensive	Very Inexpensive	Expensive	Very Expensive	Extremely Expensive

D: SUGGESTIONS

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Page 2 of 2

Figure 10.2: Pilot Phase Research Questionnaire

Appendix C: Testing Phase Questionnaire on the Accuracy and Usability of the System

This questionnaire is for an academic research work for a dissertation titled: **"SMART PHONE BASED AIRPORT SCREENING SYSTEM FOR INFECTIOUS DISEASES"**. Your assistance will be highly appreciated.

Indicate your choices using [√ or ×]

A: GENERAL DEMOGRAPHIC DATA

<table>
<tr><td colspan="2">Location</td><td colspan="6"></td></tr>
<tr><td colspan="2">Gender</td><td colspan="6">Age Bracket [years]</td></tr>
<tr><td>Male</td><td>Female</td><td colspan="2">16 - 25</td><td>26-35</td><td>36 - 45</td><td>46 - 55</td><td>Over 56</td></tr>
<tr><td></td><td></td><td colspan="2"></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Education Level</td><td colspan="4">Job Position</td></tr>
<tr><td>Primary School</td><td>Secondary School</td><td>College</td><td>University</td><td>Student</td><td>Business Person</td><td>Health Worker</td><td>Professional (Employee)</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

B: PROPOSED SMART PHONE BASED INFECTIOUS DISEASE SCREENING SYSTEM

Kindly rate the proposed smart phone based screening system					
	1/5	**2/5**	**3/5**	**4/5**	**5/5**
Temperature Accuracy (Temperature Measurement)					
Consistency (Temperature Readings)					
Prediction Accuracy (Probability of Disease Prediction)					
Usability (User Friendliness)					

Page 1 of 2

Indicate your choices using [√ or ×]

C: SUGGESTIONS

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Page 2 of 2

Figure 10.3: Testing Phase Research Questionnaire

Appendix D: Use Case Forms

Table 10.1: Add Passenger Contact Use Case Form

System: Border Screening System	
Use Case Name: Add Passenger Contact	**Group ID:** A
Primary Actor: Passenger	**Use Case ID:** UC-006
Stakeholders: Health Worker	**Priority (H, M, L):** H
Goal: To add passenger contact information to the system	
Trigger: Symptoms successfully saved by the server application	
Inputs: email, phone number, source location, destination location	
Relationships: Included in: Screen Passenger	
Preconditions: Symptoms must exist, device is connected to server application.	
Basic Flow:	
Actor	System
1. Enter contact details: email, phone number, source country, city	1. Save passenger contact details
Alternate Flow: None	
Post Conditions on Success: Add Follow Up Date	
Post Conditions on Failure: None	
Output: Contact details saved	

Table 10.2: Add Passenger Symptoms Use Case Form

System: Border Screening System	
Use Case Name: Add Passenger Symptoms	**Group ID:** A
Primary Actor: Passenger	**Use Case ID:** UC-007
Stakeholders: Health Worker	**Priority (H, M, L):** H
Goal: To add passenger symptoms into the system	
Trigger: Temperature Detected	
Inputs: Temperature, Headache, Stomach Pain, Muscle Pain, Bleeding	
Relationships: Included in: Screen Passenger	
Preconditions: Temperature Detected, device is connected to server application.	
Basic Flow:	
Actor	System
1. Enter symptoms: headache, stomach pain, muscle pain, bleeding	1. Save passenger symptoms
Alternate Flow: None	
Post Conditions on Success: Add Passenger Contacts	
Post Conditions on Failure: None	
Output: Passenger symptoms saved	

Table 10.3: Add Device Use Case Form

System: Border Screening System	
Use Case Name: Add Device	**Group ID:** A
Primary Actor: Smart phone application	**Use Case ID:** UC-008
Stakeholders: Administrator, Health Worker	**Priority (H, M, L):** H
Goal: To register a device in the system	
Trigger: Connect device to server application	
Inputs: Sender ID, Application ID	
Relationships: Included in: Connect Device	
Preconditions: None	
Basic Flow:	
Actor	System
1. Sends sender ID and application ID to GCM server 2. GCM server registers device to the GCM notification API and sends back the registration ID 3. Sends registration ID and device name to screening system server application	1. Idle 2. Idle 3. Saves registration ID and device name. 4. Marks the device as configured.
Alternate Flow: None	
Post Conditions on Success: Device registration records saved in the system	
Post Conditions on Failure: None	
Output: Device successfully configured.	

Table 10.4: Detect Temperature Use Case Form

<table>
<tr><td colspan="2">System: Border Screening System</td></tr>
<tr><td>Use Case Name: Detect Temperature</td><td>Group ID: A</td></tr>
<tr><td>Primary Actor: Temperature sensor application</td><td>Use Case ID: UC-009</td></tr>
<tr><td>Stakeholders: Passenger, Health Worker</td><td>Priority (H, M, L): H</td></tr>
<tr><td colspan="2">Goal: To detect the temperature of the passenger and send it to the server application.</td></tr>
<tr><td colspan="2">Trigger: Passenger movement</td></tr>
<tr><td colspan="2">Inputs: reflected Infra-red light</td></tr>
<tr><td colspan="2">Relationships:

Included in: Screen Passenger, Display Alert</td></tr>
<tr><td colspan="2">Preconditions: None</td></tr>
<tr><td colspan="2">Basic Flow:</td></tr>
<tr><td><u>Actor</u></td><td><u>System</u></td></tr>
<tr><td>1. Detects passenger movement and measures the passenger body temperature.
2. Sends the detected temperature data to the server application.</td><td>1. Idle
2. Receives and analyzes the temperature data
3. Saves temperature data and generates a random passcode.
4. Displays passcode to the passenger</td></tr>
<tr><td colspan="2">Alternate Flow: None</td></tr>
<tr><td colspan="2">Post Conditions on Success: Display information updates</td></tr>
<tr><td colspan="2">Post Conditions on Failure: None</td></tr>
<tr><td colspan="2">Output: Temperature successfully detected and sent to a specific health worker</td></tr>
</table>

Appendix E: System Screen Shots

Figure 10.5: Splash Screen Screenshot

Figure 10.4: Configure Device Screenshot

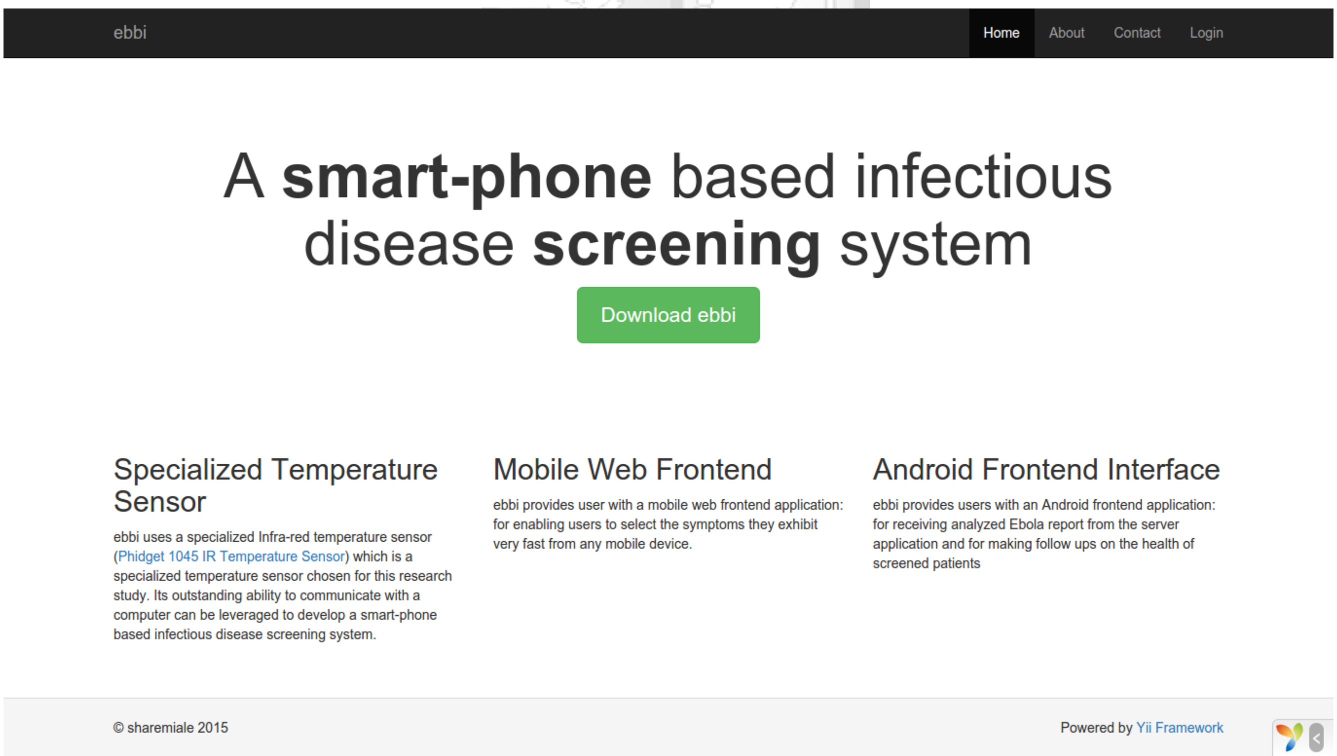

Figure 10.6: Frontend Website Screenshot

Appendix F: Test Case Forms

Table 10.5: Display Screening Results Test Case

Test Case Name	Display Screening Results	**Test Case Number**	5
Brief Description	Test the action of displaying screening results		
Pre-conditions	The user has installed the android application and launched it. The user has already registered and connected to the online server application.		
Step	**Action**	**Expected Response**	**Pass/Fail**
1	User clicks on the "Screening results" button at the Temperature page of the application.	"Screening Results" page appears with the screening report of a passenger.	Pass
Post-conditions	None		

Table 10.6: Display Alert Test Case

Test Case Name	Display Alert	**Test Case Number**	8
Brief Description	Test the action of displaying alerts to the passenger		
Pre-conditions	The user has to navigate to the display web application		
Step	**Action**	**Expected Response**	**Pass/Fail**
1	User navigates to the display web page	A yellow page with black navigation bars at the top and bottom appears. It will display the current messages from the online server application	Pass
Post-conditions	none		

Table 10.7: Send Notification Test Case

Test Case Name	Send Notification	**Test Case Number**	4
Brief Description	Test the action of sending notifications from the server application to registered Android devices		
Pre-conditions	Android devices must be registered with the GCM server		
Step	**Action**	**Expected Response**	**Pass/Fail**
1	The developer runs a web URL that sends a message to a registered Android device	Push notification appears on the status bar of the Android device.	Pass
Post-conditions	Push notification sent		

Appendix G: General Demographic Survey Result Summary

Table 10.8: General Demographic Survey Results shows the results of a survey conducted using Appendix B: Pilot Phase Questionnaire on the Ebola Screening Process and Appendix C: Testing Phase Questionnaire on the Accuracy and Usability of the System.

Table 10.8: General Demographic Survey Results

	Target Population	**Distribution**	**Percentage**
Respondents	Actual Population Size	32	100%
Gender	Male	20	62%
	Female	12	38%
Age Bracket	16 – 25	19	59%
	26 – 35	4	13%
	36 – 45	6	19%
	46 – 55	2	6%
	Over 56	1	3%
Education Level	Primary School	0	0%
	Secondary School	1	3%
	College	2	6%
	University	29	91%
Occupation	Student	15	48%
	Business Person	1	6%
	Health Worker	8	26%
	Professional (Employee)	7	23%