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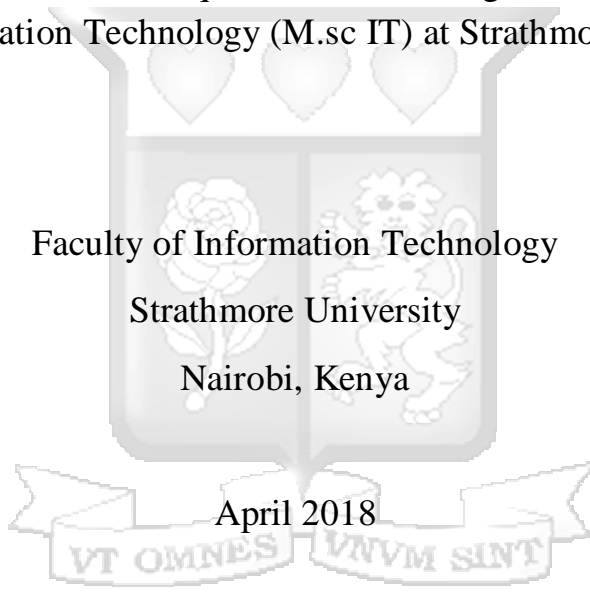
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Fuzzy Expert Based Real Time Monitoring System for Patients with Chronic Heart Failure through IOT

ISAACK MWENDA MURIUKI

094794

A Research proposal submitted to the Faculty of Information Technology in partial fulfillment for the requirement of the degree of Master of Science in Information Technology (M.sc IT) at Strathmore University



Faculty of Information Technology
Strathmore University
Nairobi, Kenya

April 2018

Declaration page

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 thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

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Approval

With the approval of supervisor,

Dr. Joseph Orero, PhD

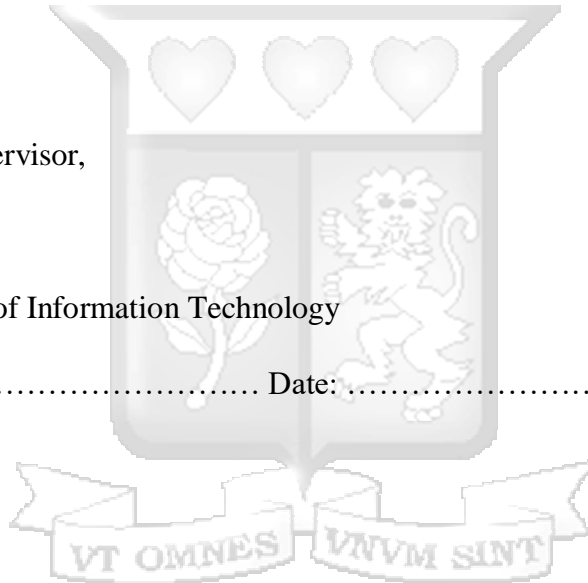
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Abstract

Data from the World Health Organization has placed CHF as the number one global killer. It remains the only cardiovascular disease with an increasing hospitalization burden and a continuous drain on health care budgets. Heart failure is a complex clinical syndrome of symptoms that suggest the heart is unable to pump blood efficiently as it should. Heart failure signs and symptoms may include irregular heart rate, blood pressure, fatigue and weakness. The hard reality, with which doctors contend every day, is that the effects of these conditions often manifest too gradually for people to recognize. It falls to the healthcare system to deal with these diseases after they've advanced to a serious stage, often at a great financial cost.

Effective therapy and treatment in CHF patients require thorough continuous monitoring of patients vitals. Doctors require information on patients; blood pressure, heart electrocardiography activities heart rate and temperature to predict the heart failure attacks and respond swiftly. The typical way to diagnose and monitor CHF patients is by use of bedside patient monitoring systems which requires monitoring within the confines of the hospital. Such monitoring equipment are available in very few hospitals in Kenya and that is an impediment to proper therapy and treatment for CHF patients. The challenges faced in using the existing methods include; lack of flexibility for the patient as there is need for long term monitoring in a hospital setup, financial burden on the patients when they are hospitalized, obtrusive nature of the current monitoring systems making it not suitable for monitoring outdoors.

This research applies scrum methodology to design, develop and test a fuzzy based expert system for real time monitoring of chronic heart failure patients through IoT. The IoT architecture contains sensors to capture heart rate, heartbeat, and temperature values from the patients and transmit values from the Arduino board to an IoT server via a GSM communication module. A mobile application will be developed to enable the care givers to monitor the patient remotely. The recommended vital parameters will be keyed to the system to enable it detect anomalies. As a result, patient's doctor and care-givers can see CHF patients vital current health conditions in real-time and get sms alerts in case of anomalies' to enable them respond swiftly. This model reduce re-hospitalization, enables adjustment of therapy to accommodate change in the patient's condition and reduces death rates caused by CHF.

Acknowledgement

I would first like to immensely thank my supervisor Dr. Joseph Orero for his consistent guidance and patience through the entire research period. I would also like to thank my parents and my brother for constantly motivating and supporting me. May God bless you all.

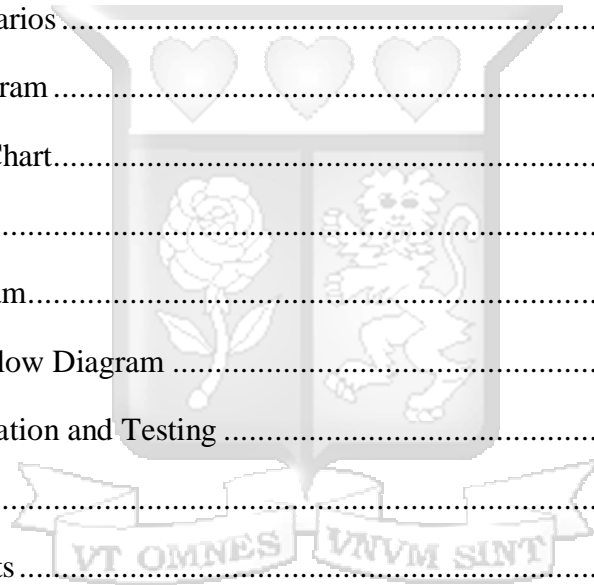


Table of Contents

Declaration page	ii
Abstract.....	iii
Table of figures.....	ix
Chapter 1: Introduction.....	1
1.1 Background	1
1.2 Problem statement	1
1.3 Research Objectives	2
1.4 Research questions	2
1.4 Justification for the study.....	2
1.5 Scope/Delimitation.....	3
Chapter Two: Literature Review	4
2.1 Introduction	4
2.2 Chronic Heart Failure	4
2.2.1 Parameters Used in Diagnosing Chronic Heart Failure	5
2.3 Patient Monitoring	6
2.3.1 Categories of Patient who need Physiological Monitoring	6
2.3.2 Measurement standards for individual-patient monitoring applications	7
2.4 Current Patient Monitoring systems	7
2.4.1 Single-Parameters Monitoring Systems.....	7
2.4.2 Multi-Parameter Patient Monitoring Systems	8
2.5 Challenges of Current Monitoring Systems in Kenya.....	8
2.6 Internet of Things.....	9
2.6.1 Internet of Things Architecture.....	9
2.6.2 Device to Cloud Model	11

2.7 Machine to Machine Communication.....	12
2.8 Ubiquitous Computing Framework	13
2.8 Fuzzy Logic.....	14
2.8.1 If-Then Rules and Fuzzy Inference	14
2.8.2 Fuzzy Logic in CHF Patient Monitoring	15
2.9 Conceptual Model	17
Chapter 3: Research Methodology	19
3.1 Introduction	19
3.2 Research Design.....	20
3.2.1 System analysis and System Requirements	20
3.2.2 System Design.....	21
3.2.3 System implementation.....	21
3.2.4 System testing.....	21
3.3 Target Population and Sampling frame	22
3.4 Data Collection	23
3.5 Data Analysis.....	23
3.7 Research Quality Aspects	23
3.7.1 Validity	23
3.7.2 Reliability	23
3.8 Ethic Considerations	23
Chapter 4: System Design and Architecture.....	24
4.1 Introduction	24
4.2 Questionnaire Analysis.....	24
4.2.1 Age Group.....	24
4.2.2 Ability to use Mobile Phone	25

4.2.3 Having been hospitalized Due to Heart Failure	25
4.2.4 Ability to Access Mobile Health Information	26
4.3 Requirement Specifications	26
4.3.1 Functional Requirements	26
4.3.2 Non Functional Requirements	27
4.4 System Architecture	27
4.5 System Analysis	28
4.5.1 Use Case Diagram	28
4.5.2 Use Case Scenarios	29
4.5.2 Sequence Diagram	30
4.5.3 System Flow Chart.....	31
4.6 System Design	32
4.6.1 Context Diagram.....	32
4.6.2 Level 1 Data Flow Diagram	32
Chapter Five: Implementation and Testing	34
5.1 Introduction	34
5.2 System Components	34
5.2.1 Hardware Components	34
5.2.2 Application Layer.....	35
5.2.3 Sensor Data Analysis.....	36
5.2.4 Fuzzy Rules	36
5.3 System Testing.....	37
5.3.1 Functionality Testing	37
5.3.2 Usability Testing.....	38
5.3.3 Implementation of Experiments.....	40



Chapter 6: Discussions	41
6.1 Introduction	41
6.2 Challenges faced in chronic heart failure patients monitoring.....	41
6.3 Existing approaches for chronic heart failure patients monitoring	41
6.4 Current Chronic Heart Failure Patients Monitoring Technologies	41
6.5 Model for real-time monitoring of Chronic Heart Failure Patients.....	41
6.6 Advantages of the model as compared to the current methods of monitoring	42
6.7 Disadvantages of the model for monitoring of chronic heart failure patients	42
Chapter 7: Conclusions and Recommendations	43
7.1 Conclusions	43
7.2 Contributions to Research.....	43
7.3 Recommendations	44
7.4 Suggestions for future research	44
References	45
Appendix A	48
Questionnaires	48
Research Questionnaire	48
Usability Testing Questionnaire	49

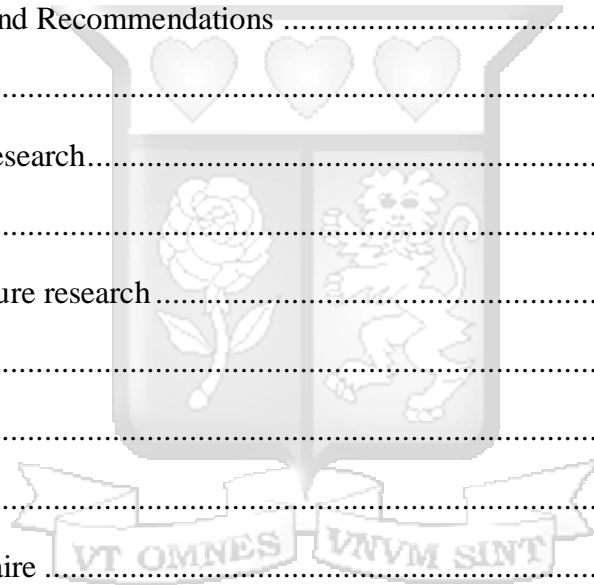


Table of figures

Fig 2.1 Single Parameter Monitoring system (Crone, Bill, Healthcare Systems Engineer, Analog Devices, 2011)15

Fig 2.2 Multi Parameter Monitoring system (Crone, Bill, Healthcare Systems Engineer, Analog Devices, 2011).....16

Figure 2.3 IOT Layout Structure (Kopetz, 2011).....19

Figure 2.5: Device to cloud model (Google Cloud, 2017).....20

Figure 2.4: Architecture of M2M system (Weyrich, Schmidt, & Ebert, 2014).....22

Figure 2.5: Categories with triangular membership functions (Rojas, 1996).....26

Figure 2.6: Categories with trapezium-shaped membership functions (Rojas, 1996).....27

Figure 2.5 Fuzzy Inference System Steps (Caballero & Mitrani, 2000).....28

Figure 2.7 Fuzzy Membership Sets for Heart rate sensor (Oliva et al., 2017).....29

Fig 2.6 .Proposed Architecture of the real time patient monitoring system.....30

Fig 3.1 Scrum methodology reference card (KOCH, 2006).....31

Figure 4.1 Ability to use mobile phone.....38

Figure 4.2 having been hospitalized due to heart failure38

Figure 4.3 Ability to access mobile health information38

Figure 4.1 System Architecture.....40

Figure 4.2 Use case Diagram.....41

Figure 4.3 Sequence Diagram.....43

Figure 4.4 Flow Chart Diagram.....44

Figure 4.4 Context Diagram46

Figure 5.1 Board Architecture.....48

Figure 5.2 Sample CHF patient vital sign alert51

Definition of terms

Internet of Things (IoT) - refers to the inter-connection of everyday objects which are often equipped with ubiquitous intelligence (Kopetz, 2011) .

Machine To Machine (M2M) - describes technology that enables networked devices to exchange information and perform actions without human intervention (Sanyal, 2010) .

Heart Diseases- Heart disease describes a range of conditions that affect your heart. Diseases under the heart disease umbrella include heart attack, Heart failure, Arrhythmia and Heart valve problems (Flynn, Ellery, & Mason, 2014a).

Chronic Heart Failure- Is a complex clinical syndrome that is frequently characterized by an underlying structural abnormality or cardiac dysfunction that impairs the ability of the left ventricle (LV) to fill with or eject blood, particularly during physical activity (Fenton & Burch, 2007).

SpO₂- is an estimate of the amount of oxygen in the blood. It is the percentage of oxygenated hemoglobin (hemoglobin containing oxygen) compared to the total amount of hemoglobin in the blood (oxygenated and non-oxygenated hemoglobin) (Pinkerman, Sander, Breeding, Brink, & Curtis, 2013).

ECG- is a test that checks for problems with the electrical activity of your heart. An EKG shows the heart's electrical activity as line tracings on paper (Pinkerman et al., 2013).

Heart Rate- is the speed of the heartbeat measured by the number of contractions of the heart per minute (bpm). The heart rate can vary according to the body's physical needs, including the need to absorb oxygen and excrete carbon dioxide (Pinkerman et al., 2013).

Abbreviations

API - Application Programming Interface

CHF - Chronic Heart Failure

ETSI- European Telecommunications Standards Institute

DES-Data Encryption Standards

DFD-Data Flow Diagram

HCI-Human Computer Interface

IOT-Internet Of Things

MOH-Ministry Of Health

M2M-Machine To Machine

RFID-Radio Frequency Identification

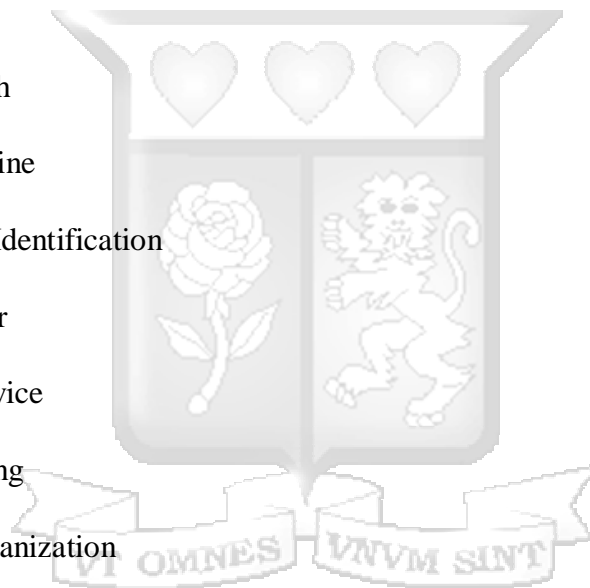
SSL-Secure Socket Layer

SMS-Short Message Service

UC-Ubiquitous Computing

WHO-World Health Organization

WSN-Wireless Sensor Network



Chapter 1: Introduction

1.1 Background

In Kenya today the probability of dying from cardiovascular diseases, diabetes chronic respiratory diseases and cancer before the age of 70 is 70% for males and 63 % for females (World Health Organization, 2015). The number of Kenyans suffering chronic heart failure and other heart diseases is likely to increase, health experts have warned (MERAB, 2016). This patient's lie under the category that requires close and efficient monitoring to enable them control the conditions before they become life threatening.

Rural populations in Kenya, which mostly comprise of low socioeconomic status, face unique barriers to such recommended high-level health care especially for chronic heart failure monitoring and management. For many, there is little access to reliable monitoring equipment and the distance to and cost of travel to hospitals that have the facilities can be prohibitive. These challenges result in poor clinic attendance, poor continuity of care and a break down in patient-monitoring.

Embracing new technology innovations is of prime importance in creating and maintaining medical product competency. Machine-to-machine communication enabled by different connectivity options like Wi-Fi, NFC, GSM form the basis of Internet of Medical things which can be then linked to the cloud platform, on which captured data can be stored and analyzed (Sanyal, 2010). Better health is central to human happiness and well-being (World Health Organization, 2015). It also plays an important role in economic progress sine healthy citizens live longer and are more productive. Real time remote monitoring system can help keep people with chronic heart failure healthy, allow individuals to have a more independent life and a quick action can be triggered which is crucial as few minutes can save lives for people with heart failure. Remote patient monitoring also serve to reduce the number of hospitalizations, readmissions and lengths of stay in hospitals—all of which help improve quality of life and contain costs.

1.2 Problem statement

Chronic heart failure (CHF) remains the only cardiovascular disease with an increasing hospitalization burden and an ongoing drain on health care expenditures. Current methods to

monitor CHF requires the patient to be confined in a hospital where the doctors constantly monitor his vitals through the multi-parameter monitoring equipment. This method is quite costly and requires high human capital. Kenya health care professionals encounter a high demand for quality CHF patients monitoring services. Unfortunately, Kenya health sector has inadequate crucial health personnel. WHO recommends at least 23 doctors, and nurses per 10,000 people. Kenya has one doctor and 12 nurses per 10,000 people (Ministry of Health, 2014). The burden of monitoring the patients is left to relatives who have to closely monitor them reducing their productivity. Due to this challenges, chronic heart failure patients lack the adequate monitoring attention required.

To address this the researcher will develop an expert system using fuzzy logic inference engine to facilitate remote patient monitoring through Internet of things. This will ensure an easier, long-term monitoring tool that helps keep chronic heart failure patients healthy and allows them to have a more independent life.

1.3 Research Objectives

- i. To analyze the current challenges of chronic heart diseases patient monitoring in Kenya.
- ii. To review the current models and systems used in chronic heart failure patient monitoring in Kenya.
- iii. To review and develop the expert system model that can be used for remote chronic heart failure patient monitoring.
- iv. To test the developed prototype.

1.4 Research questions

- i. What are the current challenges of chronic heart diseases patient monitoring in Kenya?
- ii. What are the existing chronic heart failure patients monitoring methods and systems used in Kenya?
- iii. How to review and develop an efficient model that would be applicable in remote chronic heart failure patients monitoring?
- iv. How feasible and scalable is this technology in solving the proposed solution?

1.4 Justification for the study

The study will enable Kenyan medical care givers to operate more effectively by offering timely, remotely accessible and quality patient monitoring services to their chronic heart failure patients

at a reduced cost. To the chronic heart failure patients, the study will give them the opportunity to have their vitals examined remotely by health professionals as part of the treatment plan through devices that they can afford. For researchers, the study will provide a basis for further research not covered.

1.5 Scope/Delimitation

This research deals with developing a fuzzy expert based monitoring system to monitor the patient with chronic heart failure through IoT. The study will help in understanding fuzzy expert system based real time monitoring through IoT, its benefits and challenges encountered while implementing it in hospitals in Meru County. This research is limited to public health facilities/ hospitals within Meru County.



Chapter Two: Literature Review

2.1 Introduction

This chapter presents descriptions for chronic heart failure and critically reviews existing patients monitoring models and systems. It will also cover past relevant studies, identifying the gaps established. It then goes deeper to analyze Internet of things, fuzzy expert systems and machine to machine communication technologies and their role in solving the issue of CHF patient real-time remote monitoring. The researcher will also expound on the proposed prototype and the benefits derived from it.

2.2 Chronic Heart Failure

Chronic heart failure is an ongoing condition in which the heart muscle is weakened and can't pump as well as it supposed to (Fenton & Burch, 2007). The ventricles become larger and/or thicker and either can't contract or relax efficiently as they should. The condition is commonly caused by; previous heart attack, coronary heart disease, high blood pressure and cardiomyopathy (Flynn, Ellery, & Mason, 2014b).

There are two main types of heart failure: Systolic heart failure which occurs when a patient heart muscle can't pump blood out of the heart as well as it should and diastolic heart failure when the heart muscles become stiff and do not easily fill up with blood (Fenton & Burch, 2007). Chronic heart failure (CHF) remains the only cardiovascular disease with an increasing hospitalization burden and an ongoing drain on health care expenditures. The prevalence of CHF increases with advancing life span, with diastolic heart failure predominating in the elderly population (Pinkerman et al., 2013).

There are several symptoms that can point to chronic heart failure: Cough a persistent cough or even wheezing can signal chronic heart failure. The coughing may be dry, or it may produce phlegm that is white or pink from tinges of blood. Shortness of breath: Getting out of breath during activity or even during rest or while sleeping can be a sign of chronic heart failure. Loss of appetite: Feeling like your stomach is full or even experiencing nausea can be a sign of chronic heart failure. Fatigue or weakness: People who have chronic heart failure sometimes experience a consistent lack of energy and even difficulty doing what they normally do. Need to urinate at night: While this can be a symptom of other conditions, it can also signal chronic heart failure. Fast or irregular pulse: If your pulse seems to be uneven or too rapid, it could be a signal of chronic heart failure.

Palpitations: A sense that the heart is racing or pounding can be a symptom of chronic heart failure. Swollen feet, ankles, or abdomen: Also called edema, this buildup of fluid in the lower extremities can also cause inexplicable weight gain. Fluid can also build up in your mid-section. Either way, this may be a symptom of chronic heart failure (Flynn et al., 2014b). Medical care gives administer treatments which include limiting fluid intake, eating less salt, and taking prescription medicine. In advanced cases a pacemaker or defibrillator may be implanted to assist in blood pumping (National Heart Foundation of Australia, 2015).

2.2.1 Parameters Used in Diagnosing Chronic Heart Failure

To help diagnose chronic heart failure, a doctor orders one or more of the following tests: Echocardiogram: It uses sound waves to create a video image of your heart. It helps the doctor determine how much blood your heart is pumping through the left ventricle, which is the heart's main pumping chamber. It can also highlight problems with the heart's valves and show damage from previous heart attacks. Electrocardiogram (ECG): It records the heart's electrical activity through a series of electrodes that are attached to the patients' skin. The electrical impulses your heart generates show up as waves on a monitor or printed on paper. This helps your doctor see problems with your heart's rhythm or heart attack damage that may be the underlying cause for chronic heart failure. Chest x-ray: Chronic heart failure can cause fluid to build up in your lungs. Using a chest x-ray, the doctor can see that fluid buildup and rule out other possible explanations for the symptoms (Flynn et al., 2014b).

Gregg Fonarow recommends management of chronic heart failure is best if done in by a team (Fonarow, 2006). The team may comprise a cardiologist, nurse, dietitian, physiotherapist, pharmacist, occupational therapist, psychologist, palliative care specialist and/or other healthcare professionals. The patients' family members also play a very vital role in the team. An individualized care plan should be developed with the healthcare team taking into consideration the severity of the patients' heart failure, healthcare preferences and other health problems he/she may have. The remote patient monitoring system is of key importance to the team through providing access to the patients' current physiological signs.

2.3 Patient Monitoring

Patient monitoring refers to a continuous measurements or observations of a patients' physiological function with the intent of guiding management decisions, including when to make medicinal interventions, and assessment of those interventions (Jon Berg, 2005). The most monitored signals are the intra- arterial saturation of oxygen, electrocardiogram and cardiac output. A patient monitor provides physiologic input data and alert caregivers to potentially life-threatening events.

Patient monitoring is classified by the target of interest, such us: cardiac monitoring, which generally refers to continuous electrocardiography with assessment of the patients' condition relative to their cardiac rhythm (Seeq, n.d.). Blood pressure monitoring which is measured either noninvasively with an inflatable blood pressure cuff or invasively through an inserted blood pressure transducer assembly. Hemodynamic monitoring, which monitors the blood flow and blood pressure within the circulatory system. Others include childbirth monitoring, blood glucose monitoring and neurological monitoring (Alwan David R.Riley, Leanne M.d'Espaignet, Edouard TursanMathers, Colin DouglasStevens, Gretchen AnnaBettcher, Douglas, 2010).

2.3.1 Categories of Patient who need Physiological Monitoring

There are at least four categories of patients who need continuous physiologic monitoring: Patients with a life-threatening condition e.g. a patient who has suffering from an acute heart attack. The second category are patients with unstable physiologic regulatory systems e.g. a patient whose respiratory system is suppressed by anesthesia. The third category include patients with high risk of developing a life-threatening condition e.g. patients who have just been discharged from a post open-heart surgery, or a premature infant whose heart and lungs are not fully developed. The fourth category include patients in a critical physiological state e.g. patients with septic shock or multiple trauma (Crone, Bill, Healthcare Systems Engineer, Analog Devices, 2011). Proper care of the critically ill patient requires prompt and decisions so that life-saving therapy can be appropriately administered. ICUs established in Kenyan hospitals are however overwhelmed by the demand therefore more flexible and affordable remote based systems should be innovated to provide this much needed service.

2.3.2 Measurement standards for individual-patient monitoring applications

For health status measures to be used at the individual-patient level, several essential measurement standards must be met. First, the measurement standards should be useful for individuals differing in diagnosis, age, severity and comorbidity, the measures should tap a variety of health concepts, each of which should assess the full range of health, from disability to well-being. Second, the measurement standards should be easy to administer, score and interpret. This is because most clinic visits are brief and the functional assessment is currently not a reimbursable expense. Third, measures should be highly reproducible over time and have a small standard error of measurement for use in longitudinal monitoring. Fourth, measures should be valid indicators of the constructs they are hypothesized to represent, show sensitivity to clinical change and have evidence of validity for individual-patient applications. Fifth, to yield clinically-useful descriptions of function across diverse patient groups, both at a single point in time and over time, measures should exhibit minimal floor and ceiling effects (percentage of the sample achieving the worst and best possible scores, respectively). Finally, measures should yield highly accurate and precise scores that have a small standard error of measurement for use in clinical decision-making. (McHorney & Tarlov, 1995).

2.4 Current Patient Monitoring systems

Below are some of the current monitoring systems today based on number of physiological signs they can measure.

2.4.1 Single-Parameters Monitoring Systems

Single parameters monitoring systems are used to measure only one physiological sign at a time. The technology used is quite obsolete however it is largely used in developing countries due to its availability in low cost and easiness in maintenance. The single parameter monitoring system is commonly used to measure blood pressure, ECG(Electrocardiograph) monitor, and SpO2(Oxygen Saturation in Blood) (Crone, Bill, Healthcare Systems Engineer, Analog Devices, 2011). The figure below shows a single parameter monitor.



Fig 2.1 Single Parameter Monitoring system (Crone, Bill, Healthcare Systems Engineer, Analog Devices, 2011)

2.4.2 Multi-Parameter Patient Monitoring Systems

A MPPMS is used to measure various critical physiological signs like Electrocardiograph, Respiration Rate, Blood pressure etc. Due to its wide variety of applications MPPMS plays a very significant role in the field of medical care. The MPPMS continuous improvement help to put out the vital multiple physiological measurements signs to the medical care givers from one single monitor.



Fig 2.2 Multi Parameter Monitoring system (Crone, Bill, Healthcare Systems Engineer, Analog Devices, 2011)

2.5 Challenges of Current Monitoring Systems in Kenya

Kenya health sector has inadequate crucial health personnel with one doctor and 12 nurses serving 10,000 people (Ministry of Health, 2014) . WHO recommends at least 23 doctors, and nurses per 10,000 people. When the healthcare per patient ratio is high it leads to poor quality health care services, high risk to patient injury and ultimate hospital acquired infections, poor working conditions and overworking of the healthcare givers.

According to Dr Misango Kenya public health care sector has less than 50 ICU beds which serve over forty million Kenyans. Each ICU bed is required to have a complete set of associated monitoring equipment such as; infusion pumps, patient monitoring systems, suction apparatus and mechanical ventilator. The current minimum costs of a heart monitor is Kes 750, 000 (Dr Misango (The Critical Care Society of Kenya), 2013). When a family has a loved one admitted into an ICU for CHF monitoring they are required to pay a varying fee of Kes 3,000 per day in public hospitals while private hospitals charge up to Kes 30,000 per day (Okech, 2014).

Chronic Heart failure patients also often face economic, emotional and social relations problems. They lack the adequate resources to hire personal homecare nurses and doctor to monitor their

vitals. The burden of care and monitoring is borne by relatives who are forced to stay close to the patient at all times in order to monitor their symptoms and alert the doctors in case of an emergency (Angelo & Egan, 2015). This reduces the productivity of such people in the society leading to increased poverty levels.

In Kenyan rural setups, consistent chronic heart failure healthcare is practically inaccessible. Additionally current systems available in select hospitals lack modern innovations such as, mobile collaboration which enables easy information sharing and discussion in-app chat forums about critical medical cases among healthcare professionals from multiple remote locations. There is a need to develop a comprehensive solution that is affordable, efficient and real time. An IoT based remote monitoring solution can be applied in such rural places to provide medical care givers with continuous patient physiological signs transmitted via GSM network.

2.6 Internet of Things

Internet of Things (IoT) is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers and ability to transmit data over a network without human-to-human or human-to-computer intervention (Kopetz, 2011). For IoT consumers, the technology has the potential to deliver solutions that significantly improve health, energy efficiency, education, security and many other day to day aspects of life. For companies, IoT provides solutions that improve decision-making and productivity in manufacturing, retail, agriculture, health and other sectors (GSM Association, 2014). The IoT concept lies on the capability of many objects around us to interact and cooperate with each other in order to achieve common goals e.g. a pervasive healthcare. Advancement in IoT has enabled integration of devices capable transmitting data over the internet on the state of health of patients in real time to doctors who in turn provide the required assistance to the patients (Boza, Cortés, Cuenca, & Alarcón, 2015).

2.6.1 Internet of Things Architecture

Figure 2.3 below shows the structure of the internet of things. In the sensor network level, sensors will identify and gather information from objects. Sensors help measuring things and help decide the current status of the environment to be controlled. Heart rate and temperature sensors, actuators and intelligent devices at the edge of the IoT can be easily integrated into the system. Sensors may

use various protocols allowing connection flexibility over the whole lifecycle. Sensors are connect through wireless or wired mediums. Unique sensor IDs and encryption technologies ensures verification of devices and integrity of the services in the network. The transmission network level contains the integration of network for communication, network management center, information center and intelligent processing centers. It acts as the transfer point between the sensors & actuators and enables protocol conversion to and from an IP network. The gateway connects through various WAN technologies like mobile (3G/4G) other Internet connections. A range of networking options can save development time & cost. The application level contains integration of the Internet of Things with the professional industry technology and help organizations in achieving monitoring procedures, data analytics and intelligence. The datasets may range from energy and environment data to that collected from healthcare sensors among other fields. The application layer provides the following functions: Device management provides the management tools for the management and configuration of the IoT devices. The field based devices can be managed and monitored by command line interfaces or SNMP. IoT data processing from the sensors is stored and processed on the server. Interfaces to external processes allow for a high degree of optimization and automation in the value chain. This enables integration of additional enterprise systems like ERP and PPS. Web and mobile applications are used for the presentation of the results to the users.

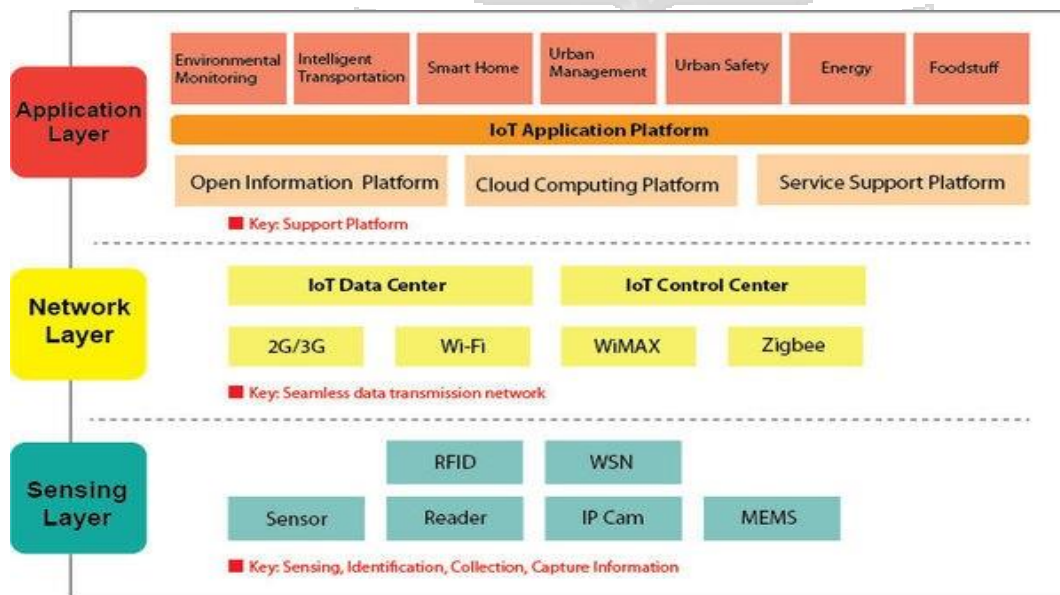


Figure 2.3 IOT Layout Structure (Kopetz, 2011)

2.6.2 Device to Cloud Model

The real value of IoT is found in the data that connected IoT devices can generate. Connection between the IoT devices to the cloud is vital for acquiring sensor data information that health care professionals can use to monitor their patients remotely (Kopetz, 2011). Device-to-cloud communication involves an IoT device connecting directly to an Internet cloud service like an application service provider to exchange data and control message traffic. It often uses wireless connection e.g Wi-Fi or wired connection i.e Ethernet, if deployed in remote areas gprs cellular data through a GSM module can be used (David Hamilton, 2016).

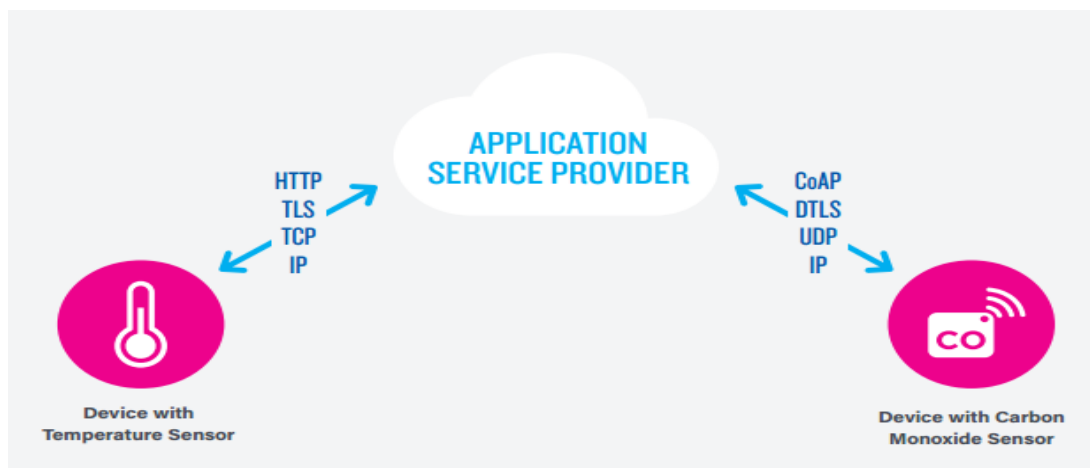


Figure 2.5: Device to cloud model (Google Cloud, 2017)

Once an IoT project is up and running, the sensors produce a lot of data. Through ingestion, the information is imported from the IoT devices into Cloud Platform services for storage, processing, and analyses. Cloud services offers an affordable, scalable and efficient functions to handle all that data and make it work as expected (Google Cloud, 2017).

On the cloud platform pipelines manage data after once it arrives, similar to how parts are managed on a factory line. This includes tasks such as: data conversion where sensor data is converted into another format e.g. converting a captured device signal voltage to a calibrated unit measure of temperature. Aggregating data and computing: by combining data you can add checks, such as averaging data across multiple devices to avoid acting on a single device. This ensures that you have actionable data even if a single device goes offline. Data computation can also be added to the pipeline to enable streaming analytics to. Enriching data: the device-generated data can be

combined with other with other datasets, such as traffic or weather data, for use in subsequent analysis. Moving data: processed data can be stored in one or more final storage locations (Al-Turjman, 2016).

Building IoT solutions involves solving challenges across a wide range of domains. Device to cloud platform brings scale of effective infrastructure, networking, storage and analytics features that can be used to make the most of device generated data.

2.7 Machine to Machine Communication

Machine to machine describes any technology that enables networked devices to exchange information and perform actions without human intervention (Sanyal, 2010). Through M2M, devices use network resources to communicate with remote application infrastructure for the purposes of monitoring and control, either of the “machine” itself, or of the surrounding environment. M2M therefore doesn’t simply create a passive data collection point but also offers an intelligent inter-machine co-ordination ecosystem. Amid rising healthcare expenses and the increasing prevalence of chronic diseases, the healthcare industry is adopting M2M technology to enhance health care services and reduce patient health care expenditure (VERIZON, n.d.). The researcher intends to use M2M communications by employing sensors to capture patients physiological signs e.g. heart rate, which is relayed through a wireless network to the cloud where it will be translated into usable information e.g. patient requires attention.

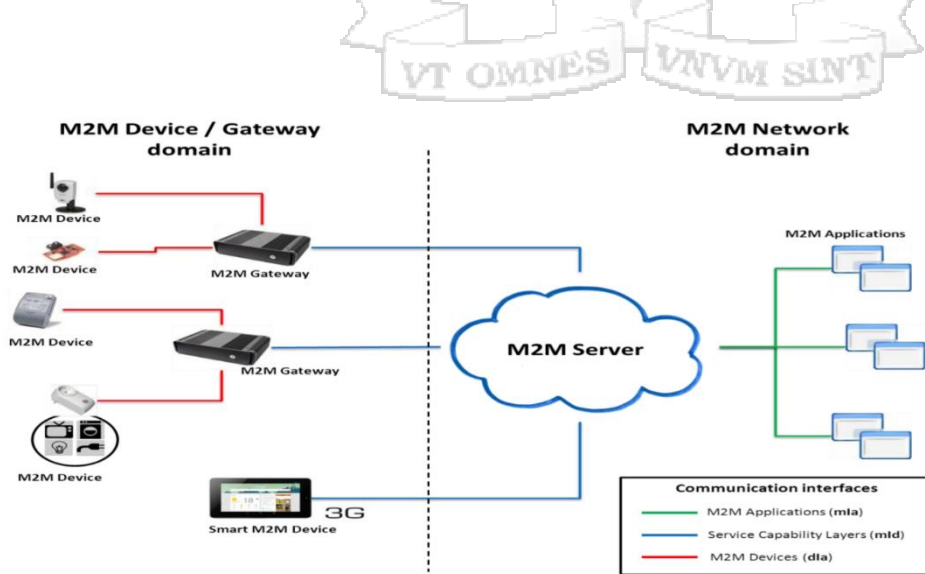


Figure 2.4: Architecture of M2M system (Weyrich et al., 2014)

2.8 Ubiquitous Computing Framework

Ubiquitous Computing (UC) is a concept in computer science which allows computing to be done anywhere and everywhere, in any format and location, in contrast to desktop computing which occurs using a device (Suresh & Vaidya, 2014). Moore's Law states "that processor speeds, or overall processing power for computers will double every two years" (Geraci, 2013). The primary name behind this innovation, Ubiquitous Computing, is Mark Weiser and his main aim was to achieve smart device collaboration (Weiser & Weiser, 1993). UC allows us to integrate a computer system so naturally into the environment that we use it without even noticing it.

Ubiquitous computing envisions the transfer of physical spaces into active information spaces. The ubiquitous smart spaces will consist of various ubiquitous devices and applications and their collaborations provides intelligent services to users. This implementation has become technically feasible thanks to rapid progress of network technologies and mobile communication devices. Therefore, due to this concept of making a digital environment that is responsive to people there emerged the concept of Internet of- Things. Consequently, this now allows the development of extremely small and inexpensive low end computers.

Ubiquitous Computing has six main key enabling components namely; sensor technology, microelectronics, communication technology, localization technology, machine-to-machine communication (M2M) and human-to-machine interface. The integration of these components enhances computer usability by placing the devices in the environment to gather information, store and process it to meet user's various needs. Sensors are the central component of the Ubiquitous Computing technology. They record external physical aspects of the external environment, such as light, temperature, humidity, motion and moisture, and relay it as a digital signal. Microelectronics ensures efficient design of integrated circuits, capacitors, resistors and inductors for microprocessors (Suresh & Vaidya, 2014).

Communication technology plays a fundamental role in UC to ensure strong and reliable communication networks. The adoption of IPv6 will enable a huge addressing pool for every device to have its own routable Internet Protocol address and mobile IP for mobile communication. This ensures communication is everywhere due to full deployment of wireless and mobile devices. Localization technologies make it easy to locate data and objects mainly through wireless transmissions and satellite positioning systems such as GPS. They have a precision of 1 meter

indoors and 10 meters outdoor respectively. M2M communication allows both wired and wireless systems of similar type of devices to communicate. This allows efficient flow of data from the various IoT nodes to meet various user needs (Suresh & Vaidya, 2014). Ubiquitous Computing also requires a good human-machine interaction which can be achieved by appropriate user interface such as touch screens and keypads. This enables users to instruct the infrastructure efficiently either to retrieve information or to react to an environment change (Babkin, 2011).

In conclusion UC envisions a world where computers, sensors and digital communication technologies are inexpensive and available everywhere. Research for UC in healthcare sector brings forth a myriad of opportunities ranging from wearable computing technology to remote monitoring systems to solve health related issues (Suresh & Vaidya, 2014). As the computers shrink in size and as they get integrated in our lives, few years later, we may not even recognize the presence of the computing device taking care of us more than we would take care of ourselves.

2.8 Fuzzy Logic

Modern fuzzy logic was developed by Lotfi Zadeh to model those problems in which indefinite data must be used or in which the rules of inference are formulated in a very general way making use of diffuse categories (Zadeh, 1988). Fuzzy logic can be conceptualized as a generalization of classical logic. In fuzzy logic there are not just two alternatives but a whole continuum of truth values for logical propositions. A proposition X can have the truth value 0.3 and its complement X^c the truth value 0.6. Depending to the type of negation operator that is used, the two truth values must not be necessarily add up to 1 (Caggiano, 2014).

2.8.1 If-Then Rules and Fuzzy Inference

Inference systems can be based on fuzzy logic operators. Knowledge that can only be formulated in a fuzzy, imprecise manner can be captured in rules that can be processed by a computer. Representation of knowledge as rules is the most popular form. "If x is A then y is B (where A and B are linguistic values defined by fuzzy sets on universes of discourse X and Y). A rule is also called a fuzzy implication. " x is A " is called the antecedent or premise. " y is B " is called the consequence or conclusion" (Hajek, 2010). Examples: *If visibility is low, then flying is dangerous, If pressure is high, then volume is small, If a banana is yellow, then it is ripe.*

Imprecise data represented by fuzzy categories, leads to new fuzzy categories which represent the conclusion. In expert systems this kind of result can be transformed into a crisp value or be

processed further. The advantage of formulating fuzzy inference rules is their low granularity (Harder, n.d.). There are several alternative ways to transform a measurement into fuzzy categories. A frequent approach is to use trapezium or triangular -shaped membership functions (Rojas, 1996).

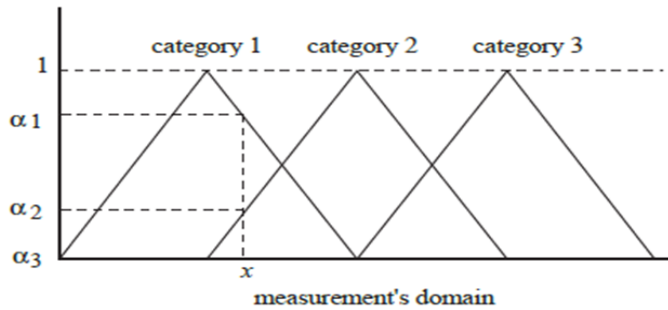


Figure 2.5: Categories with triangular membership functions (Rojas, 1996)

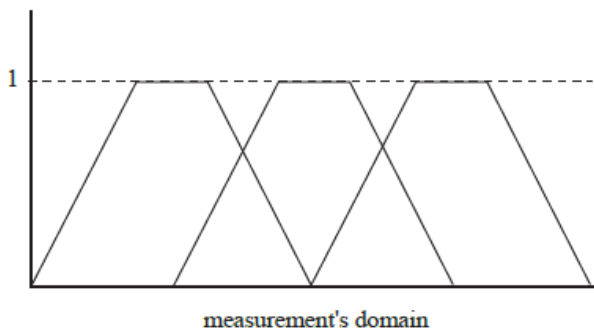


Figure 2.6: Categories with trapezium-shaped membership functions (Rojas, 1996)

Figure 2.5 above shows how a measurement interval are subdivided using triangular-shaped membership functions and Figure 2.6 shows the same kind of subdivision using trapezium-shaped membership functions. The transformation of a measurement x into a fuzzy category is given by the membership values α_1 , α_2 , α_3 derived from the membership functions (as shown in Figure 2.5). An important problem is how to transform the membership values α_1 , α_2 , α_3 back into the measurement x , that is, how to implement the inverse operation to the fuzzifying of the crisp number. A popular approach is the centroid method.

2.8.2 Fuzzy Logic in CHF Patient Monitoring

In this research fuzzy logic has been chosen as the model to detect abnormal vital signs for the chronic heart failure patients and trigger a notification alert to the doctor and relative. The model

that allows the researcher to define rules to detect and rank normal and abnormal values of a CHF patient. Fuzzy logic is a multivalued logic where truth values lies between any real numbers 0 and 1. Fuzzy logic handles the partial truth concept, in which the truth value range between completely false and completely true (Hajek, 2010). In decision-making it is necessary to evaluate different options and leave out those that do not fit certain previously established procedures. If the procedure are mathematically quantifiable, a mathematical model is formulated for the evaluation process (Caballero & Mitrani, 2000).

The researcher used the following Fuzzy logic procedure: fuzzification, whereby the input data are gathered by the sensors and then using membership functions they are converted to a fuzzy input set. The second step involves building up fuzzy logic rules Inference, the system is going to operate based on the set of IF-THEN rules. The IF part of the rule is called the antecedent, while the THEN part of the rule is called the consequent. Rules are constructed from linguistic variables. These variables take on the fuzzy values that are represented as words and modeled as fuzzy subsets of an appropriate domain. The final step of the fuzzy logic system involves turning the fuzzy variables generated by the fuzzy logic rules into real values again which can then be used to perform expected action. With the help of membership function the fuzzy output is finally mapped to crisp output.

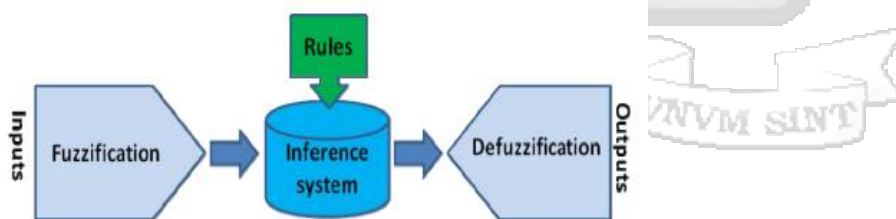


Figure 2.5 Fuzzy Inference System Steps (Caballero & Mitrani, 2000)

Considering the resource limited nature of the Arduino Uno microcontroller platform, three membership functions are to be chosen for each input in a remote patient monitoring system with three input sensors namely a heart rate (ECG) sensor, temperature & humidity sensor and heart beat sensor. In adult chronic heart failure patients, resting heart rate ranges between 60 and 70 bpm. This is proportionally lower with age. The mean heart rate is slightly lower in males than in females of the same age. In patients with heart failure, resting HR of more than 80 bpm could cause myocardial dysfunction which further deteriorates their condition. Using the heart rate sensor, the

ambient heart rate data from the heart rate sensor is to be grouped into three fuzzy sets (low, medium and high).

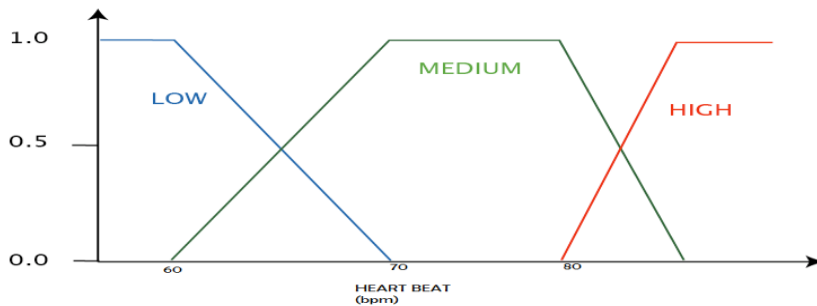


Figure 2.7 Fuzzy Membership Sets for Heart rate sensor (Oliva et al., 2017)

2.9 Conceptual Model

The conceptual framework below connects the reviewed literature with the research problem and the research objectives.

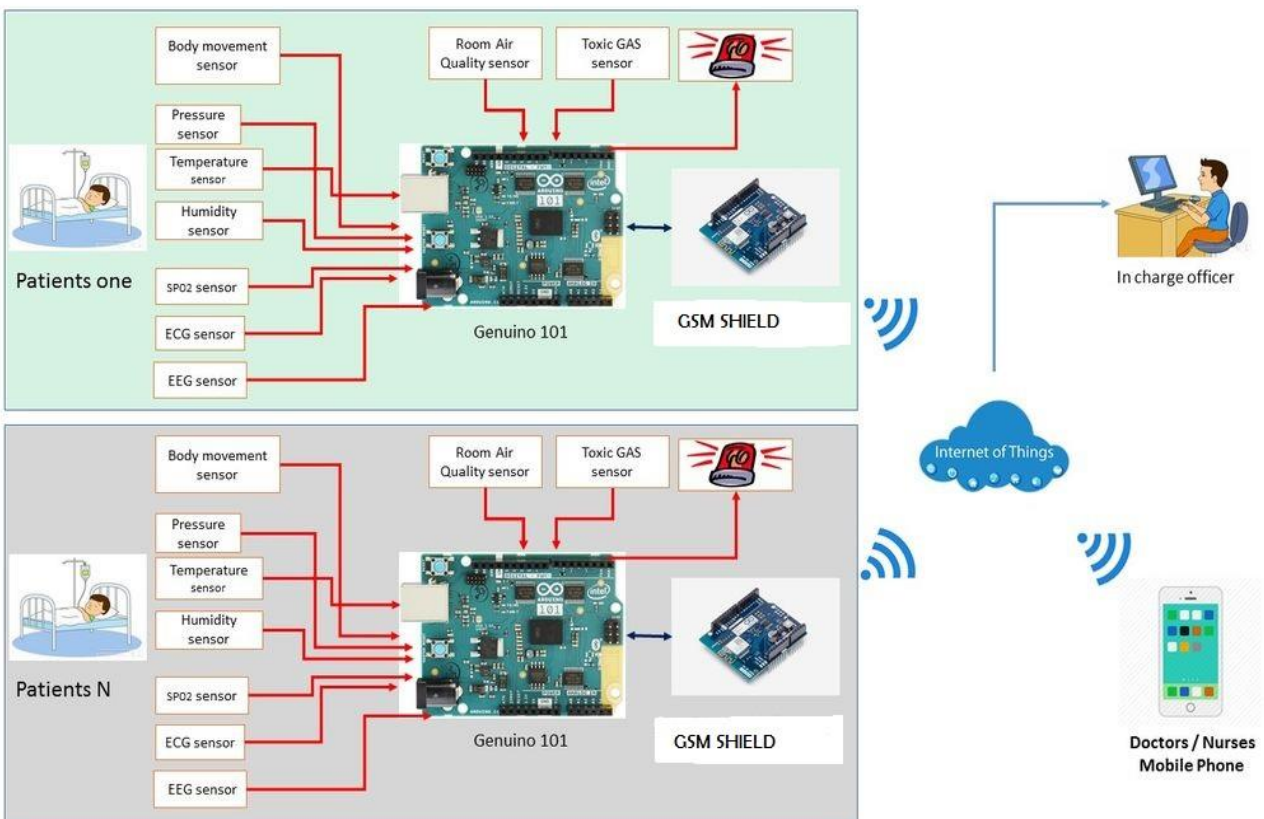


Fig 2.6 .Proposed Architecture of the real time patient monitoring system

The proposed system will contain an Arduino Microcontroller with vital signs sensors directly connected to it. A GSM shield will be used to transmit data from the board to the IoT server for storage, data analysis and classification. The researcher will connect to the IoT server to display the patient data in an android application that will be used by the doctors or patients relatives. The proposed system provides better solution over traditional methods. It increases the quality of service as well as the capacity of ICU unit. The application of this system is not limited to ICU unit, it may extend as a portable health monitoring device for older people as well as monitoring babies and people having heart diseases.



Chapter 3: Research Methodology

3.1 Introduction

The aim of this study was to develop an IoT based patients monitoring system to monitor the CHF patients in real-time. This chapter explains the research methodology that was used, the stages in the research, location of the research, and purpose of the research, data collection techniques and analysis that were used.

The researcher used scrum methodology in developing the prototype. Scrum is founded on empirical process control theory, or empiricism. Empiricism asserts that knowledge comes from experience and making decisions based on what is known. Scrum employs an iterative, incremental approach to optimize predictability and control risk. The Scrum framework consists of Scrum Teams and their associated roles, events, artifacts, and rules. Each component within the framework serves a specific purpose and is essential to Scrum's success and usage (Schwaber & Sutherland, 2013).

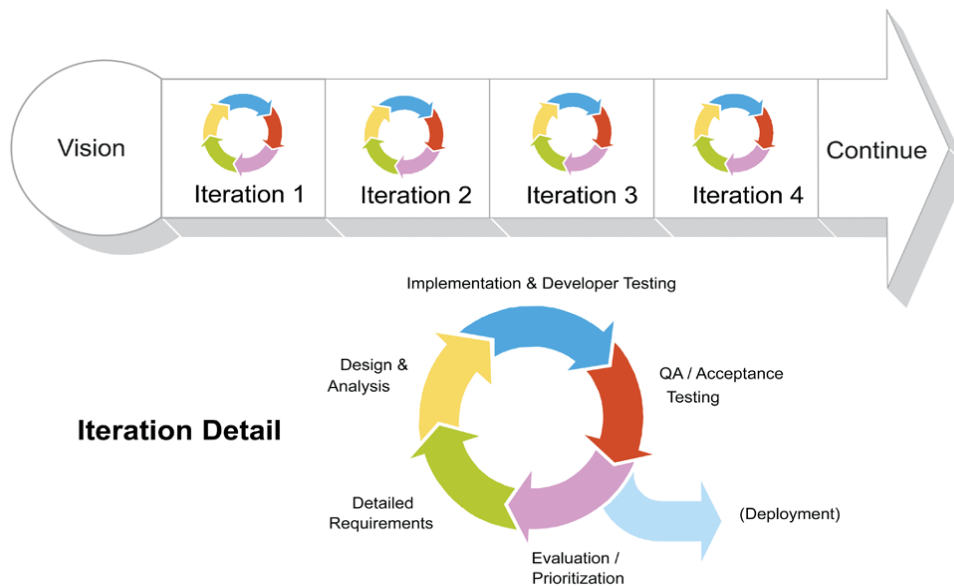


Fig 3.1 Scrum methodology reference card (KOCH, 2006).

As illustrated in the fig 3.1 above the prototype will be built in a series of fixed-length iterations called sprints that give the researcher a framework for releasing the prototype on a regular cadence for testing and review by the supervisors. Milestones—i.e., the end of a sprint—come frequently, bringing with them a feeling of tangible progress with each cycle that focuses and energizes the researcher. A typical waterfall style development is phased-based, sequential and plan-

driven(CDC, 2009). Scrum delivers new features every few weeks instead of focusing on a big release in the future. This will allow the researcher to identify pitfalls early and solve them before more time and resources are wasted.

The researcher choose scrum methodology because it has a well-defined approach and framework for organizing and controlling a software development project. Despite the inability of the researcher to match a few commercial Scrum environments, there was ample opportunity for him to engage in specific agile practices within the framework of Scrum that support the fundamental software engineering skills that he needs to research on, learn and practice. Selecting Scrum as the framework for researchers' projects had the advantage of introducing software process at a level that captures foundational software engineering practices and is manageable within the constraints of a thesis project.

3.2 Research Design

The study was carried out using experimental design and quantitative research methodology. Through experimental design this research identified a problem in the domain of chronic heart failure patients monitoring where there is need to innovate remote patient monitoring solutions that are more flexible and have an alert mechanism. Simulation data will be used to test the formulated fuzzy logic model to check if it achieves the expected action –trigger alert message.

Through quantitative research relevant data was subsequently collected and analyzed appropriately and sound conclusions were drawn using questionnaires. In addition the researcher reviewed both conceptual literature concerning concepts and theories and empirical literature consisting of earlier studies, which are similar to the one proposed. Concepts and theories include those relating to IoT and the technologies that encompass it such as sensors and microcontrollers. This information aided in understanding the problem and consequently laid the foundation for the development of the proposed solution.

3.2.1 System analysis and System Requirements

This study will use object oriented analysis approach. By applying object-oriented design, the researcher will create a prototype that is flexible to change and developed with economy of expression. The study will use use-case modelling and dataflow diagrams. This will help the researcher to effectively identify the system functionality and provide a visual representation of

the flow of information (i.e. patient physiological data) within a system. The system requirements of the system were obtained through analysis of documents, questionnaires and interviews conducted. Experts were interviewed from different fields i.e. doctors, developers and a patient. This was done in order to create a balance in the kind of solution to be developed.

3.2.2 System Design

Structured design will be used to conceptualize into several well-organized elements of solution. Structured design is concerned with solution design. Structured design will give the researcher a better understanding of how the problem is being solved. Structured design also makes it simpler for the researcher to concentrate on the problem more accurately.

Data Flow Diagram, will enable the researcher to identify the information provided by and delivered to users who interact with the system processes, i.e. the data needed in order to complete the patient monitoring processes and the information needed to be stored and accessed.

Use case diagrams will be used to gather the requirements of the system including internal and external influences. These requirements are mostly design requirements. Hence, when the system will be analyzed to gather its functionalities, use cases will be prepared and actors will be identified.

3.2.3 System implementation

The real time patient monitoring system main component will be the Arduino (IoT Development Board) which will be used as a main controller of this system. All the others sensors will be directly connected to it. A GSM shield will be used for connecting the board with the cloud. The thinger.io IoT platform will be used for real time data streaming and visualization for hospital monitoring. A mobile application will also be developed using Ionic framework on android platform for doctors/nurses or relatives to monitoring the patient based on sensors data. In case of emergency the caregivers are notified through sms notification to act accordingly.

3.2.4 System testing

The researcher will perform thorough tests to identify all possible issues before releasing the prototype to the users. The purpose is to carry out the tasks that a typical user might perform. The researcher will also perform usability testing to evaluate the product or service by testing it with

representative users. The usability testing will enable the developer to identify problems before they are coded and ensure that the system is user-friendly.

3.3 Target Population and Sampling frame

In order to estimate the target population multistage sampling was used. The first stage was to identify the number of health facilities in Meru. According to (Ministry of Health, 2014), the total number of public hospitals is 33. For the study 10 facilities will be picked through simple random sampling technique. This technique will ensure fairness and easiness of assembling the sample.

Diocese	Hospitals	Dispensaries	Health Centres	Clinics	Total
Bungoma	2	3	2	-	7
Eldoret	3	14	9	-	26
Embu	2	9	-	-	11
Garissa	-	7	2	1	10
Homa Bay	2	8	13	-	23
Isiolo	-	6	-	--	6
Kakamega	2	6	5	-	13
Kericho	1	4	2	-	7
Kisii	2	9	4	-	15
Kisumu	3	5	6	-	14
Kitale	2	7	-	1	10
Kitui	2	9	-	-	11
Lodwar	1	23	2	-	26
Machakos	3	28	1	-	32
Malindi	-	6	1	-	7
Maralal	1	7	2	-	10
Marsabit	2	6	2	-	10
Meru	7	21	5	-	33
Mombasa	-	12	2	-	14
Muranga	3	17	3	-	23
Nairobi	17	52	9	-	59

Figure 3.2 Distribution of Health Facilities by county (Ministry of Health, 2014).

The second stage will be to identify the personnel to conduct the study. The study picked two people per facility based on the following criteria and availability. The first group will comprise of caregivers who will work with the real time patient monitoring system .The caregivers will help identify the current challenges faced while offering the monitoring services. The second group will comprise the patients. They patients will help to determine the feasibility of creating a patient monitoring system its benefits and potential future features.

3.4 Data Collection

Primary and secondary methodologies will be used. Primary method to be used will be interviews and online questionnaires sent out using Google forms. Secondary methods to be used will include past research on the topic, text books and publications.

3.5 Data Analysis

Data was processed and analyzed using Microsoft excel spreadsheets and visualized using Microsoft Excel. Data processing is, the collection and manipulation of items of data to produce meaningful information. Microsoft excel is a spreadsheet application that will enable the researcher to perform necessary calculations and graphical processing e.g. creating tables for easy visualization. Data collected from the sensors will include various physiological signs e.g. heart rate, temperature blood sugar level.

3.7 Research Quality Aspects

Research quality aspects is the degree to which the research was carried out correctly. Validity and reliability were used to test the quality aspects.

3.7.1 Validity

To ensure the validity of the research, the researcher will review the measurement instruments with fellow students and conduct a pilot test. This will provide a trial run for data collection procedure.

3.7.2 Reliability

In this research reliability will attained by giving respondents questionnaires to fill. After a few system features have been developed, a second survey will be initiated so as to check the correlation between the two. This will give the researcher a go ahead with the study.

3.8 Ethic Considerations

To adhere to ethical codes of conduct, the research ensured that no real patient's medical data will used. Data will be collected willingly from correspondents and no one will be coerced to share private data. Any of the correspondents private data collected will remain private and only used for analysis purposes unless otherwise defined in agreements by the respondents.

Chapter 4: System Design and Architecture

4.1 Introduction

This chapter covers the design of the proposed model by factoring in the requirements collected in chapter three through questionnaires with the probable users and other stakeholders. To make this possible design diagrams were drawn using Unified Modelling Language so that the prototype system can be completely understood before construction begins. Requirements and data analysis were also carried out at this stage.

4.2 Questionnaire Analysis

Research respondents were sampled from 33 hospitals in Meru County. Since the target population of study was chronic heart failure patients, respondent to the study was defined. A person either mother, father, sister, brother or guardian who was found to be with the patient at time of discharge formed the relative respondent during the research period. Doctors or nurses who had attended to the patient formed the doctor respondent during the research. Questionnaires were administered to the respondents at point of discharge across the 33 health facilities in order to collect information about the chronic heart failure patients in question. A total of 52 questionnaires were responded to out of the targeted 60, giving a response rate of 86.66%.

4.2.1 Age Group

Table 1 Age distribution of heart failure in an adult Kenyan Population.

Age Group	Male	Female	Total
11-20	2	2	4 (4.7%)
21-30	3	5	8 (9.4%)
31-40	4	6	10 (11.76%)
41-50	6	10	16 (18.8%)
51-60	8	12	20 (23.52%)
61-70	7	6	13 (15.3%)
71-80	5	3	8 (9.41%)
>80	5	1	6 (7%)
Total	40	45	85(100)

55.23% of the respondents interviewed belonged to the 51 and above age group, 11.76% range between 31 years to 40 years and 14.1% range between 11 to 30 years of age.

4.2.2 Ability to use Mobile Phone

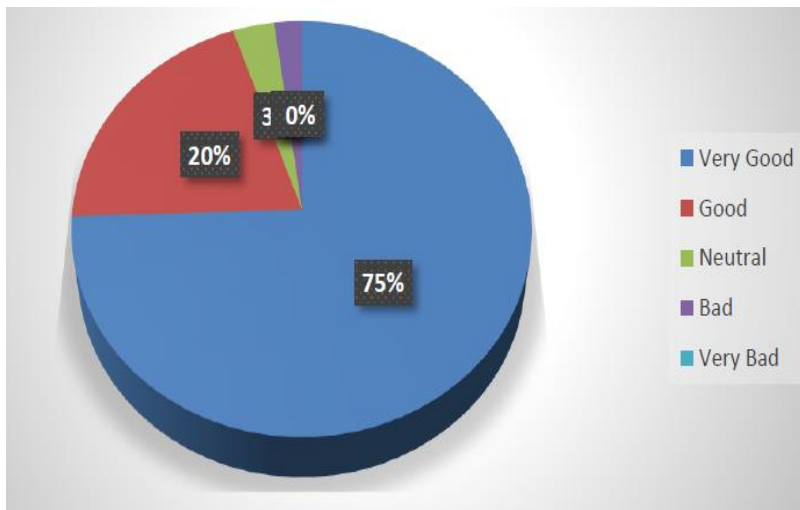


Figure 4.1 Ability to use mobile phone

75% of the respondents are very good at mobile phone usage while 20% are fairly good and only two 3 people were rated as neutral.

4.2.3 Having been hospitalized Due to Heart Failure

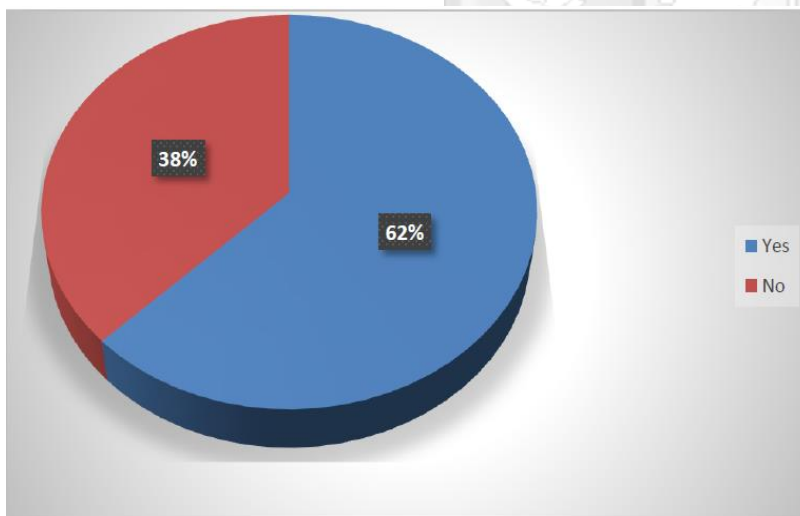


Figure 4.2 Having been hospitalized due to heart failure

According 62% of patients have been hospitalized because of chronic heart failure while 38% have never been hospitalized.

4.2.4 Ability to Access Mobile Health Information

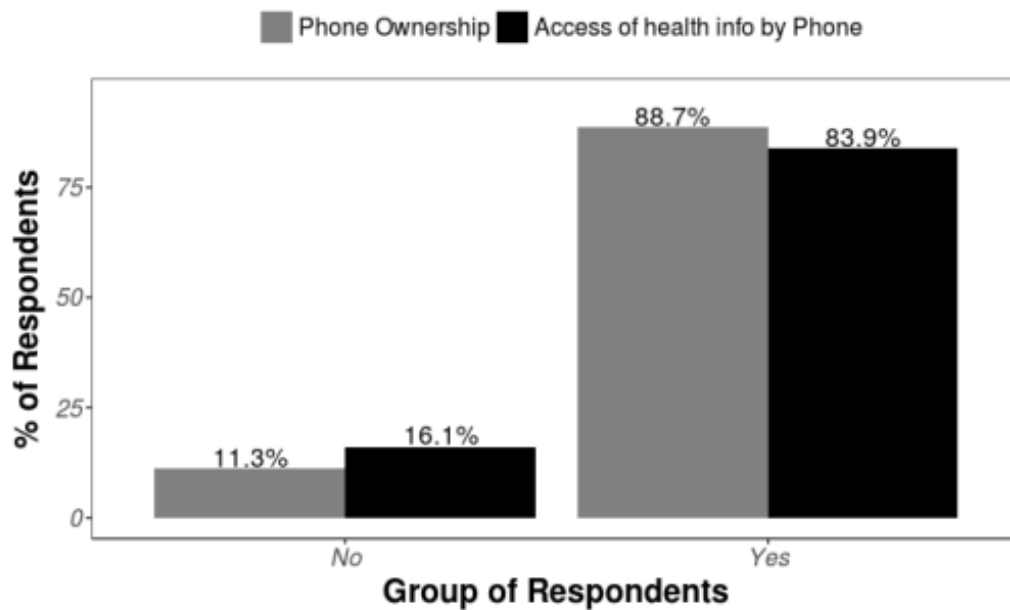


Figure 4.3 Ability to access mobile health information

Approximately 83.9% of respondents who owned mobile phones are able to access health care information through phone, especially by SMS.

4.3 Requirement Specifications

This describes the features and behavior of our CHF patient monitoring system. It includes a variety of elements that attempts to define the intended functionality and the key performance parameters that will need to be met by the system. This section covers functional and nonfunctional requirements of the prototype.

4.3.1 Functional Requirements

Functional requirements explain what has to be done by the prototype by identifying the necessary task, action or activity that must be accomplished. They include:

- i. The prototype should read analog temperature, heartbeat, ECG from the patient and humidity data from the environment.
- ii. The prototype should convert the sensor data into digital form and send it to an online MySQL database.

- iii. The prototype should send a text alert to the doctor and relative once an abnormal vital sign is captured from the patient.
- iv. The prototype mobile application should display vital readings of the patient in real time.
- v. The IoT cloud platform i.e thinger.io which is part of the prototype should save sensor readings from the device in its database and provide visualizations of the data via its web-portal.

4.3.2 Non Functional Requirements

The key Nonfunctional Requirements (NFRs) in our patient monitoring prototype include security, reliability, performance, network protocols, scalability, and mobile application usability. They serve as constraints or restrictions on the design of the system across the different backlog.

4.4 System Architecture

The CHF remote monitoring system architecture comprises all the core components of a typical IoT architecture based on the IoT Reference Model discussed in Literature review. The temperature sensor, the heart beat sensor, heart rate monitor (ECG) sensor, humidity sensor and the SIM800L module are all connected to the Arduino Uno microcontroller and cumulatively constitute the physical element of the system.

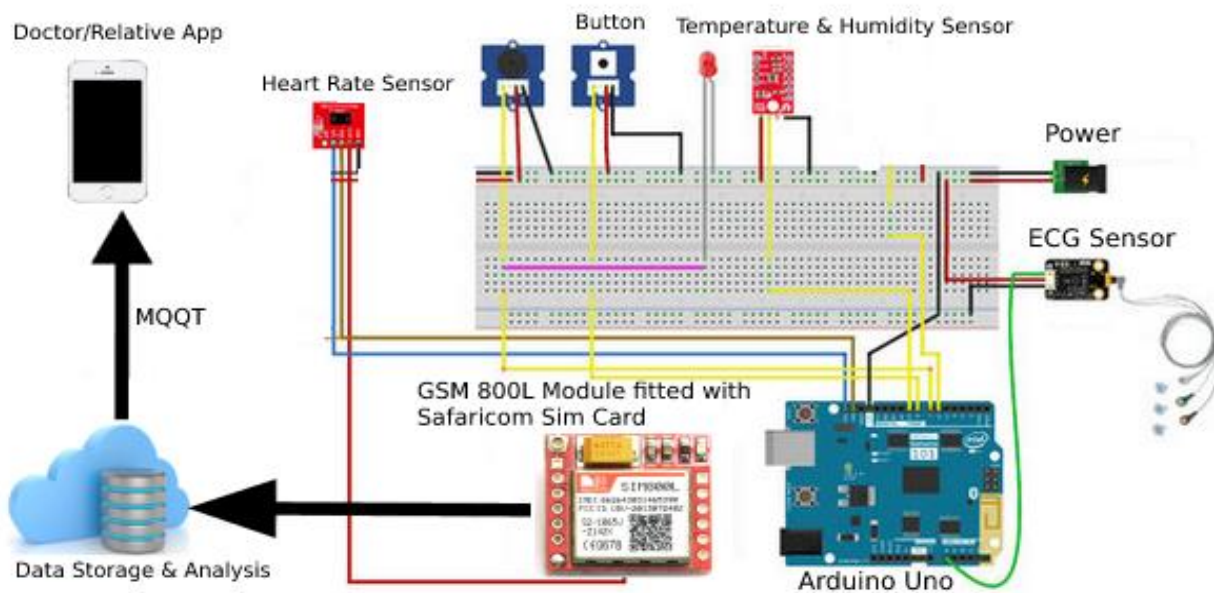


Figure 4.1 System Architecture

The Arduino Uno microcontroller converts the analog values from the sensors and converts them into digital values. The data collected is stored in a fully scalable Mysql database. The system logic is performed on the data to check if the vital signs are normal and abnormal. A sms alert is sent to the doctor and relative immediately an abnormal sign is detected. The doctor and relative are equipped with a mobile app connected to the database via a RESTful API to enable them continuously monitor the patients data.

4.5 System Analysis

4.5.1 Use Case Diagram

The use case diagram in the analysis phase is used to describe the interactions between the system users and system itself. The most common relationships captured in a use case diagram are those between the actors, use cases and system. In the remote patient monitoring system, the actors in the system are the doctors, relatives Sensor nodes, GSM communication unit and the system administrator as illustrated below:

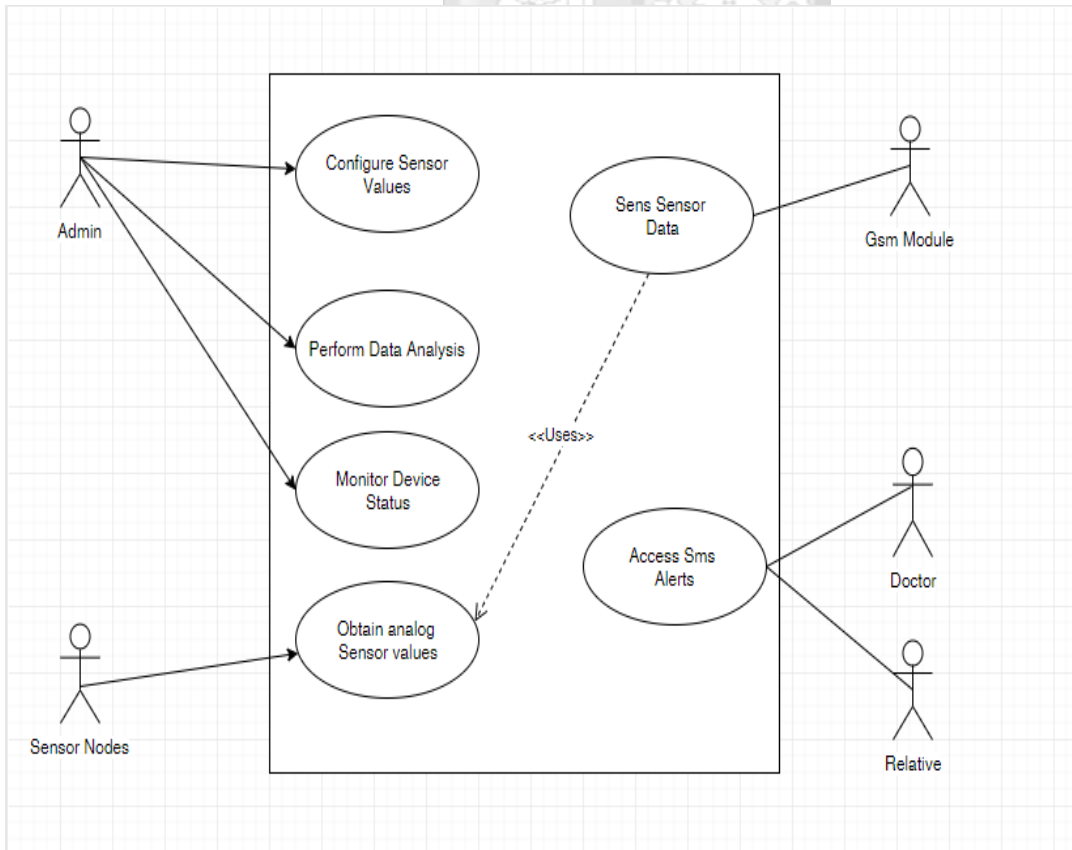


Figure 4.2 Use case Diagram

4.5.2 Use Case Scenarios

This are detailed text-based and step-by-step dialogues and interactions between the system actors and the system itself. In system analysis, the use case narrative is used to explain a complete business transaction successful or unsuccessful. The use case narrative for the proposed system is as below:

Used Case Name: Monitor Device Status

Description: The Device can be either online or offline. The system allows the Admin to check the online or offline status of the device.

Primary Actor: Admin

Trigger: Device not sending data for prolonged duration

Pre-condition

- The Device must be configured to connect to the database.
- The Device must be registered on the database.

Post-condition Device is online.

Used Case Name: Access Sms Notification Service

Description: Abnormal vital signs are reported via a text message to the relative and doctor.

Primary Actors: Doctor and Relative

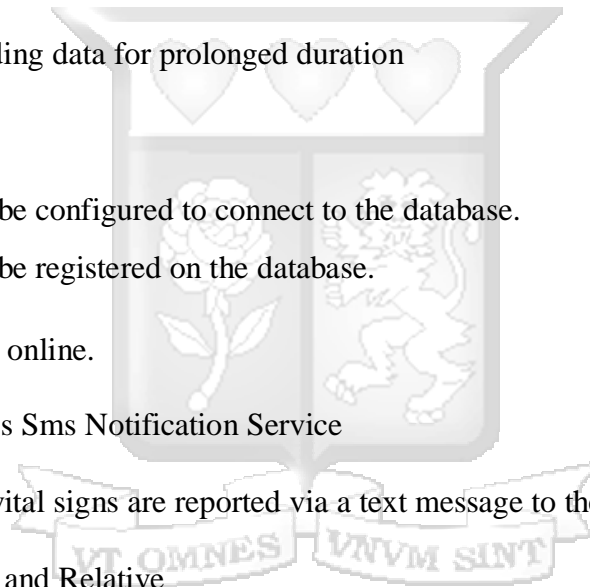
Trigger: Heart beat and Heart rate sensors capture abnormal signs from the patient.

Pre-condition

- The doctor and relative have a mobile phone.

Post-condition

- Sms alert successfully sent.



4.5.2 Sequence Diagram

UML sequence diagrams enables the researcher to model the flow of logic within the CHF patient monitoring system in a visual manner, enabling him both to document and validate the logic. Figure 4.3 is a depiction of how the patient monitoring system captures data from the sensors, sends it to the IOT database where data is continuously saved and analyzed. The end users receive notifications when a positive health emergency identification is made by the device. The sensor nodes capture analogue sensor values() to the microcontroller where it is converted to digital values. It is then transmitted via the GSM module to the IoT server via a transmit data value() message where it is continuously stored and analyzed. Once the IoT server detects and analyses a sensor reading as abnormal reading a Send text alert () message is initiated to alert the doctor and relative to take immediate action.

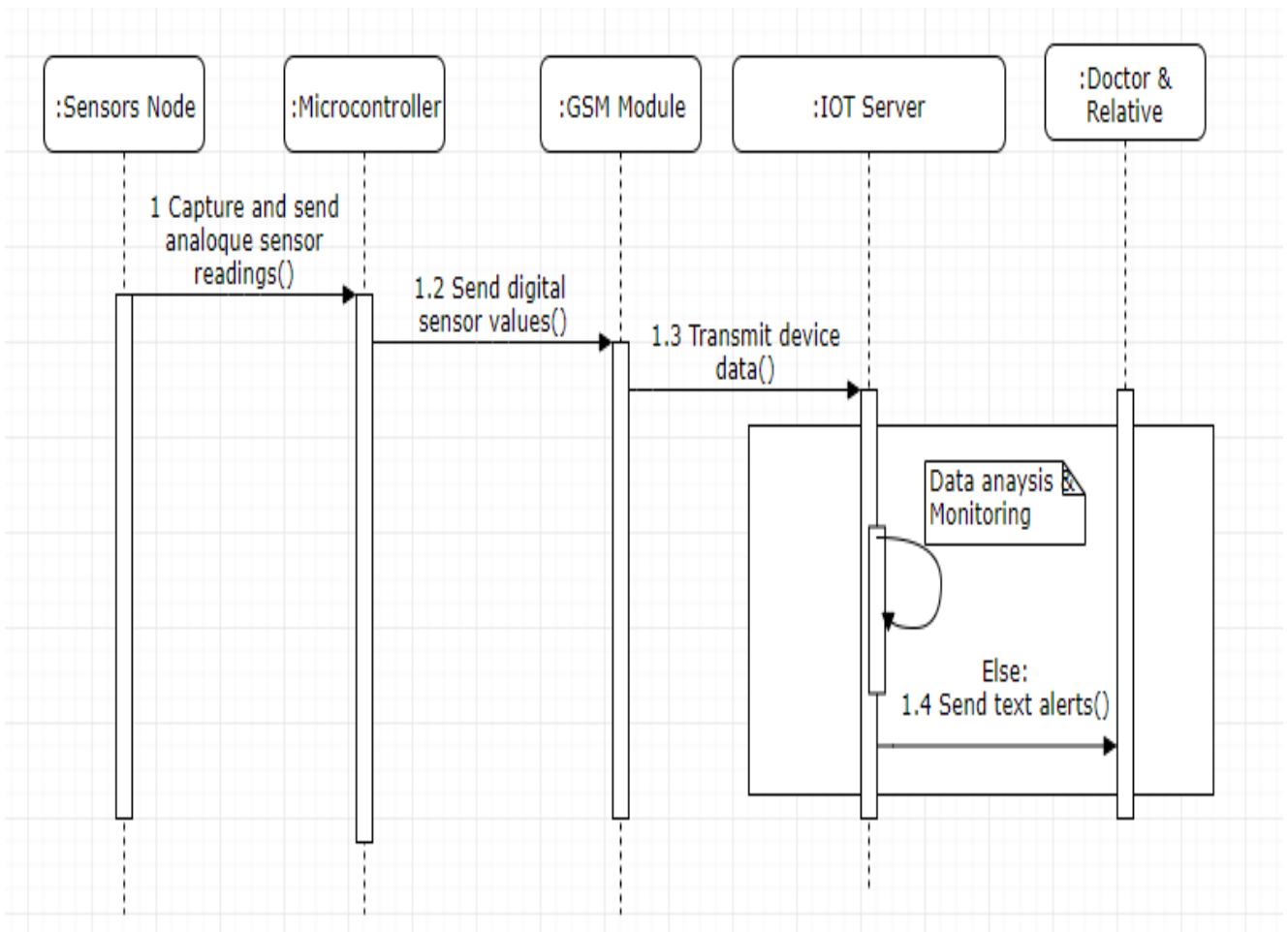


Figure 4.3 Sequence Diagram

4.5.3 System Flow Chart

Figure 4.4 below is a flowchart diagram that shows how data flows throughout the patient monitoring system and how event-controlling decisions are made. The flow chart below illustrates the capturing of data from the sensors, the conversion of the data into rules and the decision making section of the prototype system.

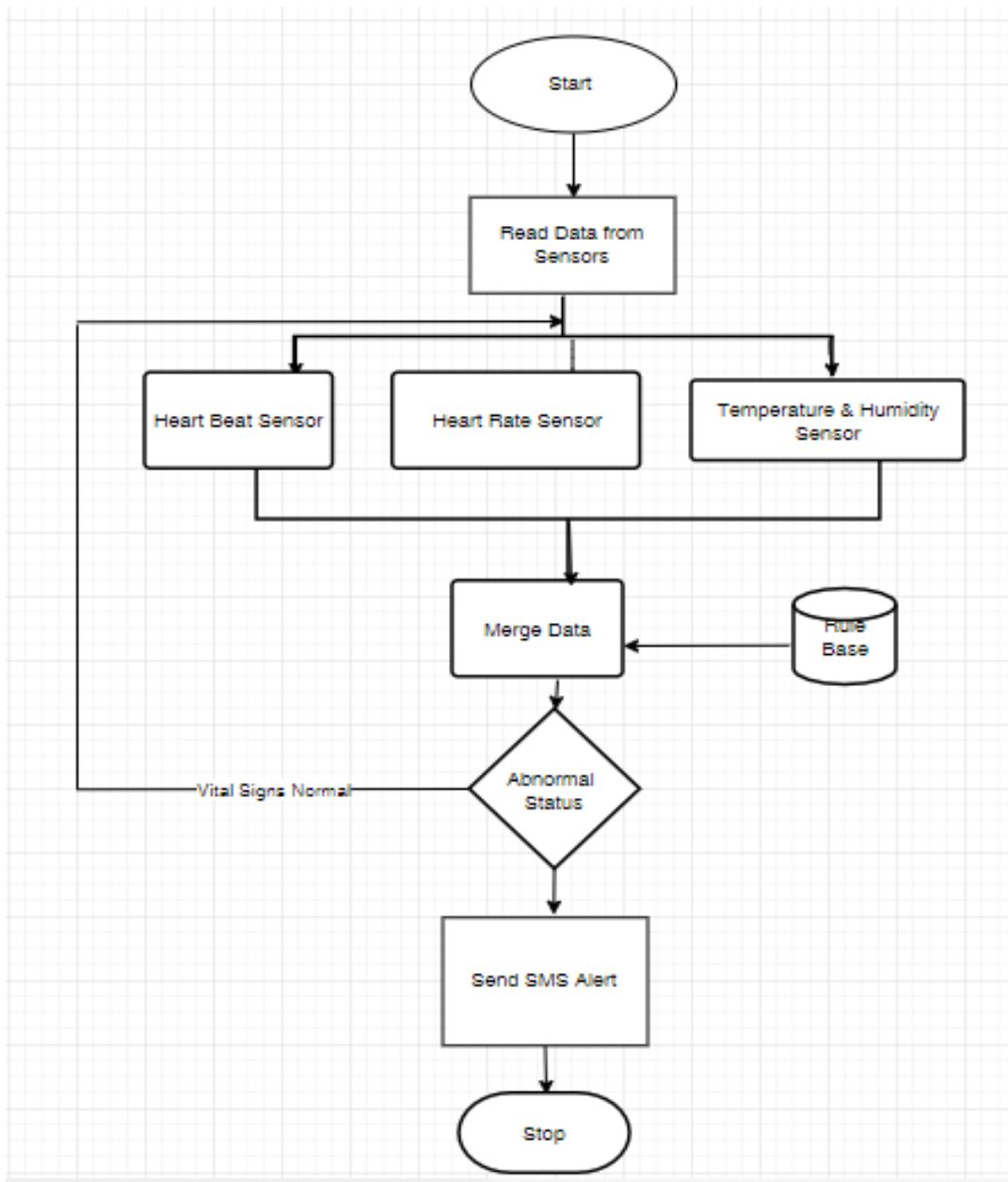


Figure 4.4 Flow Chart Diagram

4.6 System Design

4.6.1 Context Diagram

The context diagram is used to establish the context and boundaries of the system to be modelled: which entities are inside and outside of the system being modelled, and what is the relationship of the system with these external entities. The main users of the system are the patient, their relative and doctor. The sensor worn by the patient sends motion data into the system that is then analyzed and feedback sent to the doctor and relative of the patient.

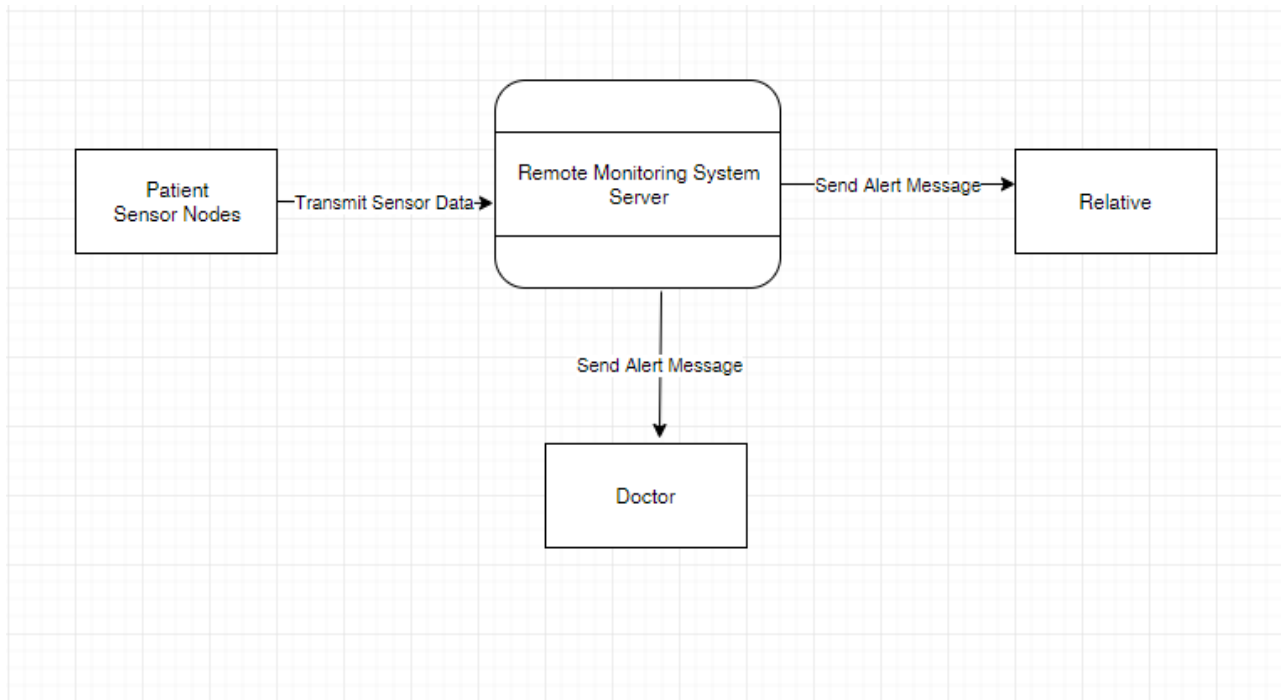


Figure 4.4 Context Diagram

4.6.2 Level 1 Data Flow Diagram

A data flow diagram (DFD) maps out the flow of information for any process or system. The context diagram above is then expanded into several inter-related processes or levels. A level 1 DFD diagram represents the system's main processes, data stores and data processes with high level details. With DFDs, it is easier for system users and non-users to understand how data flows through the system. The level 1 DFD is different from the context diagram as they illustrate the first level processes of the system. This model describes four processes. The first process is patient health data capture. The data will then be analyzed as either normal or abnormal by the IoT server.

Finally, based on the analyses, SMS messages are sent to the patient's doctor and relative's phone. The level 1 DFD of the stock prediction model is as below

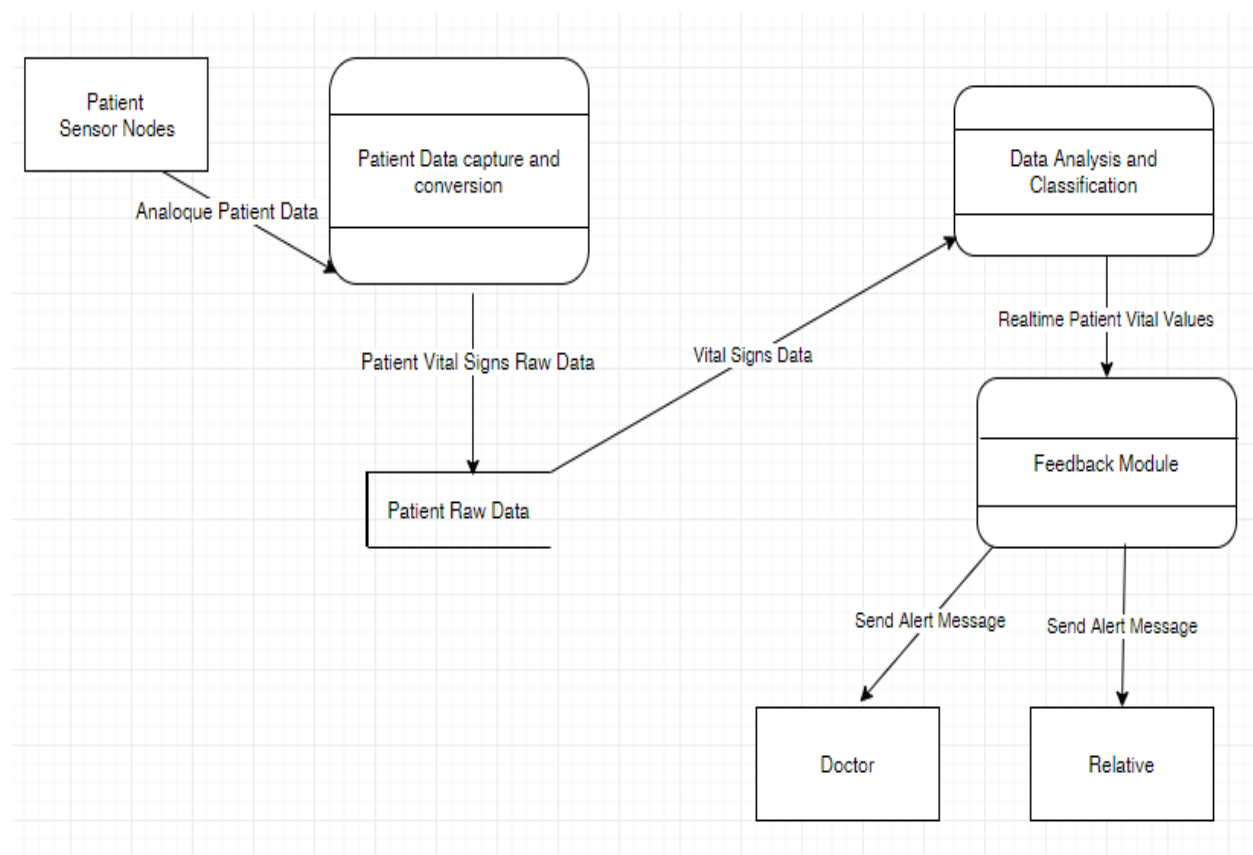


Figure 4.5 Context Diagram



Chapter Five: Implementation and Testing

5.1 Introduction

This section details the implementation and testing of the CHF IoT patient monitoring system. The implementation focuses on the different modules of the system, how they are implemented and their functionality. Testing of the system involves verifying that the system satisfies usability requirements as well as the functional requirements.

5.2 System Components

The prototype comprises of: sensor network level with a heart rate, heartbeat, temperature and humidity sensor, a transmission layer which contains a GSM module fitted with a local network SIM card, an application layer comprising of a MySQL database and a web application. The hardware was programmed using Arduino IDE. The monitoring application was developed via ionic framework and compiled for both android and iOS devices.

5.2.1 Hardware Components

Arduino Microcontroller- this is the micro-controller that will coordinate the interfacing of the GSM and sensor. Arduino uno is a ATmega328P based microcontroller board containing 6 analog inputs, 14 digital input/output pins, a 16 MHz quartz crystal, a power jack, a USB connection, an ICSP header and a reset button.

Gsm Shield -this allows the Arduino board to send and receive SMS, make voice calls and connect to the internet through the GSM Library. It will be used to transmit sensor data values to the IoT server for storage and analysis. A local network Sim card will be fitted into it.

Heart Beat Sensor – this is use's Optical Transistor's Infra-Red, and LED to detect pulsation in fingers.

Heart rate Sensor – this is used to measure the electrical activity of the heart. This electrical activity will be charted as an ECG and output as an analog reading on the web application and patient monitoring mobile application.

DHT11 Temperature and humidity sensor – this will be used to capture temperature and humidity values.

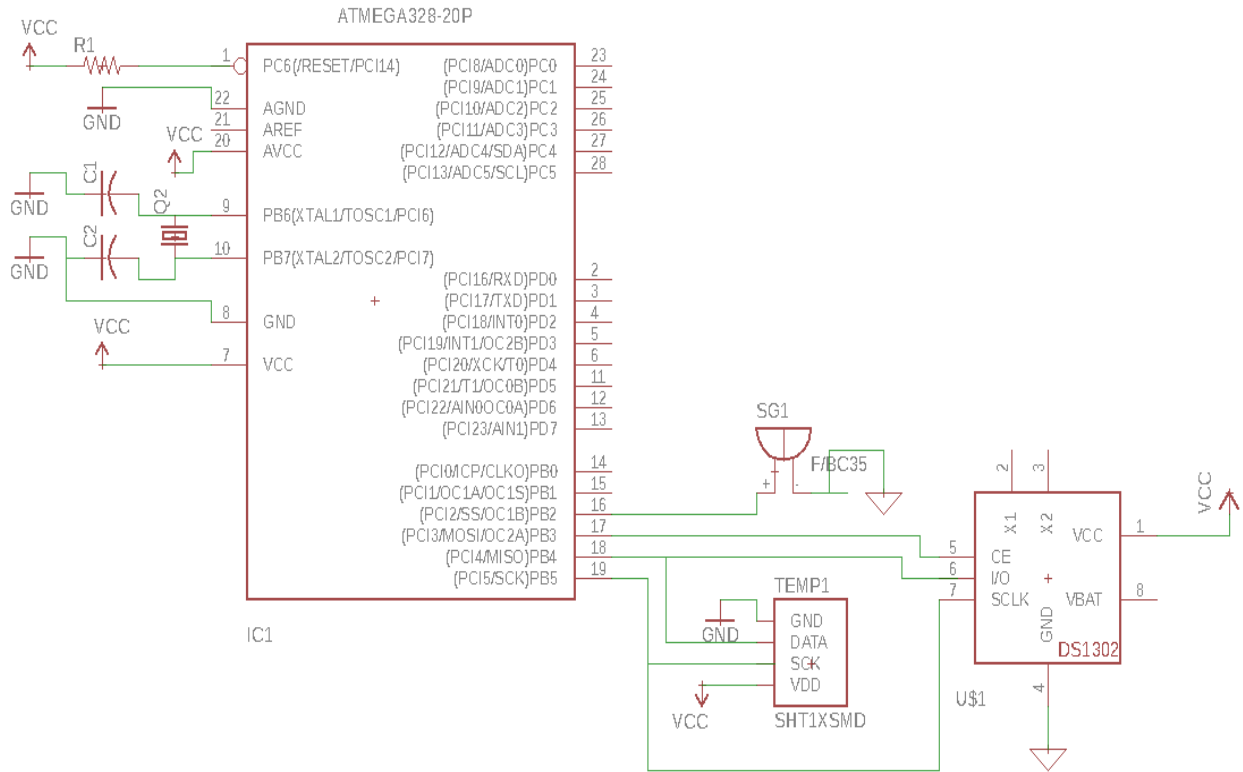


Figure 5.1 Board Architecture

5.2.2 Application Layer

This component of the prototype is responsible for data storage, analysis, and graphical presentation of the sensor data. *Data storage* is handled by a MySQL based database. MySQL provides advanced features and management tools to achieve the highest levels of IoT data scalability, security, reliability, and uptime. *Data Analysis* is performed using fuzzy logic based IF-THEN rules. The rules check data as it streams in to the database for any abnormal values. Recommended Heartbeat, Heart rate and temperature values are keyed in to the system to act as training data. Once the system detects a record of abnormal values for more than five times an sms alert is sent to the doctor and relative to act accordingly. *Mobile Application* is built using Ionic framework and compiled for both android and iOS devices. Ionic is an open source mobile SDK for developing progressive web apps and cross-platform mobile applications with ease. The mobile application will be available to the doctor and relative to enable them to monitor the patient vitals remotely.

5.2.3 Sensor Data Analysis

As stated in chapter one fuzzy logic was used in this research to analyze the sensor data as either normal or abnormal. Fuzzy logic is a multivalued logic represents a value on the closed interval $[0, 1]$, where 0 is equated with the classical *false* value and 1 is the classical *true* value. Values in $(0, 1)$ indicate varying degrees of truth (Harder, n.d.). Two groups of fuzzy IF-THEN rules are used to formulate the CHF patient monitoring system fuzzy inference engine.

One group controls the output variable localization according to values of the input variables infrared heart rate sensors (bpm) and Temperature (degrees celsius). The other group controls the output variable alarm (message) according to all inputs. An example of fuzzy rule for alarm detection is: *If (temperature is >50 Degrees) and (Heart rate is >80) Then(Alarm is alarm)*. A confidence factor is accorded for each rule and to aggregate these rules we have the choice between Mamdani or Sugeno approaches available under our fuzzy logic component explained in literature review. After rules aggregation the defuzzification is performed by the smallest value of maximum method for the alarm output and the centroid of area for the output localization.

5.2.4 Fuzzy Rules

The Fuzzy rule base contains rules generated using FISpro. The training data set was generated only to assist in initial generation of rules. Once the system is running in actual environment actual dataset from the database will be used instead. Table 5.2 below show the fuzzy rules used.

Table 5.2 Fuzzy Rules

1	<i>IF TEMP is <33 AND MONITORING TIME is > 30 MIN THEN ALERT</i>
2	<i>IF TEMP is >40 AND MONITORING TIME is > 30 MIN THEN ALERT</i>
3	<i>IF HEART RATE >80 AND MONITORING TIME is 5 MIN THEN ALERT</i>
4	<i>IF HEART RATE <60 AND MONITORING TIME is 5 MIN THEN ALERT</i>
5	<i>IF TEMP is <33 AND HEART RATE IS >80 AND MONITORING TIME is 5 MIN THEN ALERT</i>
6	<i>IF TEMP is <33 AND HEART RATE IS <60 AND MONITORING TIME is 5 MIN THEN ALERT</i>
7	<i>IF TEMP is >40 AND HEART RATE IS >80 AND MONITORING TIME is 5 MIN THEN ALERT</i>

8	<i>IF TEMP is >40 AND HEART RATE IS <60 AND MONITORING TIME is 5 MIN THEN ALERT</i>



Figure 5.2 Sample CHF patient vital sign alert

5.3 System Testing

5.3.1 Functionality Testing

The functionality tests were mainly done by the researcher, to ensure all bugs were fixed, and that the system met the main objectives of the study. The functionality testing was important in checking that the user requirements were met, and that the system executed perfectly. This was done iteratively during the entire process of system development. All these tests were done on Arduino programming platform.

Test Case	Description	Priority
Functional	Confirm that the system sends text messages when an abnormal vital sign is detected	High

Functional	Confirm that the mobile application displays the current patient data in real time	High
Functionality	Does the system correctly identify abnormal vital signs	High

5.3.2 Usability Testing

To explore the effectiveness of the application in terms of usability and experience, the researcher sought to conduct a post-test survey on a number of users within purposively sampled public hospitals within Meru County. Twelve people responded to the questions as below:

Functionality, User Experience and Usability	Respondents=12		
	Yes	No	Neutral
The device can be carried around with ease during monitoring process?	55%	5%	40%
I am willing to use the tool for to monitor my patient.	95%	5%	0
The mobile application is easy to use	83%	17%	0
The device would makes CHF patient effective	75%	10%	5%

Table 2 User experience and Usability

a) Device Portability

According to figure 5.3 below 55% of the respondents affirmed that the chronic heart failure patients would face some difficulty carrying the device around and suggested a light-weight wearable device that they can easily move around with.

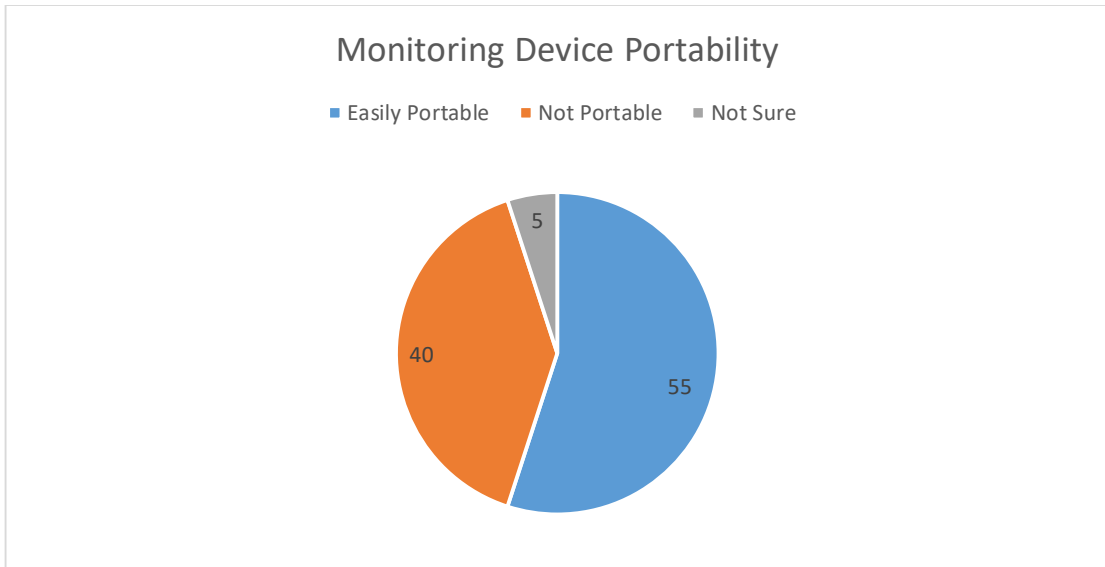


Figure 5.3 Device Portability

b) Acceptance testing

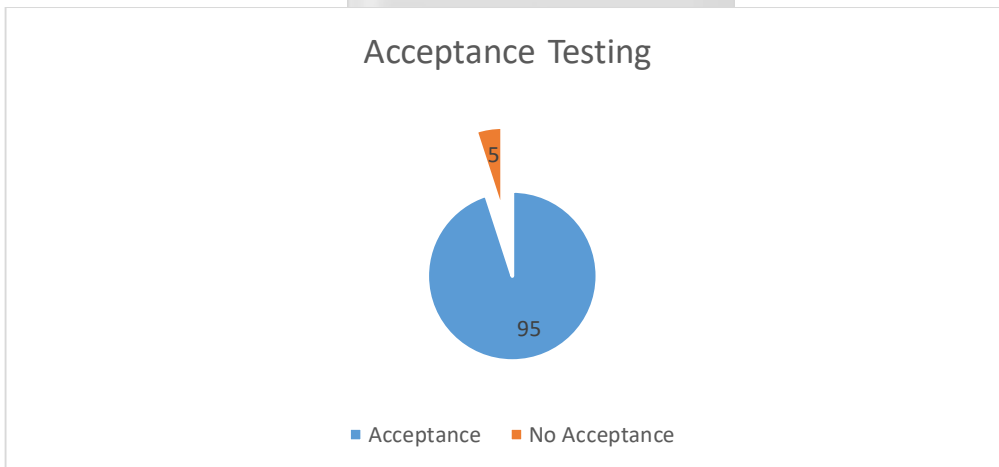


Figure 5.4 System Acceptance

The researcher sought to know how much the users would want the solution and there was 95% acceptance from the respondents. Figure 5.4 above gives an impression of what the users felt.

c) System Usefulness

From the post-survey findings, approximately 75% of the respondents consented that the tool can help monitor and improve chronic heart failure patient monitoring. Most of them added that since most of their patients are located in rural areas far from the hospitals, remote monitoring and management would be critical process at all times.

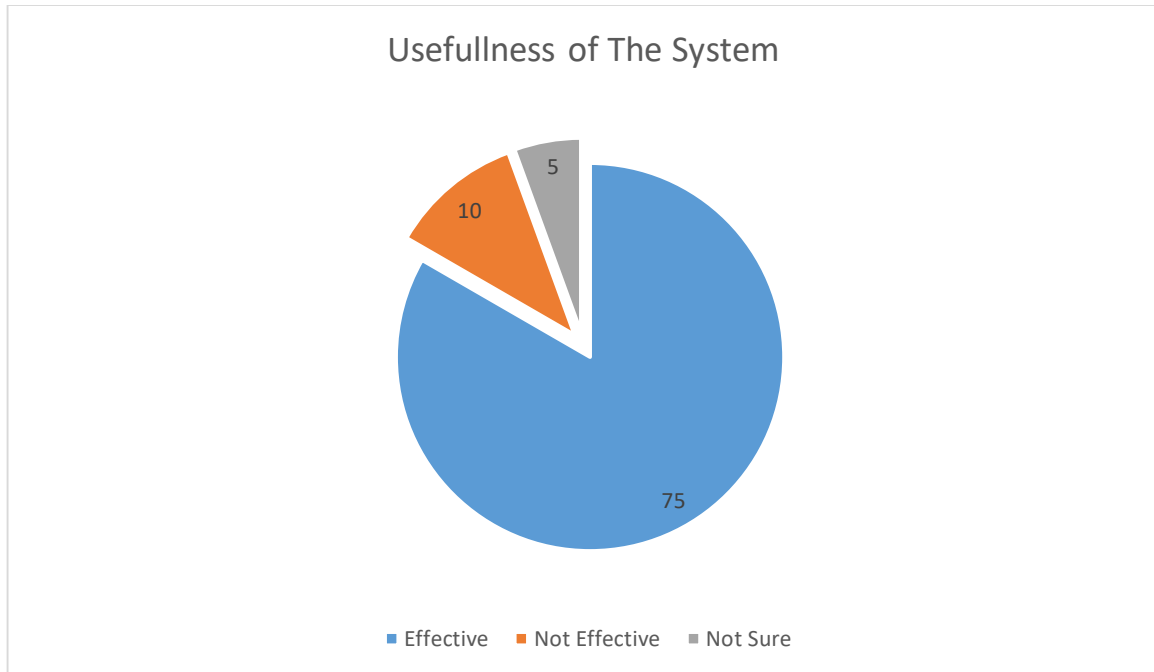


Figure 5.5 System Acceptance

5.3.3 Implementation of Experiments

To demonstrate the prototype effectiveness, the researcher used simulated data to validate each rule. This simulation produced promising results identifying abnormal data values and alert generation without any false alarm. The system was tested with twenty use cases, ten use cases with abnormal vital signs and ten use cases normal vital signs. These reference scenarios are based on real situations and they aim to reflect the CHF patients' everyday life. The experiments were implemented to validate the researcher's approach for monitoring chronic heart failure patients remotely.

Chapter 6: Discussions

6.1 Introduction

The chronic heart failure patient monitoring model development was based on the findings obtained during the research. The prototype was tested to confirm that all its functionalities conform to the research. In this chapter, an analysis was done to determine the correlation between the findings and the research objectives as well as the literature review.

6.2 Challenges faced in chronic heart failure patients monitoring

The first objective of this research as stated in chapter 1, was to identify the challenges faced by chronic heart failure patients in monitoring. Current technologies require the patient to undergo a long term monitoring procedure in a hospital setup, increasing the patients' financial burden. These barriers can result in poor clinic attendance, a break down in patient-monitoring and poor continuity of care.

6.3 Existing approaches for chronic heart failure patients monitoring

The second objective was to investigate the existing approaches used to monitor chronic heart failure patients. From the research, it was established that to monitor chronic heart failure patients had to be hospitalized. Chronic Heart failure patients besides having limitations in their physical condition, also often have economic challenges. They lack the adequate resources to hire personal homecare nurses and doctor to monitor their vitals. The study further exposes that respondents face financial challenges in the use of the existing method. The burden of monitoring the patients is left to relatives who have to closely monitor them reducing their productivity. Due to this challenges, chronic heart failure patients lack the adequate monitoring attention required.

6.4 Current Chronic Heart Failure Patients Monitoring Technologies

The third objective was to analyze technologies that are available for chronic heart failure patients monitoring. Research findings show that hospitals use multi-parameter monitors for heart failure monitoring. This is mostly used in hospital units. The literature review elaborates the multi parameter technology which is in line with the study findings.

6.5 Model for real-time monitoring of Chronic Heart Failure Patients

The fourth objective was to develop a model for chronic heart failure patients monitoring. Research shows that users find it necessary to develop a model that enables monitoring of patients, not only

in hospitals but also during their day to day activities. The model is made up of a wearable sensor based hardware which captures heart rate, heart beat and temperature. The sensor data is then analyzed as normal or abnormal using fuzzy logic inference rules. In the event an abnormal sign is detected, a doctor and the patients' family member receives a text message. A mobile application is also used to offer real time monitoring of the patient vitals.

6.6 Advantages of the model as compared to the current methods of monitoring

The proposed model offers patients invaluable assurance that someone is watching out for their health and well-being on a daily basis. Since RPM connects clinicians more directly with rich patient information, it makes their day by day schedules more productive and reduces the likelihood of burnout — bringing about clear advantages to patient care. In addition the low cost system, power consumption, maintenance and provides automatic data acquisition by using sensors that have high sensitivity and easy to handle. Malfunctioning of any sensor or motor will not affect the whole system but just a single function of the system. Users receive sms notifications once an abnormal vital sign is detected by the system.

6.7 Disadvantages of the model for monitoring of chronic heart failure patients

The disadvantages of using IoT system to monitor chronic heart failure patients are as follows: There is no internal system to detect malfunctioning of sensors or motors, Secondly, the system requires uninterrupted power supply and internet connection to function fully which might therefore result to one having an external source of power such as batteries and a backup internet supply. Thirdly, the users may require technical training to adopt and successfully implement the system.

Chapter 7: Conclusions and Recommendations

7.1 Conclusions

The objective of this research were to review the current chronic heart failure monitoring methods and then to offer a fuzzy expert based monitoring system for the solutions determined. This system monitors the patients' physical signs such as heat rate, heartbeat, temperature as well as relevant environmental indicators continuously, and provides data analyses that helps classify abnormal and normal sensor data. The system send sms alert to the patient relative and doctor once an abnormal vital sign is detected.

Based on this background, the research exposes the fact that due to the nature of chronic heart failure condition, constant monitoring of CHF patients is important. From the research findings, it is evident that most respondents face economic, emotional and social relations problems challenges using the current methods of patient monitoring. The challenge with the most negative impact is insufficient technology solutions for monitoring of CHF patients. Using fuzzy expert system based technology through IoT as described in the literature review, a prototype for real-time CHF patients monitoring was developed. Scrum methodology, used during the model development, enables the researcher to manage the constraint of the thesis project and introduce software process at a level that captures foundational software development practices.

Usability testing was also carried out to validate that the system is easy to use and acceptable to the users. It is anticipated that if fully adopted and supported, the system will help in effective monitoring of CHF patients.

7.2 Contributions to Research

The researcher has contributed a feasible solution to two growing fields in computing which are The Internet of things and real-time data capture and analysis through fuzzy logic by incorporating them into the field of patient monitoring. The developed prototype provides a comprehensive solution that is affordable, efficient and real time in monitoring chronic heart failure patients.

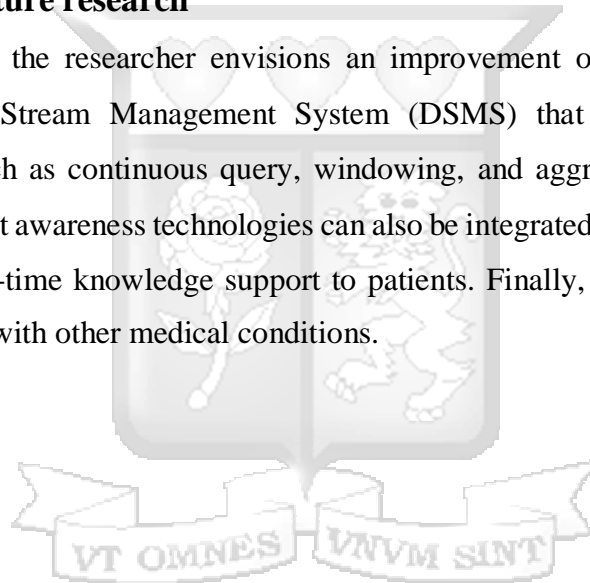
7.3 Recommendations

The fuzzy expert based patients monitoring model is undeniably an advancement that will facilitate easier management of chronic heart failure patients and is therefore a good thing to the health sector in the country. Given this premise, the recommendations are as listed below;

- i. In collaboration with the ministry of health, this model could be adopted in both public and private hospitals for monitoring within and without the hospital.
- ii. This model is a source of a lot of motion data that can be explored for further enhancements in this field. The data can be used in research in the academia. For this the researcher recommends a collaboration with universities for further research and development.

7.4 Suggestions for future research

Further to this research, the researcher envisions an improvement of this model to integrate technologies like Data Stream Management System (DSMS) that enrich real-time patient monitoring functions such as continuous query, windowing, and aggregation. Afterwards, data stream mining and context awareness technologies can also be integrated to provide more powerful mobile services like real-time knowledge support to patients. Finally, the approach can also be used to monitor patients with other medical conditions.



References

- Al-Turjman, F. M. (2016). Towards smart ehealth in the ultra large-scale Internet of Things era. *2016 23rd Iranian Conference on Biomedical Engineering and 2016 1st International Iranian Conference on Biomedical Engineering (ICBME)*, (November), 102–105. <https://doi.org/10.1109/ICBME.2016.7890938>
- Alwan David R.Riley, Leanne M.d'Espaignet, Edouard TursanMathers, Colin DouglasStevens, Gretchen AnnaBettcher, Douglas, A. (2010). Chronic Diseases: Chronic Diseases and Development 5: Monitoring and surveillance of chronic non-communicable diseases: progress and capacity in high-burden countries. *Lancet*, 376(9755), 1861–1868. [https://doi.org/Doi 10.1016/S0140-6736\(10\)61853-3](https://doi.org/Doi 10.1016/S0140-6736(10)61853-3)
- Angelo, J., & Egan, R. (2015). Family caregivers voice their needs: A photovoice study. *Palliative and Supportive Care*, 13(3), 701–712. <https://doi.org/DOI: 10.1017/S1478951514000522>
- Babkin, E. (2011). *Ubiquitous Computing. Environment*. Retrieved from <http://www.intechopen.com/books/show/title/ubiquitous-computing>
- Booch, G. (1994). *Object-oriented Analysis and Design with Applications*. <https://doi.org/10.1007/s00894-009-0527-9>
- Boza, A., Cortés, B., Cuenca, L., & Alarcón, F. (2015). Internet of things applications in production systems. In *ICEIS 2015 - 17th International Conference on Enterprise Information Systems, Proceedings* (Vol. 1, pp. 330–337). <https://doi.org/10.5220/0005378903300337>
- Caballero, A. a, & Mitrani, J. D. (2000). Fuzzy logic methodology for the comparison of construction firms. *Proc. 17th International International Symposium on Automation and Robotics in Construction (ISARC 2000)*, 1–5.
- Caggiano, A. (2014). Fuzzy Logic. *CIRP Encyclopedia of Production Engineering*, 562–568. <https://doi.org/10.1007/978-3-642-35950-7>
- CDC. (2009). *Data Collection Methods for Program Evaluation: Interviews. Evaluation ETA: Evaluation Briefs*.
- Cervantes, L., & Castillo, O. (2016). Theory and Background. In *Hierarchical Type-2 Fuzzy Aggregation of Fuzzy Controllers* (pp. 3–11). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-26671-8_2
- Crone, Bill, Healthcare Systems Engineer, Analog Devices, I. (2011). Multiphysiological Parameter Patient Monitoring. *Analog Devices, Technical Article MS-2126*, (January), 1–6. Retrieved from http://www.analog.com/static/imported-files/tech_articles/MS-2126.pdf
- David Hamilton. (2016). The Four Internet of Things Connectivity Models Explained. Retrieved January 1, 2017, from <http://www.thewhir.com/web-hosting-news/the-four-internet-of-things-connectivity-models-explained>
- Dr Misango (The Critical Care Society of Kenya). (2013). Kenya has less than 50 ICU beds for

- 40m people, says expert. *MONDAY AUGUST 26 2013*. Retrieved from <http://www.nation.co.ke/news/Expert-warns-of-state-of-critical-care/1056-1968038-89h912z/index.html>
- Fenton, M., & Burch, M. (2007). Understanding chronic heart failure. *Archives of Disease in Childhood*, 92(9), 812 LP-816. Retrieved from <http://adc.bmj.com/content/92/9/812.abstract>
- Flynn, S., Ellery, S., & Mason, L. (2014). Living with chronic heart failure. *BMJ Supportive & Palliative Care*, 4(1), 111. <https://doi.org/10.1136/bmjspcare-2014-000653.20>
- Fonarow, G. C. (2006). *How well are chronic heart failure patients being managed? Reviews in cardiovascular medicine* (Vol. 7 Suppl 1). <https://doi.org/10.1007/978-1-59745-474-2>
- Geraci, R. M. (2013). Moore's Law. In A. L. C. Runehov & L. Oviedo (Eds.), *Encyclopedia of Sciences and Religions* (p. 1364). Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-1-4020-8265-8_201029
- Google Cloud. (2017). Overview of Internet of Things. *April 19, 2017*. Retrieved from <https://cloud.google.com/solutions/iot-overview>
- GSM Association. (2014). Understanding the Internet of Things (IoT), (July).
- Hajek, P. (2010). Fuzzy Logic. In *Stanford Encyclopedia of Philosophy*. Retrieved from <http://plato.stanford.edu/entries/logic-fuzzy/>
- Harder, D. (n.d.). Mathematical Introduction to Fuzzy Logic, Fuzzy Sets, and Fuzzy Controls. Retrieved from <https://www.maplesoft.com/applications/view.aspx?sid=1409&view=html>
- Jon Berg. (2005). Patient Monitoring Systems - Current and future possibilities of Medical Informatics. Retrieved May 2, 2017, from <https://fragments.turtlemeat.com/medical-informatics/Patient-Monitoring-systems.php>
- Kopetz, H. (2011). Internet of Things. In *Real-Time Systems: Design Principles for Distributed Embedded Applications* (pp. 307–323). Boston, MA: Springer US. https://doi.org/10.1007/978-1-4419-8237-7_13
- Mahidhar, V., & Schatsky, D. (2013). The Internet of Things. *Deloitte University Press*. <https://doi.org/10.5480/1536-5026-34.1.63>
- McHorney, C. A., & Tarlov, A. R. (1995). Individual-patient monitoring in clinica practice: are available health status survey adequate? *Quality of Life Research*, 4(4), 293–307. <https://doi.org/10.1007/BF01593882>
- MERAB, E. (2016, May 12). Younger Kenyans increasingly getting heart diseases: Doctors. Retrieved from <http://www.nation.co.ke/news/Heart-attacks-number-one-killer-of-adults-over-30/1056-3199766-4b14aiz/index.html>
- Ministry of Health. (2014). Health Sector Human Resources Strategy 2014-2018. *The Strategic Management Handbook*, 1–22.
- National Heart Foundation of Australia. (2015). Heart Information - Living Well with Chronic Heart Failure, (CON-035.v5). Retrieved from <http://www.heartfoundation.org.au/SiteCollectionDocuments/Living-well-with-chronic->

heart-failure.pdf

- Okech, U. K. (2014). a Survey of Icu Setups in the Republic of Kenya This Dissertation Is Submitted in Part Fulfilment of the Requirement for Masters in Anaesthesiology At University of Nairobi Dr Umani Kevin Okech, (May).
- Oliva, F., Sormani, P., Contri, R., Campana, C., Carubelli, V., Cirò, A., ... Ammirati, E. (2017). Heart rate as a prognostic marker and therapeutic target in acute and chronic heart failure. *International Journal of Cardiology*. <https://doi.org/10.1016/j.ijcard.2017.09.191>
- Pinkerman, C., Sander, P., Breeding, J. E., Brink, D., & Curtis, R. (2013). Heart Failure in Adults. *Management*, 19(10), S108. <https://doi.org/10.1016/j.cardfail.2013.08.027>
- Rojas, R. (1996). Fuzzy Logic. *Neural Networks*, 289–310. <https://doi.org/10.1007/978-3-642-61068-4>
- Sanyal, B. (2010). M2M Technology : Challenges and Opportunities Author. Retrieved from http://www.iot-now.com/wp-content/uploads/2011/05/M2MTechnology_Challenges-and-Opportunities.pdf
- Schwaber, K., & Sutherland, J. (2013). The Scrum Guide. *Scrum.Org and ScrumInc*, (July), 17. <https://doi.org/10.1053/j.jrn.2009.08.012>
- Seeq, M. (n.d.). Cardiac Monitoring : The Importance of Detecting Heart Rhythm Disorders.
- Slevitch, L. (2011). Qualitative and Quantitative Methodologies Compared: Ontological and Epistemological Perspectives. *Journal of Quality Assurance in Hospitality & Tourism*, 12(1), 73–81. <https://doi.org/10.1080/1528008X.2011.541810>
- Suresh, V., & Vaidya, V. . (2014). Ubiquitous Computing, 7(4).
- VERIZON, S. (n.d.). Machine-to-Machine Solutions for Health Care. Retrieved from https://business.verizonwireless.com/content/dam/b2b/resources/M2M_Healthcare_Overview.pdf
- Weiser, M., & Weiser, M. (1993). Ubiquitous computing. *IEEE Computer*, 26(10), 71–72. <https://doi.org/10.1109/2.237456>
- Weyrich, M., Schmidt, J. P., & Ebert, C. (2014). Machine-to-machine communication. *IEEE Software*, 31(4), 19–23. <https://doi.org/10.1109/MS.2014.87>
- World Health Organization. (2015). WHO Statistical Information System. Retrieved from <http://www.who.int/whosis/en/>
- Zadeh, L. A. (1988). Fuzzy Logic. *Computer*, 21(4), 83–93. <https://doi.org/10.1109/2.53>

Appendix A Questionnaires

Research Questionnaire

Dear Respondent.

I am a Masters student in the Faculty of Information Technology, Strathmore University conducting a research entitled FUZZY EXPERT BASED REAL TIME MONITORING SYSTEM FOR PATIENTS WITH CHRONIC HEART FAILURE THROUGH IOT.

You have been selected to form part of this study. I kindly request you to complete the questionnaire below. The information requested is needed for academic purposes only and will be treated in strict confidence.

Kind Regards,
Isaack Mwenda

*Required

1. What is your age group? *

Mark only one oval.

- i. 18 years30 years
- ii. 31 years40 years
- iii. 41 years50 years
- iv. 51 years60 years
- v. Over 61 years



2. Kindly rate how good you are in using a mobile phone *

Tick all that apply.

- i. Very Good
- ii. Good
- iii. Average
- iv. Bad
- v. Very bad

3. Do you own a mobile phone? *

- i. Yes
- ii. No

4. Have you ever been hospitalized because of a heart failure? *

- i. Yes
- ii. No

5. Do you access health care through your phone

- i. Yes
- ii. No

Usability Testing Questionnaire

1. The device can be carried around with ease during monitoring process?

- i. Yes
- ii. No
- iii. Neutral

2. I am willing to use the tool for to monitor my patient.

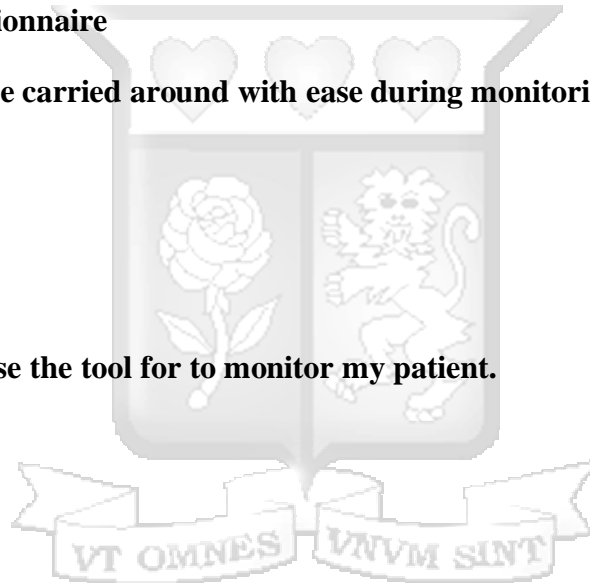
- i. Yes
- ii. No
- iii. Neutral

3. The mobile application is easy to use

- i. Yes
- ii. No
- iii. Neutral

4. The device would makes CHF patient effective

- i. Yes
- ii. No
- iii. Neutral



APPENDIX B TURNITIN REPORT

ORIGINALITY REPORT

29%

SIMILARITY INDEX

23%

INTERNET SOURCES

11%

PUBLICATIONS

18%

STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to Strathmore University Student Paper	2%
2	page.mi.fu-berlin.de Internet Source	2%
3	C. A. McHorney. "Individual-patient monitoring in clinical practice: are available health status surveys adequate?", Quality of Life Research, 08/1995 Publication	1%
4	cloud.google.com Internet Source	1%
