SPA: A Smart Phone Assisted Chronic Illness Self-Management System with Participatory Sensing

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Abstract

The medical system has not been able to effectively adapt to the dramatic transformation in public health challenges, from acute to chronic and lifestyle-related illnesses. Although acute illnesses can be treated successfully in an office or hospital, chronic illnesses comprise the bulk of health care needs and require a very different approach. Patient involvement is critical for sustainable and successful chronic disease management. Regular feed-back of relevant health data to the individual patient facilitates patient involvement. Yet, there is a lack of effective and easily deployed tools for self-monitoring and self-care, and people often do these tasks poorly, especially people at socioeconomic risk for chronic illness, such as urban minorities. Based on the most current cognitive and behavioral change research, we propose that the prevention or treatment of chronic illnesses will be greatly aided by an innovative system that can monitor a person's body, behavior, and environment during his or her daily life, and then alert the person to take corrective action when health risks are identified. In this paper, we propose a smart phone assisted chronic illness self-management system, named SPA. Our system can provide continuous monitoring on the health condition of the system user and give valuable in-situ context-aware suggestions/feedbacks to improve the public health.

1 Introduction

The medical system has not been able to effectively adapt to the dramatic transformation in public health challenges; from acute to chronic and lifestyle-related illnesses . Although acute illnesses can be treated successfully in an office or hospital, chronic illnesses comprise the bulk of health care needs and require a very different approach. There is overwhelming consensus that the prevention and treatment of cardiovascular disease, diabetes, hypertension, chronic pain, obesity, asthma, HIV, and many other chronic illnesses require substantial patient self-management.

People need to monitor their bodies, reduce physiological arousal when stressed, increase physical activity, and avoid or change harmful environments. Yet, there is a lack of effective and easily deployed tools for self-monitoring, and people often do these tasks poorly, especially people at socioeconomic risk for chronic illness, such as urban minorities. That is, people most at risk for costly chronic illnesses have the least access to self-management tools. Based on current cognitive and behavioral change research, we are convinced that the prevention or treatment of chronic illnesses will be greatly aided by an innovative system that can monitor one's body, behavior, and environment during a person's daily life, and then alert the person to take corrective action when health risks are identified. This goal reflects the view of Microsoft Corporation president Bill Gates, who noted in a recent *Wall Street Journal* article, "What we need is to put people at the very center of the health-care system and put them in control of all of their health information".

We propose to further develop a sensor-based system that conducts real-time assessment of a person's physiology, behavior, and selected environment exposures in the field. Such information is transferred via a cell phone based platform to a central data mining warehouse. More novel, however, is that we will develop algorithms to analyze individual's data to identify health risk episodes, such as when a hypertensive patient has a heart rate elevation in the absence of exercise, or an obese person is sedentary too long and then use the cell phone to provide the person with immediate feedback, so that the person can engage in health improving actions, such as engage in a relaxation response or increase movement.

Currently, smart phones and personal assistant devices, are widely used in field research to collect information from participants. For example, at random or pre-set times, a person is prompted to respond to questions. Moreover, there are numerous devices available to record physiological responses in real life, such as blood pressure and heart rate. Apart from some rather cumbersome and geographically constrained systems, there is a lack of systems that allow for real-time recording as well as feedback to the end-user of relevant physiological, cognitive, and environmental data.

We propose to build a choric illness self-management system, named SPA, on already existing technologies; however, the system we propose uses disease-relevant biological reactions, such as, elevated heart rate, to trigger the collection of relevant self-rated and environmental data. Moreover, the system automatically evaluates a person's data, identifies risk behavior based on central data mining, and offers automated and immediate feedback as to proper corrective actions. Actually, in our system, the health care professionals will also be involved, but they are involved only in the design of the data mining algorithm, the design of the questionnaires, and intervention recommendations to the participants. Integrating those technologies, our SPA system consists of three major parts, *a body area sensor network*, *a remote server* to store and analyze data, and *a group of health care professionals*. Those three parts are connected by a variety of communication networks.

The rest of the paper is organized as follows. In Section 2, the existing approaches and previous efforts that target goals similar to us are briefly discussed. We then present the system design and its novelty in Section 3. A prototype system is described in Section 4. Finally, we summarize the paper and describe future work in Section 5.

2 State-of-the-Art

The current proposal is based on three lines of research. First, chronic illness research has demonstrated the deleterious effects of environmental and psychological stress, poor health behavior, and the need for patient self-management [4]. Yet, people are often unaware of their physiology, stress, activity, and environment during daily life; thus self-management motivation and behavior are often poor. Second, research has demonstrated the value of assessing people's stress and experiences during daily life using ecological momentary assessment, in which participants carry palm pilots and answer questions when prompted at random (or pre-determined) times during the day [10].

Third, advances in sensing technology, as well as widespread use of mobile devices with Wi-Fi, Bluetooth and 3G connection, have laid the foundations of urban sensing [2, 3]. Two principal trends support the move toward urban sensing, the integration of sensors into everyday personal devices [12] and the emerging recognition of the value of people-centric sensing in urban environments [8, 14]. Daily mobile devices, such as cellular phones, are utilized to form interactive, participatory sensor networks that enable public and professional users to gather, analyze and share local knowledge [1]. Within this context, some current research focuses on incorporating modern sensing and network technologies into health care systems. One system called MIThril LiveNet [15], was deployed for a variety of proactive health care applications. It allows people to receive real-time feedback from their continuously monitored and analyzed health states, and to communicate health information with care-givers and other members of an individual's social network for support and interaction. In another health monitoring system, HARMONI [9], a middleware is developed to enable context-aware filtering through a rule-based event processing engine. The rules in the event processing engine are updated based on changes in context. Essentially, a few recent health care systems integrate biosensors and mobile devices with wireless solutions [6, 7, 16]. The advantage of such approaches is examined in a clinic setting [5, 11].

Yet, available research rarely involves a complete health care system, which our proposed system seeks to accomplish. Current technologies usually focus on single parameters, but it is optimal to assess multiple domains simultaneously (one or more physiological parameters, movement, environmental noise, etc.), because chronic illness is affected by the aggregate load. Additionally, data should be transmitted wirelessly to a central processing unit, where one can identify data patterns that indicate elevated health risk. Most important, however, is that to date information flow has been unidirectional from patient to researcher/provider. We need to take the assessed parameters and in real-time (not delayed), alert the person of the unhealthy state of his or her body or environment, this is close to the vision of Cyber-Physical Systems, a new initiative by NSF recently. Presenting tailored and timely health interventions via cell phone is vital to promoting adaptive behavior change and reducing illness burden. Finally, data mining techniques are employed in our system to optimize the network efficiency and to analyze physiological data pattern.

3 System Design

To improve health care by taking advantage of the latest sensing and communication technologies, we design SPA, a smart phone assisted chronic illness self-management participatory sensing system. There are three main functions of the system. First, it is used to collect real-time biomedical and environmental data from the participant using sensors, which will be very useful for us to understand the possible causes of the chronic illness. Second, the data analysis and data mining algorithms are used to find time-series rules and the relationship between the biomedical and environmental parameters, which will help health care professionals to design health care plans for specific participants. Third, the system automatically triggers on-line surveys and sends out alarm notifications, largely reducing the involvement of the health care professionals, which not only saves medical cost but also protects the participants as early as possible. Next, we give a detailed description of our system design, followed by the specification of the novelty of the system.

3.1 The Architecture of the SPA System

The SPA system consists of three major parts as shown in Figure 1, including a body area sensor network to collect

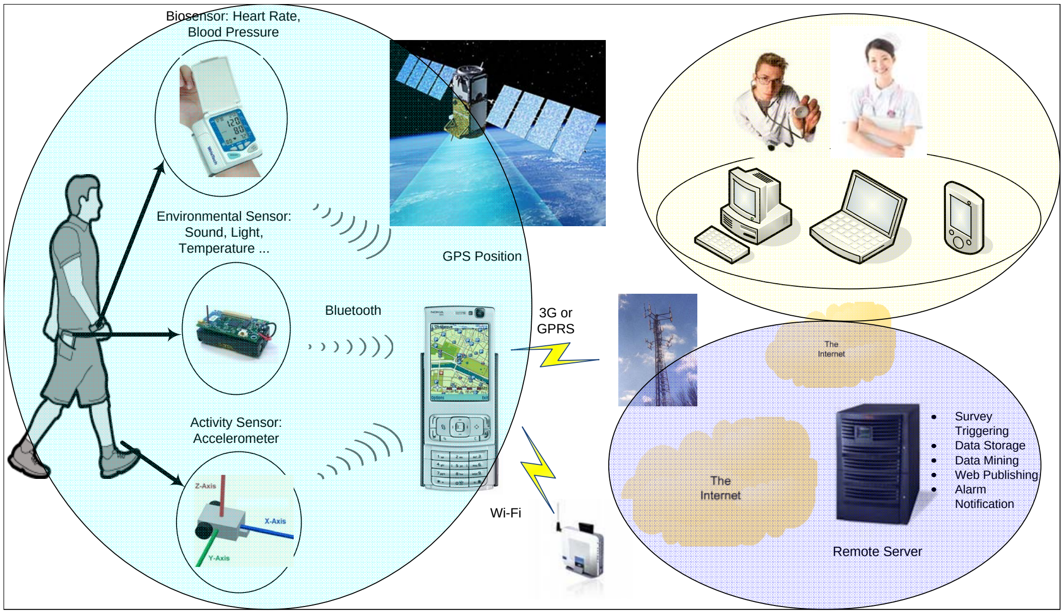

Figure 1. The architecture of the SPA system.

biomedical and environmental data, a remote server to store and analyze data, and a group of health care professionals to check records and give health care suggestions.

The body area sensor network includes a smart phone, a set of biosensors and a set of environmental sensors. The smart phone works as a base station for the body area sensor network, which can not only receive and temporarily store sensed data but also work as a router to communicate with the remote server. Moreover, the smart phone is also equipped with a GPS sensor, which can provide location information of the participant and is helpful to context-aware data analysis. A set of biosensors, such as pulse oximeter, blood pressure meter and actigraph, are attached to participant, periodically sampling the heart rate, blood pressure and movement respectively. In addition, environmental sensors are used to sample sound, temperature, humidity, and light. The communication within the body area sensor network is via Bluetooth. A TDMA schedule is devised to collect the body area sensor data. In addition to the biomedical, environmental and location data, the subjective state of the participant is also reported via random or periodical survey questions. Eventually, all sensed data and filled surveys are sent to a remote server by the smart phone.

A remote server is set up to store all collected sensor data. After these data are collected, they will be stored in a formatted data warehouse. Time series data mining algorithms are deployed at the server to discover the time-series patterns and ruled in all collected data. Multi-modality data mining algorithms is utilized to mine the correlation between the biomedical, environmental, and location data. Furthermore, multi-modality data mining algorithms will also detect the conflicts among those data and identify unusual data such as dramatic changes in the sensor readings, which health care professionals should examine and response. All above mentioned algorithms integrate the domain knowledge from health care professionals. Survey data will also be used as a calibration to measure the collected data. Follow-up investigation is necessary whenever there is a mismatch between the survey data and the sensed data. The remote server also takes care of triggering on-line surveys as well as alarm notification to the participant, based on the health care professional's suggestion or detection algorithms. In addition, it presents health records to corresponding legislated health care professionals by using access control mechanisms.

The responsibility of the health care professionals is twofold. First, they design the context-aware questionnaires and help to design the data mining algorithms using their domain knowledge. Second, the health care professionals need to check the health record from the server periodically, especially for those data which are marked as "conflict" and/or "unusual data". Follow-up suggestions are expected after the health care professionals examine the health record. In our design, we try to reduce the involvement of the health care professionals as much as possible, so most surveys and alert notifications, after they are designed, will be automatically generated by the server, based on the predetermined rules and the value of the currently received data. Only when it is in urgent cases will health care professionals be involved to provide support to the system.

The above mentioned three major parts in the SPA system are connected by using a variety of communication protocols. Within the body area network, Bluetooth is adopted to connect the sensors and the smart phone. A TDMA based schedule is designed for the smart phone to collect data from the sensors. If the smart phone is not available during the scheduled time, the sensors will store the data locally and temporarily. Thus, loose synchronization is enough between the smart phone and the sensors. Aggregation algorithms are applied when the volume of the data exceed the size of available storage. The communications between the smart phone and the server can be either WLAN or cellular network based on the network availability and energy concerns. The health care professionals usually access the health record via Internet. The data flow from the sensors to the smart phone, and eventually, data arrive at the remote server. The feedbacks and the questionnaires are initialized by the health care professionals, mostly automatically triggered by the system, and eventually delivered to participants.

Having introduced our system, we describe its novelty, which can be classified into the following aspects.

- *Real-time quality-assured data collection.* Real-time data are sampled by both biomedical sensors and environmental sensors, whereas, different monitored parameters have different real-time requirements. For example, emergency data will be reported very quickly, whereas, regular data can tolerate a long delay. All data will be collected with specific data quality requirements as defined in [13]. Adaptive sampling will be applied based on the feature of the monitored parameter, and redundant data will be filtered to reduce the volume of the delivered data. Data quality management approaches in [13] will be utilized in the real-time quality-assured data collection.

- *Multi-modality data mining and calibration.* We believe that chronic illness is related to many factors, however, the relationship between the illness and those factors has not been fully understood yet. Thus, multiple factors should be monitored to discover their possible contributions to the chronic illness. In this paper, we mainly focus on two types of sensors, biomedical sensors and environmental sensors. In addition, we also collect two types of additional data, the location information and the on-line survey answers from the participant, the first of which is necessary to get the scenario information of the corresponding data and the second of which can be used to calibrate the collected sensing data.

- *Dynamic context-aware questionnaire.* Context-aware questionnaires are designed with the help of the health care professionals to collect feedback directly from participants by interactive survey. In this case, different types of questions will be asked based on the collected data. For example, two participants having different blood pressure readings will receive different sets of questionnaires. Those context-aware questionnaires are automatically generated by the server based on some preset rules from health care professionals and the latest sensed data from the participant. To avoid increasing of the participant's nervous level caused by the sensitive survey questions, we will fill some random questions in the questionnaire. After we receive the answers, we can take out the interested answer easily. Thus, from the participant's view, they cannot distinguish the sensitive surveys from regular ones.

- *Adaptive communication protocol.* In this system, most devices, including the sensors and the smart phone, are powered by battery. Energy efficiency is one of the major concerns to extend the system lifetime and improve the availability of the system, because it is not convenient to replace or charge the battery. Because wireless communication can consume a large amount of energy, we design an adaptive communication protocol to save energy consumption. A variety of available networks with different bandwidth, energy consumption, and price, provide us opportunities to choose a suitable one to deliver the messages. For example, when the participant is in the office, he or she may have both wireless LAN or the cellular network to transmit the package. Based on the measured energy consumption of different networks, the smart phone will choose the most energy efficiency one. Of course, participants can alter choices depending on their preferences.

- *Privacy-preserving data access.* The data collected by biosensors and location information are sensitive personal information. Usually, participants are not willing to release such data to the public. Thus, all the communications in the system are encrypted and access control mechanisms are essential to regulate the users who can access the data. Only assigned health care professionals have the right to access the detailed biosensor data for the corresponding participant. Privacy-preserving approaches, which mask the detailed identity information from the participant and only present an abstracted information to the outside users, will also be utilized in the server.

4 Prototype

Based on the design described in the above section, we are developing a prototype for our system of SPA. Although it is not yet a complete system, we have implemented the main function of automatic survey and data collection. The prototype is developed based on the following facilities:

- **Biomedical sensor**: Nonin's Purelight 8000AA-WO Adult Finger Clip Sensor. The sensor measures pulse rate and blood oxygen saturation.

- **Patient Module**: Nonin's Bluetooth-enabled Avant 4100 Wrist Worn Patient Module which allows pulse rate, blood oxygen saturation to be transmitted through a Bluetooth radio to a compatible Bluetooth-enabled device. It uses two 1.5 AA batteries as internal power, supporting minimum 120 hours of continuous operation with new batteries. It weighs only 125g. The patient module is automatically activated when the sensor is connected.

- **Smart Phone**: Nokia N95-1. It has 160 MB internal dynamic memory. S60 software on Symbian 9.2 OS is installed, with S60 3rd edition user interface. It supports Java MIDP 2.0, CLDC 1.1 (Connected Limited Device Configuration (J2ME)). Connectivity features include integrated Wi-Fi (802.11 b/g) and Bluetooth wireless technology with A2DP stereo audio.

- **Server**: Dell Dimension 2400 with Intel Pentium 4 2.4 G, 1.3 G memory, and Windows XP SP2

- **Client J2ME Program Development Platform**: the S60 3rd Edition SDK for Symbian OS, Supporting Feature Pack 1. A S60 emulator is included in this platform.

- **Server Java Program Development Platform**: Java 2 SDK, SE v1.4.2_13.

The first three devices are shown on the right part in Figure 4. Pulse rate and blood oxygen saturation are sampled by the finger clip sensor, and the patient module transmits collected data to the N95-1 smart phone via Bluetooth. The smart phone is selected as the master to initiate the Bluetooth connection with the patient module as the slave device. The client J2ME program receives collected data from the patient module via service discovery protocol, and sends data to the remote server mainly via Wi-Fi connection with TCP/IP.

In addition to data transmission, a questionnaire system is implemented by the smart phone client J2ME program and the Java program on the server. Our design is displayed in Figure 2. The concurrent server program is capable of handling multiple client requests simultaneously. The network protocol currently used is TCP/IP which supports reliable, connection-oriented communication. Data are always encrypted before transmission to maintain confidentiality. Due to the smart phone's limited processing capability, only simple encryption algorithms are used. Each questionnaire is customized to each user according to data collected from the user. An example questionnaire is shown in Figure 3. The answer to the question can be compared with the sensed biomedical data. Whenever the user is prompted to complete a questionnaire, with Short Message Service, the server sends a message asking the user to start the client program on the smart phone. In that way the user can decide whether or not he or she wants to do the questionnaire. Otherwise, to be ready for the questionnaire, the smart phone client program would have to be running all the time, wasting substantial energy. Once the client program is on, it checks whether a questionnaire is available for the user. If it is, the questionnaire content is downloaded from the server, with the questionnaire being encrypted before downloading. To protect the user's privacy, the answers by the user are encrypted before being transmitted to the server, too. If desired, to validate the integrity of the answers, the server sends back the answers to the user asking for confirmation. After being confirmed, the answers are recorded in the server database.

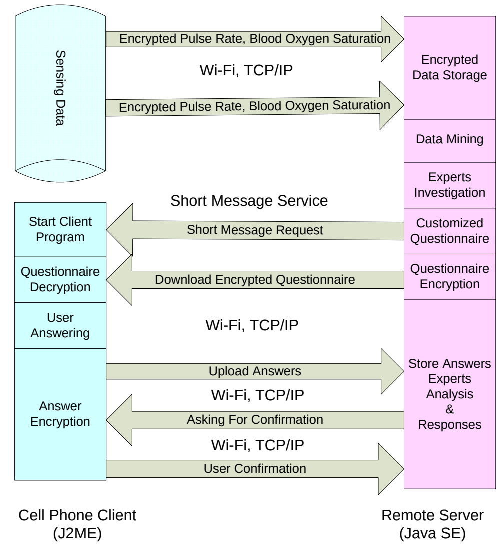

Figure 2. The interaction protocol of between a smart phone and the remote server.

All the programs developed for the smart phone are first tested in a N95 emulator for functionality, as shown as the left part in Figure 4. Then they are installed to smart phone. Currently, we have not deployed and tested our system in field, thus data analysis and data mining algorithms have not been working due to the lack of real trace, but we will have it running by the camera-ready time. Also, we plan to release the software as open source by the middle of June as well.

5 Summary and Future Work

In this paper, we propose to develop SPA, a smart phone based system that assists chronic illness self-management. In the initial step, we build a prototype that leverages smart phone and body area network of biosensors to measure a persons heart rate, blood pressure, movement, and exposure to environmental noise. The smart phone transmits personal bio-environmental sensor data from the body area network to a central server. The server collects, analyzes, and feeds back instructions to the smart phone user, based on predetermined algorithms.

We will extend our work in three ways. First, we will deploy the system and field test the system on a small sample of urban citizens to ensure its acceptability and functionality. Second, we will demonstrate the validity of the obtained data by sending to participants brief survey

1) What were you <u>doing</u> when the phone rang?

1 = Walking or running
2 = Standing
3 = Sitting down
4 = Lying down
5 = Sleeping

2) How <u>stress</u> do you feel?

1 = Very slightly or not at all
2 = A little
3 = Moderately
4 = Quite a bit
5 = Extremely

3) How much <u>energy</u> do you have?

1 = Very slightly or not at all
2 = A little
3 = Moderately
4 = Quite a bit
5 = Extremely

4) How much <u>physical activity</u> have you done in the last hour?

1 = Very slightly or not at all
2 = A little
3 = Moderately
4 = Quite a bit
5 = Extremely

5) How much do you have <u>physical symptoms or health problems</u> in the past hour?

1 = Very slightly or not at all
2 = A little
3 = Moderately
4 = Quite a bit
5 = Extremely

Figure 3. An example of survey questionnaire.

questions via the text option on the cell phone. After we collect sufficient data, we will mine the inside rules by cooperating with health care professionals. Finally, the current questions assess the participant's stress, activity, and environment, whereas in future research, we will adapt this system to monitor other physiological parameters specific to certain medical conditions, for example, blood pressure for those with hypertension, or blood glucose for people with diabetes, muscle tension for people with chronic pain. Also, future uses could monitor additional environmental risk factors, such as using global positioning to help people avoid unhealthy locations, such as for people trying to

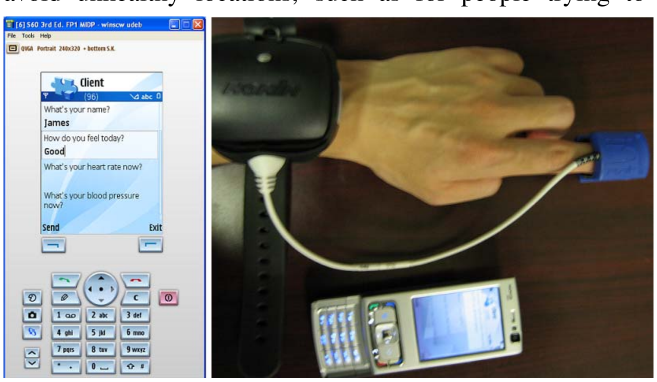

Figure 4. N95 emulator and devices.

avoid alcohol or drug use. We can envision that when the system is deployed in large scale, we will also need to solve problem of the scalability, which will be another future work.

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