RERC Report

Accessible Home Vital Signs Monitoring System

by

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Team #3

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1 Introduction

1.1 Background

With the aging baby boomer population, home health care is a growing and changing industry. The advent of telemedicine and advanced communications technology has allowed medical patient monitoring to move from the hospital to the home. By monitoring patients' statuses remotely, health care facilities can free up hospital beds and doctors' time for more critical patients. An integral part of remotely monitoring a patient's condition is the vital signs monitor.

There are many clients who are in need of an accessible home vital signs monitoring system. To make this device as accessible as possible, we have to address the many needs of all of our clients. An overview of these needs can be seen in three of our clients: Mat, Sani, and Dolores. Mat is a 52-year-old male in good physical condition. He is blind and works as a radio commentator. Mat just had a small stroke, and his doctor wants to monitor his vital signs from home for the next 90 days. Mat does not like devices that are very technologically advanced, but lives with his vision-impaired wife who loves the internet. Sani is a 31-year-old female who recently experienced a head injury from an automobile accident. This accident has left the right side of her body paralyzed (her dominant side). Sani is a lawyer and is now working part time from home. She must sleep in a hospital bed, and she administers pain medication to herself using an infusion pump. Her doctor monitors her vital signs by a computer system that is installed in her home. Sani does not want to appear sick to her family and friends. She would like a vital signs monitoring device that blends in with the other furniture in her home. Our last client is Dolores. She is an 86-year-old female who lives with her son, his wife, and her grandson. Dolores is deaf and has severe arthritis. She also has heart problems that cause her to receive infusions at home. These infusions are normally administered by one of her family members. Dolores' grandson Tyler is 11 years old, and he likes all kinds of electrical gadgets. He loves to help his grandmother collect her vital signs and send them to her doctors on the computer.

1.2 Purpose of the Project

The purpose of this project is to create an accessible home vital signs monitoring system. Although there are already similar devices on the market, it is our goal to design a monitoring system that meets our clients' specific needs. This device will improve our clients' quality of life by allowing health care professionals to monitor them from home, rather than from a bed in a hospital or nursing home. Our clients want to maintain their health, not appear sick to their friends, and continue to live with their families. The device we design will allow them to do these things. It will be accessible to the vision and hearing impaired, and it will be cost effective. Most systems available today are very expensive, and our purpose is to make an affordable device that is also accessible and easy to use.

2 Project Design

2.1 Alternative Design

2.1.1 Thermometer

To measure body temperature, a thermistor circuit will be used. The probe chosen for this is the Welch-Allyn # 02893-000 Sure Temp 690 Oral Probe from DREMed.com. For our use as an oral temperature probe, the thermistor needs to be linearized (calibrated) around 98.6° F (37°C), for a temperature range of at least 90-104° F (32-40°C). After being linearized, the signal will be filtered, amplified, and then passed to the microprocessor where it will be analyzed and sent to an LCD screen to be displayed.

The thermometer will be tested by placing the probe in a beaker of water heated to a certain temperature and comparing the resulting temperature given by the thermometer to the actual temperature of the water. We feel an appropriate temperature range to test this would be from 32°C to 40°C. Final testing will be done by taking group members' temperature with the thermometer and comparing the reading with that taken by a commercial digital thermometer.

2.1.2 Pulse Oximeter

To measure blood oxygen saturation, a pulse oximeter will be used [16]. The circuit design can be seen in Fig 1. A finger probe will be constructed, rather than bought (to reduce cost). The finger probe that we will use with our device will need a red LED, a NIR LED, and a photodiode. The LEDs will be placed opposite the photodiode within a casing that can be clipped to a finger. One LED will work at a red wavelength (660nm) and the other at a near-infrared (NIR) wavelength (910nm). Also, in the probe will be a photodetector that will detect the light transmitted through the finger.
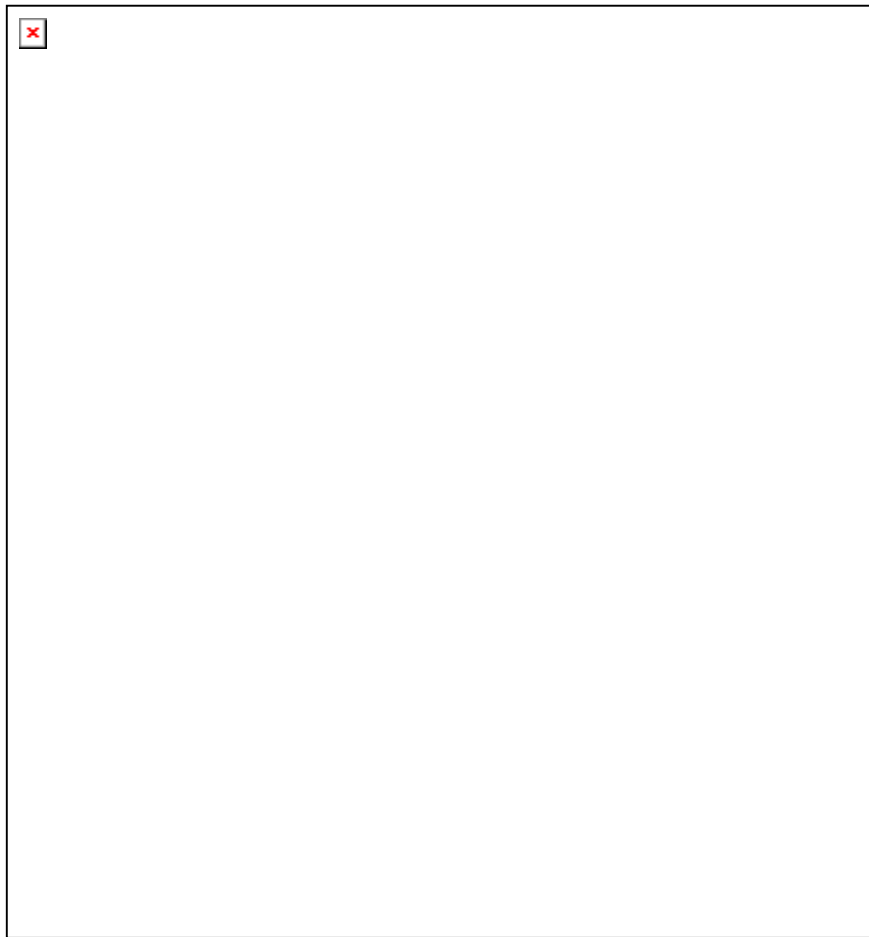

Figure 1. Pulse Oximeter Circuit Diagram

Calibration of the pulse oximeter will be done through the lookup table stored on the microprocessor. Manufacturers of pulse oximeters determine calibration curves or lookup tables for their devices. The pulse oximeter will be calibrated tested through a pulse oximeter simulator, a device designed to test the accuracy of pulse oximeters. We plan to find a simulator to use at a local hospital or the UConn Health Center.

Heart Rate

Pulse oximetry will also be used to determine heart rate. There are pulsatile signals detected in the intensity of the detected light by the photodiode. One pulse is one cardiac cycle. The microprocessor will count the pulses to determine heart rate (beats per minute), which will be displayed on an LCD screen. This function will be tested by comparing the heart rate given by the pulse oximeter to that of a group member taken manually.

2.1.3 Non Invasive Blood Pressure

Blood pressure will be automatically measured through the oscillometric method [15]. The blood pressure cuff used will be a DRE Adult single lumen cuff from DREMed.com. The cuff will be inflated by a Sensidyne AA Series Micro Air Pump. A microprocessor, second to the microprocessor controlling the rest of the device, will control the inflation of the cuff. The sensor used to sense cuff pressure will be the NPC-1210 low-pressure sensor from GE. Once the pressure sensor determines that the cuff has been inflated to 160mmHg, the cuff will deflate slowly at a rate of 2-3mmHg/sec. Deflation will occur through a release valve (brand to be determined).

As blood begins flowing through the brachial artery again, it will cause small pulsations that will be picked up by the pressure sensor in the cuff. This waveform will be analyzed by the microprocessor to determine the systolic and diastolic pressures. Due to the safety issues that arise with automatic blood pressure systems, we have incorporated a "kill switch" into our design [18]. If at any time during the blood pressure measurement the user wants to stop the inflation of the cuff and rapidly deflate it, they just need to press the vital signs monitor "On/Off" button. This will cut power to the whole device and open the pressure release valve. This method bypasses the microprocessor, avoiding any software bugs that an emergency stop button might encounter.

The automated blood pressure system will be calibrated experimentally. This will be done through establishing a threshold voltage by which correct pressure measurements for systolic and diastolic pressures can be made. Final testing of the device will be done by comparing its blood pressure readings to those of a sphygmometer.

2.1.4 Respiratory Rate

Respiratory rate in this design will be measured using a thermocouple. The thermocouple will be clipped to the client's nose and will measure the change in temperature caused by inspiration and expiration (Fig. 2). The thermocouple will convert the changes in temperature it detects to changes in voltage. Through experimentation, voltages thresholds will be set to define the changes in temperature that correspond to inspiration and expiration. By counting the number of inspiration and expiration pairs that occur in a given period of time, we can determine respiratory rate.

Figure 2. Image of Thermocouple Nose Clip

The voltage from the thermocouple will be linear over our range (approx. 65°F to 98°F), so the signal from the thermocouple only needs to be filtered and amplified before being A/D converted and processed by the microprocessor.

As mentioned previously, this circuit will be calibrated experimentally. Voltage output from the thermocouple will be measured for inspiration and expiration. From these measurements voltage thresholds will be set for inspiration and expiration. Testing will be done by comparing the readings from

our respiratory rate monitor to those taken by the Biopac respiratory belt from the Biopac software used in the ENGR 166 lab.

2.1.5 Weight

Weight will be monitored by digital bathroom scale. The scale that will be used is the Homedics SC-200 Digital Scale. We plan on taking apart the scale and breaking the connection between the circuit and its digital display. From here we will connect the scale's circuit to our output display. The scale will already have been calibrated and tested by its manufacturer. We will do additional testing by comparing known weight values (dumbbells) to the values displayed by the scale when we place the weights on it.

2.1.6 USB Device

Vital signs readings will be stored via a USB flashdrive. This device will then be connected to a computer to download vital signs. The USB device that we decided to use is the Philips PDIUSBD11. This device uses I2C technology to connect to the microprocessor. This allows for easy communication between the two. By writing a computer program in the microprocessor, we will be able to send the data received by the machine to the USB device and then to the computer.
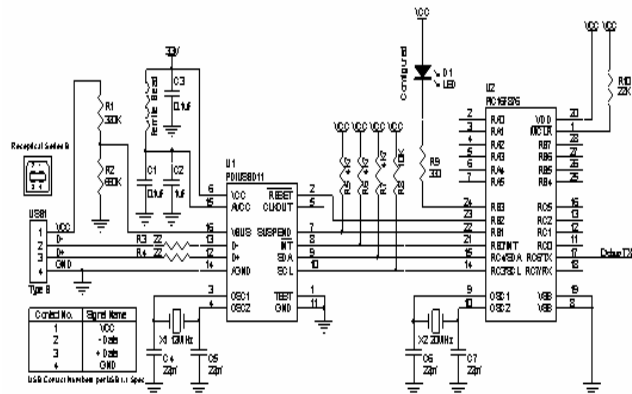

Figure 3. Sample USB Schematic

2.1.7 Power Supply

The device will mainly be run from an external power source by using a power cord. It will also be equipped with backup batteries in case of a power failure. For the power supply, we plan on using a very generic universal power cord, which will plug into the back of our device and then also plug into the wall. For the backup power supply we determined the best way would be to use nickel cadmium rechargeable batteries.

2.1.8 Secure E-mail System

In other designs, we sent the vital signs data through a secure website. Another viable option that we explore in this design is a secure e-mail system. This can be accomplished through certifiedmail.com. This website provides the software necessary to protect e-mail using transparent encryption. It provides easy to use software that the recipient of the e-mail does not need to download in order for complete security to occur. There is no password required and information is automatically secured every time with the Certified Mail software. It is also possible to track the e-mail to determine that the e-mail was received and who opened it. A one-time download and $10 per month provides these features.

2.1.9 Processing, Display, and Alarm

The processor we are going to use for this design is the Blackfin ADSP-BF535P Digital Signal Processor by Analog Devices. Like the PIC microcontrollers, the Blackfin contains an internal analog to digital converter. We will use the PF pins (I/O ports on microcontrollers) on the Blackfin to function as inputs for the transducers and outputs for the LCD screens and speaker. Due to the Blackfin's abilities, it should be the only microprocessor we need for our device. The Blackfin can take C/C++ code as well as LabVIEW Vi's.

After the data has been processed the information will be sent to 4 different areas: the LCD display, the speech module, the speaker, and alarm. The process and parts to produce audio include the Magnevation SpeakJet IC in conjunction with the TTS256 Text to Code IC to produce speech. To play these sounds (and the alarm), a commercial .5W, 8 Ohm speaker will be purchased. The alarm will include audio and visual features that will turn on when the client's vital signs become abnormal.
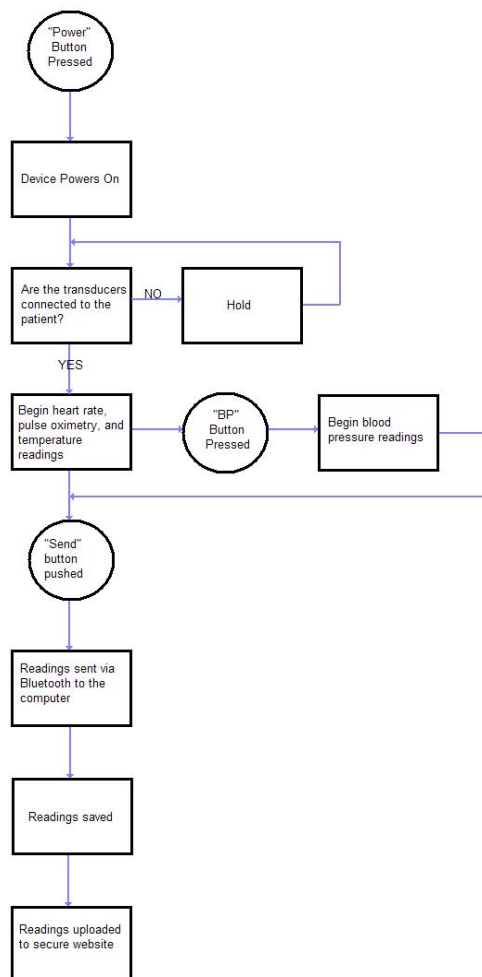
2.2 Final Design

Figure 4. Flowchart of Accessible Vital Signs Monitor Operation

2.2.1 Thermometer

To measure body temperature, a thermistor circuit is used. The thermistor is in the form of a commercially purchased, oral temperature thermometer that was converted into a temperature probe. In order to reduce costs and make a recognizable probe, a digital thermometer was purchased from CVS and all of the circuitry pulled out of it, leaving just the casing and the thermistor in the tip. A hole was drilled in the cap of the thermometer with a drill press so that a cable purchased from RadioShack (6-ft. shielded cable, 1/8" plug to stripped wires) could fit into the thermometer. The thermistor leads and these cable leads were soldered to a small piece of PCB, inside the thermometer casing. This completes the thermometer probe (Fig. 5).

Figure 5. Thermometer Probe with Attached Cable

The thermistor within the probe converts changes in temperature to changes in voltage. Unfortunately, thermistors are inherently non-linear.   This output can be linearized over a small range of temperatures through the use of a Wheatstone bridge (Fig. 6).
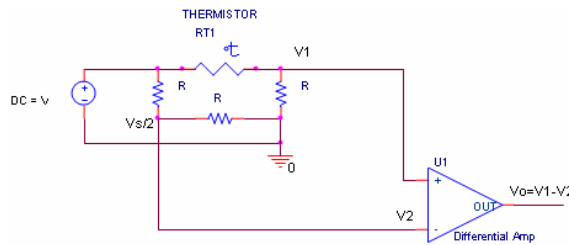

Figure 6. Thermistor Linearizing Circuit [11]

The value of the resistors, R, used to linearize the thermistor will be determined from the reference temperature and other values given by the manufacturer (β or α) using the above equations. For our use as an oral temperature probe, the thermistor needs to be linearized (calibrated) around 98.6° F (37°C), for a temperature range of at least 90-104° F (32-40°C). When linearizing the thermistor, we must be careful to keep the accuracy of the thermometer high ($\pm$ .1°C) so as to be able to take appropriate measurements.

After being linearized, the signal is sent to a3rd order Butterworth low-pass filter to remove any noise. The cutoff frequency for the filter is about 60Hz to remove any noise from room lights and other sources ($f_c = \dfrac{1}{2\pi R_2 C}$) [9]. The final circuit for the thermometer is seen below (Fig. 7).
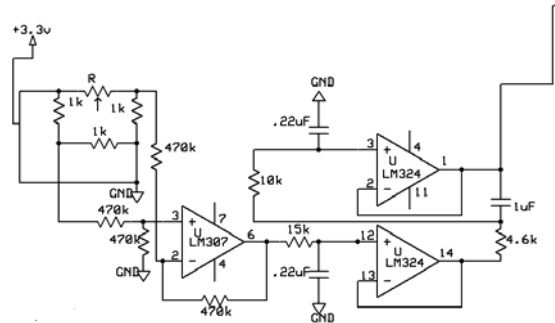
Figure 7. Completed Thermometer Circuit Including Amplifiers and Filter

Because we did not have the manufacturer's thermistor coefficient data, we had to determine our temperature versus resistance curve experimentally to calibrate the thermometer. The thermometer was calibrated by calculating a curve that relates thermistor resistance to temperature in degrees Fahrenheit. Calculations yielded the following equation:

$$T_{°F} = \frac{1}{\dfrac{-2.82857}{V_0 + 1.65} + .857143} + 133.199 \, .$$

Final testing done by taking group members' temperature with the thermometer and comparing the reading with that taken by a commercial digital thermometer, showed that the thermometer was accurate to within .5°F.

2.2.2 Pulse Oximeter

To measure blood oxygen saturation, a pulse oximeter is used. Pulse oximetry uses the optical properties of blood to determine oxygen saturation. Due to the scattering effects of blood, Beer's Law does not apply for a pulse oximetry system [19]. Therefore, blood oxygen saturation equations are good for theory but not for practice [19]. Pulse oximeters are usually calibrated by comparing the oximeter R value (SpO_2 ratio) to the oxygen saturation ratio obtained from *in vivo* samples using human test subjects. Manufacturers of pulse oximeters do this and determine calibration curves or lookup tables for their devices. Because of this need for *in vivo* testing for calibration, even if we constructed a pulse oximeter from scratch, we would not be able to test it or calibrate it. Therefore, to save time in construction, we purchased a commercial fingertip pulse oximeter to incorporate into our monitor. The pulse oximeter chosen is the Drive Reflectance Fingertip Pulse Oximeter (Fig. 8).

Figure 8. Drive Fingertip Pulse Oximeter.

For simplicity, the signal from the pulse oximeter is taken across the photodiode. It was found by mapping the pins that connect to the ribbon string that connect to the photodiode and power source (Fig. 9).
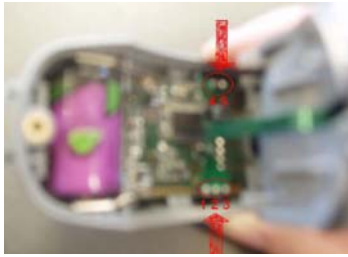
Figure 9. Mapped Pulse Oximeter

Pins 1 and 5 were found to connect across the battery, and pins 2 and 3 connect across the photodiode itself.

Since the voltage/blood oxygen saturation curves for this pulse oximeter belong to Drive and we did not have access to them, we calibrated the pulse oximeter by setting a voltage threshold, above which the LCD screen on the monitor outputs "98% Blood Oxygen Saturation". This voltage threshold was set by scoping the outputs of pins 2 and 3, while the pulse oximeter was operating on the finger of a healthy individual (Fig. 10).
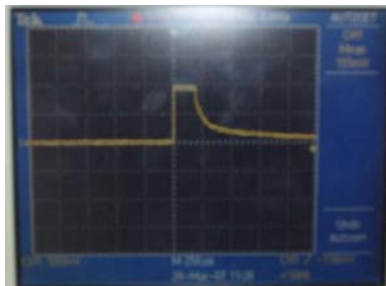

Figure 10. Pulse Oximeter Signal Across the Photodiode

The voltage threshold for when the photodiode is detecting the light transmitted through the finger of a healthy adult was found to be approximately, 250mV. Though the pulse oximeter in our monitor will not actually measure blood oxygen saturation, it is included because it is an important vital sign to monitor. Should we have been able to calibrate a pulse oximeter, we could have constructed one from the pulse oximeter design in the alternative design.

2.2.3 Non Invasive Blood Pressure

Blood pressure is automatically measured through the oscillometric method [15]. This is done by wrapping a blood pressure cuff around the upper arm and inflating it until the pressure around the arm due to the cuff collapses (or occludes) the brachial artery. The cuff is then slowly deflated. As the cuff deflates, blood starts pumping through the brachial artery causing minute vibrations of .5 to 1 mmHg in the cuff [4]. The pressure at which these vibrations start is the systolic pressure, and the pressure at which they stop is the diastolic pressure [5]. When the blood pressure "Start" button on the vital signs monitor is pressed, the blood pressure cuff is inflated to about 40mmHg above normal (160mmHg). The blood pressure cuff used is a Large Adult Cuff from CVS (Fig. 11).

Figure 11. Adult Large CVS Blood Pressure Cuff

The cuff is inflated by a Hargraves Fluidics CTS Series Micro Air Pump. The microprocessor controls the inflation of the cuff. The sensor used to sense cuff pressure is the MPX2050. Once the pressure sensor determines that the cuff has been inflated to 160mmHg, the cuff will deflate slowly at a rate of 2-3mmHg/sec. Deflation occurs automatically at this rate through the tubing with the help of two pin holes. A basic circuit for the automated blood pressure system is seen in Figure 12. The pump and valve are powered by the battery and controlled by the microprocessor. The pressure sensor also receives power from the battery, and it sends signals to the microprocessor.
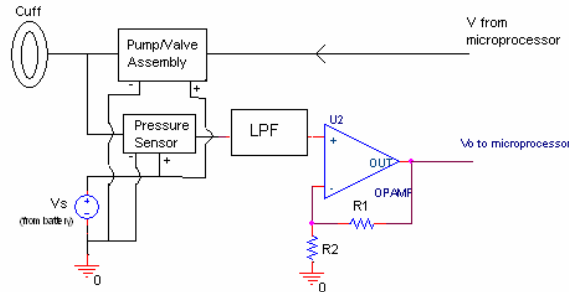

Figure 12. Automated Blood Pressure System Circuit

As blood begins flowing through the brachial artery again, it causes small pulsations that are picked up by the pressure sensor in the cuff (Fig. 13). This waveform is analyzed by the microprocessor to determine the systolic and diastolic pressures.
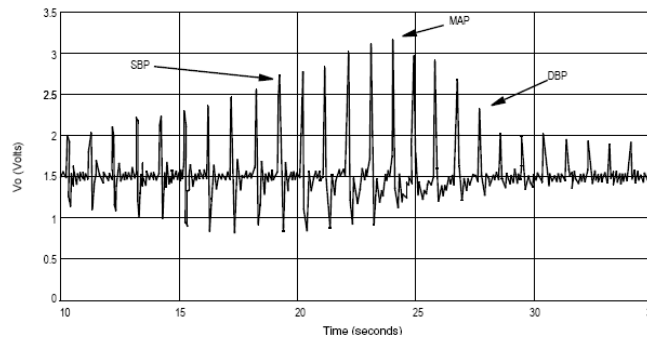

Figure 13. Blood Pressure Waveform Picked Up by Pressure Sensor [17]
Where: MAP = Maximum Arterial Pressure
SBP = Systolic Blood Pressure
DBP = Diastolic Blood Pressure

A threshold voltage level has been set by experimentally comparing blood pressure readings from a sphygmometer to those detected by our pressure sensor. Once pulsations peak above the threshold level, the voltage is recorded and from that value the systolic pressure determined. The microprocessor continues to monitor the blood pressure readings, and the diastolic pressure is taken when the voltage drops below the threshold voltage[18].

Due to the safety issues that arise with automatic blood pressure systems, we have incorporated a "kill switch" into our design [18]. If at any time during the blood pressure measurement the user wants to stop the inflation of the cuff and rapidly deflate it, they just need to press the vital signs monitor "On/Off" button. This will cut power to the whole device and open the pressure release valve. This method bypasses the microprocessor, avoiding any software bugs that an emergency stop button might encounter.

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As stated previously, the automated blood pressure system was calibrated experimentally while relying on the work done by Wattanapanitch et al [18]. This was done through establishing a threshold voltage by which correct pressure measurements for systolic and diastolic pressures could be made. Final testing of the device was done by comparing its blood pressure readings to those of a sphygmometer. Nevertheless, we expected and encountered slight differences in the measurements from our device and the sphygmometer because of the inherent degree of imprecision in manual blood pressure measurement.

2.2.4 Respiratory Rate

Respiratory rate is measured using a thermocouple. The thermocouple is clipped to the client's nose and measures the change in temperature caused by inspiration and expiration (Fig. 14). The thermocouple converts the changes in temperature it detects to changes in voltage. Through experimentation, voltages threshold were set to define the changes in temperature that correspond to inspiration and expiration. By counting the number of inspiration and expiration pairs that occur in a given period of time, we can determine respiratory rate.

Figure 14. Image of Thermocouple Nose Clip

The respiratory rate probe itself was made with a two-way 3.5mm retractable cable. By pulling the jacks off each end of the cable, one end was soldered to the thermocouple and the other end to a 3/32" phone plug.

The circuit for the thermocouple is powered by the battery. The voltage from the thermocouple is linear over our range of interest (approx. 65°F to 98°F), so the signal from the thermocouple only needs to be filtered and amplified before being A/D converted and processed by the microprocessor. The thermistor circuit uses the same low pass filter as the thermometer circuit (Fig. 15).

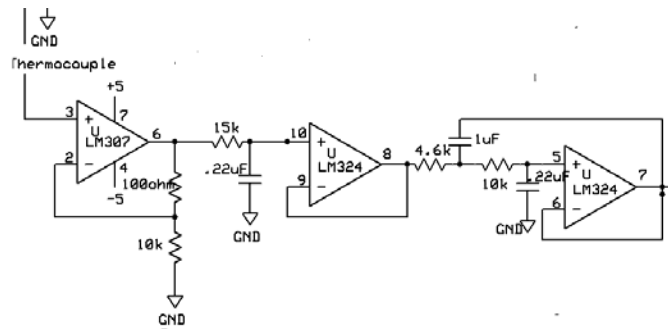

Figure 15. Circuit for Respiratory Rate

As mentioned previously, this circuit was calibrated experimentally. Voltage output from the thermocouple was measured for inspiration and expiration (Table 1).

Table 1. Thermocouple Testing Data

State	V_{out} (thermocouple & amplifier)
Room Temperature	.527V
Exhale$_1$	.540V
Inhale$_1$	.526V
Exhale$_2$	.545V
Inhale$_2$	.520V

From these measurements the voltage threshold was set as .535V.

2.2.5 Weight

Weight is monitored through a commercial digital scale (Homedics SC-202 Digital Scale) that is connected to our device. Determining to connect the scale to the monitor was done through experimentation. Opening up the scale, two load cells were found at the rear corners. The positive and negative outputs from these load cells were connected together at the same spot on the PCB (Fig. 16).
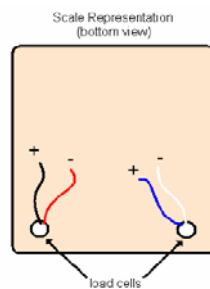

Figure 16. Location of Load Cells in Scale

Because the signal from the scale cannot be taken after it has been processed by the microprocessor within the scale, it was taken from these two load cells. The load cell signal was then processed through an instrumentation amplifier and filtered (Fig. 17).
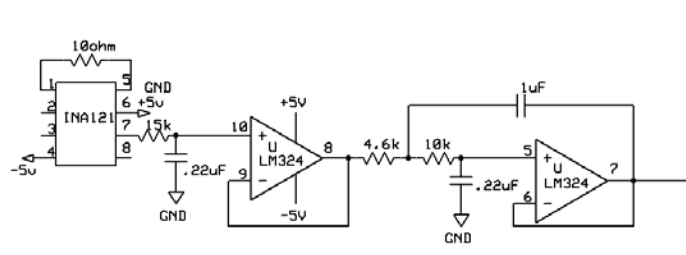

Figure 17. Scale Circuit Schematic

The scale itself had already been calibrated and tested by its manufacturer, but we still had to calibrate our scale (the signal we are processing). This was done by having lab members stand on the scale and comparing the voltage coming from our circuit to the weight displayed on the digital scale LCD (in pounds). The equation relating weight to voltage found by this was $W = 9000V_0 - 32374$, where W is weight in pounds and V_0 is the voltage out from the filter of the scale circuit.

2.2.6 Microprocessor

The main component of this system is Microchip PIC16F877 microprocessor shown below. The PIC16F877 is a 40 pin 8-bit microcontroller that was chosen due to the fact that it is capable of processing every aspect of the monitor. This chip is required to make every part of the monitor function. Needing only 5V to power up, the microprocessor was used to read the voltages sent to it by the probes, convert

this reading to digital data, and send this result to the LCD display. The analog pins used for analog inputs were AN0, AN1, AN2, AN3, and AN5. After the voltage was read into the analog pins, the corresponding digital number was used in calculating the correct number to be sent to the LCD screen. The internal A/D conveter does this using the following equation.:

$$\frac{Vin}{5V}*1024 \qquad Where:$$

$$Vin = Voltage\,input\,to\,ana\log pin$$
$$5V = reference\,voltage\,of\,5V$$
$$1024 = number\,of\,bits\,in\,A/D$$

To configure the analog to digital converter, the ADCON0 and ADCON1 registers were used. The ACON0 register controls the operation of the A/D converter. Each vital sign required its own A/D conversion. This was done by changing bits 5-3 as needed, to select the appropriate input channel. Also, FOSC/32 was selected for the conversion clock. The ADCON1 register controls the function of the port pins. Since all of our inputs were analog, bits 3-0 were configured as "0000", allowing for all analog inputs. Also, the result of the A/D conversion was right justified (bit 7). Shown below is a sample of how the AN0 pin was initialized for the body temperature.

```
void init_a2dtemp(void)
{
        ADCON0=129; // select Fosc/32, AN0, A/D on
        ADCON1=128; // select right justify result.
        ADON=1;                   // turn on the A2D conversion module
        DelayMs(50);
}
```

2.2.7 LCD Screen

The digital information from the output of the microcontroller will be sent to a character LCD screen (Fig. 18).

http://www.crystalfontz.com/products/1602l/CFAH1602L-YYH-JP_front_bl_on.jpg
Figure 18. LCD Screen

The CFAH1602L-GGH-JP LCD screen is ideal for our design due to its easy to read characters, ideal size, and wide viewing angles. It measures 122mm x 44mm, with a viewing area of 99mm x 24mm, and a character height of 8.06mm. Since this screen has a wide viewing angle, clients will have no problem seeing their vital signs from their bed. Also, the yellow backlight makes this LCD screen easy to read, especially in dark or dim-lighted areas. The 99mm x 24mm viewing area makes the screens easy to read from a distance as well.

2.2.8 Speech Output

As well as being displayed onto the LCD screen, the vital signs are also spoken. This was made possible by utilizing the SP03 text-to-speech module, which takes strings of ASCII text and produces the resulting speech.
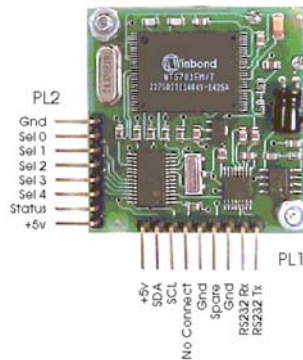
Figure 19. SP03 Module Image

This was made possible by the use of RS232 serial communication. The only pins that needed to be used on the SP03 were the Rx, Tx, ground, and 5V pins. A SP232ACP, 16-pin chip was used to convert the TTL to serial.

The Rx and Tx pins from the SP03 were connected to the corresponding pins 13 and 14 on the SP232ACP, then sent to pins 25 and 26 on the PIC16F877. To communicate between the SP03 and microchip, USART was used. This communication allows the SP03 to speak a line of text, by sending it a sequence of commands.

Command byte Transmitted to SP03 Module	Acknowledge byte returned from SP03
Command 0x80	0x01
Full Volume 0x00	0x00
Speech Pitch 0x04	0x04
Speech Speed 0x02	0x02
Text 'H'	'H'
Text 'e'	'e'
Text 'l'	'l'
Text 'l'	'l'
Text 'o'	'o'
NULL 0x00	0x00
SP03 will now speak the text	0x00 indicates text loading is complete

Figure 20. SP03 Commands

To send the SP03 a line of text, a small subroutine had to written. This subroutine, programmed in C, allows the microchip to send the SP03 text one character at a time. To play these computer generated sounds, a speaker was used.

2.2.9 Secure Website

After the client's vital signs have been gathered and recorded, they need to be sent to their primary healthcare provider. To maximize client privacy, an encrypted, password protected website is used, to which the client can upload their vital signs. To ensure that the website is secure, HTML encryption software will be used to encrypt the contents of the website, allowing only those with the correct username and password to access it. This website is currently being stored on the BME server. An approved username and password are required to enter the site. When access is granted, the user is brought to a page where they can choose to upload any files on their computer. Once the file(s) are uploaded, they are saved to a database on the server. The user can then download these files or leave the website. A physician or remote healthcare provider can access these files through the same site sequence.

2.2.10 Power Supply

        To power the monitor we are using an 11.4V lithium ion rechargeable battery pack
Although lead acid batteries can sometimes produce more voltage, lithium ion batteries are safer and will
recharge quicker. These batteries are internal to the device and can be recharged with the included wall
charger. The need for a rechargeable battery is so the client can take their vital signs even if the power is
gone and so that the system can be portable.
        Regarding the power source, it will be in charge of taking power from a battery and transferring
that power into our system. To bring down the voltage levels, linear voltage regulators are used.

2.2.11 Bluetooth

        To increase accessibility, we added a Bluetooth option to transmit the data collected by the vital
signs monitor to the client's computer wirelessly. The weak signals that Bluetooth uses, combined with
frequency hopping, makes it a secure way to transmit data. The EmbeddedBlue eb505-SER OEM
Bluetooth Serial Module from A7 Engineering provides Bluetooth connectivity for our monitor (Fig. 21).

Figure 21. EmbeddedBlue eb505-SER OEM Bluetooth Serial Module

 The interface between our processor and the eb505-SER radio is done through UART communication.
When a connection is made to another Bluetooth device, the link will appear as a cabled serial connection
which eliminates the need for any special wireless protocol knowledge. Assuming that our clients'
computers are not Bluetooth ready, a USB Bluetooth dongle provides connectivity on the PC end.
        Our Bluetooth communications system was calibrated through UART communication. It was
programmed to set up a network with the Bluetooth USB dongle when it detects it. The Bluetooth system
was tested by acquiring vitals signs from the monitor and sending them to a computer in the design lab to
which the USB dongle is installed.

2.2.12 Pushbuttons and Casing

        Three-buttons were used in our design. This was intentionally done to create an easy and non-
threatening user interface. Two square buttons (one to transmit data, the other to inflate the blood
pressure cuff) with wings (allowing the button to be "snapped" in) are on the front on the monitor. A
rocker switch on the left side of the monitor turns the device on and off. This differentiation between the
function buttons and the on/off switch was also done to increase accessibility and ease of use.
        In order to safely enclose the internal circuitry of our design, a plastic enclosure needs to be
manufactured. A casing from BoxEnclosures was ordered and holes for the buttons, LCD screen, and
probes machined in the machine shop and design lab

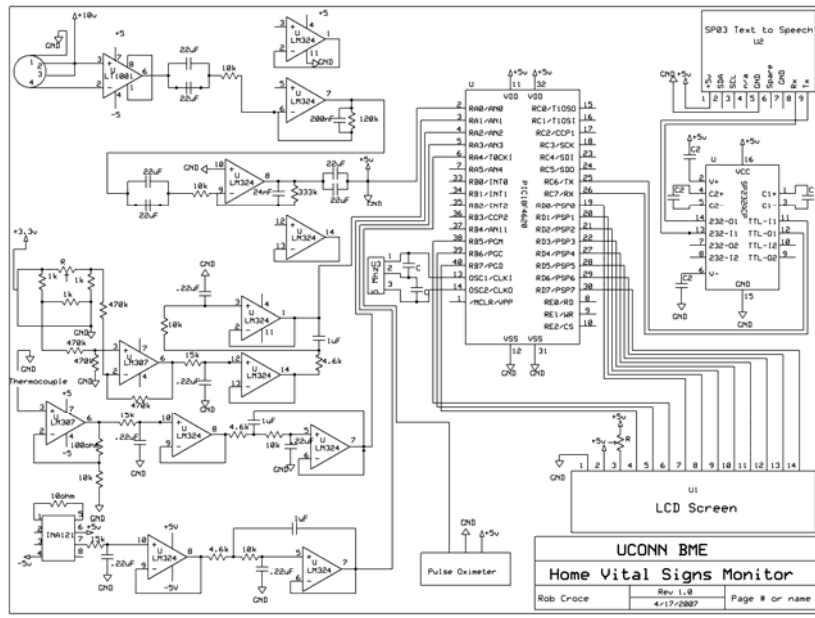**2.2.13 Accessible Vital Signs Monitor Circuit Diagram**

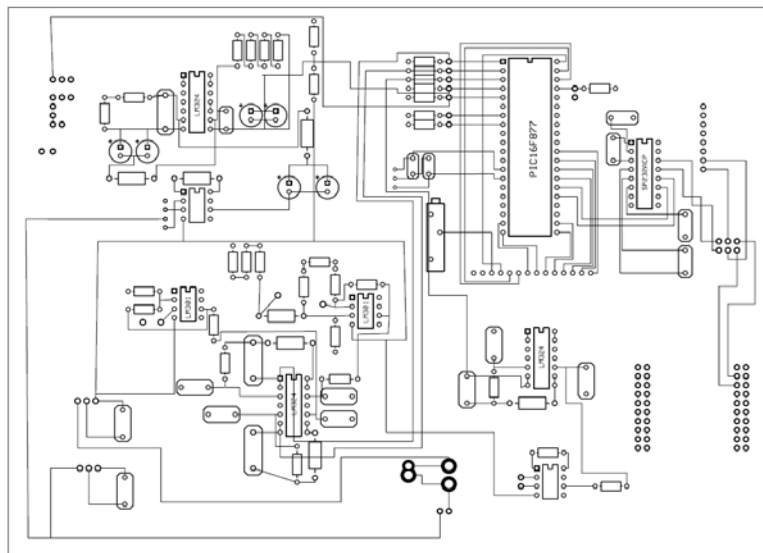**Figure 22.** Accessible Vital Signs Monitor Circuit Diagram

Figure 23. PCB Diagram of the Board

The previous figure combines all of the above subunits into a circuit diagram. This is a basic diagram of our complete vital signs monitor (Figs. 22, 23).

2.3 Prototype

2.3.1 Overview

The Accessible Home Vital Signs Monitoring System uses noninvasive existing medical technologies to monitor a client's vitals signs from home. It includes probes to monitor six (6) different vital signs: heart rate, blood pressure, temperature, weight, blood oxygen saturation, and respiratory rate. A 16x2 character LCD screen displays a client's vital signs as they are acquired, and a speaker outputs the spoken vitals signs from a text-to-speech module. A rocker switch on the left side of the monitor turns

the device on and off, and four jacks on the right side of the monitor accept probes that acquire 4 of the 6 vital signs. When depressed, a square, red button on the bottom, left corner of the monitor sends the acquired vital signs to a computer via a Bluetooth module within the device. The square, green button on the bottom, right corner of the monitor starts the inflation of the blood pressure cuff. A cloth casing and cover provides style and pouches on the back of the monitor to hold probes and accessories (Figs. 24, 25, 26, 27).
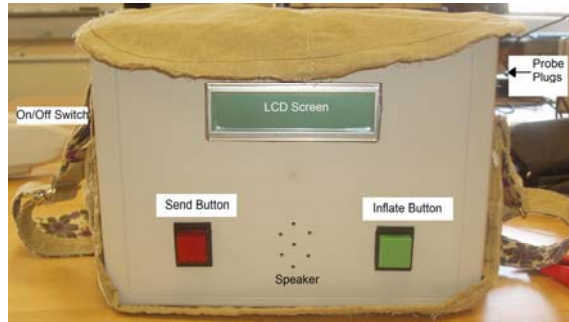
Figure 24. Front View of the Accessible Home Vital Signs Monitoring System Monitor

Figure 25. Side View of the Accessible Home Vital Signs Monitoring System Monitor

Figure 26. Open View of Top of Accessible Vital Signs Monitoring System Monitor

Figure 27. Read View of the Accessible Home Vital Signs Monitoring System Monitor

2.3.2 Probes for Vital Sign Acquisition

Four detachable probes are included with the Accessible Home Vital Signs Monitoring System. Each of the four probes plugs into a jack on the right side of the monitor. All four probe plugs are different sizes and only fit into one jack on the right side of the monitor.

The thermometer probe is attached to a 6-ft cable that ends in a 1/8" phone plug. To use, the probe plug must be inserted into the corresponding 1/8" phone jack and the thermometer placed under the tongue (Fig. 28).

Figure 28. Thermometer Probe

The respiratory rate probe included is on a retractable cable. This probe terminates in a 3/32" plug. On the other end of the probe is a thermocouple which measures changes in temperature (Fig. 29). To measure respiratory rate, the plug must be inserted into the corresponding 2/32" plug on the right side of the monitor. Breathing regularly with the mouth closed (through the nose only), the thermocouple end of the probe must be clipped or held up to the nose so that the thermocouple hangs under one of the nostrils.

Figure 29. Thermocouple Probe on Retractable Cable

To measure weight, a digital bathroom scale is included with a 1/4" phone plug that connects to the corresponding jack on the monitor. To use only as a bathroom scale, do not plug the scale into the monitor. When the scale is plugged into the monitor, the weight measured is saved by the microprocessor and sent with the other vital signs to the computer via Bluetooth. The scale is activated by stepping on it (Fig. 30.

Figure 30. Digital Bathroom Scale that Can Be Used as a Stand Alone or as Part of the Monitoring System

The last part to be plugged into the right side of the monitor is the blood pressure cuff (Fig. 31).

Figure 31. Blood Pressure Cuff

The cuff plugs into the connector at the top of the right side of the monitor, which leads to the air pump. For safety, the cuff does not inflate immediately upon power-up of the system. To operate, wrap the cuff around the upper arm, aligning the artery mark on the cuff correctly. When ready, press the blood pressure button and the cuff will begin to inflate. The cuff will automatically deflate upon reaching 160mmHg. Should any discomfort occur during blood pressure measurement, the cuff can be immediately deflated by turning off the monitor (toggle the on/off button on the left side of the monitor to the "off" position). The blood pressure system measures not only but pressure, but also heart rate.

Blood oxygen saturation is measured through a pulse oximeter that is installed inside the monitor. The pulse oximeter is mounted to the inside rear of the monitor (Fig. 32).

Figure 32. Pulse Oximeter Mounted Inside the Monitor

The pulse oximeter is accessed through a hole drilled in the top of the monitor. To activate the pulse oximeter and measure blood oxygen saturation, stick a finger in the rubber-lined hole on the top of the monitor (Fig. 33).

Figure 33. Pulse Oximeter in Use

2.3.3 Monitor Communications

Upon power-up, the LCD screen displays a welcome message to the user (Fig. 34), which is echoed auditorally at the same time by a spoken message.

Figure 34. Welcome Message Display on the LCD Screen on Power-up

Vitals signs can be acquired in any order, but they must be taken one at a time. As each vital sign is being measured, a message is displayed on the LCD screen indicating as such (Fig. 35).
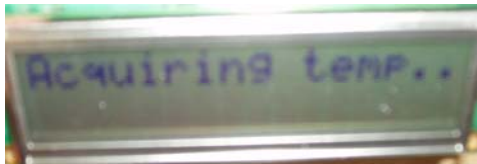

Figure 35. Example of the Message Shown While the Monitor is Taking a Vital Sign

Once the vital sign is acquired, it is displayed on the LCD screen as well as spoken by the text-to-speech module through a speaker on the front of the monitor (Fig. 36).

Figure 36. The Speaker is Mounted Inside the Front of the Monitor, Behind the Speaker Holes in between the Two Buttons

Once all (or any) of the vital signs have been measured, pressing the red button sends them via Bluetooth to the computer. The Bluetooth module within the monitor is activated as soon as the device is powered. A phantom serial port connection is automatically made between the Bluetooth module and the Bluetooth dongle (also included). If the Bluetooth dongle is not plugged into one of the computer's USB ports, the "Send" button will have no effect (Fig. 37).

Figure 37. Bluetooth Dongle Plugged into One of the Computer's USB Ports

Once the Bluetooth dongle has been plugged into the computer, the Bluetooth module may have to be installed. To check to see if the Bluetooth module needs to be installed, press the "Send" button and see

if the data sends. If the module needs to be installed, the following steps can be followed to do so, once the monitor and computer have been turned on.

Once the vital signs have been sent to the computer, they can be save (as a text file), and then uploaded to the secure website. A mock-up of the website is currently held on the Team #3 website on the BME server (Fig. 38).
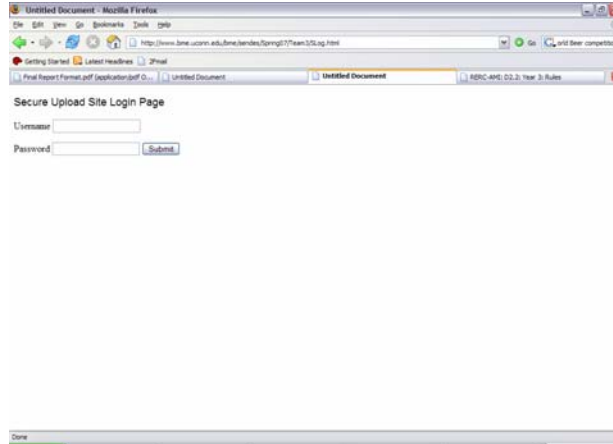

Figure 38. Secure Login Site

Once the client logs in, they are taken to a site where they can upload their files (Fig. 39).
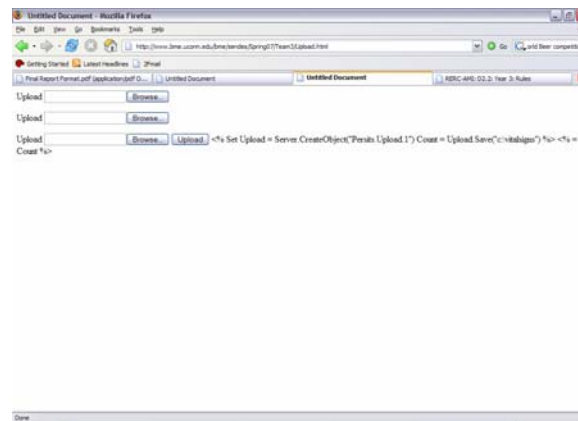
Figure 39. Upload Site When the User Can Upload up to Three Files at a Time

Once upload, the client is taken to a site containing the files that they have just uploaded. This site also allows the vital signs files to be downloaded. A remote healthcare provider can use the same path to download vital signs files, simply by not entering a file name in the upload field on the Upload Site.

2.3.4 Client Testing

Because our clients our hypothetical, we tested our device with our clients by simulating their disabilities. The Accessible Home Vital Signs Monitoring System was tested by simulating blindness and dominant side paralysis. Only the use of the monitor was tested, as from the RERC project brief it is assumed that the clients can already use a computer or have family or assistants that can use a computer. Multiple subjects were tested plugging in and using the probes and the monitor.

2.3.4.1 Partial Paralysis

Simulating partial paralysis on the dominant side, subjects were able to plug all of the probes into the side of the device one-handed.

Figure 40. Subject Inserting the
Scale Plug into the Jack

Figure 41. Subject Plugging
Probes in with One Hand

Though it was difficult, the subject was also able to attach the blood pressure cuff using only one hand. This should not pose a problem to our clients because they all have assistance available at home.

Figure 42. Subject Simulating Partial Paralysis Wrapping the Blood Pressure Cuff Around His Arm

2.3.4.2 Blindness

To simulate blindness, subjects were blindfolded and asked to operate the device. With no description of the device, subjects were able to plug all of the plugs into the proper jacks, locate buttons, and use the pulse oximeter.

Figure 43. Subject Using Touch to
Find the Thermometer Probe

Figure 44. Blindfolded Subject
Plugging in the Probes

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Figure 45. Subject Finding and Operating the Blood Pressure Button

Figure 46. Blindfolded Subject Using the Pulse Oximeter

3 Budget

Table 2: Design Budget

ORDER DATE	Beg. Budget	VENDOR	COST	CREDITS	ITEM RCVD.	DESCRIPTION
1/1/2007	$2,000.00					
1/3/2007		Analog Devices	$48.62		1/15/2007	Blackfin BF535 Processor
1/3/2007		Crystal Fontz	$176.97		1/9/2007	122mm x 44 mm PCB Size, Green LED Backlight
		Crystal Fontz		$95.79	2/22/2007	Credit for returning (5) crystal Fontz LCD Screens RMA: DP7245
1/3/2007		Whole Sale Point	$26.95		1/9/2007	Homedics Digital Bathroom Scale
1/3/2007		Digi Key	$16.40		1/9/2007	USB Chip and Linear Voltage Regulator
1/4/2007		Open Tip	$26.64		1/16/2007	9V Rechargable Battery
1/22/2007		ACRONAME	$115.95		1/29/2007	Devantech Speech Synthesizer
1/30/2007		Newark IN One (w/o shpg)	$4.41		2/1/2007	Infrared LED-Fairchild Semi Conductor
1/30/2007		Omega Eng.	$47.00		1/31/2007	Glass Insulated T/C's 5 PK
1/30/2007		Digi Key	$32.35		2/5/2007	Sensor Pressure, Photodiode 2.xx2.8mm, LED 3mm
2/13/2007		Hargraves Fluidics	$57.47		2/26/2007	Micropump E-Z Mount
2/13/2007		America RX.Com	$172.74		2/15/2007	Fingertip Pulse Oximeter # 18700
2/20/2007		CT Fluid Power (without shipping)	$37.60		2/26/2007	Parker Pneumatic Valve
3/28/2007		Amazon	$43.93		3/30/2007	Homedics LED Digital Bathroom Scale
3/28/2007		A7 Engineering	$214.00		3/30/2007	eb505 Development Kits on 50% student sponsor ship
4/6/2007		Digi Key	$29.04		4/10/2007	Microchip w/2 day shipping
4/17/2007		Battery Space	$56.34		4/20/2007	Li-ion 18650 11.1V Battery & Smart Charger
4/17/2007		Digi Key	$30.06		4/19/2007	PIC18F4620
4/18/2007		Box Enclosures	$38.04		4/20/2007	Instrument Case
4/23/2007		Express PCB	$232.42		4/30/2007	PCB Board
4/25/2007		Digi Key	$29.40		4/26/2007	PIC16F877 Microchip
		Newbury Comics	$8.47		3/1/2007	3.5mm retractable cable
		Jo-Ann Fabrics	$10.62		4/25/2007	Sew on snaps and velcro
		Target	$13.80		4/25/2007	Pocket Hobo shoulder bag
		CVS	$4.23		4/25/2007	Nasal strips
		Radioshack	$31.05		4/23/2007	Assorted jacks, plugs, IC sockets, perf. Board
		Radioshack	$25.83		4/25/2007	PC boards, resistors
		CVS	$10.60		1/19/2007	BP cuff, large
		CVS	$7.05		1/9/2007	digital thermometer
		Radioshack	$8.46		2/4/2007	mini jack, one-end stripped wire
		Radioshack	$42.39		4/4/2007	Bluetooth dongle
		Mansfield Supply	$3.70		4/3/2007	1/4" OD Plastic Tee
		Newbury Comics	$16.95		3/24/2007	Retractable earbuds
TOTAL EXPENDITURES	$1,624.76	Petsmart	$5.28		4/4/2007	1/4"ID tubing, Air connectors package
		TOTAL CREDITS:		$95.79		
		REMAINING BALANCE	$654.18			

Table 3. Estimated cost to manufacture

VENDOR	COST	DESCRIPTION
Crystal Fontz	$27.37	122mm x 44 mm PCB Size, Green LED Backlight
ACRONAME	$115.95	Devantech Speech Synthesizer
Omega Eng.	$47.00	Glass Insulated T/C's 5 PK
Digi Key	$12.78	Sensor Pressure
Hargraves Fluidics	$57.47	Micropump E-Z Mount
America RX.Com	$151.74	Fingertip Pulse Oximeter # 18700
CT Fluid Power (without shipping)	$37.60	Parker Pneumatic Valve
Amazon	$43.93	Homedics LED Digital Bathroom Scale
A7 Engineering	$49.00	eb505 Serial Bluetooth module
Battery Space	$39.99	Li-ion 18650 11.1V Battery & Smart Charger
Box Enclosures	$17.99	Instrument Case
Express PCB	$232.42	PCB Board
Digi Key	$29.40	PIC16F877 Microchip
Radioshack	$8.46	mini jack, cable with stripped ends
CVS	$5.99	Digital thermometer
CVS	$9.99	Large BP cuff
Radioshack	$42.39	Bluetooth dongle
Radioshack	$3.99	phone plugs
Radioshack	$2.99	3/32" phone jacks
Radioshack	$3.79	Rocker switch
Radioshack	$2.99	3/32" plugs
Radioshack	$2.99	Open circuit button
Radioshack	$2.99	Open circuit button
Target	$12.99	Pocket Hobo bag
Jo-Ann Fabric	$2.99	Sew on snaps
Newbury Comics	$15.99	Retractable cable
Petsmart	$5.28	1/4"ID air tubing and connectors
Lab	$30.00	Assorted resistors, capacitors, op amps, wires, etc.
Total	$1,016.46	

We'd like to note that this manufacturing cost could be brought down under $1000 by using a 2-layer PCB instead of 4-layers (we did this due to time constraints) and by constructing a pulse oximeter from scratch. Taking this things into account would put the manufacturing costs for one unit around $800-$900. Either total ($1000 or $800) is far below current vital signs product prices.

4 Conclusion

Though in the end our prototype was never fully functional, it was designed and built with the principles and performance measures of universal design in mind (as listed by the RERC-AMI website - http://www.rerc-ami.org/ami/projects/d/2/udg/). An obvious improvement to the project is the finished construction of a working prototype, but as everything worked on the boards, we expect that this would just require more time. Aside from this, an alarm system for dangerous vitals signs (as described in the alternative design, but never implemented) would be an excellent addition to improve client safety and health.

As healthcare moves out of the hospital and into the home, reliable technology for monitoring clients' health is needed. Vital signs monitors provide basic, yet important, information about a client's physical well being. Unfortunately, many of the vital signs monitoring systems available today are very expensive and inaccessible. Most are designed for hospital use and have complicated interfaces that do not blend well with the home environment. More devices are needed that are designed specifically for home use by clients, their families, and caregivers.

The accessible home vital signs monitoring system described in this report fulfills the need for an accessible, user-friendly, home-use vital signs monitor. The simple 3-button design makes the device easy to use for all ages and abilities. To provide comprehensive health care monitoring, our device is designed to record the following six (6) vital signs: body temperature, blood oxygen saturation, heart rate, blood pressure, weight, and respiratory rate. Accessibility is addressed through the speech module, auditory and visual alarms, large LCD screens, and buttons customized with Braille or Universal Symbols. These features allow us to meet the needs of our clients with a device that is accessible to the hearing and visually impaired, those with motor skills impairment, and clients of all ages.

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