Mobile Health Monitoring System for Community Health Workers

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Abstract: The leading global cause of high mortality has been identified to be chronic non-communicable diseases such as stroke, cancer, chronic respiratory conditions, heart disease, diabetes etc. These diseases affect communities both from the rural and urban areas. Deaths as a result of these diseases are relatively higher in rural communities as most of them have limited access to health care services. The limited access to health care services by rural communities is due to the difficulty experienced by governments in bringing those services to rural communities. Contributing factors to the difficulty is the inaccessibility of those communities and shortage of resources such as health professionals. The authors in this paper share the sentiment that community health workers can play a major role in assisting governments to deliver health services to rural communities regardless of their location. This paper therefore presents an application that supports health workers in diagnosing and monitoring non-communicable diseases in rural communities.

- **Keywords:** Non-communicable diseases, Android application, mobile health application

I. Introduction and Background

The leading global cause of high mortality has been identified to be Chronic non-communicable diseases (NCDs) such as stroke, cancer, chronic respiratory conditions, heart disease, diabetes etc. [1]. Cardiovascular diseases (CVDs) were found to be the major cause of NCD deaths in 2008 and they account for more than 15 million deaths worldwide, a statistic which is more than twenty per cent of global mortality [2]. Furthermore, more than ten per cent of global deaths are caused by hypertension, which is the leading risk factor for mortality [2]. The dominance of hypertension in global adult population was estimated to be approximately 25 per cent in 2000 and has been predicted to increase by about 70 per cent by 2025 [3]. Research has also shown an increase in hypertension cases in rural areas [4]. Non-communicable diseases in general are affecting rural communities most, [5] and [6]. This raises concerns as governments in developing countries still have challenges in delivering health services to rural communities.

Majority of the current healthcare technologies and health diagnostic devices are used in clinics or hospital environments. Due to the difficulty to access these facilities in rural areas the underlying symptoms of NCDs cannot be adequately monitored. This could lead to difficult or even incorrect diagnoses [7] of NCDs.

There are factors that are responsible for the lack of access to health care facilities in rural and remote areas in developing countries. These factors include transportation, health insurance and income and shortage of health care providers.

In developing countries, such as South Africa, Nigeria, Kenya etc., the majority of the rural communities are situated in remote areas where access to them is limited by poor road infrastructure or geographical landscapes. These factors also hinder the roll out of health services in those areas. There limited health care facilities in such areas, results into people having to stand in long queues at clinics and hospitals, sometimes for the whole day. In many rural areas there is no access to clinics and hospitals at all and even where there is access, it usually requires citizens to travel far to reach the nearest facility [8].

Furthermore in the South African context, South Africa has diverse communities with a large part of the population that needs significant medical attention being situated in those rural areas with under resourced health facilities. The South African Census in 2011 [9] indicated that the dependant population (those aged 0 – 14 or above 65) is found mainly in rural areas. This is the population segment that generally does not have means to travel and hence has difficulty accessing health facilities. A shortage of human resources is also cited as one of the hindering issues in delivering quality health care to the citizens by the government [10]. The limited existing health resources and facilities are also burdened by the scourge of tuberculosis and HIV and AIDS. To address accessibility of health care services, the South African government has adopted and supports the deployment of community health workers in communities and schools [11]. These community health workers need low cost mobile equipment and resources for use during their visits to the community. There is therefore an urgent need for intervention in rural communities in a cost effective way. These include health care devices such as blood pressure meters and blood sugar meters, among others.

In this paper we present a mobile health application that can be used by community health workers to collect observations in remote rural areas. This application makes

use of mobile health devices to take health care services to the people regardless of their location. The solution presented in this paper takes into account the South African demographics.

The paper is organized as follows; section II presents an overview of the requirements of our proposed mobile health system. In section IV, we present a description of the mobile health application in detail. In section V we present evaluation of our proposed system. In section VI we conclude the paper and acknowledgements in section VII.

II. RELATED WORK

Research works that are aimed at providing technological solutions for community health workers are limited. Research works in [12],[13] and [14] focus on surveys on solutions that are provided to health workers in different countries and the use of mobile technology by health workers. Research works that are closely related to our technology solution that can aid community health workers are the research found in [15],[16] and[17]. The research work by Ngabo et al. in [17] however solely focused on addressing pregnancy monitoring, maternal and child birth deaths. The work by Mena in [15] and by Grossman in [16] focuses on blood pressure monitoring using mobile technologies. There is a need for a technology solution that can combine all necessary NCD related monitoring in a single application such as glucose, cholesterol and others in addition to blood pressure. Such solutions need to also be able to transmit messages in a format compliant with the HL7 standard [18].

III. MOBILE HEALTH APPLICATION

As delivering health services to rural communities remain a challenge for many governments, technological innovations that can increase prevention and control of NCDs are needed. Wearable health devices such as ambulatory blood pressure (ABP) monitors are a step in the right direction. ABP monitors are portable, fully functional automatic devices that record blood pressure from a subject of care (patient) for a self-determined period of time, while users conduct their daily activities [19]. This method can be effective in monitoring cases of hypertension as it provides real time information and eliminates the need to visit a healthcare facility to take blood pressure readings.

Our proposed mobile health monitoring system enables faster computerization of data that has been recorded. This improves the quality and efficiency of delivering healthcare services to rural communities far better when compared to paper based traditional data collection processes which need to be followed by transcription to computer systems [20]. It is therefore meant to provide support to community health workers in delivering health services to their communities. It allows continuous monitoring and subsequent transmission to a standalone server in order to allow both the professional healthcare provider to offer an extensive health feedback. It also allows the national health authority to have an extensive clinical database for data mining and analysis of potential risk factors that can aid in the speedy delivery of health service to the citizens.

Based on background presented in this paper and the intended environment for the proposed mobile system, the authors propose the requirements of a mobile health system to support community-based health workers are as follows:

A. Light weight

As health workers travel long distances on their day to day activities, it is ideal for them to carry light weight devices. It is then required for an application meant for health workers to run on light weight devices such as tablets or smart phones.

B. Intermittent Internet connectivity

Areas that are travelled by community health workers often do not have Internet or have poor Internet connectivity. An application developed to aid health workers therefore needs to have the capability to function on both online and offline modes.

C. Blood pressure, heart rate and glucose measurements

This research paper contributes towards addressing delivery of NCD related health services. The application therefore needs to be able to be take and process blood pressure, heart rate and glucose readings. These reading closely related to most common NCDs.

D. Feedback to health worker and the subject of care

Community health workers are often not professionally trained on health. As a result they are not expected to have an expert knowledge and ability to interpret observations that they take from subjects of care. The application therefore needs to have intelligence to interpret the observations and provide feedback to both the subject of care and the health worker. This is to cater for the cases such as in which a subject of care requires urgent medical attention. An example of such cases is a case in which a subject of care's blood pressure would be critically high or critically low.

E. Historical preview

Conclusions cannot be drawn from single readings on blood pressure and/or glucose on a subject of care. A historical preview of the observations recorded from a subject of care needs to be supported for intelligence to be gathered. The mobile health application therefore needs to support ability to take subject of care observations more than once.

IV. APPLICATION DESCRIPTION

In this section we present functional and technical descriptions of our proposed mobile health application.

A. Functional description

The application provides technology for real time, dependable and intelligent health monitoring by health workers in the field. It integrates a set of wearable wireless sensors with a mobile computing device, such as a

smartphone or tablet. The sensors are attached to the subject's body, usually the finger. The reading is then performed and data are collected by the sensor. The data is transmitted to the mobile device, which analyses the data in real-time and provides immediate, personalised feedback to the health worker. The data is also sent to a remote server via the mobile device's internet connection (if and when it becomes available). From this server, healthcare professionals can access the current and historical data of a subject of care to provide expert medical feedback and to support in clinical decision making. This data could also be sent to the national health authority to enable better planning and more effective and efficient allocation of healthcare resources. Figure 1 shows a communication among components in our mobile health system.

Figure 1: Mobile health system communication

B. Technical Description

In this section we describe the technical features of the mobile health monitoring application. This features show how the function requirements described in section II are addressed.

The application is implemented as an Android [21] application. It makes use of Java, SQLite and is designed to run on any Android v4.2+ powered mobile device. The application integrates wirelessly with an ambulatory blood pressure meter, a pulse oximeter, a stethoscope and a glucometer.

Data is received from these sensors using a specialised protocol over a Bluetooth connection. The application includes a specialised protocol stack to handle the interpretation of a health device's data transmission protocol and to handle the sending and receipt of messages to and from each device.

Figure 2 depicts a code snippet of a protocol stack in this case representing a Stethoscope protocol stack. The model of a Stethoscope used as a test for this application works as follows:

- A Bluetooth connection between the Stethoscope and the mobile Android device is established.
- A user selects and uploads a file from the Stethoscope screen and the file transmission begins immediately.
- While file transmission is in progress, the application waits for the command `0x0F` (`TRANSMISSION_COMPLETE_COMMAND` variable in the code snippet) which signals the end of transmission of the file.
- On receipt of the 0x0F command, the cached data in the buffer are processed.

Data received from sensors and into the mobile Android device are processed by the central server to decide on messages to send to either a health worker or the subject of care. If abnormal readings are detected, the health worker is notified through a text message. This intelligence is only implemented on the server side to minimize processing on the mobile device which would consume more battery power. Critical and life threatening observation readings such as abnormally high or low blood is processed on-board to cater for areas without Internet connections.

Data obtained from the sensors are also geo-coded using the mobile Android device's Global Positioning System (GPS), if available. The data is then uploaded to a central server and linked to the subject of care (patient). This provides a historical log of readings taken for a particular subject of care.

```
  while(availBytes != 0 || !uploadComplete){
          if(dinput.available() >0){
             state  =  (state  ==  -1?  0:
state);
             int          length          =
dinput.available();
             while     ((state+length     <=
maxLengthOfBuffer)      &&      (read      =
dinput.read(testData, state, length))>0){
                  if(     (testData[0]     ==
(byte)0xB0  ||  testData[1]  ==  (byte)0xB0)  &&
!sent){
         state = 0; sent = true;
mmOutStream.write(StethoscopDeviceCommand.STA
RT_UPLOAD_COMMAND());
          continue;  }
  . . .
  if(state          >          0          &&
Arrays.copyOfRange(testData,                2,
4).equals(TRANSMISSION COMPLETE COMMAND)){
```

Figure 2: Stethoscope protocol stack

The Android mobile application uses Internet connection, when available, to incrementally upload data in JavaScript Object Notation (JSON) [22] to the central server using the Hypertext Transfer Protocol (HTTP). An example of a message in JSon format is as depicted in Figure 3.

The data representation is compliant with the HL7 [23] messaging format. The application supports intermittent network connectivity and fault tolerant upload of this data – for instance, if Internet connectivity is lost during an upload, it allows for the incomplete upload to be resubmitted later when connectivity is re-established.

On the central server, the received data are stored in a database and linked to the subject of care's electronic

record. There is a secure web application which allows authorized health professionals to view this data, to analyse it and to provide expert medical feedback.

{"registration":{"other":{"geometry":{"type":"Point","coordinates":[28.287718199635652,-25.743805733583176]},"language":"Afrikaans"},"addresses":[{"postCode":"01678","addressLines":[{"addressLine":"45 Tristan Ave"}],"countryIdentifier":"ZA","stateTerritoryProvince":"GT","suburbTownLocality":"Groenewaard"}],"electronicCommunications":[{"medium":"Mobile (cellular) telephone","detail":"0721234567"}],"identifiers":[{"designation":"8756778945"}],"names":[{"familyNames":[{"surname":"Msiza"}],"givenNames":[{"sequenceNumber":"1","name":"Lindokuhle"},{"sequenceNumber":"2","name":""}]}],"additionalDemographicData":{"sex":"Male","birthDate":"1995\/01\/05"}},"created_at":"2014\/01\/05 02:07:07","chw_id":"1","visit_id":"77e7cec3-952c-

Figure 3: Subject of care registration information

V. Mobile health application Evaluation

The application was evaluated in a lab environment. The purpose of the evaluation was to test how far the application satisfies the functional requirements presented in section II. A scenario used while evaluating the application is:

Consider a community health worker designated to work with a health facility say a clinic. The health worker will by default have their details registered with an online database. The community which the health worker will be responsible for is the community to which the clinic is designated to. The health worker registers online before they can be able to sign in into the mobile application while making home visits.

While doing the home visits, a subject of care may already exists in an online database and linked to the clinic. If the subject of care already exists, the health worker selects the subject of care's name on the application and proceeds with taking observations. If the subject of care does not exist, the health worker will need to register and upload the new subject of care details. The health worker then selects the subject of care and takes the observations. Finally, the health worker uploads the observations linked with the subject of care. In absence of Internet connection, the application needs to store the observations on the local file system. On establishment of Internet connection, the application needs to upload any pending observations from the local file system to the central server.

The application was then evaluated based on this scenario. The application was found to satisfy all requirements in section II. It satisfies the light weight requirement as it runs on Android devices which normally come as smart phones and tablets. It satisfies the intermittent Internet connectivity requirement by having a background process that monitors the Internet connectivity status. On establishment of Internet connectivity, the process initiates the uploading process of any pending observation stored locally on the device. The feedback requirement is satisfied by utilising the MOBI4D service [24] to deliver notifications to the health worker and the subject of care. Historical preview is enabled by linking each observation upload to the server with an individual subject of care.

VI. Conclusion and Future Work

In this paper an application that is meant to support community health workers is presented. Requirements for the application to effectively support a health worker are presented. The functional and technical description on how the application satisfies the requirements are presented. The evaluation of the application in a laboratory environment is also presented.

As part of future work, the application will be rolled out and evaluated further in the field. The evaluation criteria of the application will be designed using the guidelines presented in [25]. Post-test questionnaires will be prepared for the field workers to give feedback after using the application. Results obtained here will be used to improve the application. The performances of the application in different devices with different technical specifications still need to be carried out as well. This will be done to ensure that even health workers in possession of low end mobile devices will still be able to use the application efficiently.

The mobile application presented in this paper is only part of a larger health project that seeks to integrate technological health solution in South Africa. More developments are envisaged in this direction.

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VIII. References

[1] A. Alwan, D. R. MacLean, L. M. Riley, E. T. d'Espaignet, C. D. Mathers, G. A. Stevens, and D. Bettcher, "Monitoring and surveillance of chronic non-communicable diseases: progress and capacity in high-burden countries," *The Lancet* , vol. 376, no. 9755. pp. 1861–1868, 27-Nov-2010.

[2] W. H. Organization, *Global health risks : mortality and burden of disease attributable to selected major risks*. Geneva, Switzerland: World Health Organization, 2009.

[3] P. M. Kearney, M. Whelton, K. Reynolds, P. Muntner, and P. K. Whelton, “The Global burden of hypertension: analysis of worldwide data,” *Lancet*, vol. 365, pp. 217–223, 2005.

[4] S. Pastakia, S. Ali, J. Kamano, C. Akwanalo, S. Ndege, V. Buckwalter, R. Vedanthan, and G. Bloomfield, “Screening for diabetes and hypertension in a rural low income setting in western Kenya utilizing home-based and community-based strategies,” *Global. Health*, vol. 9, no. 1, p. 21, 2013.

[5] A. Bhagyalaxmi, T. Atul, and J. Shikha, “Prevalence of risk factors of non-communicable diseases in a District of Gujarat, India.,” *J. Health. Popul. Nutr.*, vol. 31, no. 1, pp. 78–85, Mar. 2013.

[6] B. M. Mayosi, A. J. Flisher, U. G. Lalloo, F. Sitas, S. M. Tollman, and D. Bradshaw, “The burden of non-communicable diseases in South Africa,” 2009. [Online]. Available: http://www.sudafrica.cooperazione.esteri.it/utlSudafrica/EN/download/pdf/The burden of non-communicable diseases in South Africa.pdf. [Accessed: 04-Jan-2014].

[7] O. Aziz, B. Lo, J. Pansiot, L. Atallah, G.-Z. Yang, and A. Darzi, “From computers to ubiquitous computing by 2010: health care,” *Philos. Trans. R. Soc. A Math. Phys. Eng. Sci.*, vol. 366, no. 1881, pp. 3805–3811, Oct. 2008.

[8] T. E. Allison, “FACTORS AFFECTING ACCESS TO HEALTH CARE FOR RURAL ARIZONA MINORITIES,” 2005. [Online]. Available: http://www.nursing.arizona.edu/Library/Allison_TE.pdf. [Accessed: 28-Nov-2013].

[9] “Census 2011.” [Online]. Available: http://www.statssa.gov.za/publications/P03014/P030142011.pdf. [Accessed: 02-Aug-2014].

[10] R. Visser, R. Bhana, and F. Monticelli, “The National Health Care Facilities Baseline Audit: National Summary Report.” Health Systems Trust, 2013.

[11] N. Languza, T. Lushaba, N. Magingxa, M. Masuku, and T. Ngubo, “Community health workers a brief description of the HST experience,” 2011. [Online]. Available: http://www.healthlink.org.za/uploads/files/CHWs_HSTexp022011.pdf. [Accessed: 04-Jan-2014].

[12] B. BUEHLER, R. RUGGIERO, and K. MEHTA, “Empowering Community Health Workers with Technology Solutions,” *IEEE TECHNOLOGY AND SOCIETY MAGAZINE*, pp. 44–52, 2013.

[13] R. Braun, C. Catalani, J. Wimbush, and D. Israelski, “Community Health Workers and Mobile Technology: A Systematic Review of the Literature,” *PLoS One*, vol. 8, no. 6, 2013.

[14] “Taking Innovation to Scale: Community Health Workers, Promotores, and the Triple Aim.” [Online]. Available: https://www.phi.org/uploads/application/files/dwjet18q0tvqvzg9iwizi6ts5shmektcxn9tntu7rrp5tugfk5.pdf. [Accessed: 01-Aug-2014].

[15] L. J. Mena, V. G. Felix, R. Ostos, J. A. Gonzalez, A. Cervantes, A. Ochoa, C. Ruiz, R. Ramos, and G. E. Maestre, “Mobile Personal Health System for Ambulatory Blood Pressure Monitoring,” *Comput. Math. Methods Med.*, vol. 2013, 2013.

[16] E. Grossman, “Ambulatory blood pressure monitoring in the diagnosis and management of hypertension.,” *Diabetes Care*, vol. 36 Suppl 2, no. Supplement_2, pp. S307–11, Aug. 2013.

[17] F. Ngabo, J. Nguimfack, F. Nwaigwe, C. Mugeni, D. Muhoza, D. Wilson, J. Kalach, R. Gakuba, C. Karema, and A. Binagwaho, “Designing and Implementing an Innovative SMS-based alert system (RapidSMS-MCH) to monitor pregnancy and reduce maternal and child deaths in Rwanda,” *Pan Afr. Med. J.*, vol. 13, no. 31, 2012.

[18] “Health Level Seven International - Homepage.” [Online]. Available: http://www.hl7.org/. [Accessed: 02-Aug-2014].

[19] T. G. Pickering, D. Shimbo, and D. Haas, “Ambulatory Blood-Pressure Monitoring,” *N. Engl. J. Med.*, vol. 355, no. 8, pp. 850–851, Aug. 2006.

[20] R. Shahriyar, M. F. Bari, G. Kundu, S. Ahamed, and M. M. Akbar, “Intelligent Mobile Health Monitoring System (IMHMS),” in *Electronic Healthcare SE - 2*, vol. 27, P. Kostkova, Ed. Springer Berlin Heidelberg, 2010, pp. 5–12.

[21] Google, “Android.” [Online]. Available: http://www.android.com/. [Accessed: 05-Jan-2014].

[22] C. Spence, J. Devoys, and S. Chahal, “Architecrutre Software as a Service for the Enterprise,” 2009.

[23] “ISO/TS 22220:2011 - Health informatics -- Identification of subjects of health care.” [Online]. Available: http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=59755. [Accessed: 09-May-2014].

[24] I. Makitla and T. Fogwill, “Mobi4D: Mobile Value-Adding Service Delivery Platform,” in *IT Convergence and Services SE - 6*, vol. 107, J. J. Park, H. Arabnia, H.-B. Chang, and T. Shon, Eds. Springer Netherlands, 2011, pp. 55–68.

[25] mHimss, “Selecting a Mobile App: Evaluating the Usability of Medical Applications,” 2012.

[26] “Telemedicine Africa.” [Online]. Available: http://telemedafrica.co.za/. [Accessed: 06-Jan-2014].