Abstract
We present a networked application to monitor vital signs in patients without affecting their daily routines. The proposed application, which provides a monitoring and management environment, is practical especially in the case of elderly and young patients. We describe the implementation of the application, which targets reading the heart rate (HR) and blood pressure (BP) signs of patients remotely, in a context where multiple patients are considered concurrently. The application includes a control unit that analyzes remote readings, prioritizes them following their urgency, alerts health specialists for alarming readings, and feeds a server application where a database of all monitored patients stores history of the readings for each patient.

Keywords: Embedded systems, Applications of Embedded Systems, Health, wireless health monitor, Wireless sensors.

1. Introduction
Health care is an essential concern for everyone. Individuals are becoming increasingly aware of the need to evaluate their conditions; and governments are equally concerned about providing sufficient and adequate care to their citizens. In many countries, attempts exist to develop platforms to allow the use of available technologies to serve the advancement of health care services. The Internet, networked applications, embedded systems, and nanotechnology are all examples of technologies that are being increasingly used in developing solutions to various problems in health care. In the last few decades, continuous technological advances have brought hope to solve many health related problems including diagnosis, testing, and even surgery. Technologies like embedded systems, nano-electronics, robotics, and the Internet have made microsurgery, remote surgery, and implantation based diagnosis possible and practical solutions in many contexts.

In this paper, we consider the problems of people who suffer from high or low blood pressure and irregular heart rate and who do not have full awareness about the consequences; thus, are unsure of the proper actions to take when symptoms appear. While some people assume that taking medication for a given period of time can resolve a high-pressure problem, others ignore regular checking of blood pressure as long as they do not complain of any clear symptoms. In fact, it cannot be emphasized enough that hypertension patients must consult a doctor regularly to measure pressure and determine a treatment plan. Statistics conducted worldwide show that most failures in hypertension therapy result from the lack of cooperation between patients and physicians. In many cases, the required cooperation is simply taking regular periodic readings of the vital signs of the patient.

The main problem is that the current methods for reading blood pressure and heart rate are still intrusive and patient limiting; they require direct interface with the patient’s body, and they often require his/her presence for extended periods at a health facility. Even portable devices, which can be worn by the patients to monitor their vitals for extended periods of time away from the clinic or the doctor’s office do not provide real time feedback about the changes in someone’s situation. For these reasons, researchers in both academia and industry became more interested in developing technologies and tools that can provide readings of the vitals of a patient, including the blood pressure and heart rate, without much disruption to his/her daily routines. This is made possible with the continuous advances in embedded system technologies, telecommunication networks, and sensor technology. Needless to say is that any achievement in the field can simplify the task of the physician and provide the patient with better care. In addition, the benefits of any developed technology for this purpose are especially apparent in the case of elderly and young children patients who are difficult to monitor and control.
The work in this paper addresses the main questions:
Is it possible to automate the process of monitoring the blood pressure and heart rate of patients using existing technologies and infrastructure? Can such automation be scaled up to cover multiple patients in an efficient way?

In this paper, we develop a networked system for monitoring blood pressure (BP) and heart rate (HR) to be used in hospitals or with patients at home. The system consists of:

A. Embedded system monitor: bracelet with sensors for BP and HR. The embedded system can be programmed to take readings at specific times or open for remote control.

B. Control unit to log patient data and analyze readings from different monitors. The unit is also responsible for dispatching emergency calls for health specialists when alarming readings are received.

C. A control application that runs at the control unit or at a server system. This application has the task to manage the accounts of different patients, to handle the readings received from different monitors, and to build and manage the history files of each patient. The intended application consists of two main parts:
   a. A database to store patient data and records and to produce reports on the status of each patient.
   b. An interface program to handle the communications with the embedded monitor. The interface program is also responsible for the management of the database of the application (adding new patient records, deleting and updating records, generating reports, etc.). In addition, The interface allows the user, usually a health care professional, to control the embedded device remotely by sending messages to operate or to stop the monitor at designated or chosen times.

D. Wireless connection between the monitor and the control unit. In the proposed setting, a hospital or a care giving center, the communication between the embedded monitor and the control unit can be achieved via Radio Frequency (RF) communication, which is inexpensive and easy to implement.

E. Communication between control unit and third party (parent, doctor, etc.). This communication can be carried either over the Internet or over the cellular networks (GSM, 3G, etc).

This paper is organized as follows. In Section 2, we review the work and discuss similarity with existing solutions. In Section 3, we describe the specification of the proposed application and the main components involved in the implementation. In sections 4, 5, and 6; we describe, in details, the components that make up the proposed application. Then, in Section 7, we conclude the paper and list the potential future extensions.

2. Related Work

Reading the vitals of patients is a major task that cannot be overlooked in any health care process. Improving the techniques and tools used to read blood pressure (BP) and heart rate (HR) has been the focus of many researchers in both academia and industry. We review the main related works that deal with the development of advanced BP and HR monitors. In [2], the authors report the design of an electrocardiogram (ECG)/BP telemonitor using photoplethysmographic (PPG) measurement of BP, microcontroller technology, wireless communication, and long term memory devices (24 hours). The work in [3] describes a monitoring system that uses implantable CMOS based sensor to provide 24/7 monitoring of the BP. The data collected by the sensor is read telemetrically using an external unit that should be carried close to the skin (at about 8 cm from the sensor). Readings in the external unit can be transmitted to a central unit for display, analysis, or storage. iHealth [9] have developed a Wireless Blood Pressure Wrist Monitor that attaches to the hand of the patient with a cuff. This wrist monitor is linked through a wireless connection to a mobile application that can be used on a smart phone to track display instantaneous readings and history of readings. The wrist monitor is also equipped with a motion sensor system to guarantee accurate readings when different positions of the user are assumed. In other words, the device can be seen as a BP monitor that uses a smart phone as its display. The work reported in [4, 5] mentions the development of a monitor for BP and HR of patients to be recorded and displayed either locally or remotely by a wireless connection. The interesting concept is the use of non-intrusive monitoring techniques to read the signs. In addition to the classical oscillometric method, the author discusses the optical method (photoplethysmographic or PPG for short) that relies on one of two techniques. Transmission performed by shining a light through the skin of the patient from
an LED installed at one side of a body part. The light is then collected on the other side of the body part using a photodiode; which allows analysis of the characteristics of the light that passes through the skin. Reflection, on the other hand, is done by collecting the reflection of the light that is sent through the skin. In this case, both the LED and the photodiode are placed on the same side of the body part. Characteristics of the light wave are derived from its reflection (what was not absorbed in the skin). Ideal places of use are the forehead and chest. Finally, [1] describes a monitoring device to record the vitals of a patient over a wireless connection. A patch is fixed to the patient's head along with a processing unit. Optical and electrical waveforms generated by the patch determine the patient's vitals. The proposed solution uses an optical system to measure BP by determining the variation in the optical waveform generated by the patch after it is reflected in the body. This variation is then translated to an electrical waveform that is transmitted to the monitor central unit for analysis.

In this work, we base our approach on results reached in the existing works and develop an integrated framework for the monitoring of BP and HR of multiple patients concurrently. It is a networked application that is useful in different settings including hospitals, long-term care centers, and baby sections in hospitals. The application can also be deployed for single users, and is not limited in terms of choosing the type of sensors or meters. The main advantage is the possibility of analyzing patient data automatically for prioritization of the readings and creating notifications and facilitating the work of health professionals and caregivers. Furthermore, the application, accessible over the Internet, will easily integrate in any E-Health framework. This is actually an ongoing discussion with researchers working on evaluating the deployment of an E-Health application in the Kingdom of Saudi Arabia.

3. Specification of the Monitoring System

Figure 1 shows a high level representation of the BP and HR monitoring system.

Figure 1. Architecture of the monitoring application.

The figure shows the three main parts in the system along with the interconnection among them:

1. On the patient side, an embedded BP and HR monitor has the responsibility of providing the reading and filtering of data while receiving control commands and executing them (mainly to operate the monitor or stopping it).

2. The control unit application has the task to receive the readings from the monitor and process the information in two ways:
   a. If the readings are not alarming, the application passes the reading with the ID of the monitor to a server system that hosts a database of all patients. The data is stored in the databases for history.
   b. If the readings are alarming, the application sends a message to the number associated with the source monitor. As in the first case, the application passes the information for storage in the database.

In both cases the information received from the monitors are processed for a graphical or numerical display on the server system that is directly connected to the control unit.

3. The communication between the modules of the system is carried out as follows:
   a. Between the monitor and the control unit, the communication is over RF waves.
   b. Between the control unit and the server system, the communication is direct through serial connection.
   c. Between the control unit and the destination smart or mobile phone, the communication is over GSM (3G) networks. This connection can be modified to be between the server and the smart phone. In the latter case, the information sent to the smart phone will be more detailed. However, for the time being...
we consider that the control unit will send the information to the phone because that will be faster, especially in very urgent cases. An extension of the whole application is possible in way that the user can access the files remotely on the server system to check the history of any patient he selects.

In the following sections we detail the description of each of the above mentioned components in the system along with our plan for implementation.

4. Portable BP and HR Monitoring Device

The BP and HR monitoring device is a simple embedded system that can be implemented using a microcontroller or simple logic circuit. The main task of the proposed device is to perform the readings and transmit the collected information to the control unit via RF. For this reason the monitoring device can be simplified to the degree that it can implement either of the following two workflows. In both case, the device can be implemented using simple logic circuit without the need for a microcontroller. This is essential since it contributes to reducing the cost of the device so it is affordable for anyone. In Figure 2, the first workflow (a), the device does not perform any check on the collected information. Instead it is passed directly for the control unit which will be responsible for the analysis. Although this workflow pauses a higher cost on communication (based on the scheduling of transmissions), it might be needed in specific cases where every reading is needed for the diagnosis. On the other hand, the workflow in (b), permits the device itself to decide on which readings to send by performing a comparison against a predefined threshold. This workflow is useful to save on transmission power. Our intention is to implement the monitoring device using the two workflows with an option to preset the device to follow either of the two before it is given to the patient. An extension to this proposition is to make it possible to select the workflow from the device itself, but we need to evaluate how much risk this presents in terms of the accuracy of readings and safety of the patient.

5. Analysis

The main component of the proposed system is the control unit, which has the major task of compiling the readings gathered by the different monitoring devices in the network. Consequently, the unit decides on the action to be performed on the compiled data. If the data is alarming, the reading is sent directly to the designated phone number of the person in charge (this might be a doctor, a care giver, or a relative). In addition, the reading itself is sent to the server machine to be added to the database of the patients. In both cases, the server system displays the readings in a user friendly interface for the person running the application. Such interface would facilitate the task of the user to monitor the different devices registered in the application. The flowchart shown in Figure 3 shows the main task of the control unit. In the flow, the unit evaluates the readings received from the monitoring devices and decides on sending alarms or not based on the thresholds that are preset for the specific device.

The control unit is composed of the following elements:

1. Microcontroller: Two options are available for the microcontroller of the E-WATER system, PIC16F876A and PIC 16F877A [8], which both are high performance RISC CPU’s. While both microcontrollers can do the job of running the embedded system, PIC16F877A has the advantage of containing an analog to digital converter. The main characteristics of the PIC microcontrollers include:
   a. Only 35 single-word instructions to learn
   b. All single-cycle instructions except for program branches, which are two-cycle
   c. Operating speed: DC – 20 MHz clock input
   d. DC – 200 ns instruction cycle
   e. Up to 8K x 14 words of Flash Program Memory,
   f. Up to 368 x 8 bytes of Data Memory (RAM) in the form of internal registers

In addition, the PIC microcontrollers can be programmed using the C language, which is easier to learn and work with than machine specific Assembly Language. Translation into PIC instructions can be done using compilers like PIC C [8].

2. Memory Unit: we use an EEPROM -Electrically Erasable Programmable Read Only Memory-24LC16B, which is a 16k bit memory unit. The device is organized as eight blocks of 256 * 8 bit memory with a 2-wire serial interface. Low voltage design permits operation down to 2.5 volts with standby and active currents of only
The 24LC16B also has a page-write capability for up to 16 bytes of data. The memory unit will be used mainly to store the thresholds for different devices, the messages to be sent for the phones, and the phone numbers associated with each monitoring device.

Figure 2. Left: simple workflow and Right: workflow with check in the device.

3. Signal Converter: we use the MAX 232 which converts signals from an RS-232 serial port to signals suitable for use in the microcontroller (TTL logic). The MAX232 is a dual driver/receiver and typically converts the receive/transmit (RX and TX) signals, as well as the Clear To Send and Ready To Send (CTS and RTS) signals.

4. GSM Modem: We use the F1003 GSM MODEM, which supports SMS and CSD functions. The modem is inexpensive and has already been used in industrial settings. The F1003 modem supports the RS232 interface, which makes it possible to connect to the Microcontroller through the MAX232 converter.

6. Server Application
The main role of this module is to process the readings of the monitoring devices for different clients and prepare reports on the medical situation of patients. For this, a database is designed to host the records for the different patients. We first discuss the design of the database and then we describe how the application processes reports. The main objective of the database is to provide storage of the data collected by the monitoring devices, where different records of patients are defined and easily accessed. In the future, the proposed database can be extended to include variety of data that is useful to different types of reports like the medical background of the patients and the recommendations for each type of readings for the patients. This becomes useful when integrating the application with E-Health systems is discussed. Currently, the proposed database consists of four main tables:

1. Patient: This table holds data on the patients who are using the monitoring devices. The table includes fields like Name, Patient_ID, Address Telephone Number, and Device_ID. The latter field is used to identify the system that is installed at the client’s site. The table also includes two fields that are common with other tables: the Patient_ID and the Device_ID. The former, which is the primary key of the table, is common with the Report table and the latter is common with the Device table, which is not shown in the above diagram.

2. Report: This table holds the information of an Report, which includes the Patient_ID, the Report_ID, and the Report_Type (could be daily, monthly, or urgent).

3. Reading: This table includes the fields Type (monthly, weekly, or hourly), the Date and Time, the Device_ID and the Patient_ID.

4. Thresholds: This table defines the values limits that should be monitored for the specific patient.

The proposed database structure remains of manageable size and allows for ease of interface since the number of patients usually monitored in the application is usually limited.

The main task of the server application is to interface the control unit to the database of patients. The application has to update the records of each patient based on the readings received from the control unit and to generate reports based on those records. In addition to that, the application should generate reports about the data in the records. For example, reports on the yearly history, differences in readings between different patients and categories of patients based on gender, types of sickness, or age for example.
7. Conclusion and Future Work

We presented a framework for monitoring blood pressure and heart rate of patients to be used in order to automate the process monitoring the vital signs of patients in hospitals and care centers. At the same time, the proposed application can also be used on individual level in a home for a patient who needs regular reading of the vital signs. The characteristics of the proposed application include:

1. A networked application to improve monitoring blood pressure and heart rate.
2. Useful in hospitals and at home.
3. Inexpensive implementation of the control unit and the monitoring device.

An extension that is under consideration of the application is to implement a framework for remote control of the monitoring devices. The user of the server application, mainly a health professional, can control the monitoring device remotely with some predefined commands that should be used only in specific situations. These commands include two main sets:

1. Turning it on or off based on the patient record or the doctor’s request.
2. Changing the frequency of readings; for example, from hourly to daily.

On another level, discussions are already underway with a current Saudi E-Health project coordinators to evaluate the proper means to integrate the proposed monitoring network application in the E-health framework that is still in its early stages.

References