A Wearable Kids’ Health Monitoring System on Smartphone

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ABSTRACT
Advances in information and communication technologies resulted in wearable and mobile health monitoring systems. Nowadays, several commercial products and academic studies are available to measure and monitor vital signs of people using wearable and wireless sensors. However, most of these applications have remained in research laboratories and are not being used pervasively while our survey pointed out that there is a high demand for this kind of solutions in the society. In this paper, we examine some of the practical challenges in developing health monitoring systems for children by designing, developing and evaluating a simple wearable mobile health monitoring system for children. The project started with a survey among parents to understand user requirements, also we interrogated a doctor as a domain expert, and finally a wearable prototype of the system was developed and evaluated. Our finding shows that downsizing the wearable sensors increases the acceptability of these devices for children; however, placing different sensors in one point would decrease accuracy of data, but analyzing relationship between different measures based on domain experts’ knowledge helps increasing reliability of the system results.

KEYWORDS
Pervasive healthcare, Ubiquitous Computing, Wearable computing, Mobile computing, Health monitoring system.

INTRODUCTION
The main goal of a health monitoring system is to identify a situation in which a person moves from a healthy state to a compromised state. For individuals with particular diseases, everyday activities could pose situations that quickly threaten their health. For instance, some changes in physical activities or dietary patterns of diabetic individuals can lead to life threatening. From diabetes management point of view, a hypoglycemic shock can really be dangerous for an artificial pancreas [1]. Therefore, the ability to estimate and guard against these critical situations is an important step on the path to save humans’ life.

Nowadays, wearable physiological sensors are being used in a wide variety of applications including home health care, elderly monitoring, and physical training [2]. These systems can provide non-invasive physiological measurements such as heart rate, movement from accelerometers, and skin surface temperature. However, there are many challenges to collect precise data and analyze it correctly to realize compromised states. For example, one of the crucial measures for a wide range of diseases especially for a child is internal body temperature, which cannot be extracted precisely from non-invasive measures. In fact, non-invasive measures such as skin temperature and heart rate are subject to many factors like the environmental conditions, clothing, activity level, and have a complex relationship to internal temperature. In order to solve the problem of inaccuracy of non-invasive measures several studies have been conducted. Some of the studies have tried to estimate human vital signs based on multiple inputs including individual anthropometrics, metabolic rate, clothing characteristics, and environmental conditions; however, some others have used artificial intelligence-based methods to calculate vital signs i.e. core temperature from heart rate [3].

Before developing and implementing a wearable health-monitoring system, the main questions, which should be answered by the system designer, are as follows.

• Which diseases are more critical for potential users, and how the monitoring system could be useful to control the implications?
• Which vital signs should be controlled for each disease?
• Which sensors should be selected to collect the most valuable data without negative implications for users?
• How should data be analyzed to realize compromised state?
• How should the system react in a critical situation?

Early childhood (defined as between 0 and 5 years of age) is one of the most critical developmental periods in our life. In fact, developing wearable monitoring systems to control health state of children leads to improving health level of society and saves parents time to care their children. Therefore, in this project we have developed a wearable

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health-monitoring system for kids, which can log and communicate health-related data. The study started with reviewing current state of the art in health monitoring systems area. A questionnaire was designed and published to evaluate the main idea of the project and collect requirements of potential users. Also we interviewed a doctor as a health professional during different steps of design and development of the system. The system has been developed and evaluated with an iterative approach.

The next two sections, describe our findings from literature review and requirements analysis. In the section 3, a brief description of system design and development steps is represented. The fourth section elaborates results of evaluation, and after the discussion part, we have concluded our findings in the last section.

RELATED WORK
Over the past few years, several commercial products have been emerged to measure vital signs. Most of these devices are wearable and can wirelessly communicate with near computing devices. Also many academic studies have been done on personal healthcare and remote health monitoring systems. The main focus of this kind of systems is to monitor more vulnerable people such as elders, and children. Some of the researchers, focused on analyzing and correlating different signs such as voice, body temperature, and heart rate to find meaningful patterns of different diseases [4], while some others have worked on power efficiency and downsizing wearable sensors [5]. Also, smartphone platform, as an inseparable part of our life, has been considered in developing health-monitoring systems by some researchers [3]. Rodriguez et al. [6] has classified monitoring systems into three main categories. Solutions in the first group capture signals and react in an offline mode. The second group systems have the capability of remote real-time processing, and systems in the third category provide local real-time processing. iCare is a mobile health monitoring system for the elderly that processes blood pressure, GPS and ECG data in real-time. iCare also provides some additional medical guidance to the user[7]. The architecture of our monitoring system is similar to the iCare system. In both systems, the mobile application receives physiological data, processes them, sends the results, and automatically alerts. However, in iCare system, the mobile application sends the data to a remote server to analyze and provide medical consultant to the users. In addition, since the iCare users are elders the physiological data, sensors and processing rules are completely different from our monitoring system.

The Intelligent Mobile Health Monitoring System (IMHMS) [8] is another health monitoring system, which is constituted of three main components: a wearable network of biosensors, a local server, and a central remote server. The wearable biosensors collect and send physiological data of patients to a local server via Bluetooth, WLAN (802.11) or ZigBee. The local server could be a PC or a smartphone. Then the local server sends collected data to a central intelligent medical server, which can learn patient specific thresholds. The intelligent server mines the data using data mining techniques such as neural nets. In fact, IMHMS is a public health record management system while our system is a real-time personal alert system.

Zheng and et al. [9] have designed and developed a wearable mobile system to provide continuous monitoring of vital signs for cardiovascular patients. The system composed of a wearable shirt with electrocardiogram, respiration and activity sensors, a portable patient unit with GPS sensor, and a medical service center. The system architecture is similar to the IMHMS [8] but the data types are different.

iCalm is a wireless sensor platform for long-term measurement of elettrodermal activity, motor activity, temperature and blood volume pulse [5]. The biosensors collect data and transmit it to a local server through wireless and Bluetooth network. In addition, a webserver shows the data gathered from sensors. The main focus of iCalm project is increasing energy efficiency and reliability of biosensors while in our project; we have developed a simple prototype sensor to collect physiological data and more focused on data analysis part of the system.

The Kids Health Monitoring System (KiMS) [4] uses wearable acoustic sensors with an embedded signal processing capability to detect various signals such as coughs, sneezes, and cries of the kids in day-care facilities. Furthermore, The KiMS receives body temperature and heart rate data from the wristband style device to detect probable infections and recognize activities of children. The KiMS reacts in an offline mode and data processing is done after data collection while our system recognizes compromised state and alerts in real-time.

REQUIREMENT ANALYSIS
The early idea of the project was design and development a health monitoring system for kids that can recognize kids’ fever and alert in an appropriate way. At the first step of the project, we evaluated the usefulness of our main idea and tried to discover requirements of potential users by designing a questionnaire and conducting an online survey. We sent the online questionnaire to 60 parents of children of two preschool in Sweden, and we received 21 answers. According to the results of the questionnaires, 20 respondents found an alerting system that can recognize kid’s fever during night from slightly useful to extremely useful. Also 19 parents found useful a health monitoring system, which could alert if their child would be sick in childcare center. In addition, 7 respondents agreed with giving a mobile phone to their kid to monitor his/her health state while 4 parents disagreed, and other 10 respondents were neutral. Moreover, most of the parents prefer to be informed about their kid’s sickness by receiving SMS and e-mail from system rather than seeing real-time information on a webpage. One of the challenges of using wearable devices for children is accepting device by them. According to the results of our survey, most of the respondents found
making an attractive shell for the sensors as the easiest way to their child to accept the device compared to hiding sensors in kids’ clothes.

The survey results helped us to discover users’ requirements and define system functionalities, but since the system is a health monitoring system, it should be reliable regarding healthcare principals and standards. Therefore, we interviewed a doctor, discussed the idea of the project, and reviewed the first requirements. The main findings from our interview with the doctor are as follows.

• This system could be really useful for the kids with chronic infections and the diabetic children; however, the system should be used in a non-critical situation which means in the urgent cases the child should be cared in a clinic or hospital.

• In order to detect fever and infection problems of children the skin temperature could not be a precise estimate of core body temperature. In fact, we need to add some other vital signs such as heart rate, activity level, and oxygenation of a kids’ hemoglobin to the system to recognize kids’ sickness.

• The best place to measure the body temperature is in the ear.

• The best sampling period for measuring body temperature and heart rate is 10-15 minutes.

• In the medical references, there are defined thresholds with specific variances for each vital sign that should be considered generally for all children. But sensitivity of the system could be increased for some of the high-risk patients.

• The main correlation between the body temperature and the heart rate is that in the infection risk situations, for 1°C increase of the temperature the heart rate grows about 10 beats/minute.

SYSTEM DESIGN
The design and development of the system was an iterative process involves cycling through understanding the design problem, analyzing user requirements, constructing the system, and evaluating the design decisions. In this section, the design space and various design alternatives to build the system are briefly described, and finally the system architecture is elaborated.

Design space analysis
According to the literature review and our interview with the doctor, non-invasive measures cannot be a precise estimation of the human vital signs [3].

“While the measures can provide a wealth of physiological information, they are quite different from what a physician might measure in a clinical setting where more controlled or invasive techniques are available. Often the measures from the non-invasive sensors are not specific to most health states of interest and can reflect the output of multiple latent variables.”

There are two different strategies to calculate a more precise amount for vital signs. The state of the art models are using different factors such as environmental condition, personal characteristics, and adding other none-invasive measures, while some other studies try to use probabilistic models to extract one measures from another one [3]. In this study, the heart rate of the kid is added to the system to improve precision of decisions.

According to the reviewing state of the art in the health monitoring system field, there are three main design alternatives for developing a health monitoring system: [6]

• An offline system
• A real-time system with a remote server
• A real-time system with a local server

With regard to our system domain and identified requirements, the system should be real-time to alert the compromised situations. Also, since the focus of this project is developing a personal health monitoring system for parents, a local server is enough to collect and analyze health-related data of a child. The local server of our system is a smartphone because the new generation of smartphones has a wide variety of capabilities such as supporting different communication protocols, powerful processors, high volume memory, and different sensors.

Moreover, by reviewing related works, we can conclude that the data analysis part of the system could be designed based on three different approaches. The first approach is defining independent thresholds for each non-invasive measure. That is the system should alert when the received data exceeds the predefined upper limit or the observed data is less than defined lower limit. The other approach is designing the monitoring system as an expert system in which the expert’s knowledge about analysis of different vital signs and relations between them is embedded. The last approach is designing a learner system, which could learn from data of different children to detect critical situations. Designing a system to monitor vital signs as independent measures is a straightforward and basic step. This approach is implemented as Manual Threshold Setting in the system. Designing an expert health monitoring system needs a long time to work with domain experts and extract their knowledge to define clear rules in the system. We have implemented some general and simple rules in the system as Recommended Threshold Setting. For example, if the heart rate increases about 10 beat/minute with 1°C increasing the body temperature, the system will alert.

One of the crucial challenges in developing pervasive health monitoring systems is selecting appropriate sensors for each vital sign [5]. Body temperature can be measured via a diverse array of sensors. All of these sensors infer the temperature by sensing some changes in a physical characteristic. There are two main categories of these
sensors: contact and noncontact. The noncontact sensors such as infrared sensors are more precise and immediately react to the temperature change. In this project, three different temperature sensors are evaluated and one of them is selected regarding precision and efficiency.

The other challenge in the design and building wearable health monitoring systems is placing sensors. According to our interview with the doctor, inside of the ear is the best place to measure body temperature, but it is really hard to convince a child to wear a sensor in her/his ear for a long time. Therefore, we decided to put the temperature sensor in an armband that can fix the sensor under the kid’s arm. Also the armband is an appropriate device to place the pulse sensor to measure the heart rate of the kid.

System Architecture

Based on above design decisions and results from requirements analysis, the designed system consists of two main components: the mobile application as a local server, and the wearable device (see Figure 1).

The mobile application

The mobile application plays a vital role in the system by receiving physiological data from wearable device, processing data and alerting after detecting a critical situation. The mobile application is developed on the android platform and has three main use cases. The screenshots of the main pages is represented in Figure 2.

- **Settings**: The first use case is setting which enables the user to enter her/his information into the application. As we mentioned in the design space analysis part, there are two different approaches to set the thresholds. A Manual Threshold Setting to define upper and lower limits for each measure, and a Recommended Threshold Setting which calculates the normal value of body temperature and heart rate based on age, gender, and weight of the kid. Also, in third part of the setting the user can choose informing methods such as alarming, receiving SMS, or e-mail.

- **View History**: The user of smartphone can review the stored data of body temperature and heart rate in two parallel graphs by clicking on the view history button.

- **Start collecting data**: The most important use case of the mobile application is connecting to the wearable device and collecting the physiological data. The user can search available devices and select a device to connect. In fact, this mobile application can collect data from all sensors supporting data transmission via Bluetooth. After connecting to the wearable device the body temperature and heart rate will be appeared on the screen and stored in a file on the smartphone.

The wearable device

The wearable device is constituted of 4 main parts: a TMP102 digital temperature sensor breakout from Sparkfun, a pulse sensor to measure heart rate, a Mini Pro...
Arduino microcontroller (3V), which collects and transmits data every 5 minutes, and a Bluetooth Mate Gold communication module from Sparkfun to send the data to the mobile application (see Figure 3).

**Figure 3. Wearable Device**

**EVALUATION**

In order to confirm the feasibility of monitoring vital signs with the system, the reliability of the wireless alarms, a simple experiment has been conducted. In this experiment, a 5-year-old kid wore the wearable device, and we started capturing body temperature data by the monitoring system (see Figure 4).

**Figure 4. The wearable armband style device on the kid’s arm**

Coincide with observing temperature data by monitoring system the skin temperature of the kid was measured by a commercial medical thermometer as a reference. The experiment was repeated 20 times and result of the experiment showed an acceptable error in captured data. The average observed deviation was 0.19°C and the maximum deviation was 0.31°C. (see Figure 5)

**Figure 5. Evaluation of body temperature data reported by the health monitoring system**

Also we found out that the Bluetooth connection is not a reliable channel to communicate. During our experiment we expected to receive 24 observations; however, we just received 20 complete sample data. In fact, we lost about 17% of the data packets thus we decided to increase the frequency of observations to ensure that the system collects necessary amount of data.

Since the system is developed in an iterative process, the reliability and validity of different parts of the system has been evaluated from the early steps of the project. For example, the usefulness of the system has been evaluated through a survey, and more that 90% of respondents found it useful. In addition, to select an appropriate thermal sensor, three different sensors were evaluated: the first sensor was a steelhead waterproof touch sensor, the second one was a TMP102 digital temperature sensor breakout, and the third one was a non-contact Infrared thermometer (TMP102MLX90614). The comparison between these three sensors showed that the infrared sensor is the most precise, but it is not an energy-efficient alternative, and after a short time (about 10 minutes) it stops sending data. The steelhead sensor is not an accurate sensor and needs a 5V power supply to work. But the digital breakout sensor is the most efficient option with an acceptable precision.

Moreover, since the mobile application should be developed before the wearable device, a software prototype of the wearable sensors was developed to send temperature and heart rate data manually via Bluetooth. Therefore, we evaluated the mobile application functionalities such as alarming, sending SMS and email before preparing the wearable device.

**DISCUSSION**

We started the project by sending a questionnaire to the potential users, and most of the respondents were inspired by the main idea of the project. But the question is that why have most of the studies been remained in the research centers while there is a considerable demand for these systems in the society? During designing and developing our system we encountered several practical challenges that describe answer of this question. For example, to realize the health state of a child we need to have several physiological data, which should be collected from various sensors, and usually these sensors should be placed in different parts of the body. But increasing number of sensors acceptability of the wearable device by a child decreases. Therefore, a health monitoring system for kids should be able to collect the most important data from limited parts of the body. In addition, because of the smaller physical size of the children, their wearable devices should be smaller which means we need high-level technologies to compact the biosensors. In our project, we have planned to use a smartphone as a wearable device for children but during the evaluation we found out that even smallest smartphones could not be used as wearable device for kids while the other health monitoring systems i.e. for elders usually assume smartphone as a wearable device.

An effective approach to overcome this problem is using smaller processors to collect data from worn sensors and
send data to a smartphone as a local server. The smartphone can analyze physiological data in real-time and alert in the critical cases. However, current network technologies like Bluetooth are not reliable ways to implement this architecture, but the next generation of Bluetooth might provide a more stable connection.

CONCLUSION
In this project, we designed and developed a mobile health monitoring system for kids using wireless sensors. According to our findings, this kind of monitoring systems are not suitable for critical situations, but many children suffering from chronic diseases and their family can benefit a lot from the system. Parents of these children spend so much time and energy to care and monitor their kid’s health. By using a reliable health monitoring system, not only can the parents save their time for their job and other useful activities but the kids can also have a natural life like other children. While advances in information and communication technologies have opened new horizons in front of the healthcare systems, there are still several challenges that should be solved by collaboration between engineers and medical professionals. For example, during conducting the experiments we lost some of data packets because of unreliability of Bluetooth technology. To compensate the lost packets, the period of observation has been decreased from 10 minutes to 5 minutes. Moreover, we experienced instability of power supplier when we selected the infrared sensor as the most precise temperature sensor. To handle power supply challenge we substitute the infrared sensor with a more efficient one. Also when we tried to measure body temperature, we found out that the skin temperature is not a precise estimation of core body temperature; therefore, we needed to extract systematic rules from the domain knowledge to analyze the correlation between collected data to draw more reliable conclusions on whether an individual health state is compromised.

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