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# Affordable Remote Health Monitoring System for the Elderly Using Smart Mobile Device

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**Abstract:** Aging population has been growing as life expectancy increases. In the years to come a much larger percentage of the population will be dependent on others for their daily care. According to a recent report more than 11 million seniors live alone in the USA. These seniors may face serious consequences when they have an emergency situation. However health-monitoring systems are often not affordable for many seniors. The remote health monitoring system presented in this paper addresses the challenge to provide caregivers an emergency alert system for the elderly based on monitoring of their heart rates, 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. We expect that this affordable remote health-monitoring system can be used to help seniors who live alone be safer and healthier. *Copyright © 2015 IFSA Publishing, S. L.*

**Keywords:** Health monitoring, Remote elderly monitoring, Breathing monitoring, Emergency alert.

## 1. 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, 2] (Fig. 1). Note that the caregiver support ratio is the ratio of the population aged 45–64 to the population aged 80-plus.

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 monitor the elderly. Unlike when caring for a newborn, there are not many monitoring devices for home use available on the market intended for use on the elderly available to help caregivers keep elderly dependents comfortable and healthy in a home setting without a monthly service charge.

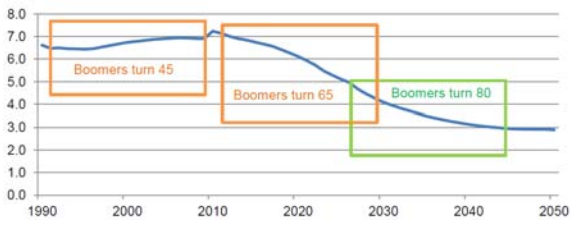



**Fig. 1.** Caregiver support ratio [2]. The calculations were based on REMI (Regional Economic Models, Inc.) 2013 baseline demographic projections.

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 [3].

In the research community, there are a few systems that have been developed for breathing monitoring of the elderly. For example, Fook, *et. al.* [4] 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.* [5] present wireless patch sensor for remote monitoring of heart rate, respiration, activity, and falls.

An affordable health monitoring device was developed for the elderly in [6]. The measurements from the multiple sensors in the "Sensor Pad" were used to evaluate situations where an elderly dependent resides. A vibration sensor in the device measures breathing activities. A pressure sensor is utilized to initiate the measurement of the breathing activities. Additionally room temperature was measured to detect general emergency. The health monitoring system will notify predefined caregivers the situation when it determines an emergent circumstance. One issue of the device was that the dependent must physically contact on the Sensor Pad to be monitored.

The present work is an extension of the device [6]. We added a heart rate monitoring sensor and a corresponding Android app to give the elderly more freedom to be off the Sensor Pad. By having this additional sensor and an Android app the caregivers will be able to collect more accurate information about their elderly dependents. The goal of this project is to provide the capability to send automatic alerts to caregivers and/or 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 the caregiver. 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 elderly dependent.

- 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 entered range. This will help ensure the dependent is comfortable.
- The device must be able to measure the heartbeat of the dependent in case the dependent is off the Sensor Pad.
- The device must allow the dependent 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. Section 3 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.

## 2. Monitoring Hardware Design

Two major components in hardware were developed for the remote health monitoring system: Breathing activity detection and heart rate measurement.

### 2.1. Breathing Detection

The critical component of this project is the breathing detection sensor. The sensor pad shown in Fig. 2 is created for breathing movement detection. This unit is made up of one pressure sensor and three piezo vibration sensors. It was 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 was 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 were spread out to detect movement in different areas of the sensor pad and the pressure sensor was 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 was purchased and Velcro was sewn to it. The fabric could then be draped over the back of the recliner and the sensor pad could be securely placed on it.

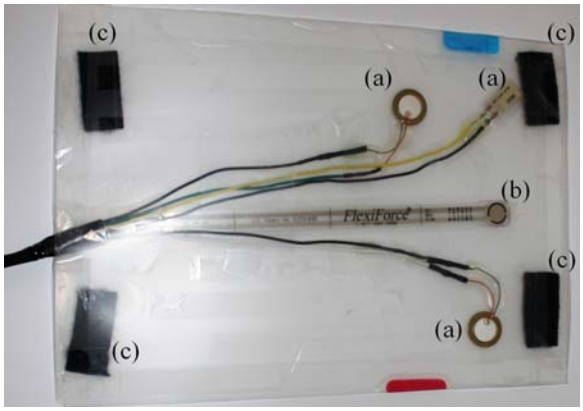



**Fig. 2.** Sensor pad.
(a) Vibration sensor; (b) Pressure sensor; (c) Velcro that is used to help the sensor pad stay in position.

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 Master Silver [7] 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 [8], shown in Fig. 3, was chosen due to its low cost and adjustable precision temperature sensing.

Inside of the breathing sensor pad there was one FlexiForce Pressure Sensor (Fig. 4) for the sole purpose of enabling motion detection when pressure is applied.

There were also three piezo vibration sensors (Fig. 5) spreading out inside the sensor pad to detect breathing movement.

**Fig. 3.** Maxim Integrated DS18B20 temperature sensor.


**Fig. 4.** FlexiForce pressure sensor.

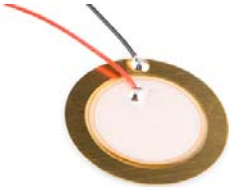


**Fig. 5.** Piezo vibration sensor.

An LCD screen was used for the primary purpose of displaying the current room temperature. Since the device only needed to display alphanumeric characters, a basic 16×2 character LCD was chosen. The LCD was equipped with a backlight to make it easier to read the screen in a dark room. A toggle switch was purchased and connected to the backlight control pins which allowed the user to switch the backlight on or off.

A large red pushbutton switch was used to allow the dependent to press it when they required assistance. A large size was chosen to make it easier for an elderly person to find and press it.

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

An actual prototype of the circuitry for the control system is shown in Fig. 6 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.

The wiring diagrams are shown in Fig. 7 and Fig. 8 to show the circuits. To reduce complexity of the diagrams the LCD diagram is shown in a separated figure.

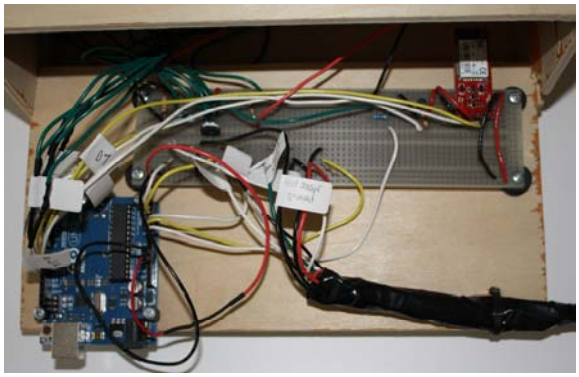


**Fig. 6.** Initial prototype of the control system.

All of the user interface elements that the dependent needs to interact with are conveniently mounted on the device enclosure. As seen in Fig. 9 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.

## 2.2. Heartbeat Measurement

The Pulse Sensor Amped [9] was used to measure the heart pulse signal (Fig. 10). The heart pulse signals are represented as voltage fluctuation from the sensor that uses photoplethysmography (PPG).

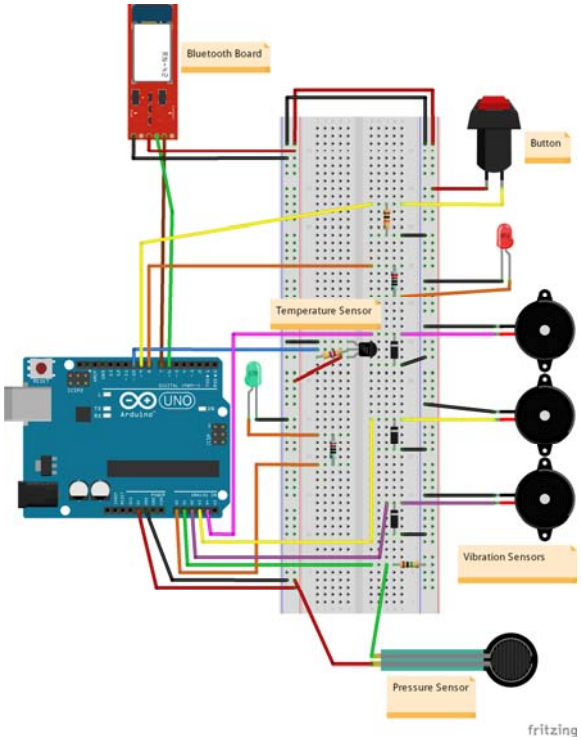



**Fig. 7.** Wiring diagram excluding LCD.

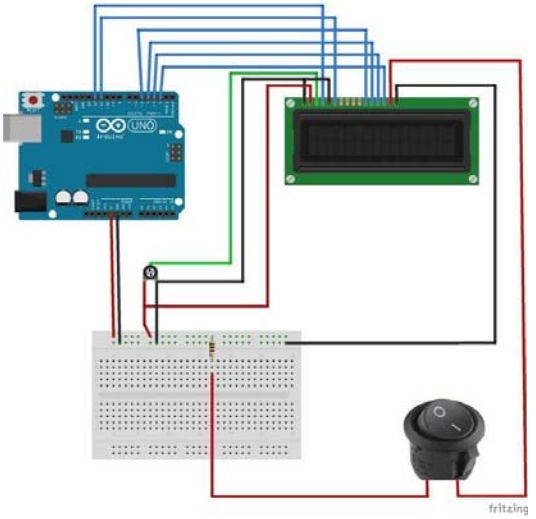



**Fig. 8.** Wiring diagram for an LCD and a switch.

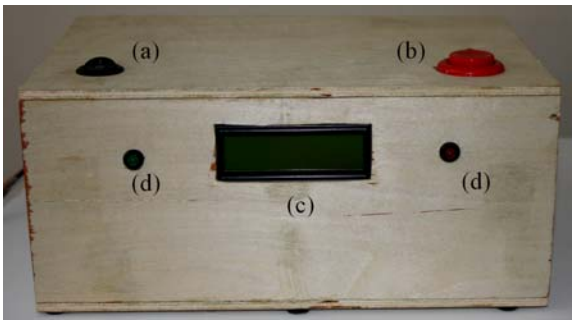



**Fig. 9.** Monitor front view. (a) LCD backlight toggle switch; (b) Pushbutton; (c) LCD screen; (d) Green and Red LEDs.

**Fig. 10.** Pulse Sensor Amped.

PPG is a low-cost optical technique that can be used to detect blood volume changes in the microvascular of tissue [10]. It is often used non-invasively to make measurements at the skin surface. We used beats per minute or PBM to determine the pulse rate from [11].

Using the Pulse Sensor Amped, the heartbeat measurement module was implemented as shown in Fig. 11.

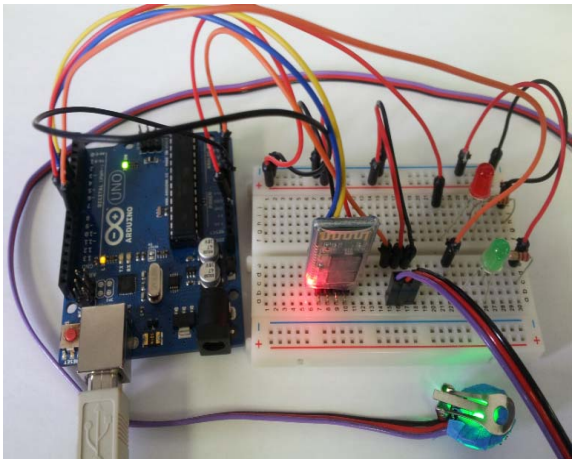


**Fig. 11.** Heartbeat measurement prototype.

## 3. 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 was 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 hasn't 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 1). For example, "77:0" would mean the current room temperature was 77°F and there were no alerts.

**Table 1.** Alert code.

| Alert code | Alert Type |
|---|---|
| **0** | No alert |
| **1** | Help button was pressed |
| **2** | Movement not detected |

## 3.1. 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 detecting 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 (Fig. 12) and a non-breathing object (Fig. 13).

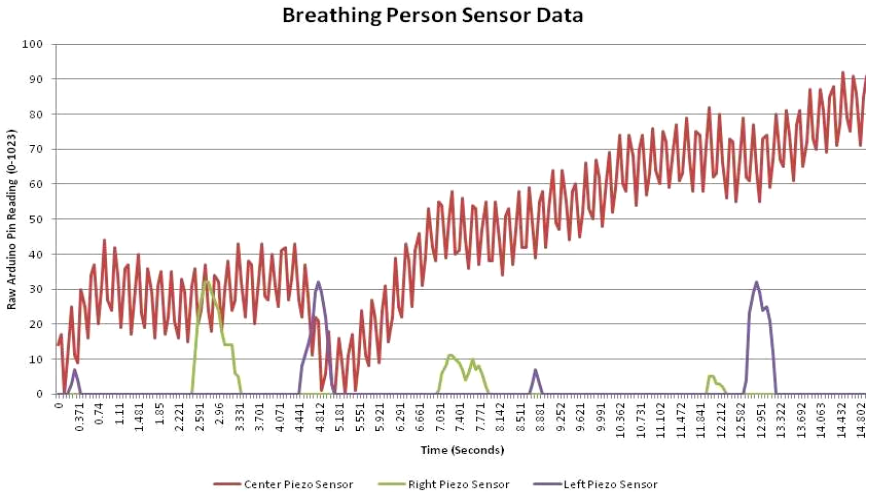



**Fig. 12.** Sensor data for a breathing person.

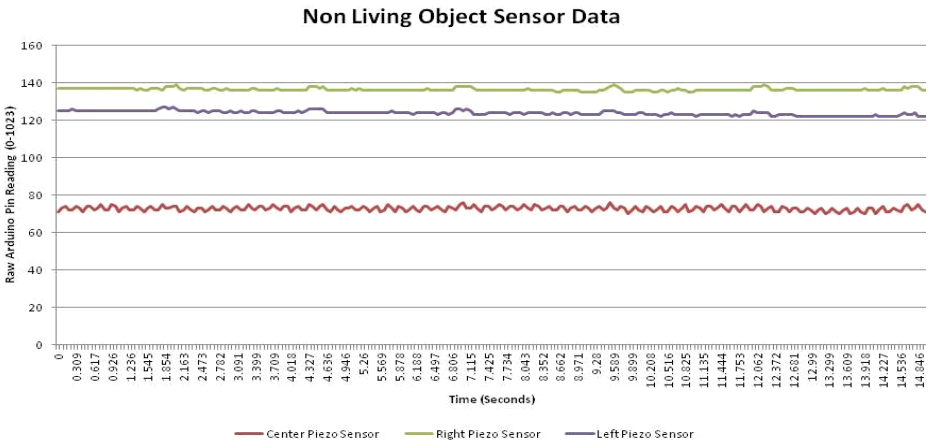



**Fig. 13.** Sensor data for a non-breathing object.

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.

### 3.2. Android App – 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. Fig. 14 shows what the application looks like with each section labeled.

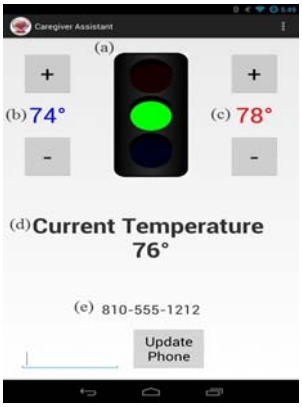



**Fig. 14.** Android app – Caregiver Assistant user interface. (a) Temperature status indicator; (b) Minimum room temperature setting; (c) Maximum room temperature setting; (d) Current room temperature display; (e) Alert phone number display and update field.

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.

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's outside of the range in the current settings. If it's 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 be done. If the code isn't 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 2.

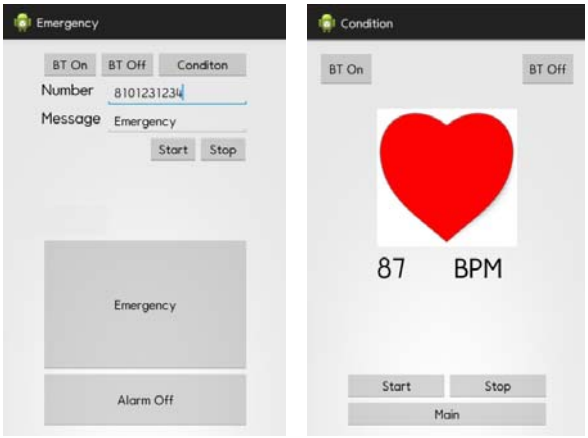
**Table 2.** Predetermined Text Messages.

| 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 |

### 3.3. Android App – Heart Rate Monitoring

The user interface consists of a series of clickable buttons that perform actions and edit the phone number (Fig. 15 (a)).

The heartbeat measurement device is connected to the Android app through Bluetooth. BT On button connects the app to heart rate monitoring device. The current location is automatically updated in either every 10 seconds or when position changes above 10 meters. When Start button is pressed, the heart rate measurement device starts sending pulse rate signals to the app. The emergency message can be sent either when the user clicks Emergency button manually or when the heartbeat per minute is below/above the predefined value automatically. Fig. 15 (b) shows a current heart rate.




(a) (b)

**Fig. 15.** Android application user interface for heartbeat measurement.
(a) Main control screen, (b) Heartbeat visualization.

## 4. 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.

## 5. Conclusions and Future Work

Overall the proposed system was successful as each of the system criteria was met, as demonstrated in the previous section. 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. Similar to competing devices, the alerts require phone service in the form of an Android device. However, by sending the alerts to a caregiver or family member, this 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. The option could be set from the Android application to avoid needing additional hardware.
- 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.

## References

[1]. W. Hamilton, Baby boomers may have no one to care for them in old age, *Los Angeles Times*, January 2015, http://www.latimes.com/business/money/la-fi-mo-baby-boomers-may-have-no-one-to-care-for-them-in-old-age-0130826,0,2883385.story#axzz2v7YvAMTE

[2]. D. Redfoot, L. Feinberg, A. Houser, The Aging of the Baby Boom and the Growing Care Gap: A Look at Future Declines in the Availability of Family Caregivers, January 2015, http://www.aarp.org/content/dam/aarp/research/public_policy_institute/ltc/2013/baby-boom-and-the-growing-care-gap-insight-AARP-ppi-ltc.pdf

[3]. Philips, *What Lifeline Costs*, January 2015, http://www.lifelinesys.com/content/lifeline-products/what-lifeline-costs

[4]. V. F. S. Fook, *et al*., Non-intrusive respiratory monitoring system using Fiber Bragg Grating sensor, in *Proceedings of the 10th International Conference on e-Health Networking, Applications and Services*, 2008, pp. 160-164.

[5]. A. M. Chan, N. Selvaraj, N. Ferdosi, R. Narasimhan, Wireless patch sensor for remote monitoring of heart rate, respiration, activity, and falls, in *Proceedings of the 35th Annual International conference of the IEEE EMBS*, 2013, pp. 6115-6118.

[6]. M. Clark, J. Kwon, G. Tewolde, Health Monitoring Device for the Elderly, in *Proceedings of the 5th International Conference on Sensor Device Technologies and Applications (SENSORDEVICES' 14*), 16-20 November Lisbon, Portugal, 2014, pp.59-63.

[7]. Bluetooth Mate Silver, Jan. 2015, https://www.sparkfun.com/products/12576

[8]. Maxim Integrated DS18B20 Prgrammable resolution 1-wire digital thermometer, Jan. 2015, http://www.maximintegrated.com/en/products/analog/sensors-and-sensor-interface/DS18B20.html

[9]. Pulse Sensor, Jan. 2015, http://pulsesensor.myshopify.com/products/pulse-sensor-amped

[10]. John Allen, Photoplethysmography and its application in clinical physiological measurement, *Journal of Physiological Measurement*, Vol. 28, Issue 3, 2007.

[11]. Pulse Sensor Amped, Arduino Code v1.2 Walkthrough, Jan. 2015, http://pulsesensor.myshopify.com/pages/pulse-sensor-amped-arduino-v1dot1