Development of Mobile Based In-Home Patient Monitoring System for the Management of Chronic Disease of Indigenous Communities in a Developing Country

Rakibul Hoque[1(✉)], Golam Sorwar[2], Ashir Ahmed[3], and Rafiqul Islam[3]

[1] University of Dhaka, Dhaka, Bangladesh
rakibul@du.ac.bd
[2] Southern Cross University, Gold Coast, Australia
Golam.Sorwar@scu.edu.au
[3] Kyushu University, Fukuoka, Japan
ashir@ait.kyushu-u.ac.jp,
rimaruf@mic.med.kyushu-u.ac.jp

Abstract. Indigenous people of developing countries have serious shortage of health support including lack of health professionals and technology. It is often difficult for the indigenous people to receive consultation in the hospitals when they face any chronic disease. In Bangladesh, there are 54 groups of indigenous communities with a base of estimated 3 million in number. There are 300 government registered doctors and nurses, and 800 community health workers to provide health services to approximately 3 million people. By the invention of Information Technology, health care services have been modernized and more accessible in recent times. Information Technology has made the health services available at the door of general people. In recent years, there is large number of people in the indigenous community uses internet in their smart phones. As, there is not enough health care organizations and professional doctors in the indigenous community, for this reason, it will be useful and compatible to provide mobile phone-based services to the people. Mobile phone-based health services have great potentiality in reducing 'digital divide', and acts as a crucial tool for supporting indigenous community especially chronic disease affected people staying at home. This paper aims to develop, implement and evaluate a mobile based integrated framework for in-home or community care and rural health centers' patient monitoring and health management.

Keywords: Indigenous communities · In-Home monitoring · Chronic disease

1 Introduction and Problem Identification

The diseases (i.e. diabetes, asthma, hypertension, cardiac diseases, paralysis, cancers of different types and depression) that undergo more than three months or more are called chronic disease (Bodenheimer et al. 2002). These are the common and direst diseases causing large number of deaths every year in the whole world. Poor eating habits,

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tobacco use, lack of physical activity, unhealthy lifestyle are the major causes of such diseases. Every year, a vast majority of people worldwide are affected by chronic diseases, and this fact causes burden of the disease is alarming. Since 2001, chronic disease results in almost 60% of all deaths and the rate is predictable to climb to 73% by 2020. The chronic disease cannot be cured fully, not even it disappears. As a result, chronic disease causes long term health and economic sufferings for both individual and families. As of now, the countries of both low and middle incomes are in a probable state of approximate loss of $7.3 trillion due to chronic diseases by 2025, which is an annual loss of about 4% for those countries (Kelland 2011).

In 2005, a longitudinal study in 23 fast-growing countries revealed that the chronic diseases were accountable for 50% of deaths and illness (Abegunde et al. 2007). With regard to this serious issue, the World Health Organization (WHO) anticipated that the deaths occurred from chronic diseases to increase by 15% within the period of 2010 to 2020, with a higher increase of over 20% in African and South-East Asian counties (Garenne et al. 2014). Although a limited number of studies exists in Bangladesh context, which is a low-ranked middle-income country, the evidence shows that chronic diseases are accountable for more than half of mortality (51%) every year, and possesses almost half of the burden of expenditure caused by diseases (41%).

Indigenous people of developing countries have serious shortage of health support including lack of health professionals and technology. Hence, every year the countries have to take disproportionate burden for patient with chronic disease. Mainly indigenous people are the underserved people of a country who are mostly detached from direct development activities. Moreover, extreme poverty and improper health facilities made the people of the indigenous communities vulnerable to several health problems. Normally, in comparison to other population, a higher number of diabetes, heart disease, tuberculosis, HIV/AIDS and many other disease patients are observed among the indigenous communities (Marrone 2007). In Bangladesh, there are 54 groups of indigenous communities with a base of estimated 3 million in number. The characteristics and the way of life of the indigenous community are remarkably different from other citizens in Bangladesh (Islam and Odland 2011). Their unconscious foods habit and unhealthy daily lifestyle cause them chronic diseases such as diabetics, heart disease, and cancer. For the treatment of the chronic diseases, patients have to face difficulty for consultation in every period of time (Whiting et al. 2011).

There exists a considerable and widespread health service inequality between indigenous and non-indigenous communities in Bangladesh. This inequality deprives the indigenous community from the common fundamental rights in the society, including health facilities (Rahmatullah et al. 2012). The ratio of the number professionally qualified Health Care Providers (HCP) is very poor in compared to the number of patients in indigenous communities. In Bangladesh, there are 300 government registered doctors and nurses, and 800 community health workers to provide health services to approximately 3 million people (El Arifeen et al. 2013). Thus, it is often difficult for the people to receive consultation in the hospitals when they face any chronic disease. Most of the time, it is seen that indigenous people take health services from village doctors, who do not have any formal medical training but provide medical treatment in the indigenous community for the common illness. For their healthcare they also rely on Baddya or Homeopathic practitioners, pharmacists and drug-sellers who lack formal medical training. Often, based on faith, they also seek treatment from the spiritual teachers, who obtained expertise from their ancestors (Rahman et al. 2012). Under such circumstance, scope and experience of getting common and conventional healthcare supports for chronic diseases for the indigenous people in Bangladesh still remains very unsatisfactory.

By the invention of Information Technology, health care services have been modernized and more accessible in recent times. Information Technology has made the health services available at the door of general people. In this regard, E-Health technology provides many benefits such as assisting in self-management, reducing the need for frequent physical visits and treatment spending. However, the indigenous communities, especially in developing countries such as Bangladesh, suffer from 'digital divide' in case of receiving E-Health care due to lack of accessibility to digital devices like smart-phones and computer with internet services. Furthermore, in developing countries, many difficulties, such as lack of infrastructure, health professionals, social resistance, and lack of readiness to accept technology among the indigenous people, make it difficult to receive the benefits of E-health like IT-based hearth services (Hoque et al. 2014).

In recent years, there is large number of people in the indigenous community uses internet in their smart phones. As, there is not enough health care organizations and professional doctors in the indigenous community, for this reason, it will be useful and compatible to provide mobile phone-based services to the people. Mobile phone-based health services have great potentiality in reducing 'digital divide', and acts as a crucial tool for supporting indigenous community especially chronic disease affected people staying at home. As chronic disease needs constant monitoring it can provide proactive and preventive solutions by ensuring availability of doctors who will give instructions and emergency treatment for chronic diseases.

As healthcare specialists and policy makers are looking for newer ways to reduce healthcare expense through improving healthcare system and service delivery, smart phone-based health services can regularly impart significant roles to facilitate in active prevention and proactive chronic diseases management by decreasing related medical expenses and increasing patient outcomes.

This project aims to develop, implement and evaluate a mobile based integrated framework for in-home or community care and rural health centers' patient monitoring and health management. In most of the cases, the existing systems mainly emphasis on monitoring the vital signs in human body. Yet, in the low-resource setting, it is impractical to provide adequate number of specialized monitoring to monitor the vital signs. This project takes into account the limitations and issues of existing in-home health monitoring facilities from the perspectives of both health professionals and chronic patients, and aims for designing and development of a framework that would enable a remote point-of-care (POC) of various health monitoring capabilities, and minimize the complexity of health monitoring for the end users.

Indeed, most of the systems proposed in the literature are specially designed for a specific application scenario. Hence, implementation of a specific system requires an ad hoc information and communication infrastructure. Without an integrating framework, it is technically and economically infeasible for the caregivers to maintain a collection of heterogeneous special purpose monitoring systems. Besides, each of the systems comes with its own user interface. This hinders the acceptance of monitoring systems to healthcare professionals as it is extremely difficult for a person to be familiar with a diverse collection of interfaces.

2 Literature Review

With the rapid change in digital health technology, the practical utility of smart phones in providing healthcare services are becoming ubiquitous (Rise et al. 2016). As the penetration of smart-phone has been increasing for last two decades, the pervasiveness of the scope of using biosensor enabled smart-phone platform has increased accordingly. Today, the benefits of smart phone in home healthcare are better realized (Munos et al. 2016). For example, the use of various types of biosensors such as optical, accelerometer, electrochemical, surface plasmon resonance (SPR) and near field communication (NFC) biosensors in smart phones for remote POC monitoring (Zhang and Liu 2016). The remote POC can simplify three important tasks in which the smart phones based POC can assist remotely in managing chronic disease. These are: (1) providing reminders to the patients to follow guidelines, (2) to provide feedback on the performance or health track records, and (3) register and interact with the service providers. In this regard, WHO has recommended to distribute of IT-based remote POC services across the service providers (Bauer et al. 2014).

In today's time, people do not like to visit doctors as it needs more time and money, especially for the inhabitants in the remote areas (Ajami and Teimouri 2015). In such reality, the biosensors in the smart phone can enable remote services like remote POC diagnostics, which is useful for the reduction of frequent doctor visits and expensive diagnosis, and enhancing the health performance and health deterioration tracking (Sun et al. 2016). The application of biosensors in the smart phones can be as cheap as less than $20, making it cost-effective and more practical to serve the purpose of serving the underprivileged population, especially in the context where the 'digital divide' prevails severely. Furthermore, in many instances, biosensors in the smart phones can assist in remote POC services, which ultimately can replace the cumbersome and expensive medical tests that require frequent visiting laboratories.

The biosensors integrated in the peripheral modules (e.g. camera, Bluetooth, audio receivers and UBS ports) in the smart phones can detect sensitive electrochemical signals, which make it possible to discontinue many bulky equipment typically used for detecting same sensitive signals (Sun et al. 2016). Such multi-purpose use of biosensors in the smart phones makes it convenient to adopt and adhere to IT-based health services, especially in the long-run treatment for chronic diseases (Sun et al. 2016). Besides, the lack of time of the doc tors distributed for the more patients make it harder to health service providers to identify some symptoms.

With the considerable development in micro/nanotechnology in the lase 10 to 15 years, such scope is highly potential because of the availability of a wide range of biosensors that are compatible with biomedical science. A successful case of application of such technology is the use of telemedicine for the prisoners which prevented the incontinence of moving the inmates to central hospital, unless it is emergency (Ajami and Arzani-Birgani 2013). Another notable usefulness of biosensors in the smart phones is the real-time detection of illicit drug use by tracking electrodermal activity, body temperature, and acceleration (Carreiro et al. 2015). For the elderly patients with chronic diseases who are incapable to moving and visiting doctors can be better served with remote POC by using smart phones with integrated biosensors (Ajami and Teimouri 2015). Beside the benefits of being cheap, convenient and portable, the other benefits of smart phone based remote POC include enhanced scalability real-time health status analysis, environment monitoring and food evaluation, which is significant in taking proactive and quick actions to manage chronic diseases (Zhang and Liu 2016).

The continuous follow-up and periodic checkup are essential for the chronic disease management. In such scenario, the wide-spread adoption of POC can eliminate the government's burden of the reducible expense incurred in the healthcare system (Sun et al. 2016). According to Benharref and Serhani (2014), by promoting the service-oriented architecture (SOA) based framework to facilitate remote POC, the governmental and private healthcare systems can minimize various chronic disease driven burdens faced by them. Another economic benefit of using remote POC is that it would save the enormous cost of biomedical information for future clinical research (Munos et al. 2016). Moreover, with the increasing use of Internet of things (IoT), a new and powerful smart health industry is also increasing the opportunity of using biosensor based remote POC.

3 The Framework

The overall framework is depicted in Fig. 1. The system consists of 3 nodes: data acquisition node, Transmission node, and Base Station node (sub-center).

3.1 Acquisition of Bio-signals

The first step in the monitoring system is the acquisition of physiological signals from a patient's body using portable/wearable bio-sensors. Patient may locate in home or rural health care centers in remote areas or any other outdoor environment implemented on mobile phone. Clearly, the biosensors should be low-cost and comfortable to use to be acceptable to the patients. In Bangladesh, various low cost locally produced wearable sensors exist to measure various physical parameters, such as, blood pressure, oxygen level, ECG signal, heart rate, blood sugar, body temperature, respiration rate, skin hydration, body motion, and brain activity.

3.2 Wireless Transmission of Bio-signals

After acquisition of the bio-signal, the measured data will be transmitted to a central database, located in a neatest hospital that can be accessed by healthcare professionals. Portable/wearable bio-sensors usually come with Bluetooth wireless connectivity to provide access to the acquired signals from a short distance. The ubiquitous phones are used to receive and pre-process the data and then transfer them to a central database via GPRS/4G mobile network technology. Patients may have a constant connection or an

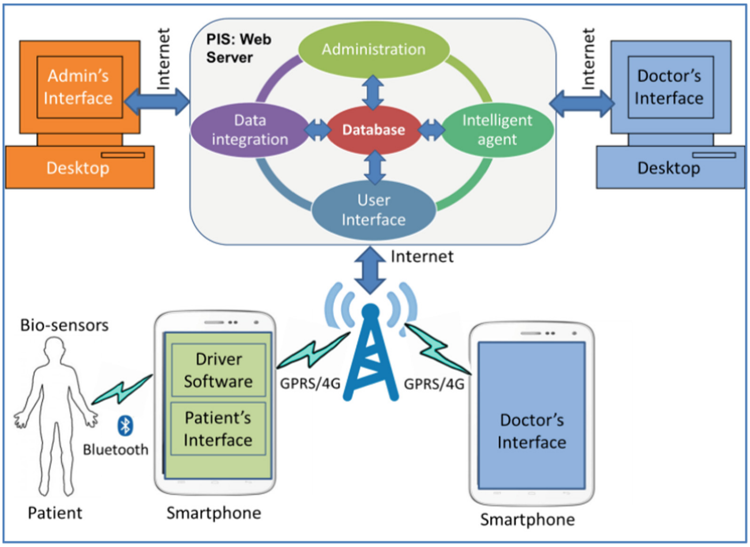


Fig. 1. The proposed framework

intermittent connection based on their needs. A bio-sensing system is thus completely defined by the physical sensing system along with the software running on the phone that coordinates the transmission of the measurements from the sensors to the base station node.

3.3 Patient Information System

Central to the proposed system is a Patient Information System (PIS) running on a base station node. In the future multiple "Base Station" nodes can be interconnected to create a distributed network using a peer-to-peer relationship. Each base station node may represent anything from a small node in a rural area health center to a large node in a local hospital. It defines an abstract interface to receive the measurements about the patients from varying sources. The interface specifies only the format of information exchange leaving the implementation details to the monitoring systems. A bio-sensing system is compatible with PIS if its driver software, running on the phone, transmits the data according to this interface. It is this abstract interface that enables the PIS to receive data from heterogeneous systems. The PIS is driven by the database storing all the patient information. The database stores patients' information coming from all possible sources such as laboratory test, imaging test, and those acquired by the remote bio-sensors. Finally, the PIS provides consistent and coherent web-based Interfaces to healthcare professionals as well as to the patients. If necessary, for example in the case of emergency, the base station node can directly communicate with a specialist consultation. If any clinical test is required, the rural center/hospital will complete those tests and directly send the report to the specialist doctor through Internet for their further diagnosis.

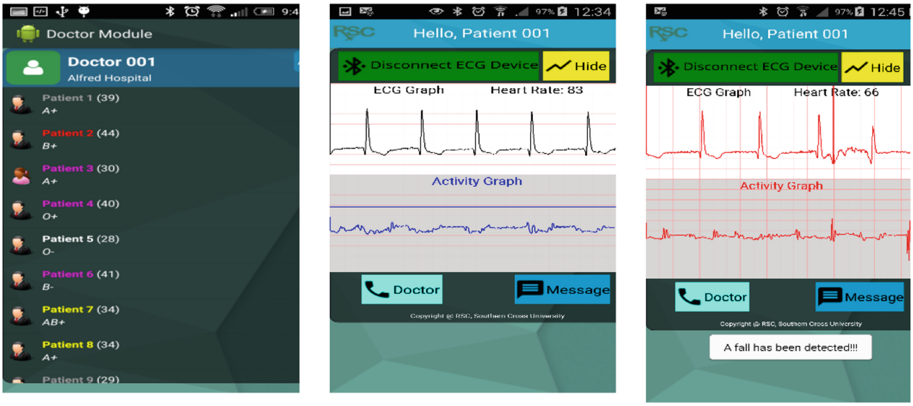
3.4 Intelligent Agent

One of the major issues to be addressed for successful adaptation of an in-home monitoring system is scalability. As the system grows in terms of number of patients and systems, automation of patients' risk assessment, prioritization, and recommendation becomes essential. Therefore, advanced artificial intelligence techniques should be employed to prioritize the patients based on the expert knowledge in the relevant domain. Since most artificial intelligent algorithms are computationally intensive, they are expected to run on the base station node server system. However, the smartphones are general purpose computing devices with processors, memory, and wireless connectivity managed by an operating system. Their main limitation is that they are low-powered devices. Therefore, low-complexity intelligent algorithms can also run on the smartphones that can detect critical conditions and alert relevant personnel using text messages.

One of the salient features of this framework is that it is scalable and it supports heterogeneous bio-sensors. The smart phone is a general-purpose computing device that can support various software and connectivity. Similarly, the PIS is also a general-purpose system defined by its abstract interface and driven by the underlying database. This general-purpose setting enables easy integration of a new monitoring device. The new monitoring systems only need to provide 'driver software' that will run on the smartphones. The drivers will access the signals from the bio-sensors and transmit them to the database hosted in the web-server.

4 Initial Prototype

As a proof-of-concept (Jahan and Chowdhury 2014), we implemented an initial prototype of the framework, presented in the previous section, using off-the-shelf bio-sensors and open source technologies. Initial implementation of the prototype focuses on heart related problems and fall detection because of their prevalence as a chronic disease. For continuous acquisition of ECG signal from a patient, we used the commercially available Heart & Activity Monitor. This single channel bio-sensor uses wireless Bluetooth technology for real-time transmission of ECG and accelerometer data. The driver software for receiving the data from the sensors and transmitting to the base station was implemented in a Samsung Galaxy mobile phone running on Android platform. The driver software also provides interfaces to doctors and patients for visualization of ECG signal (Fig. 2(a)). The driver software at the mobile phone implements an algorithm to detect falls from the accelerometer data. Since a fall is a critical condition, it needs to be detected at the mobile phone. This will enable alerting the relevant personnel directly without relying on the Internet connectivity to reduce the communication latency and uncertainty. Thus, we implemented the threshold-based fall detection algorithm. The essential idea of scheme stems from the observation that the magnitude of acceleration during fall is greater than those during normal activities. Therefore, the algorithm continuously computes the magnitude of acceleration in three-dimensional space from the acceleration values along three axes. If at any point the magnitude of acceleration exceeds a threshold (imperially defined) then it assumes that a fall has been occurred. Figure 2(b) shows that at the time of the fall, the magnitude of acceleration exceeds this threshold.



(a) (b)

Fig. 2. (a) Doctor's portal showing a list of patients; and (b) Patient's portal showing the ECG graph and the magnitude of three-dimensional acceleration. It follows from the graph that the magnitude of acceleration crosses the threshold τ during the fall.

5 Implication and Conclusion

No previous study in Bangladesh has explored the scopes and possible resultant benefits of using remote POC for chronic disease using smart phones integrated with biosensors and software driver, let alone for the indigenous communities. After observing the benefits of remote biosensor based POC in the developed countries, and developing our own prototype, we are optimistic about reducing the existing 'Digital Divide' and inconvenience of the people in the indigenous communities, and as well as contributing in the better management of their chronic disease and achieving wellness. Once proven cost effective and useful, our proposed system (app) would be commercially available for the smartphones.

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