Wireless Patient Monitoring Device

Final Project Proposal

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E90: Senior Design Project
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Abstract

We plan to design a physiological monitoring device that communicates wirelessly to a computer/remote data collection station. The device will measure the physiological data utilizing a tympanic thermometer, pulse oximeter sensor and electrocardiogram electrodes. The culmination of the project will be a portable device that collects and transmits data collected from the sensors and a software application for real time display of the data stream.

Introduction

Continuous monitoring of physiological parameters is of great importance in both bedside and ambulatory settings as it is necessary for proper treatment and/or diagnosis of several medical conditions. There are numerous patient monitoring systems available commercially that measure various vital signs such as heart rate, temperature, blood pressure and temperature. Our wireless patient monitoring module is geared towards ambulatory patients for monitoring purposes in a home setting. Since the device is designed for continuous monitoring, the comfort of patient is considered a key design criterion.

The major part of the project will be dedicated towards processing of sensor data and circuit design. All the circuitry for analog processing of the data will be designed and simulated in software before implementing on a breadboard. Other tasks include working with the wireless module and creating a software application for sensor data display.

This proposal outlines the technical background required for the project and description of the major tasks along with a tentative schedule.

Technical Discussion

Electrocardiograph

The electrocardiograph is an instrument used to produce a graphic representation of the electrical activity of the heart, the electrocardiogram (ECG or EKG), as measured by body-surface electrodes. It is an invaluable tool in the diagnosis of cardiovascular diseases, the monitoring of patients while under anesthesia, and occasionally used for diagnosis of non-cardiac diseases.

The Electrocardiogram

The activity of the heart can be approximately modeled by an electric dipole, also called the cardiac vector. The magnitude and orientation of the dipole characterize the current state of the heart along the cardiac cycle. To measure these qualities, lead vectors are defined such that, when electrodes are placed along two different vectors that lie in the same plane as the cardiac vector, it can be fully defined. For example, two lead vectors, a_1 and a_2, can be defined at different angles in the cardiac vector plane (Figure

1). The voltage measured within either lead is the component of the cardiac vector, M, in the direction of that particular lead. In Figure 1, the voltage measured in the a_1 direction is $V_{a1} = |\mathbf{M}|\cos\theta$. Since **M** is orthogonal to lead a_2, its component V_{a2} is zero. Both leads are necessary to uniquely describe the cardiac vector, but information can still be collected using a single lead.

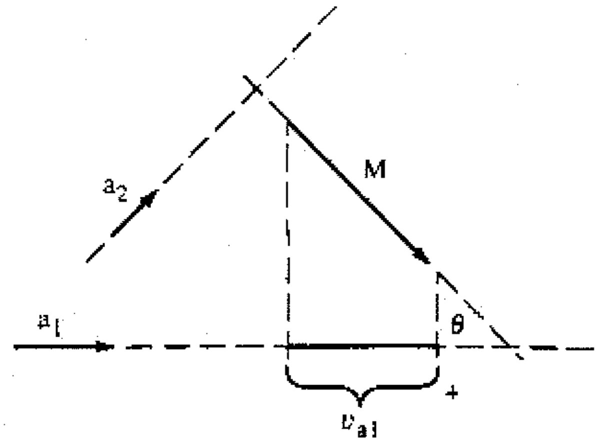

Figure 1. Lead vectors a_1 and a_2 in relation to the cardiac vector M.

Three basic leads have been defined for the frontal-plane ECG (the plane along the front of the chest). These leads use the convenient markers of the right arm (RA), left arm (LA), and left leg (LL) to define lead vectors Lead I, Lead II, and Lead III that create an equilateral triangle across the center of the chest known as Eindhoven's triangle (Figure 2). In this project, the voltage across Lead I will be the main focus.

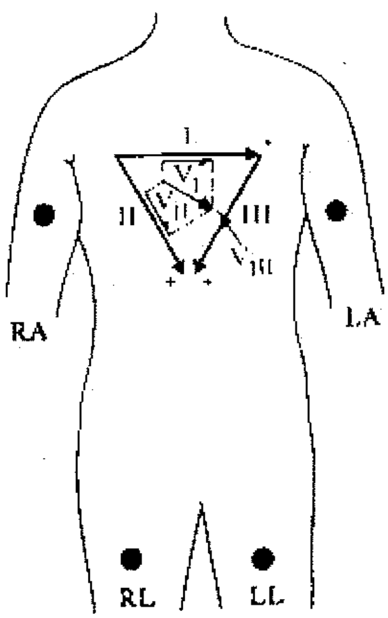

Figure 2. Eindhoven's triangle.

The Electrocardiograph

To measure the voltage across Lead I, electrodes will be placed at locations RA, LA, and LL (Figure 2). The waveform created by the potentials measured by these electrodes will then be processed by the electrocardiograph and sampled by an ADC. The digitized waveform will then be transmitted wireless to a base station to be further processed and stored to be referenced later. This progression is described in block diagram form below in Figure 3.

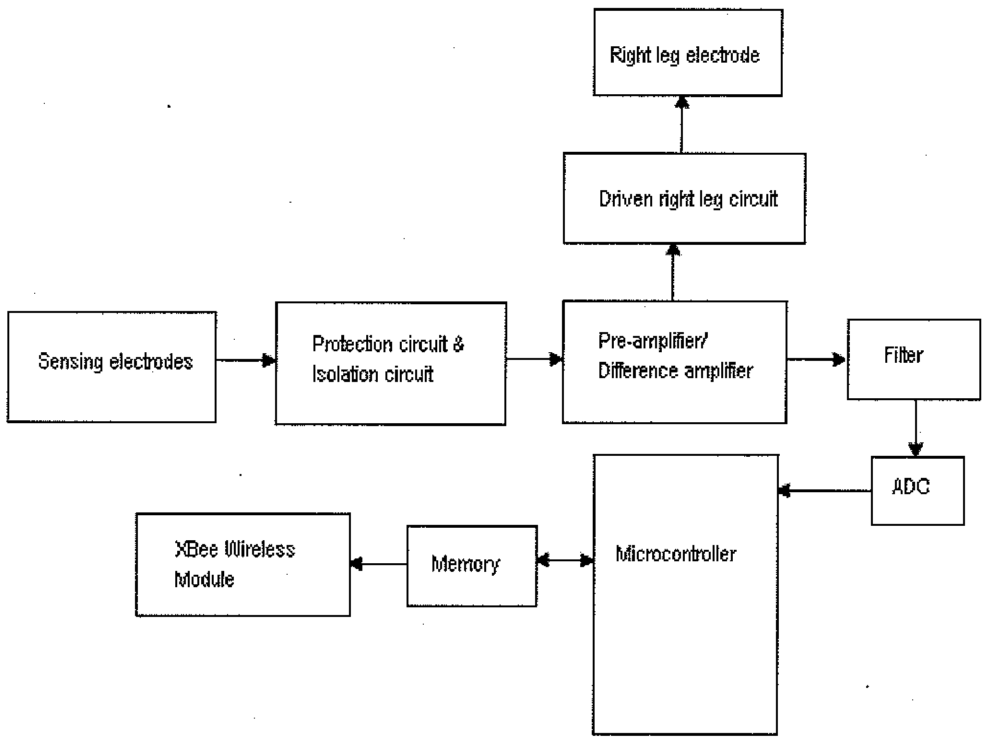

Figure 3. ECG circuit block diagram

Protection circuit and patient isolator

To protect both the instrumentation and the patient from the dangerously high voltages that may appear across the electrodes, circuitry will be put in place to limit the amount of current that may flow through the electrodes.

Preamplifier/Difference amplifier

The voltage in Lead I is measured with a difference amplifier that not only amplifies the ECG, but also cuts out any common mode voltage. This is especially important as the body intercepts a large amount of 50 or 60 Hz noise from surrounding electrical devices.

Filter

For patient monitoring purposes, the frequency range for the ECG is 0.05-30Hz. A band-pass filter will be implemented to give the electrocardiograph these characteristics.

Pulse Oximeter

Definitions:

Diastole: relaxation of heart muscles
Reduced hemoglobin (Hb) - hemoglobin unbound to oxygen molecule.
Oxygenated hemoglobin (Hb02) - hemoglobin with a bound oxygen molecule.
Sp02- pulse oximeter measurement
Sa02- arterial blood's actual oxygen
Systole- contraction of heart muscles

Oxygen saturation of the blood is an important physiological parameter that medical personnel use as an indication of various respiratory conditions. Hemoglobin, a respiratory pigment, present in the red blood cells provides a binding mechanism for oxygen. When hemoglobin is combined with oxygen molecules, it changes color. An oxygenated hemoglobin is bright red while a deoxygenated hemoglobin molecule is bright red. This change in color is used in the application of pulse oximetry for to estimate arterial blood saturation level.

Principles of pulse oximetry

A pulse oximeter sensor shines light of two different frequencies through a capillary bed such as the finger and the ear lobe. The two frequencies of light, red (660 nm) and infra red (940 nm) are chosen so that there is a large difference in the absorption of these lights by oxygenated and reduced hemoglobin. The opaqueness of the Hb and HbO_2 for a light of certain frequency is called its extinction coefficient. The extinction coefficient of Hb and HbO_2 for various frequencies is shown in Figure 4.

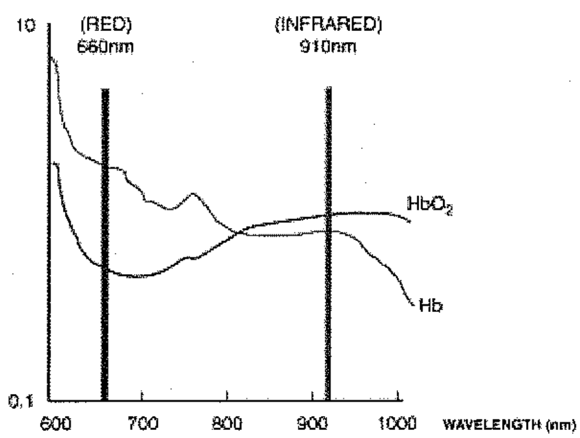

Figure 4. Extinction coefficients of Hb and HbO_2.
(http://www.oximetry.org/pulseox/principles.htm)

As seen from the figure, while the extinction coefficient of HbO_2 is higher that that of Hb at infrared frequency (940 nm), the reverse is true at 660 nm. This implies that if SaO_2 increases, the absorption of infrared light will increase while the absorption of the red light will decrease.

The light transmitted through the tissue bed is absorbed by tissues and bones along with components of the blood. Therefore, it is necessary to distinguish between the tissue/ bone absorption and absorption by hemoglobin. The pulse oximeter takes advantage of the pulsatile nature of the arterial blood for this purpose. The absorption of light by hemoglobin increases during systole and decreasing during diastole. The total absorption of light comprises of a DC component caused by tissues, bones and non-pulsating arterial blood and an AC component due to the changes in the arterial size during systole and diastole.

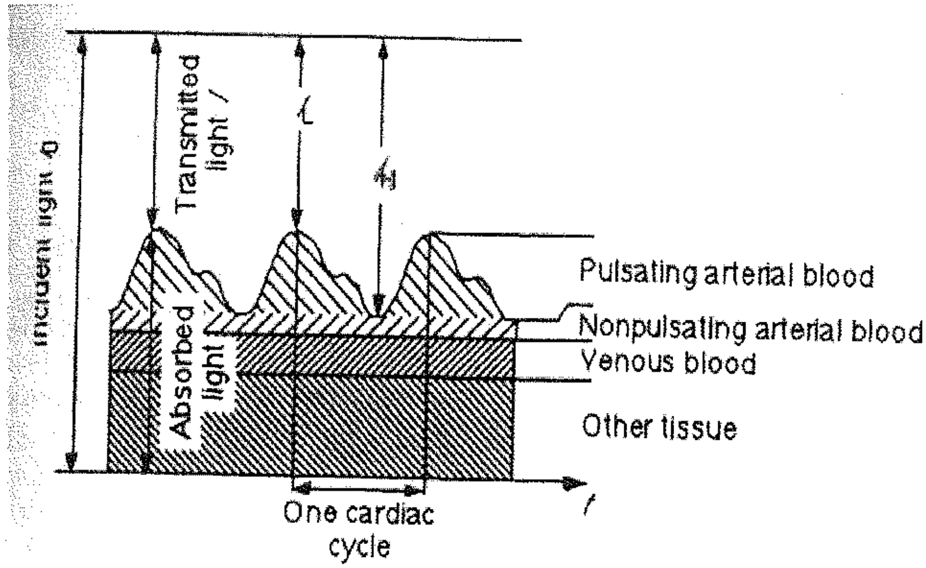

Figure 5. AC and DC components of the total absorption of LED light. I_L represents the least transmitted light and I_H represents the maximum transmitted light in one cardiac cycle. (Page 46 Figure 4.4 Design of pulse oximeters)

In order to account for different emission intensity of red and infrared LEDs, the measured light intensities have to be normalized. This normalization is done by dividing the transmitted intensities with the by the peak transmitted values of each wavelength. The ratio 'R' is then calculated as follows:

$$R = \ln (I_{L,R} / I_{H,R}) / \ln (I_{L,IR} / I_{H,IR})$$

where $I_{L,R}$ = normalized least transmitted red light
$I_{H,R}$ = normalized maximum transmitted red light
$I_{L,R}$ = normalized least transmitted infrared light
$I_{H,R}$ = normalized maximum transmitted infrared light

Theoretical calibration curve:

The functional oxygen saturation can be calculated from the ratio R using the following equation:

$$SaO_2 = \frac{\varepsilon_{Hb}(\lambda_R) - \varepsilon_{Hb}(\lambda_{IR})R}{[\varepsilon_{Hb}(\lambda_R) - \varepsilon_{HbO_2}(\lambda_{IR})R] + [\varepsilon_{HbO_2}(\lambda_R) - \varepsilon_{Hb}(\lambda_{IR})]R} X\ 100\%$$

$$where, \varepsilon_{Hb} = extinction\ \ coefficient\ \ of\ Hb$$

$$\varepsilon_{HbO_2} = extinction\ \ coefficient\ \ of\ HbO_2$$

Pulse oximeter circuit block diagram

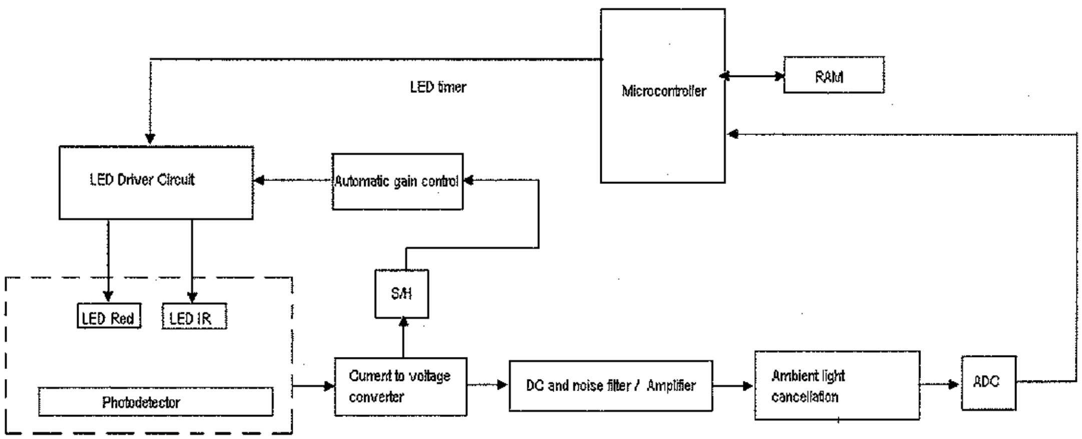

Figure 6. Block diagram for a pulse oximeter.

The basic components of the pulse oximeter circuit are shown in Figure 6. The main purpose of the LED driver circuit is to convert drive voltage to drive current. An H-bridge arrangement of transistors can be used to ensure that only one of the LED is on at a time. The switch timing between the two LEDs is dictated by the microcontroller.

The photodiode generates a current proportional to the received light. This current must be converted to voltage. The sample and hold is used to adjust the intensity of each of the LED to control the intensity of emitted light. The resulting voltage will consists of a large DC component and a small AC voltage. The DC component has to be filtered and the AC component has to be amplified. The output is then fed to an ADC after which it is routed to the microcontroller.

ZigBee

ZigBee is a low power wireless technology based on the IEEE 802.15.4 standard for wireless personal area networks. It operates on industrial, scientific and medical radio bands and is widely used for medical data collection. Zigbee protocols are designed for applications that require low power consumption and low data rates. Its low power feature is a key for the project as the portable module has to be battery operated. Zigbee allows throughput in the range of 20-250 kb/s and has a coverage range of around 100 meters. These features satisfy the data transmission rate and range requirements for the sending sensor data from the portable module to a base station/computer in a home setting.

Thermistor-based temperature sensors

Thermistors are semiconductors that are whose resistance changes with its temperature. The thermal coefficient of a thermistor (α) is the change of resistance per unit change in temperature. Thermistors can be classified into two kinds depending on the value of α. Negative Temperature Coefficient (NTC) thermistors have a negative α and its resistance decreases with temperature. On the other hand, the resistance of Positive Temperature Coefficient (PTC) thermistors increases with temperature. The following equation shows the temperature dependency of the thermistor resistance.

$$R_t = R_0 e^{\{\beta(T_0 - T)TT_0\}}$$

$$where, \beta = material\ cons\tan t$$

$$T_0 = s\tan dard\ reference\ temperature, K$$

The temperature coefficient is a nonlinear function of temperature. However, a linear approximation can be made for a small range of temperature.

Software design

One of the major components of the project is to design a software application to display and record the data transmitted from the module to a computer. A Graphical User Interface (GUI) will be created using Matlab for this purpose. The software will only perform simple data processing such as calculating heart rate from the ECG data and generating alerts if some of the parameters do not lie within a specified range.

Power consumption and batteries

In determining the specifications necessary for a battery to power the portable unit, the power consumption of the different components was computed. The main power draw is due to the transmission of data via the Zigbee module, but the microcontroller and the operational amplifiers also draw current that cannot be ignored. Lithium batteries were selected as they provide a good energy-to-weight ratio. The batteries were chosen to ensure that the unit can operate for 10 hours before needing to be recharged. The energy requirements for the battery are tabulated below.

XBEE series 1 module	45 mA
PIC16LF877A microcontroller	35μA

TLV277X operational amplifiers (x6)	6mA
Total current draw:	51.035mA
Number of hours to operate:	10 hrs
Energy capacity needed:	510.35mA hrs

Figure 7. Battery energy requirements.

Task Description

The tasks required for the successful completion of the project are listed below along with a brief description. A table of activities showing Needs/Feeds, the critical path and the Gantt chart for the project are also presented.

Task A: Working with the microcontroller

- This task will involve familiarizing with the microcontroller and programming to control sampling of sensor data and synchronization of data storage and communication with the wireless module.

Task B: Working with temperature sensor

- The tympanic temperature sensor will be used for temperature measurement data. The processed analog signal will be converted to digital data using an ADC and sent to the microcontroller for storage. By the end of this task, we hope to acquire experience with the microcontroller to accomplish successful data acquisition and storage.

Task C: Working with the wireless module

- This task will involve gaining familiarity with the ZigBee module and setting the desired configurations required to establish a point-to-point wireless communication. By the end of this task, we should be able to transmit temperature data successfully from the sensor unit to a base station/computer.

Task D: Test ECG and pulse oximeter sensors

- The ECG electrodes and pulse oximeter sensor will be connected to a subject to understand and evaluate the output data from the sensors.

Task E: ECG analog signal processor design

- The various components of ECG analog signal processing such as the amplifier and filters will be designed in Multisim and implemented on a breadboard. Real time transmission of ECG data to the computer will be completed by the end of this task.

Task F: Pulse oximeter analog signal processor design

- Analog processing units of pulse oximeter sensor data will be completed in Multisim and on breadboard.

Task G: Integrate all analog circuitry

- For this task, all the analog signal processing circuitry will be connected to the microprocessor unit. Data acquisition from all three sensors will be performed simultaneously and all the data will be transmitted wirelessly.

Task H: Finalize features for the software application
- The features and required capabilities required from the software application will be discussed and finalized.

Task I: Design the software using Matlab
- The software tool will include a Matlab GUI for sensor data display.

Task J: Design PCB layout
- A PCB layout for the complete circuit will be created.

Task K: Assemble hardware and test
- Upon receipt of the PCB, all the components will be assembled and tested.

Task L: Prepare and deliver mid-semester project report
- The progress made in the project so far will be presented.

Task M: Create a draft project report
- At this stage, we'll start working on compiling a project report.

Task N: Prepare and deliver final project presentation
- The accomplishments of the project will be presented.

Task O: Create final project report
- Detailed description of all the tasks and the achievements will be presented in the final project report.

Activity	Needs	Feeds	Duration	Effort	Action
A	---	C	15	60	Working with the microcontroller
B	---	C	5	20	Working with the temperature sensor
C	A,B	G	10	40	Working with the wireless module
D	---	E,F	13	52	Test ECG and pulse ox sensors
E	D	G	12	48	ECG analog signal processor design
F	D	G	25	100	Pulse oximeter analog signal processor design
G	C,E,F	J	4	16	Integrate all analog circuitry
H	---	I	2	8	Finalize features for the software data processing
I	H	K	15	60	Design the software using Matlab
J	G	K	11	44	PCB layout and order
K	I,J	M	7	28	Assemble hardware and test
L	Midterm	M	6	24	Prepare and deliver mid-semester project report
M	K,L	O	7	28	Create a draft project report
N	---	O	17	68	Prepare and deliver final project presentation
O	M,N	---	10	40	Create final project report

Figure 8. Needs and Feeds table of activities.

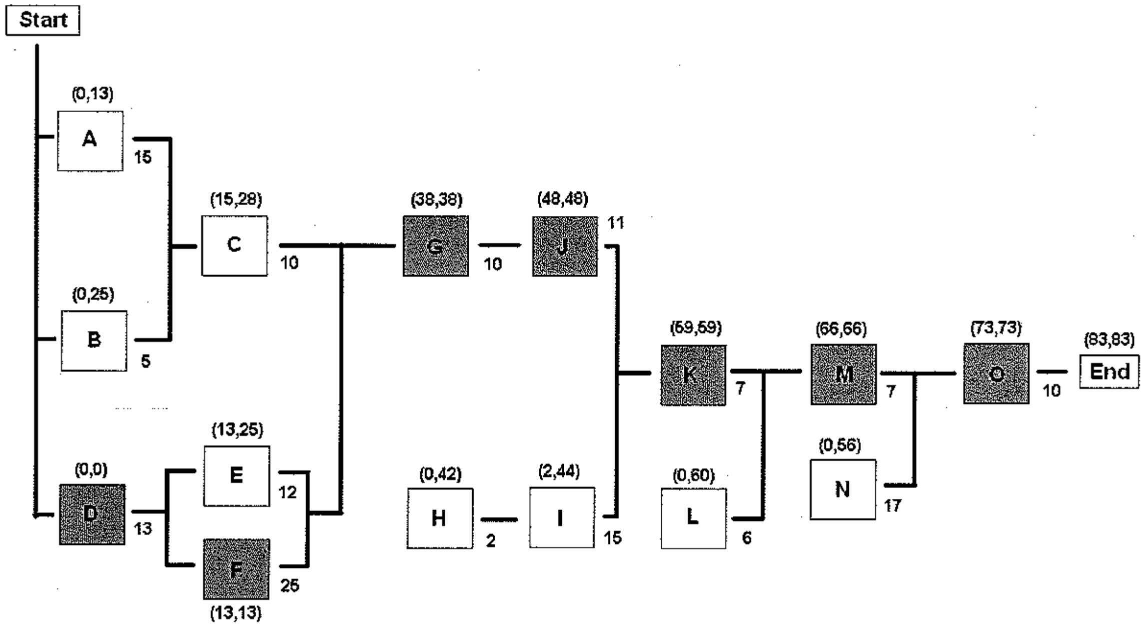

Figure 9. Critical path diagram for the project. The critical path is shown in gray.

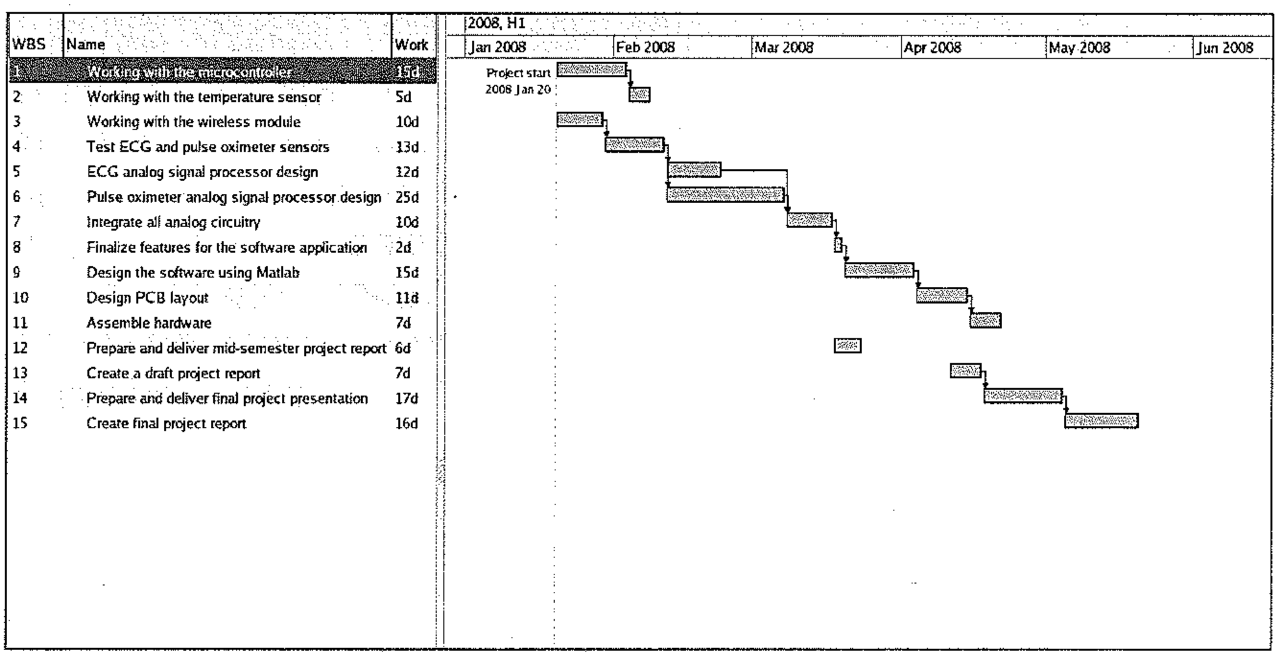

Figure 10. Gantt chart for the spring 2008 semester.

Required Hardware

1. Microcontroller ($10)

We are planning to use PIC15LF877A, an 8 bit microcontroller, for the project. This MCU has a low voltage operation which is required for our design. It also has a 10-bit ADC required for high resolution data.

2. Patient Isolator

Since the device will be battery operated, the patient isolator will not be incorporated in our final circuit. However, during the project period, an external patient isolator will be used as a safety measure.

3. Pulse Oximeter Sensor

We are currently in touch with Nellcor, a leading manufacturer of pulse oximeters, to receive a sensor donation for the project. We'll either be working with a Oxisensor II adhesive sensors or Oximax reusable sensor from Nellcor.

Oxisensor II
http://www.nellcor.com/prod/Product.aspx?S1=POX&S2=&id=13

Oximax Reusable sensor
http://www.nellcor.com/prod/Product.aspx?S1=POX&S2=SEN&id=12

4. ECG electrodes ($13.77 for 50 electrodes from Grogan's Healthcare)

Soft cloth electrodes available from 3M Healthcare will be used for the ECG measurements. The electrodes are breathable and stretchable to ensure patient comfort. In addition, the electrodes have solid electrode gel to improve conduction.

Website:
http://www.grogans.com/servlet/shop?cmd=I&id=3M9641

5. Temperature Sensor

A thermistor based tympanic temperature sensor will be used for temperature monitoring. We have received a sample sensor from NovaMed. The NTC based temperature sensor has a comfortable fit that ensures easy placement and minimizes the risk of tympanic membrane perforation.

Preliminary tests were performed to verify that the sensor behaved as expected. For the purpose of the project, a linear approximation will be made for calibration purposes as the body temperature varies over a small range.

6. Zigbee Wireless ($19)

Xbee ZigBee OEM Module will be used for wireless transmission. This module has an indoor range of 30m and operates within the ISM 2.4 GHz frequency band. This module requires a supply voltage in the range of 2.8 – 3.4 V and has a transmit current of 45 mA at 3.3 V.

Website:
http://www.maxstream.net/products/xbee/xbee-oem-rf-module-zigbee.php

7. Batteries ($10)

In order to meet the power specifications discussed above, three Panasonic Nickel Metal Hydride rechargeable AAA batteries were chosen. Each battery weighs 13 grams, has a capacity of 700mAh, and provides a nominal voltage of 1.2V. The batteries will be connected in series to obtain a nominal voltage of 3.6V. To ensure the proper voltage for the XBEE module, a voltage divider will have to be used. The rechargeability of these batteries is a key feature as it minimizes environmental impact and reduces overall cost for consistent use of the portable unit.

8. Printed circuit board ($60)

After all the sensor components are integrated and tested, a PCB layout for the complete circuitry will be created. Once all the components are assembled on the PCB, the circuitry will be encased for protection and easy handling.

Project Costs

Microcontroller	$10
Temperature sensor	(Possible donation)
Pulse Oximeter sensor	(Possible donation)
Printed circuit board	$60
Zigbee Wireless	$19
ECG electrodes	$14
Operational amplifiers	$ 5
Battery	$10
Total cost	$118

Project Qualifications

Through courses such as Fundamentals of Digital Systems (E15) and Electronic Circuit Applications (E72) we have had experience with microcontrollers and analog circuit design that will be required for the successful completion of the project. In addition, we have conducted thorough background research of bio-signals such as ECG that we will be working with in the course of the project.

Real world design considerations

One of the key design criterions for wireless patient monitoring is the comfort and safety of the patient. Therefore, as described in the "Hardware Required" section above, each of the sensors are chosen accordingly. In addition, the power supply that will be used for the wireless module is a Panasonic Lithium battery which is not listed as an EPA hazardous waste. Therefore, this will have minimal environmental impact.

References

Webster, John G. "Design of pulse oximeters"
Webster, John G. "Medical instrumentation", Third Edition.
Principles of applied biomedical instrumentation