

A Low-cost Adaptable and Personalized Remote Patient Monitoring System*

Eva Lee
Georgia Institute of
Technology
Atlanta, GA
USA
eva.lee@gatech.edu

Yuanbo Wang
Georgia Institute of
Technology
Atlanta, GA
USA
wangc@gatech.edu

Robert Davis
University of South
Carolina School of Medicine
Greenville, SC
USA
rdavis@ccihealth.org

Brent Egan
University of South
Carolina School of Medicine
Greenville, SC
USA
began@ccihealth.org

ABSTRACT

Remote patient monitoring systems (RMS) have gained increasing popularity in recent years. RMS have great potential to improve medical services by providing more affordable, timely, and accessible care. This paper describes an effective low-cost RMS that is readily deployable. The system targets chronic disease patients and attempts to reduce patient visits to the hospital and healthcare costs. The system is comprised of three modules: (1) an application for data acquisition, processing, and transmission, (2) an adaptable set of “personalized” sensors for measuring vitals and reporting emergency situations, and (3) a secure communication module for remote patient-physician interactions. The users interface with the RMS through an application installed on a mobile device. Using a return of investment (ROI) cost-benefit analysis and a cohort of 2.7 million patients, we estimate that through the implementation of such a system, the patients and the healthcare system would see benefits within one year.

CCS CONCEPTS

• **Social and professional topics ~ Remote medicine**

KEYWORDS

Remote patient monitoring system; telehealth, timely access; chronic disease; affordability; security; digital healthcare system.

1 INTRODUCTION

With an aging population and the continuous rise of healthcare costs, more affordable and accessible care must be explored. It was estimated that about half of all adults—117 million—suffer from one or more chronic health conditions [1]. An emerging approach to reducing costs and providing patients with more accessible care is through remote monitoring systems (RMS). RMS allow patients to have more frequent interaction with healthcare providers, and expand the reach and influence of healthcare providers to patients between regular office visits.

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2 METHODS

2.1 Overview and Design Concept

In this study, we design a prototypical mobile-based RMS that includes three necessary components for effective remote patient monitoring and chronic disease management. The system can 1) measure and securely upload patient vitals through affordable and customizable sensors; 2) provide encrypted two-way communication capability between patients and physicians; 3) detect patient movements and alert healthcare providers in the event of sudden falls or emergency health situations.

2.2 Sensors

A variety of sensors have been developed for monitoring symptoms associated with various types of chronic diseases. Table 1 provides a list of best low-cost sensors with wireless connectivity, along with their price and the chronic conditions that they monitor. These sensors are selected primarily based on financial considerations while ensuring robust quality and easy operation. In order to achieve lowest cost in deployment of our RMS system (ensure affordability to users), we personalize the sensors for patients according to their individual conditions.

Table 1. Best Low-Cost Sensors, Price, and Chronic Conditions that They are Capable of Monitoring

Sensor	Chronic Conditions	Price
Weight Gurus Digital Body Fat Scale [2]	Diabetes, Pain (Arthritis), Heart disease, Obesity	~\$40
Boso-medicus prestige BP Monitor [3]	Hypertension, Diabetes, Pain (Arthritis), Heart disease, Obesity, Stroke	~\$56
NeuLog™ Spirometer Sensor [4] + NeuLog™ WiFi™ Connection Bundle [5]	Asthma, Chronic Lung Disease, Obesity	\$153 (sensor) + \$214 (WiFi connection bundle)
Accu-Chek Aviva Connect Blood Glucose Monitoring System + Test Strips [6]	Diabetes	\$30 (system) + \$190 (100 test strips)
Nonin Onyx II 9560 Bluetooth Oximeter [7]	Asthma, Chronic Lung Disease, Heart Failure, Sleep Apnea	\$330
WinHealth Wireless Body Thermometer [8]	Cancer, HIV (immunocompromised)	~\$60
Rapid Response Medical Alarm with auto fall detection [9]	Pain (Arthritis), Frailty, Heart disease, Stroke	~\$36/month

2.3 Communication Module

The communication module is set up to allow the patient to interact with medical staff remotely, ask questions or discuss treatment progress on a more personal level. Our RMS incorporates Skype's AES-style encryption. Skype-to-Skype calling and video calling products ensure that Protected Health Information (PHI) are encrypted, and is free to use and easily installed on smart mobile devices [10].

2.4 Data Acquisition and Processing Module

The TeleCARE system [11] has proven successful in the remote monitoring process for treatment of patients with cardiovascular diseases. Our design integrates two of its components into our system – the data acquisition module, which is responsible for collecting data from patient's medical devices and sending them for further processing, and the data processing module, which is used to receive measured data from patients and provide analysis and visualization.

2.5 Smartphone Application

To establish a user-friendly and highly mobile system, we implement a smartphone application that provides an interface to accessing all these technologies. The application will require fingerprint/password access to protect patient identity. It will be implemented on the most prevalent Android and iOS platforms.

3 RESULTS AND DISCUSSION

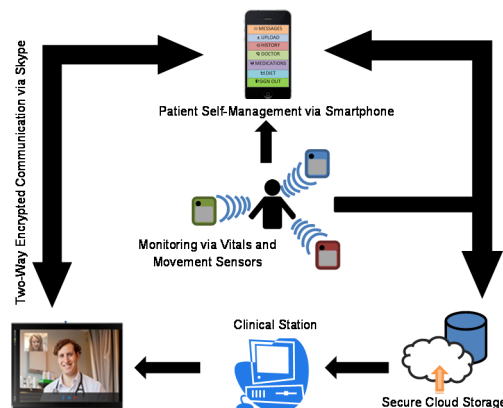


Figure 1: Prototype RMS system architecture.

Figure 1 shows the prototype architecture of our RMS. Customized sensors for individual patients take vital measurements and upload them to both the smartphone application and the secured cloud storage. Patients manage their chronic conditions through the smartphone application. Physicians download patient vitals securely through the cloud storage. Two-way communication between physicians and patients is achieved via Skype's video conferencing technologies.

4 COST-BENEFIT ANALYSIS

To evaluate the feasibility of implementing the RMS designed in this study, we perform an ROI estimation on 2.7 million patients from the Care Coordination Institute that covers 737 clinical sites, mainly in South Carolina [12]. Among these patients, almost 1 million have more than one chronic condition, and more than 0.1 million have more than three chronic conditions.

Considering hardware, software, personnel, and management costs, we estimate year one ROIs of 0.65, 0.03, 0.19, 0.13, 0.11, 0.3, and 0.57 respectively for patients with incrementing number of chronic conditions (Table 2). The total ROI in year 1 for the entire patient cohort is 0.41, which means that each dollar invested in this system is projected to yield \$1.41 in return. As more patients adopt the RMS service and the technology operations become more automatic, ROIs for later years are expected to increase steadily. By the end of year 2, the project total ROI is 0.80.

Table 2. ROI Analysis by Number of Chronic Conditions

Number of Chronic Conditions	Mean Out-of-Pocket Spending [13]	Year 1 Total Savings	Year 1 ROI	Year 2 ROI
0	\$343	\$407,588,600	0.65	0.82
1	\$795	\$7,475,786	0.03	0.82
2	\$1,134	\$37,867,817	0.19	0.75
3	\$1,760	\$11,414,186	0.13	0.66
4	\$1,814	\$1,970,436	0.11	0.63
5	\$2,314	\$653,447	0.3	0.71
6	\$3,815	\$88,790	0.57	0.82

5 CONCLUSIONS

In this paper, we present a prototype design of a personalized remote patient monitoring system. Our design focuses on patients with one or more chronic diseases. Our RMS addresses growing needs of device and disease compatibility, secure two-way communication, as well as affordability and adoption/compliance. Though our approach is tailored to meet the needs of today's market, we expect the Smartphone-based system will continue to appeal to the growing, aging population as an entertaining and motivating way for patients to take charge of their personal health.

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