

MINISTERE DE L'ENSEIGNEMENT
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MINISTRY OF HIGHER
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Division of Academic Affairs, Research and Cooperation

End of course dissertation in view of obtaining a Master of Engineering at the National Higher Polytechnic School of Douala (NHPSD), of the University of Douala.

Field: Electrical Engineering and Intelligent Systems.

Major: Automation and Control of Industrial Systems

THESIS: **DESIGN AND PROTOTYPING OF A MEDICAL
DEVICE FOR AUTOMATIC HEALTH DATA
COLLECTION STORAGE AND MANAGEMENT –
The Health Pad**

**Done from the 1st of March to the 30th of June 2022, at the Incubation Centre ENSPD,
and CBC Health Services - Nkwen Baptist Hospital.**

By

NCHOFON TAGHA GHOGOMU

Industrial Supervisor

M. NKENE Patrick

Head of the Incubation Centre ENSPD

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Dedication

To My Parents and Brothers.

I love you.

Acknowledgment

Out of the unending list of people who have been helpful to me in one way or the other, I will like to offer my sincere appreciation to:

- The Director of the National Higher Polytechnique School of Douala, Prof. Ruben MOUANGUE for always keeping his doors open to me and always ready to help.
- The dean of studies, Dr Samuel EKE who supervised my dissertation
- The head of department of Electrical engineering and intelligent systems. Dr YEREMOU Aurélien
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- My big, prayerful and loving family who always support and wish the best for me.
- Miss Jecolia Longtchi, my elder sister, who has always stood by me
- Mr Bertrand Ndakena, who has guided my first steps in this institution.
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- Polytechnic Douala English Students Association (PODESA)
- All those far and wide who have contributed to who I am today.

A special vote of thanks to my parents, Mr Ghogomu Victor Tagha, regional pedagogic inspector of mathematics for the West Region of Cameroon, and Mrs Ghogomu Florence of the CBCHS at Nkwen Baptist Hospital, and my junior brothers: Njeunwi, Ndhanui, Kwashini, and Ghouvy. They have been so selfless in giving me this priceless gift of education.

Foreword

The National Higher Polytechnic School of Douala

Cameroon has many engineering schools that train citizens to take up engineering roles, with the aim of fostering technological development. It is in this context that the National Higher Polytechnic School of Douala was created on May 11, 2020 by presidential decree. It took over from the Ex-Faculty of Industrial Engineering of the university of Douala.

It is located in PK 17 Logbesou, in the third campus of the university of Douala. The National Higher Polytechnic School of Douala is an institution of higher learning led by its current director, Prof. Ruben MOUANGUE. It offers the following training courses:

A) Engineering curriculum in the following specialties:

- Quality-Hygiene-Security-Industrial Environment Engineering;
- Computer and Telecommunications Engineering;
- Maritime and Port Engineering;
- Process Engineering;
- Civil Engineering;
- Energy Engineering;
- Automotive and Mechatronics Engineering;
- Mechanical Engineering;
- Physical Engineering and Biomedical Technology;
- Electrical Engineering and Intelligent Systems.

B) Engineering science curricula in the following specialties;

- Mechanics and Materials;
- Geophysics, Water and Environment;
- Electronics, Electrical Engineering, Automation and Telecommunications;
- Energy;

- Applied Chemistry;
- Data Science and Artificial Intelligence.

C) Professional Master courses in the following specialties;

- Hydrocarbons and Sustainable Development;
- Geothermal and Infrastructure;
- Metal and Mechanical Construction;
- Industrial Engineering and Maintenance;
- Thermal Engineering and Energy;
- Computer Engineering option Software Engineering;
- Mechatronics and Technical Management of Equipment.

The following diplomas are awarded:

- Design Engineer for the respective engineering curriculum.
- Bachelor's, Master's and Doctoral degrees in engineering sciences;
- Professional Master's degree for the Professional Master's program.

Students are admitted by file study in the case of the Professional Master's program, and through a competitive examination for the first year (GCE A level) and the third year (Bachelor's degree) in the case of the other two programs.

Abstract

More than ever before, health monitoring is becoming very essential. To have quality health monitoring systems, we need to be able to properly collect, store, safely and securely manage the highly confidential health data of patients. In this work, we seek to improve health data collection, storage and management through the design and prototyping of a medical device – The health Pad. This is a tablet-sized medical device with embedded medical sensors which will greatly facilitate the process of health data collection and subsequently patient monitoring. This prototype has two core branches: Hardware and Software. We bring together medical sensors that collect clinical parameters of a patient like temperature, pulse, cardiac rhythm, and state of the patient. With the help of a microcomputer, we program these sensors to collect the required data when prompted by the doctor, with the help of a progressive web app that runs on the Health Pad. A web application is built to enable patients and doctors create their accounts online. At the end, verified medical professionals will use this medical device to clerk or monitor patients, and the medical data from the sensors plus notes from the doctor will be sent real time to the patient's portal. This will enable the patient to access his past medical data by simply login in to his account. Subsequently, when the patient returns to the hospital, with his permission, the doctor can access his medical history from the table health pad and create new entries for that day's consultation or follow up. To arrive at this, we used hardware tools including: The raspberry pi 4, camera, and touch display, the MLX90614 Non-Contact Infrared temperature sensor, DFRobot Pules an ECG senor. Software tools include the Python proگرامing language, Flask, Vue.js. Porteous, and PyCharm IDE. In perspective, we intend to incorporate smart algorithms into the webapp to predict and give early signals based on a patient's medical history.

Key words: Medical device, Health data, Real time, Monitoring, Medical history.

Resume

Plus que jamais, le suivi de la santé devient très essentiel. Pour disposer de systèmes de qualité de surveillance de santé, nous devons être en mesure de collecter, stocker, et gérer en toute sécurité les données de santé hautement confidentielles des patients. Dans ce travail, nous cherchons à améliorer la collecte, le stockage et la gestion des données de santé à travers la conception et le prototypage d'un dispositif médical - The Health Pad. Il s'agit d'un appareil de la taille d'une tablette avec des capteurs médicaux intégrés qui faciliteront grandement le processus de collecte des données de santé et, par la suite, le suivi des patients. Ce prototype a deux branches principales : matériel et logiciel. Nous rassemblons des capteurs médicaux qui collecteront les paramètres cliniques d'un patient tels que la température, le pouls, le rythme cardiaque et l'état du patient. À l'aide d'un micro-ordinateur, nous programmons ces capteurs pour collecter les données requises lorsque le médecin lancera le prompt, à l'aide d'une application Web progressive qui s'exécute sur le Health Pad. Une application Web est conçue pour permettre aux patients et aux médecins de créer leurs comptes en ligne. À la fin, des professionnels vérifiés de la santé utiliseront ce dispositif médical pour gérer ou suivre les patients, et les données médicales des capteurs ainsi que les notes du médecin seront envoyées en temps réel au portail du patient. Cela permettra au patient d'accéder à ses données médicales partagées en se connectant simplement à son compte. Par la suite, lorsque le patient reviendra à l'hôpital, avec son autorisation, le médecin pourra accéder à ses antécédents médicaux à partir du carnet de santé informatisé et créer de nouvelles entrées pour la consultation ou le suivi du jour. Pour y parvenir, nous avons utilisé des outils matériels, notamment : le raspberry pi 4, l'appareil photo et l'écran tactile, le capteur de température infrarouge sans contact MLX90614, DFRobot Pules et un capteur ECG. Les outils logiciels incluent le langage de programmation Python, Flask, Vue.js. Porteous et PyCharm IDE. En perspective, nous intégrerons des algorithmes intelligents dans l'application Web pour prédire et donner des signaux précoces basés sur les antécédents médicaux d'un patient..

Mots clés: Dispositif médical, Données de santé, Temps réel, Surveillance, Antécédents médicaux.

Table of Content

Dedication.....	i
Acknowledgment.....	ii
Foreword.....	iii
Abstract.....	v
Resume.....	vi
Table of Content	vii
Table of Figures	ix
Table of Table	x
Abbreviations.....	xi
Introduction.....	1
Chapter 1 State of the Arts of Health Monitoring	3
1.1 Overview of Hospitals and Processes.....	3
1.1.1 Hospital Overview.....	3
1.1.2 Hospital Processes.....	4
1.2 Overview of Health Monitoring	6
1.2.1 Generalities of Health Monitoring	6
1.2.2 Health data collection.....	8
1.3 Difficulties in Effective Health Monitoring	15
1.3.1 Access to health facilities and infrastructure.....	15
1.3.2 Poor Data Preservation.....	16
1.3.3 Cost.....	16
1.3.4 Doctor to Patient ratio	16
1.3.5 Poor Data Analysis.....	16
1.4 Modern Health Monitoring Tools and Technology.....	17
1.4.1 Tools.....	17

1.4.2	Technology	19
Chapter 2	Material and Methods.....	27
2.1	Methods of Analysis	27
2.1.1	System Overview	27
2.1.2	Functional Analysis.....	29
2.2	Presentation of Material.....	33
2.2.1	Hardware tools	33
2.2.2	Software Tools	37
Chapter 3	Result and Discussions.....	39
3.1	Medical Data Collected	39
3.1.1	Temperature	39
3.1.2	Heart rate	40
3.1.3	Electrocardiogram	42
3.1.4	Camera	44
3.2	Web Application.....	45
3.3	Physical Structure	47
Chapter 4	Conclusion and Perspective	49
Bibliography		51
Appendix A.....		54

Table of Figures

Figure 1.1A&E Sub model	5
Figure 1.2 OP Sub model.....	5
Figure 1.3 Inpatient Sub model.....	6
Figure 1.4 Example of a Patient Observation Chart [30].....	13
Figure 1.5 BP monitor [31].....	14
Figure 1.6 Blood Glucose meter [32].	15
Figure 1.7 Patient Monitor [36]	17
Figure 1.8 Apple Watch [29]	18
Figure 1.9 The Cardio-Pad and Accessories [9]	19
Figure 1.10 Sensor block diagram	20
Figure 1.11Electronics of glucose sensors.....	24
Figure 1.12 Three OpAmp Instrumentation Amplifier [33]	24
Figure 1.13 Data analysis.....	25
Figure 1.14 Data visualization [18]..	26
Figure 2.1 Project Breakdown Structure.....	28
Figure 2.2 Horned Beast Diagram	29
Figure 2.3 Octopus Diagram of the Health Pad.....	30
Figure 2.4 FAST Diagram of the Health Pad	31
Figure 2.5 Use Case Diagram	32
Figure 2.6 Raspberry pi 4 [25].....	33
Figure 2.7 Raspberry pi Touch Screen [25].....	34
Figure 2.8 Raspberry pi Camera v2 8MP [25].....	34
Figure 2.9 Contactless IR Temperature Sensor	35
Figure 2.10 DFRobot PPG Heart Rate Sensor [35].	35
Figure 2.11 DFRobot ECG Heart Rate Sensor [35]	36
Figure 2.12 ADS 1115 16Bits.....	36
Figure 3.1Heart Rate Sensor placed at index finger	40
Figure 3.2 Unstable pulse Rate at the start	41
Figure 3.3 The ECG Complex [26].....	42
Figure 3.4 First ECG Plot	43
Figure 3.5 Second ECG Plot.....	43

Figure 3.6 Third ECG Plot.....	43
Figure 3.7 Forth ECG Plot.....	44
Figure 3.8 The Health Pad - Hardware	47

Table of Table

Table 3.1 Temperature variation with distance in °C	39
Table 3.2 Cost Analysis	47
Table 3.3 Comparative study between The Health Pad and the Cardio-Pad	48

Abbreviations

ADC: Analogue to Digital Converter
AI: Artificial Intelligence
API: Application Program Interface
APTE: Application des Techniques d'Entreprise
A&ED: Accident and Emergency Department
BMI: Body Mass Index
CSI: Camera Serial Interface
DES: Discrete Event Simulation
DSI: Display Serial Interface
ECG/EKG: Electrocardiogram
EEG: Electroencephalogram
EMR: Electromagnetic Resonance
FAST: Functional Analysis System Technique
GPIO: General Purpose Input Output
I2C: Inter-Integrated Circuit
IDE: Integrated Development Environment
ML: Machin Learning
NCDs: Noncommunicable Diseases
ONMC: L'Ordre National des Médecins du Cameroun
OPD: Out Patient Department
REST: Representational State Transfer
SDG: Sustainable Development Goals
SPO2: Oxygen Saturation
WHO: World Health Organisation
YMAU: Yale Model African Union

Introduction

Let us begin by asking ourselves a few core questions.

What?

Increasingly, the world's health care system is being put to taste. With the prevalence of Noncommunicable Diseases (NCDs) and other illnesses, the presence of wars and sociopolitical unrest, the discovery of newer health threatening issue and conditions, to name a few, health monitoring becomes very essential. Unfortunates most underdeveloped and developing countries receive the greatest hit. From the sustainable development report for African countries, it can be observed that most African countries still battle with SDG 3: Good Health and Wellbeing [1]. At the Yale Model African Union I 2022 which held in Kigali Rwanda in the month of May, of which I was part, the committee of Infrastructure and Energy discussed: "Developing Technology to Address Medical Crises and Establishing Programs to Ensure Fair Distribution of Medical Technology" [2]. This shows the rising importance of medical technology in today's world, and this shows how pertinent the fight for quality health is.

Why?

With Africa being our case study, the continent is experiencing a significant growth in population. But, the creation of health facilities and medics to match the population isn't growing accordingly. In addition, cost and distance becomes a barrier to the natives as most of them live below the poverty line. This makes health monitoring farfetched for the natives. On the other hand, the benefits of proper health monitoring cannot be overemphasized. Proper clinical decisions are made, prompt interventions happen because health conditions are identified early on, and patients get to understand their situations better when they are followed up regularly.

In the course of this research, we discovered that to have quality health monitoring systems, we need to be able to properly collect, store, safely, and securely manage patient's highly confidential health data.

Objectives

Over the years several solutions have sprouted locally and internationally to solve issues related to proper health data management. Most of them happen to be electronic record management systems which still lags behind.

Therefore, we seek to improve health data collection, storage and management through the design and prototyping of a medical device – The health Pad. This is a tablet-size medical device with embedded medical sensors which will greatly facilitate the process of health data collection, and subsequently, patient monitoring. The device will be used by medical professionals and the platform can be accessed by both patients and doctors. With the creation of this device, we hope to significantly reduce the ills associated with poor health data management especially in underdeveloped and developing countries.

Outline

This work is presented in four main chapters.

- In the first chapter of this work, we will go through the context of this studies. As it concerns medical institutions and a core component of their process, we will walk through what goes on in a medical setting. We will also understand the key aspects of hospitals which is health monitoring and control. Given that health data collection is indispensable for every hospital process, we will to at some instances of collection of patient's medical data. We will look at a few modern tools used for health monitoring and round up with the technology.
- In the second chapter, we will discuss the system in its entirety. By breaking down the system into its core sub components, we will understand how these various components interact between themselves. The tools and technologies used in the realization of this prototype will also be discussed here.
- We will discuss the results obtained from the implementation of this system in the third chapter, and end with a suitable conclusion and perspectives.

Chapter 1

State of the Arts of Health Monitoring

In this chapter, we will begin by clearly explaining the context: hospital overview and processes. We will move on to discourse the state of the art of medical monitoring. We will talk about how monitoring is done and the technologies used in the process of health monitoring. We will also dig deep into the electronics behind these devices used for medical data collection.

1.1 Overview of Hospitals and Processes

Let us have an overview of a hospital and her interior processes.

1.1.1 Hospital Overview

A hospital is a health care institution providing patient treatment with specialized health science and auxiliary healthcare staff and medical equipment. [3] Over the ages, what we now have as modern-day hospitals, has evolved so rapidly. They vary in sizes and the number of complicated cases they can handle. Let us look at the basic types of hospitals.

- ***General or Acute care:***

This is one of the commonly known type of hospitals. They handle a variety of health cases like disease and injury. [4] Most importantly, they also have emergency units to take care of urgent threats to health. They vary in size and infrastructural facilities.

- ***District or Regional:***

A district hospital typically is the major health care facility in its region, with large numbers of beds for intensive care, critical care, and long-term care. It is also referred to as a regional hospital and serves a geographical region larger than a single local or rural area. District or regional hospitals also serve specific needs that cannot be met by local or rural hospitals like treatment of rare diseases and also offering a round the clock emergency services.

- ***Specialized:***

Unlike general and district hospitals, a specialty hospital is primarily and exclusively dedicated to one or a few related medical specialties. Some examples include rehabilitation centers, children's hospitals, long term acute care facilities, and hospitals that deal with specific health issues like cardiac, orthopedic, oncology just to name a few. A perfect example of a specialized hospital is the *Shisong Cardiac Center in Cameroon*.

- ***Teaching:***

Teaching hospitals give offer healthcare to patients while teaching prospective medical professionals like doctors and nurses. These hospitals are mostly linked to a medical school and are involved in medical research.

- ***Clinics:***

They mostly focus on outpatient service. Non the less, they may have a few beds to take care of minor health issues.

1.1.2 Hospital Processes

A typical general hospital can be abstracted in three main units; Accident and Emergency (A&E) department, outpatient clinics, and inpatient units. In real life these units are coupled and share hospital resources, and are within the same boundaries of the hospital. [5] In reality, these departments are interconnected and share the same resources. We will be adopting the Discrete Event Simulation (DES) model to better comprehend these three.

1.1.2.1 Accident and Emergency sub model

Here, with take out the A&E department and separately analyze it. Later on, we will see how links to the inpatient department. Usually, patients with emergency but having physical strength walk into the hospital. They get themselves registered, and based on their complains, a suitable triage is made for them. Normally, they get examined by the doctors, carry out further examinations and test, return to the doctor with results and are treated. They can be prescribed drugs, admitted and or sent home based on their health results.

In the case of serious emergency, the normal order is broken and patients are taken directly to the treatment cubical. Base on their response to the emergency treatment procedures or first

aid, they are either hospitalized or sent home. The A&E sub model can be seen in the figure below.

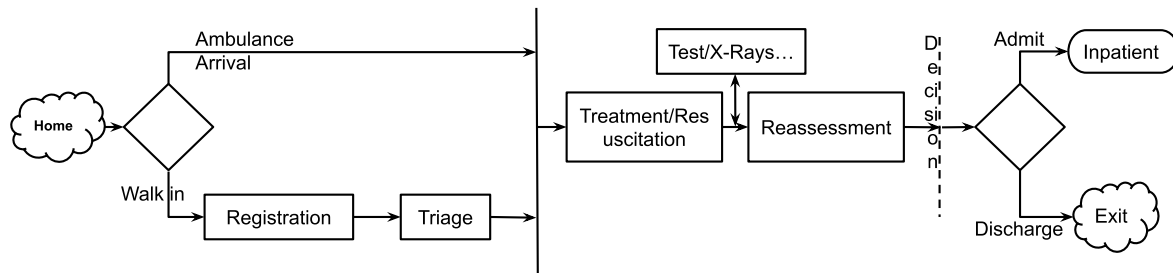


Figure 1.1A&E Sub model

1.1.2.2 Out Patient sub model

Here, we take out the out-patient department (OPD) and separately analyze it. This is the normal route patients use when they get to the hospital. Patients coming to consult for the first time, patients coming for follow up or referred patients usually get to the OPD first. After registration, the patient is directed to the clinic where he gets to meet a general practitioner or a specialist. Based on the complains of the patient, he is sent to the laboratory for lab tests and analysis or to the radiology or imagery unit. From there, he gets back to the doctor who prescribes drugs and is sent home. A patient whose case is severe is admitted. Patients coming for follow up go through the same process just that the best is done for them to meet the doctor who attended to them earlier. The figure bellow represents the OPD sub model

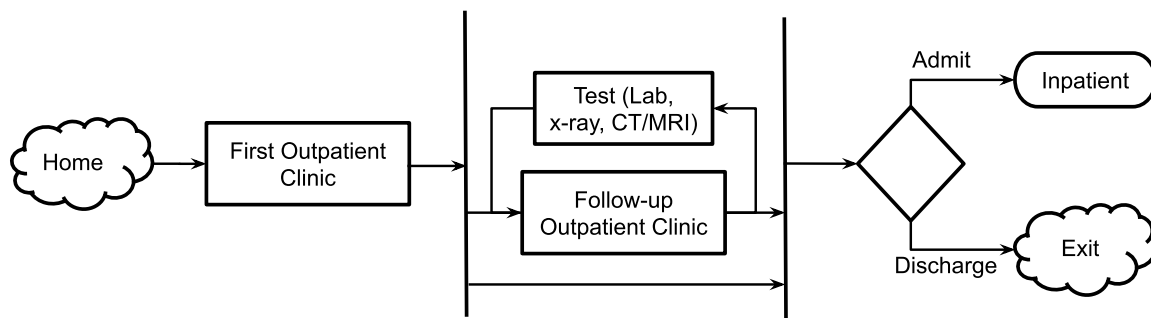


Figure 1.2 OP Sub model

1.1.2.3 Inpatient sub model

This model helps us understand the course of a patient when admitted. Patients get into this model either through the A&E Department, OPD or referral from a general practitioner. Upon admission, patients are taking into a word based on their age, gender, complication type and other factors. There in the word, they are regularly monitored and are regularly given their

drugs. A doctor visits them on a daily bases but are available in case of emergencies. The patient at this point lives in the hospital. When the patient recovers and the vital sign stabilizes, he/she is discharged and is free to go home. They are cases of readmission where a patient shortly after discharge present unfavorable symptoms. The figure below illustrates this sub model.

Throughout this overview of hospitals and hospital processes, we have been able to better

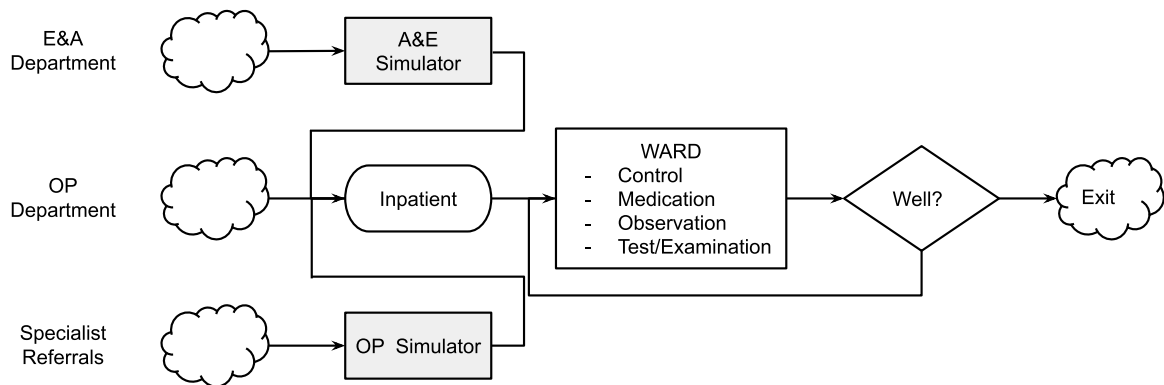


Figure 1.3 Inpatient Sub model

understand our context in which our study will be focused. Through the discrete simulation model, we have been able to individually study the interlinked parts of the hospital. It is worth noting that in almost every single stage of all the mentioned sub model, patient's personal and health data are being collected and recorded. Data collection is an integral part of the hospital. We can find a variety of medical equipment/tools used by health professionals to ensure sound clinical decision making. In the next section of this chapter, we will explore the state of the arts of health monitoring.

1.2 Overview of Health Monitoring

Having had a solid base about health institutions and the flow process within them, let us deep dive into their primary objects which is the core of this dissertation.

1.2.1 Generalities of Health Monitoring

In medicine monitoring is the observation of a disease, condition or one of several medical parameters over time [6]. This is done by regularly measuring vital signs or specific parameters

of an individual, usually with the help dedicated medical tools. It is worth mentioning that monitoring is a very important practice for the control of non-communicable disease like diabetics and hypertension.

Upon arrival at the hospital, patients, as discoursed above in the discrete event simulation model, go through some registration process then into the clinics. During these steps, personal and medical data of the patient is recorded. This data is usually recorded in their hospital books or cards. Basically, we can classify medical monitoring based on the target parameters, or based how it is performed.

1.2.1.1 Non-Invasive and Invasive monitoring

- Non invasive monitoring:

According to Wikipedia, a medical procedure (monitoring in this case) is defined as non-invasive when no break in the skin is created and there is no contact with the mucosa, or skin break, or internal body cavity beyond a natural or artificial body orifice. For example, deep palpation and percussion.

- Invasive monitoring:

According to Wikipedia, an invasive test is a type of medical procedure that requires trained medical providers to use instruments that cut skin (or other connective tissue) or that are inserted into a body opening.

1.2.1.2 Classification based on targeted parameter

Here we classify based on the parameter of interest. Some of these classes include but not limited to:

- Cardiac monitoring:

It is also referred to as electrocardiography (ECG/EKG). In this case, the state of the patient is assessed based on the observed cardiac rhythm. Heart monitors are used to access patient's cardiac rhythms in acute medical care units, emergency services and EKG departments. Health professionals certified at the paramedic level are qualified to interpret ECGs. Invasive and non-invasive methods can be used to monitor patient's cardiac rhythm.

- Respiratory monitoring:

There are a few different ways through which we can monitor respiration. Through pulse oximetry SpO₂, we can measure the saturated percentage of oxygen in blood. Through Capnography, EtCO₂ we measure the end tidal carbon dioxide concentration. We also measure the respiratory rate of patients.

- Body temperature monitoring:

This involves keeping track of the body temperature. There exist several technics and tools used to measure a patient's body temperature. It ranges from a simple mercury in glass thermometer to infrared contactless electronic thermometers.

- Neurological monitoring:

This deals with monitoring parameters of the brain like the brain waves through a process known as electroencephalography (EEG), bispectral index (BIS) EEG monitors are used for this type of monitoring. They also require a certain level of expertise to interpret the results.

The classification list based on the targeted parameter goes on. Now with a basic mastery of the mode of classification of monitoring techniques, lets better understand the concept of health data which is key to monitoring.

1.2.2 Health data collection

From the generalities of monitoring, monitoring can seem to be so focused on particular areas. In our context, many people rarely do regular checkup unless they have specific health issues that need attention. For example, cardiac patients will regularly need to monitor their hearth to take prompt action as the need arises. In this section, we will take two main scenarios to see understand how data is collected and how important regular data collection is.

1.2.2.1 Outpatient consultation

When a patient falls ill, he is rushed to the hospital with his hospital book. At the hospital, he is registered and if he has no hospital book, he buys one. On a side note, the hospital book is a means by which patient's data resulting from consultation, laboratory test and drug prescription is stored. After registration, the patient's vital signs are taken (Age, weight, temperature, blood pressure), while waiting to be directed to a suitable doctor. These vital signs are recorded in the hospital book. At the doctor's office or clinic, the patient goes through a clerking.

Patient Clerking

Clerking refers to the act of collecting and documenting a patient's full medical history, physical examination, working and differential diagnostics and a suitable treatment plan. This is usually the first point of information gathering, by medics, about a patient's condition when the patient arrives the hospital. Most if not all the information gathered during clerking is recorded in the patient's hospital book. Below is a structure to help us better understand clerking and the health data collected in the process [7].

A) Patient Details

This is one of the first information that is collected. This include basic information that can be used to identify the patient. This information includes:

- Full Name
- Date of Birth
- Home Address
- Patient Unique Identification number

Usually, this information is found on the hospital book but in case where the documentation is done away from the hospital book, this information is added.

B) Location Details

The current location details of the patient is recorded in the continuation sheet

- Hospital
- Ward

All the information collected thus far are basic information of the patient. We will move in to another set of data collected during this process.

C) Introductory Information

This set helps us properly begin the notes.

- Date
- Name and role of doctor
- Entry notes

D) Presentation of Complaint (PC)

Here, data pertaining to specific issues presented by patient is recorded. It is very brief and of few words.

E) History of Presenting Complaint (HPC)

In this section, the presenting complaint is expanded. The expanded data depend on the complaint presented by the patient. Using chest pain as the presenting complaint, the data collected will look like this:

- Site: Detailed location of the pain for example
- Onset: Whether pain came suddenly or gradually for example
- Character: Nature of the pain for example (sharp, burning, ...)
- Radiation: If pain moves to any other location
- Associated symptoms
- Time course
- Exacerbating/Relieving factor: What makes the pain worse or lighter for example
- Severity.

F) Past Medical and Surgical History (PMH)

In this section, we document the patient's past medical history and any significant hospitalization and surgical history the patient might have.

G) Drug History (DHx)

Here, we document the patient's drug history including the current medication the patient is on, patient's drug allergies and any drug compliance issues.

H) Family history (FHx)

This is a documentation of a disease that runs through the family.

I) Social History (SHx)

In this section, we document all social activities of a patient that might be related to the given medical condition.

- Occupation
- Smoking history
- Alcohol history

- Recreational drug history

J) System Review (SR)

This involves screening and documenting any observation of any other body system which might or might not be related to the stated complain.

K) Clinical Observation

This is a documentation of clinical observations.

- On Examinations (O / E): General inspections
- Observations (Obs/Vitals): Patient's current observations, vital signs e.g., pulse, heart rate, temperature, oxygen saturation, just to name a few.
- Focused clinical examination findings: This includes focused examinations related to the finding like lab test, Radiology results, cardiovascular observations, etc.

L) Management Plan

From all the findings gather so far, you need to document your management plan. This could include the next steps, drugs to purchase and things to do.

M) Completion

This document is concluded with the name, signature and other identifying parameters of the doctor.

Through the breakdown of the clerking process, we have been able to fully grasp the nature of the type of data collected and the general flow. This structure is not standard and varies from hospital to hospital and also the nature of complain. With the overview of the consultation process, let us have look what an inpatient model could look like.

1.2.2.2 Inpatient Observations

We have explored the basic data collected in the out-patient department. When a patient's case gets critical and cannot be controlled at home, that patient gets admitted. In the ward, the patient is closely monitored and prompt decision is taken. This means, more data is collected and in a more regular manner. In this section, we seek to have a deeper understanding of the inpatient model in relations to data collection.

Ward Rounds

These are formal visits by a team of medical experts to an admitted patient mainly for medical assessment of the patient and planning. This is an integral part of inpatient care and in most local hospitals, ward rounds are done on a daily basis excluding weekends. To better understand data collection during this process, let us look at the data we will typically find in the ward round notes.

A) Patient Details:

This is the basic details that identifies the patient like gender, age, occupation etc

B) Issues:

This section has a summary of what the patient is being treated for or any problem that is being address. This information is accompanied by what is being done to treat it.

C) Bloods:

This is the most recent investigative details about the figures of the various components of the blood. Components include Hb (Hemoglobin), Crp (C-Reactive protein), Wcc (White blood cell count), and other relevant figures. It is important to make a comparison between the present values and the most recent. Arrows can be used to indicate the trend (whether or not the figures are increasing, decreasing or stabilizing)

D) On Examination (O/E):

Here we write down the details gotten after observing our patient. This includes the state of the patient, results from palpitation, how the patient feels.

This section is ended with the impression. The impression serves as a guideline to future plans.

E) News:

This is updated information like the blood pressure, temperature, heart rate and related data.

F) Plan:

At the end of the notes, a treatment plan is done based on the findings and observation so far. This could include requesting more examinations, taking a new drug, continuing or stopping a current therapy, or discharge, amongst others.

Patient Bedside Observation

Besides ward rounds, nurses regularly get the vital signs of patients. This observation is more regular than the ward rounds and can be done several times daily. The results of the vital signs are recorded on an observation chart. Data like temperature is plotted to better visualize the

North West London Hospitals NHS Trust										Patient Name:	
Medical Observation Chart										Hospital No:	
BP Aim: / mmHg										DOB:	
DATE											
BO											
Weight											
Time											
2 6 10 14 18 22 2 6 10 14 18 22 2 6 10 14 18 22 2 6 10 14 18 22 2 6 10 14 18 22 2 6 10 14 18 22											
Temperature											
40°C 39°C 38°C 37°C 36°C 35°C											
Blood Pressure											
180 160 140 120 100 90 80 70 60 50 40 30											
Pulse											
100 90 80 70 60 50 40 30											
Respiration											
30 25 20 15 12 10 8 6 5											
O ₂ Sat											
100% 98% 96% 94% 92% 90% 88% 86% 84% 82% 80% 78% 76% 74% 72% 70%											
FIO ₂											
Atmosol											

Early Warning Score

Score	3	2	1	0	1	2	3
Heart Rate	<40	41-49		50-100	100-110	111-129	>130
Blood Pressure (Systolic)	<70	71-80	81-99	100-160		160-199	>200
Respiratory Rate	<10			10-20	21-25	25-30	>30
Oxygen saturation (%)	<85	85-89	90-94	>95			
Conscious level		Confused Agitated		Alert	Voice	Pain	Unresponsive

If temperature > 37 degrees Celsius: score = 1

If the patient has a total score between 1 and 4 inform the nurse in charge and repeat the observations after 30 minutes

Call for help or advice if there is a score of 3 in any of the parameters or a total score of 5 or more:

Monday-Friday 9am-5pm: call patients own team
Out of hours: Call site practitioner: bleep 932

Document below: a single score of 3 or a total score of 5 or more

[illegible]

Figure 1.4 Example of a Patient Observation Chart [30].

trend. These results can also be presented during the ward rounds to give the medical team better understanding of how the patient is responding to treatment. An example of a bedside observation chart is found below [8].

As seen in this section, a lot of data is being collected in the inpatient department, which is very essential for proper medical follow up of patients. We will look at the last example where regular health data collection is very essential.

1.2.2.3 Non-Communicable Disease (NCD) Control.

When we talk of health monitoring, we can't leave out NCDs. Some key facts about NCDs from the World Health Organization (WHO), as recent as April 2021, include the following:

- They are responsible for the death of 41 million people each year and which is equivalent to 71% of global deaths.

- Cardiovascular diseases account for most NCD deaths, or 17.9 million people annually, followed by cancers (9.3 million), respiratory diseases (4.1 million), and diabetes (1.5 million).
- 77% percent of the deaths occur in low and middle-income countries.

People from all age groups and all backgrounds are exposed to NCDs. It is triggered by unhealthy lifestyle, unhealthy eating habits, drinking and smoking, and very little or no body exercise. Poverty is also closely linked to NCDs. Some of the metabolic risk factors include:

- Raised Blood Pressure
- Overweight/obesity
- Hyperglycemia (High blood glucose level)
- hyperlipidemia (high levels of fat in the blood)

Prevention is the best way to combat NCDs but in this thesis, we focus on those with NCDs. We control or prevent NCDs by controlling the associated risk factors. Here on, we will look at its control.

NCDs Control

Some hospitals have dedicated clinics to cater for noncommunicable diseases. These clinics educate patients on the best monitoring practices and also assist patients monitor these important vital signs. Early identification of abnormalities enables rapid intervention. Data monitored during clinic days include:

A) Body Mass Index (BMI):

This is the measurement of your body fat based on your height and weight. It is measured in **Kg/m^2** It is calculated by dividing the weight by the square of the height of the patient.

B) Blood Pressure:



Figure 1.5 BP monitor [31].

This is the measure of the systolic pressure (Heart pushes blood out), and the diastolic pressure (rest between beats), of the heart. It is measure in millimeters of mercury (**mmHg**) They are measure through blood pressure monitors. These devices were fully mechanical but modern versions are almost completely electrical.

C) Blood Glucose level:

This is the measure of the glucose level in the blood and is measured in millimoles per liter (**mmol/L**) or milligrams per deciliter (**mg/dL**). This is done by pricking the finger with a needle and putting blood on a stripe which is inserted into the machine for analysis. The data is recorded in the patient's hospital book and recommendations are given to them. For patients who can afford the tools, they can follow up themselves more regularly and report their results when next they get to the hospital.



Figure 1.6 Blood Glucose meter [32].

1.3 Difficulties in Effective Health Monitoring

For effective monitoring to occur, health data needs to regularly be collected and properly preserved. In our local communities, several obstacles get in the way of effective health monitoring. In this section, we look at the core disturbances for proper medical monitoring.

1.3.1 Access to health facilities and infrastructure.

A significant size of the population, especially those living in remote areas, have inadequate or no medical facilities at their disposal. Some patients even need to travel to nearby cities in search of health facilities. With the prevailing sociopolitical crises in Cameroon, affected villages cannot boast of their facilities and several medical professionals were compelled to flee.

Also, some medical facilities lack good medical tools to carry out monitoring of specific issues. This leaves the villages with no one to attend to them when they get to these facilities.

1.3.2 Poor Data Preservation

One of the greatest barriers to sound health monitoring is the poor preservation of past medical data. As know, the hospital book/card is the main means of health data storage in Cameroon. These books can easily be destroyed, get missing or forgotten. But a patient's medical history can only be accessed with the help of this book. In most hospital, cases of patients misplacing their books or having their books destroyed by pests and rodent have been recorded.

Also, issues related to the poor presentation of a patient's medical data in patient's hospital book by a former doctor, can make things even more complex for the present doctor. Hospitals also keep record of patients especially admitted patients but retrieving them when next eh patient comes is very difficult. In situations link this, portions of patient's health data can get missing. As a result, proper monitoring becomes overwhelming.

1.3.3 Cost

The burden of consultation cost rest entirely upon the shoulders of patient. There are very few schemes created to assist the local population get quality healthcare. Government health institutions are relatively cheaper but very populated whereas the private sector is more expensive. The associated cost therefore becomes overwhelming especially for a great majority of people who live below the poverty margin. As a result, just those who can afford get the chance to be regularly monitored.

1.3.4 Doctor to Patient ratio

The doctor to patient ratio in our community is overwhelmingly low. As a results, most patients need to go through very long queues before meeting a health professional. This is a very demotivating factor to regular consultation because many people can't afford to waste an entire day at the hospital when they don't even feel ill. As such, many prefer to wait till the issue becomes severe and beyond their control. This discourages effective monitoring.

1.3.5 Poor Data Analysis

There are cases of patients who present the same complains to different doctors and they give the patient very distinct diagnosis. This has caused a multitude of patient to wonder around with health issues and spend a lot on drugs that don't even make them feel better. They

hopelessly wait for that day when they will find the right doctor who will diagnose them rightly. This happens when a vital data is skipped or not spotlighted. Mostly, the nature past data presents is self to medical professionals isn't visually appealing and unlinked. Mentally correlating data is assiduous and lengthy thus avoided by most medical doctors.

1.4 Modern Health Monitoring Tools and Technology

With the world of biomedical technology quickly evolving, better and more efficient biomedical devices are being created to improve health care and patient monitoring. In the domain of health monitoring, there is a lot being done to also foster remote monitoring. Remote monitoring is a potential solution to the problems of rural health care which suffers from the lack of medical infrastructure and medical professionals. We seek to explore some of these tools used for monitoring at health units and at a distance.

1.4.1 Tools

1.4.1.1 Patient Monitor

This is the most used device in the hospital to monitor patients in critical health conditions. They can be found in wards, intensive care units, theater, and specialized clinics. Patient monitors measure, record, distribute and display combinations of biometric values such as heart rate, SPO2, blood pressure, temperature and more. High-capability, multi-function monitors are typically used in hospitals and clinics to ensure a high level of quality patient care. They are equipped with several props which transmits data from the various sensors to the monitor which is later displayed on the screen. The sensors are fixed on the patient for the entire duration of monitoring.



Figure 1.7 Patient Monitor [36]

The patient monitor varies in size, shapes, amount and quality of data displayed on the screen. Also, they have sensors with very high accuracy. The values displayed on the screen can hence be documented or written down in the patient's monitoring notes. These monitors are not used for rapid vital sign collection as done in the out-patient department.

1.4.1.2 Smart devices

We are in the technological age and most smart device manufacturers are growing interest in helping their clients monitor their health. They do this by embedding sensors and using appropriate software technics to wirelessly measure important. The most common includes: number of steps, miles walked per day, pulse and temperature. Most often, these capabilities come as a bonus to those who purchase these items. The data however is stored in the owner's phone or account and retrieved if needed. These data are hardly associated to the patient's medical record gotten from the hospital. Let us look at outstanding examples.

The Smart watch

Apple is known to be the leading producer of smart watches. Besides the amazing communication and web browsing features offered by the watch, they are known for the role it plays for health data and performance tracking of the person putting them on. These watches are linked to the phone and by accessing the health app, you have your cumulative health data. Below is a figure of the watch displaying vital data of a user.



Figure 1.8 Apple Watch [29]

Smart Phones:

Most smart phones have the embedded sensors too that permits them to track a few health-related parameters of the user. The data is stored locally in the health app that comes with the phone.

1.4.1.3 The Cardio-Pad

The Cardio-Pad invented by Arthur Zang, a Cameroonian engineer in the year 2011, is one of the most talked about biomedical inventions in Cameroon. The Cardio-Pad is a medical instrument used to record and analyze heart activity of a patient in a bid to provide a diagnostic. Its primary focus was to ensure that cardiac patients in remote areas can have equal access to proper heart monitoring [9].

The Cardio-Pad comes with a complete 12 lead ECG prop which is connected to the patient for proper analysis of the cardiac rhythm.



Figure 1.9 The Cardio-Pad and Accessories [9]

1.4.2 Technology

So far, we have explored the domain of Health Monitoring firstly by understanding the context, then going to the pitfalls in effective health monitoring and ending with some of the modern tools used to monitor patients. In this section which concludes the chapter, we will spotlight key concepts behind the technology of health monitoring. As observed, the key to effective monitoring is proper health data collection. Without proper collection of medical data, the rest of the process will be found wanting. Biomedical sensors play this role of data collection. To ensure clean diagnostics, the data collected over time needs to be properly analyzed. With the advent of data analysis tools like AI and ML, predictions with a high accuracy margin can be identified. The end is to make perfect clinical decisions for patients based on their data.

1.4.2.1 Sensors

A sensor in its simplest form is a device that receives a stimulus and responds with an electrical signal [10]. In context, stimulus refers to a physical, chemical or biological quantity, property

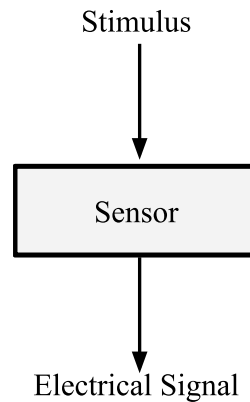


Figure 1.10 Sensor block diagram

or condition that is being studied. This stimulus is often also referred to as the measurand. The measurand can be the patient's body temperature, glucose level, pulse, or any property being measured. Sensors have become a very essential part of our every modern technology. Transducers step in when the stimulus cannot be directly interpreted by the sensor. They convert one measurand to another which can be interpreted by the sensor.

A typical sensor will comprise of more than just a direct sensor in its self. It combines a series of transducers, a direct sensor and perhaps a conditioner. Conditioners come in to serve as a communication interface between the sensor and the system receiving the output of the sensor. This assembly is referred to as the measurement chain and can be represented as shown in the figure below.

Sensor Classification

There exist several ways of classifying sensors. A sensor can be referred to as either active or passive [11].

- Active Sensors:

An active sensor does not need an additional energy source to operate but directly generates electrical signals in response to external stimulus. It is generally based on the principle of a physical effect that directly converts impulses into electrical energy [12]. Some of these effects include the thermoelectric effect for temperature measurement, photoemission effect, Induction, Hall effect, to name a few. Common examples of passive sensors include the thermocouple and photodiode.

- Passive sensors:

On the other hand, passive sensors need an external power supply to operate. They are sensible to the quantity being measured. On their own, they cannot provide an electrical signal. They have properties that react to stimulus which can later be interpreted after passing an electric signal through them. Some common examples of passive sensors include: thermistor and a strain gauge. Examples of physical properties exploited here include: resistivity and dielectric constant.

Sensor Performance

The performance helps us better appreciate and understand a given sensor. To conclude on the sensor's performance, we look at certain characteristics.

- Input-output characteristics:

This describes the evolution of the output in relation to the corresponding input. Given an input signal e , and an output signal S , the sensor with a transfer function F , can be represented with the help of the mathematical equation:

$$S = F(e)$$

- Span or Full Scale (FS):

This is the full range of stimuli that may be converted by a sensor. This is the interval between the maximum value and the minimum value of input that can be interpreted by a sensor.

- Sensitivity:

The sensitivity of a sensor is the ratio of variation of the output signal with respect to the corresponding variation in the input signal. The way this is calculated varies based on the linearity of the sensor. For a linear sensor, the input-output characteristic can be represented by a straight line whose gradient reflects the sensor's sensitivity. For a nonlinear sensor, the sensitivity is calculated for a given measurement. Using the above equation, we have:

$$\text{Sensitivity} = \frac{\Delta S}{\Delta e}$$

- Linearity:

This characteristic tells us whether the input-output characteristics of a sensor can be approximated to a straight line, that is can be defined by the equation of a straight line: ($y = mx + c$). By expressing the absolute value of the difference between the measured value and theoretical value as a percentage of the span, we get the linearity error.

$$\delta_l = \frac{|y_{measured} - y_{theory}|}{FS} \times 100\%$$

- Accuracy:

The accuracy of a sensor tells us the highest deviation to expect, as represented by a sensor, from the ideal value of a stimulus at its input. Inaccuracy tells us the extent to which the sensor is accurate. The inaccuracy for a given span is expressed as the error to range ratio. This ratio might appear small for a short range but could be threatening at a greater range.

- Resolution:

We can define the resolution of a sensor as the smallest increment of stimulus that can be perceived by the sensor.

- Repeatability (Reproducibility):

This is the sensor's ability to represent the same value under presumably identical conditions. It is expressed as the maximum difference, $\Delta y_{measured}$, between the readings obtained from two calibration cycles. It is expressed as a percentage of the full scale or range:

$$\delta_r = \frac{\Delta y_{measured}}{FS} \times 100\%$$

- Reliability:

This is the sensors' ability to repeatedly respond the same for a given stimulus. That is always producing the same results for a given input.

- Uncertainty:

This is the expression of the limitations of our sensor. For readings with NO ZERO ERROR, the uncertainty is half the resolution while for measurements with ZERO ERROR, the uncertainty is equivalent to the resolution.

- Speed:

This is simply how quickly a sensor response to a stimulus. This can be expressed by calculating the response time, the fundamental frequency or the pass band.

There are several parameters that help us better understand our sensor and what to expected from them when we put them to use. We have so far been able to understand a few of the core parameters.

1.4.2.2 Biomedical sensors

Biomedical sensors in themselves are sensors. These sensors are a class of sensors used for biomedical purposes. Their working principles is basically the same. The only difference is that they are made purposely for biological systems, and going further, the kind of biological system. Let us examine two sensors used for biomedical purposes:

Blood glucose sensor:

Diabetes is one of the leading causes of death in the world [13]. Diabetes is a chronic, metabolic disease characterized by elevated levels of blood glucose (or blood sugar), which leads over time to serious damage to the heart, blood vessels, eyes, kidneys and nerves. To control diabetes, patients regularly measure their glucose level using the glucose meter. Without diving deep, glucose has electrochemical properties which can be exploited to measure its concentration in blood. The process in point form:

- Patient picks finger to get a little about of blood.
- The blood is introduced into a test strip with imprinted electrodes.
- A fixed voltage is applied across the electrodes and the output current is monitor. This current linearly matches the glucose concentration in the blood sample.

An electronic diagram of this sensor can be seen below [14]. This current value at the output is interpreted by a microcontroller and the final result is sent to the display screen of the meter. By exploiting the electrochemical properties of glucose in blood, we can effectively set up a glucose meter and monitor those living with diabetes

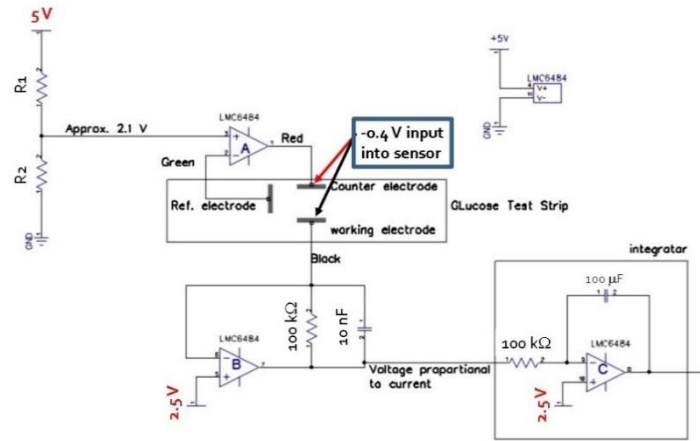


Figure 1.11 Electronics of glucose sensors

The ECG:

Cardiovascular disorder also accounts for a great percentage of general deaths. This tends to increase the demand for these sensors. Basically, an ECG sensor translates the biopotential signal of the body into exploitable electric signals. Biopotential is the electric potential measure between the cells of the body [15]. In simpler terms, ECG is the measure of the electrical activities of the heart.

It is worth noting that these signals are very small and vary from microvolts to millivolts. Thus, these signals need to be amplified for proper interpretation. Noise and interference are also not inevitable when working with biopotentials. It is worth noting that biopotential amplifiers can be somewhat dangerous if they don't have a high input impedance as the signal being amplified is drawn from the body. So, safety first [16].

The best amplifiers used in this case are instrumentation amplifiers for their high input impedance and significant voltage gain.

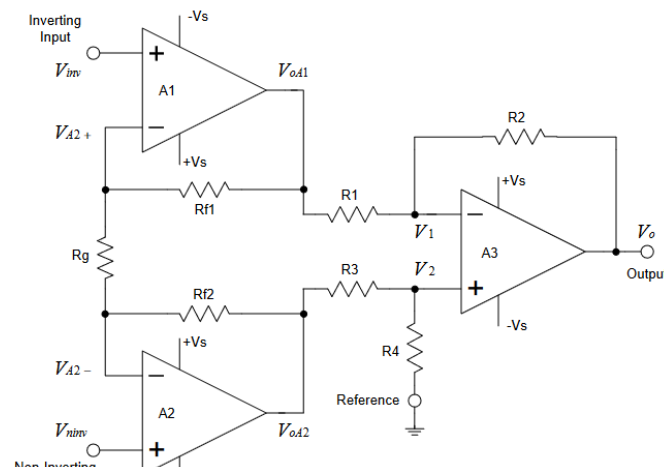


Figure 1.12 Three OpAmp Instrumentation Amplifier [33]

For a simple three lead ECG electrode, V_{inv} , V_{ninv} , and Reference will be connected to the right arm, left arm and Left foot respectively. These wires are carefully insulated and shielded to prevent noise and interference from the environment.

There exist several types of sensors and they operate by exploiting a biological, physical, or chemical property of the body on which they are designed for. Let us explore data visualization.

1.4.2.3 Data Analysis, and Visualization

When data accumulates over time, it becomes very bulky and difficult to manage. Sometimes, understanding the data also becomes stressful. Notwithstanding, data is key to productivity. This compels us to get as much data as possible. As such we need the right tools to manage this voluminous data.

Data Analysis

Data analysis can be defined as a process of inspecting, cleansing, transforming, and modelling data with the goal of discovering useful information, informing conclusions, and supporting decision-making [17]. This comes after our sensor or hardware has delivered the required data. We have principal four forms of data analysis.

- Descriptive: This is the foundation of data analysis. It seeks to present or describe the data under studies. It gives an answer to the question “*What Happened?*”.
- Diagnostic: Here, we seek to understand why something happened. It answers the question “*Why did this happen?*”
- Predictive: Here, we seek to do a forecast of what is most likely to happen. It answers the question “*What will likely happen?*” It uses data obtained from the result of descriptive and diagnostics to understand patterns and clusters which is powerful for forecasting.
- Prescriptive: From the results of predictive analysis, powerful tools like AI and ML are employed to provide precautions to take to prevent or cause something to happen.

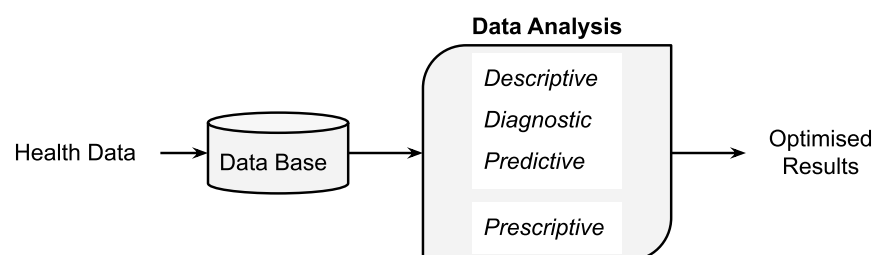


Figure 1.13 Data analysis

Data Visualization

Very large amount of data is hard to absorb and understand. This is where data visualization steps in. In brief, it's a process of unifying diverse medical data coming from various sources and transforming it into visual content (infographics and mini-infographics, charts, tables, timelines, scatter plots, or others) [18]. The goal of data visualization in healthcare is to help the medical professional to easily and quickly interpret the analyzed data, quickly spot trends and make informative results.



Figure 1.14 Data visualization [18]..

When data is presented in an many as shown in the figure above analyses becomes easier and spotting out issues becomes simple.

Throughout this Chapter, we have been able to see deeply understand the state of the arts of health monitoring by exploring the hospitals, monitoring technics, difficulties in effective monitoring and we rounded up with modern health monitoring tools and technologies. With this understanding, we can move und to detailly understand our system. We will be looking at the state of the arts in the next chapter.

Chapter 2

Material and Methods

2.1 Methods of Analysis

2.1.1 System Overview

About the Health Pad

The Health Pad is a tablet-size electronic device with inbuilt medical sensors, linked to a central Electronic Medical Record system (EMR). It facilitates the collection and secured storage of patient's basic vitals, as done during the normal consultation and monitoring process. The vital signs of patients collected by the Health Pad at current prototyping phase include: pulse, temperature, ECG, state of the patient (through picture/video), and text (weight and written observation). These values are automatically stored/updated on the patient's personal portal, bearing the time this data was collected. The Online Electronic Medical Record System permits individual patients to log in and see their health data. Doctors can access and update the patients record only through the Health Pad after a secured authentication process. At the online portal (EMR), analysis of health data can be performed and through AI and ML technics, predictions and exact calculations can be made

Idea Origin

This project was born after a series of research, interviews of healthcare providers, interviews with patients and personal experience. We can better understand why after looking at a group of issues.

- *Storage of health data:* Patients in Cameroon use hospital books for consultation and follow-ups. These books easily get lost or destroyed. As a results, the medical history of a patient cannot be perfectly traced.
- *Prescription:* Without sufficient information about a patient's history, wrong decisions are bound to be made. The nature of the books, poor handwriting of previous doctors, high patient to doctor ratio, gives most doctors the reluctance to go through patient's

past medical history. They consequently omit import parts causing them to give wrong drugs to patients

- *Manual transfer/upload of health data:* The process of manually and completely transferring patient's data to his portal can be very boring and laborious.
- *Data analysis from authorities:* Mostly, the reported figures about a prevailing health issue is usually questioned because these figures are based on approximation and don't reflect the reality.

Gravity of the stated concerns:

As a result of the above listed concern, patients could get into casualties as severe as:

- i. Death
- ii. Wrong prescription
- iii. Double expenditure
- iv. Medical error
- v. Delay in drug administration

Intended Users

The Health Pad is designed for, and will be used by doctors, medical officers and health unit to facilitate the consultation process of their patients, and to have patient's data properly managed. This data is updated directly on the patient's online portal.

On the other hand, patients will be able to log into their online portal to view their medical data and other useful information about their health.

System tree diagram

The system is made up of two main parts: The Health Pad physical hardware and an online portal. Below is a decomposition diagram of the system.

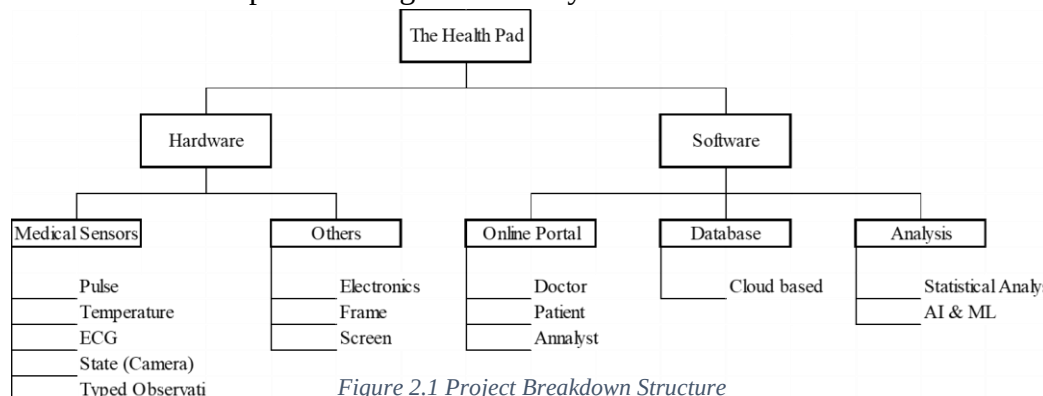


Figure 2.1 Project Breakdown Structure

2.1.2 Functional Analysis

The functional domain of a product aims to produce a complete, unambiguous and technology-agnostic definition of the design problem space [19]. Functions describe the purposes of the engineering system and functional analysis is used to identify what functions the health pad should perform, their logical structure and interactions to satisfy stakeholder requirements efficiently.

Functional analysis is a structured approach to identifying and correlating the functions that our product must perform during its lifetime [20]. There are two main types of functional analysis with complementary aims. The external analysis, focused on the system user and the identification of its service functions, helps to visualize the interactions of the health pad with the External Systems. On the other hand, the internal analysis, focused on the system designer and transforms service functions into internal and technical functions.

2.1.2.1 External Analysis:

We will carry out the external analysis of our system using two main tools provide by the APTE method [21]. We will be exploring the horned beast diagram and the octopus' diagram.

- *Horned Beast Diagram*

This diagram is used to determine the needs to which the technology answers [22]. In coming up with this diagram, we need to ask ourselves the following questions.

- i) Tow whom does the product serve?
- ii) What does the product work on?
- iii) What does the technology do?

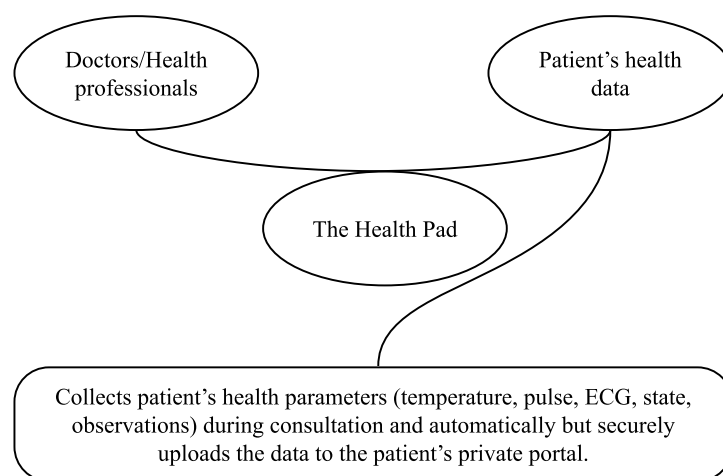


Figure 2.2 Horned Beast Diagram

With the answers we get from these questions, the horned beast diagram of the health pad is represented in the figure above

- Octopus Diagram

The identification of the external environment and the formulation of the need of the system can be done by means of the Octopus diagram or intersections graph. This diagram consists of the product, in the center, and around it, elements of its environment (external environment) [23]. An arrow is used to show three different categories of connections:

- i) The system allows one external System to modify the status of another one.
- ii) The system modifies the status of the external system.
- iii) The system is modified by the external system.

Primary functions (Fpi) bind together two External Systems, whereas secondary (Fsi) functions connect just one. Accordingly, the functions of the Health Pad are stated here below:

Fp1: Upload patient's medical data to portal

Fp2: Access patients health data on the online portal

Fp3: Collect patients vitals through medical sensors (temperature, pulse, ECG, camera)

Fp4: Collects doctor's observation and remarks about patient in the form of text.

Fs1: Use device

Fs2: Get clean energy

Fs3: Respect the norms, environment and security.

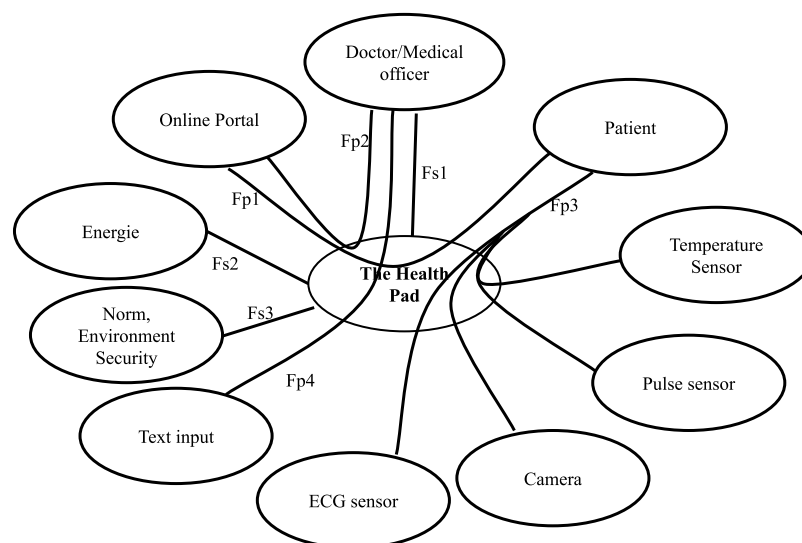


Figure 2.3 Octopus Diagram of the Health Pad

2.1.2.2 Internal Analysis:

The external functional analysis gives us an overview of our system, but the methods cannot be employed to examine the internal system functionalities. To do an internal system analysis of our system, the Functional Analysis System Technic (FAST) is being used [24]

- Functional Analysis System Technic:

The FAST diagram is a hierarchical representation that translate high-level functions to lower-level functions performed by our system. We build it from left to right, which corresponds to the “why” to “how” logic, with low level functions on the right. The first level of decomposition corresponds to the first level requirement (FR), while the second level of decomposition associates to the technical requirement (TR) of the system. The figure here below is the Health Pad FAST diagram.

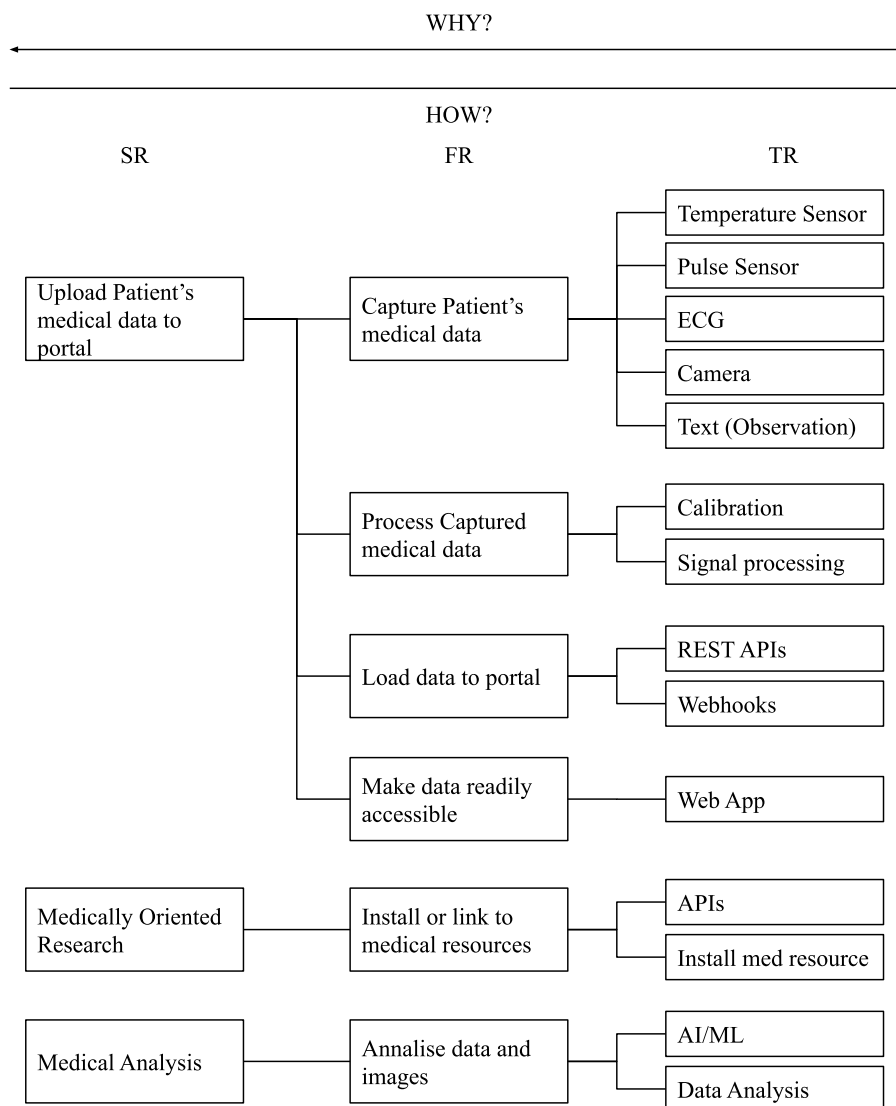


Figure 2.4 FAST Diagram of the Health Pad

- Use Case Diagram

The use case diagram is another helpful tool that permits us better understand the interior functioning of the system. It shows how the user and the various components interact with each other.

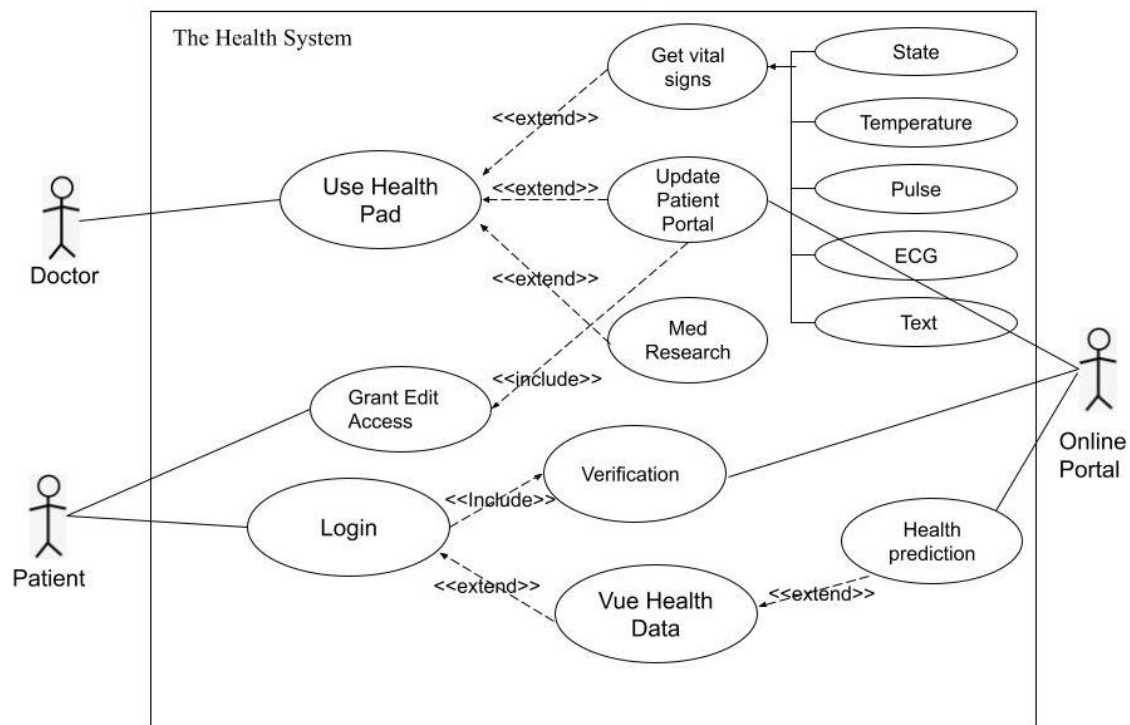


Figure 2.5 Use Case Diagram

Thus far, we have been able to demystify the system and we have seen how the various interior and exterior components come together to make the system work. With these understandings, we will move on to explore the materials and tools employed to design this system.

2.2 Presentation of Material

To realize the health pad which will enhance health data collection, storage, and management, a set of several hardware and software tools were employed. We will look at these tools in this section. They will primarily be divided into hardware and software tools.

2.2.1 Hardware tools

These are the physical components of the health pad that can be touched and felt. They form the physical body structure of the device. This set can mainly be classified into three main groups namely: Input, processing and output. As we present them here below, we will be stating to which category they fall. We will also present the role played by this component and their selection over other components as the need arises.

2.2.1.1 *The Raspberry pi 4*

This is one of the most important hardware components of this prototype. It is the motherboard of the system. It houses the processor and all other peripheral devices are connected to it.

The Raspberry pi 4 is a credit card-sized single-board computer [25]. It has a 1.5GHz 64-bit ARM Cortex-A72 central processing unit (CPU). The system on chip is linked to a random-access memory (RAM) of capacity either 2GB, 4GB, or 8GB. The choice is made when buying the board. It also has several ports and general-purpose input and output pins (GPIO), through which we can connect and communicate with other components and devices.

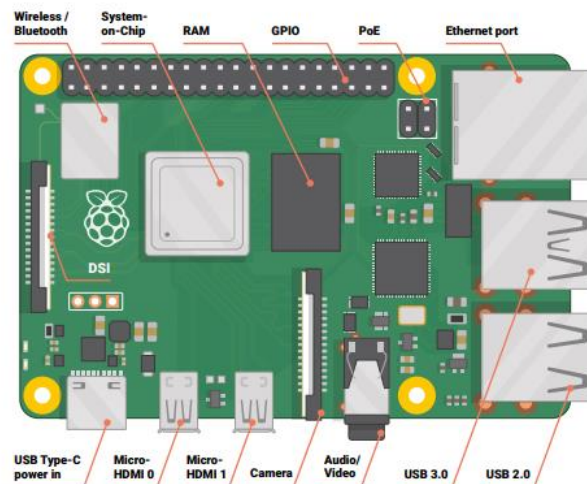


Figure 2.6 Raspberry pi 4 [25]

In the context of this work, the raspberry pi 4 with 8GB of RAM was chosen. The raspberry pi when compared to other boards is very flexible and has several helpful modules embedded in

it. With the numerous GPIO pins and ports, the raspberry pi 4 makes the communication with our sensors and other components like the camera and touch screen very convenient. Its relative processing speed is also commendable, and above all, relatively affordable.

2.2.1.2 The Raspberry pi touch screen.

The official Raspberry touch display is ideal for this project because it easily integrates to the pi. The raspberry pi has a specially dedicated port (Display Serial Interface - DSI) for the screen. It's a 7-inch touch display and perfect for this project. It is also beautiful and can smoothly fit into the case we design. It will serve as the display unit of this prototype and because of its touch functionalities, it will also be used as an input device.



Figure 2.7 Raspberry pi Touch Screen [25]

2.2.1.3 The Raspberry pi Camera.

The Raspberry pi camera V2 with a resolution of 8MP is used in this project to get information on the state of patients. It is ideal as it also has a dedicated port on the pi 4 known as the camera serial interface (CSI), which enables smooth communication between the camera and the pi. Images and videos play a great role in observing the progress in the state of health of a patient thus, adding a camera as one of the sensors will go a long way to enhance health monitoring.

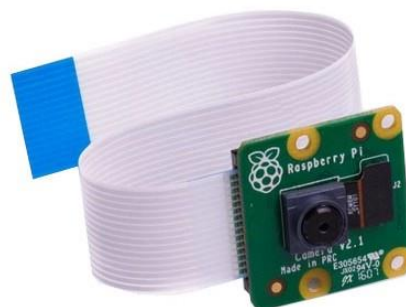


Figure 2.8 Raspberry pi Camera v2 8MP [25]

2.2.1.4 Infrared Temperature Sensor.

One of the first parameters taken upon arrival of a patient at the hospital is the temperature as it plays a great role in early diagnosis and monitoring. We will be using the Songhe GY-906 MLX90614 Non-Contact Infrared (IR) Temperature module. It uses an Inter Integrated Circuit (I2C) communication protocol to communicate with the board. It can collect temperature values of the environment and the object (patient) placed Infront of it. It is advised to place the sensor at a distance of 5cm from the surface of the patient. It measures temperature within the rage -70°C to about 380°C with a sensitivity of 0.5°C. It has an operational voltage of 3-5V.



Figure 2.9 Contactless IR Temperature Sensor

2.2.1.5 Pulse Sensor

Another important parameter is the pulse in beats per minute. To have these values, we will be using the DFRobot Analog/Digital PPG Heart Rate Sensor SKU: SEN0203. By toggling between the D and A switch, we can change the form of the collected data. It can be powered by a source of 3.3volts to 6volts (5volts is recommended). It has an operating current of 10mA and below. It has a dimension of 28mm by 24mm, thus very portable an easy to handle. This sensor generates analogue signals. Since Raspberry pi isn't good at directly interpreting analogue signals, we will use an ADC converter which will intern communicate these values through the I2C communication protocol. It is advices for the patient to be still when pulse value is being collected and the senspr is adviced to be placed on an immobole part of th body.

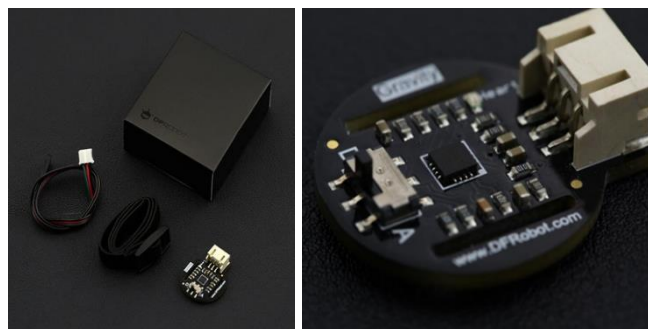


Figure 2.10 DFRobot PPG Heart Rate Sensor [35].

2.2.1.6 ECG Sensor module

This sensor is used to carry out electrocardiography on a patient. The interpreted output of this sensor is a wave-like signal which clearly interprets the cardiac rhythm of the patient. We will be using the DFRobot Analog ECG Heart Rate Sensor SKU: SEN0213. It has an inbuilt filter to assist in noise filtering for the production of and almost pure signal. It is powered by 3.3volts to 6volts (5vols is recommended). It operates at a current value of less than 10mA. It also communicates through an I2C protocol with the help of an ADC module.



Figure 2.11 DFRobot ECG Heart Rate Sensor [35]

2.2.1.7 ADS1115 16-Bit ADC

The Raspberry pi is without an internal analogue to digital converter. To link the pi to sensors whose output is an analogue signal, we used the ADS1115 16-Bit ADC - 4 Channel with Programmable Gain Amplifier. This module converts the analogue signals to digital signal and communicates with the raspberry pi through the I2C communication protocol. It is very convenient to work with and very portable.

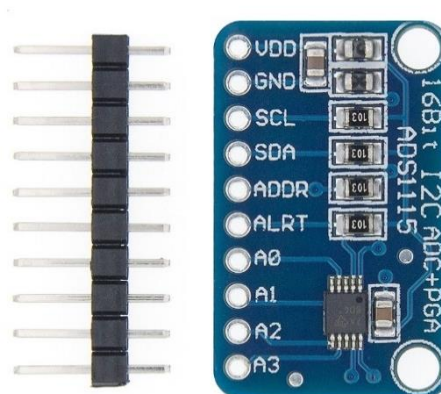


Figure 2.12 ADS 1115 16Bits

2.2.2 Software Tools

In this section, we will be exploring all the software tools used for the development of this prototype. The software tools refer to the intangible components of the health pad that cannot be touched and felt. They include programs/software, programming languages and programming techniques.

2.2.2.1 *Python Programming Language*



Python is a high-level, interpreted, general-purpose programming language. It was founded by Guido van Rossum who started working on it in the late 1980s as a successor to the ABC programming language and first released it in 1991 as Python 0.9.0.

It is a very easy to learn programming language with a less aggressive programming syntax. It can be exploited for a wide range of applications including but not limited to normal programming, data analysis, web and app development/programming, Artificial Intelligence (AI), Machine Learning (ML) and a lot more. It is the most suitable programming language for the raspberry pi. Because of this and its easy integration to other systems, it was chosen.

2.2.2.2 *Flask*



Flask is a micro web framework written in Python. It is worth noting that a Web Framework represents a collection of libraries and modules that enable web application developers to write applications without worrying about low-level details such as protocol, thread management, and so on. Flask was created by Armin Ronacher of Poccoo, an international group of Python enthusiasts formed in 2004 and had its initial release in 2010.

In this project we will be using Flask to create REST Application Program Interface (API). REST is a set of architectural constraints and stands for representational state transfer and was created by computer scientist Roy Fielding. With the help of Flask, we can easily communicate with the web app through API keys.

2.2.2.3 *Vue.js*



Vue.js is an open-source model–view–viewmodel front end JavaScript framework for building user interfaces and single-page applications. It was created by Evan You, and is maintained by him and the rest of the active core team members. The first source code commit to the project was dated July 2013, and Vue was first released the following February, in 2014.

In this work we will be using Vue.js to build the frontend (user interface) of our web application. It will communicate with the node js and Flask (backend), through RESTful APIs. It was chosen because of its simplicity and suitability for fast prototyping.

We also explored the Angular CLI framework in the later part of the project for its robustness.

2.2.2.4 *PyCharm*



With all these, having a suitable software to facilitate the coding process will be very helpful. PyCharm is an integrated development environment (IDE) used in computer programming, specifically for the Python programming language. It is developed by the Czech company JetBrains (formerly known as IntelliJ). It provides code analysis, a graphical debugger, an integrated unit tester, integration with version control systems (VCSes), and supports web development with Django as well as data science with Anaconda.

Given that there was a lot to be done using the python programming language, PyCharm was very suitable for this project. Notwithstanding, some work was done using the Thonny Pi IDE that comes with the Raspbian operating system for the raspberry pi.

2.2.2.5 *Proteus*

Proteus is an application used for building and simulation of electronic circuits. It was used in this project to build the circuit board which is embedded onto the board.

All these tools outlined in this chapter were used in the realization of the system. In the next chapter, we will see the results when all these tools are brought together.

Chapter 3

Results and Discussion

In this section, we will be unfolding the data collected upon implementation of the prototype further broken down in the previous chapter. With the Health Pad, we automatically collected clinical data of a sample patient with different environmental and physical variable. With this data, we arrived the results which will be discussed hereto.

3.1 Medical Data Collected

The prototype principally has four main embedded sensors: Temperature sensor, Pulse sensor, ECG Sensor, and because the state of the patient is important for monitoring, we have a camera.

3.1.1 Temperature

In order to quickly measure the temperature of the patient, we used the Songhe GY-906 MLX90614 Non-Contact Infrared temperature sensor. It was observed that the temperature reading of our patient fluctuated with distance and the body part on which the sensor is pointed to. Temperature was collected at distances ranging from less than 1cm to 1m. The temperature was also taken at various parts of the body. To better understand the results the temperature was taken alongside the temperature of the environment. Bellow is a table that shows helps us understand the variation.

- Body Temperature Data

The ambient temperature throughout this experiment lied between 32.00 °C and 29.89 °C

	Distance from body surface						
Body Part		<1cm	5cm	10cm	20cm	30	40
	Chest	50.77	47.45	43.61	42.03	38.17	34.61
	Forehead	46.73	43.17	37.25	31.55	29.29	28.31
	Palm	46.49	43.57	39.33	33.03	30.79	29.83
	Neck	/	/	/	/	/	/

Table 3.1 Temperature variation with distance in °C

- Discussion

The temperature greatly varies with distance and the body surface on which the sensor is pointed. The measure body temperature of the patient with a verified clinical thermometer was 37.1 °C.

The observes best spot for positioning the thermometer is directly pointing the sensor to the forehead of the patient at a proximity of 10cm.

Despite these results, the Non-Contact Infrared temperature sensor used in this project needs further lab analysis to improve robustness. Another IR sensor with a higher precision and robustness should be considered.

3.1.2 Heart rate

We measure the pulse in beats per minutes of the patient using the DFRobot Analog/Digital PPG Heart Rate Sensor. Firstly, it was discovered that the position of the sensor greatly mattered. After several alterations, the fingertip especially of the index finger was the considered our perfect spot.



Figure 3.1Heart Rate Sensor placed at index finger

The pulse data was subsequently observed and plotted over a period of thirty seconds. In the first case, the patient was shaking at the first few second of data collection. In the second Plot, the patient was relatively at rest during the entire duration of data collection.

- Unstable Patient in the first few seconds

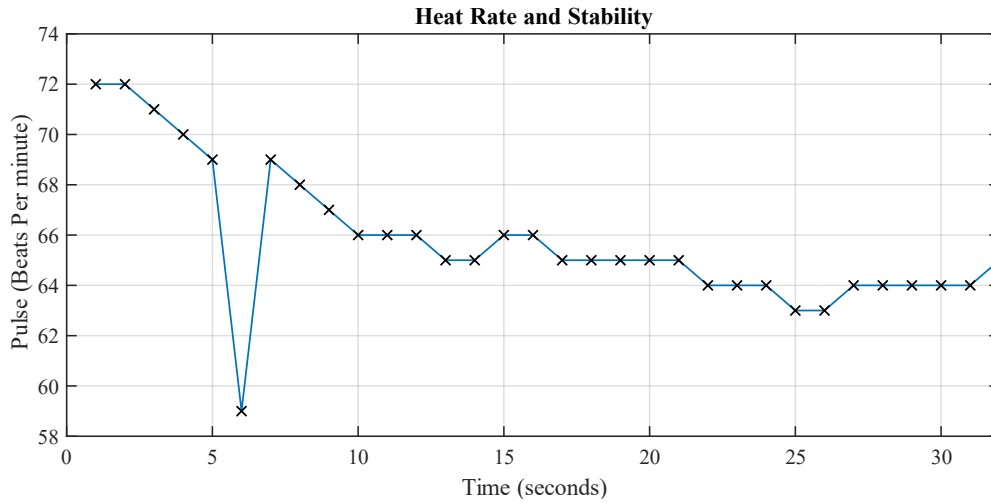
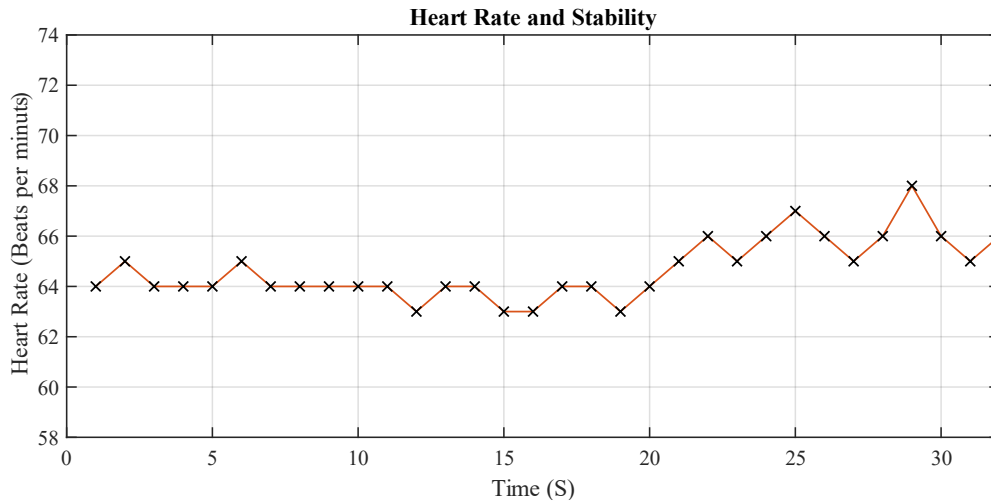


Figure 3.2 Unstable pulse Rate at the start

- Relatively more stable pulse rate



- Discussions

It is necessary to obtain accurate reading. Speed is also very essential. Bringing both factors together, it is required for the patient to stay still when the pulse is being collected. Also, the algorithm listens to the data till it observes some stability in the line.

For a given heart rate x_i , and a fixed number, n , of congestive heart rate $x_i, x_{i-1}, \dots, x_{i-n}$, we calculate the standard deviation of the set heart rates by the equation:

$$\sigma = \sqrt{\frac{1}{n} \sum_{i=n}^i (x_i - \bar{x})^2}$$

As $\sigma \rightarrow 0$, the pulse for the n consecutive heartrate is considered stable. The smaller n , the faster the pulse is obtained.

3.1.3 Electrocardiogram

To better comprehend the results obtained from the ECG heart rate sensor, it is necessary to have some preunderstandings about the ECG complex. There are a set of wave segments that we seek to identify in the results [26].

- P wave: Atrial depolarization
- PR segment: Depolarization of the atrioventricular node (AV node)
- PR interval
- Q wave: Ventricular Septal Depolarization
- R wave: Resultant or major ventricular muscle depolarization.
- S Wave: Basal Ventricular depolarization
- ST interval
- T wave: Ventricular repolarization.
- QT interval
- U wave: From unknown sources or out of phase electrical activities

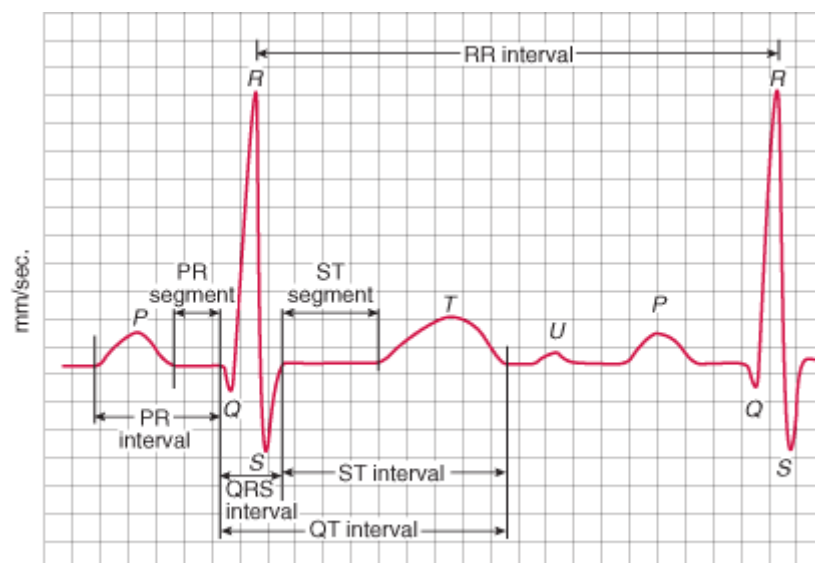


Figure 3.3 The ECG Complex [26]

Based on this, the patient's heart wave form was captured using a three lead ECG electrode placement. We clearly spotted the various segments of the cardiac wave. In as much as the three lead ECG electrode is not as accurate as the 12 leads, the results show that using a 12 lead is most likely going to improve the quality of the wave form produced.

It is worth noting that the rhythm was captured during an interval of six seconds and the patient was still during some portions of the experiment.

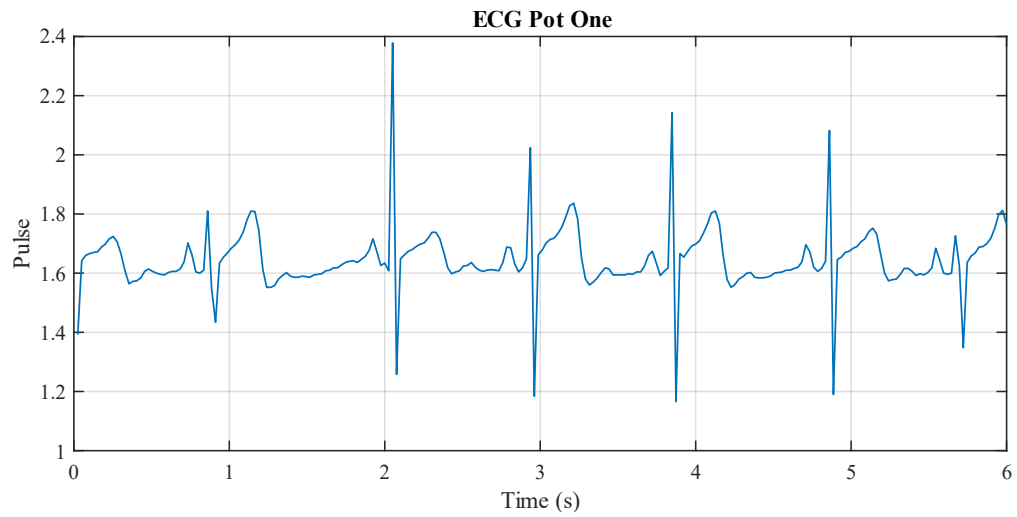


Figure 3.4 First ECG Plot

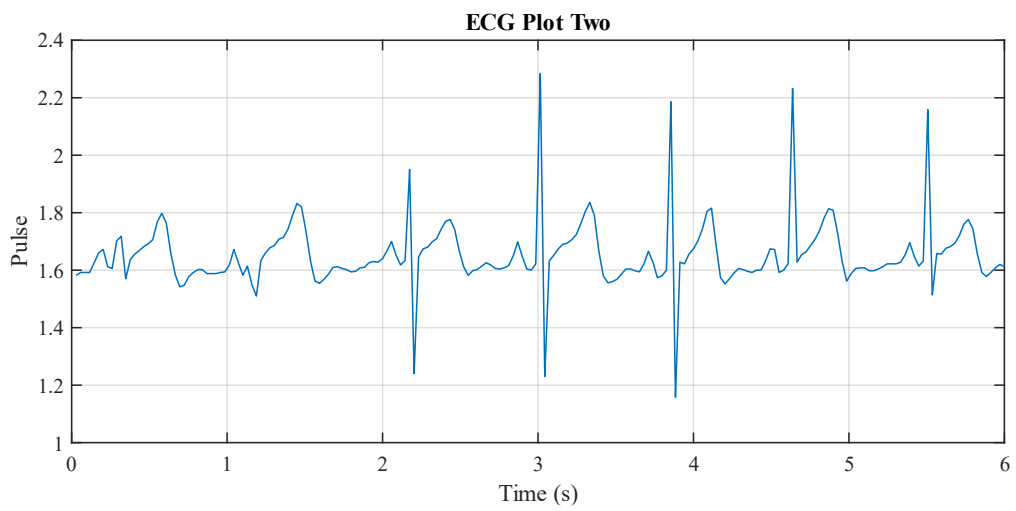


Figure 3.5 Second ECG Plot

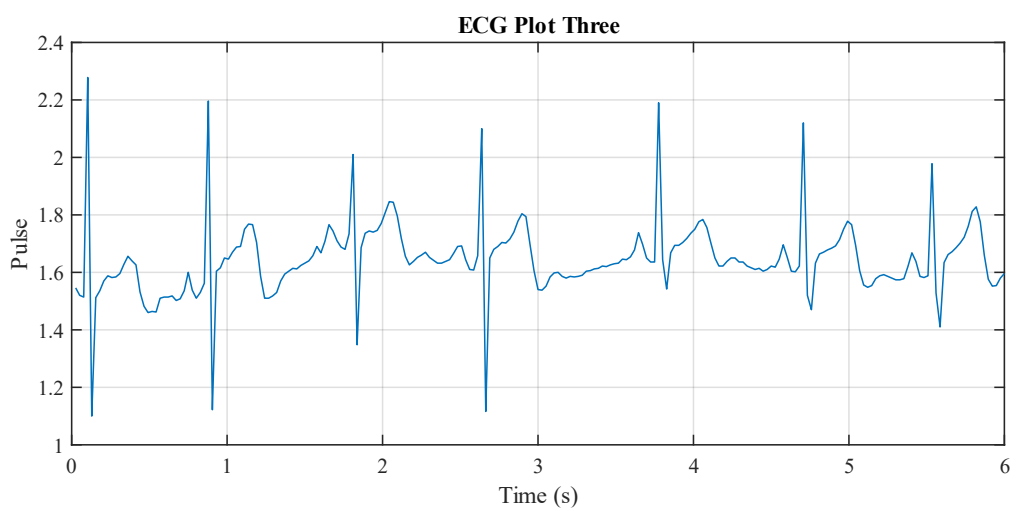


Figure 3.6 Third ECG Plot

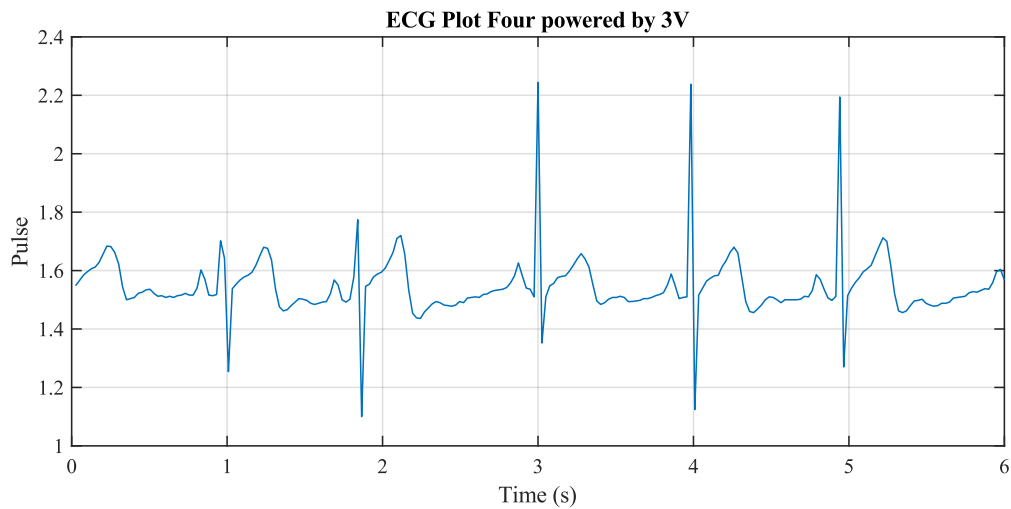


Figure 3.7 Forth ECG Plot

- Discussion

The results obtained are very close to what was expected. But it is important that when the results are being taken:

- i) Patient needs to be still throughout the examination duration.
- ii) A 12 lead ECG electrode should be used for a more stable and clean results.

3.1.4 Camera

With the help of the camera, the state and physical information of a patient can be recorded. But this functionality is not being exploited very much. With images of a patient, we can properly monitor progress and make smart decisions. This could be a wound, and accident etc

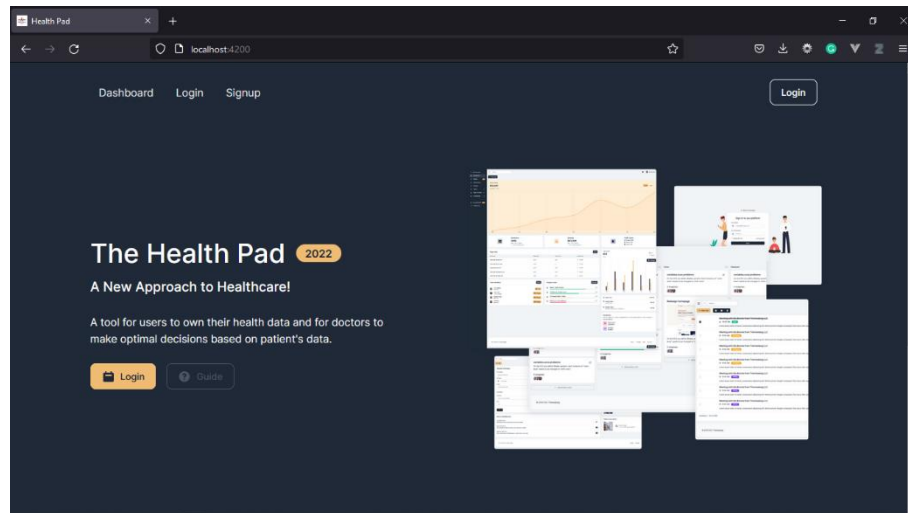


- Discussion: Images and videos can be taken by the device but we need to step up the image and video quality by improving the resolution of the camera.

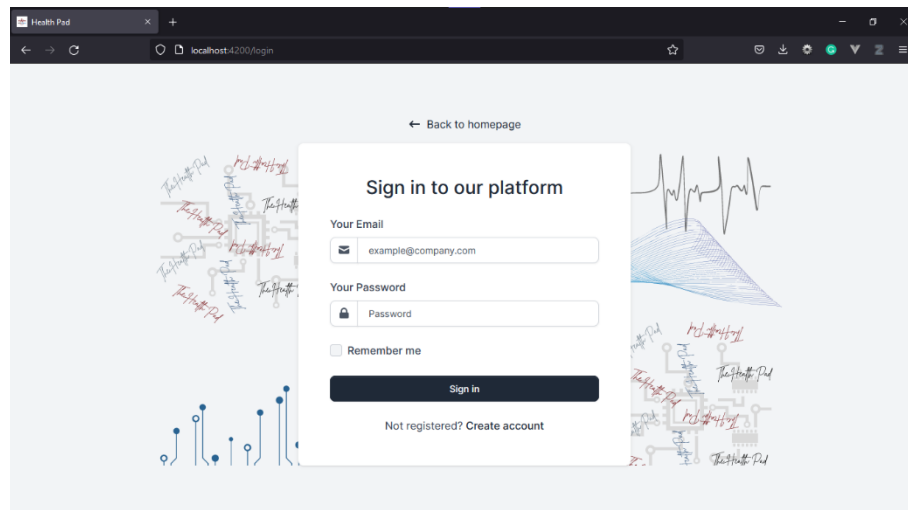
3.2 Web Application

It was our goal to setup a web application for health data visualization purposes. This was done and a few images of the interfaces are presented below.

- Home page:



- Login Page:



- Registration:

In this stage of the prototype, just verified doctors are allowed to use the platform. They are verified using their Cameroon National Order of Doctors ID (L'Ordre National des Médecins du Cameroun – OMNC ID). Patients are not required to enter an ONMC ID

- Dash board:

On the doctor's dash board, upon clicking on the **'Get'** Button of the corresponding parameter, the value is loaded real time from the device's sensor. This is stored against the corresponding patient ID.

The patient can now access all the data when he logs in.

- Discussion:

The application is able to register, login, and facilitated the collection and storage of medical data as required. One of the primary aims was to enhance health data visualization and with the application, this is possible.

3.3 Physical Structure

All the hardware parts were brought together and carefully mounted. We obtained a tablet sized medical device with pots to plug peripheral sensors and devices. The result can be seen in the figure below.



Figure 3.8 The Health Pad - Hardware

- Discussion:

A circuit board was printed and embedded to enable the communication between the Health Pad and the sensors.

Cost Analysis

Below is a table showing the expenses for this prototype.

No	Item	Price (FCFA)	Shipping	Custom Duties	Total (FCFA)
1	Raspberry pi 4 8GB	69000	64000	10000	143,000
2	Raspberry pi 7 Inch touch Display	45000	48000	18000	111,000
3	Raspberry pi 8MP Camera	20000	/	/	20,000
4	DFRobot ECG sensor	13000	/	/	13,000
5	DFRobot Pulse sensor	8000	/	/	8,000
6	16 Bits I2C ADS 1115	2000	/	/	2,000
7	Raspberry pi premium case	10,500	60000	/	70,500
8	PCB circuite design	/	/	/	0
9	Others	40000	/	/	40,000
	Total	207,500	172,000	28,000	407,500

Table 3.2 Cost Analysis

- Discussion

At the moment most of the parts were being bought, they were not available locally and we had to buy them abroad and ship them. This caused the price of realization to almost double. The custom duties could have been waived if I had the signature of a school authority to indicated that the parts were for academic research purposes.

Though this is a fully functional prototype, the price per tablet is fully acceptable. In perspective, we intend to use less expensing micro controllers and print the circuits locally. In addition to this and large-scale production, the table will be affordable for an average Cameroonian doctor.

Comparative study with the Cardio-Pad

Because we think of the Cardio-Pad when The Health Pad is mentioned, let us do a brief comparative study of both systems.

No	Item	Cardio-Pad	Health Pad
1	Purpose	Send Patient's heart data to cardiologist for analysis.	Stores patient's data Realtime in their portal for future use.
2	Access to patient's data	Cardiologist.	Any verified medical doctor.
3	Health data collected	Cardiac rhythm.	Temperature, Pulse, Cardiac rhythm, Picture, Doctor's Notes
4	Target	Patients with heart disease.	Every patient.
5	Data Privacy	Patients don't own and control access as much.	Patients own their data and control access to it.
6	Online Platform	/	Integrated Health Portal thanks to a Web application.
7	Price	3 299 USD	Produced at < 1 000 USD

Table 3.3 Comparative study between The Health Pad and the Cardio-Pad

- Discussions

With this, The Health Pad is undoubtable full of several functionalities that the Cardio-Pad doesn't. Above all, the discrepancy in the estimated price of both items is so large. The Health Pad certainly has potentials for growth and expansion. The health pad stands a chance of easing the process of digitalization of the health system which has for years been a far-fetched issue in Cameroon and most African countries.

Chapter 4

Conclusion and Perspective

In this dissertation, we saw the setbacks in effective health monitoring in most underdeveloped and developing countries. We explored medical processes and we noticed that proper health monitoring begins with good health data collection and preservation. In this light, we designed and realized a prototype, a medical device that improves health data collection, storage and management. Using the right programming techniques and tools, we were able to prove the concept. With the Health Pad, the clinical data of a patient was automatically collected and stored in his health portal. The patient can access his portal to see his medical history. With this, we can proudly say that our objectives were attained.

Limitations

Though we now have a good working prototype, the project experienced some limitations. At the time this is written:

- The device needs to be connected to the internet to properly function. As a result, the pad will not be efficient in areas without internet connection.
- Though very portable, the shape of the device is not very convenient as users will normally prefer a flat tablet.
- At the moment, the device is powered externally thus not suitable for use in areas with extended periods of blackouts.
- In as much as the platform stores and organizes data for future use, it is not yet capable of carrying onboard data analysis and predictions.

Mindful of these setbacks, it is our greatest desire to continue working on this project beyond the scope of this thesis.

Perspective

In view of the potentials engulfed in this project and its capabilities of greatly improving healthcare in Cameroon and Africa, we have the following in view;

- Research and make the system robust even in remote areas that suffer poor internet connectivity and energy shortage.
- Harness the power of data analysis, AI and ML, to analyze patient's data for early prediction and notification of certain abnormalities. These suggested results will go a long way to improve the quality of medical decision made by doctors, and improve the forecasting in the health sector.
- Step up the security level of the application and improve the user experience.
- Improve the form of the pad and make it more esthetically pleasing.
- Explore embedding more sensors on it.
- Explore making the pad from more environmentally friendly materials.

This brings us to the end of this work. We understood the context and the science behind medical technology, we analyzed this system and brought out the tools required for its implementation, we obtained acceptable results and we explored future work to be done on this system. With this, we are certain of the potentials embedded in this device and how instrumental it can be in our various hospitals and health units.

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Appendix A

A.1 Nkwen Baptist Hospital

The first month of my internship was spent at the Cameroon Baptist Convention Health Services (CBCHS), in Nkwen Baptist Hospital. Throughout my medical exposure at this hospital, I had the opportunity to visit thirteen departments. There I observed the medical technologies being used in the healthcare process. A representation of my time spent in the various departments of the hospital can be seen in the chart below. The rest of my internship was done at the incubation center where this work was concretized.

No	Departments	Cameroon Baptist Convention Health Services																													
		28 Feb - 6 March						7 - 13 March						14 - 20 March						21 - 27 March						28 March - 3 April					
		Week 1						Week 2						Week 3						Week 4						Week 5					
		M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S		
1	BME Department																														
2	Theatre																														
3	Intensive care unit																														
4	Dental Surgical Unit																														
5	Laundry																														
6	Electrical Department																														
7	ECG, X-Ray, Ultra Sound																														
8	Neonatal Service																														
9	Ear Nose Throat																														
10	Laboratory																														
11	Software Engineering																														
12	Mechanical Engineering																														
13	Radiology (CT Scan)																														

A.2 The Yale Model African Union.

The Yale Model African Union I was an initiative brought forth by the Yale International Relations Association of Yale University. This conference ran from May 13 to May 15, 2022 in Kigali Rwanda. It brought together students from universities throughout the world to participate in an experiential simulation of the African Union. It provided a platform for young leaders, future diplomats, innovators and changemakers to explore the inner working of the African Union, while practicing international diplomacy, as they assumed the roles of representatives of African countries and non-governmental organisations.

The aim of the conference was to develop participant's understanding of international African affairs and diplomacy on the continent. This is meant to allow these future leaders to become acquainted with the various economic and political dynamics that governs the development and growth of the continent. This conferences also helps the delegates develop their

argumentative and reasoning skills and afford them the opportunity to apply these skills in an environment conducive for their growth.

I was in the committee of Infrastructure and Energy and I was assigned the country Nigeria. In this committee, we were working towards a resolution covering two important and connected issues: Medical technology and Sustainable development. We had two discussion topics:

- i) Developing Technology to Address Medical Crises and Establishing Programs to Ensure Fair Distribution of Medical Technology
- ii) Addressing the Adverse Effect of Climate Change on Infrastructure and Protecting Sustainability Efforts

In the course of this thesis, the first topic was greatly of interest to me and greatly contributed to the development of this work. In addition to these diplomatic conversations and debate, we had workshops. And I took part in the following workshops:

- Globalisation and International Cooperation.
- Entrepreneurship and Innovation.

We heard from world-class experienced professionals. We engaged with other inspiring delegates and came up with resolutions which will be sent to the United Nations for review.

I earned the Honourable Mention Award of this department. More about this program can be found on their website at: <https://www.yalemodelau.org/>

