PROXIMUS

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March 7, 2006

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
V5A 1S6

Re: ENSC 440 Design Specifications for the Wireless Monitoring System

Dear Dr. Rawicz:

The attached document, *Design Specification for the Wireless Monitoring System*, contains the design requirements for the product we are building. The Wireless Patient Monitoring System we are building will significantly alleviate the inconvenience that patients experience from the wires that connect them to conventional bedside monitoring devices.

This document encloses the design specifications for phase one of our project. This design specification provides an overview of our system, as well as the high-level software design of our system, and detailed hardware decisions.

If you have any questions or concerns, please do not hesitate to contact us at proximus-ensc440@sfu.ca.

Sincerely,

Zues Rawji
Chief Executive Officer
Proximus

Enclosure: *Design Specification for the Wireless Patient Monitoring System*

Design Specifications for the Wireless Monitoring System

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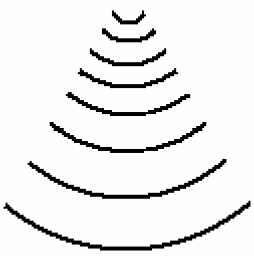
Executive Summary

Proximus is currently developing an innovative solution that can be seamlessly integrated into existing hospital networks. Our *Wireless Monitoring System* (WMS) will increase the ease of monitoring patients in their hospital room, both for the patient and the healthcare workers. We aspire to make patient monitoring more transparent, resulting in increased efficiency of hospital staff and less impact on the patient. Sensors will be small and comfortable for patients.

We will achieve this transparency using reliable wireless technology which will comply with hospital regulations to ensure minimal noise and interference. Each hospital room will have a local wireless network, consisting of sensors and a data logger. A wireless solution will reduce human interaction in the monitoring process resulting in less human error as well as reduced patient risk and increased staff efficiency.



The data logger will receive and organize data which it receives from the sensors in the hospital room. The data will be displayed directly on the data logger facilitating immediate monitoring of the patient by healthcare workers. Phase one of our development will include using a laptop as the data logger for proof of concept, as well as developing the associated software, and developing the wireless sensor bank.[1]

Phase two of our development will include sending data received by the data logger through an already existing hospital network to enable a second means of patient monitoring. The data logger will transmit data through the hospital network to a centralized location where the patient can be monitored from. By allowing the patient to be monitored from a centralized location and not just in the hospital room, quicker responses to the patient can be made. Phase two of our development will include modifications of the laptop software so that it may be used on the central location module. In addition, the main focus of phase two will be to remove the laptop from the system, and develop the data logger module.[2]

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[1] http://www.allproducts.com/manufacture98/gotom/product3.jpg
[2] https://marltoncomputers.com/catalog/images/computer.jpg

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1 Introduction

The *Wireless Monitoring System* (WMS) is a system which empowers medical staff to monitor patients while maintaining the mobility desired by patients. The patients can be monitored within certain proximity of the bedside Data Logging Module (DLM). The development of the WMS will be carried out in two phases. Phase one focuses on the development of the sensor modules and the software that will run on the DLM, whereas phase two focuses on the integration of a Central Location Module into the WMS. The CLM will allow for the central monitoring of hospital patients.

The focus of this document is discuss the design decisions targeted around phase one of the project.

1.1 Scope

This document describes the design specifications for phase one development of the WMS. Phase one is described in detail in our functional specifications document and amounts to a proof of concept device [12]. The design specifications described in this document are based on our functional specifications for phase one.

This design specification document provides high level design overview of phase one and the specific tasks and features of the corresponding subsystems. Key subcomponents discussed in this document include the Bluetooth transmitter/receiver module, the chosen microcontroller, A/D converter, sensors (both temperature and electrocardiogram), wireless protocol chosen, software designed for the system, and the design of the Graphical User Interface (GUI). The test plan is also provided to verify that the proof of concept devices complies with all phase one functional requirements.

1.2 Acronyms

°C	Celsius, a unit of temperature based on the freezing and boiling points of water
°K	The SI unit of temperature where it has a linear relationship to Celsius. 0 °C is 273.15 °K.
A/D	Analog to digital conversion, conversion of continuous analog signals into digital binary format
AC	Alternating Current
API	Application Programming Interface, programming interface by which applications can access the operating system and system resources
AT	Asynchronous Transfer
Bps	Bits per second, unit of measurement of baud rate

CLM	Central Location Module
CMRR	Common-mode Rejection Ratio
CRC	Cyclic redundancy checking is a method of checking for errors in data that has been transmitted on a communications link.
DB9	The DE-9 (9 pin D-shell connector) is a type of D-subminiature electrical connector most commonly used for the RS 232 port on the IBM AT and compatible computers.
dBm	Power level in decibels per 1 milliwatt
DC	Direct Current
DIP	Dual Inline Packaging, the regular integrated packaging on most breadboards.
DLM	Data Logging Module
DSP	Digital signal processing, computer manipulation of analog signals that have been converted to digital form
ECG	Electrocardiogram, a graphical record of the cardiac cycle
EMC	Electro-Magnetic Compatibility
EMI	Electromagnetic Interference
EPROM	Erasable Programmable Read-Only Memory, is a type of computer memory chip that retains its data when its power supply is switched off.
ESD	Electrostatic discharge, also called static electricity
FCC	Federal Communications Commission
GHz	GigaHertz (10^9 Hertz)
GUI	Graphical user interface, the screens of the software that the user interacts with
Hz	Hertz, Cycles per second
I/O	I/O Input/Output
ID	Identification
I^2C	Inter-Integrated Circuit, is a serial computer bus invented by Philips that is used to attach low-speed peripherals to a motherboard, embedded system, or cell phone.
kB	Kilobytes, 10^3 bytes where 1 byte is 8 bits.
kHz	Kilohertz (1000 Hertz)
LED	Light emitting diode
LSB	Least significant bit
MFC	Microsoft Foundations Classes
MHz	Megahertz (1 000 000 Hertz)
mm	Millimeter, 10^{-3} meters
ms	Milliseconds, 10^3 seconds
MSB	Most significant bit
mW	Milliwatt (0.001 watt)

mV	10^{-3} Volts
nA	Nano amps, or 10^{-9} amps
OEM	Original Equipment Manufacturer.
Op-amp	Operational Amplifier
OS	Operating system, software to interface between application and hardware
PC	Personal Computer
PCB	Printed circuit board, a thin board to which electronic components are fixed by solder
PDIP	Plastic Dual-In-Line Package. Refer to DIP.
PIC	A microcontroller developed by Microchip Technologies Ltd.
ppm	Parts per million
QRS	QRS complex, name of the electrocardiogram waveform. The various peaks and troughs of a waveform are named P, Q, R, S, and T
RAM	Random Access Memory, a kind of storage device that can be stored or accessed in any order
RF	Radio Frequency
SBM	Sensor Bank Module
µA	Micro amps, or 10^{-6} amps
UL	Underwriter’s Laboratories
UNC	University of North Carolina
USART	Universal Synchronous/Asynchronous Receiver/Transmitter
USB	Universal Serial Bus, an external peripheral standard for communication between a computer and peripheral devices
V	Volts
WMS	Wireless Patient Monitoring System

1.3 Intended Audience

This document is intended for designers and manufacturing personnel. Designers will use this document as a foundation for actually designing the phase one system to ensure that it satisfies all functional requirements described in [12]. Manufacturing personnel will use this document for verifying the performance and requirements of their final product.

1.4 Referencing Convention

Throughout this document there will be numerous references to our functional specifications document [12]. The following convention will be used:

R[n/priority] Functional specification description.

The functional specification number is denoted by n. The priority is given by A, B, or C and is displayed after the functional specification description. The priority number convention is as follows:

A	Functional specification is required for both the proof of concept, and the final production system.
B	Functional specification is for just the proof of concept.
C	Functional specification is for just the final production system.

2 System Overview

Figure 1 illustrates the system block diagram for the proof of concept. The system consists of two modules: a sensor bank that is composed of multiple sensor modules worn by a patient and the DLM placed by the bedside.

The individual sensor modules within the sensor bank will transmit the data measured by the sensors, to the DLM via a Bluetooth link. The DLM receives these measurements simultaneously from all sensor modules, and performs the necessary error checking that is built into the Bluetooth protocol to ensure no data is corrupt. The data is then processed and placed into individual buffers on the DLM so that the GUI can read and display the data accordingly. Medical staff will be given the choice of whether they wish to display this data in analog format (a wave), numerical format, or a combination of both.

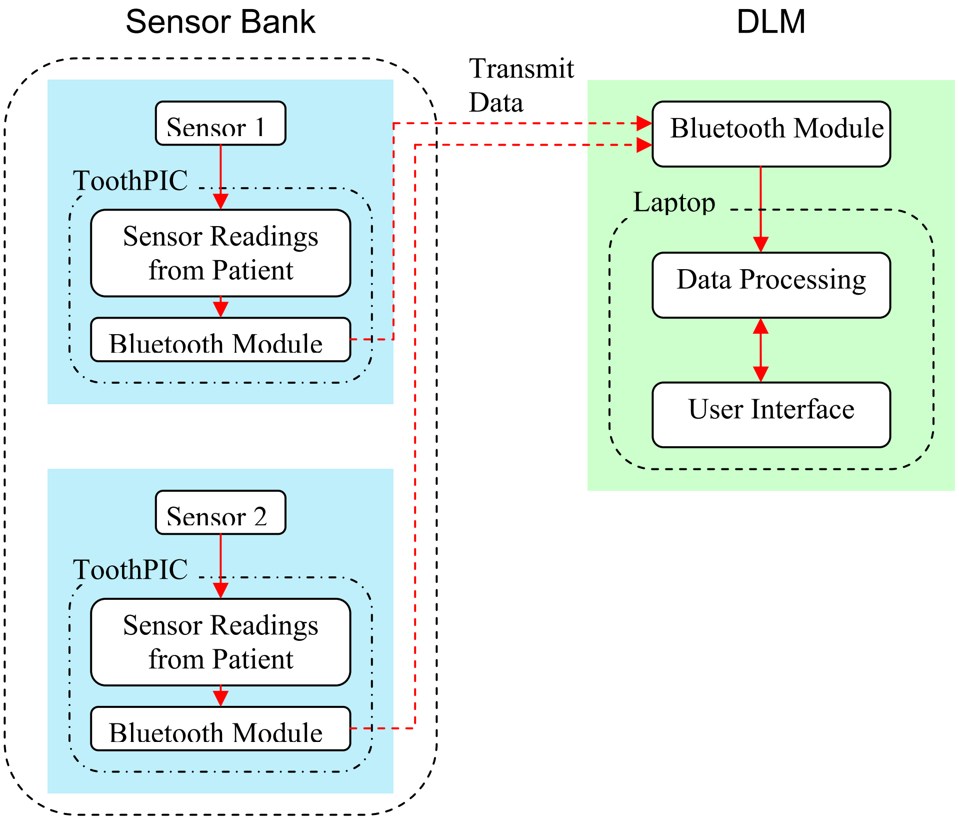

Figure 1: System Block Diagram for Phase One

The ToothPIC is a solution that has been chosen as the Bluetooth interface on the sensor modules; further information about the ToothPIC solution will be discussed in subsequent sections.

3 Major Design Decisions

3.1 Communication Technology

We have chosen Bluetooth for our communication technology. The following summarizes why we have chosen Bluetooth:

- It provides simple wireless capabilities for convenient, short range wireless communication between devices, which complies with R[52/A] and R[86/A].
- Bluetooth has its own error checking means to ensure proper data transmission. This complies with requirements R[17/A], R[49/A], R[57/A], R[67/A], R[92/A], R[93/A], R[108/A], R[112/A], R[121/A], R[122/A], and R[123/A].
- The transmission power required for the Bluetooth protocol will not be of a harmful level to the user which complies with R[115/A].
- The Bluetooth protocol falls within the allowable band for transmission regulated by the FCC. This complies with requirements R[116/A], and R[117/A].
- Bluetooth protocol will transmit data continuously as long as a connection is open. This complies with requirement R[88/A].
- Bluetooth supports point-to-multipoint transmission in parallel which is required for R[61/B], R[118/A], and R[119/A].
- Class 1 Bluetooth was chosen because it provides long range connectivity improving patient mobility. Also, the sensors are required by R[54/A] to be EMC compatible which BlueTooth provides.
- The Bluetooth protocol has built in mechanisms to deal with multi-channel interference. This complies with requirement R[14/A], R[111/A] and R[113/A].
- Bluetooth transmission occurs independent of the path chosen for wireless transmission as long as the transfer exists within certain proximity of each other. This complies with R[109/A].
- The entire Bluetooth stack has been developed for Proximus with the module chosen, thus reducing development time.

3.2 DLM

A laptop has been selected to act as our DLM. The following is the summary of why the laptop was chosen.

- It can easily be made compatible with Bluetooth with a USB point-to-multipoint adaptor. This complies with R[87/A].
- It has excellent resolution for displaying data.

- Because of standard operating conditions of a laptop, clearly requirements R[68/A] and R[69/A] are met.
- The display and dimensions of a laptop complies with requirements R[63/A] and R[64/A].
- The adapter used to power the laptop is CSA and UL approved which complies with R[70/A] and R[71/A].
- All the necessary hardware required for the DLM also exists in a laptop
- Implementation of GUI is easily accomplished using pre-existing windows architecture and programming languages.
- The laptop is lightweight, complying with R[62/A].

3.3 Implementation Changes

In our functional specifications we outlined some functional requirements for our phase one proof of concept device which have been moved to phase two of development. The following requirements are being reconsidered in light of design information learned since creating the functional specifications document.

3.3.1 Sensor Bank

R[15/A]	Sensor bank shall not interfere with any hospital equipment.

- R[15/A] should be R[15/C]. In the time allotted for phase one, we will not be able to test this and so we do not guarantee it for proof of concept.

3.3.2 General Sensors

R[19/A]	The sensors themselves shall be no bigger than the existing sensors currently being used in hospitals.
R[22/A]	The casing for the sensors shall be made of a non-toxic material, in order to not harm the users.
R[40/A]	When the power supply is low, the sensor module will emit an acoustic warning.

- R[19/A] should be R[19/C]. This will not be attainable for phase one due to our time constraint. The required hardware would have to be custom made for our sensor application which is not feasible in the given time frame for phase one. Instead we are using a more general purpose hardware which has additional features and is more bulky than the ideal custom hardware.
- R[22/A] should be R[22/C]. Casing for the sensor will only implemented for the marketed product due to time constraints.
- R[40/A] should be R[40/C]. As of now this feature will only be included as a marketed product due to time constraints.

3.3.3 Temperature Sensor

R[25/A] The temperature sensor will have a maximum error of 2%.

- R[25/A] should be R[25/C]. For proof of concept the temperature circuit and sensor will be made as best as possible given our time and financial constraints.

3.3.4 ECG Sensor

R[26/B] The ECG sensor will have a maximum error of 10% in order to illustrate sensor accuracy for proof of concept.

- R[26/B] should be R[26/C]. Error of the ECG circuit will require calibration to an actual hospital ECG device and we expect that we will not have time to do this before the phase one due date.

3.3.5 Wireless Communications

R[55/A] Each sensor module will only have a maximum window to transmit its data to the DLM. This window for transmission will ensures that no timeouts occur, or that communication between the DLM and the sensor module does not hang.

R[120/A] All data transfer packets will have a maximum window to transfer to avoid timeouts.

- R[55/A] will not be implemented since Bluetooth implements its own transmission scheme embedded in their protocol as a means for error control and flow control.
- R[120/A] will not be implemented since Bluetooth implements its own error control scheme to ensure no timeouts occur.

4 System Hardware

Various hardware components are used for the development of phase one of the WMS. For the sensor module, a combination of amplifiers, transducers, passive components, and the ToothPIC integrated solution is used. For the DLM, a laptop is being used so that all resources can be focused on the development of the software of the DLM. A laptop contains all the necessary hardware needed in order to comply with all the functional requirements desired.

4.1 Electrocardiogram Design

This section will discuss the design and implementation of the ECG circuit prior to integration into the ToothPIC Bluetooth Module. This will also entail the hardware outlined in the wireless ECG sensor that verifies requirement R[20/C].

4.1.1 General

Electrical current is generated through potential created by heart movement. The heart wall contraction spreads electrical currents from the heart throughout the body. Different potentials are created through different points in the body [4]. The electrodes used are put onto the skin surface, which are made with biological transducers.

The electric potential is an AC signal with bandwidth that is approximately 0.05 to 100 Hz with a 1mV peak-to-peak. This is in the presence of a much larger external high frequency noise plus a 50/60-Hz interference normal-mode and common-mode voltages.

Therefore, the common-mode is comprised of two parts: 50/60-Hz interference and a DC electrode offset potential. Other noise can come from the movement of the patient based on the skin-electrode interaction, muscle contractions and electromyographic spikes, EMI and noise from electronic devices.

The selection of resistors, op-amps, instrumentation amplifiers, capacitors and electrodes will be done in a manner to reduce the amount of external noise from the DC electrode potential.

Figure 2 shows a block diagram of the ECG circuit.

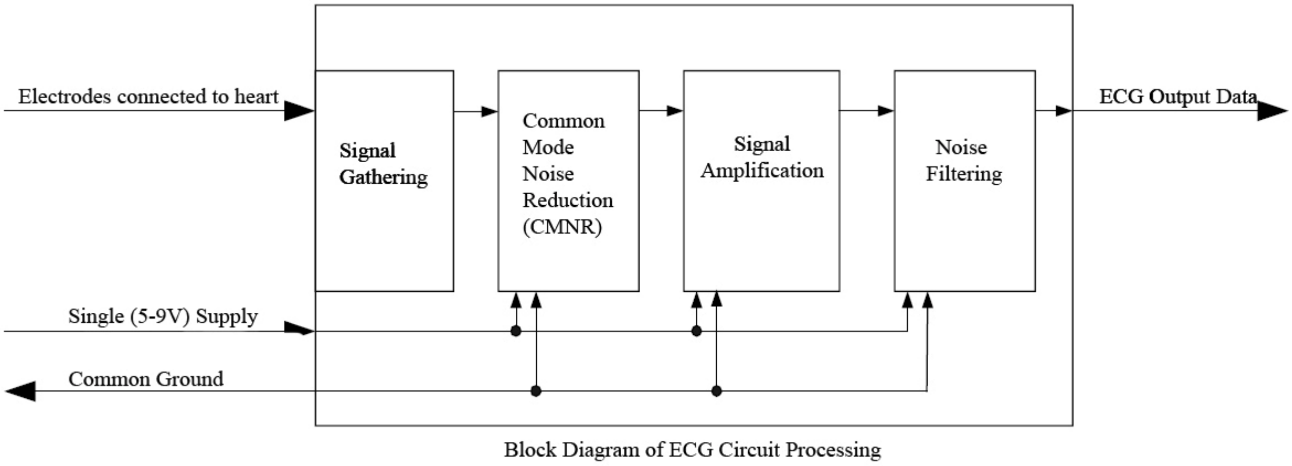

Figure 2: ECG Circuit Block Diagram

The block diagram above consists of four main stages. The first stage gathers the ECG signal from the input electrodes. The second stage is the Common Mode Noise Reduction, and its purpose will be to decrease the common mode noise between the two electrodes placed near the heart [5]. The third stage is Signal Amplification; amplification is required as the signal from the heart is very small. The final stage is noise filtering; a filter is required here to eliminate noise due to EMI and other external interferences. Finally, the output of the ECG will be driven to the analog port of the Bluetooth device.

4.1.2 Electrode Placement

Placement of the electrodes is very important. There will be three lead wires coming from the wireless ECG sensor. In the connection of the three, there will be one placed at the bottom left or right leg, one on the left ventricle and one on the right atrium. The reason for this placement strategy is explained in the UNC Health Care hospital manual [6].

Figure 3 shows the correct placement of electrodes on the body.

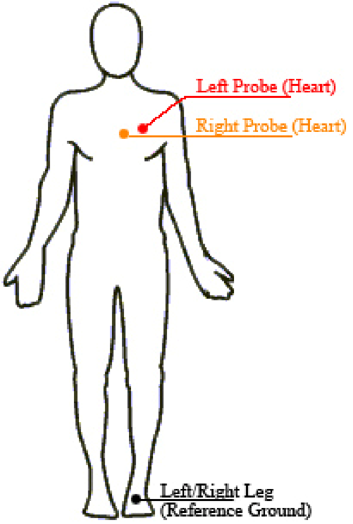

Figure 3: Electrode Connections to Human Body

The placement strategy of the electrodes shall now be explained. The left/right leg probe serves as a body ground; without this connection to the leg, the signal would not be obtainable. The two probes connected near the heart are done so in order to reject common-mode noise. This allows the heart beat signal to be extracted and averaged in order to acquire an accurate signal.

The connections will be made using bio-thermal conducting pads that comply with R[2/C] and R[28/A]. These disposable pads will be 44x50mm wide and contain minimal noise due to the extremely clean surfaces [7].

4.1.3 Supply Voltage

The system supply voltage in this biophysical monitoring system will be that of a low, single-supply level. The reason for having a single supply level is because the sensors will run on a single-supply battery, due to the compact size of this design. Hence, voltages between 3.3 and 5.0 V supplies will be used.

4.1.4 Amplifiers

4.1.4.1 Instrumentation Amplifier

Amplifier choice is very important to help eliminate noise due to common-mode noise rejection. The AD623ANZ will be used to implement the instrumentation amplifier [9]. Using this amplifier will comply with requirements R[26/B], R[30/A], R[31/B], R[32/B], R[33/B] and R[34/B]. Some of the Instrumentation Amplifier Requirements are:

- Stability in low gain (G = 1 to 10)
- High common-mode rejection (CMR)
- Low input bias current (IB)
- Good swing to the output rail

- Very low offset and drift
- 8-pin DIP package
- Low cost solution

The AD623ANZ was chosen to implement the instrumentation amplifiers because it has a common-mode rejection of 70dB, 25 nA Max Input Bias Current, 550 µA Max Supply Current, 5 ppm Gain Drift and up to a 6V single supply. Therefore, the AD623ANZ is the ideal choice for amplifiers in order to verify R[29/A]. The internal schematic of the instrumentation amplifier is shown in Figure 4.

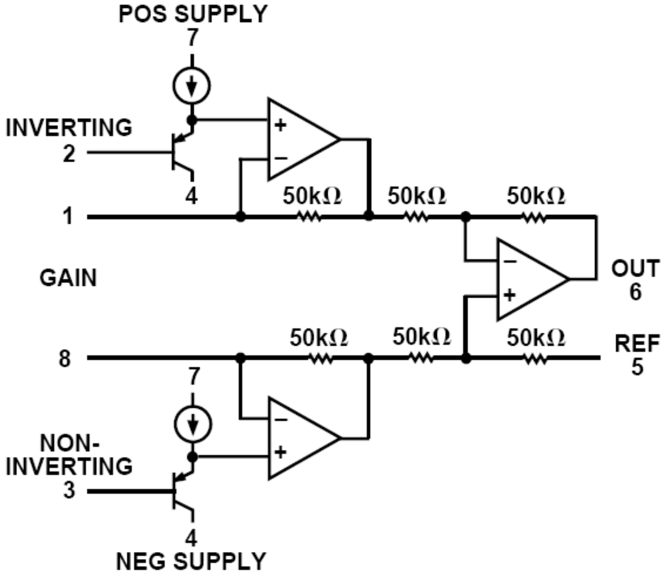

Figure 4: Internal Architecture of AD623ANZ

The gain can be set using a resistor along Pin 1 and Pin 8. We have chosen a gain of 10. To calculate resistance R_G, the following calculation was performed using data from the spec sheet for the AD623ANZ as

$$R_G = 100k\Omega(G-1).$$

Thus, in order to maintain a gain of 10, resistance R_G must be 900kΩ. The use of an instrumentation amplifier is merited by its characteristics of reducing AC line noise common to both inputs, and its ability to amplify the differential signals present on the inputs. The higher instrumentation common-mode rejection will result in reduction of common noise within the body. To further reject the noise in the 50-60Hz range, an operational amplifier deriving common mode voltage is used to invert the common-mode signal. This signal is driven it back through the patient's leg and acts to cancel out the bias current produced.

4.1.4.2 Operational Amplifier

The choice for the operational amplifier is the OPA344 [8]. This was chosen was made in order to comply with requirements R[26/B], R[30/A], R[31/B], R[32/B], R[33/B] and R[34/B] for the ECG circuit. The Operational Amplifier specs that are for the ECG circuit are:

- Low noise in high gain (Gain = 10 to 1000)
- Rail-to-rail output
- Very low offset and drift
- 8-pin DIP package
- Low cost solution
- -40 to 85ºC range (compliant with requirement R[36/A])
- 2.5V to 5.5V operating range

Other advantages of using this op-amp is that it is capable of working in extreme temperatures, hence, there shall be minimal variation due to temperatures. This meets our requirements of operating at room temperature in a hospital environment. This op-amp is capable of operating between 2.5V and 5.5V, as our desired voltage range is between 3.3V to 9V. Finally, this device has a low costing 8-DIP packaging, which makes it easy for prototyping the ECG circuit, as it fits nicely into the breadboard.

4.1.5 Frequency response

Standard -3-dB frequency for patient monitoring is 0.05Hz to 30Hz, while diagnostic grade monitoring requires 0.05Hz to 100Hz or more. All ECG front ends must be AC coupled to remove artifacts from the electrode offset potential, though important features of the ECG waveform have extremely low frequency characteristics. Therefore, a low-pass filter could easily be used after the output from the instrumentation amplifier with the end frequency set at 60Hz. To do this, a 0.47µF capacitor and a 6kΩ resistor were used to have an approximate cutoff frequency of 60Hz. This will help to comply with R[29/A] of the functional requirements.

4.1.6 ECG Circuit

The ECG circuit was based on the modifications of many ECG circuits obtained from online sources. After a couple redesigns of the operational circuit, it was reduced to the current schematic shown in Figure 5.

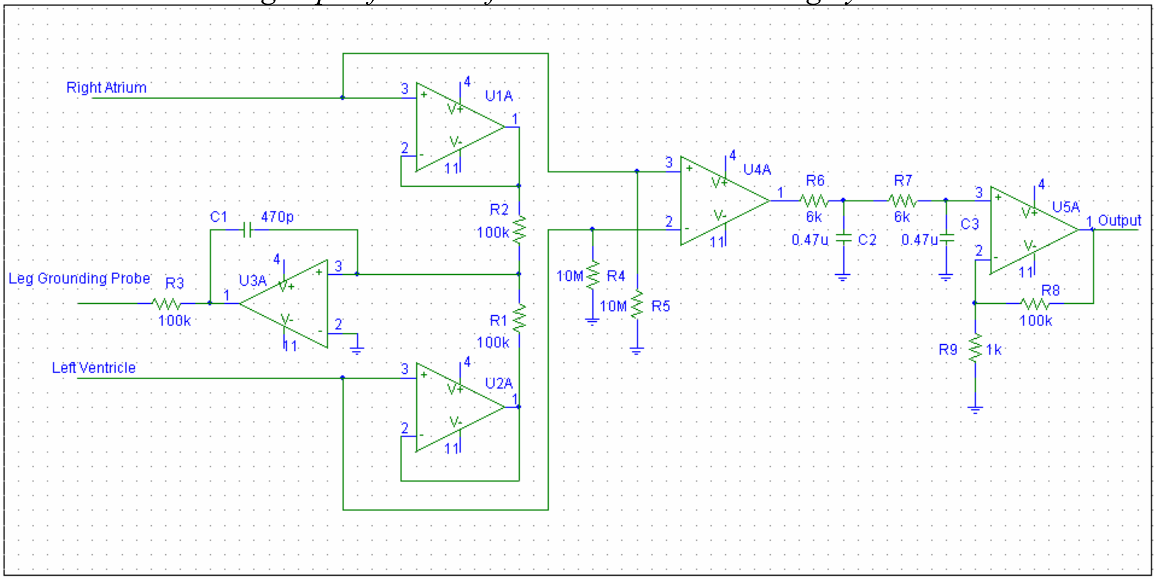

Figure 5: ECG Circuit Schematic

In this circuit, U1A and U2A are the OPA344 op-amps that are used as voltage followers from the right atrium and left ventricle. The resistors R1 and R2 act as load bearing resistors. They limit the amount of current through the op-amp and help prevent loading the electrodes. The electrodes are fed into U4A. This is the instrumentation amplifier that is simplified into a basic op-amp. A resistor, $R_{G,}$ of 900kΩ will be used to give the instrumentation amplifier a gain of 10. The instrumentation amplifier acts as filter to noise due to the nature of an instrumentation amplifier.

An instrumentation amplifier helps to eliminate common-mode voltages which are parts of the signal which pertain to noise or current throughout the body [ECG2]. To eliminate this, the CMRR is between 70dB and 105dB. Common-mode voltage is the voltage in the signal which both electrodes see in the signal. Since the two electrodes will have different potentials, then, the idea is to eliminate signals that are of the same characteristics in the body, and then average the two signals coming in.

The reference point is in the connection between R1 and R2 which connects to an integrator and then to the leg. This acts as a reference point for the body to the two electrode signals. Plus, it helps eliminate any bias currents flowing through the patient’s body.

After, the next stage is to go through a two-stage low-pass filter. The filter is set to 60Hz with a drop of 40dB per decade. Most importantly, this is done to eliminate noise from the signal because the body can act as an antenna when wires are attached to it.

Finally, the output of the low-pass filter is finally put into another OPA344 with a gain of 10. This output would give a peak-to-peak value of 2.25V.

4.2 Temperature Sensor Hardware

The temperature sensor will be mounted on an armband that will encircle the patient's upper arm. The actual sensing element will be positioned to be in the patient's armpit. This will enable us to measure the temperature in a noninvasive manner. Placing the sensor in the armpit will also minimize the error due to ambient temperature in the hospital room which will satisfy requirement R[30/A]. In addition, all components used in the design of the temperature sensor operate independently of atmospheric pressure fluctuations to satisfy requirement R[24/A].

4.2.1 Temperature Transducer [10]

We will use the Analog Devices AD592CN as a temperature transducer. The AD592CN is a linear temperature dependent current source with a transfer function of 1 μA/°K. The transfer function from 0 to 50 °C is shown in Figure 6 below.

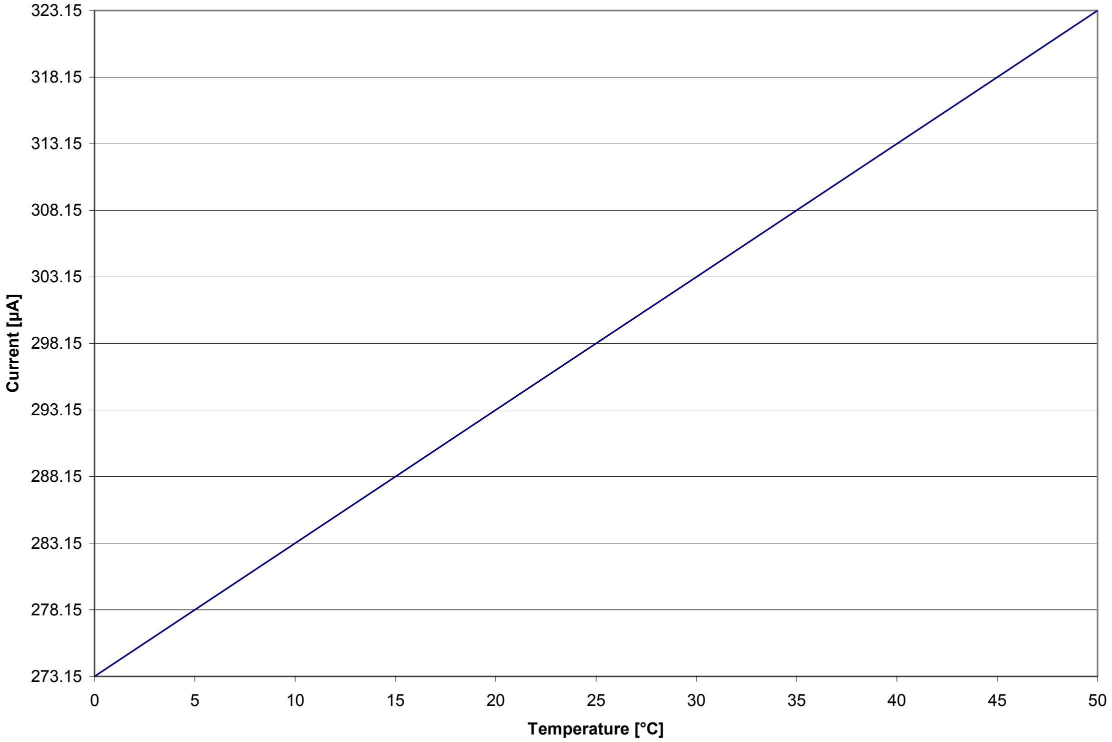

Figure 6: AD592CN Transfer Characteristics from 0 to 50°C

Over a measured temperature range of 0 to 70 °C the typical error of the AD592CN is 0.4 °C and the maximum error is 0.8 °C. This transducer is well suited for our application since it can easily be powered by a battery (R[37/A]). In addition, since it is a current source the AD592 is immune to voltage drops and voltage noise over long lines due to its high impedance current output. This complies with the functional specification R[29/A].

4.2.2 Signal Conditioning

We would like to condition the output signal of the temperature transducer so that the temperature range of 0 to 50 °C corresponds to a voltage of 0.0 to 5.0 V. To accomplish this we use the circuit shown in Figure 7 below.

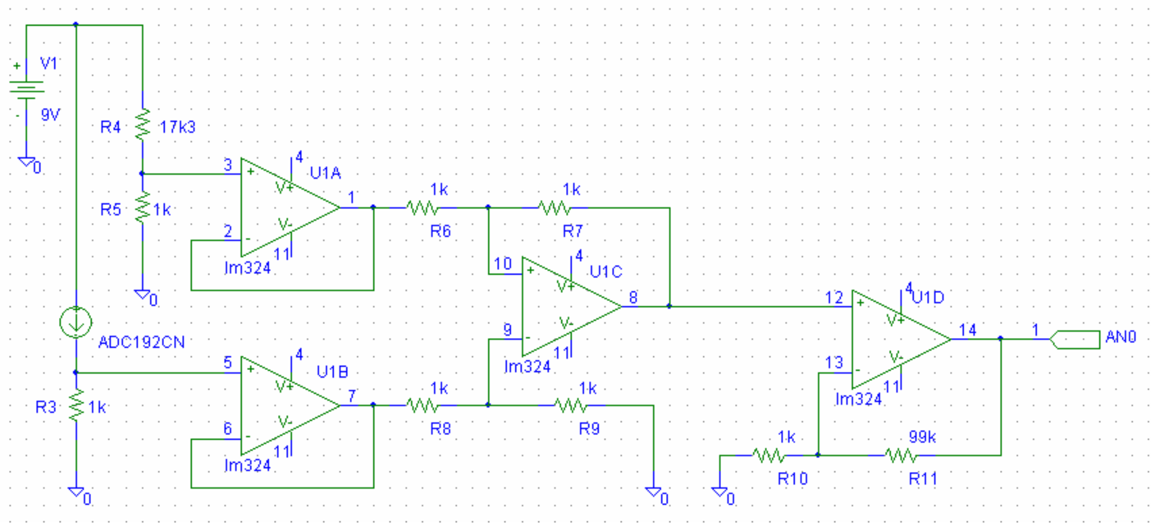

Figure 7: Signal Conditioning Circuitry

The op-amps used are LM324 op-amps [11]. The LM324 is a high-precision low-power op-amp which can be operated from a single supply such as a battery. It operates in the temperature range of 0 to 70 °C which complies with functional specification R[29/A]. Amplifiers U1A, B and C form a differential amplifier stage with a unity gain and high input impedance.

In the design of this circuit, Proximus has considered the offset of 273.15. This offset is subtracted through the difference amplifier stage since the linear relationship of the temperature transducer is in μA/°K as opposed to μA/°C. With the subtraction of 273.15mV from the signal, the output from the differential stage is the μA/°C and then is amplified to increase resolution of the circuit.

Amplifier U1D provides a gain of 100. The output of this circuit is interfaced directly to the analog to digital input of the microprocessor specified in section 4.3.1. Since the analog to digital converter on the microcontroller has a 10-bit resolution the temperature resolution over the range of 0 to 50 °C is 0.05 °C. This meets the functional specification R[35/A].

4.3 ToothPIC Stamp Edition Module

The ToothPIC Stamp Edition solution was chosen for numerous reasons. Firstly, the ToothPIC Stamp Edition contains built-in hardware components that are necessary for the acquisition and transmission of sensor data. The ToothPIC contains a microcontroller, A/D converters, ample memory, and a completely developed Bluetooth stack. The ToothPIC can also be powered by a simple 5V DC battery, allowing us to use a low-cost power source.

Secondly, the firmware to be developed on the ToothPIC can be programmed in C, which eliminates the ramp up time required to learn the language as the developers at Proximus are experienced in C programming.

Thirdly, the ToothPIC solution is PDIP packaged which makes it mountable onto a breadboard allowing for easy integration with sensor hardware. Furthermore, testing and debugging the hardware becomes a lot easier using a breadboard mounted approach.

Furthermore, since the ToothPIC module contains all the necessary components required for proper transmission, requirement R[110] clearly is met. In addition the module will be powered with a battery to comply with R[37/A].

The ToothPIC module provides an entire solution with integrated components and a quick-to-market development cycle that makes it ideal for Proximus to use under the strict time constraints.

4.3.1 PIC Microcontroller

The ToothPIC module has a PIC18LF6720 microcontroller where the bulk of the sensor data acquisition and management will occur on the sensor module. The PIC is a standard component available from Microchip Technology Inc. The microcontroller performs at 20 MHz, which is sufficient enough to acquire and process the ECG and Temperature data and pass it onto the Bluetooth interface to transmit to the DLM.

The memory available to store, process, buffer, and queue up data is composed of 128kB Flash, 3.5K Ram, 1K EPROM, and up to 512 kB I2C external memory.

Below is a diagram of the PIC18LF6720 in Figure 8.

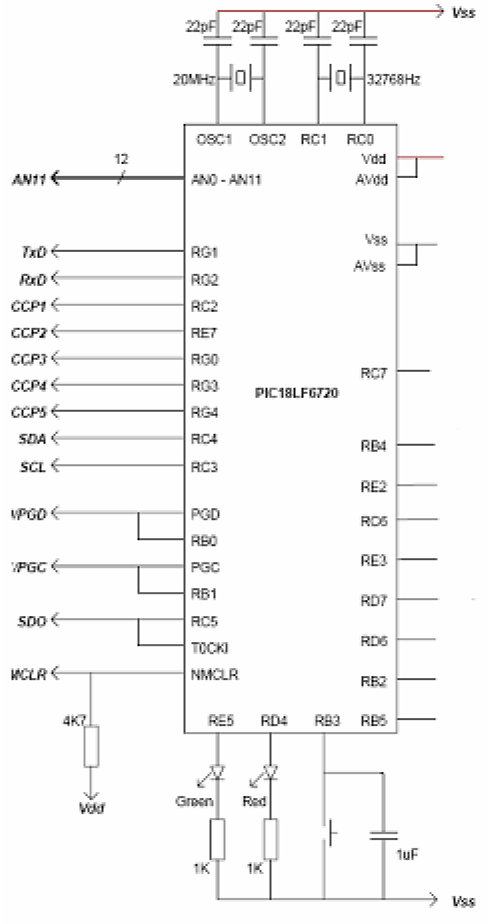

Figure 8: PIC18LF6720 Diagram

The PIC18LF6720 supports a serial UART interface. Pins TxD, RxD, CCP1-5, SDA and SCL are used as the communication from standard serial communication ports for development purposes. A further contributing factor in the decision of using ToothPIC is the provided simplicity of plugging the Serial UART into a DB9 connector for ease of connection to a computer for development.

4.3.2 A/D Converter

The A/D converter in the microcontroller converts the analog sensor measurements to digital values using one of the twelve on-chip 10-bit A/D converters. The incoming analog signal should be in the range of 0 to 5V for a successful A/D conversion. The sampling rate is customizable. For the ECG circuit to make an accurate signal, approximately 400 samples per second is required to create a clean digital output in order to comply with the resolution requirement R[31/B], and R[32/B].

The temperature readings will be converted at approximately 5 samples/sec. This coupled with the accuracy provided by the temperature circuit will comply with

R[35/A]. The digital signal output for the PIC processor is over a range between 0V and 1.8V.

A/D conversions are essential for the acquisition of analog signals in order to transmit them through a digital network.

4.3.3 Bluetooth Interface

The ToothPIC module contains a class 1 Bluetooth radio with 100m range which complies with R[105/B]. The module uses Bluetooth protocol V1.1. The Bluetooth RF frequency range is from 2.401GHz to 2.480 GHz segmented into 79 channels. The use of this frequency complies with R[116/A]. The communication latency via point to multipoint transfer is around 30ms to 50ms which complies with R[66/C]. The maximum data rate is about 50-90Kbaud. Figure 9, as shown below, illustrates the pin lay out of the Bluetooth module on the ToothPIC.

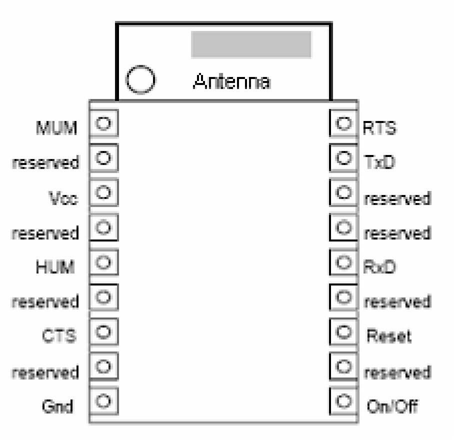

Figure 9: Pin Layout for BlueTooth Module on ToothPIC

The pin description is given below in Table 1.

Table 1: Serial UART

PIN Name	Description
TxD	Serial data output
RxD	Serial data input
CTS	Clear To Send: Flow control input to Bluetooth input. When low, Bluetooth will Output data on the TxD line.
RTS	Flow control output from Bluetooth. When high, do not send data to Bluetooth
HUM	Data type input to Bluetooth – Low to send AT commands, high to send data for Transmission.
MUM	Data type output from Bluetooth – Low if AT response message, high if received data.
Reset	Reset – Low to operate, high for at least 10ms to reset.
Vcc	5 V power supply peak requirement 250mA.

The Bluetooth module contains a link controller, which performs all the real-time functions of the Bluetooth baseband protocol layer including data transfer and connection management [1].

Another contributing factor in the decision of this module is that the entire Bluetooth stack has been developed for Proximus, leaving only the application layer to be developed by Proximus. This greatly reduces the time required to develop the firmware on the module.

4.3.4 Power Features

The ToothPIC's power consumption is dominated by the Bluetooth chip whose peak current consumption is 250mA during the transmission. The average current consumption will be considerably lower and will depend on Bluetooth usage. The ToothPIC can be powered with a 5V regulated input to the V_{DD} pin with a supply voltage of 4.5-5.5V. The ToothPIC will operate effectively down to 3V although class 1 Bluetooth performance is not guaranteed at this voltage. Alternatively, an unregulated input between 5V and 10V may be supplied to the V_{IN} where it will be regulated by a 400mA regulator. The maximum RF output power is 100mW or +20dBm. However when the range is limited to 10m in compliance with R[105/A], functional requirement R[114/A] is met as well as R[94/B].

The ToothPIC isn't the best solution for power consumption, due to the maximum power consumption of the module being 450mA. However, our power consumption will be well below this value as all the features of the ToothPIC solution are not being utilized. In addition, lower power consumption can be attained if a separate microcontroller and Bluetooth module are integrated together in a customized solution.

4.3.5 Bluetooth Stack

The ToothPIC developers, Flexipanel, have aided the development of the Bluetooth firmware by adding services. These services feature the Flexipanel server which creates user interfaces on multiple platforms including PCs. The services include such things as: Bluetooth communication, interrupt service routines, memory management, sleep-safe real time clock and calculator options already integrated into the firmware.

Implemented into this design, Flexipanel has also designed firmware called OpenTooth. This is a package that detects and recognizes Bluetooth devices within a 10m range, allowing OEMs to add Bluetooth capability to access control products. The advantage of having this firmware already implemented is that there is a great advantage in time-to-market information. The software already includes the Bluetooth protocol and stack. This is a key reason why this solution was chosen.

The firmware that is to be implemented can be developed using the OpenTooth development Kit [3].

4.4 DLM Hardware

Since the DLM hardware is composed of a laptop primarily, all the hardware required will be the same hardware supplied on a laptop. Furthermore, a standard point-to-multipoint Bluetooth adapter is plugged into the laptop via a USB interface. This acts as a multipoint Bluetooth receiver to receive all sensor data transmitted from the multiple sensor modules and transmit requests to these multiple sensor modules. This complies with requirements R[53/A] and R[56/A].

5 Bluetooth Communications Protocol

The wireless communication between the sensor bank and the DLM is a simplex transmission. A handshaking protocol has to be used in order to ensure no data is corrupt during transmission. The Bluetooth protocol has a unique way of identifying whether or not the data received is meant specifically for our application or other applications that may use the same frequency band for data transmission. Furthermore, the Bluetooth protocol has a means to error check to ensure that all data reaches the DLM uncorrupted. Therefore, since all communication between the sensor bank and the DLM is done using the Bluetooth protocol, the sensor module packet will be encapsulated within the payload section of the Bluetooth frame.

5.1 Bluetooth Packet Format

The Bluetooth protocol frame is shown in Figure 10.

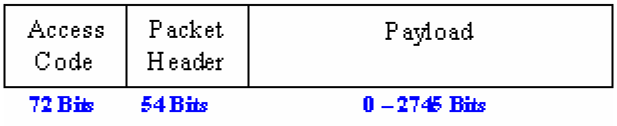

Figure 10: BlueTooth Frame

The access code is based on the master's identity and master's system clock, which provides a means for synchronization. The access code is unique for the channel being transmitted over, and all packets transmitted on the same channel will use this specific code.

The packet header contains error correction, retransmission, and flow control information. The error correction information is used to correct faults in the payload and header itself [2].

The payload portion of the packet is where the sensor module packet frame will be placed into.

5.2 Sensor Module Packet Frame

The sensor module packet frame is encapsulated within the payload of the Bluetooth packet as shown in Figure 11. The sensor module packet format is as shown below:

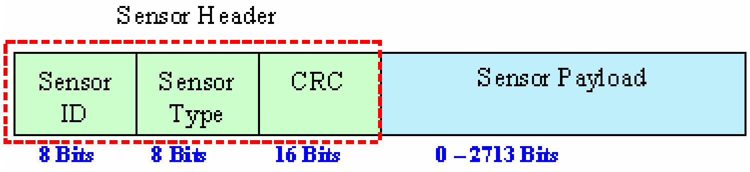

Figure 11: Sensor Module Packet Frame

The sensor ID is based on a numerical ID number that will be hard coded into the sensor module. This value will be used by the DLM to keep track of which sensors are connected to it, and will be of further use when the CLM will be incorporated into the system for phase two. A single byte has been allocated for this since the maximum number of Bluetooth devices windows will register using the point-to-multipoint Bluetooth receiver, is seven. Therefore each bit will represent a different sensor ID, with the most significant byte being reserved for a disconnect command that can be processed by the DLM in phase one, and also the CLM in phase two.

The sensor type will represent which type of sensor measurements is being transmitted. A pre assigned value will be given to the sensor indicating its type. For example, an ECG sensor could be denoted as having a sensor type of `0x01`, whereas a temperature sensor could be `0x02`. A single byte has been allocated for the sensor type field as the maximum number of sensor types that will be supported by the WMS will be `255`.

The CRC portion of the packet will contain a checksum for the sensor payload portion of the packet. The CRC will be used to carry out error checking on the DLM side of the system, and will later be used to carry out error checking on the CLM side of the system for phase two. The algorithm used to calculate the CRC over the sensor payload is illustrated, in Figure 17, in section 6.3.

The sensor payload contains the digitized raw sensor data that will be transmitted to the DLM. Once transmitted, this data will be processed and displayed.

6 Software

The overall design for the software of the system is shown below in Figure 12. The software has been designed to be modular, making it easy to develop in an object orientated way. Furthermore, the flow of data has been illustrated clearly in the diagram. The different modules in the diagram will be described clearly in subsequent sections.

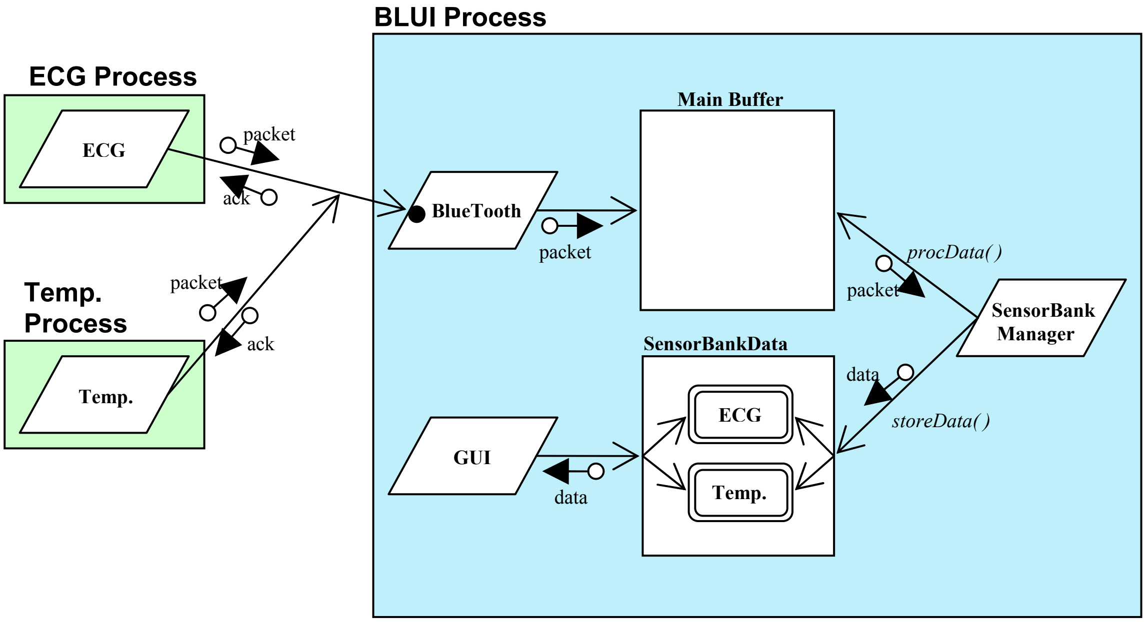

Figure 12: Phase One Collaboration Diagram

6.1 Sensor Module

The firmware on the sensor module is only responsible for getting the sensor readings taken by the sensor, encapsulating these readings into the sensor module packet format, and transmitting these packets via a Bluetooth link to the DLM. Below, in Figure 13, the software design of the sensor module is illustrated in a flowchart.

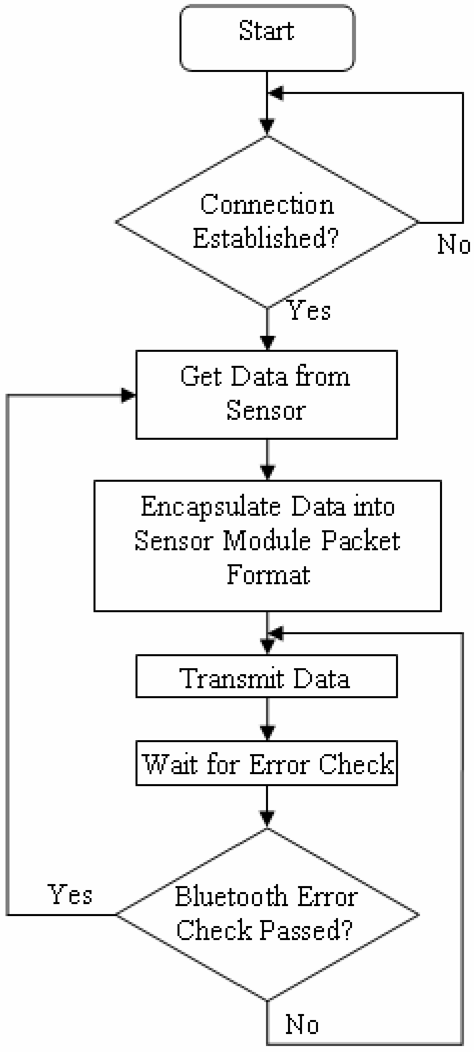

Figure 13: Sensor Module Flowchart

6.2 Data Logging Module

The main purpose of the DLM firmware is to receive data simultaneously from multiple sensors and place it into a buffer for the software on the DLM to process and display. Figure 14, as shown below, illustrates the receiving algorithm used on the DLM to gather the data and place it into a main buffer.

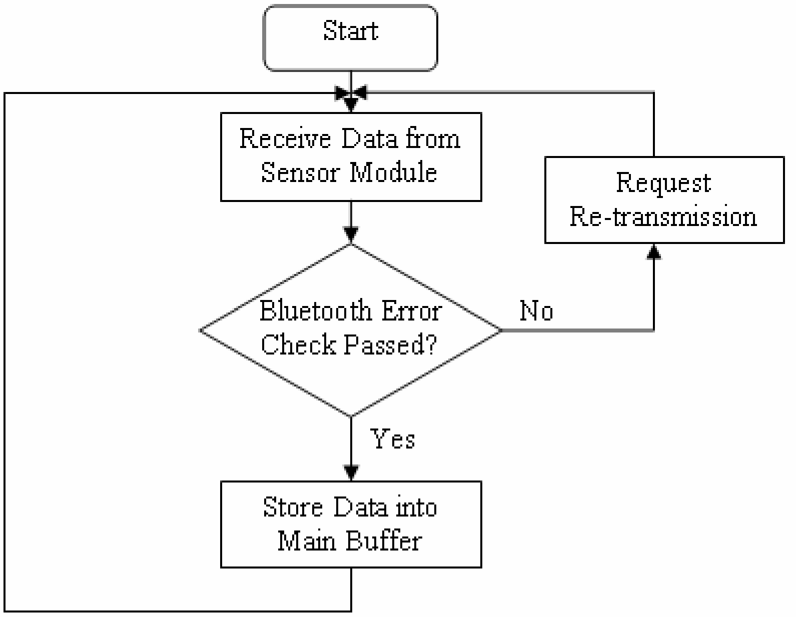

Figure 14: Flowchart for Data Receiving Algorithm via BlueTooth Link

Once the data has been placed into the main buffer, a processing thread takes the data and strips off the sensor module packet format headers and places the data into designated buffers corresponding to the sensor ID within the sensor module packet format header. Further processing is conducted on this data depending on the sensor type, in order to put it into a more displayable format.

Once the data is formatted, the GUI displays the data from the designated buffers. Figure 15, as shown below, illustrates the processing and displaying of data by the DLM.

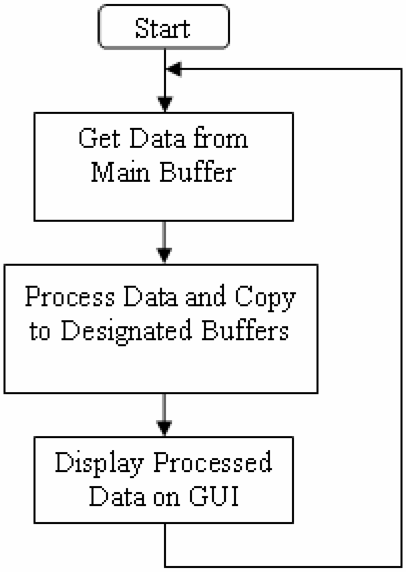

Figure 15: Flowchart Illustrating Processing and Displaying of Sensor Data

The DLM firmware has the functionality to establish a connection with additional sensors as desired by the medical staff. When a sensor is added to the list of sensors to monitor, an interrupt is fired that will jump into a service routine where a connection will be established with the sensor module being added. Figure 16, as shown below, illustrates this interrupt service routine.

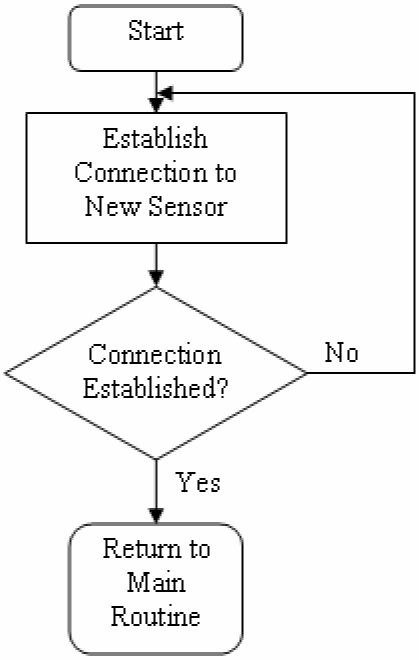

Figure 16: Sensor Addition Interrupt Service Routine

6.3 CRC Algorithm

The algorithm designed to calculate the CRC is implemented on both the sensor module, and the DLM. On the sensor module, the CRC is calculated over the sensor data stored in the sensor payload. On the DLM, the same calculation is performed and compared with the CRC value that's calculated on the sensor module. If both values are equal, than the data received from the sensor module is intact. The algorithm designed to calculate the CRC is illustrated below in Figure 17.

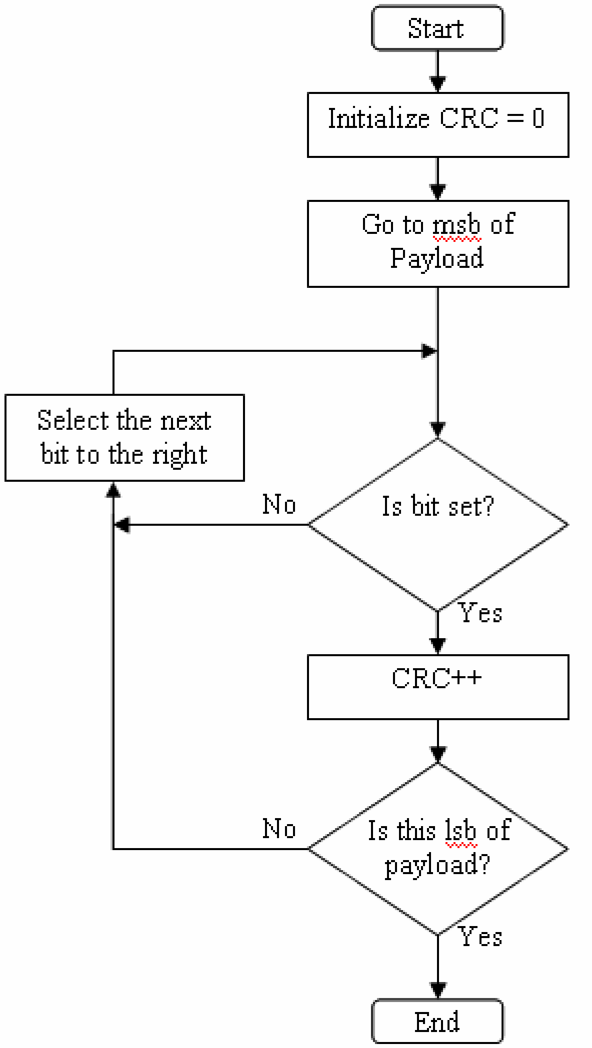

Figure 17: Algorithm Design for CRC Calculation

7 User Interface

7.1 DLM Graphical User Interface

The GUI designed for phase one is for the DLM. The purpose of the GUI is to display all the sensor data in a clear and concise manner for medical staff to analyze while local to the patient. MFC is used to develop the GUI. A screen capture of the GUI designed is shown below in Figure 18.

Figure 18: Screen Capture of DLM GUI

A global set of menus is provided to allow the user to select various options provided to them. One functionality of these menus will be that it will allow medical staff to add additional sensors to be monitored by the DLM, thus creating multiple sub-windows. This is in compliance with R[83/A]. Additional menus will be added during development when the need arises.

A sub-window is created for each sensor connected to the DLM via the Bluetooth link. Each sensor sub-window will be placed vertically below the previous sensor sub-window. This approach ensures that the readability of the sensor data will not be compromised and cluttered with unnecessary complexity. The eyes will naturally fall from top to bottom of the display. When more sub-windows are created than can be displayed on screen at one time, a vertical scroll will allow the user to scroll down to view other sub-windows in order to analyze sensor measurements.

The maximum number of sub-windows that will exist at any time is seven. This is in compliance with Windows only recognizing a maximum of seven Bluetooth devices connected to it at once via the point-to-multipoint Bluetooth adapter. At the bottom of the GUI, a status indicator will exist illustrating how many sensors are being displayed currently and what the maximum number of sensors is that can be displayed at once. This is in compliance with R[79/A].

A menu will be provided for each sub-window to allow medical staff to access settings for the display such as toggling between analog and digital display, scale of the axis, and precision of digital display. An additional option will be available for medical staff to select a combination of both a digital and analog display. This will be of use for sensor readings such as temperature. The digital display will provide an instantaneous quantitative measurement; where as an analog display will provide the temperature over a range of time. The analog and digital display formats have been designed in order to comply with R[75/A], R[76/A], and R[77/A].

The analog display for the GUI will express the time axis as the horizontal axis, and the sensor measurement placed on the vertical axis. The values will be of increasing order from left to right, and bottom to top on both axes respectively. This follows common convention of displaying graphical data.

Additionally, the size of the analog and digital display is such that medical staff can view it clearly from the foot of a patient’s bed. This is in compliance with R[74/A].

The various options available to the user via the menus can be accessed either by mouse or the keyboard attached to the DLM. This complies with requirement R[80/A].

The basis for the design of the DLM GUI is to ensure maximum readability while maintaining a clear and concise format of display for local analysis.

7.2 Sensor Module User Interface

The user interface for the wireless sensor module is quite simple, with a visual indicator LED that remains lit when the device is in use and data is being transmitted. Consequently, when no data transmission is occurring the LED will not be lit. This design complies with R[44/A].

In addition, a single button will be available to toggle the sensor module on and off. The user interface is designed so that the user can operate the sensor module with a single hand. This is to comply with R[43/A].

The basis for the design sensor module user interface is to maintain simplicity and ease of use for the user. The design of the user interface for the sensor module complies with R[45/A].

8 Test Plan

This section outlines the testing for the WMS.

8.1 Sensor Tests

Test Number	*Description*	Functional Specification
1	The sensors will be attached to a test subject and the output will be monitored over one hour while the test subject moves around. The readings will be monitored to ensure that they are not distorted over that time by the movements and skin secretion.	**R[28/A]**
2	The wireless sensors will be tested in a refrigerator and oven to make sure that the sensors are working properly at 0-45 ˚C.	**R[36/A]**
3	Ensure that the data indicator lights up when the data is being transmitted.	**R[44/A]**
4	The sensor modules will be tested through a selected range of weather conditions to ensure that it operates correctly in varied humidity conditions.	**R[24/A]**

8.1.1 Temperature Sensor

5	Temperature readings from the sensors will be compared with various environments temperature samples to ensure that the readings are accurate.	**R[29/A]**
6	The temperature sensor will be attached to a test subject and the temperature will be monitored as the patient moves through various environments with different temperatures to ensure that the sensor has low sensitivity to temperature variance.	**R[30/A]**

8.1.2 ECG Sensor

7	The sensors will be attached to a test subject	**R[28/A]**

	and the output will be monitored over one hour while the test subject moves around. The readings will be monitored to ensure that they are not distorted over time by movement and skin secretion.	
8	A 300 Hz signal will be applied with amplitude of 2 mV to the ECG pads and ensure that the circuit detects it.	**R[31/B]** **R[33/B]**

8.2 Wireless Transmission

Test Number	*Description*	Functional Specification
9	A data request message will be sent from the DLM via Bluetooth to the sensor module. Upon receiving this request the sensor module will transmit a bit-stream to the DLM. This will verify that we have a reliable communication channel and that the data received is correct.	**R[52/A]** **R[53/A]** **R[122/A]** **R[123/A]**
10	While one sensor is communicating with the DLM, communication will begin with the second sensor to ensure that the data received from each is valid. Next, the first sensor will be disabled to ensure that this does not interrupt the communication between the DLM and the second sensor.	**R[11/B]** **R[13/A]** **R[14/A]** **R[112/A]**
11	Communication will be initiated between two sensor modules and the DLM to verify proper operation of the life of one battery.	**R[17/A]**
12	A data request will be sent from the DLM to a sensor module. After receiving the data, another data request will be sent to ensure that the data received is the same as before. At this point, a data acknowledge message will be sent to the sensor module, followed by another data request to verify if the data has been replaced. This will ensure that the sensor module only deletes data when it receives a data acknowledge message.	**R[49/A]** **R[50/A]** **R[53/A]**
13	Wireless communication will be initiated	**R[105/B]**

	between the DLM to the sensors to verify that communication persists between the DLM and sensors, while the distance between them is varied from 0 to 10 meters.	

8.3 Data Logger

Test Number	*Description*	*Functional Specification*
14	A sine-wave of 300 Hz with amplitude of 2 mV will be transmitted from a sensor module to the DLM to ensure that it can be displayed properly.	**R[31/B]** **R[33/B]**
15	During normal operation tests will be conducted to see if the data sent by the sensors is received by the DLM and is displayed properly.	**R[61/B]**
16	A circular buffer will be filled with known values on both the sensor module and the DLM. For one hour data requests will be made from the DLM to the sensor to ensure that the data received is the correct value expected from the circular buffer. A running tally will be kept of the number of transmissions that were correct vs. incorrect to verify our desired accuracy.	**R[67/A]**
17	The DLM will be placed in a refrigerator and an oven to verify that it operates correctly from 0-45 ˚C.	**R[68/A]**
18	The DLM will be tested through a selected range of weather conditions to ensure that it operates correctly in varied humidity conditions.	**R[69/A]**
19	Patient temperature, ECG and pulse rate will be verified on the DLM display from a distance of10 meters.	**R[74/A]** **R[75/A]** **R[76/A]** **R[77/A]**
20	Verify that the display correctly identifies the number of sensors that are attached.	**R[79/A]**

21	Tested in Test 1	**R[86/A]**
22	Verify that when the DLM receives incorrect data it asks for a retransmission of the data.	**R[93/A]**
23	Verify that sensors can form a wireless connection to the DLM from a distance of 10 m.	**R[94/B]**

9 Conclusion

The design specifications provided in this document describe the tentative design for phase one of the WMS. Although some design decisions may change as the development proceeds, this document will nevertheless act as a clear basis for design and will be modified as necessary.

Development of phase one is intended to be completed by April 2006, when a proof of concept device will be fully functioning as described in our functional specifications [12].

Further information regarding all aspects of the WMS can be acquired from our CEO, Zues Rawji, at zrawji@sfu.ca.

10 References

BlueTooth

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