A PROJECT REPORT

On

DIGITAL TRACKING AND CONNECTIVITY OF SAMPLES FOR INTEGRATED DIAGNOSTIC SYSTEM

By

ADELOWO EYITOPE IBUKUNOLUWA

(EEE/14/7852)

Supervised by:

DR F. M. DAHUNSI

Submitted to:

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINERING,
SCHOOL OF ENGINEERING AND ENGINEERING TECHNOLOGY
FEDERAL UNIVERSITY OF TECHNOLOGY AKURE

IN PARTIAL FULFILMENT FULFILLMENT FOR THE AWARD OF BACHELOR IN ENGINEERING (B.ENG) IN ELECTRICAL AND ELECTRONICS ENGINEERING

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DECEMBER 2019

CERTIFICATION

This is to certify that *Adelowo Eyitope Ibukunoluwa* with matriculation number *EEE/14/7852* has successfully completed the required final year project work, and has compiled this report in accordance with the regulations guiding the preparation of project report in the department of Electrical and Electronics Engineering, Federal University of Technology Akure, under my supervision. This is in partial fulfillment of the requirements for the award of Bachelor of Engineering degree in the department of Electrical and Electronics Engineering, Federal University of Technology, Akure.

_____ _____

Student's signature Date

_____ _____

Dr. F. M. Dahunsi (Project Supervisor) Date

_____ _____

Dr. J. J. Popoola (Head of Department) Date

DEDICATION

This project report is dedicated to my supervisor, Dr. F. M. Dahunsi, for her guidance and support on many key decisions taken on the path to bringing the project work to a successful completion.

ACKNOWLEDGEMENTS

I appreciate my supervisor, Dr. .F. M. Dahunsi for her motherly assistance and encouragement in ensuring the completion of the project. I particularly appreciate her disposition towards ensuring the project was carried out with good faith in solving a real problem. I also appreciate her effort in providing access to the school laboratory for convenience in carrying out this project.

ABSTRACT

Diagnosis may involve the collection of medical samples for further diagnosis at a medical laboratory. One of the failures of diagnosis and inefficiencies in the diagnostic system is the existing transport system which does not have adequate facilities to ensure that the integrity of samples are maintained from sender to receiver. The aim of the project was to prototype an IoT medical sample holder that shared data about its current state to a medical laboratory information system, as part of an integrated diagnostic system, so that qualitative inference may be made about the integrity of the samples, and allow for digital tracking of the samples during transport.

Prototyping the sample holder involved software development and hardware design. The system was deployed on Heroku, a cloud hosting service, and was tested by transporting the completed IoT sample holder within a short distance, while observing its transmitted data on the online platform. The hardware design was highly modular and utilized Arduino. All tests were within 100m distance without actual blood samples. The sample holder and its dummy content was successfully tracked, and data of interest uploaded that may be integrated into a diagnostic system.

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LIST OF ABBREVIATIONS

AHIMA: American Health Information Management Association

AI: Artificial Intelligence

CDC: Centre for Disease and Control Prevention

EHR/EMR: Electronic Health Record / Electronic Medical Record

FUTA: Federal University of Technology Akure

HIM: Health Information System

IATA: International Air Transport Association

IEEE: Institute of Electrical and Electronics Engineers

IETF: Internet Engineering Task Force

IHR: International Health Regulations

IoT-D: Internet of Things Devices

ITU: International Telecommunication Union

MLSCN: Medical Laboratory Science Council of Nigeria

NISRN: National Integrated Specimen Referral Network

SAAT: School of Agriculture and Agriculture Technology

TAT: Turn Around Time

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CHAPTER ONE

INTRODUCTION

Diagnosis is a critical in the success of the field of medicine. A clinician's ability to diagnose accurately is central in assessing prognosis and prescribing effective treatment. (BMJ 2009;338:b946). Medical diagnosis, otherwise referred to as just diagnosis, is the process of determining which disease or condition explains a person's symptoms and signs ("Medical diagnosis", n.d.). Diagnosis may involve the collection of medical samples for further diagnosis at a medical laboratory. Results of such further diagnostics become feedback for reaching a conclusion in prescribing effective treatment. The entire process involved in carrying out diagnosis, equipment involved, data, and all stakeholders (medical officer, patient, etc) form a diagnostic system.

Diagnostic systems have evolved from the use of paper for record keeping to the use of computers. Today, medical diagnosttic systems are basically the application of information technology. According to Merriam-Webster's dictionary, information technology is the use of computer systems, software, and networks for processing and distribution of data, which in this case, is clinical data. Clincal data refers to health information associated wuth regular patient care. It falls into six major types (Data Resources in the Health Sciences, 2019):

i. Electronic health record
ii. Administrative data
iii. Claims data
iv. Patients/ disease registries
v. Health surveys
vi. Clinical trials data

Nowadays, modern laboratories are faced with huge volume of information. A medical laboratory information system (LIS), otherwise called a medical laboratory information management systems (LIMS) is software designed to assist in the management of the information generated in the laboratory. The digitization of information and the application of information technology in the medical field is comparatively advantageous to paper-based health information system (Bosch-Capblanch, et al., 2017)

An integrated diagnostic system may therefore be defined as a system established to effectively combine the processes, equipment, medical officers, data, and other relevant systems required to efficiently carry out medical diagnosis. One of such relevant systems is the medical laboratory information system (LIS). Laboratory information systems are critical components of the operation of clincal laboratories. It is designed to manage all operations involved in laboratory activities, and plays a major role in organising digital data involved in medical diagnosis.

1.1. Problem Statement

In 2017, the Global Grand Challenge sponsored by the Bill & Melinda Foundation identified that a well implemented centralised laboratory has the potential to achieve high throughput testing with multi-purpose platforms at low cost. However, the function of existing laboratory services in the developing world remains poor due to multiple factors.

One of the key failures of diagnosis and inefficiencies in the diagnostic system is because of the use of paper based systems for record purposes. The major problem associated with paper based systems of data management are the introduction of errors in recording data. It often necessitates that tests from which recording errors arise be repeated. (Schultz, 2012). The implication is that time, money, and equipment are wasted in failed tests.

In addition, the Bill & Melinda Gates foundation, in the Global Grant Challenge also identified that sample transportation in the developing world setting is uncoordinated or otherwise ineffective. A visit to few diagnostic centres revealed that no dedicated sample transport system exists in the country. Medical institutions therefore result to the existing transport system which does not have adequate facilities to ensure that the integrity of samples are maintained from sender to receiver. For example, a source identified how drivers may abandon sample holders at bus stations if communication failure occurs between drivers and receiver. Mishandling of sample holders also occurs in the existing transport system because of lack of education in sample transport.

Further connected to the problem in the transport system is the inability to evaluate sample integrity during transportation. Medical institutions therefore cannot make accurate inference on how transport conditions affect the integrity of samples and make informed decisions.

1.2. Motivation for the Project

The primary motivation for this project was the desire to proffer solution to a problem in the medical sector using technology within. The project calls for an opportunity to apply internet of things (IoT), data science, which are major subjects in today's world. Also included is the opportunity to apply root cause analysis (RCA), design thinking, and system design in proffering a solution.

Data science is a field that uses scientific methods, processes, algorithms and systems to extract knowledge and insights from structure and unstructured data. (Data Science, n.d.). The process involves capturing data, maintaining or storing the data, processing (data mining, classification, etc.), analysing (regression, qualitative analysis, predictive analysis, etc.) and finally communicating the result of the entire process to make appropriate decision. In today's world, data is becoming more valuable with the passing of time. Large amounts of data are used to design artificial intelligence systems and train machine learning models. Data is therefore key in the development of our modern world. The project involves gathering data; hence, playing a role in data acquisition. This data could be proven to be valuable in ways unimagined.

Internet of Things is a term used to describe electronic devices connected to the internet. Usually, the devices can make information decisions from data obtained from the internet or send data that can give greater insight into operations. The total installed base of IoT devices is projected to amount to 75.44 billion worldwide by 2025. At the time of this report, the estimated number of IoT devices was 26.66 billion (Internet of Things - number of connected devices worldwide 2015-2025, n.d.) Application of IoT is consequently an interesting area to work on.

It is also of much interest to apply design skills in proferring a solution to the problem at hand. The project enables me to utilise skills in firmware development, circuit design, and system design to create a working prototype. It also also calls for critical thinking and management to produce the a working prorotype with the lowest cost possible. These are tasks that call for a practical approach to engineering compared to a theoretical means of equations and concepts.

Another motivation is the opportunity to apply design thinking. Design thinking is the pocess for creative problem solving (Design Thinking, n.d.) Having had some experience with hardware

design engineering, successful implementation of the project serves as an opportunty to add credibility to my status as a forthcoming engineer, and furthering a career in hardware design.

The project also helps to lay special importance on the need for an efficient transport system and it's development. Among the sustainable development goals (SDG 3) is good health and wellbeing. Seeing this project helps achieve the one of the SDGs, it may serve as a good platform to apply for grants, funding, and attract developers to properly develop the system.

Lastly, the ability to track samples and make their information digitally available serves as an extension for existing laboratory system's to add. The potential for future integration with the medical laboratory systsms may further place demand on such a system and may allow for a solution that is scallable.

1.3. Aims And Objectives

1.3.1. Aim

The aim of this project is to prototype an IoT medical sample holder that shares data about its current state to a medical laboratory information system, as part of an integrated diagnostic system, so that qualitative inference may be made about the integrity of the samples, and allow for digital tracking of the samples during transport.

1.3.2. Objective

The objective of the project are to:

i. To implement an interconnected laboratory network that will efficiently track patients, specimens and data to and from various types of settings, ensuring quality diagnostic services are provided.
ii. To integrate (i) above to a smart sample holder.
iii. To evaluate the performance of (i) and (ii) above.

1.4. Scope of The Project

The project seeks to create a first prototype showing basic features of an IoT sample holder. Therefore, the data being synchronised with the cloud are temperature of sample holder (storage

temperature of the samples), location of the sample holder for tracking purposes, may include vibration and/or rotation. In practice, it may be obtaining more data than has been measured to make better inference. This project will only address the above-mentioned parameters.

It is anticipated that it may become important to supply information to medical officers via a medical laboratory information system. This additional information (inference made from tracking samples during transport) obtained from the sample holder, may be made available to another medical LIS already being utilised in the medical sector. However, this project would be modelling an LIS by using an online interface and/or an Android mobile app. These will serve as the interface for medical officers.

Considering the possibility of future integration with other medical LIS, time constraint in delivering the project as well s cost, the sample holder will not seek to be developed for any medical LIS, but only for the custom-made web interface.

1.5. Expected Contribution to Knowledge

IoT devices are increasingly being integrated into several facet of the health sector, although advances in the developing countries are lagging. At the end of this project:

i. Medical officers can have accurate information about the quality of their medical samples in transit and take appropriate decisions.
ii. The data obtained from the system can be presented in a form that can be integrated with a LIS or form part of an Electronic Medical Record (EMR)

There is economic potential in setting up a dedicated medical samples transport system for the Nigerian environment.

CHAPTER TWO

LITERATURE REVIEW

Background of Study

The need for an integrated diagnostic system in the scope of this project is a consequence of the increasing amount of data to be managed by medical centers. The quest for solutions has led to many efforts in an attempt to shift from the paper-based method of recording to electronic methods, all having a unified purpose to increase the efficiency and accuracy of recording patient medical information (Fertig, Park, and Toth, 2019). In order to properly understand the context of this discussion, it is important to have a look at some history in the world of medicine, and how medical information has been managed.

2.1. Medical Recording System

Information may simply be defined as data that has meaning. Health information, therefore, is medical data that has been collected and processed to have meaning. According to the American Health Information Management Association (AHIMA), Health information is the data related to a person's medical history, including symptoms, diagnoses, procedures, and outcomes. Health information records include patient histories, lab results, x-rays, clinical information, and notes. A patient's health information can be viewed individually, to see how a patient's health has changed; it can also be viewed as a part of a larger data set to understand how a population's health has changed, and how medical interventions can change health outcomes. (American Health Information Management Association, 2019).

The Oxford Dictionary defines a system to be *"a set of things working together as parts of a mechanism or an interconnecting network; a complex whole."* We may consider this definition in this context to be analogous to medical information management. Therefore, defining a medical information system or health information system (HIM), it is the practice of acquiring, analyzing, and protecting digital and traditional medical information vital to providing quality patient care. It is a combination of business, science, and information technology. (American Health Information Management Association, 2019).

2.1.1. History of Medical Recording Systems

Medical records have a surprisingly long and illustrious history, stretching back to ancient civilizations like those in Egypt, Greece and Rome. Just as today medical records are our only evidence that a medical procedure or attempted cure has taken place, ancient stone tablets (Synapse Medical Services, 2019). Ancient Mesopotamia (modern day Iraq parts of Iran, Syria and Turkey). Rich civilisations flourished, including the Sumerians and the Babylonians more than 5000 years ago. Even at such a distant time in history, these civilisations understood the importance of medical records. Records in the form of clay tablets written in cuneiform (one of the oldest writing styles have been discovered by archeologists. These records show that their purpose was to document the patient's history, just like today.

The first known record is Egyptian from 1600 BC, but it is not a proper patient record, rather a written document on papyrus describing surgical treatment of war wounds. The knowledge of Greek medicine was kept and developed by the Arabs into so-called Islamic Medicine during the Islamic Golden Age, from the eighth century to the thirteenth century. The Arabs introduced the concept of hospital and the use of hospitals. They also were the first to keep written records of patients and their medical treatment. Students were responsible for keeping the patient records, which were later edited by doctors and referenced in future treatment (The History of the Patient Record and the Paper Record, 2018).

History also tells of the Swedes and other ancient civilizations that took note of medical data. Considering more recent times according to AHIMA, healthcare professionals realized that documenting patient care benefited both providers and patients in 1920. Patient records established the details, complications and outcomes of patient care. Documentation became wildly popular and was used throughout the nation (America) after healthcare providers realized that they were better able to treat patients with complete and accurate medical history. Health records were soon recognized as being critical to the safety and quality of the patient experience. This was the case in America. In Sweden the paper based patient record system was developed and refined until 1980 when computerized patient record systems started to become more common and it was more or less completely digitalized by 2007 (The History of the Patient Record and the Paper Record, 2018). In the past, the ability to get any information was usually tedious but now, information retrieval and management operation have been made possible with few clicks. Nigeria, though still

a developing country has not been left out in this technologically advanced world. Technology has been able to permeate various sectors of the Nigerian economy but unfortunately, the Nigerian health sector has been found wanting, and most hospitals in Nigeria still rely on the paper based way of keeping health records of patients (Ajala, Jinmisayo, and Emuoyibfarhe, 2015).

To foster understanding of Nigeria's position in health records, consider this example: In America, considering more recent times rather than antiquity, health records found its roots back to the 1920. Paper medical records were steadily maintained from the 1920s onward, but the advancing technology of the '60s and '70s introduced the beginnings of a new system. The development of computers encouraged pioneering American universities to explore the marriage of computers and medical records (Brooks, 2015). Brooks (2015) tells us that these universities often partnered with large healthcare facilities. Patient information would be generated and electronically recorded at a specific facility—and it was accessible only at that healthcare location. This obviously restricted the software's usefulness and viability on the market. Other hindrances to early electronic heath records included computer performance limitations and exorbitant pricing.

Brooks (2015) also discussed the huge leaps in healthcare software development. The advent of computerized registration meant patients were able to benefit from a more efficient electronic check-in process for the first time ever. The introduction of the master patient index (MPI), a database of patient information used across all the departments of a healthcare organization, was also a massive success. This encouraged software developers to create with a new focus on individual hospital departments. Departments like Radiology and Laboratory adapted well to the new software, and computer healthcare applications began to show up in the market.

He continued that these applications still faced limitations because computer applications were being used within healthcare walls, but none of them could communicate with each other or be viewed by neighbouring departments; thus, healthcare was without a communicative, cross-departmental electronic record system.

After President George W. Bush called for computerized health records in 2004, the HER revolution began in America. In 2009, President Obama passed an act that required the adoption of Electronic Medical Records by 2014 for seventy percent of the primary care provider population. On the contrary, because electronic evidences were not admissible in Nigerian courts, there have been legal implications in EMR usage. (Akor & John-Mensah, 2016).

2.1.2. Electronic Medical Recording Systems in Nigeria

Ajala, et al. (2015) defined it as a record in digital format that is theoretically capable of being shared across different health care settings. According to them, it may include a range of data, including demographics, medical history, medication and allergies, immunization status, laboratory test results, radiology images, vital signs, personal statistics like age and weight, and billing information.

Although implementation of clinical information systems in general and EHR in particular has had limited success, work has still been ongoing by private bodies to investigate the hindrances and methods to implement them. EMR prototypes have been developed to solve practical problems attached to the conventional paper-based records system (Funmilayo, Jinmisayo, & Ozichi, 2015) and some have been proven to significantly boost productivity; for example, Life Support Eye Clinic, Lagos (Ogundipe O. , 2011). In spite of the important function of medical record, it has come under severe threat by the manual system of medical record keeping. This system involves taking down patient data on pieces of papers, which are then put in to the files and filed in cabinets. Researchers have observed that missing pieces of information often occur with this system (Obotu, Ph.D, and Ogezi, 2018).

Several recommendations and proposals have been put forward for the implementation of EMR and Hospital management systems. Although commercial solutions exist, the cost of implementing and managing them still remains relatively high. (Attah, 2017).

Paper-based recording systems have proven their inefficiency. With many Secondary Healthcare facilities (General Hospitals) in Nigeria without electronic health records, healthcare delivery is sometimes impaired with the current use of cards. The increasing number of patients seeking health care services requires faster and more efficient records keeping. Attah (2017), properly identified this problem, as well discussing the prospects and challenges in implementing electronic health record in Nigerian secondary healthcare facilities.

2.1.3. Integrated Diagnostic Systems and Technology Driven Diagnostic Systems

In view of harnessing the potentials of an integrated diagnostic system, digital tracking of samples provide a means for medical centers to have organized information about samples in transit. In 2017, the Bill and Melinda Gates foundation identified the need for innovations in integrated

diagnostic systems. They sought novel ways to implement interconnected laboratory networks that will efficiently track patients, specimens and data to and from various types of settings, ensuring quality diagnostic services are provided and can inform treatment and care decisions (Innovations for Integrated Diagnostic Systems (Round 19), 2017); thus promoting digital tracking of samples during transportation. This is the scope of this project.

Artificial intelligence (AI), an emerging field of computer science, has the potential to give medical insight to the medical profession. Computer technology provides the medical profession tools for gathering medical data, processing power, as well as fast storing and retrieving capabilities. Schizas, et al (1994) demonstrated this. Conclusively, this is what an integrated diagnostic system entails. As a means to develop an integrated diagnostic systems, this project seeks to contribute to the data available for processing through digital tracking (or connectivity) of samples. An integrated diagnostic system as 'smart health'.

The adoption of smart health is a global discussion. It is also the 3rd UN SDG. As related to diagnostics, 'diseases of affluence', such as diabetes and cardiovascular disease, are increasing in developing countries. Infectious diseases still impose the greatest health burden. Annually, just under 1 million people die from malaria, 4.3 million from acute respiratory infections, 2.9 million from enteric infections and 5 million from AIDS and tuberculosis. Other sexually transmitted infections and tropical parasitic infections are responsible for hundreds of thousands of deaths and an enormous burden of morbidity. More than 95% of these deaths occur in developing countries. Simple, accurate and stable diagnostic tests are essential to combat these diseases, but are usually unavailable or inaccessible to those who need them. (Mabey, Peeling, Ustianowski, and Perkins, 2004). In the past decade, public-sector investment in diagnostic-test development has been largely investigator driven. The United States National Institutes of Health funds test development through its grants to small businesses. The Welcome+ Trust has also supported diagnostics research and development, as do the United States Centers for Disease Control and Prevention and the defense departments of some developed countries. In 2004 Bill and Melinda Gates Foundation announced a US $200 million 'Grand Challenge' for addressing inequities in global health. One of its areas for funding is the development of technologies that would allow the assessment of individuals for multiple conditions or pathogens at the point of care. A number of initiatives for specific diseases have also focused on diagnostics development in recent years.

Current developments in patient health monitoring devices are readily integrated into the cloud. Cloud connectivity provides healthcare computing features, enables data storage and analysis, and allows medical personnel to be notified appropriately. Adoption of the cloud in healthcare will continue to evolve and accelerate due to the increasing usage of IoT-enabled smart devices. Many of these will form part of an integrated diagnostic system. For example, IBM announced a new business unit, Watson Health that will offer cloud-based access to its analytical power for interpreting healthcare data. The Watson Health Cloud will be an open-source but secure platform on which care providers and researchers can share and translate health data for better insight into trends, which will help them make more-informed decisions, thereby improving overall patient outcomes. Google also launched the Cloud Healthcare Application Programming Interface (API) to make it easier for health organizations to collect, store, and access health data. The industry-grade API platform allows users to run advanced analytics and machine learning based predictive models on electronic health records. In addition, Google signed a key cloud computing deal with Flex, a traded electronics manufacturer, which provides components for a huge number of medical devices around the world.

Smart health and integrated diagnostic systems are a global trend. The essence of an integrated diagnostic system cannot be over-emphasized. Health monitoring platforms are incorporating IoT-enabled smart devices to improve healthcare. Synergistic integration of the Internet of Things (IoT), cloud computing, and big data technologies in healthcare have led to the notion of "smart health." Smart health is an emerging concept that refers to the provision of healthcare services for prevention, diagnosis, treatment, and follow-up management at any time or any place by connecting information technologies and healthcare. As a significant breakthrough in smart healthcare development, IoT-enabled smart devices allow medical centers to carry out preventive care, diagnosis, and treatment more competently. We aimed to summarize the available information about recently approved devices and state-of-the-art developments through a comprehensive, systematic literature review. The combination of IoT with real-time, remote patient monitoring empowers patients to assert more control over their care, thereby allowing them to actively monitor their particular health conditions. (Kang, Park, Cho, and Lee1, 2018).

Smart health is a major up-and-coming research topic that is based on emerging ICT and has attracted cross-disciplinary researchers. The use of IoT helps automate the entire patient care

workflow. In other words, IoT-enabled smart devices have started to facilitate treatment services and strategies by healthcare providers. Patients can use these smart devices anywhere and immediately transmit their health conditions, in our case, samples data, and test results using IoT-enabled devices and integrated apps, making it easier to fit testing into daily life. For doctors, real-time digital tracking makes it easier to stay up-to-date with samples state in transit.

A growing number of organizations have a greater understanding of the value of the cloud and are putting their data in the cloud so that authorized parties can have access to the data from any location when needed.. Many efforts have been made to bring this technology into the health sector, but few have integrated this into their system even though there have been clear evidences of the increased productivity in doing so (Ogundipe O. , 2011). Recommendations and demos have been made (Ajala, Jinmisayo, and Emuoyibfarhe, 2015), and companies like Fasmicro are already testing a beta version of an EMR (Ekekwe, 2018).

Integrating EMR has the potential to tap into the essence of the 4th industrial revolution, which is the impact of data in the world today. Going digital is only the first step to keying into the possibilities. Going digital will provide better statistics for the government and other organizations. The dataset obtained from laboratory results can improve diagnosis and medical care through deep learning algorithms by checking results against extensive database of clinical reports and laboratory studies.

It will also allow doctors to track clinical path of a patient via remote access. In other words, a medical officer can access a patient's history from anywhere and anytime regardless of the point of data collection. With mobile app technologies, access to medical records (by medical officers) and access to medical officers (by patients) can be made more convenient and efficient.

This project seeks to track samples digitally, featuring IoT and smart health as part of an integrated diagnostic system. This inevitably would make use of a web interface and/or mobile app to present real-time information about sample to medical officers. Nigeria apparently does not have a developed samples transport system that is positioned to take advantage of data. This project will also demonstrate that.

2.2. Packaging Samples for Transport

For the scope of this project, samples are limited to blood, urine, and may include saliva. Ideally, the transport of specimen is guided by international standards and regulations. These are updated on a regular basis and are based on guidelines from Recommendations on the Transport of Dangerous Goods made by the Subcommittee of Experts on the Transport of Dangerous Goods (UN SCETDG), a subcommittee of the United Nations Economic and Social Council.

All laboratory specimen are potentially hazardous. An infectious substance is defined as a substance containing a viable microorganism, such as a bacterium, virus, rickettsia, parasite or fungus that is known or reasonably believed to cause disease in humans or animals. The efficient transport and transfer of samples requires co-ordination between the sender, logistic providers, carrier and the recipient to ensure safe transport and arrival on time and in proper condition. Samples are transported according to Medical Laboratory Science Council of Nigeria's (MLSCN) guidelines on safe transport of infectious substances (Tosan, et al., 2018). The document identifies two categories of samples that are of interest to this project: category A (UN2814) and category B

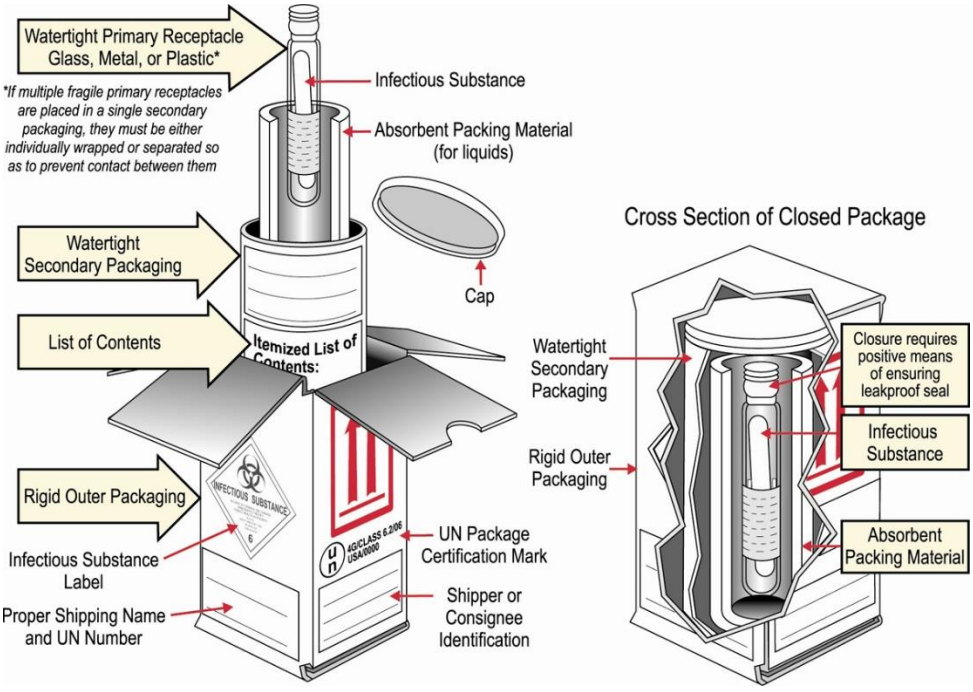

Figure 2.1: Triple packaging system

(UN3373).

It is the responsibility of all persons sending samples to the laboratory to adhere to policy and regulations, and to ensure that samples sent to the laboratory do not present any risk to whoever

may come in contact with it during transportation or when in the laboratory. Specimens/samples may be transported to laboratory by authorised hospital staff, general practitioner, patients, or courier. Regulations for transport of samples are designed to prevent contact of the public, workers, property, and the environment from the harm that may occur if exposed to the samples in transit. Regulations include hazard communication, labels, and markings on the outside of the packaging and other necessary information to properly identify the material and respond efficiently in case of emergency. (Erhabor, et al., 2018).

In 2001, the Centre for Disease and Control Prevention (CDC) established an office in Nigeria. Working with the federal and state ministries of health to address preventable diseases. Included in her goals is to respond to disease outbreaks. With the outbreak of Ebola, the CDC sent out a bulleting on how to safely deal with specimens from people who might have Ebola. Given in the guidelines was the triple packaging as shown in figure 1 (Guidance for Collection, Transport and Submission of Specimens for Ebola Virus Testing, 2018).

This method of packaging was equally adopted by MLSCN in their guidelines for safe transportation of infectious substances. The guidelines also show correct labelling for transport and identification. For goods to be shipped by air, some specific hazard labels are of importance. However, transporting by road, the most common means, do not specifically require the hazard labels.

The World Health Organization describe a basic triple packaging system, which has been reproduced above. This system of packaging is used for all infectious substances. It consists of three layers as follows (pictorial representation in figure 2.1):

i. Primary receptacle. A primary watertight leak-proof receptacle containing the specimen. The receptacle is packaged with enough absorbent material to absorb all fluid in case of breakage.
ii. Secondary packaging. A second durable, watertight, leak-proof packaging to enclose and protect the primary receptacle(s). Several cushioned primary receptacles may be placed in one secondary packaging, but sufficient additional absorbent material shall be used to absorb all fluid in case of breakage.

iii. Outer packaging. Secondary packaging are placed in outer shipping packaging with suitable cushioning material Outer packaging protect their contents from outside influences, such as physical damage, while in transit. The smallest overall external dimension shall be 10x10 cm.

Figure 2.2: Infectious substance, category A label, IATA hazard label

Figure 2.3 Miscellaneous hazard label

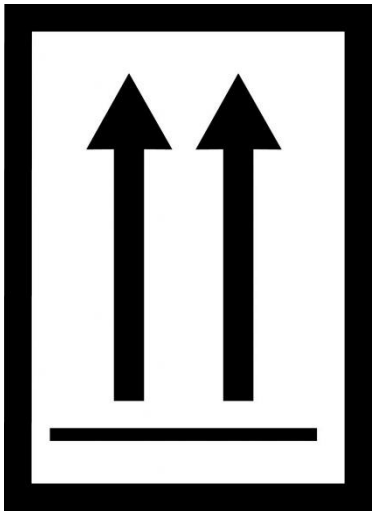

Figure 2.4: Package orientation label

2.2.1. Transport Box

Safety transport boxes are used to ship laboratory specimen. Lippi, et al. (2011) say that there is little information on their capacity to maintain suitable transportation temperatures. Their method was to monitor the inner temperature of commercially available transport boxes during an 8-h transportation period in the heat. They discovered that temperature stability was unsatisfactory during approximately 64% of the transportation time (i.e., from 125 to 450 min), and concluded that transport boxes might be unsuitable for shipping specimens over long periods. It should be noted that their temperature of interest was relatively cold compared to Cryocab mentioned above.

Lippi, et al (2011) monitored the inner temperature of the samples. Correct transportation of samples is crucial for the delivery of correct and quality assured results. Samples that have deteriorated due to bad conditions during transport to the laboratory will never lead to a quality result. The World Health Organisation recommends the continuously monitoring samples in transit (World Health Organisation, 2015). They recommend attention be focused on:

i. Safe transportation of samples: packed properly to protect the carrier, the general public, but also the laboratory.

ii. Timely transportation of samples: within the appropriate time frame; hence it is important to keep track of the time the samples spend in transit before arrival at destination.

iii. Transportation under proper conditions: within a temperature interval required to optimize sample preservation. The laboratory could encourage clients to use temperature logs that record the temperature throughout sample transport to check that the temperature has not become too high or too low

Therefore if samples are received in a bad state due to incorrect transport, or if they are packed in an unsafe manner, finding the cause of the problem can to be facilitated using a connected samples holder, and appropriate corrective and preventive actions be undertaken.

Samples transported to the laboratory by courier, taxi or car are classified as UN 3373 Biological Substance Category B and must be packaged and marked in accordance with Packaging Instruction P650 packaged and labelled are not subject to any other requirements of ADR and any method of transportation can be used. Generally, transport boxes should fulfil the following condition (Cork University Hospital, 2018).

i. The transport box/ pouch must be made of smooth impervious material such as plastic or metal, which can easily be disinfected or cleaned.

ii. The transport box/pouch must be capable of being secured.

iii. The box/pouch must retain liquid in the event of leakage of a sample

iv. The box must clearly label with the UN 3373 diamond shaped mark and the proper shipping name 'Biological Substance, Category B'. Emergency contact telephone number in case of emergency; for example, if there is a leakage of samples or if the box is found unattended. The label must clearly state that the box must not be opened or tampered with by unauthorised personnel.

In addition to the UN 3373 packaging instructions (P650), inidividual institutions may include their own requirments. In other to follow international best practices, the UN 3373 serves as a minimum requirment for packaging.

Figure 2.5: UN3373 mark

2.3. Transportation of Specimen

Samples are usually transported by available means. In Nigeria and within the scope of our review, the transport method in view is local surface transport. This is typically transporting by road. Transportation may also be by air if necessary. Although Zipline operating in Rwanda and Ghana delivers blood using drones to hospitals and not samples, they reveal what is possible in air transport.

2.3.1. Local Surface Transport

Local surface transport is the transport of specimen from

i. Doctor's office/surgery to a laboratory
ii. Hospital to a diagnostic laboratory
iii. One laboratory to another

The main responsibilities of shippers are classifying the biological materials or infectious substances, identifying the proper shipping name and UN number, correctly packaging, marking and labelling the packages, documenting the shipments for transport and customs requirements,

arranging transport with carrier and notifying the receiver of shipments. (Health and Safety Department, 2019). The principles of safe transport by this means also follow international practices. To ensure that the material is transported safely and arrives on time and in good condition, efficient transport and transfer of infectious materials require good coordination between sender carrier, and the receiver. (Directors of WHO Collaborating Centers for Biosafety and other advisers). This coordination is fostered by synchronising active data collected while samples are in transit.

2.3.2. Transportation of Samples in Nigeria

An evaluation of the conformity of Nigeria to international health regulations was carried out in 2017. There are 3,068 private medical laboratories registered within the country with the landmass of 910,770 sq. m and human population of approximately of 188 million (2015), 36 states with 774 LGAs. According to the evaluations, it was established that no samples transportation system exists within the country No established system is in place for transporting specimens from intermediate level/districts to national laboratories, only ad hoc transporting. A specimen transportation system is a fundamental element for making proper laboratory diagnosis in a timely manner, providing accurate surveillance, and response to infectious disease outbreaks. The specimen referral and transportation system has been established only for some specific infectious diseases such as polio, measles and influenza as a form of Ad-hoc system in Nigeria. No system is in place for transporting specimens from intermediate level/districts to national laboratories including cold chain. During the site visit to the Mainland Infectious Disease Hospital, in Lagos, and University of Lagos Teaching Hospital, all of which are in Lagos, it is confirmed that the specimen transportation including cold chain is established. The system enabled the laboratories in these institutes to perform microbiological tests properly and in a timely manner. However, it must be noted that the system is ad hoc rather than structured. (Joint External Evaluation of IHR Core Capacities of the Federal Republic of Nigeria, 2017). Recommendations were given for priority action.

i. Enhance the laboratory infrastructure and resources available to sustain an integrated national laboratory network.

ii. Implement Strengthening Laboratory Management Toward Accreditation Programme for the national laboratory network with a focus on biosafety, biosecurity and quality assurance.
iii. Develop a robust sample and vaccine transportation system which ensures cold chain.
iv. To adopt basic laboratory information sharing system among the relevant stakeholders.

Following the evaluation, the recommendations have yielded tangible results. Through supportive visits to healthcare facilities, Faruna, Akintunde, and Odelola (2019) identified challenges in samples transport in Nigeria. It was discovered that the diagnostic landscape is characterized by multiple models of clinical sample transfer mechanisms with resultant inefficiencies such as inflated costs, long turnaround time (TAT) for results, disproportionate testing burden on labs among others. In addition, remote and hard to reach terrains continue to pose a severe threat to the success of scale-up efforts.

Verifying further visits to medical centers in Akure, Ondo State, they also identified that in Nigeria, transport was conducted through non-standard, parallel systems, leading to long turnaround times and lack of visibility. This led to the setting up of a National Integrated Specimen Referral Network (NISRN) – established by the Nigeria Ministry of Health with donor support – is a cost-effective system currently being implemented by GHSC-PSM using third-party logistics (3PLs) providers to transport specimens from collection centers to testing laboratories.

They went further to assesses the impact of using the private sector to transport samples in the NISRN project. A descriptive method was used to assess 3PL performance. Specimen quantities transported by the 3PLs providers over six months were compared to the quantities transported in the period prior to implementation. Using the 3PLs instead of health facility staff, specimens were moved from facilities with backlogs to laboratories with capacity to analyze specimens quickly through the enhanced laboratory network. Before the NISRN, 116,046 viral load samples were tested, and 6,459 packs of reagents were used to cover 1,700 facilities over six months. During a comparable six months of operationalizing the NISRN, 277,536 viral load samples were tested, and 10,369 packs of reagents used to cover 3,114 facilities, translating into a significant increase of 38% of samples tested, 21% of reagents used; and over 83% increase in the number of facilities receiving testing services. They concluded that leveraging the private sector to transport samples enhanced testing laboratory network efficiencies. This resulted in substantial increases in viral load

samples tested, reagents used, and facilities accessing testing. This approach led to an expansion of services, and a robust optimized sample referral network that can respond more easily to public health emergencies. Utilization of the private sector is a sustainable, cost-efficient framework. Utilizing 3PL providers increases patient access to services and allows facility staff to focus on their traditional role rather than transporting specimens.

Their study also demonstrated how inference may be made from data collection over a period of time. They utilised a logistics management information system (LMIS) for HIV an TB commodidites were bimonthly reports are collected for analysys.

2.4. Maintaining Samples Integrity

Biobanking refers to the process by which samples of bodily fluid or tissue are collected for research use to improve our understanding of health and disease. Other information, such as height, weight and questions about things that may have a bearing on health (e.g. family history and lifestyle) may also be recorded at the same time, to provide the context for the samples. (Healthtalk, 2018). For diagnosis, transportation of samples may be inevitable. The accuracy of test results is dependent on the integrity of specimens; thus it is of utmost importance for the integrity to be maintained. Some parameters are more important to measure.

2.4.1. Time

By default, all samples should arrive at their destination in the shortest time possible. This has been inferred throughout all discussions in this review.

2.4.2. Orientation

Blood tubes, urine containers, etc. containing liquid into the box in an upright position whenever possible. The specimen transport box (STB) should always be in an upright position (Calgary Laboratory Services, 2019). This is indicated using the label in figure 4. It is especially important for blood tubes to be transported vertically in the closure-up position because the upright position reduces hemolysis and in nonanticoagulated tubes. (Ellervik & Vaught, 2015) This position prevents fibrin from attaching to tube closure. Gentle handling and transport reduces the risk of shaken samples and subsequent hemolysis. It is therefore important to keep track of the rotation and vibration of the transport box.

2.4.3. Temperature

The blood cold chain is a system for storing and transporting blood and blood products, within the correct temperature range and conditions, from the point of collection from blood donors to the point of transfusion to the patient. Deviations from specified temperature ranges and conditions during storage and transportation of blood and blood products can seriously affect the viability of the constituents of blood, thus leading to reduced clinical benefits. It can also increase the risk of bacterial proliferation in blood components during storage and may cause potentially life-threatening transfusion reactions, such as septic shock and even death. (World Health Organisation). It is therefore imperative to ensure that the temperature of samples in transit is within tolerance limits to ascertain the integrity of samples.

Some of the common blood tests are:

i. Complete blood count
ii. Blood chemistry test
iii. Blood enzyme tests
iv. Blood tests to assess heart disease risk.

The complete blood count is the most common blood test. The test measures many different parts of the blood such as red blood cells, white blood cells, platelets, hemoglobin, and hematocrit. Blood chemistry test includes blood glucose, calcium, electrolytes, and kidneys. Blood enzyme tests include troponin, creatine kinase, etc.

In other cases, blood samples may not be immediately utilized at point of collection, but is transported to a laboratory or held in storage. It is generally known that cold storage preserves some organic content. In the context of diagnosis, how does temperature affect the integrity of samples and why is it important to store and/or transport blood samples at low temperatures?

Alrokayan (2000) answered this question for blood collected for the purpose of DNA tests. He studied the effect of temperature during storage of blood on DNA (deoxyribonucleic acid) extracted from it or on DNA stored as such. The storage temperatures for blood (4 and -20°C) yielded similar amount of DNA. His results indicated that DNA stored at -20°C was most intact than the DNA samples stored at 4°C or at room temperature.

Olson et al. (2011) investigated similar effects on temperature and concluded that Blood packages shipped overnight by commercial carrier may encounter extreme seasonal temperatures. Therefore, considerations in the design of shipping containers should include protecting against extreme ambient temperature deviations and maintaining specimen temperature above 22°C or preferably near 30°C. His study was on specimen that did not require low temperature; nevertheless, temperature variations was discouraged.

Ibrahim et al. (2015) also studied the effects of storage temperature and time on stability of two samples. It was concluded that Samples of tacrolimus should be analyzed immediately or stored at either +4°C or −20°C, while samples of cyclosporine A should be analyzed immediately or stored at −20°C. Further tests on effect of temperature are that of Feng et al. (2014)

Palmer et al. (2017) reiterated that number of studies in critically ill patients are conducted outside the hospital. In the Nigerian context, not many hospitals are equipped fully with diagnostic facilities. They continued that specimens should ideally be transported from out-of-hospital setting to a laboratory using dry ice, but this approach is expensive and may not be feasible in some circumstances. They, therefore set out to examine the impact of temperature during transport of specimens on the precision of biomarker concentrations. They concluded that can be transported at 4°C on gel packs for 24h with minimal effects on precision.

Work has been done to maintain temperature of samples in transit. To reliably transport blood samples for cryoglobulin analysis, Nahm, et al. (2012) created a sample transport device

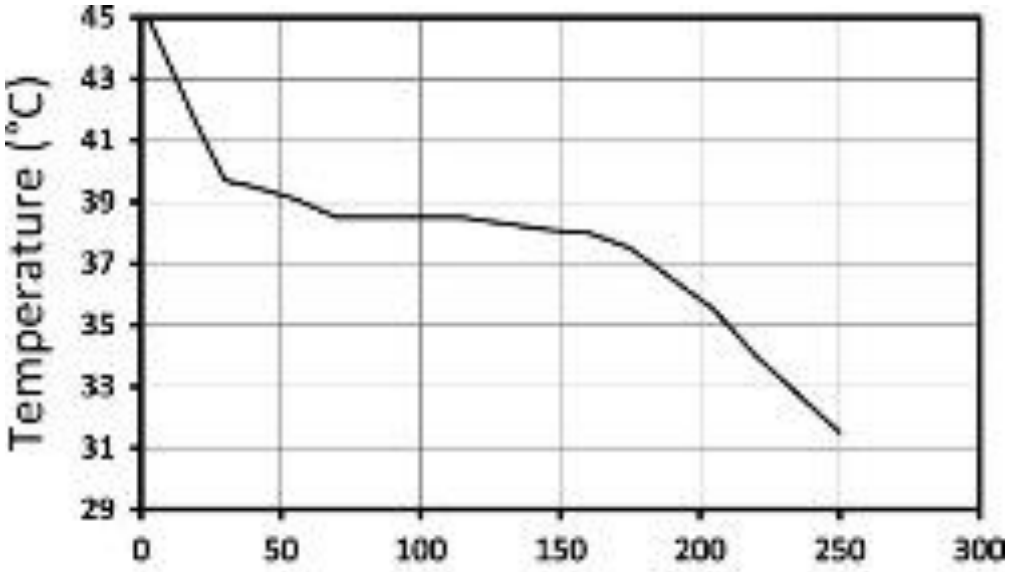

Figure 2.6: Temperature of sample kept in cryocab over time

containing a mixture of two waxes that solidifies at 38°C and maintains sample temperature at 38°C. Samples arriving at the laboratory at 37 to 38°C increased to 95% from 34% with the use of the device. The image below shows the performance of their device. It was called Cryocab. Cryocab was possible using *n*-docosane and *n*-eicosane, which are long-chain alkanes (paraffin waxes) with no specific toxic properties and which have high heat of fusion and melting at 43.5°C and 36°C respectively. When they are mixed at approximately 1:1, the mixture melts at 38°C and can maintain 38°C for several hours as the material undergoes phase transition. However, similar material is not yet applicable for lower temperatures.

Storage temperature depends on the test to be taken and the kind of sample obtained. For example, Serum should be stored at 4–8°C until shipment takes place, or for max. 7 days. When kept for longer periods, serum samples should be frozen at −20°C or lower and transported to the testing laboratory on frozen ice packs. For dried blood spots, samples are not considered biohazardous and can be shipped without special requirements or special documentation from the site of collection to the laboratory. For oral fluids, if the daily ambient temperature is below 22°C, samples should be shipped to the laboratory within 24 hours. At higher temperatures samples should be kept in a refrigerator (4–8oC) until they can be shipped to the laboratory on ice. The samples are also usually not considered biohazardous and can be shipped without special requirements or special documentation from the site of collection to the laboratory.

The resuspended pellet (of urine) may be stored at 4°C and shipped within 48 hours to a measles reference laboratory. Alternatively, it may be frozen at −70°C or lower in viral transport medium and shipped on dry ice (solid carbon dioxide) in a well-sealed screw-capped vial to protect against CO2 contamination. Nasopharyngeal specimens should be refrigerated and shipped at 4–8°C to arrive at the testing laboratory within 48 hours. The suspended pellet and the supernatant should be stored separately at −70°C or lower and shipped to the testing laboratory on dry ice in well-sealed screw-capped vials to protect against CO2 contamination.

Although samples do not need to be kept refrigerated or frozen during transport, it is advisable to store them in a cool place and transport them to the laboratory as soon as possible. Nevertheless, this requirement is based on specificity. As a general rule, serum specimens should be shipped to the laboratory as soon as possible (National Center for Biotechnology Information, U.S. National Library of Medicine, 2012).

Conclusively from the preceding discussion, it is sufficient to say that it is important to track the average temperature of samples in transit, and to keep track of how often the containers are opened, and the time taken for samples to arrive at their destination for the purpose of making inference on the integrity of the samples.

2.5. Technology Driving Diagnostic Systems

2.5.1. Internet of Things in Health Care

Internet of Things devices (IoT-D) have limited resource capacity. But these devices can share resources. Hence, they are being used in variety of applications in various fields including smart city, smart energy, healthcare etc. Traditional practice of medicine and healthcare is mostly heuristic driven (Sonune & Kalbande, 2017). Our understanding of the digital revolution can enhance healthcare with data-driven medical science. Various healthcare companies now provide remote healthcare services; for example, Zipline operating in Rwanda and Ghana, delivering blood using drones. Healthcare professionals are also adapting remote healthcare monitoring practices so as to monitor patients who are either hospitalized or executing their normal lifestyle activities at remote locations (e.g. REALDRIP by TREP Labs). Wearable devices available in the market calculate different health parameters and corresponding applications pass the information to server through their proprietary platforms. However, these devices or applications cannot directly communicate or share the data.

There needs an API to access health and wellness data from different wearable medical devices and applications. Sonune and Kalbande (2017) proposed and demonstrated an API to connect different wearable healthcare devices and transfer patient personal information securely to the doctor or health provider. This kind of data sharing is important for the development of an integrated diagnostic system. Khazbak, et al. (2017) also explored the problem of uploading medical data using radio interface. Their concept, they say, along with the proposed schemes hold great promise and is of equal importance to developing and developed countries promising considerable cost savings.

IoT technology now allows doctors to monitor patient health data in real time. Recently, some pioneering studies have investigated patient health monitoring using advanced bioengineering technologies combined with an IoT-embedded device. Noninvasive biosensors that allow for real-time patient monitoring promise to improve patient satisfaction, to increase the timeliness of care,

to boost treatment adherence, and to drive improved health outcomes. For example, sensors based on stretchable material enable noninvasive and comfortable physiological measurements by replacing the conventional methods that use penetrating needles, rigid circuit boards, terminal connections, and power supplies. Currently, the need for noninvasive health monitoring has led researchers to utilize alternative analytes, such as tears, urine, sweat, and saliva (Kang, Park, Cho, and Lee1, 2018). This same idea of patient monitoring also identifies with samples tracking. In general, it connotes digital tracking.

In addition to these recently developed devices, some IoT-enabled smart devices, such as iBGStar (Sanofi Inc., Paris, France), PixoTest (iXensor, Taipei City, Taiwan), and Elemark (BBB Inc., Seoul, Korea), are already commercially available. These products feature a patient health-monitoring dongle for a smartphone or their own mobile device. The data measured using the devices are automatically transferred to a cloud server, so that trends can be instantly tracked, and results can be shared with doctors who can easily check the medical records of the patients and consistently give them feedback. Consequently, patients can receive a customized and highly personal care experience, and clinics and hospitals are able to address problems proactively and reduce readmissions. Simultaneously, shared health records allow hospitals to customize their own patient database to fit seamlessly into the standard hospital workflow; thus integrating the various components of their operations or activities.

Undoubtedly, IoT technology has dramatically changed the healthcare industry by transforming the way devices, apps, and users connect and interact with each other for delivering healthcare services. A tangible benefit of the IoT is real-time, remote monitoring of patient health. As previously discussed, patient health monitoring via smart devices provides solutions for emerging problems in healthcare services, such as the increasing number of acute and chronic diseases (Vegesna, Tran, Angelaccio, and Arcona, 2017) Sensors have been integrated into a variety of platforms, including watches (Reeder and David, 2016), soft lenses, skin patches, (Jang, et al., 2017) wristbands, shoes, belts, and smartphones, which aim to collect and transfer health data (e.g., heartbeat, blood pressure, glucose levels, and body movements). These data are stored in the cloud and can be shared with authorized person such as physicians, insurance companies, participating health firms, or external consultants, and allow them to look at the collected data regardless of their location, time, or device.

2.5.2. IoT Protocols for Digital Tracking

For IoT based, it is undeniably evident that wireless transfer of data will occur. Methods of wireless data exist which are currently being implemented in IoT-D. A lot of protocols have been developed and standardized by Internet Engineering Task Force (IETF), Institute of Electrical and Electronics Engineers (IEEE), International Telecommunication Union (ITU), and other organizations, while many more are still in development. Among the wireless protocols, the generally known are Bluetooth and Wi-Fi.

Salman and Jain (2019) carried out a survey of protocols and standards for IoT. Their aim was to give insight to developers and service providers about alternatives for different layers of protocols in IoT and how to choose among them. Through the paper, they classified sections based on networking layers to: data link, network routing, network encapsulation, and session layers. At each layer, they presented most of the finalized standards and highlighted several drafts. In addition, they reviewed IoT management protocols and discussed some of the existing security standards and work provided at different levels of standardizations, as well as several challenges that still exist in IoT systems and that are being solved by researchers. The identified protocols were

i. IEEE 802.15.4e
ii. IEEE 802.11ah
iii. WirelessHART
iv. Z-Wave
v. Bluetooth Low Energy
vi. ZigBee Smart Energy
vii. DASH7
viii. HomePlug
ix. G.9959
x. LTE-A
xi. LoRaWAN
xii. Weightless
xiii. DECT/ULE
xiv. EnOcean

As a result of the internet infrastructure in Nigeria, the cellular network remains the most practicable solution for mobile IoT-D due to the limitations of internet facilities available via Wi-Fi. Because IoT-D do not require heavy bandwidth, the 2G cellular network is suitable for most applications requiring the internet. This does not otherwise the possibilities of using other protocols for the tracking of samples. Catherwoord, et al. (2018) implemented a community based IoT personalized wireless healthcare solution. They presented an advanced Internet of Things point-of-care bio-fluid analyzer; a LoRa/Bluetooth-enabled electronic reader for biomedical strip-based diagnostics system for personalized monitoring. They undertook test simulations (technology trial without patient subjects) to demonstrate potential of long-range analysis, using a disposable test 'key' and companion Android app to form a diagnostic platform suitable for remote point-of-care screening for urinary tract infection (UTI). The 868 MHz LoRaWAN-enabled personalized monitor demonstrated sound potential with UTI test results being correctly diagnosed and transmitted to a remote secure cloud server in every case. . LoraWAN presents promising possibilities for mobile applications; however, limited by infrastructure, it works better when transfers occur in direct line of sight. Giving the Nigerian environment, line-of-sight application during transport may not be practicable.

2.5.3. Cellular Network Application for IoT and Digital Tracking

Mobile phones worldwide is generating an unprecedented amount of human behavioral data both at an individual and aggregated levels. The study of this data as a rich source of information about human behavior emerged almost a decade ago (Oliver, Matic, and Frias-Martinez, Mobile Network Data for Public Health: Opportunities and Challenges, 2015). Since 2014, and according to the International Telecommunications Union, the number of mobile phone subscriptions exceeds the world's population. This high level of adoption applies to both developing and developed economies and to nearly all socio-economic statuses. As an example of how fast mobile phone adoption is growing, in 2014 the level of mobile penetration ranged from 90% in developing countries to 128% in developed economies, compared to 79–87% in 2011 (International Telecommunication Union, 2014).

A mobile (or cellular) network is a wireless network composed of towers, called Base Transceiver Stations (BTS), which give coverage to a geographical area. The coverage area of each individual

BTS is called a cell and is typically divided in three sectors each one covering 120°. Although this is the typical case it is possible for a BTS to have just one-directional sector or more than three sectors to handle areas with high density of population. The geographical area covered by a BTS depends mainly on the power of the individual antennas. Depending on population density, BTS coverage typically ranges from <1 km2, in dense urban areas, to >4 km2, in rural areas. For simplicity, it is common to assume that the cell of each BTS is a 2-dimensional non-overlapping polygon, which is typically approximated using Voronoi diagrams (Oliver, Matic, and Frias-Martinez, 2015). Simply, this approach gives a good approximation of the coverage area of each BTS. In practice, to build the "real" diagram of coverage, one has to consider several factors in the mobile network, including the power and orientation of each antenna.

The Nigerian Communications Commission (NCC) disclosed that 2G network has remained the most pervasive in Nigeria with 90 percent of the population connected to it. (ITPulse, 2018). Although many carriers have already shutdown their 2G network (Lecht, 2018), it is unlikely that this will happen in Nigeria; hence maintaining its relevance.

CHAPTER THREE

METHODOLOGY

3.1. General System Overview

The project seeks to create a prototype having the basic functionality that may be further developed. Figure 7 depicts the structure of the entire system. Basically, the sample holder sends real-time data about itself to a remote server. Further action of data and presentation continues from there. “Miscellaneous” represents any other sensor that may be deemed important but was not considered in this project. For example, some interfaces may be made available on the system in case of expansion. A website will be developed to present the data sent from the sample holder. In the course of this project, “cloud” may refer to the website and every other software component that exists apart from the samples holder.

The process of developing the prototype will consist of three stages:

i. **Conceptualization**: block diagram creation; component identification, interfaces, functionality, and cost evaluation
ii. **Design**: schematic creation and simulations; firmware development for electronic system, and web development.
iii. **Prototype and testing:** component purchase and system assembly; system performance evaluation in lab.
iv. **Submission and presentation:** evaluation and comments from medical centers and real-life situations.

The entire system is divided into two: software and hardware. These two parts can be developed independently of each other. The hardware consists of the sensors, the samples holder, and every other electronic or electrical part that remains physically connected or attached to the samples holder. The software consists of the web interface and the cloud; however, because of the nature of the firmware, it would be a part of the hardware design.

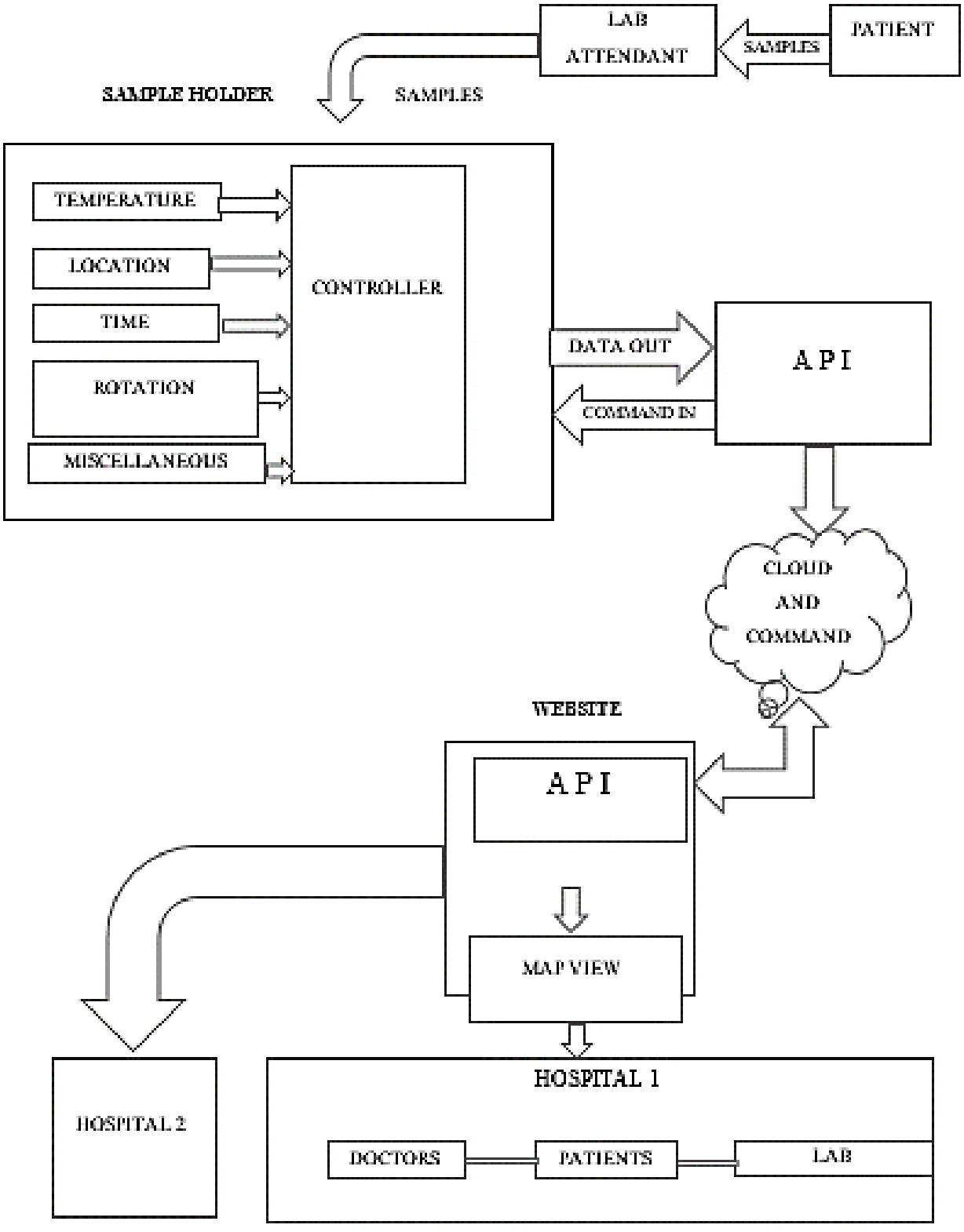

Figure 3.1 System block diagram

3.2. Hardware Design and Function Specification of Hardware

The hardware design consists of the sensors, the electronics, and the samples holder. The sample holder would have the electronics and sensor integrated into it. The following sections would explain the major block diagrams in the design process, the ideas behind their choice, as the role played in the functional specification of the system. Because the project seeks to implement a prototype, it would not be necessary for the hardware to have stringent characteristics. For example, the sample holder's battery ought to have a discharge time of a least 6 hours. The system also ought to be able to account for situations when the cellular network is not available. Although this is very much practicable, the extra complexity involved as well as other unforeseen problems that may arise may beyond justification to be featured in the first prototype.

All raw data about the sample's status would be obtained from the electronics attached to the sample holder. The hardware is required to perform the following basic functions:

i. Obtain ambient temperature of the samples
ii. Obtain its current position in latitude and longitude
iii. Determine its current orientation
iv. Keep track of time locally.
v. Be able to transmit all of the above to the internet.

Generally, the block diagram in figure 3.1 gives a broad overview of the system's function. Other requirements the sample holder would have include the following:

i. Audio feedback when armed by sender
ii. Blinking LED indicator to show active status
iii. Battery powered

3.2.1. The Controller

A microcontroller is a computer on a single integrated circuit. It is sometimes called a system on a chip (SoC). This implies having basic parts for a functioning computer: RAM, processor, etc. The computer (microcontroller) works as the control device, whose circuit's operation is determined by the software (firmware) written; by extension, directing the entire functions of the sample holder.

The choice of controller is the Atmega328P. It was chosen for its size, cost, and availability in the market. In addition, it is the controller of choice for the popular development board, Arduino, and is widely supported by a large online community; thus allowing for rapid prototyping and development. Although the Arduino Nano would be occasionally used to test, the final circuit would only have the Atmega328P microcontroller on the circuit.

Arduino Nano features the *Atmega328P* microcontroller. In the course of this project, "Arduino" and "microcontroller" may be used interchangeably except explicitly stated.

3.2.2. The Location

GPS stands for Global Positioning System. It is a network of satellites that uses a mathematical process of trilateration to determine the exact position of any object with a GPS signal receiver.

To get the exact position of the sample holder in terms of latitude and longitude, a GPS module would be used. In practice, the hardware may not be able to receive GPS signal at all time. Various GPS modules exist and vary in sensitivity, accuracy, and cost. The module of choice is *Neo 6m V2*. This is due to it being widely supported.

For GPS to function optimally, a clear view of the sky is necessary. It makes a clear path for GPS signals from satellites to reach the receiver. The system would be such that it sends its latest available location to the cloud.

3.2.3. The Time

A real-time clock is an electronic device that keeps an accurate record of the present time. Most microcontrollers can keep track of time using their internal timers. These are suitable for measuring short time intervals. The Atmega328P has an internal timer that can measure elapsed time up to about 40 days, but may have deviated by minutes. In the eventuality that power is not available, the Arduino would lose its time data; hence, the need for a real-time clock (RTC). Real-time clocks have independent power supplies usually from a coin or button cell (Li-ion battery).

The RTC to be used is *DS3231* and it interfaces with the Arduino via I2C. This choice was due to avai*l*ability and cost.

3.2.4. Temperature

The temperature of interest is the ambient temperature of the cooler's storage volume. The temperature sensor would have closest contact with the samples as it has to be in the vicinity of the samples. The temperature sensor of choice: *DS18b20*. It has a metallic rod which houses the temperature IC. The protruding metallic part of the sensor that will penetrate the sample holder and will lie in the direct atmosphere of the samples, makes for easier handling and less cost in improvising a solution in using the IC to the right.

3.2.5. Rotation

Rotation would be detected using a tilt sensor. A tilt sensor operates by making use of a metallic ball to make electrical connections between two contacts internally when upright. Depending on the degree of tilt, the metal ball rolls away from the contacts and breaks the connection. Hence, rotation can be noted. This would be useful to determine if the sample holder remained upright throughout its transit period.

An accelerometer could be also used to perform the same action. In fact, a 3-axis accelerometer could be used to detect exact amount of rotation in degrees but this would add to the complexity of the firmware. Rotation as far as 90° from the upright position is important to note; variations in-between may be considered in subsequent iterations.

3.2.6. Cellular Network

The cellular network is the channel for the sample holder to connect to the command server through internet. Internet connection would be through the 2G network using a GSM module.

The module of choice is *SIM800L* because of availability of resources to operate, and cost. In addition, the 2G network is best suited for the low bandwidth application that the sample holder would operate in, though a data subscription would still be required. It also requires less power compared to higher standards, and has wider coverage in Nigeria than the 3G network.

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3.2.7. Power Supply

Although not included in the block diagram, a battery is absolutely necessary for the sample holder's operation. Typical 5V DC supply would be provided. Obvious considerations for a battery is a lithium ion (Li-ion) rated at a minimum of 7800*mAh* or more. This is because the GSM module could consume as high has 2A of current during a transmit transmitting. A Li-ion is the most practicable considering weight, portability, and space.

However, Li-ion batteries pose more risk during operation compared to other battery types. A battery management module would be used to ensure the battery's use are within safe limits. The battery management module would also be responsible for managing the charge current of the battery. The current choice is based on the *TP4056.*

3.2.8. Miscellaneous

This block was put in place to consider future expansion or unforeseen sensors or features that may be adapted to the samples holder. For example, it might be required at some future time to include haptic feedback. Consideration for this would be done by leaving some connection points from the circuit design.

3.3. Measuring Sample Integrity

For the scope of this project, the work of measuring sample integrity will be left to the medical officer. The data obtained would be presented to medical officers who may then apply their expertise to determine the integrity of the samples.

This project would necessitates that Sambox be put to the test in real-life scenarios. Performance evaluation would be based on the following:

i. Amount of data available from Sambox within given timeframe.
ii. Percentage of time Sambox failed to perform its specified function during operation
iii. Tolerance of Sambox to transportation environment in Nigeria, also determined by how often Sambox fails to carry out its function.

3.4. Data Format for Exchange

Popular data formats for information exchange include XML, HTML, JSON, etc. Exact choice of format to be used would be determined from performance evaluation; otherwise, custom format would be implemented. Processing of this format would be done on the cloud.

3.5. Cost and Funding

Prototyping of the system would incur cost to be used in the following areas:

i. Component and sensor purchase
ii. Purchase or rent of tools and equipment
iii. Purchase of existing sample holder for modification if possible. Otherwise, it may be required to produce a custom type.
iv. Miscellaneous.
v. Cloud services

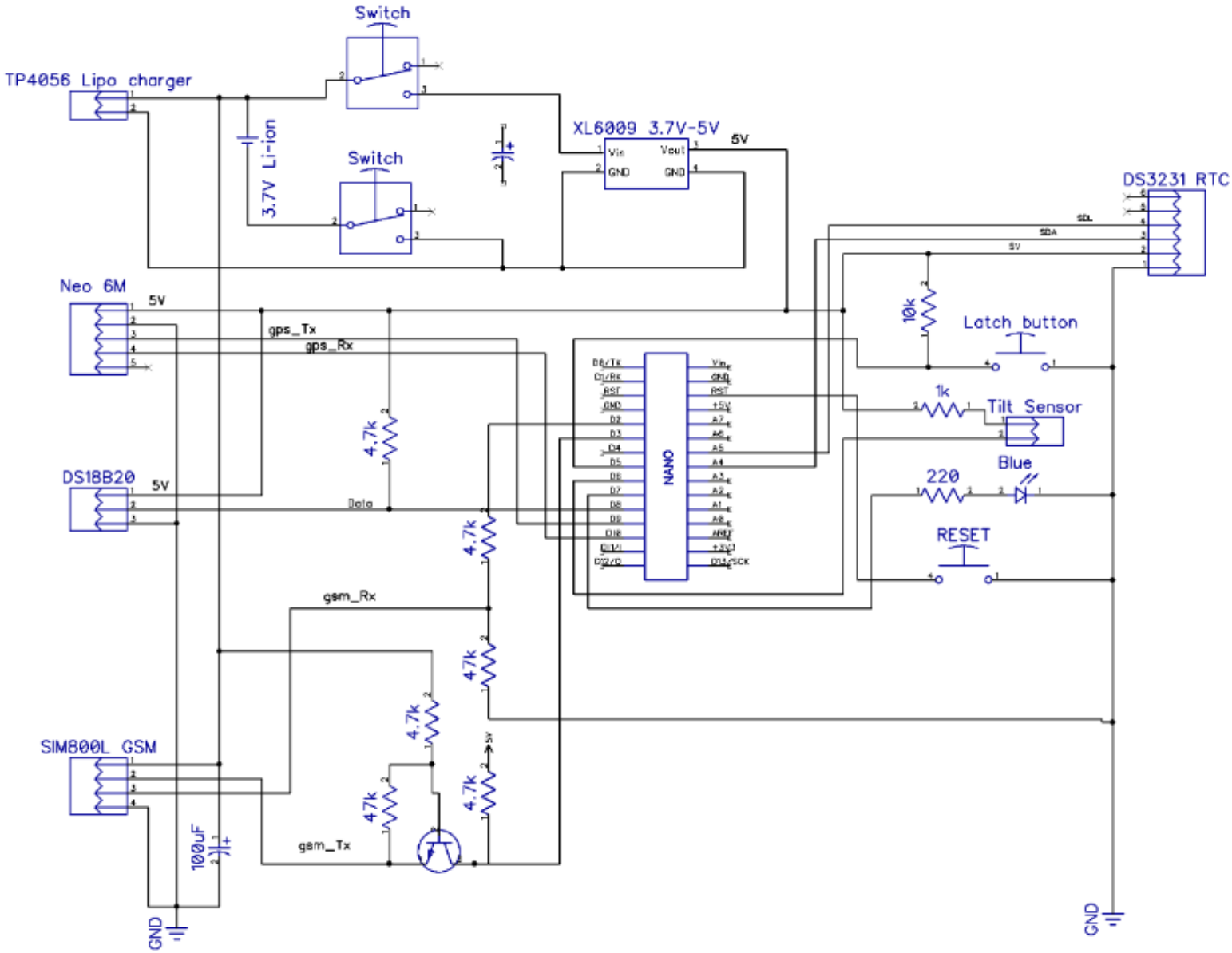

Figure 3.2 Circuit diagram

Figure 3.3 List of components and price

S/N	COMPONENT	QUANTITY	COST(₦)
1	NeO-6M GPS module	1	3000
2	Sim800l GSM-GPRS module	1	2000
3	Ds18b20 waterproof temperature sensor	1	900
4	Li-ion 3.7V 7800maH single cell	1	600
5	XL6009 Boost DC LM2577 module	1	600
6	TP4056 18650 700mA Lipo charger module	1	150
7	16MHz crystal oscillator	2	100
8	2.54mm female SIL header	1	100
9	Tilt sensor	1	50
10	Atmega328P microcontroller	1	1000
11	DS3231 real-time clock	1	700
12	Shipping	-	500
13	PCB		5000
14	Miscallaneous	-	5000
15	Transportation	-	4000
TOTAL	24700		

3.6. Software Specification and Design

The software is in two parts—the firmware and the web application. The firmware sits on the microcontroller and directs the transmission of data to the web interface. It does two basic functions: collect data and transmit to the cloud. The web app is a server that receives data from the sample holder and presents it for the medical officers. It sits in the cloud. Component of the software can be seen in the system block diagram. The web app is designed in various modules with various anchor tags and links for navigating through the entire system by the left side of most of the pages on the system user interface. The design modules is classified into the following with their pages:

i. Admin/hospital 1 module for login and signup, account creation, assigning samples to university hospitals, viewing sample result, viewing sample result
ii. Lab attendant for login, providing samples details. Map viewing
iii. Doctors
iv. Patients
v. Hospital 2 / receiving end

3.6.1. Application programming interface (API)

It is a communication protocol between a client and a server (sample holder and the cloud) intended to simplify the building of client-side software. It has been described as a "contract" between the client and the server, such that if the client makes a request in a specific format, it will always get a response in a specific format or initiate a defined action.

Two Application programming interface was used in this project, the first one is the cloud storage API for reading and writing data on it while the second is the API which is built on the web application. The second API allows the microcontroller to communicate and send data received from the sensors to the Mongo DB cloud manager. It also allows the web application to write and read data on Mongo DB cloud manager and it delivers the data to the hospitals via the web application.

The second API was developed using Node.js. Node.js is a server-side platform wrapped around the JavaScript language for building scalable, event-driven applications. The API was developed in such a way that it receives data from the cloud manager every 5 minutes. The API also passes

the latitude and longitude values of a particular location into the Google map URL which can be viewed by Doctors, Patients and Lab Attendants in the web application built for the hospitals.

3.6.2. Google Map

Google Map is a web service that provides satellite imagery, aerial photography, street maps, 360° panoramic views of streets (Street View), real-time traffic conditions, and route planning for traveling. It is used provide detailed information about the test sample location. It offers aerial and satellite view of the sample location, with the help of the Google Maps application program interface (API), the hospital stakeholders can view the location of the samples as it being transported.

3.6.3. Hospital 1

The lab attendant is the person who receive the patient specimens, analyze the specimens and package it in order to transport it while the doctor is a physician assigned to the patient for treatment, only the patient, lab attendant and the doctor assigned to a patient has access to the information of the patient and the location of the samples on the website but for this to happen, the hospital 1 has to register the patient, doctor, lab attendant and the hospital 2 in charge, after the transportation of samples is successful, the hospital 2 will send the result to the affected people.

3.6.4. Hospital 2

This is the hospital that receives the test samples from the hospital 1, the medical laboratory scientist in the hospital helps in testing, interpreting and communicating critical patient results to the hospital 1 via the website, after the results has sent, diagnostics testing which includes treatment and follow-up, Physician follow-up, referrals and consults, discharge process and patient compliance is carried out by the hospital 1.

3.6.5. Firmware Development

The software for the microcontroller is developed using the Arduino integrated development environment (IDE). The programming language used for its development is C++, the standard language of the Arduino platform. The firmware is kept up-to-date a https://github.com/EyitopeIO/Final-year-project

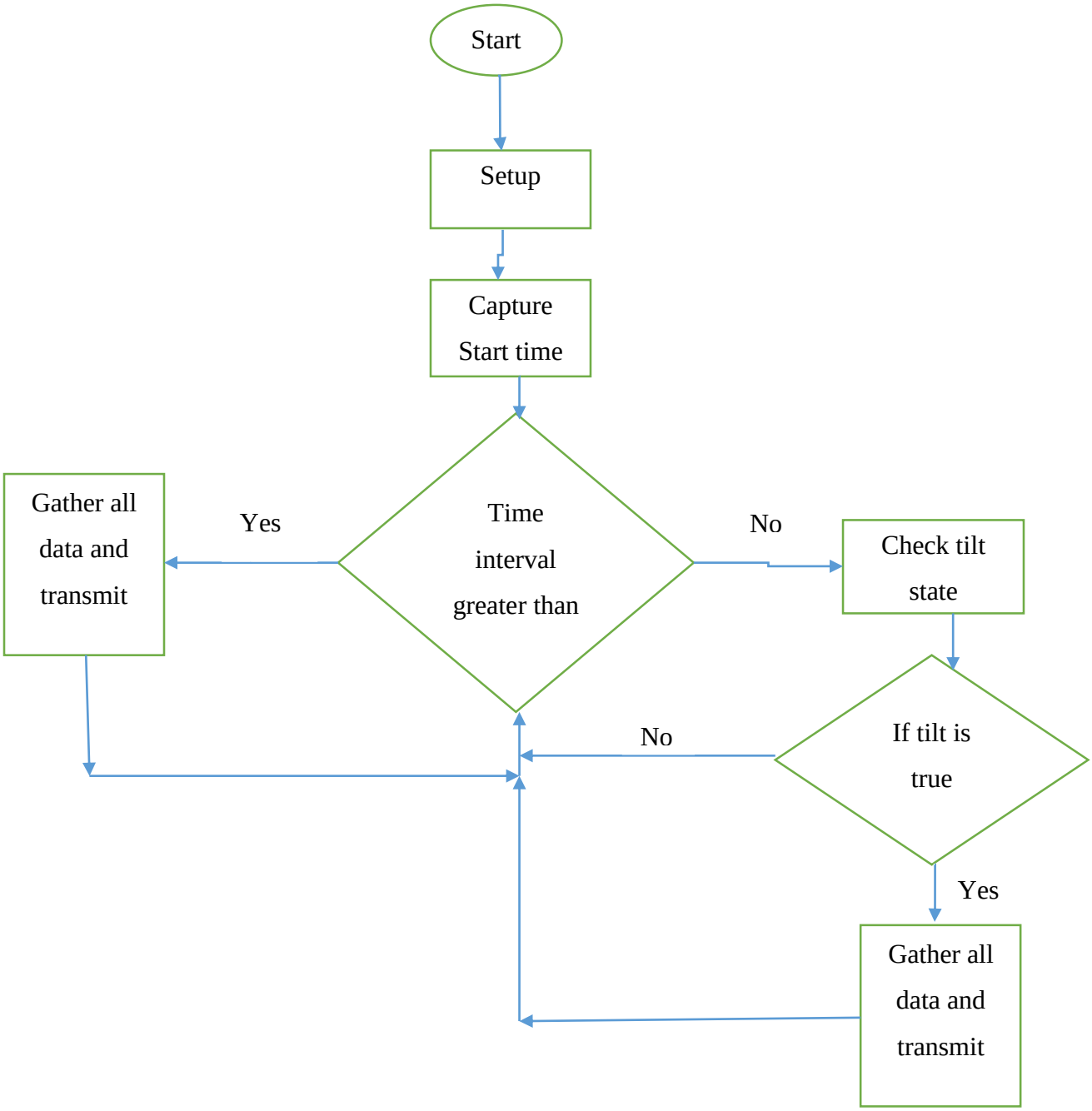

Figure 3.4 Firmware flow chart

CHAPTER FOUR

SYSTEM IMPLEMENTATION

This section describes the implementation details of the project web application and hardware. The web app is designed in various modules with various anchor tags and links for navigating through the entire system by the left side of most of the pages on the system user interface. The hardware is designed to be equipped on the sample holder.

4.1. Hardware Implementation

The hardware implementation includes individual block tests, module tests, prototyping, and debugging the firmware.

4.1.1. Circuit Assembly

The circuit was assembled on a veroboard after full functionality was ensured on a breadboard.

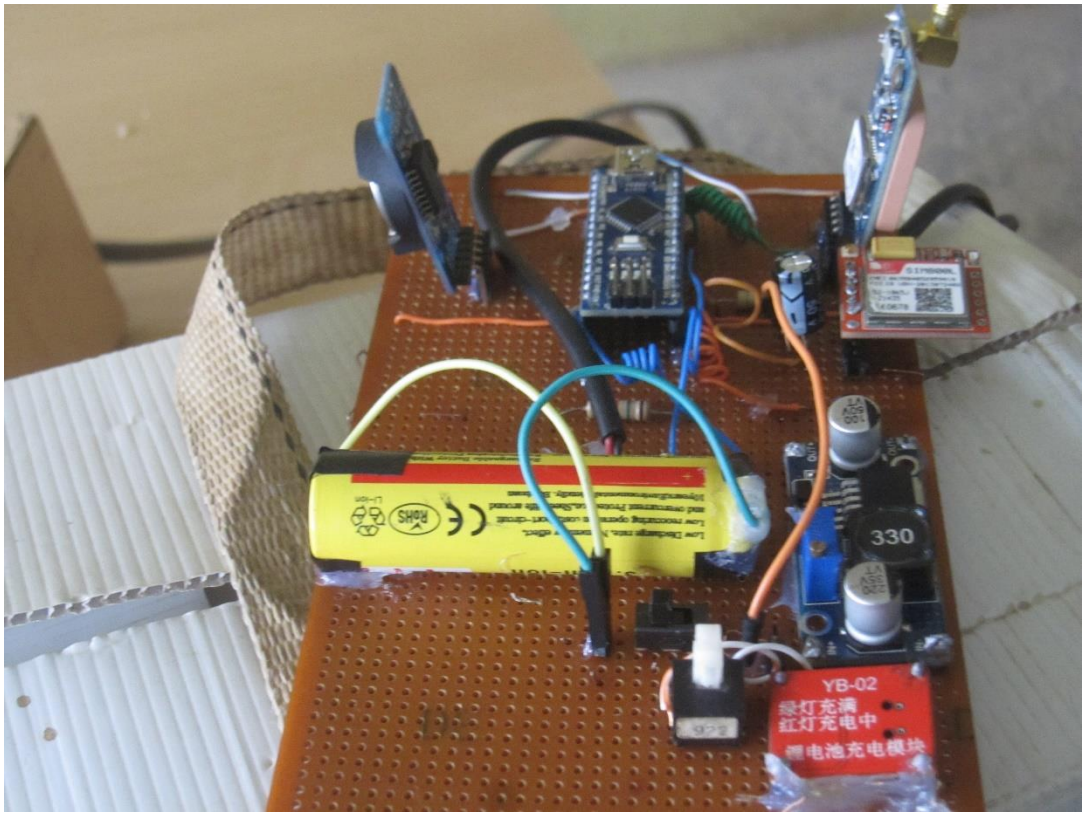

Figure 4.1 Circuit assembly on veroboard

The system was run on fully on both battery power and cabled power (USB) and fully functionality was verified in both cases

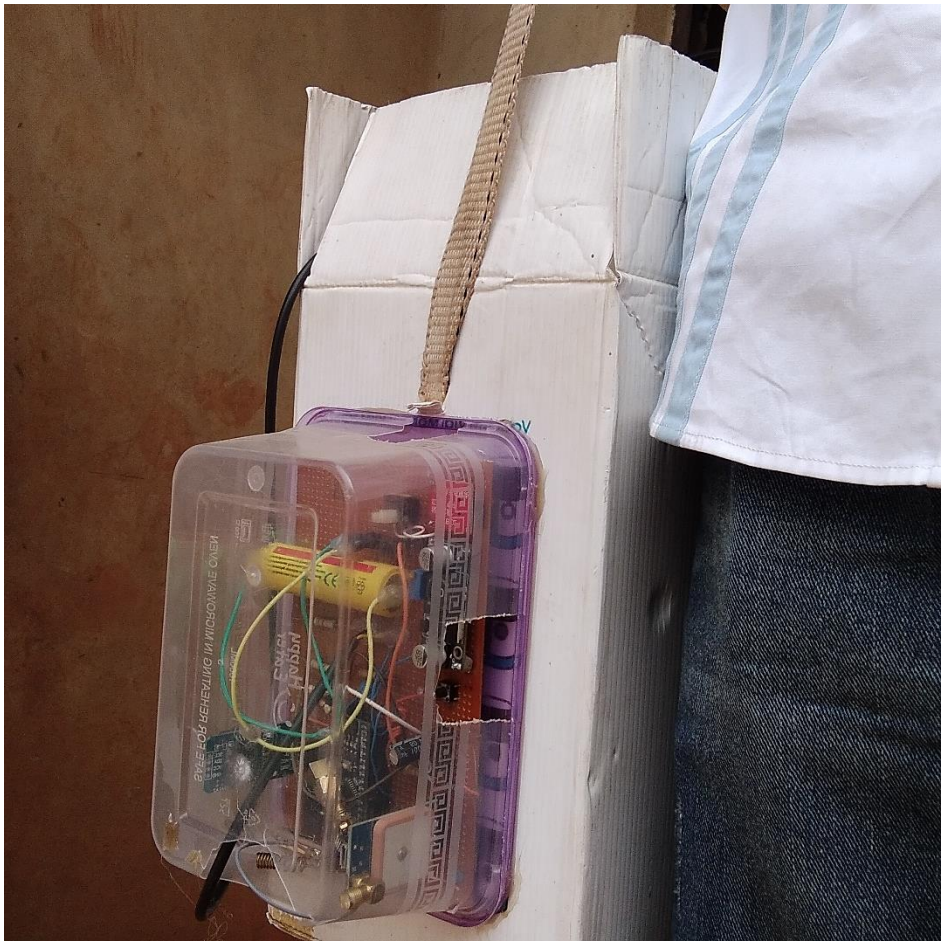

Figure 4.2 User holding complete sample holder

4.1.2. Data Format

The image below shows the data format of transmitted data during prototyping. The data is in this format: temperature, longitude, latitude, current time, time of tilt, transmit state, start time. The

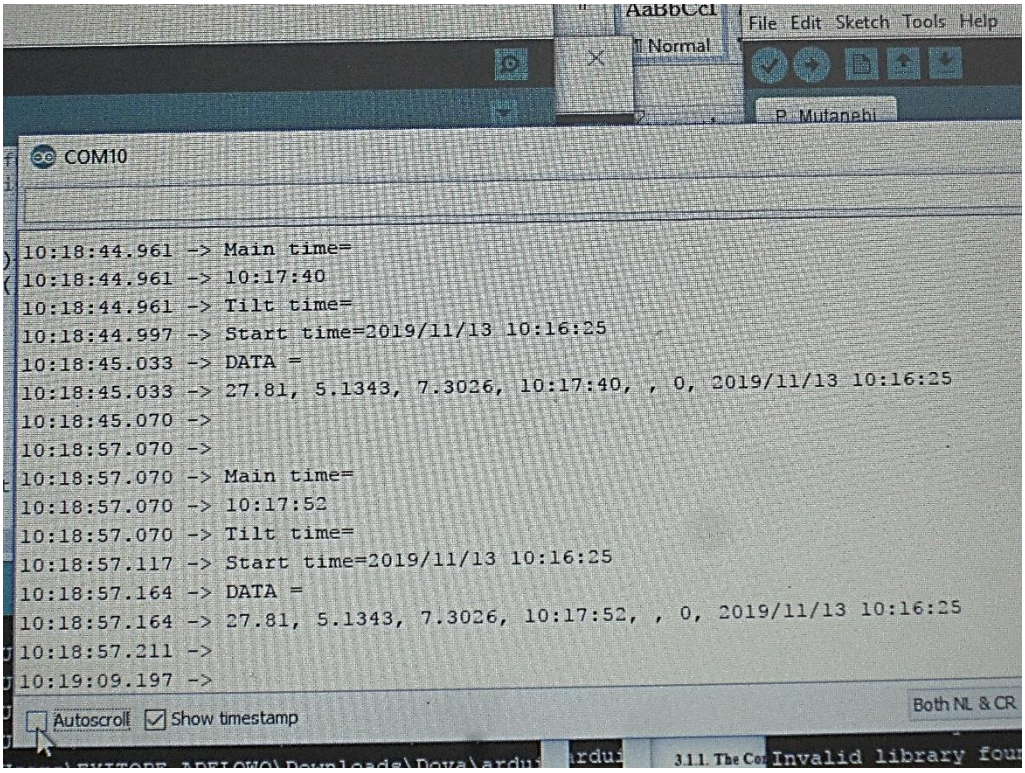

Figure 4.3 Data format monitoring during prototyping

transmit state is set to one by default but becomes zero after the first transmission. It is used as an indicator.

4.1.3. System Testing

The system was deployed on Heroku, a cloud hosting service, and was tested by transporting the samples holder within a short distance, while observing its transmitted data on the online platform. Data from the sample holder was successfully logged to the web platform as shown in figure 4.2 when the system was powered at the School of Engineering and Engineering Technology (SAAT), FUTA. Figure 4.3 shows the sample's movement being tracked for a short distance.

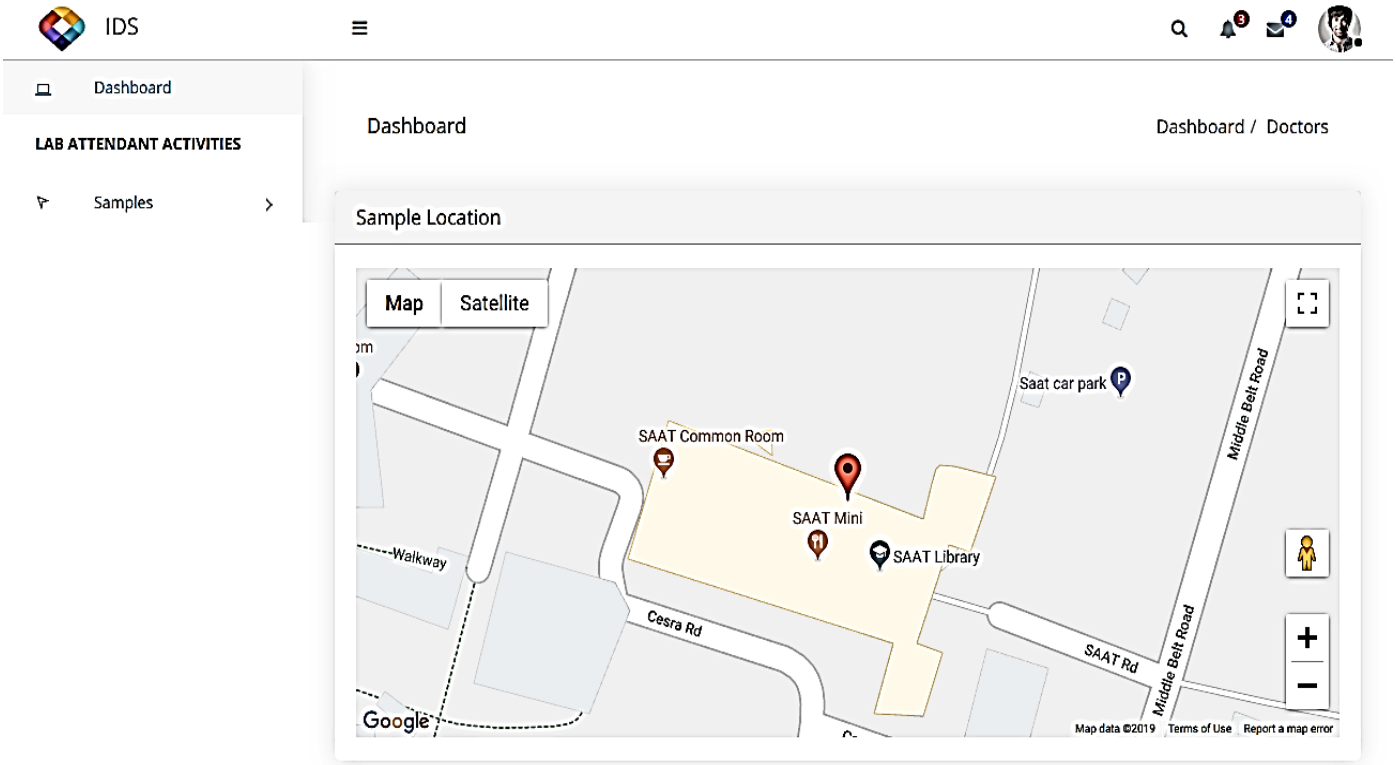

Figure 4.4 Dashboard showing sample holder location

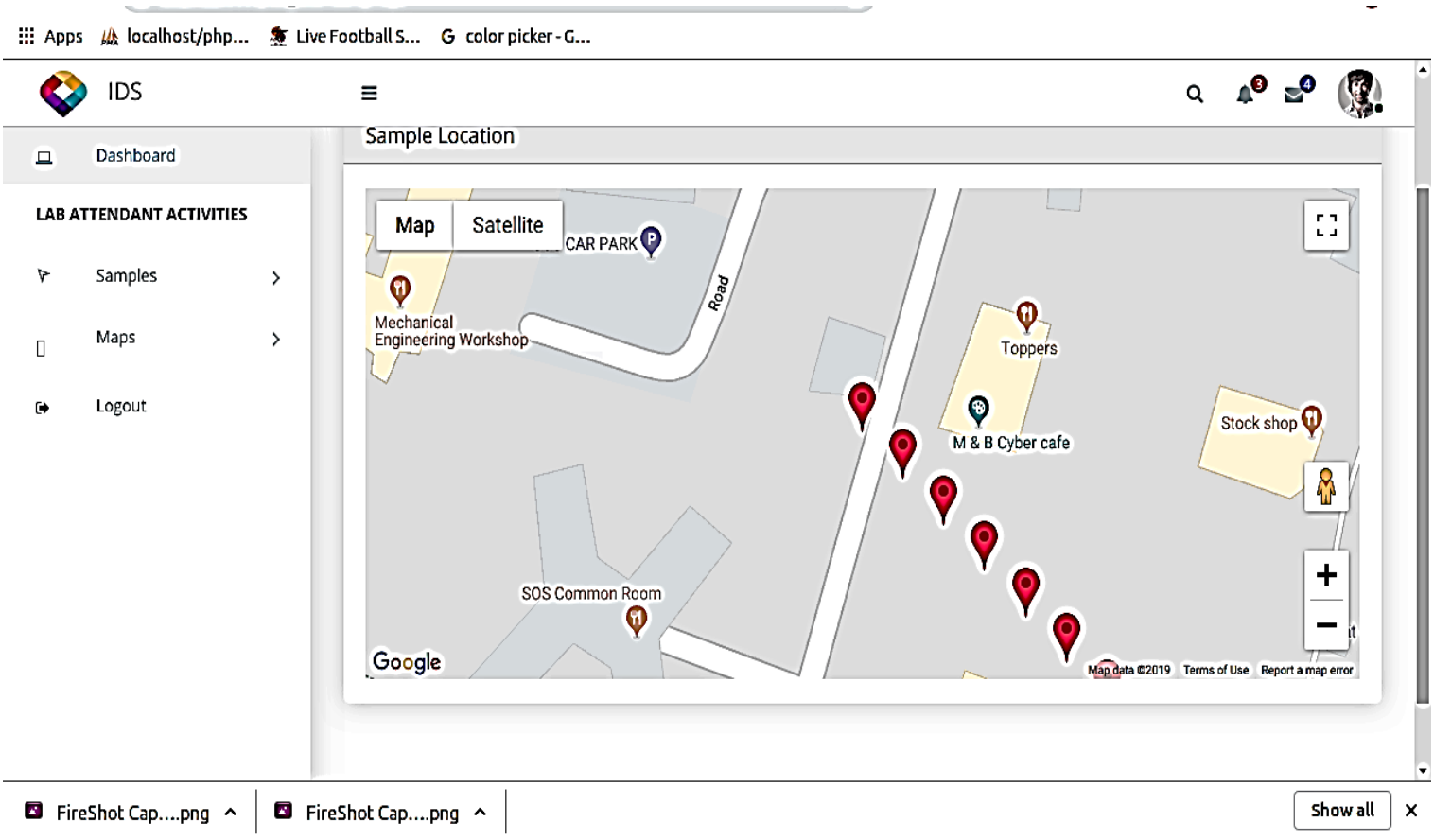

Figure 4.5 Dashboard tracking sample holder movement

4.2. Comparative Analysis

The project may be put forward for comparison based on several factors, particularly based on the functionality of the entire system. Areas for comparison are the user interface and user experience for the online platform, and amount of inference available for the user which is made by processing the acquired data from the sample holder.

Firstly, the projects user interface is entirely online. Unlike the EMR in Ajala, Jinmisayo, and Emuoyibfarhe (2015), which is a desktop application, the platform cannot be accessed without an active internet connection. Many LIS are designed for standard use. Sepulveda and Young (2013) suggested ways of designing LIS for the goal of optimising the operation of clinical laboratories. In it he considered notification management, order entry and processing, data mining, document management, graph and statics, quality control, among other features. Although standard software may be characterised by these features, they were clearly beyond the scope of this project; thus, not put into consideration.

Of primary importance to this project was the development of a samples holder, which was fitted with a sensor. Because the data is presented online, medical officers have no way of accessing this data locally and evaluate the integrity of the samples on arrival. However, Zaninotto, et al., (2012) had all data of their medical container (sample holder) recorded and obtained locally, and decision about the integrity of the sample made on arrival. For example, any sample whose temperature was higher than 25°C on arrival was discarded, and also samples whose transportation time exceeded 3hrs. But this project sought to provide realtime sample tracking. Thus, temperature data was sent along side location data.

Many similarities in purpose existed in the online interface, but fewer in the sample holder, particularly the implementation of realtime sample tracking in the developed world. Nevertheless, the goal of maintaining sample integrity remained common to all.

CHAPTER FIVE

5.1. Conclusion

Featuring IoT in the project, samples tracking may be carried out. In this project, the following are particularly important to note:

i) The temperature of a sample in transit can be successfully and monitored remotely.

ii) The location of the sample in transit (longitude and latitude), the most critical element as regards tracking can also be carried out. In addition, it may be presented in a user friendly manner using Google Maps API.

iii) A medical officers can conveniently have access to the data in (i) and (ii) above and make inference about the sample's integrity.

iv) Prototyping an IoT sample holder is very much practicable using local resources.

However, as much as listed points above were achieved, the entirety of the project's cope was not attained. For all practical purposed, it would have been advantageous to:

i) Evaluate the performance of the system with real blood samples.

ii) Determine the exact runtime period of the sample holder.

iii) Take the system for a few test runs on travel routes taken by courier service providers to evaluate performance of the system.

Challenges faced in executing the project, among others were:

iv) Difficulty getting information from hospitals as regards the processes involved in the transportation of samples.

v) Late access to the component required to implement the project. Due to transportation cost, market location, and funding, sourcing for components required on average 12 hours overhead.

vi) Unpredictable power supply, cutting out work time on the project.

vii) Tools needed for the project were not readily available because equipped prototyping labs were not available.

5.2. Recommendations

The first prototype performed its basic functions but was limited in the number of test conditions used to evaluate its performance. For example, the operating time of the system after a full charge was not evaluated. Other tests not carried out include reaction to network unavailability, resistance to mechanical forces during transport, and how the system performs in varying temperature conditions. Standard tests would require comparison to established global metrics to set the direction for improvement.

Because of the nature of prototyping, and the limited tools available, it was absolutely necessary that a container made of sturdy foam be used. Obtaining the container type of interest proved to be problematic as it wasn't readily available on the market. The consequence of this was several trips to various locations in search of containers costing time and money. The needed container was eventually an abandoned UNICEF container at an old government medical stores. Generally, having every tool and component needed in a single place before commencement of the project wasn't considered, hence several delays during the course of its development. It is recommended that development be done in a dedicated environment.

Mentioned above were a few tests not carried out on the system. Particularly important was debugging. No feature was put in place to respond to worst-case scenarios during operations because the test environment was well controlled. In practice, prototypes are tested in both controlled and working environments.

Finally, for such a system as this, it should be developed such that minimal human intervention is needed during operation. Starting with the online interface, a user is required to refresh the page to see most recent updates from the sample holder. Ideally, it could be automated. On the sample holder itself, making permanent connections was not practical due to insufficient components. Because the firmware did not feature self-correcting measures during operation, occasional resets were necessary. Use of PCBs for developments and more debugging periods would be ideal.

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APPENDIX A

The firmware for the project was compiled from three separate files using Arduino IDE, which have been labelled as PART A, B, C below. For the firmware to be successfully compiled, each file must be within the same folder. Third party libraries were used from various websites, but can all be found together at *https://github.com/EyitopeIO/Final-year-project*.

PART A

```
#include "RTClib.h"
#include <OneWire.h>
#include <TinyGPS++.h>
#include <SoftwareSerial.h>

extern char first_transmit;

extern const int status_led;
extern const int tilt_sensor;
extern const int arm_button;

extern float celsius;
extern float lattitude;
extern float longitude;

extern String current_time;
extern String tilt_time;
extern String start_time;

void blink_(int time_);
void fetch_temperature(void);
void fetch_location(void);
void inline fetch_time(String time_);
void setup_rtc(void);
void setup_temp_sensor(void);
void setup_gsm(void);
void transmit_data(void);   //defined in 3rd file
void smartDelay(unsigned long ms);   //GPS function
char *ftoa(char *a, double f, int precision);   //float to integer


extern SoftwareSerial gps_uart;
extern SoftwareSerial gsm;
extern OneWire temp_sensor;
```

```
extern RTC_DS3231 rtc;
extern TinyGPSPlus gps;


void setup()
{
  pinMode(status_led, OUTPUT);
  pinMode(tilt_sensor, INPUT);
  pinMode(arm_button, INPUT);
  Serial.begin(9600);
  gps_uart.begin(9600);
  gsm.begin(115200);
  setup_temp_sensor();
  setup_rtc();

  Serial.println(F("Waiting for button"));
  while(digitalRead(arm_button) == HIGH) {    //Wait till system is armed
    blink_(100);
  }


  DateTime now = rtc.now();
  start_time   =   String(now.year())+'/'+   String(now.month())+'/'+   String(now.day())+   "   "+
String(now.hour())+':'+
              String(now.minute())+':'+ String(now.second());
  first_transmit = '1';
  Serial.println(F("\nLOOP STARTS"));
}


void loop()

{

  unsigned long time_now = millis();
  first_transmit = '0';
  while((millis() - time_now  <= 20000))  {   //Every 5 mins, but 10s for testing
    if(digitalRead(tilt_sensor) == HIGH){
      digitalWrite(status_led, HIGH);
      DateTime now = rtc.now();
      tilt_time = String(now.hour())+ ':' + String(now.minute())+ ':'+
                  String(now.second());
      //transmit data if tilted here
      digitalWrite(status_led, LOW);
    }

    blink_(500);

  }
```

```
  digitalWrite(status_led, HIGH);
  fetch_temperature();
  fetch_location();
  DateTime now = rtc.now();
  current_time = String(now.hour())+ ':' + String(now.minute())+ ':'+
            String(now.second());
  transmit_data();
  digitalWrite(status_led, LOW);
  //  Serial.println("DATA = "); Serial.print(DATA); Serial.println('\n');
}


void blink_(int time_)

{
  digitalWrite(status_led, HIGH);
  delay(time_);
  digitalWrite(status_led, LOW);
  delay(time_);
}
```

PART B

```
const int status_led = 11;    //Change circuit diagram from pin 7
const int tilt_sensor = 6;
const int arm_button = 5;

char first_transmit;    //set to a '1' for first transmit, '0' for rest of time

byte i;     //Temperature sensor main variables
byte present = 0;
byte type_s;
byte data[12];
byte addr[8];
float celsius;

String current_time = "";    //Current time from RTC
String tilt_time = "";    //time  of tilt
String start_time = "";    //time system is armed

float lattitude = 0.0000;
float longitude = 0.0000;

SoftwareSerial gps_uart(9,10);   //GPS, Rx, Tx
SoftwareSerial gsm(2, 3);   //GSM, Rx, Tx
OneWire temp_sensor(8);   //temperature sensor, ds18b20
```

```
RTC_DS3231 rtc;
TinyGPSPlus gps;


void setup_temp_sensor(void) {
 if (!temp_sensor.search(addr)) {
//    Serial.println(F("No more addresses."));
//    Serial.println();
    temp_sensor.reset_search();
    delay(250);
    return;
  }
//  Serial.print("ROM =");
//  for( i = 0; i < 8; i++) {
//    Serial.write(' ');
//    Serial.print(addr[i], HEX);
//  }
  if (OneWire::crc8(addr, 7) != addr[7]) {
//    Serial.println(F("CRC is not valid!"));
    return;
  }
//  Serial.println();
  switch (addr[0]) {
    case 0x10:
//      Serial.println("  Chip = DS18S20");  // or old DS1820
      type_s = 1;
      break;
    case 0x28:
//      Serial.println("  Chip = DS18B20");
      type_s = 0;
      break;
    case 0x22:
//      Serial.println("  Chip = DS1822");
      type_s = 0;
      break;
    default:
//      Serial.println("Device is not a DS18x20 family device.");
      return;
  }
}



void fetch_temperature(void)
{
  temp_sensor.reset();
```

```
  temp_sensor.select(addr);
  temp_sensor.write(0x44, 1);    //start conversion, with parasite power on at the end
  delay(1000);
  present = temp_sensor.reset();
  temp_sensor.select(addr);
  temp_sensor.write(0xBE);
//  Serial.print(F("  Data = "));
//  Serial.print(present, HEX);
//  Serial.print(" ");
  for ( i = 0; i < 9; i++ ) {         // we need 9 bytes
    data[i] = temp_sensor.read();
//    Serial.print(data[i], HEX);
//    Serial.print(" ");
  }
//  Serial.print(F(" CRC="));
//  Serial.print(OneWire::crc8(data, 8), HEX);
//  Serial.println();
  int16_t raw = (data[1] << 8) | data[0];
  if (type_s) {
    raw = raw << 3;
    if (data[7] == 0x10) {
      raw = (raw & 0xFFF0) + 12 - data[6];
    }
  }
  else {
    byte cfg = (data[4] & 0x60);
    if (cfg == 0x00) raw = raw & ~7;
    else if (cfg == 0x20) raw = raw & ~3;
    else if (cfg == 0x40) raw = raw & ~1;
  }
  celsius = (float)raw / 16.0;
//  Serial.print(F("  Temperature = "));
//  Serial.print(celsius);
//  Serial.print(F(" Celsius, "));
}


//void fetch_time(String time_)
//{
//  /*
//   * For some reason, this function didn't work.
//   * I eventually copied this content into the
//   */
//  DateTime now = rtc.now();
//  time_ = String(now.hour())+ ':' + String(now.minute())+ ':'+
//          String(now.second());
```

```
//}

void setup_rtc(void)
{
  if (!rtc.begin()) {
  }
  if(rtc.lostPower()) {
    rtc.adjust(DateTime(F(__DATE__), F(__TIME__)));
  }
}


void fetch_location(void)
{
  gps_uart.listen();
  smartDelay(1000);
  lattitude = gps.location.lat();
  longitude = gps.location.lng();
}

  /*
   * E.g. 23.45,7.4434,6.3323, 23:43:12, ,0, 1997/12/9 09:43:12
   *     jsond={"rotation":     0,     "temperature":23.45,     "latitude":7.4423,     "longitude":6.3323,
"sample":None}
   */

char *ftoa(char *a, double f, int precision)
{
  const long p[] = {0,10,100,1000,10000,100000,1000000,10000000,100000000};
  char *ret = a;
  long heiltal = (long)f;
  itoa(heiltal,a,10);
  while(*a != '\0') a++;
  *a++ = '.';
  long desimal = abs((long)((f-heiltal) * p[precision]));
  itoa(desimal,a,10);
  return ret;
}


  // This custom version of delay() ensures that the gps object
// is being "fed".
static void smartDelay(unsigned long ms)
{
  unsigned long start = millis();
  do {
```

```
    while (gps_uart.available()) {
      gps.encode(gps_uart.read());
    }
  } while (millis() - start < ms);
}
```

PART C

```
extern SoftwareSerial gsm;
String DATA = " ";    //Data format for transmit

//const String apn = "web.gprs.mtnnigeria.net";
const String apn = "etisalat.com.ng";
const String url = "idsapp.herokuapp.com/api/sample/details/save";

void transmit_data(void)
{
  int state = 0;
  Serial.println(F("\nTRANSMIT START"));

   DATA = String("{") +
        String("\"temperature\":") + String(celsius,2) + String(",") +
        String("\"longitude\":") + String(longitude,4) + String(",") +
        String("\"latitude\":") + String(lattitude,4) + String(",") +
        String("\"rotation\":") + String(20) +
        String("}");

  Serial.println(DATA);
  httpSend();
//        "," +
//        "\"tilt_time\":" + tilt_time + "," +
//        "\"first_transmit\":" + first_transmit + "," +
//        "\"start_time\":" + start_time +
//        '}';

//  while( !(state >= 7) ) {
//
//    switch(state) {
//
//      case 0:
//      Serial.println(F("\nState = ")); Serial.println(state);
//      DATA = String("{") + "\"temperature\":" + String(celsius,2) + String("}");
//      Serial.println(String("\n") + "DATA:" + DATA);
//      httpSend();
//      state = 1;
```

```
//      break;
//
//      case 1:
//      Serial.println(F("\nState = ")); Serial.println(state);
//      DATA = String("{") + "\"longitude\":" + String(longitude,4) + String("}");
//      Serial.println( String("\n") + "DATA:" + DATA);
//      httpSend();
//      state = 2;
//      break;
//
//      case 2:
//      Serial.println(F("\nState = ")); Serial.println(state);
//      DATA = String("{") + "\"latitude\":" + String(lattitude,4) + String("}");
//      Serial.println( String("\n") + "DATA:" + DATA);
//      httpSend();
//      state = 3;
//      break;
//
//      case 3:
//      Serial.println(F("\nState = ")); Serial.println(state);
//      DATA = String("{") + "\"current_time\":" + current_time + String("}");
//      Serial.println(String("\n") + "DATA:" + DATA);
//      httpSend();
//      state = 4;
//      break;
//
//      case 4:
//      DATA = String("{")  + "\"tilt_time\":" + tilt_time + String("}");
//      httpSend();
//      state = 5;
//      break;
//
//      case 5:
//      DATA = String("{") + "\"first_transmit\":" + first_transmit + String("}");
//      httpSend();
//      state = 6;
//      break;
//
//      case 6:
//      Serial.println(F("\nState = ")); Serial.println(state);
//      DATA = String("{") + "\"start_time\":" + start_time + String("}");
//      Serial.println(String("\n") + "DATA:" + DATA);
//      httpSend();
//      state = 7;
//      break;
//
```

```
//      default:
//      Serial.println(F("All data sent."));
//    }
//  }
  Serial.println("\nDONE");
  delay(1000);
}


void runsl() {
  Serial.println(F("In runsl..."));
  while (gsm.available()) {
    Serial.print("GSM: ");
    Serial.print((char)gsm.read());
    Serial.println();
  }
}

void httpSend(void)
{
  gsm.listen();
  Serial.println(F("\n in httpSend()..."));
  gsm.println(F("AT\r"));
  runsl();//Print GSM Status an the Serial Output;
  delay(2000);

//  gsm.println(F("AT+CGREG?\r"));
//  runsl();
//  delay(200);

//  gsm.println(F("AT+CSCLK?\r"));
//  runsl();
//  delay(50);

  gsm.println(F("AT+SAPBR=3,1,Contype,GPRS\r"));
  runsl();
  delay(500);
  gsm.println("AT+SAPBR=3,1,APN," + apn + String("\r"));
  runsl();
  delay(500);
  gsm.println(F("AT+SAPBR=1,1\r"));
  runsl();
  delay(500);
  gsm.println(F("AT+SAPBR=2,1\r"));
  runsl();
  delay(2000);
```

```
  gsm.println(F("AT+HTTPINIT"));
  runsl();
  delay(500);
  gsm.println(F("AT+HTTPPARA=CID,1"));
  runsl();
  delay(500);
  gsm.println("AT+HTTPPARA=URL," + url);
  runsl();
  delay(500);
  gsm.println(F("AT+HTTPPARA=CONTENT,application/json\r"));
  runsl();
  delay(500);
  gsm.println("AT+HTTPDATA=600,10000\r");
  runsl();
  delay(500);
  gsm.println(DATA);
  runsl();
  delay(5000);
  gsm.println(F("AT+HTTPACTION=1\r"));
  runsl();
  delay(5000);
  gsm.println(F("AT+HTTPDATA=0,1000\r"));
  runsl();
  delay(1000);
  gsm.println(F("AT+HTTPTERM\r"));
  runsl();
  delay(500);
  gsm.println(F("AT+SAPBR=0,1\r"));
  runsl();
}
```

APPENDIX B

The block diagram (figure 3.1) shows the modular nature of the sample holder's circuitry, apart from the power supply module. Also not shown are other electronic components (LEDs, resistors, transistors)

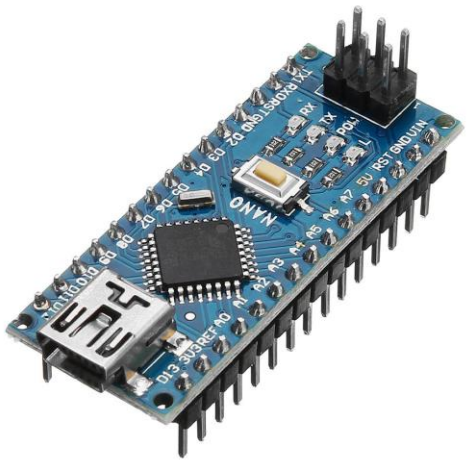

Figure B1: Arduino Nano

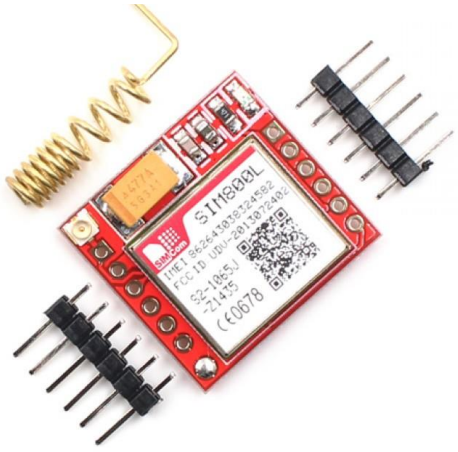

Figure B2: Sim800l GSM module

Figure B3: Neo 6M V2 GPS module

Figure B4: DS3231, RTC

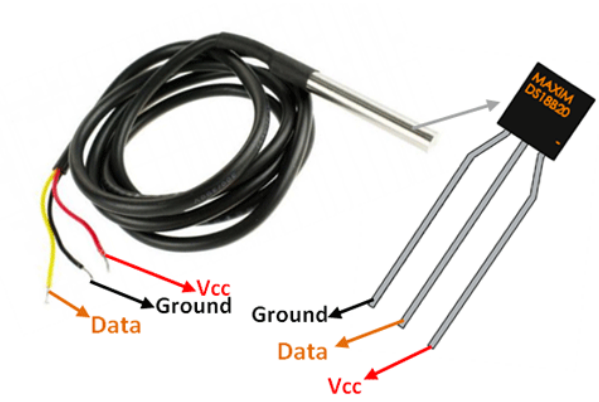

Figure B5: ds18b20, temperature sensor

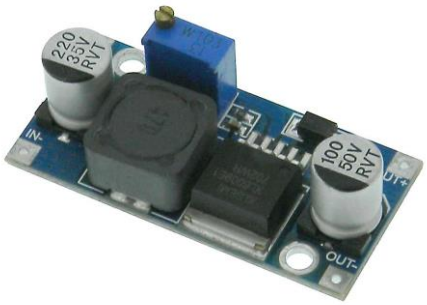

Figure B6: XL6009, boost converter