Remote Health Monitoring Device for the Elderly

Development of an Affordable and Easy-to-use Breathing Monitoring Device

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***Abstract*— In the USA, the oldest of the baby-boomer generation just started to reach retirement age a few years ago. In the years to come, a much larger percentage of the population will be dependent on others for their daily care. There are not many low-cost monitoring devices available on the market to help caregivers keep dependent elderly people comfortable and healthy in a home setting without a monthly service charge. The device presented in this paper addresses this challenge to provide caregivers an emergency alert system for the elderly based on monitoring of their breathing activities and room temperature measurements. The device also allows the dependents to make on demand request for assistance. The remote communication is enabled through the cellular telephone services; so there is no special or additional subscription services needed. This is essential to make the device more affordable for the elderly.**

Keywords-health monitoring; remote elderly monitoring; breathing monitoring; emergency alert.

I. INTRODUCTION

The oldest of the baby-boomer generation just started to reach retirement age a few years ago. In the years to come a much larger percentage of the population will be dependent on others for their daily care. In fact, the ratio of caregivers to boomers needing care in 2010 was 7.2 to 1 and is expected to decrease to 2.9 to 1 by 2050 [1].

Being a caregiver for an elderly relative can be a very demanding experience. Therefore, there will be higher demand on devices that help caregivers to remotely monitor the elderly. Unlike the devices in the market that are available for newborn care, there are not many products for home use intended for elderly monitoring applications. Such devices would be of critical value for caregivers to help keep elderly dependents comfortable and healthy in a home setting without a monthly service charge.

There are only a handful of elderly monitoring devices on the market that offer features such as help at the push of a button and fall detection. Not only are these devices lacking potential life-saving features such as movement detection and room temperature monitoring, they also require a monthly service fee in addition to an existing telephone line. For example, Philips Lifeline, a popular elderly monitoring device, requires a subscription with plans starting at $29.95 per month [2].

In the research community, there are a few systems that have been developed for breathing monitoring of the elderly. For example, Fook et al. [3] present non-intrusive respiratory monitoring system for detection of life threatening systems in bed ridden patients. The system uses Fiber Bragg Grating pressure sensors mounted on beds for continuous monitoring of the respiratory rate of patients without requiring them to wear any device.

In the wearable bio sensors category, there are a number of devices available for many different monitoring applications. As an example, Chan et al. [4] present wireless patch sensor for remote monitoring of heart rate, respiration, activity, and falls.

The goal of our project is to monitor breathing movement of elderly dependents and provide the capability to send automatic alerts to health care professionals in case of abnormalities. Data analysis is conducted to study the nature of the data and minimize false alarms, so users do not lose confidence in the device and stop using it. Additional feature of temperature monitoring is also incorporated to ensure that the dependent stays in a comfortable environment. If the room temperature exceeds a pre-set limit, an automatic alert is sent to the care giver. The device also allows the dependent to request assistance on demand, by pressing a help button.

Here is a list of criteria that our monitoring device will meet in order to benefit both the caregivers and the dependent elderly.

- The device must alert the caregiver if no breathing movement is detected. This will allow the caregiver to get emergency help right away.
- The device must not produce false breathing movement alarms. False alarms would dramatically decrease the usefulness of the motion detection feature and could frustrate users to the point of not using the feature.
- The device must be able to monitor room temperature and alert the caregiver if the temperature is outside of the preset range. This will help ensure the dependent elderly is comfortable.
- The device must allow the dependent elderly to request assistance. This request could be for anything from needing a drink to needing help getting to the bathroom.

The rest of this paper is organized as follows. The next section details the hardware design of the monitoring device.

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Section III presents the software design, which is made up of the software running on the embedded microcontroller and the software for the Smartphone app. Finally, the project results are discussed and concluding remarks as well as future recommendations provided.

II. MONITORING HARDWARE DESIGN

The critical component of this project is the breathing detection sensor. The sensor pad shown in Figure 1 is created for breathing movement detection. This unit is made up of one pressure sensor and three piezo vibration sensors. It is built by placing the sensors between two clear plastic folder dividers. The folders are held together using both extra strength double sided tape as well as epoxy. Electrical tape is also used to hold the wires together where they exit the sensor pad. The sensors were positioned in a way to help minimize the risk of false alarms. The vibration sensors are spread out to detect movement in different areas of the sensor pad and the pressure sensor is located near the vibration sensors to make sure the dependent is on the sensor pad correctly before enabling breathing alerts. Lastly, there are four pieces of Velcro on the back of the sensor pad. These were used to help the sensor pad stay in position when using it in a recliner. A rectangular piece of cotton fabric is purchased and Velcro sewn to it. This fabric could then be draped over the back of the recliner and the sensor pad could be securely placed on it.

Figure 1. Sensor pad. (a) Vibration sensor; (b) Pressure sensor; (c) Velcro that is used to help the sensor pad stay in position.

The data collection and processing of the breathing sensor device is handled by the Arduino Uno microcontroller, which offers 6 analog inputs and 14 digital I/O pins. This is a commonly available and inexpensive microcontroller that is excellent for quick proof-of-concept and prototyping.

Wireless communication between the Arduino microcontroller and Android devices is done using a Bluetooth interface module. For this project, the Bluetooth Mate Silver [5] is used, which gave reliable connection and reasonably good range.

A temperature sensor is used for monitoring the room temperature. For this purpose, the Maxim Integrated temperature sensor DS18B20 [6], shown in Figure 2, is chosen due to its low cost and adjustable precision temperature sensing.

Figure 2. Maxim Integrated DS18B20 temperature sensor

Inside of the breathing sensor pad there is one FlexiForce Pressure Sensor for the sole purpose of enabling motion detection when pressure is applied. There are also three piezo vibration sensors spread out inside the sensor pad to detect breathing movement.

An LCD screen is used for the primary purpose of displaying the current room temperature. A basic 16x2 character LCD is sufficient for the task, since the information to be displayed is simple alphanumeric characters. The LCD is equipped with a backlight to improve its readability in a dark room. A toggle switch is connected to the backlight control pins to allow the user control the backlight on or off.

A large red pushbutton switch is used to allow the dependents to press it when they require assistance. The choice or the large size is to make it easier for an elderly person to find it when looking to press the pushbutton.

Two LEDs are mounted on the front panel of the device for use as indicator lights. A green LED is used to indicate that the dependent is on the sensor pad and the breathing monitoring is active. A red LED is used as a warning indicator. It would blink for a short duration if the help button is pressed or if no breathing motion is detected while a dependent elderly is on the sensor.

An actual prototype of the circuitry for the control system is shown in Figure 3 below. In the final implementation the microcontroller and all the other components will be assembled on a printed circuit board, to make a clean and robust device.

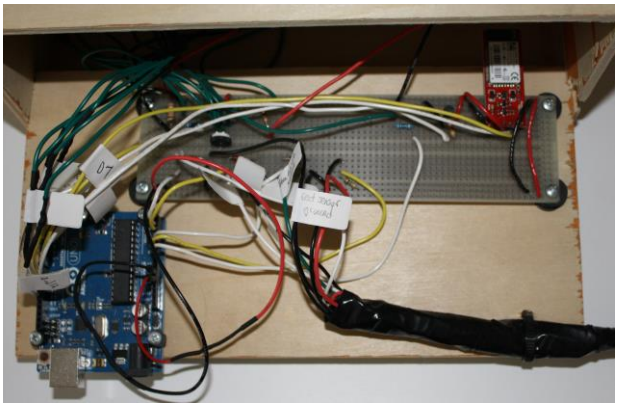

Figure 3. Initial prototype of the control system

The wiring diagrams that describe the circuit design are shown in Figures 4 and 5. To reduce complexity of the diagrams the LCD diagram is shown in a separate figure.

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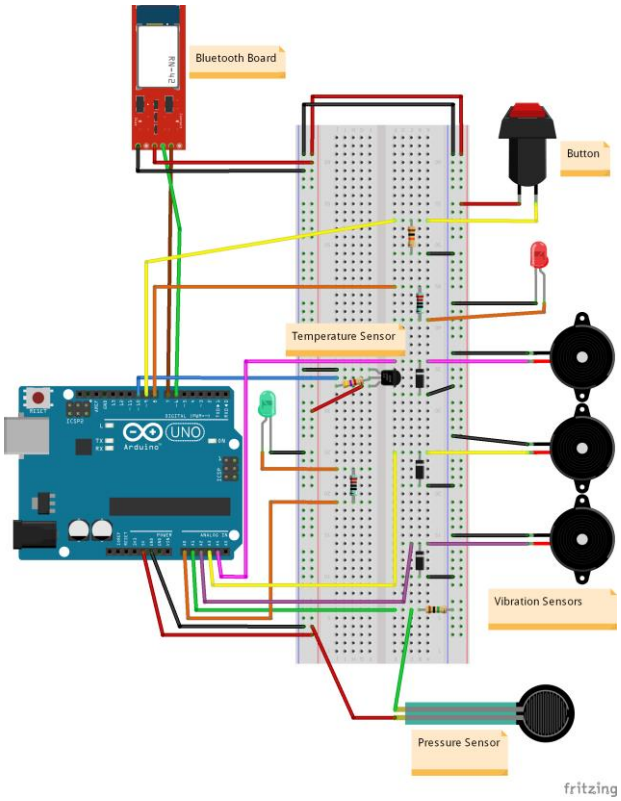

Figure 4. Wiring diagram excluding LCD

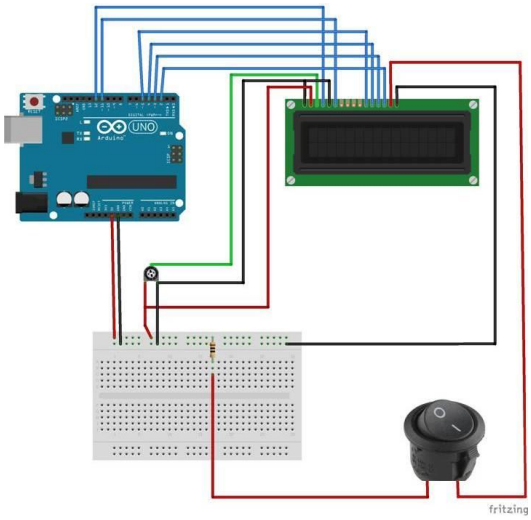

Figure 5. Wiring diagram for an LCD and a switch

All of the user interface elements that the dependent elderly needs to interact with are conveniently mounted on the device enclosure. As seen in Figure 6 below, the LCD screen and LEDs are mounted on the front of the box for easy viewing whereas the toggle switch and help button are mounted on top for easy pressing.

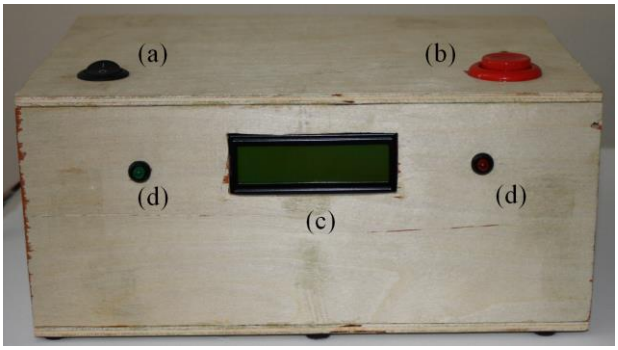

Figure 6. Monitor front view. (a) LCD backlight toggle switch; (b) Pushbutton; (c) LCD screen; (d) Green and Red LEDs

This prototype system is powered by a 9V battery. The design is verified to meet its functional requirements through basic testing by the authors and a few random subjects.

III. MONITORING SOFTWARE DESIGN

There are two software programs developed for the monitoring system. The Arduino software dealt with data from the various hardware and sensors whereas the primary purpose of the Android software is to get data from the monitoring device and send text message alerts to healthcare providers when needed.

The Arduino application starts by initializing all of the variables and hardware components. It then constantly loops through the various functions which include checking for a pushed button, updating the room temperature, sending data to the Android device, checking for breathing movement, and toggling the LEDs if necessary. Software timers are used to limit how often the room temperature is checked and how often information is sent to the Android device. These timers are also used to create breathing movement detection time frames which will be further discussed later.

When the Android application starts, it loads previously saved data such as the contact phone number and the desired room temperature range. If this data has not been updated it will load the default room temperature range of 70-80°F and notify the user that they need to enter a phone number so that alerts can be sent. At start-up the application also automatically connects to the Arduino Bluetooth board. A new thread is created that waits to receive data from the Arduino. Each time data is received, the user interface elements such as the current temperature are updated. The data is also evaluated to determine if a text message needs to be sent. Further details about this are discussed later.

A simple data structure is created for the communication between the Arduino and Android devices. During every communication, the Arduino device sends data made up of two integers separated by a colon. The first number is the current temperature (in Fahrenheit) and the second is an alert code (Table I). For example, "77:0" would mean the current room temperature is 77°F and there are no alerts.

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TABLE I. ALERT CODES

Alert Code	Alert Type
0	No alert
1	Help button was pressed
2	Movement not detected

Alert codes are used to inform the care provider if they need to give attention to the user. They could be triggered by the user pressing the help button, or automatically by the sensor when it determines that the breathing state of the person is below a specified threshold value.

A. *Breathing Movement Detection*

Breathing movement detection is a bit complex. To be enabled, the reading from the pressure sensor pin has to be at least 0.3 volts. When enabled, there are motion detection time windows. Each window is 25 seconds long. During these windows the software keeps track of the minimum and maximum readings for each of the three vibration sensors. At the end of the window, it takes the difference for each of the sensor's minimum and maximum values and compares the difference with set threshold values. This method was found to work well experimentally for detecting the difference between a breathing person (Figure 7) and a non-breathing object (Figure 8). If all three differences are below the set threshold values, the emergency alert is set and sent to the Android device. This also enables fast toggling of the red LED for 8 seconds. After each detection window ends, all of the variables are reset to prepare for the next window.

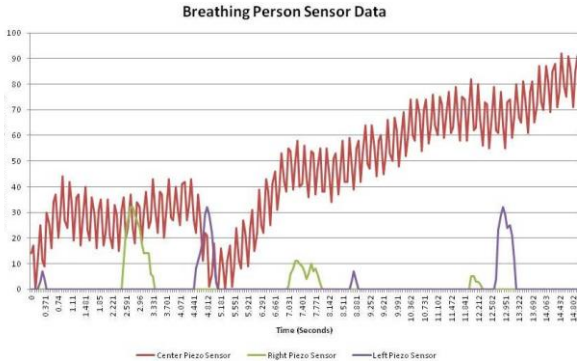

Figure 7. Sensor data for a breathing person

B. *Android Application – Caregiver Assistant*

The Android application, titled Caregiver Assistant, has been designed and tested to operate on any Android device with OS 2.3 or newer. The application allows the user to change settings such as the desired room temperature range and the phone number where text alerts are sent. It also acts as a second room temperature display. Figure 9 shows what the application looks like with each section labeled.

The first thing the Android application does after it establishes a Bluetooth connection with the Arduino device is to send it a short message. This is how the Arduino device is notified that the Android device has been connected. Following this the Arduino immediately sends temperature data that is displayed on the Android device right away.

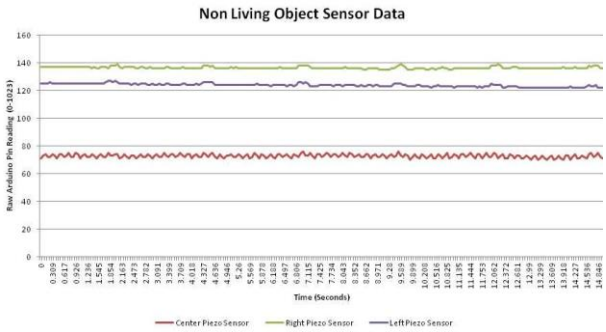

Figure 8. Sensor data for a non-breathing object

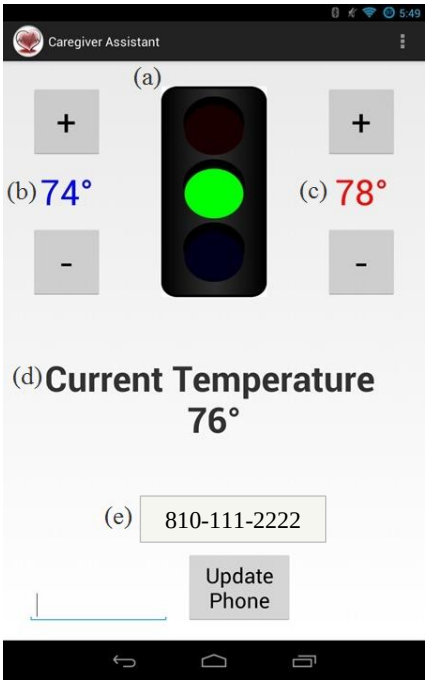

Figure 9. Android application user interface. (a) Temperature status indicator; (b) Minimum room temperature setting; (c) Maximum room temperature setting; (d) Current room temperature display; (e) Alert phone number display and update field

In the Android application, there is a thread that waits to receive data from the Arduino device. Once data is received a few things occur. First the information needs to be split to separate the temperature from the alert code. Next, the temperature on the display is updated. It also checks this updated temperature value to see if it is outside of the range in the current settings. If it is outside of the range, then a text message alert is sent indicating that the room temperature is either too warm or too cold. It then looks at the alert code. As stated earlier, if the alert code is 0 then nothing needs to

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be done. If the code is not 0 then it would send the text message alert for either a button press or no breathing detected. Sample text messages for all of these instances can be seen in Table II.

TABLE II. PREDEFINED TEXT MESSAGES

Alert Type	Text Message
Temperature Alert	Temperature Warning - Current room temperature is 62 which is outside of the current desired range
Alert Code = 1 (Button Press)	I need assistance (Button pressed)
Alert Code = 2 (Emergency)	EMERGENCY - Help ASAP

IV. DISCUSSION

In this section the analysis of the device's operation is presented. After initial testing of the breathing monitoring device that was presented in this paper the following observations are made from evaluations on how well the system meets its initial requirements.

- The device must alert the caregiver if no breathing motion is detected
  - An emergency text message is sent to the caregiver if not enough movement is detected.
- The device must not produce false breathing movement alarms
  - A pressure sensor is included in the sensor pad to disable motion sensing when the user is not on the sensor pad. This eliminates false alarms caused by the user not sitting on the sensor pad.
  - Data was collected both with people and with non-breathing objects on the sensor pad. Using the data, thresholds for each vibration sensor were set accordingly. This eliminates false alarms when the user is on the sensor pad.
- The device must be able to monitor room temperature and alert the caregiver if the temperature is outside of the entered range.
  - The caregiver can use the Android application to set a desired room temperature range.
  - A text message alert is sent to the caregiver if the temperature goes outside of the range indicated in the Android application.
- The device must allow the dependent to request assistance.
  - The dependent can press a large red button if they need the caregiver for any reason.
  - The device will send a text message to the caregiver, indicating that the button was pressed and the dependent needs help.

V. CONCLUSION AND FUTURE WORK

A prototype of a fully-functional elderly monitoring device was developed that is able to monitor breathing movement and room temperature, and alert the caregiver whenever assistance is needed. Overall, the proposed system was successful as each of the system criteria was met, as demonstrated in the previous section. Similar to competing devices, the alerts require a phone service that supports text messages and a smartphone that can run Android App. However, by sending the alerts to a caregiver or family member directly, the proposed system eliminates the additional service fee that the competition requires to operate their call centers.

Although the presented elderly monitoring device was successful, the following improvements could be considered to make the device even better.

- Implement a wireless version of the sensor pad for easier device placement
- Add an option to allow fall risk alerts. An alert can be sent to the caregiver if the elderly dependent gets up.
- Add the ability to add multiple contact phone numbers within the Android application, allowing more than one person to be contacted in emergency situations.
- Add a momentary toggle switch to allow the user to cycle through various predefined text messages instead of only being able to use the general "I need help" message.

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