Journal of
Health & Medical Informatics

ISSN: 2157-7420

Research Article Open Access

Development of a Mobile Monitoring System for Asthmatic Patients

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Abstract

Chronic diseases are leading to high cost of health care. Adoption of mobile phone with the evolution of real time monitoring of patients in their locality using sensors can reduce the rate of death occurrence from asthma. This paper presents a wearable sensor for monitoring heart rate, air quality, humidity and temperature known for triggering asthma attack. The system design and the architecture involve the relationship between the wearable device, the mobile device, the central storage and the stakeholders. The experimental testing from this system revealed that mobility monitoring devices are very feasible for monitoring the daily health status of an asthma patient.

Keywords: Asthma; Patient; Mobile; Sensors; Arduino

Introduction

In recent years, heart disease has been a major widespread public health problem in most countries. The healthcare system is experiencing a paradigm shift from standard clinical procedures to personalized assessment and treatment. With this new model of health care, doctors/ physicians can measure the dynamics of ailment progress, calculate health risks, tailor individualized therapeutic protocols, as a result, effectively reduce costs of giving and obtaining health care. Treatment of chronic diseases, especially those involving respiratory disease could significantly benefit from such efficient and inexpensive approaches.

Asthma in the world today is a widespread chronic respiratory ailment which involves the lung. According to the World Health Organization asthma is a serious public health problem with over 100 million people suffering from asthma worldwide. It is characterized by variable and recurring symptoms, reversible airflow obstruction, and bronchospasm. Symptoms include occurrences of wheezing, coughing, chest stiffness, and shortness of breath.

Asthma remains associated with significant preventable morbidity and mortality. Self-management aided by a healthcare professional is imperative to keep signs controlled and to prevent exacerbations. Bergstrom et al. stated that 62% of children died of Asthma in 2008 [1]. The real time and remote monitoring by the doctors in conjunction with smartphone applications for the children and its caregivers can prevent some of these deaths [2].

Traditionally, the hospitals and health clinics use spirometer and peak flow meter to identify any signs or symptoms of asthma. Peak flow meter will monitor the strength of lung exhalations by measuring the air flow in one breath cycle. The recorded value is Peak Expiratory Flow Rate (PEFR) which is used to determine the severity of bronchospasm and the degree of airway obstruction of the patient. Using all this information, the doctors are able to monitor and determine the asthmatic condition. Patient need to take a deep breath as deep as they can and then blow hard as fast as possible and repeat the process about two to three times. However, this method brings some negative feedback to patients as they feel dizzy after use the device. It is a very patient dependent tool and patient must give full cooperation so that the device will be able to detect the clinically important reduction.

On the other hand, the proposed asthmatic monitoring system will be capable of monitoring patient ubiquitously, since the system makes use of wearable sensors on the patients. In the case of extrinsic asthma, the sensors is able to collect patient's environmental data and send wirelessly to a connected mobile application that will analyze and make some expert decisions based on the information gathered from the sensors. These expert decisions based on predefined rules, could be to alert the patient of imminent danger or to send short message service (SMS) to third parties (hospitals/Ambulance and so on). Dinko Oletic et al. estimated that by 2025, the number of patients with asthma will grow by more than 100 million [3]. With this rising prevalence, the expenditures of healthcare system for patient treatment are expected to rise, together with workload of the medical staff [4].

Literature Review

Possible candidates for physiological function monitoring in asthma include respiratory rate (both frequency and duration of respiratory phases), heart rate, SpO_2, and detection of wheezes with wheezing being most specific symptom for asthma. For the purpose of this project, only the heart rate of the patient is important to us.

The Figure 1 depicts the basic interactions and dataflow within a mHealth system comprising of the patient in his/her locality transmitting with sensor and mobile phone his/her health data over the air through Bluetooth, internet and Wi-Fi to the stakeholders (specialists, family and so on).

Gizem et al., designed a split-ring resonator-based strain sensors characterized for glaucoma detection application. The authors' focus was to design and fabricate a SRR-based sensor, simulate and experimentally characterize the SRR-based sensors. They made use of a silver conductive paint to form the sensors realized on flexible substrates made of cellulose acetate and latex rubber. Their approach to the system development was to measure the scattering parameters

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Received December 10, 2018; **Accepted** January 03, 2019; **Published** January 18, 2019

Citation: Fasidi FO, Adebayo OT (2019) Development of a Mobile Monitoring System for Asthmatic Patients. J Health Med Informat 10: 324.

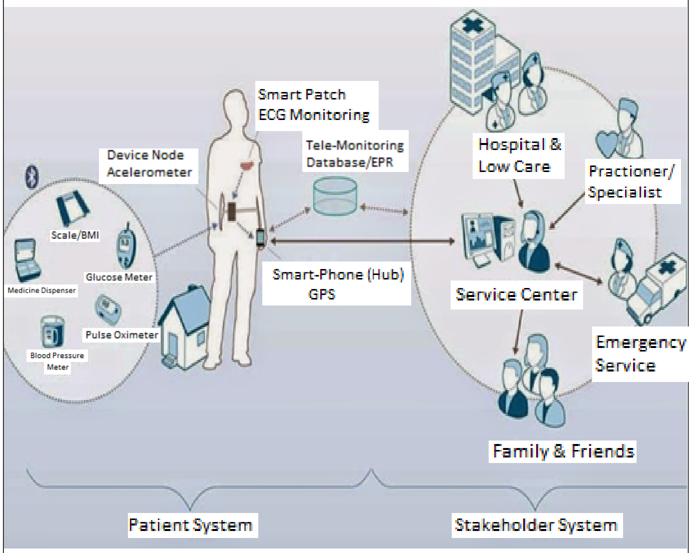

Figure 1: mHealth Ecosystem

between the ports of the antennas, and obtain the characteristics of devices with different curvature profiles, excite and interrogate the devices using a pair of monopole antennas and finally develop finite-element based models to analyze the operation of the devices and to optimize the sensor structure. The authors contributed to knowledge by fabricating a glaucoma-detecting SRR sensors using silver conductive paint. The limitation of the system was that the SRR device method is not a novel method for continuous monitoring of glaucoma [5].

Fuchao suggested in a publication of the Department of Health and Human Services that in order to keep glucose at a healthy level, people with diabetes need to keep a balance between three important aspects: diet, exercise and diabetes medicine in daily routine. He then developed a mobile personal health care system for patients with diabetes. His objectives were to develop a mobile health care application and integrate the application with a wearable sensor. He made use of Android SDK for developing the mobile app [6].

Jongyoon et al. suggested that a wearable system suitable for ambulatory stress monitoring must strike a balance between two criteria: information content and comfort. They worked on ambulatory stress monitoring with minimally-invasive wearable sensors. Their objectives were to build a platform that employs minimally invasive sensors, hardware miniaturization, and wireless technologies, and can record uninterruptedly for periods of up to thirteen hours a number of physiological variables known to be influenced by stress [7].

Nur Ilham and Malarvili worked on the design of an asthmatic severity monitoring tool. They focused on designing a GUI (Graphical User Interface) to detect the severity of asthma by using MATLAB software. Their research method started with gathering relevant and detailed literature review on the capnography, then, the GUI layout was designed first before implementation process by using MATLAB software. Last step was GUI optimization by adding up patient information and patient medical background parts. They were able to development a GUI to detect and monitor the severity of asthma [8]. While their tool was a simple one, its limitation was that the complete monitoring tool was not produced to monitor severity of asthma; the GUI can only analyze carbon dioxide (CO_2).

Virone et al. proposed system architecture for smart healthcare based on an advanced Wireless Sensor Network (WSN). It specifically targets assisted-living residents and others who may benefit from continuous, remote health monitoring [9].

Mansingh et al. worked on real-time monitoring and detection of asthma symptoms on resource-constraint mobile device. They stated that advanced technologies in portable devices such as phones and wireless body sensor systems present open doors for consistent monitoring of patient's health condition and transmission of observed data to medical experts. By utilizing the capabilities of internal sensors, smart phones can serve as veritable assistive tools for monitoring and alerting asthma patients and their care providers on early symptoms of asthma exacerbation [10].

Narendra et al. proposed a remote healthcare monitoring system using wearable sensors. They stated in their work that due to advancement in technology a low-power networked systems and medical sensors are merged as Wireless Sensor Networks (WSNs) in healthcare [11]. WSN constitute a new means to address the issues of managing and monitoring chronic diseases, elderly people, post-operative rehabilitation patients, and persons with special disabilities. Wearable sensors are attached to the patient body forming Wireless Body Area Network (WBAN) to monitor changes in patient's vital signs closely and provide real time feedback to help maintain an optimal health status. The sensors sense physiological data from the patient's body and wirelessly send them to the microcontroller using radio transceiver. The microcontroller controls the functionality of other components in the sensor node and processes the sent data locally [12,13].

Materials and Methods

The wearable device was designed using Proteus Virtual System Modelling (VSM) software and implemented using an arduino board, sensors and connecting wires for signal flow, programed using C programming language. A mobile application was also developed using MIT app inventor online software, then cloud storage was incorporated for storing the patient's vital signs and location as they are being measured by the wearable device in real time. The major approach to actualizing this is interfacing the mobile app with the wearable device *via* Bluetooth, and storing the data collected unto central cloud storage *via* the internet. In order to sense the patient's data both the patient's vitals like heart rate and environmental factors like humidity, different sensors would be used to retrieve these data [14,15]. These sensors include;

i. **Humidity sensor:** It measures of how damp or moist the surrounding air of the patient.

ii. **Temperature sensor**: It reads the temperature of the patient's environment.

iii. **CO_2 Sensitive sensor**: a sensor that detects the CO_2 level in the surrounding air.

iv. **Localization sensor:** This is the GPS receiver of the mobile phone, which tells the exact location of the patient at any instance of time.

Real-time information retrieval

In order to retrieve the sensors' data, a mobile application was developed. The application will run on a smart phone and retrieves the data wirelessly using Bluetooth Low Energy (BLE) technology as communication standard. These data are being processed by comparing it with some pre-defined values in the application's instruction and gives an output that would be determined by those values.

Emergency response

Should any deviation from the normal factors threshold of the environmental parameters like temperature level, humidity level and so on which can ultimately trigger an asthma attack, the mobile application will immediately notify the patient of his/her health status and environmental threats and/or send an alert message including the patients location coordinates and address to some predefined numbers on the system based on the application logic rules.

Development tools

During the development of this system both hardware and software tools were incorporated.

The software tools include:

Arduino ide

The Arduino Integrated Development Environment (IDE) is the development environment for Arduino sketches. It is based on C/C++ without 80% of the instructions. It contains a text editor for writing code, message area, a text console, a toolbar with buttons for common functions and a series of menus. It connects to the Arduino hardware to upload programs and communicate with them. Arduino programs are called sketches (arduino.cc, 2018) (Figure 2) [16,17].

Components of the architecture: The architecture is three tier architecture which involving:

i. **The first tier:** This level of the system architecture is the locality of the wearable user (patient). This tier is made up of the body sensor (wearable) attached on the body of the patient, preferably the patient's wrist and a smartphone with the "SaveMe" mobile app installed on it.

a. **Sensor node/body sensor:** Sensor node as the "player" in the first tier of the asthma monitoring system architecture is a collection of different sensors interconnected through buses. It is a node in a sensor network that is capable of performing some processing, gathering sensory information and communicating with other connected nodes in the network. In the case of our project, a distinct wearable with three on board sensors act as the sensor node for data gathering. These sensors include:

1) An optical pulse sensor

2) Temperature and humidity sensor (DHT11)

3) MQ135 gas sensor

The wearable interface with the mobile application and the stakeholders in the third tier of the architecture *via* Bluetooth and Short Message Peer-to-peer Protocol (SMPP) respectively; The wearable in its design contains a SIM card module and a Bluetooth module for communication.

b. **Mobile app:** Smartphones specifically android phones make use of some special mobile application to communicate directly with the wearable visualize the patient data and send the data to a central storage (Cloud). In view of that, an android mobile application will be developed using MIT App inventor. The app will reside on the patient's android mobile phone, its purpose is to display the data from the wearable in a readable and understandable format to the user (patient) and push the data including the patients location and address to the cloud *via* internet so that the stakeholders in the third tier of the architecture can access the patient data for proper diagnosis of the patient. This mobile application communicates with the wearable *via* Bluetooth and reach to the cloud *via* internet.

ii. **Second Tier:** The component ("player") in this tier is the central storage (cloud). The cloud storage used is the Google firebase. Data from the mobile app are pushed to the cloud. Authenticated users (stakeholders and the patient) access the cloud storage *via* the internet. The stakeholders in this case need the cloud for analysis, diagnosis of the patient and decision making.

iii. **Third tier:** This tier of the asthma monitoring system architecture is a composition of important people to the patient's heath, these people/stakeholders are external to the system that is; they do not communicate with the wearable locally. These people/stakeholders include; family, friends, doctors, hospital personnel, asthma specialists, police and ambulance/rescue service responsible for diagnosing and saving the patient through received patient's vitals, patient's location and address, warning and emergency alerts from the mobile device and wearable in the patient's locality.

The purposes of the stakeholders are to save the asthma patient from cardiovascular attacks whenever the wearable detects an exacerbation in the patient's vital signs and make suitable decision and recommendation from the diagnosis for proper health management, then provide quick help to the patient by locating the patient using the received current device location and address (Figure 3).

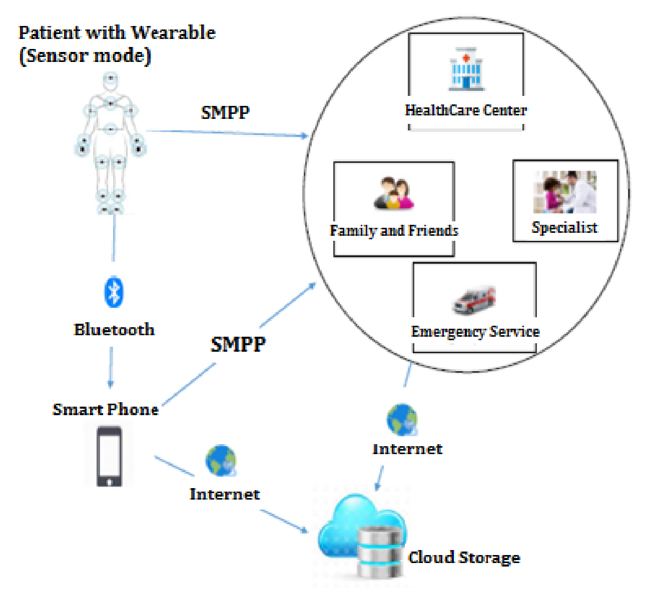

Figure 2: Architecture of the asthma monitoring system.

System implementation

Implementation phase of a system is the next phase to be considered after a successful design of the system. It involves the process of defining how the system should be built (i.e., physical system design), ensuring that the system is operational and used, and ensuring that the system meets quality standard (i.e., quality assurance). The main purpose of implementation is to construct system elements that meet the requirement developed in the early stage of the system life cycle. These elements are then integrated to form intermediate aggregates and

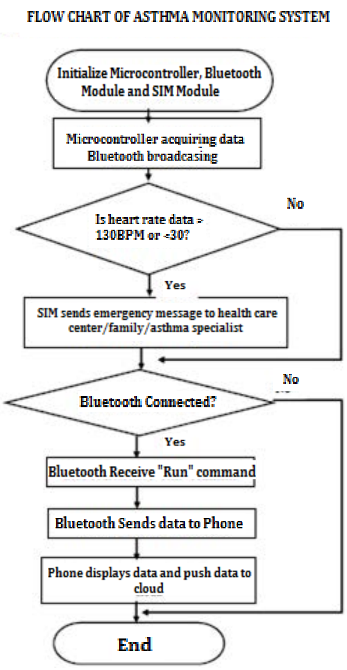

Figure 3: Flow chart of the asthma monitoring system.

ultimately the system desired system. Testing of the system follows after the implementation, testing is done to measure the system conformity to specification and to ensure ease of use by users of the system.

The asthma monitoring system consist of a hardware and a software part, the hardware part which is the wearable is implemented using arduino microcontroller (arduino UNO), pulse sensor, gas sensor (MQ135), temperature and humidity sensors (DHT11), Bluetooth module (HC-05), SIM module (SIM 800 L), connecting wires, battery, proteus software for circuit design and arduino IDE for microprogramming, while the mobile application is implemented using MIT App inventor, the central storage used is the Google firebase.

System requirement

At the implementation stage it is important to specify the hardware and software need of the system in order to develop the system to meet the specification.

i. The hardware required for the implementation of the system includes:

ii. Internet enabled computer system

iii. Electrical components for the monitoring device

iv. Soldering iron and solder

v. Meter tester

Also, there are some specific software used for the implementation of the asthma monitoring system, some of this software are installed on the computer for the implementation while some are internet-based (online), these software programs include: 51

i. Arduino IDE v1.8.5

ii. Proteus VSM

iii. MIT App inventor 2

iv. Internet-enabled PC and mobile phone

Mobile device specification: The mobile devices used during the implementation of the asthma monitoring mobile app (SaveMe) are android smartphones and tablets. There are certain specification such phones must have, these specifications are:

i. Android OS of version 4.x and above

ii. Text-to-speech support

iii. Bluetooth connectivity

iv. GPS enabled

v. Wi-Fi

Mode of data storage

Two kind of storage were used for this project, they include the local database provided by app inventor (TinyDB) and a public central storage (Google firebase).

The tinydb: As the name connotes, “tiny”, it actually a tiny database used for storing local data permanently on the device running the application. It was used in this project as a local database for storing the user’s personal details for authentication purpose.

Google firebase: Google firebase is a public cloud for data storage and analysis. In the design of this system, a firebase account was created for patient data storage. These data are gotten from the mobile device *via* the internet. Access to the database is given to the admin in this case the doctor or healthcare giver and the patient. Both parties can view the data, but the admin has the ability to read and write to the database. The information from this data is used for patient diagnosis and provision

Figure 4: Snapshot of a user’s data viewed in the Google firebase cloud storage.

of help to the help (Figure 4).

Location update

The "SaveMe" app makes use of the GPS on mobile phones to listen and retrieve the coordinates of the mobile phone and address of the user's current location. The location details are useful for locating the user in case of exacerbation or asthma attack on the user.

For the purpose of testing the location is retrieved in a second interval, the interval between two received locations coordinates would be in meters, 200 meters interval would be used for the final implementation.

Results and Discussion

System testing

The following table describes the Mobile app testing which is tested for device compatibility and response time (Table 1).

Test conclusion: From Table 1 above, it can be concluded based on the test result from those three devices that the "SaveMe" mobile app works fine only on android Operation System (OS).

Also from the data collected on normal asthma-free people, shown in Table 1, we can conclude that message alert to the "stakeholders" is triggered by extreme heart rate data value that is beyond 55 the normal threshold set during the device implementation. Heart rate rises when we indulge in any strenuous activity. Therefor this system sometimes may trigger false alarm, but would be in rear cases when the asthma patient is going through a rigorous activity and there is no attack.

Pictorial representation of the asthma monitoring system: After a successful implementation of the asthma monitoring wearable device and the mobile application for data visualization, snapshots of the device and all the activities by the mobile app was taken. Here in this section, we provide a pictorial demonstration of the working of the system. The app was tested on android mobile phone (Figure 5).

This is the first screen shown to the user after a successful installation of the app on his/her mobile phone. It provides the user with two options; "Register" and "Login". After a successful registration of an account, the "Register" button is disabled to ensure the app is used by only a user (patient).

Registration page: The registration page is the page where the user provides his/her basic information about. This information is used by the involved specialists for diagnosis, and used by the app for authenticating the user during login. The form provided in this page collects data into the following records on the database (TinyDB) and also push firebase cloud storage:

SIN	Age	Status	Heart rate (Bpm)	Did stakeholder receive SMS?
1	24	In class	77	No
2	12	Jogging	204	Yes
3	10	Idle	101	No
4	31	Washing	120	No
5	20	Relaxing	125	No
6	7	Idle	100	No
7	33	Idle	79	No
8	20	Playing football	190	Yes
9	19	Idle	100	No
10	5	Idle	120	No

Table 1: Wearable device testing-test for message trigger.

Figure 5: Welcome Screen.

i. Profile picture
ii. Full name
iii. Phone number
iv. Password
v. Device number
vi. Sex
vii. Age
viii. Address
ix. Health history of the patient.
x. Doctor's name
xi. Doctor's phone number

The below figure shows the following Registration page (Figure 6).

Login page: This page is displayed either after a successful first user sign up or when the "login" button is clicked from the "Welcome Screen". This is the portal to the user's dashboard after a successful user authentication. This user authentication is done using the user's phone number and password (Figure 7).

Dashboard: This is the screen where the user connects to the monitoring device and views his/her vital signs as they are being recorded in real time (Figure 8).

Profile page: This page displays the information about the user. User can edit these details whenever he/ she likes, he/she can also save the details on the page to a file on the phone (Figure 9).

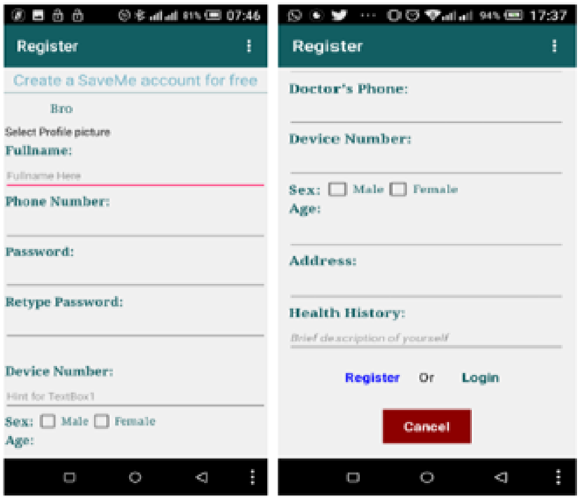

Figure 6: Registration page.

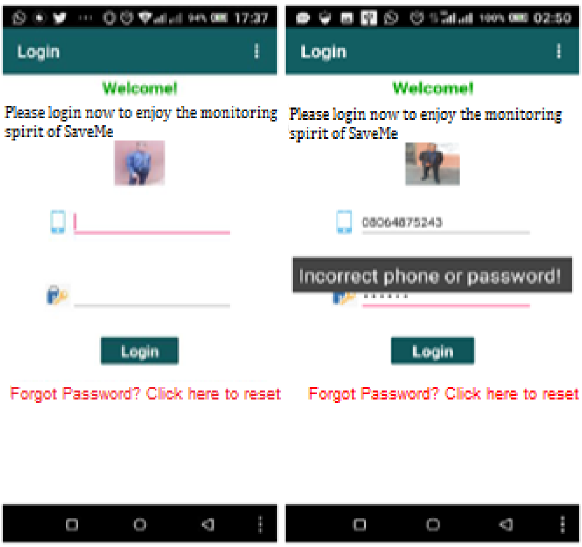

Figure 7: Login page.

Get help page: This is the android activity started when the user clicks on Help on the Dashboard and then location. On this page the user is able to read his/her location coordinates and address. The user can also use the record button to record a "Save for a rainy day" voice message, in case of an exacerbation or attack, the user clicks on the play button to play the recorded voice message. He can also add stakeholders' number and send SMS to the registered numbers should he need urgent help (Figure 10).

Cloud connectivity page: On click of the "View Data" button, the user is able to view his vital sign and location details on the central storage (Google firebase) (Figure 11).

Add stakeholders page: From the Figure 12 below, the user can use the add button to add stakeholders number, from Figure 10 above,

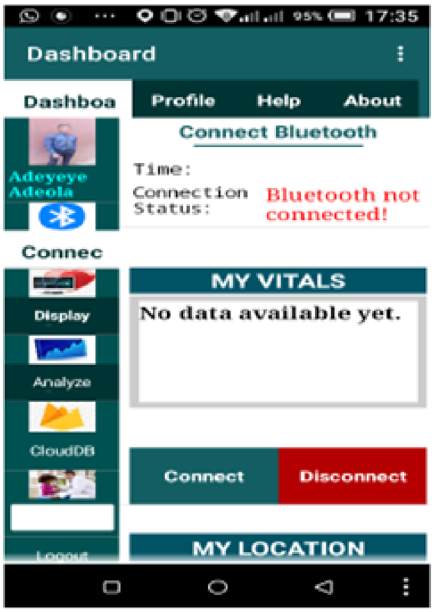

Figure 8: Dashboard screen.

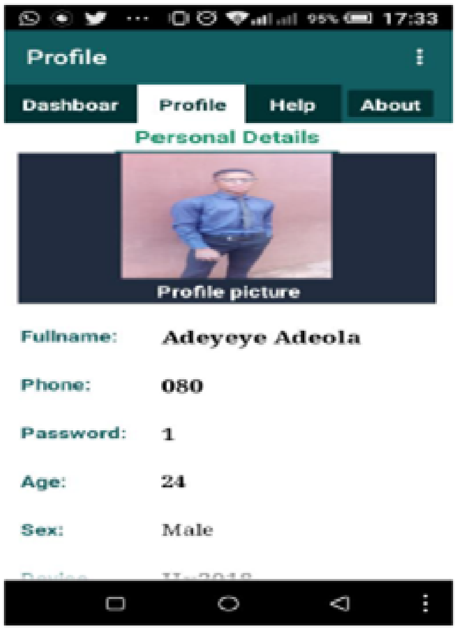

Figure 9: Profile page.

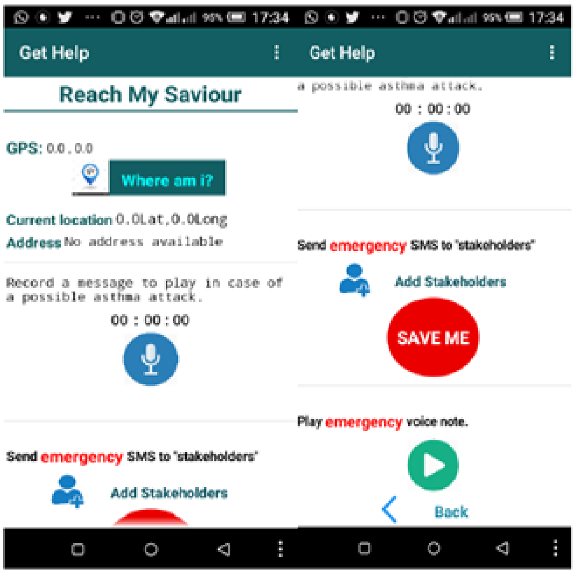

Figure 10: Get help page.

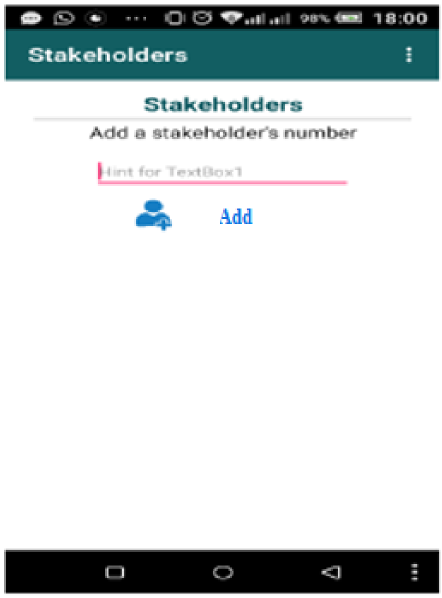

Figure 12: Add stakeholders page.

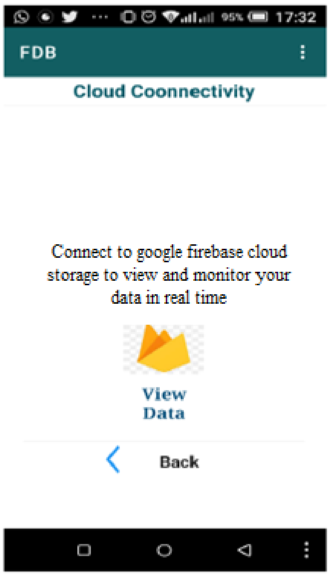

Figure 11: Cloud storage connection page.

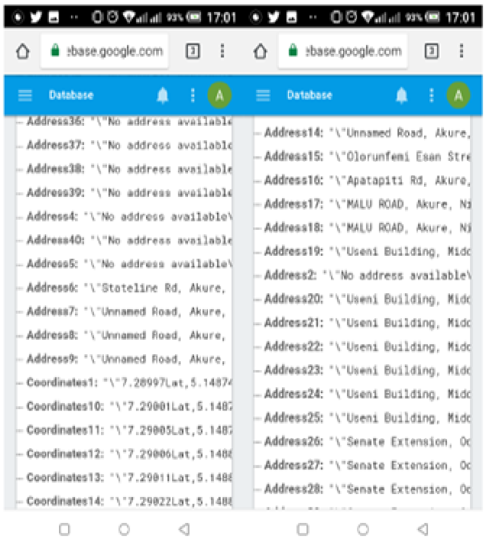

Figure 13: User's address and coordinates.

he sends SMS to these numbers whenever he is in trouble and needs urgent attention (Figure 12).

Data values: The Figures 13 and 14 below represent the layout of the secondary and primary activities respectively. On the screens are displayed the corresponding readings related to two different values. The Figure 13 shows the location and address data of the user of the SaveMe monitoring application, these data are the one collected using the GPS listener of the mobile device the user uses. The location and the address data as shown in the figures are collected and displayed on the Google firebase account of the user. The Figure 14 shows the heart rate of the user, the temperature, the humidity and the air quality of the user's environment. These data are collected from the connected wearable sensor over Bluetooth and displayed on the SaveMe mobile app. The SaveMe mobile app forwards these data to the firebase cloud storage where the user and the stakeholders such as his doctor can

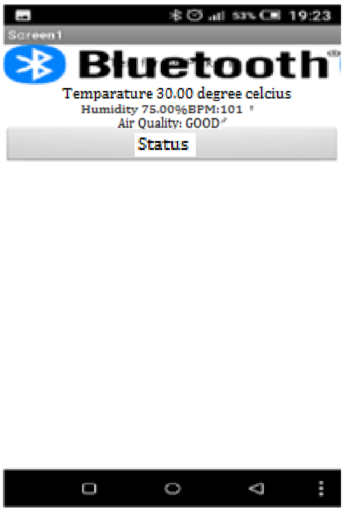

Figure 14: User's heart rate and environmental data.

view the data. These data also are used to determine when to alert the stakeholders about an emergency (Figures 13 and 14).

Conclusion

The hike in the cost of providing and getting health service to people with acute diseases like asthma using the traditional means of monitoring chronic disease patients and the proliferation in global usage of smart mobile phones are the major drive of this project. In view of alleviating these challenges, an asthma monitoring system is developed.

Using internet, Short Message Peer-to-Peer Protocol (SMPP) and Bluetooth technology, this wearable is able to assist an asthma patient monitor his/her health in real time by displaying data on the mobile application alerting the patient of probable dangers in his environment, alerting the patient's doctor, or families or emergency centers and sending the patient's vitals to the cloud for diagnosis by the patient's doctor.

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