mDROID – An Affordable Android based mHealth System

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Abstract: This paper presents a novel approach towards the development of a portable, user-friendly and affordable mHealth System using Android based mobile devices. The Android application captures personal, biometric and medical data of a patient and combines them to generate an XML based medical record which is then uploaded to a server. The medical data are gathered from different sensors interfaced to an Arduino UNO board. The data are then converted into packets, which are transmitted on request to the mobile phone using Bluetooth. The XML report makes the *mDROID* system robust for query and inter-operability at the server end and also for merging with standardized XML based medical repositories. The *mDROID* system is designed for use by minimally trained health workers in the field.

1 INTRODUCTION

Providing affordable and scalable healthcare is one of the most important development goals, and one which may pose many technological challenges. Research by Cisco (CVNI, 2013) projects that by the end of the year 2016, there will be approximately 10 billion mobile devices in use around the world. *mHealth* refers to using mobile phone technology in providing healthcare. In recent years, mHealth has shown promising growth mainly because of the fact that it can alter how healthcare is delivered, the quality of patient experience, and the cost of health care (Wang and Liu, 2009). The most common activity in mHealth has been the creation of health call centres, which respond to patient inquiries. This was followed by using SMS for appointment reminders, using telemedicine, accessing patient records, measuring treatment compliance, raising health awareness, monitoring patients, and physician decision support.

With advances in technology, wearable sensors have been integrated with mobile phones for monitoring health. Despite mHealth having several advantages in personal healthcare, a 2011 global survey of 114 nations undertaken by the World Health Organization found that mHealth initiatives established in many countries have several issues resulting in variation in adoption (WHO, 2011). mHealth has shown maximum adoption in developed countries mainly because mHealth applications for personal health are available only on high-end expensive mobile phones. Thus, mHealth has grown in developed countries whereas it is still at an exploratory stage in under-developed nations (Mechael et al., 2010).

In developing countries, data are manually collected by community health workers for (rural) Health Centres. These data are collected in the field and written "in rough" on paper. Later, these readings are manually uploaded onto servers. The various stages require constant scrutiny to ensure reliability (Otieno et al., 2012). Manual entry makes the whole system both cumbersome and vulnerable to human errors. Moreover, an important aspect of any mHealth implementation is ensuring that the data are exchangeable. Existing systems frequently overlook the fundamental requirements of interoperable data standards (WHO, 2012).

All the factors discussed above demand an mHealth solution which (1) has an automated system for collection of medical data by health workers with minimal training, (2) consists of all basic medical sensors and is yet portable, (3) is affordable for mass usage in under-developed countries, and (4) collects data in a format that can be easily exchangeable and usable within heterogeneous systems. The proposed *mDROID* system has been designed to address all these aspects keeping in mind the "pain-points" of community workers. The all-in-one *mDROID* system uses an Android based device to capture medical data through various electronic sensors with ease, com-

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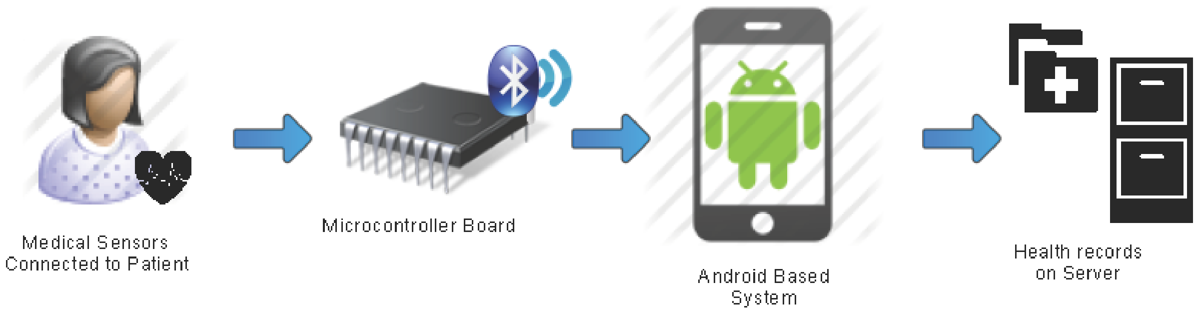

Figure 1: End-to-End Data Flow of the *mDROID* System.

bines them with personal and biometric information of the patient to form an XML based medical report, which can be uploaded to the server on request.

Technologies like *mDROID* will facilitate heathcare workers in monitoring the health of local populations at regular intervals, especially at the bottom of the pyramid, thereby empowering healthcare officials to track epidemics and take necessary steps to prevent them. It will also allow policy makers to understand the correlation between health and environmental factors and make changes to suit the population of the locality.

2 METHODOLOGY

The *mDROID* system is broadly divided into two major parts. The first part consists of getting medical data from various sensors on the Android phone. The second part involves development of an Android application for processing the data received and generating medical report to be sent to a server. Figure 1 depicts an overview of the data flow from sensors to the server.

2.1 Obtaining Medical Data from Sensors to Android Device

The *mDROID* system supports multiple medical sensors. The system was designed to make the sensors work efficiently in capturing multiple data simultaneously rather than a one-by-one approach, which is time consuming, inefficient and possibly less reliable. Concurrent capture is achieved by using an intermediate platform that is capable of connecting to multiple sensors simultaneously and transmitting to the Android based device. The data from multiple sensors are combined to form packets, which are then transmitted to the Android device through one of the connectivity options supported by Android and Arduino. The *mDROID* system uses Bluetooth as the mode of communication between the two platforms. The two main components of the microcontroller program are: (1) formation of medical data packets, and, (2) managing data transmission through Bluetooth.

2.1.1 Formation of Medical Data Packets

The clinical data obtained from the sensors are categorized into (1) discrete data points, and (2) continuous data streams. The former category comprises the measurement of discrete physiological parameters such as temperature, pulse rate, oxygen saturation in blood etc., whereas the latter covers measuring graphical medical parameters such as ECG, which is required to be plotted on a graph over an uninterrupted time interval.

While acquiring the discrete parameters, the microcontroller program fetches different data points from multiple medical sensors and couples them together into data packets. This feature allows all the sensor data points collected at one time to be transmitted together. Coupling readings from different sensors makes it possible to correlate the different physical parameters. Each data packet consists of a frame start delimiter, end delimiter, sensor identifiers, sensor data start and end delimiters, and actual sensor data, as depicted in Figure 2. These delimiters are required because some bytes are often lost during transmission in Bluetooth communication. The packet Start and End delimiters help in distinguishing complete data packets from incomplete ones, which is necessary in building a robust system. Sensor identifiers are used to label particular sensors' data. This allows the *mDROID* system to form custom data packets depending on the specific sensors requested by the user application, supporting flexibility in the set of sensors used by an application and eliminating the need for maintaining a fixed sequence of sensors in the data packets.

The continuous data stream is acquired separately without coupling the values with any other sensor data.

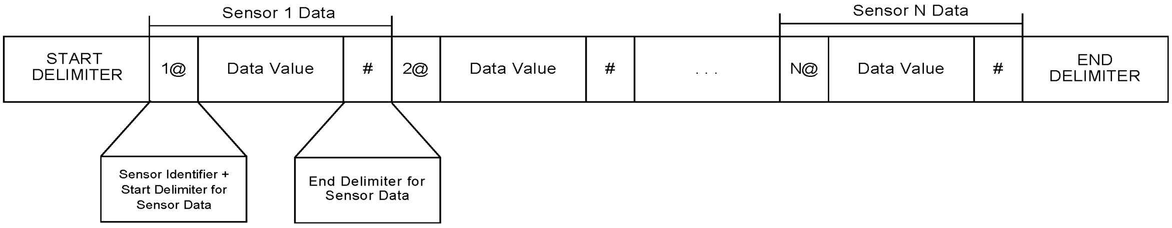

Figure 2: Design of Data Packet.

2.1.2 Data Transmission through Bluetooth

The microcontroller program controls what is to be transmitted and when. The system continuously listens for a request for a data packet or continuous stream of data identified by a REQUEST byte. On receiving a request byte, it identifies whether the request is for a discrete data packet or a continuous stream of data. In the former type case, it fetches the values from the sensors, couples them into a data packet, transmits the packet to the application, and goes back to the listening state. In case of a request for a continuous stream, it starts fetching and transmitting a stream of values, until it receives a STOP request after which it goes back to the listening state.

2.2 Android Application

The second major part of the *mDROID* system consists of the Android application that forms the core of the system.

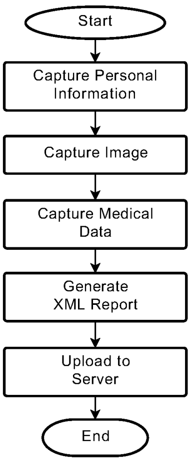

Figure 3: Overview of the *mDROID* Application.

Figure 3 shows a broad overview of the Android application. The app handles the Bluetooth connectivity with the Arduino UNO board for fetching the medical data packets/data stream from it.

Depending on the requirement, the app requests for a data packet or a stream of data from the Arduino board. In case of data packets, the application decomposes them to obtain the data of individual sensors. The design of the application allows the data to be viewed on the application screen individually or collectively through a pragmatic interface. The algorithm for obtaining the data from a data packet is depicted in Figure 4.

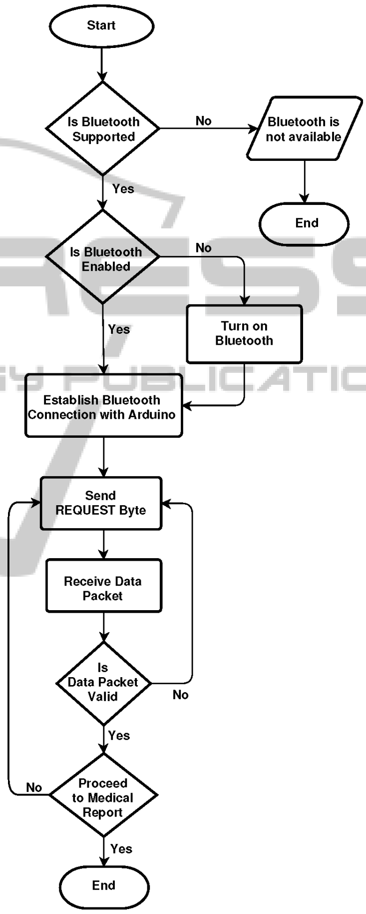

Figure 4: Medical Data Acquisition in Android through Bluetooth.

In case of a stream of data, the application first sends the corresponding request to the Arduino board, starts receiving the data stream, plots a graph for a specific time interval, and sends a stop request to the board on completion of the time interval.

In addition to medical data from the sensors, the application also collects personal information of the patient, viz., name, age, sex, phone number etc.

The application also utilizes the integrated camera of the device to capture patient image, which serves as biometric information of the patient. This feature introduces a sense of authenticity to the system in that it will make it hard for a health worker to forge medical records.

Once the personal, biometric and medical data of the patient are obtained, the application combines them to generate an XML based medical report. The application also allows for this report to be sent to a server on network availability, completing the end-to-end data flow.

3 IMPLEMENTATION

The components used in the implementation of the *mDROID* system were carefully selected keeping in mind portability and low power consumption. Also, special emphasis was paid to design the user interface of the mobile phone application in such a fashion that a minimally trained health worker can capture and upload data with ease.

3.1 Medical Sensors and Arduino Program

In the current version of the *mDROID* system, the main parameters captured are Body Temperature, Pulse Rate, Oxygen Saturation, Galvanic Skin Response and ECG.

3.1.1 Body Temperature Sensor

The body temperature was captured using a sensor which has a TMP102 digital temperature sensor at its kernel. It gives a 12-bit, 0.0625 °C resolution and provides an accuracy of 0.5 °C. It can monitor temperature ranging between -25 °C to +85 °C. Since this sensor works at a voltage range of 1.4V to 3.6V DC and provides an easy two-wire serial interface, it works as a perfect match for *mDROID*.

3.1.2 Oxygen Saturation and Pulse Oximeter

Pulse oximetry is a non-invasive method for indicating the arterial oxygen saturation. Oxygen saturation is defined as the amount of oxygen dissolved in blood. To measure oxygen saturation, two different light sources with wavelength of 660 nm (red light) and 940 nm (infra-red light) are used. By measuring the absorption spectrum of the two light sources, oxygen saturation is measured. The pulse oximeter used for *mDROID* system works at 3.3Volts.

Pulse rate measures the average number of pulses per minute. The pulse rate is obtained from the pulse oximeter sensor which measures the peak to peak time interval between the pulses and calculates the average.

3.1.3 GSR - Galvanic Skin Response

GRS is recorded by a sensitive ohm-meter which measures the electrical conductivity of the skin. Sweat glands which are under the control of sympathetic nervous system change the conduction level of the skin with variation in the psychological state of the person. The sensor for GSR for the *mDROID* system works at 3.3 Volts which allows portability and can run easily on batteries.

3.1.4 ECG - Electrocardiogram

ECG is one of the most common tools useful to monitor the status of health of the heart. For a detailed study, a 12 lead ECG is preferred but arrhythmia can be monitored from a single lead ECG. *mDROID* is currently designed to capture a 10 second single lead ECG data in the form of an image.

The system uses an INA321 instrumentation amplifier at the kernel. A second order filter was utilized to filter the noise and capture the ECG in the monitoring mode (critical band of 0.5Hz - 40 Hz). The data were sampled at 250 samples per second. These data are saved in the form of an image in the *mDROID* app.

3.1.5 Arduino Program

The *mDROID* system uses the Arduino UNO R3 board. The code is written using the open source Arduino 1.0.4 software. The e-Health Sensor Shield and e-Health library is used for interfacing the Arduino board to the medical sensors. RN-42 Bluetooth Module is used for the Bluetooth transmission using the Serial Port Profile (SPP). Any device communicating through Bluetooth is required to first enter the passcode for pairing with the hardware. Once a device has been paired, it can start communicating.

3.2 Android Application

The *mDROID* application is developed using the Android SDK 2.3.3 Java platform. Android was chosen for the implementation of the system owing to its widespread use, affordability, and extendability. The application supports any device running Android version 3.0 and above with Bluetooth 2.0.

There are four major components of the Android application: (1) obtaining patient information, (2) obtaining patient image, (3) obtaining medical data, and (4) combining all data into a medical report to be uploaded to server.

3.2.1 Obtaining Patient Information (Personal Data)

The first component in the patient record system is obtaining the general information about the patient. As soon as the user launches the app, he/she is displayed a form to be filled on the app. The module collects the name, age, sex, and phone number of the patient and performs suitable validations on the data entered before allowing the user to proceed. The various validations imposed by the system are as follows[1]:

- All the entries must be filled. No field can be left blank.
- Name and Sex can take text values. Age and phone number should be numeric values.
- Sex can take only **M** or **F** as values.
- Phone number must be 10 digits.

3.2.2 Capturing Image (Biometric Data)

After properly entering acceptable values in the personal data of the patient, the user is navigated to capture an image of the patient, which serves as biometric information of the patient. Once an image is captured, the user has the option of either capturing another image (if he/she is not satisfied with the current image) or proceeding to capture the medical data. The latest captured image is taken into account.

The image name contains the timestamp when the image was captured and is of the form "IMG_yyyymmdd_hhmmss_X.jpg", where X is a random number. This allows the image to be uniquely identified on the server by minimizing the probability of different image files having the same name.

3.2.3 Obtaining Medical Data

This component is responsible for establishing Bluetooth communication with the sensor hardware and fetching medical data from the sensors. After the personal and biometric data are successfully acquired in the application, the user is navigated to proceed to collection of medical data. The user is required to select the desired hardware from a list of available Bluetooth devices to initiate a connection. Once the connection is established, the user can hit a button to begin the data exchange with the microcontroller.

The medical data are displayed to the user in the app. The design of the GUI allows the user to view all the discrete medical data at once or particular data individually. Figure 5 shows a screenshot of the Android app. The medical data displayed are the averages of the latest five values retrieved from the sensors. Every time a new value is received, the average is updated and used. The implementation allows capturing of a 10 second ECG of the patient. The ECG data is plotted separately and is saved as an image.

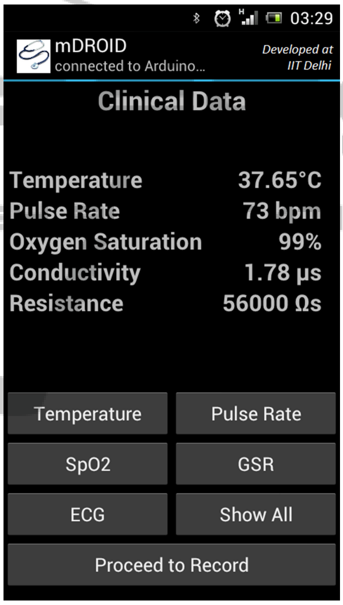

Figure 5: Screenshot of *mDROID* App.

3.2.4 Generating XML Record

Medical record generation is another crucial aspect of the *mDROID* system. The design of the medical record is based on XML because of its simplicity of representation, versatility and widespread acceptance as a vehicle for information exchange in the modern era.

This component is used to put all the pieces of the system together. After the acquisition of desired medical data, the application generates a complete medical record based on the user session and stores it on the Android device. A sample medical record generated by the application is depicted in Figure 6. If the user wishes, he/she can choose to upload this data record onto the server.

The xml record along with the captured image file and ECG image is uploaded on the server, where the

[1]The specific choices described below only illustrate that these data must be checked for conformance to a specified format

```xml
<?xml version='1.0' encoding='UTF-8' standalone='yes' ?>
<mhealth>
   <personal_data>
      <patient_name>Abc Xyz</patient_name>
      <patient_age>21</patient_age>
      <patient_sex>F</patient_sex>
      <patient_phone>0000000000</patient_phone>
      <patient_img>./Personal/Images/IMG_20130509_
                    055416_595727957.jpg</patient_img>
   </personal_data>
   <medical_data>
      <body_temperature>37.65</body_temperature>
      <bpm>73</bpm>
      <spo2>99</spo2>
      <conductivity>1.78</conductivity>
      <resistance>56000</resistance>
      <skin_conductance>-0.072000004</skin_conductance>
      <skin_resistance>3370.0</skin_resistance>
      <ecg_img>./Medical/Images/ECG_20130509_
                    055832_965910554.jpg</ecg_img>

   </medical_data>
</mhealth>
```


Figure 6: A Sample XML Report Generated by the *mDROID* App.

images are stored in separate directories. The patient_img and ecg_img tags in the xml report contain the paths of the respective image files on the server.

4 APPLICATIONS

The portable and user friendly *mDROID* system is designed to help acquire data of the patients by healthcare workers in the field. The mobile phone based system helps the health workers in acquiring patient data without any specialized or intensive training.

The *mDROID* application automatically converts all the acquired data of the patient into an XML file, which is uploaded to the server. XML allows easy consolidation, transmission and retrieval of medical records from servers. Moreover, it allows existing protocols to be used to exchange data among heterogeneous systems. The capability of XML to exchange data among different types of computing platforms enables disparate back-end systems in healthcare organizations to work together. The data records generated by the *mDROID* system can hence be easily made available to the care givers and researchers.

5 DISCUSSION

Over the recent years, mHealth is increasingly becoming a prime focus of the medical community, leading to intense work in this field. The *mDROID* system presents a simple user interface with a straightforward workflow to capture the various health parameters of patients. The choice of platform for the implementation was Android, owing to its various advantages. Android based devices are widely used and their availability is rapidly increasing over a broad range of cost and features, leading to smartphones and tablets being available at very low prices. According to the International Data Corporation (IDC) Worldwide Quarterly Mobile Phone Tracker, the Android platform crossed 80% of the smartphone market share in the third quarter of 2013 (IDC, 2013). Moreover, Android allows for the built-in utilities of the smart devices to be utilized without having to design a separate control processor. The *mDROID* system is focused on integrating multiple medical devices onto a single platform making an all-in-one package for medical data collection. This reduces the cost effectively when compared with using standalone devices for measuring each of the medical parameters. There are a host of independent medical peripherals in the market for the iPhone (iPhone Medical Devices, 2013). However, the cost of an iPhone as well as these medical add-ons is uneconomical and hence cannot be used as a cost-effective solution for the health workers working at the bottom of the pyramid. Moreover, all of these individual devices are very specific and cannot be used together with other sensors in a customisable fashion. The *mDROID* system has been designed to collect data from medical sensors while keeping them separate from the phone. The use of Bluetooth enables easier integration of newer sensors as well as replacement of sensors. This creates a potential for opening up of a market for many more such affordable sensors. The *mDROID* is a novel one-of-a-kind customisable system in mobile healthcare. XML based medical reports add the benefit of portability of medical data across platforms. Biometric information brings trust and authenticity to the system.

The Swasthya Slate (Health Tablet) developed by PHFI (Swasthya, nd) is a similar system which works on Android based tablet phones. It enables the acquisition of clinical data through electronic sensors. The price of the device costs approximately INR 30,000. It has a couple of additional sensors such as test for water quality, which we plan to deploy in our project in a later stage. However, there is no provision for capturing patient image and other metadata, or for the generation of XML based medical reports in the Swasthya Slate. The *mDROID* system is more flexible as it works on all mobile Phones running the Android platform, including the inexpensive ones; the price for the *mDROID* device is projected to be more affordable than the Swasthya Slate.

Another framework for mobile healthcare is the SANA technology developed at MIT (SANA, 2010). SANA is a reliable tool that allows health workers to transmit medical files in the form of text, image, audio, video etc. through a cell phone to a central server for archiving and incorporation into an electronic medical record, and to a remote specialist for real-time decision support. The prime focus of SANA tool is to transmit the medical information to the reach of various stakeholders in the healthcare domain. However, there is no support in SANA for utilizing electronic sensors within the mHealth system, and the user is required to feed the data manually into the Android application making the application prone to human errors.

Open Data Kit (ODK, 2009) is a framework for building user interfaces, collecting data on mobile devices, and aggregating them onto a server. The ODK framework supports generic interfaces for a class of sensors, both internal and external to an Android device, although at the time of implementation of *mDROID*, these were not released for production. While ODK has been used in some health-related projects, it is not clear to what extent the type classes of discrete and continuous medical data can be supported in the systematic manner we have outlined above.

This comparative analysis suggests that *mDROID* promises to be a more effective tool for health workers when collecting data, with authentication, at the bottom of the pyramid in developing countries. While the data authenticity is not foolproof, it offers some level of confidence that the data was genuinely captured and not forged.

6 FUTURE WORK

The *mDROID* system described in this paper relies on external sensors for obtaining clinical data and is targeted to be operated by non-experts. The next steps involve providing a framework that can attest to the provenance of the data collected. The current system captures the biometric data in the form of patient image, which is not being cross-verified. Future work involves implementation of sub-systems for acquisition and verification of biometric information of the patient as well as the health worker. Further analysis of the system reveals that the clinical data is sent over a Bluetooth connection to the Android device and then over a network to the server, both of which can act as points of network vulnerabilities. This requires investigation of ways to safeguard the privacy of the medical data over any transmissions. Additionally, the current system supports a limited range of medical sensors which are being extended to support more varieties of sensors, thereby providing a complete low cost and efficient mHealth data acquisition system. Further, the current system works using Bluetooth connectivity. Future scope involves supporting more connectivity modes, viz., Wi-Fi, ZigBee, USB, etc. Currently, the uploaded records are sent to a small server designed for storage purposes in XML format. The future work involves supporting the server with openEHR standards, and adding functionalities for extraction and exchange of medical data from the server. Also, cloud-based solutions can be used for storing and analyzing medical data collected.

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