Remote Patient Diagnosing with Healthcare Sensor Network in Rural Areas, Rwanda

by

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Abstract

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Like many developing countries, Rwanda medical needs outgrew its medical resources. Rural areas are the ones with huge burden of diseases yet with low resources. Limited number of skilled medical workers and lack of infrastructures are the major challenges that rural community faces. The purpose of this work is to develop and design an affordable remote diagnosing system based on Arduino combined with a smartphone, using various health care sensors and open-source frameworks to assist Healthcare Community workers (CHWs) in rural areas of Rwanda. The system can collect and display different vital signs through mobile technology such as Android and transmit the data via mobile wireless technologies, for doctors performing remote diagnosis. The system can also generate alerts and deliver healthcare related educational content to assist CHWs in better decision-making.

Dedication

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Chapter 1

Introduction

1.1 Background

Rwanda healthcare have shown growth for the last two decades. In fact it is now the only subsaharan country in the way to achieve the millennium development goals in healthcare[4]. Rwanda now registers close to 90% 90 per cent coverage of health insurances one of the best in the entire continent[11]. A lot of reforms have been put in place after 1994, and implementing different programs to support the health care systems. For instance, one of the big and most effective program in place is the community health workers. this program has helped in reducing the number of children death and maternal mortality death Through their training on providing basic health care services to patient in their homes[12].The biggest cause of the deaths including: malaria, diarrhea, respiratory diseases such as pneumonia and HIV/ADIS just to name a few[2]. The CHWs program assigns each cells with three CHW, where two in the group named Binome are in charge of basic health care need and children care between the age of 6 and up. the remaining one is in charge of women and newborn care. CHWs has proven to be effective, where it has alleviated the issue of shortage of human resources especially in rural community[3]. It is effective not only by providing basic healthcare to the community but also being a liaison between the citizens to the formal healthcare system.

Despite all the achievement Rwanda has made in the past, but like any other developing country, Rwanda medical needs still outgrew its medical resources. there are still issues that hinders the delivery of healthcare services to all the citizens of the country. those issues includes:

- Limited number of qualified human resource such as Doctors and nurses. In Rwanda there is only one doctor per 15428 inhabitants and one nurse per 1200 inhabitants (NISR Project 2012 census). There is a huge gap in Doctor-to-patient and Nurse-to-patient ration and this result into long queues of patients to clinics and hospitals waiting to get served. Patient might spend a lot of hours and may be days without gating access to a doctor when they are already at the clinic

- Lack of proper and sufficient equipment and tools. Many private health institutions as well as small public health care center in rural areas not only have limitation in numbers of skilled personnel but also limited capability of providing quality health services, and this many because they lack many equipment and tools that help them to do so. this issue also affect the perforce of community health workers, since most of the do not have the kind of tools when performing their diagnosis. for instance, they have to use a watch timer when diagnosing respiratory diseases when counting the number of time a patient perform the inhalation and exhalation of the air in the lungs per minute. Many of the method to diagnose their patients are base to just observing by their eyes and make assumptions basing on the sings observed. Although this might works in some cases, but can also result into making mistakes that can put the patient into danger

- Limited access to information is another great challenge faced by Healthcare systems in Rwanda. The current means of information sharing are between community health workers, clinics and the ministry of Health and they are mostly for report submissions via SMS based platform such as Rapid SMS and Web based platform such as OpenMRS. Currently there are no system in place that can share patient diagnosis information to Doctors or other stakeholders in real time or system that can deliver timely feedback and small Interventions to assist healthcare workers remotely and help them make better decisions.

- In addition to the above challenges, Geographic barriers are also a problem to the community especially those in remote areas. Rwanda is a mountainous country with few basic infrastructures like roads, bridges and other facilities that can allow patient to get quickly to the nearest hospitals or clinics. As per Ulises and Carina analysis, only 26% of the population in Rwanda are within the reach of health care facility by walk, and most of the population in the wester province can not easily access to basic health care needs[9].According to Household HealthCare Access survey conducted by IMS Consulting Group in 2012, it is say that people in resource poor settings areas in a country like India 32 per-cent of people in those areas travels more than 5km to seek OPD (Outpatient Department) treatment

Just to mention a few, these are the main challenges that the healthcare sector in Rwanda faces. and it is more challenging in rural areas due to their poor settings and many other related issues that were mentioned above. The mentioned problems present a big scope that we can not cover in this work due to the short amount of time. In this work we will only focus on how we can effectively use open-source technology to assist CHWs around the country in Rwanda. We want to have a system that can help detect and prevent diseases at their early stages by providing that first step basic patient diagnosis.

1.2 Objective

The main objective of this works is to try and provide the affordable and easy way to the Community Health workers to provide basic and accurate yet being effective diagnosing tools using open-source technologies in rural community.

also to allow them have access to quick information that can make decision making quick and more effective. Learning on the go is one of the most important part of the process that can help in saving more lives and avoid making mistakes which is also this work will be aiming at.

to try and bring together those areas with poor setting to those with more advanced settings such as the big hospitals in the cities. this work will allow CHWs work with Doctors in urban areas in real time. Doctors to perform remote diagnosis and share feedbacks with CHWs to assist them when on the field.

1.3 Structure of the paper

Chapter 2

Related Works

2.1 Mobile care (Moca) for Remote diagnosis and Screening

Moca is a mobile application project that was developed by student at MIT. the system aims at providing diagnosis and screening services in resource poor settings and has been open sourced. with the growing number of mobile coverage in the world, the system uses mobile technologies that allows it to transmit different kind of data format such as: photos, x-rays images, audio files and text to the remote medical expert around the world. medical expert can design the work flow (Question-Answer pair) document and upload it to the mobile app where community health care workers can use to diagnose patients in remote areas. the work flow allows doctors to design effective decisions supports for the community health workers in the field. The system is designed to easily integrated with already existing health care systems such as OpenMRS or OpenROSA for portability and easy access[1].

2.2 Health Care Based on IoT Using Raspberry Pi

To get the information on Non communicable and communicable diseases such as cardiovascular , diabetes and pneumonia is a challenge to many developing countries. Therefore , to overcome these problems some researches started developing low cost medical devices which can be used to assist doctors and health workers to diagnose or get an alert message in case of the emergency . As per (Surya et al 2015), it is demonstrated that by combining raspberry pi , GSM modem and ECG machine doctors and nurses will be able to get the heart beat data from patients located in different room of the hospital in real time through the SMS alert , and web interfaces. However, this system is only designed to provide information of the patients who are already in the hospitals and developing countries like Rwanda need a low cost mobile device that would enables the villages health workers to follow up the patients who are in the remote areas far from the hospitals as well as providing information

to the district doctors in real time[7].

2.3 Measuring ECG signal Using e-Health sensor platform

There has been a growing in huge number of cardiovascular diseases due to many factors including the today's stressful life. developing low cost technologies that measures the heart electrical activities to diagnosis such kind of diseases have been a trend. According to (Onder et al 2014), a system that is based to a single board using a Raspberry Pi and and the e-Health kit was developed to mostly measure the ECG signal of the heart. The system is equipped with a SD-card as a means storage unity to store the measured data before they are transferred to a computer to be processed. Heart Rate (HR) and Heart Rate Variability (HRV) are then extracted from the data with Matlab environment program on the computer that utilizes different algorithm for further investigation on the obtained data[10].

This study is provided as the first step for the future studies in patient monitoring with cardiovascular diseases. It provides the basic procedural processes in collecting patient physiological information and practices in processing the data for heart diseases diagnosis but it does not provide a clear evidence on how the system should be used neither the environment.

Chapter 3

Solution

To achieve our objective, in this work we tried to focus on the day to day activities of the CHWs. The purpose is to analyze how they carrie out their activities, what information they get when treating their patients and how they link back time to time in the health care system.The figure below describes the current work flow of the CHWs.

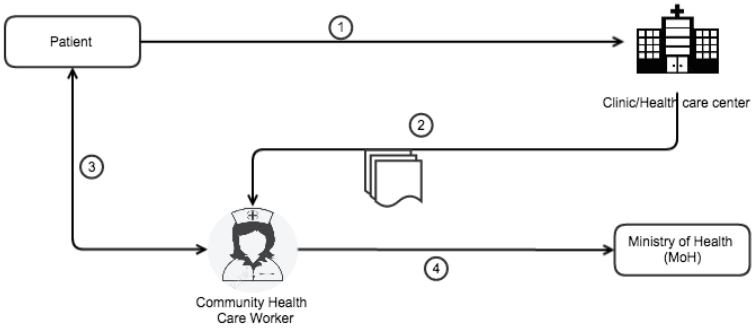

Figure 3.1: Current CHWs work flow

As the figure shows, the first step consist of a patient getting the first diagnosis by an actual clinician at the nearest clinic. The diagnosis information are then shared with the CHW living in the same or nearest vicinity with the patient. The figure also show how the information are shared only with the ministry of health in the form of reports. As mentioned above, this flow has improved the health condition of the citizens since there is that continuous and regular health service delivered by CHWs, but there are still room to improve and make it more effective.

Before getting access to a particular doctor, more emerging diseases resistant to drugs due to rudimental health care practices and eventually deaths. In developing a solution for the outlined issues, an hypothesis was developed on how mobile technologies and health-care sensors can be combined to improve community health-care values. The application of internet of things in health-care have been trending around the world where we see a lot of

solutions emerging trying to solve various issues. In Rwanda the Ministry of Health (MoH) and its partners have implemented different systems around health-care to support in the better management of activities around the country including few SMS applications such as the RAPID SMS platform that provide simple sms application functionalities that allows CHWs to conducts monitoring of women during their pregnancy, in the period of delivering and also for a short period of about one year after the baby was born. Currently in Rwanda there is no evidence of a developed project where health care sensors are used to collect different physiological data of a patient and share it in real time with a doctor for further analysis and decision making. the current existing methods patient are require to visit the doctors in order to know what it is going on in their health or CHWs use their ineffective tools that can measure some few vital signs with a huge margin of errors that can put the patient in danger and can result in bad treatment of certain diseases.

To measure our hypothesis, a one of a kind system is developed using IoT technologies. To have more impact on improving the health status of the community in rural areas, this system is developed to be used by CHWs in their every day activities. The developed solution in this work is to enhance the existing system by allowing bidirectional flow of information between CHWs and experienced medical workers. By using open source technology, the solution will solve the issue of lack of proper and accurate diagnostic tools by CHWs. The figure bellow shows how the solution will enhance the existing CHWs by allowing them to have access to more relevant tools and information to help them to make more important interventions and make quicker and effective decisions.

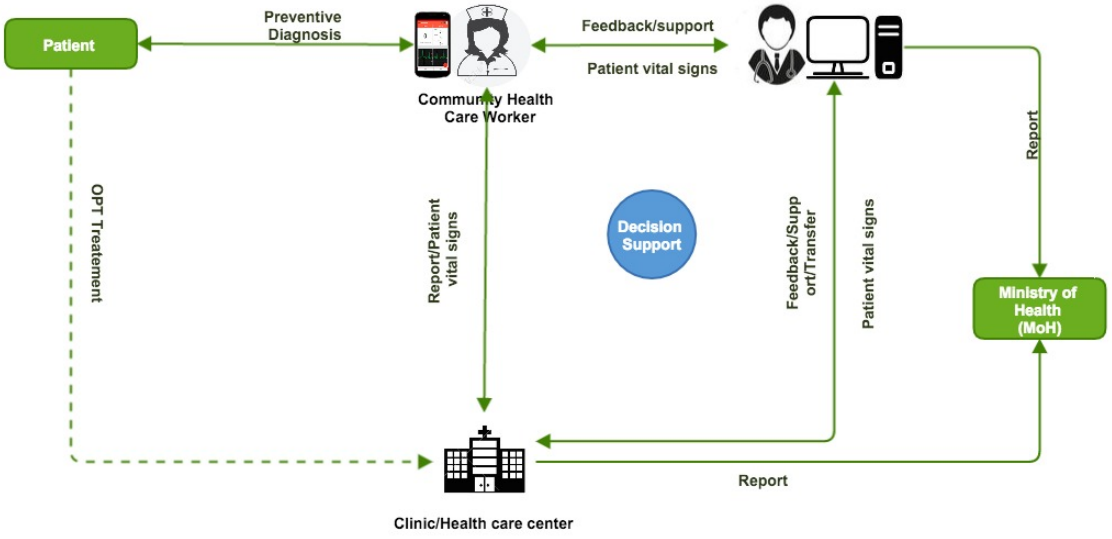

Figure 3.2: New proposed CHWs work flow

Chapter 4

System Design and Development

4.1 Introduction

A remote monitoring system prototype has been developed (RDS) by combining mobile communication technologies and health care sensor networks. The system is built on top of open-source frameworks and its written in three different languages to meet all the requirements including Java, Python and C language. In this work, a minimum viable product has been developed to achieve the objective of this research. A first version of the prototype system is divided into four main parts:

- A health care device formed buy Arduino UNO board and a third party Health Version board shield. This device can accommodate different kind of health sensors that can collect different health vital signs. for the scope of this work the prototype only have three sensors including temperature sensor, SPO2 sensors and an Electrocardiogram (ECG) sensor

- An android smartphone device with a custom coded android application. This app is used to process the information from the health device and display the diagnosis content for the CHWs. A smartphone was chosen for this work since it has more addition free sensors. for instance, Global Positioning System (GPS), Camera and Mobile connections technology are used to collect more information about the patient and patient environment such as location information. the device also play an important role in delivering information to the remote Doctors for remote diagnosis and as well as to the CHWs

- A cloud application (Dashboard) is developed with a centralized database that stores information from the CHWs health devices. the dashboard categorizes the data and plot them to make them easy readable. It allows the Doctors to access the data and performs the diagnosis to generate final conclusions about the patient health status. Through this application Doctors can communicate directly to CHWs through their

smartphones Through communication technologies that forms the forth path of the system

- Finally, a communication part that is based on the google cloud messaging (GCM). this part allow the system to provide instant real time messages. Doctors can push messages without living the application environment, messages such as feedbacks, small intervention assistance and other to the mobile phones

4.2 System Architecture

The figure below shows the system architectures including and the main building blocks of the system.

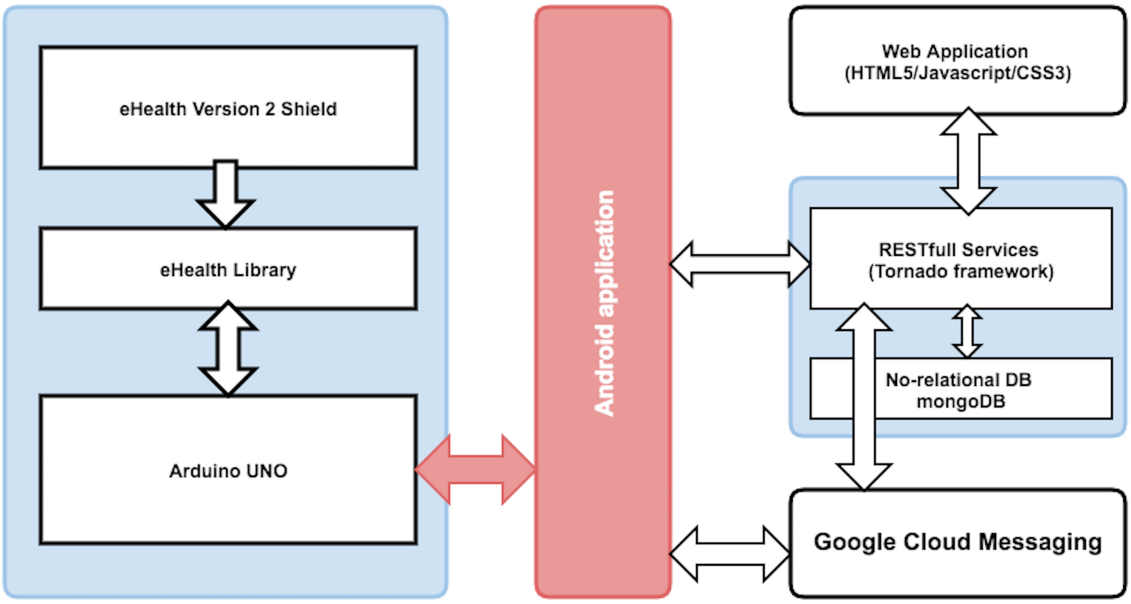

Figure 4.1: System Architecture

In this work a portable health device is developed for HCWs that can plug into into mobile smartphone device. the concept as it shown in the system architecture figure above is to provide a full stack diagnosing tool based on mobile wireless communication by leveraging already existing technologies. The system is formed by four parts as it is mentioned above. (1) part one with is a health device with three different sensors and responsible of collecting different physiological data. this device consist of an Arduino UNO micro-controller that act as an interface between the device and the second part which is the Android device and application. the communication between the micro-controller and the android device is through USB with the use of build in Android USB HOST Libraries, (2) The android application act as an information display and relay to the third part of the system which

act as the base station using mobile wireless technologies. (3) the web application consist of GUI, also this part is responsible of storing data, process and categorize them for better management, (4) the third part is linked to third party communication APIs that allows it to send back instant messages to the mobile device.

4.3 Sensors

As it is mentioned in the system architecture section, the system has three different sensors. Each sensor node measure different type of physiological information. In addition to this three sensors, the Android devices that is used to collect and display the data is also present with different sensors and some of which are used in this works to collect more information about the patients and there environment.

1. **Temperature** Sensor: this sensor is used to measure patient body heat, this sensor can be place to the patient skin such as on the finger or on the leg
2. **SPO2 (Peripheral Capillary oxygen saturation)** sensor: this sensor is responsible of estimating the percentage number of oxygenated hemoglobin compared to the total amount of hemoglobin in the blood
3. **ECG (Electro-Cardiogram)** sensor: this sensor is comprised with three electrodes positive, negative and neutral electrodes, that are placed on the patient skin. this sensor is responsible of measuring the electric activities of the patient heart for a certain amount of time

The Sensor devices mentioned above are responsible of monitoring different physiological data of the patient. The table bellow show the specifications of various physiological data that are measured by the sensors.

Parameters	**Specifications**
Body Temperature	Hypotermia: <35°C Normal : 36.5°C to 37.5°C Hyperthermia/ Fever: >37.5°C to 38.3°C Hyper pyrexia: >40.0°C to 41.5 °C
Oxygen saturation in blood (SaO2)	0% to 100%
Electrocardiogram (ECG)	Frequency: 0.5Hz – 100 Hz Amplitude: 0.25 – 1mV

Table 4.1: Various vital parameters measured by the sensors

4.4 Design and Implementation process

4.5 System Requirements

The designed system is highly described in the above sections of the chapter 4. in this section will try to describe basic requirements for each component of the system to allow the fulfillment of required use case scenarios.

n addition, the system was build around open-source frameworks and eHealth version two kit that was selected to experiment and test out our hypothesis.

- To allow the CHWs have the tools, in this case sensors and have the applied to patients. Requirements:
    1. eHealth version two kit, This kit must allow all the selected sensors and collect all signals from them
    2. Arduino Uno micro controller, The Arduino should have all the logic and functionality to process the data
    3. eHealth Library software, this library is integrated to allow the eHealth kit to work with Arduino micro controller, in addition this library should facilitate the customization and calibration of sensors
- The system should allow the CHWs to visualized the data collect from the sensors and act accordingly. For better decision making the system should also have the capability of sending the data to remote Doctors for further analysis and generate feedbacks to assist CHWs. Requirements:
    1. A smart phone device that runs android version 4.0.3 (Ice Cream Sandwich) and higher is required
    2. To connect the Arduino Uno to the smart phone An OTG cable is required for transferring the data from the micro controller to the smartphone. In addition, this cable will allow the smart phone to power up the micro controller
    3. Google Cloud Messaging (GCM) libraries and configurations, to allow the smart phone to generate alert and notification for The CHWs
- A cloud based application (Server Application) should be implemented to store and analyze data for the Doctors to judge and make some form of conclusions. Requirements:
    1. RESTFull server with minimum data manipulation web services with some business logic
    2. no-relation database system (Mongoldb Database) to store the big data generated by the sensors and integrate different resources from different third party APIs

The above requirements are designed to develop a minimum viable product functionality of the prototype. They are also designed to achieve the goal of building a cost effective system that can allow the HCWs to detect and prevent illness at their early stage. Hardware and software details will be discussed in the following points according to the requirements specified in this section.

4.6 System hardware

eHealth version two kit Shield Board

The eHealth sensor shield platform was developed to be used in the health care sector. the board can be interfaced with different other micro controllers such as Arduino, and a full stack mini computer such as Raspberry Pi. The board was build by cooking hack and can support 10 different health care sensors: body temperature, pulse and Oxygen saturation in blood (SPO2), electrocardiogram (ECG), Airflow sensor, glucometor, galvanic skin response, blood pressure sensor, accelerometer (Patient position) and electromyograph sensor(EMG).

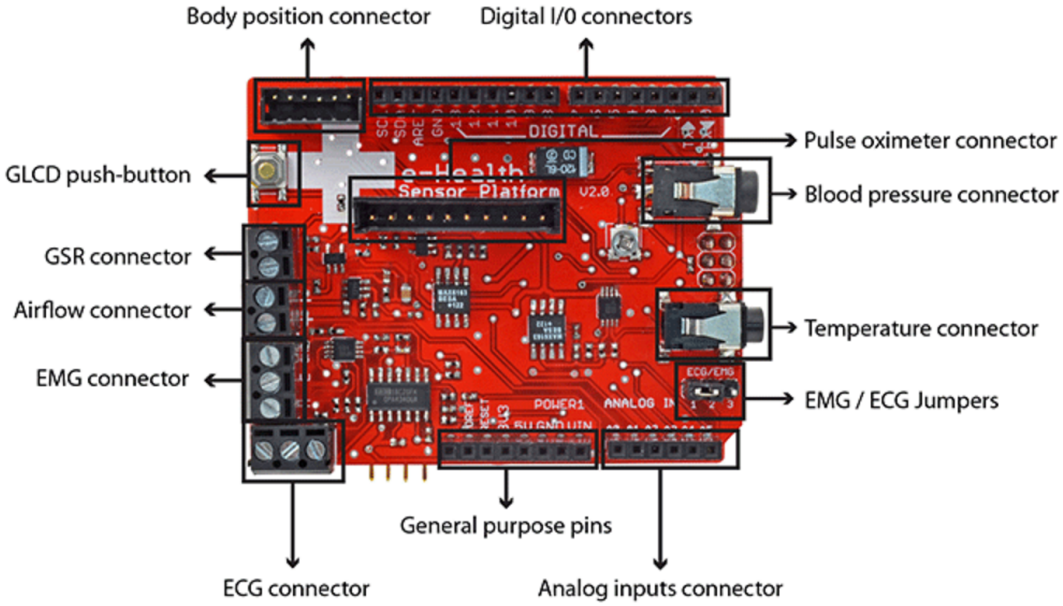

Figure 4.2: eHealth sensor shield platform

The board is also capable of supporting a number of communication protocols such as wifi and bluetooth shield board to exchange data with other devices or cloud applications. in this work only three sensors body temperature, ECG and SPO2 sensors were selected to conduct the experiments and implement the prototype.

Arduino UNO

The RDS health device is based on Arduino microprocessor technology. The Arduino is the core part since it is used to collect and process the data from the sensors through the health sensor shield board.

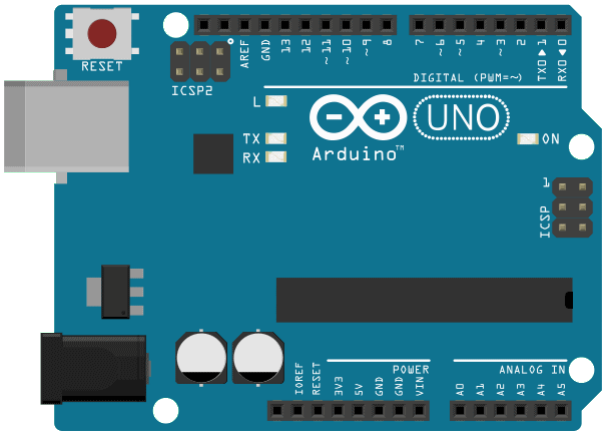

Figure 4.3: Arduino UNO micro controller board

The figure two above show the Arduino board used in the system. It provides the environment that is easy accessible and compatible to the Android environment. The eHealth shield sensor board shield was build on to work with Arduino board and its health library is easily integrated in the Arduino development environment (IDE). The figure bellow shows the Arduino Uno specification requirements used in the system.

Parameters	**Specifications**
Microcontroller	ATmega328P
Operating Voltage	5V
Input Voltage (recommended)	7-12V
nput Voltage (limit)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
PWM Digital I/O Pins	6
Analog Input Pins	6
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328P) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328P)
EEPROM	1 KB (ATmega328P)
Clock Speed	16 MHz
Lenght	68.6 mm
Width	53.4 mm
Weight	25 g

Table 4.2: Arduino Microcontroller Technical specification[6]

USB OTG cable

USB OTG cable is a special USB cable using standards that can allow an android smart phone connect and communicate with peripheral devices. USB OTG (USB On The Go) was developed to give a mobile phone the power to enable other devices, by enabling USB host feature on the android phone. A smart phone with a USB host enabled acts a hub to all connected devices and can be used to addition devices such as keyboards and other devices.

USB OTG cable was used in this work to enable the smart phone as the gateway and can read and process the information from the sensors through the micro controller.

Android smart phone

The android smartphone (Samsung Galaxy S4) unit is used to read data from the health sensors using OTG cable as an interface. By using the smartphone processing power the custom made application processes the data and visualize them on the screen for further decision making on the ground by CHWs. In addition, the addition smartphone sensors are used to collect more information such as GPS and camera. Also it can temporarily store data locally in a SQLite database as a transitional database before sending data to the cloud for avoiding loss of data in case there is a network problem. The OTG cable was chosen

not only to transfer data back and forth between the android smartphone and the e-health device but also to pawer the e-health device with the smartphone battery. the following table show the specification of the smart phone used in this study.

Parameters	**Specifications**
Screen size	5.1 in
Storage	16/32 GB internal, MicroSD slot up to 128 GB
Operating System	Androind Kit Kat
Battery Life	Up to 21 hours talk, up to 67 hours music
Camera	16 MP primary, 2 MP fron-facing
Processor	Qualcomm MSM8974AC, Snapdragon 801, Quad-core 2.5GHz krait 400

Table 4.3: Android smartphone technical specification

Server hardware

The server computer will be used to host the web application and store the data from the mobile smartphone. The server computer hardware will be able to handle all the request form the authorized users and have the power to perform or complex data manipulation. the following table show the minimum requirements of a ubuntu server.

Install Type	**RAM**	**CPU**	**Hard drive space**	
			Base system	**All tasks Installed**
Server(Standard)	1 gigahertz	512 megabytes	1 gigabytes	1.75 gigabytes
Server(Minimum)	300 megahertz	192 megabytes	700 megabytes	1.4 gigabytes

Table 4.4: Recommanded minimun Lunix server requirement

In this study a ubuntu server was used with ubuntu version 14.0.0 . for storing the data a non-relational database Mongodb was configured to save the data as collections in a non-relation fashion. The server is also configured to host a python server application with several other python package for data visualization and analysis.

4.7 System Software Design and Tools

In this section Software design and components are discussed in more details. Tools as well as libraries used in different levels of the system will be also discusses with the functionalities they implements. Sample codes to show some of the functionalities may or may not be shown here to be found in the code snippet on appendix pages.

e-Health device

The device is build on top of the e-health board kit that was developed by cooking hack, and it comes with a number of sensors. The kit is bundled with a library that provide build-in methods functions to collect and gather data from the different sensor node. The diagram below illustrates the software building block and the information flow mechanisms of the designed device. The device is compatible with Arduino micro-controller and Raspberry pi. In this study we chose to work with Arduino in this study for its many advantage it brings such as interfacing with a smart-phone easily and also provides an easy to use programming environment.

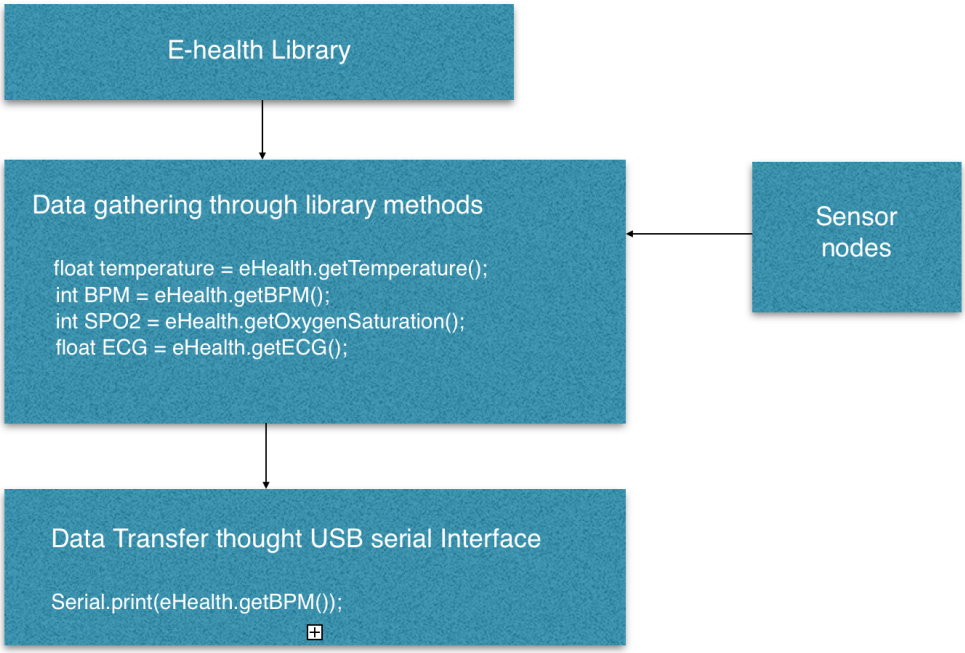

Figure 4.4: eHealth device building blocls and algorithm design

Arduino IDE is used to write functionalities that allow to access to sensors and collect sensor readings through the eHealth library that is written in C++. The IDE is also used to alter the library code to enhance the sensors readings. More libraries where used such as

serial-communication library for the Arduino to communicate with the mobile handset via bluetooth communication protocol for further experiments.

Android Application

Android Studio IDE was used to write the android application that reads data from the Arduino micro controller via the OTG cable in the form of bytes. Android Application is written using Java for android and uses a number of open-source such as the google play services library for notification often called Google Cloud Messaging Library and the OKHttp android library for data transmission over the internet to the cloud application. With the use of OKHttp android library the android smart-phone does not only used to read information, process them and to store them temporary but also as a hub between the sensor devices and the cloud application. The diagram bellow show the class design diagram of the android application. The diagram show all the minimum viable functionality of the prototype and all third party services to enhance its usability.

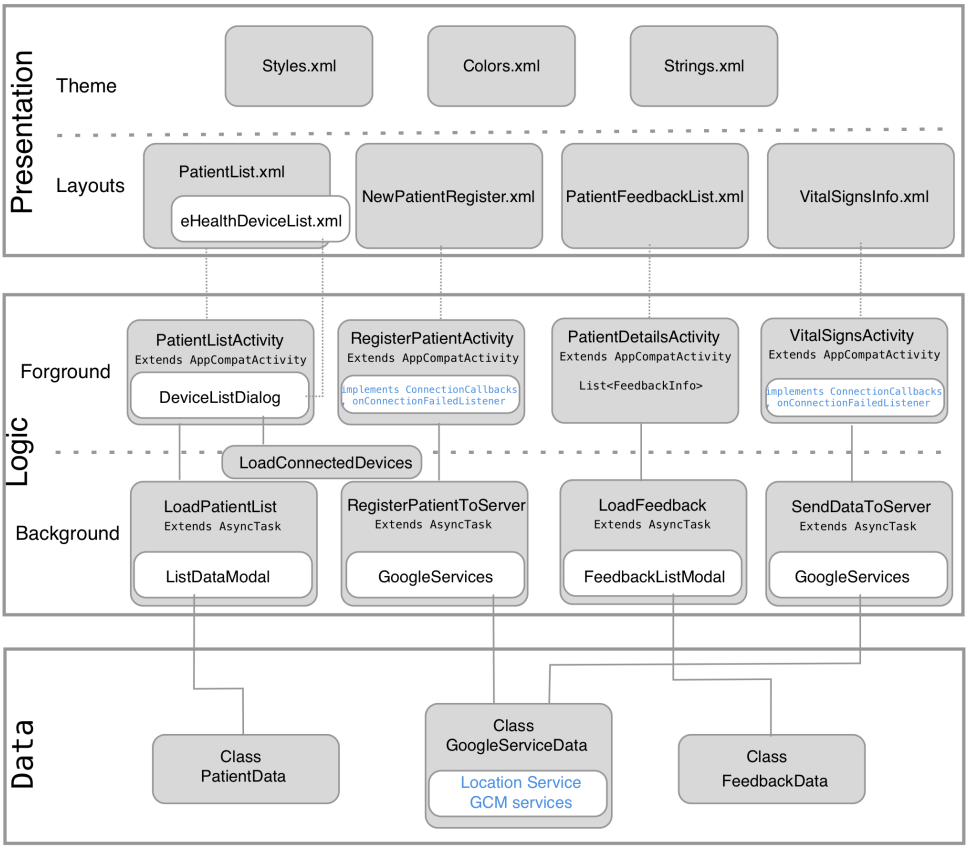

Figure 4.5: Android Application software design classes

Server Application

the server application is responsible of providing more capability of processing and storing data in a more fashioned way. As described in the previous chapters the cloud application uses web technologies and this allows the dashboard application to be accessed easily on different devices that are connected to the internet. Allowed medical Doctors and Nurses can access information at any time and provide the assistance to CHWs through the same cloud application. The following diagram show the major components of the cloud applications and the processes involved in charing data with the Android mobile application.

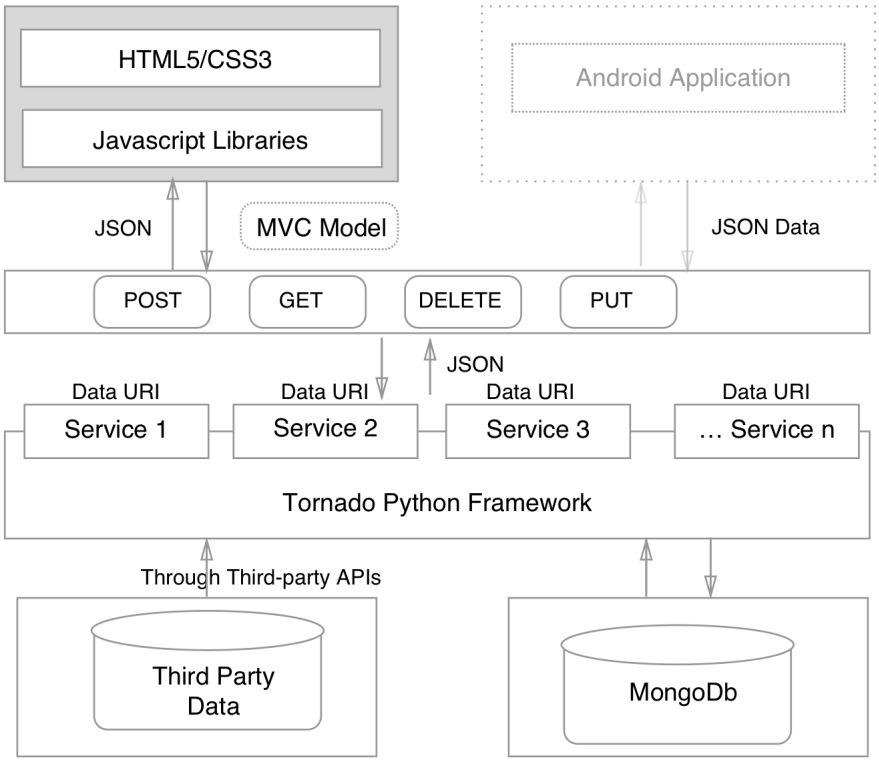

Figure 4.6: Server Application design diagram

The figure above shows for every components the technology associated. The web application is build using python and takes the advantages of the python data processing capabilities. The basic aim of the web application is to provide the linkage between the experienced Doctors and nursers after further investigation on the data is carried out. The technologies illustrated in the above figure was chosen to make the data access and processing smooth and easy to ready including:

1. The entire application is build on top of RESTful services. As Roy Fielding introduced REST (Representational state transfer) in his Doctoral dissertation, REST provides

a component based style with a clear interconnection of the components as well as the data exchange between the components. The distributed comments of the system communicate but not always through HTTP (HyperText Transfer Protocol) and with the help of different REST and HTTP verbs like GET, POST, PUT and DELETE components can request through data URIs (Uniform Resource Identifies). for instance, GET /data/api/v/56779f77b38b4664dcf6d165 shows a data URI to get information of a particular patient when Patient ID number is provided[5]

2. **Tornado**: is a python web framework that was developed original by FriendFeed. It is an asynchronous network library and it can handle many open connection due to its using non-blocking network I/O. Tornado was chosen in this work for it provides the capability of developing a distributed components based architecture, and it is suitable building data intense real time web applications dues to its supports of long pulling and web sockets. the following code snippets shoes an example of a simple Tornado application

```
import tornado.ioloop
import tornado.web

class MainHandler(tornado.web.RequestHandler):
    def get(self):
        self.write("Hello, world")

def make_app():
    return tornado.web.Application([
        (r"/", MainHandler),
    ])

if __name__ == "__main__":
    app = make_app()
    app.listen(8888)
    tornado.ioloop.IOLoop.current().start()
```

Figure 4.7: Tornado python framework application skeleton

3. **mongoDB** module was used to store the data from the android mobile application and to update the website. The information are stored into collections and each patient entry is classified as a document in the patient information collection. MongoDB is an open source cross-platform non-SQL database, in other words it is a document-oriented databases since it avoids the familiar SQL based databased structure of the table based and relational based databases. mongoDB makes the integration of data into application more easily since it provides data into JSON-like formants in the form of documents. Its flexible schemas allows the integration to store different kind of information in one place with key-value format [8].

Chapter 5

Result and Discussions

Chapter 6

Conclusion

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