February 26th, 2008

Mr. Patrick Leung
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
V5A 1S6

Re: ENSC 305/440 Design Specification for Heart Rate and Motion Monitoring System

Dear Mr. Leung:

The attached document below presents the design specification for the heart rate and motion monitoring system, implemented through ENSC 440, The Capstone Project course. The objective for this device is to monitor and analyze the healthiness of the heart through the use of heart rate and body position. The target consumer can be of all ages.

The design specification, mainly intended for Corazon team members will act as a functional checklist for our prototype device, which will be completed by end of the 2008 spring semester. Along with the general device design details, specific component design including the heart rate sensor, motion sensor, microcontroller unit, Symbian application, and test plan will also be provided in the document.

Corazon Engineering Inc. is composed of four dedicated 5th year engineering students: Michael Mao, Benny Hung, Phillip Lin, and Thomas Cho. If there are any questions or comments about our proposal, feel free to contact Michael Mao by phone at (604) 782-5636 or by e-mail at mmao@sfu.ca.

Sincerely,

Michael Mao

CFO of Corazon Engineering Inc.

Enclosure: Design Specification for Heart Rate and Motion Monitoring System

Corazon Engineering Inc.

# Design Specification

## Heart Rate and Motion Monitoring System

| | |
|---|---|
| Project Team Members: | Benny Hung<br>Michael Mao<br>Thomas Cho<br>Philip Lin |
| Project Leader: | Benny Hung, CEO<br>bennyh@sfu.ca |
| Submitted To: | Patrick Leung – ENSC 440<br>Steve Whitmore – ENSC 305 |
| Date Issued: | March 2, 2008 |
| Revision | 2.4 |

# Executive Summary

Modern day technology for medical and health monitoring devices are nowhere near the state of technology in consumer products.  Due to an increasing number of retirees (Baby boomers) and the high cost of medical related products and services, a huge market demand for low-cost medical/health monitoring devices exists in today's society.  Heart related disease; the number one killer in developed nations possesses a great threat to the health of our society both directly and indirectly from economical, environmental, political, and other aspects.  Our proposed Heart Rate and Motion Monitoring System (HRMMS) can help the general public with the awareness and prevention of heart related diseases in its early phase by analyzing heart rate with respect to the physical activity of users.  Irregular heart conditions can be sent to medical practitioners remotely through a custom application on the user's cell phone.

According to the functional specification, the HRMMS prototype device's primary functionalities are defined below:

- Ability to detect various static physical positions such as standing, sitting, lying up to four sides, etc.
- Ability to distinguish between passive (static position) and active (moving) activity during monitoring in real time.
- Ability to detect and calculate heart rate during static and dynamic positions.
- Ability to transmit heart information through a mobile device to user's cell phone using Bluetooth

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# Glossary

| | |
|---|---|
| **AC** | Alternative Current |
| **ADC** | Analog to Digital Converter |
| **API** | Application Programming Interface |
| **BPM** | Beat Per Minutes |
| **DC** | Direct Current |
| **ECG** | Electrocardiogram |
| **IDE** | Integrated Development Environment |
| **GUI** | Graphical User Interface |
| **HRMMS** | Heart Rate Motion Monitoring System |
| **SNR** | Signal-to-Noise Ratio |
| **MCU** | Microcontroller Unit |
| **OS** | Operation System |
| **PCB** | Printed Circuit Board |
| **UART** | Universal Asynchronous Receiver/Transmitter |

# 1 Introduction

The ability to detect heart rate with respect to test subjects' physical position can provide important information regarding to the subject heart's state of health. Corazon's solution is to develop a stand-alone device which will allow test subjects to attach two sensors to their body, one on the torso and another on the leg. These sensors will monitor the heart rate and position of the user and send data back to a processing unit carried by the user. The processing unit can then send monitored heart information via Bluetooth to a cellular phone. A customized software application running under Symbian OS on the phone will send data to specific locations such as the hospital or family physician office according to user's preference. Corazon Heart Rate and Motion Monitoring System's design specification, from the overall device to individual module's specific design details, motivations, and reasons are listed below in this document.

## *1.1 Scope*

This design specification will be used concurrently with the function specification throughout our product implementation timeline. The details for "the prototype device" and "the prototype and retail product" will be discussed. Reasons and motivations of our design, which matches the [RX – I] and [RX – II] requirements within our functional specification document will be justified.

## *1.2 Intended Audience*

This design specification document is intended for all members of the Corazon Engineering team. Each member of the team will develop the modules that they are responsible for and to ensure the final prototype product is implemented using design techniques listed in this document.

# 2 Overall System Design

The overall design specification for our heart rate and motion monitoring system (HMMRS) are categorized into the following subsections: Mechanical design, high-level system design, communication device consideration, electronic design, safety consideration, and PCB design and system reliability.  The prototype device will meet all of the class I and II requirements stated in our functional specification document.

## *2.1 Mechanical Design*

The figure below shows the “heart” of our HRMMS device.  The dimension of the device follows the functional specification requirement [R4-I].


**Figure 2-1 HRMMS Main Device**

Figure 2.1 above contains the following components of the HRMMS:

- Microcontroller Unit
- Heart rate sensor
- Bluetooth Module
- Power regulating circuit

The motion sensors and the heart rate sensor will be attached to the human body with flexible connectors leading back into the HRMMS main device shown in figure 2-1.

## 2.2 High Level System Design

The diagram below shows the overall HRMMS high level architecture design.

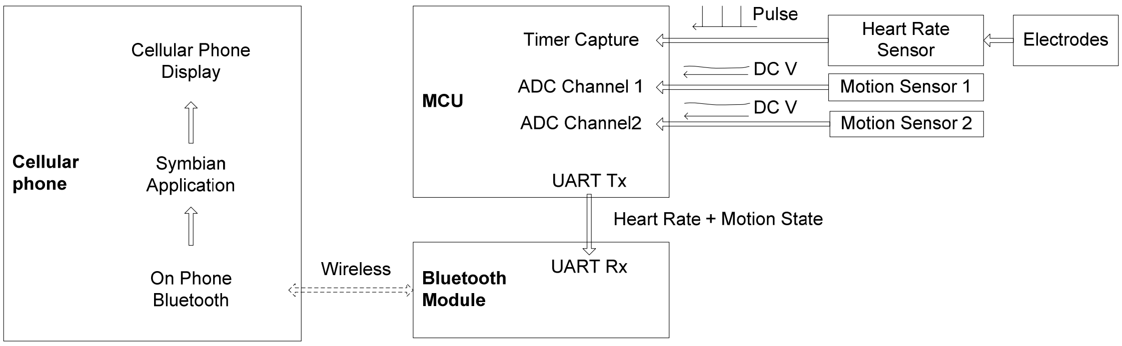


**Figure 2-2 HRMMS High Level Architecture Design**

Starting from the right side of figure 2-2, the electrodes pick up analog signal which will be conditioned by the heart rate sensor. The heart rate sensor then changes the signal into a pulse form to be used for the input of the timer capture of the MCU. The motion sensor directly outputs analog voltage data into the ADC channels of the MCU. The MCU calculates the heart rate and the motion state and transmits these two pieces of information to the Bluetooth transmitter module for wireless transmission. The Bluetooth receiver on the cellular phone will then capture the heart rate and motion state values and display them on the custom Symbian application.

## 2.3 Communication Device Consideration

Our final product requires the user to control the device using a cell phone. The most convenient and widely used short-range wireless communication standard for cellular device is Bluetooth. There are also many Bluetooth development modules available in the market.

## 2.4 Electronic Design Consideration

To build HRMMS with the lowest energy consumption and the best achievable operating reliability, choices for electronic components are made upon those two design criteria. For example, the choice for amplifiers has to be low power and low noise. Second, for designing a voltage regulator, high efficiency is the first consideration in order to provide suitable voltage to the circuits without draining excessive amount of power from the battery.

Since, HRMMS is designed to be used in motion, at anywhere, and at anytime, the electronic system has to achieve high system performance reliability under all operating environment. In a real operating environment, there are many factors that influence the system's performance. For example, temperature affects the operating speed, EMI and RF interference affect signal quality, and moisture oxidizes and shorts electrical contacts. The solutions to the above issues, first, electronics components such as amplifiers need to be able to operate between -40 °C and 50 °C. Second, analog filters and RF shields need to be applied to the system to reduce the effect of EMI and RF interference. Last, water resistant coating needs to be applied to all electrical contacts to repel any moisture that might damage the circuit.

### *2.5 Power Supply*

Power supply circuit for HMMS system regulates voltage and current for the heart rate sensor circuit and the micro-controller unit. To provide sufficient amount of current and appropriate level of voltage is the main criterion for designing a suitable power supply circuit for HMMS system's use. Moreover, power consumption is essential for designing a reliable and long-lasting system, and therefore, a switching regulator is favored over linear regulators. The design is shown below

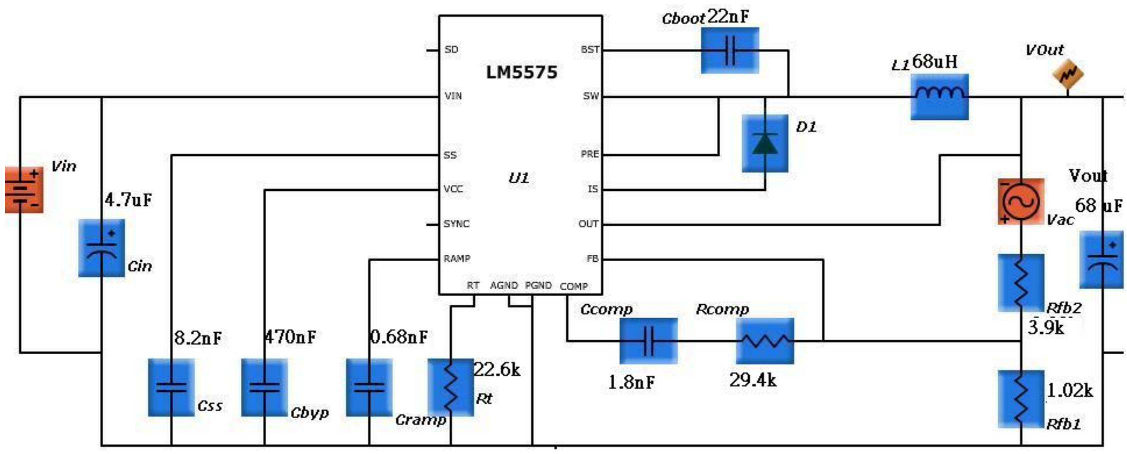


**Figure 2-3 Schematic for Switch Regulator Circuit [7]**

The above design is a step down regulator that provides 6 V and 0.75 A to 1.5 A of current and has an efficiency rating of 90%. The ECG conditioning circuit draws at least 10 mA of current, and the micro-controller requires current no more than 300 mA. Therefore, this switching regulator circuit is sufficient for HMMRS system's need.

### 2.6 Safety Consideration

Since part of the HRMMS will be attached to human body, safety is a very important factor during our device design. To protect both the user and the device, the entire microcontroller module, heart rate detection module, power regulator circuit, and Bluetooth communication module are packaged together within a plastic enclosure. All of the connecters are designed such that all metal portions are isolated with non-conductive materials, including: rubber, heat-shrink, epoxy, and various types of tapes.

The current limitation of electrical devices that are in contact with human body is 50 mA. This is achieved since the motion sensors have a maximum current rating of 1.5mA and the main module is packaged within a plastic encasing that isolates the circuitries from the test subject.

### 2.7 PCB Design and System Reliability

All of our circuits are designed using surface mount components on PCB. This decreases the size of our device, since the HRMMS is designed to be mobile and portable. However, the drawback of using surface mount components is the component mounting. Since most of the surface mount components are very small in size, the error rate of creating the circuit boards and mounting the components on the board will be higher than using normal through-hole components. The alternative solution is to send the final board design file to a 3$^{rd}$-party circuit board manufacturer.

# 3 ECG Heart Rate Sensor

The ECG heart rate sensor is used to detect and condition the heart rate signal. This section demonstrates the design approach to extract and to condition the ECG signal. Due to the power consumption and operating temperature requirement, AD623 is the instrumentation amplifier of choice. All the operational amplifiers used in the filter design are LM258 low noise low power amplifiers.

## *3.1 General ECG Signal*

Figure 3-1 below shows a cycle of a general heart beat pulse. ECG signal can be extracted by placing two electrodes across left side of the chest near the sternum. In general, ECG has amplitude of 1 mV and has the pulse width between Q and S of 40 milliseconds.

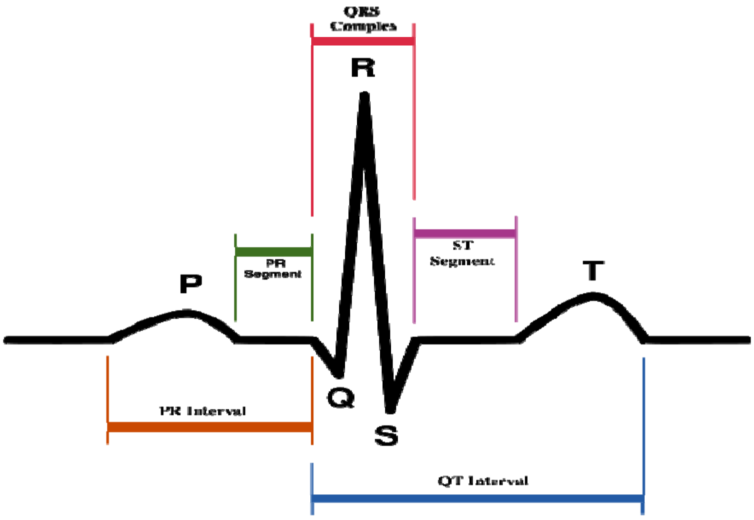


**Figure 3-1 General ECG Waveform [5]**

The above ECG waveform is the time domain representation. To design a circuit to extract the ECG waveform, it is crucial to clearly understand the frequency components which make up an ECG waveform. Therefore, FFT method is used to monitor the waveform in frequency domain.

The frequency response of ECG waveform is shown in Figure 3-2 below:

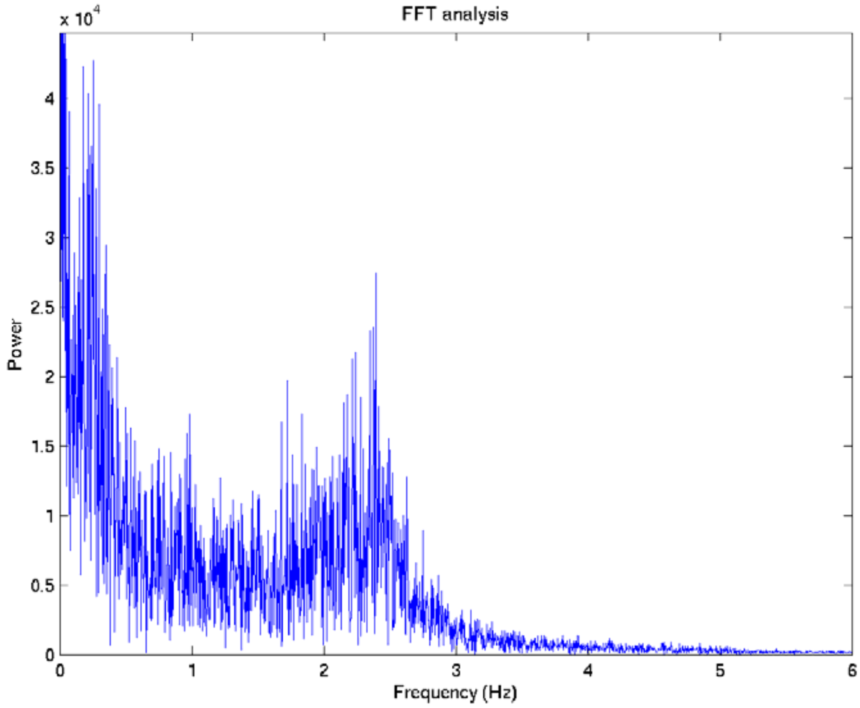


**Figure 3-2 FFT of ECG Waveform [6]**

Practically, for diagnostic purposes, ECG's frequency response is between 0.5 Hz and 100 Hz. The design of the heart rate sensor circuit is based on two major criteria, signal strength and signal clarity. Therefore, amplifiers will be used to amplify the 1 mV ECG and analog filters will be used to reduce noises outside of the ECG frequency band. The design block diagram is illustrated below:

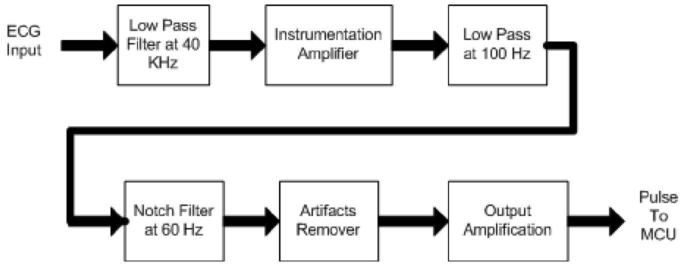


**Figure 3-3 Functional Block of Heart Rate Sensor**

Each of the functional blocks will be elaborated in the later sections.

### 3.2 Amplifier Design

According to figure 3-3, the instrumentation amplifier is used for extracting and amplifying the potential difference of the two electrodes attached to the user's chest. This potential deference is referred to as bio-potential or ECG to be exact. The design for the instrumentation amplifier and its low pass filter input stage are shown below:

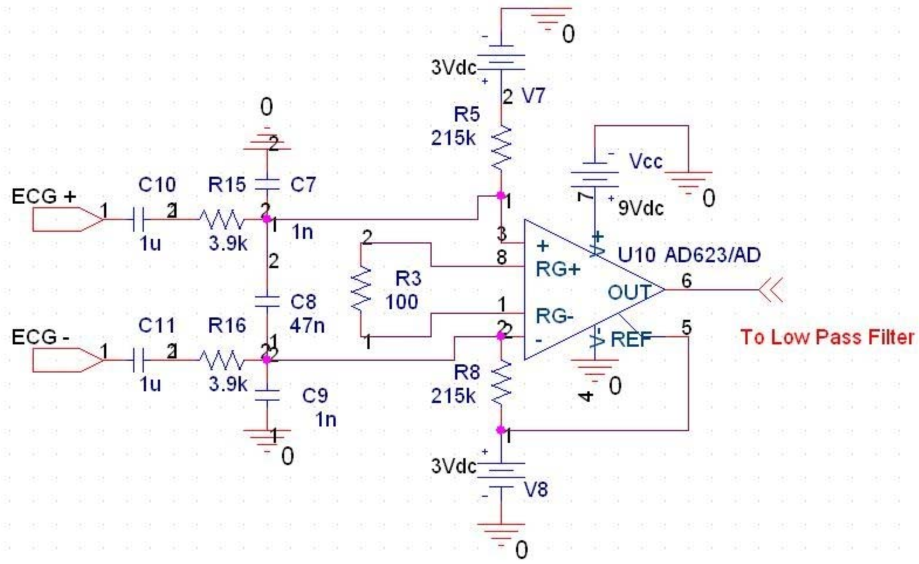


**Figure 3-4 Schematic for Instrumentation Amplifier**

This circuit can be divided into two parts, low pass filter and instrumentation amplifier. The low pass filter formed by R15 and C7 is the same for the two input leads, ECG+ and ECG-. The low pass filter has equation:

$$Fc = \frac{1}{2\pi RC} \quad \text{Eq. 3-1}$$

with such a configuration in our design, the cut-off frequency Fc, is designed to be at 40 kHz. The purpose of this is to reduce the radio frequency and magnetic interference noises, raging in MHz and GHz range. The capacitor, C8, bridging the two low pass filters is used for further reducing the high frequency noises and reject the common mode signal of the ECG.

The instrumentation amplifier, as mentioned previously, amplifies the potential difference of the ECG. AD623 has a gain in the following equation:

$$G = 1 + \frac{100K}{R3} \quad \text{Eq. 3-2}$$

In our case, to improve the signal strength of ECG, R3 is chosen to be 100 to yield a gain of 1000. This gain allows the ECG to be within 1 or 2 volt range to improve signal-to-noise ratio (SNR).

## 3.3 Filter Design

Analog filters are essential for providing quality heart beat signal. In the real operating environment, there are many ambient noises such as EMI, power supply noise, and RF noises. Both EMI and RF noises can be easily attenuated with low pass filter.

Low power consumption is the major design criteria for HMMRS' electronic system, so it is important to use the minimum number of electronic components such as amplifiers to achieve the highest system performance. For example, to design an effective analog filter, high order filters are favored. However, due to power consumption constraint, Sallen Key filter is one of a few configurations that allow us to build second order filters with a single amplifier. We will implement our low pass filter as Sallen Key configuration, and the schematic is shown as follows:

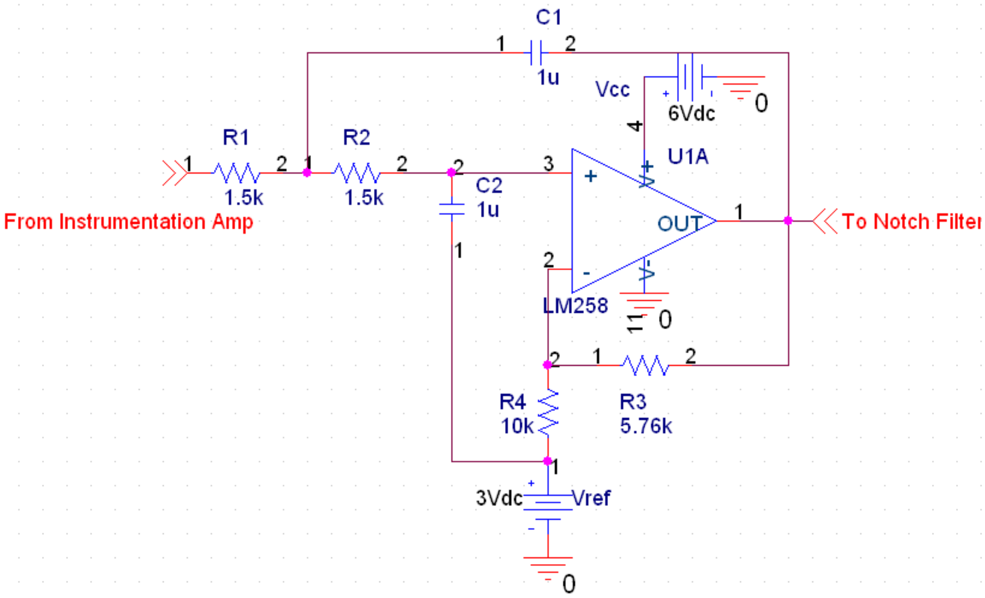


**Figure 3-5 Schematic for Sallen Key Low Pass Filter**

There are two design considerations, the stability and the quality factor. Our objective is to design for highest possible quality factor with a stable filter. R1, R2 and C1, C2 are picked to have the same values for ease of calculation.

The transfer function for the Sallen Key low pass filter is in the following equation:

$$H(s) = \frac{K}{S^2(R^2C^2) + S(2RC + RC(1-K)) + 1} \quad \textbf{Eq. 3-3}$$

,where

$$K = 1 + \frac{R4}{R3} \quad \textbf{Eq. 3-4}$$

For the system to be stable, the following equation has to meet:

$$2RC + RC(1-K)) << 4(R^2C^2) \quad \textbf{Eq. 3-5}$$

On the other hand, the quality factor can be calculated as in the following equation:

$$Q = \frac{1}{3-K} \quad \textbf{Eq. 3-6}$$

In this case, with the resistors values available, to pick the K for the highest quality factor possible with a stable design, K is chosen to be 1.736 with R4 being 10K and R3 being 5.76K. Based on the resistor and capacitor values chosen for the design, the theoretical cut-off frequency is calculated with Eq 3.1 and yields $F_c$ of 106 Hz. PSPICE is also used to simulate the frequency response for ease of illustration.

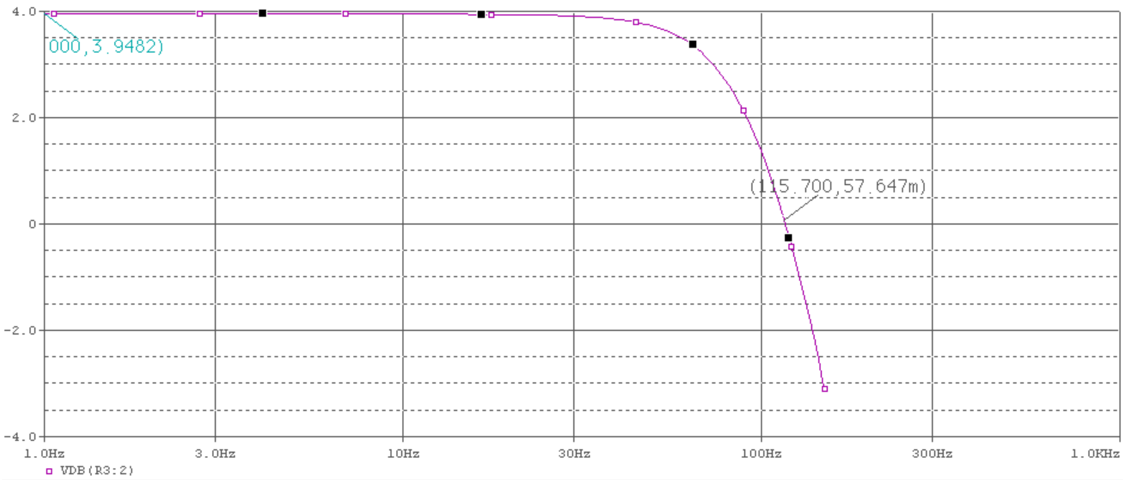


**Figure 3-6: Frequency Response of Sallen Key Low Pass Filter**

To illustrate the stability of this Sallen Key low pass filter, root locus method is applied along with MATLAB. This analysis is based on the transfer function shown in Eq. 3.3 with the K equals 1.736. The result is shown as follows:

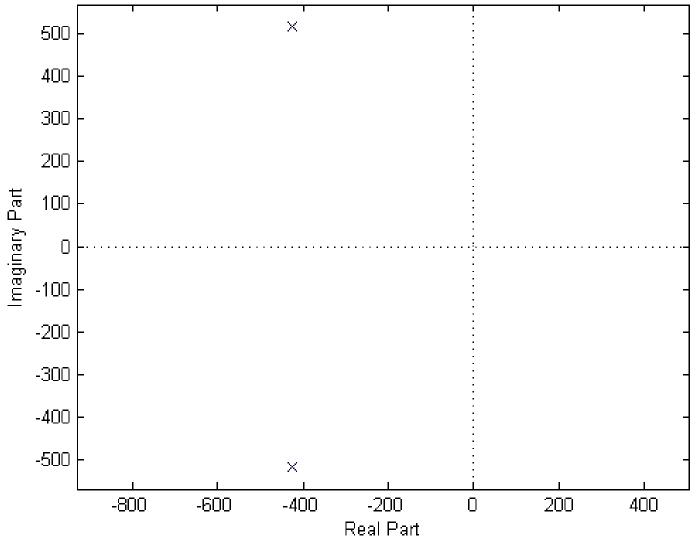


**Figure 3-7 Root Locus for Sallen Key Low Pass Filter**

As shown in the above figure, both of the poles for this low pass filter's transfer function are on the left hand side of the imaginary axis. This implies that this filter is stable.

Reducing the EMI and RF interference can be accomplished by applying low pass filtering. One other major interference in the HMMRS is the power supply noise or the AC noises, locates at 60 Hz. This noise falls into the bandwidth of the heart beat signal and contributes to the most distortion to the heart beat signal. Therefore, to reduce the power supply noise without further attenuating the heart beat signal, a notch filter with a cutoff frequency of 60 Hz is favored.

For this particular notch filter design, Sallen Key configuration is also the choice due to power consumption issue mentioned earlier. The schematic shown in figure 3-8 is the Sallen Key notch filter with the cut-off frequency of 60 Hz.

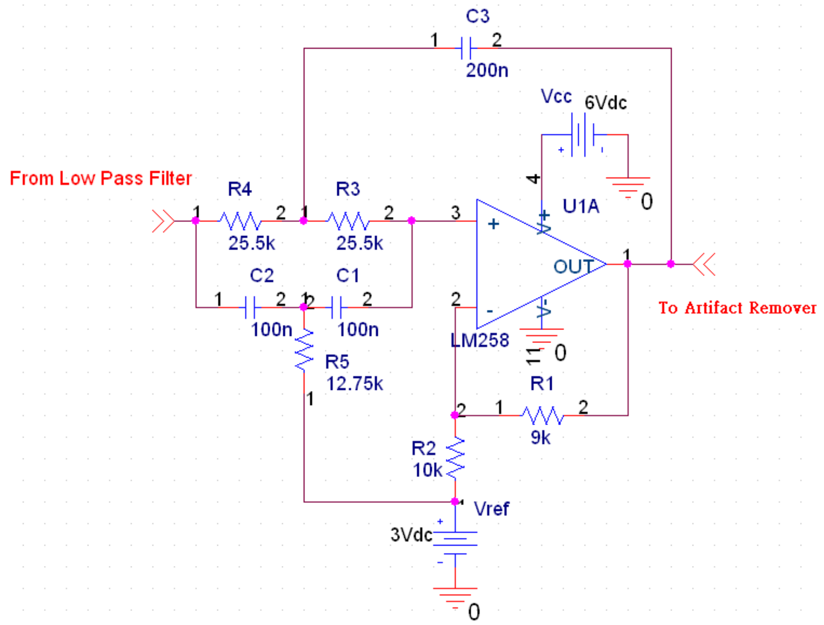


**Figure 3-8 Schematic for 60Hz Notch Filter**

Eq.3.1 is used to calculate the cut-off frequency, where in the equation, R is 25.5 kΩ and C is 100 nF. The cut-off frequency is calculated to be 62 Hz.

Because this notch filter is based on the Sallen Key configuration, stability consideration is the same as that of the Sallen Key low pass filter. R1 and R2's values are chosen to provide the biggest quality factor and the most stable system. PSPICE simulation is also performed based on this particular design, and the result is shown below:

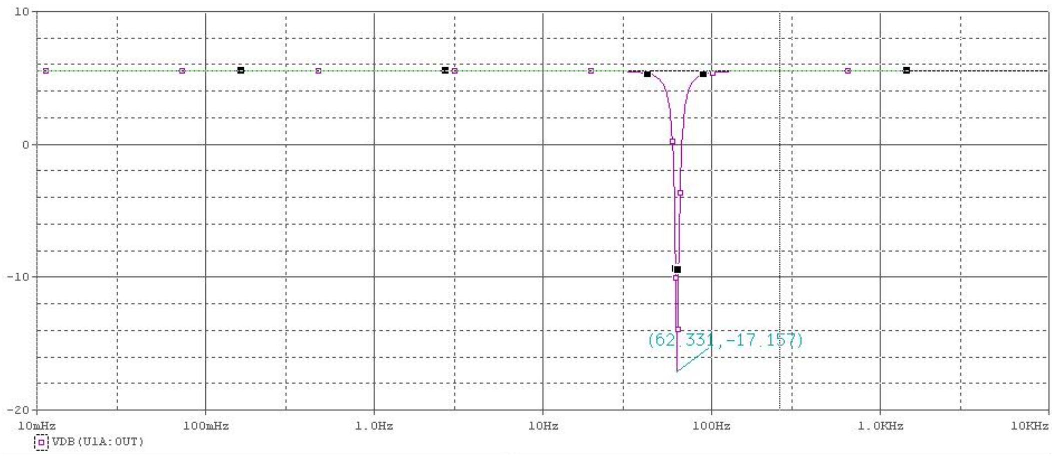


**Figure 3-9 Frequency Response for Notch Filter**

According to PSPICE simulation, this design allows us to achieve around 20 dB attenuation at 62.33 Hz. Therefore, this design is suitable for HMMRS system.

Prior to reducing all the power noise and interference which degrades the ECG signal quality, ECG signal also needs to be unaffected and undistorted during motion. This artifact can be fixed by the artifact remover circuit shown below:

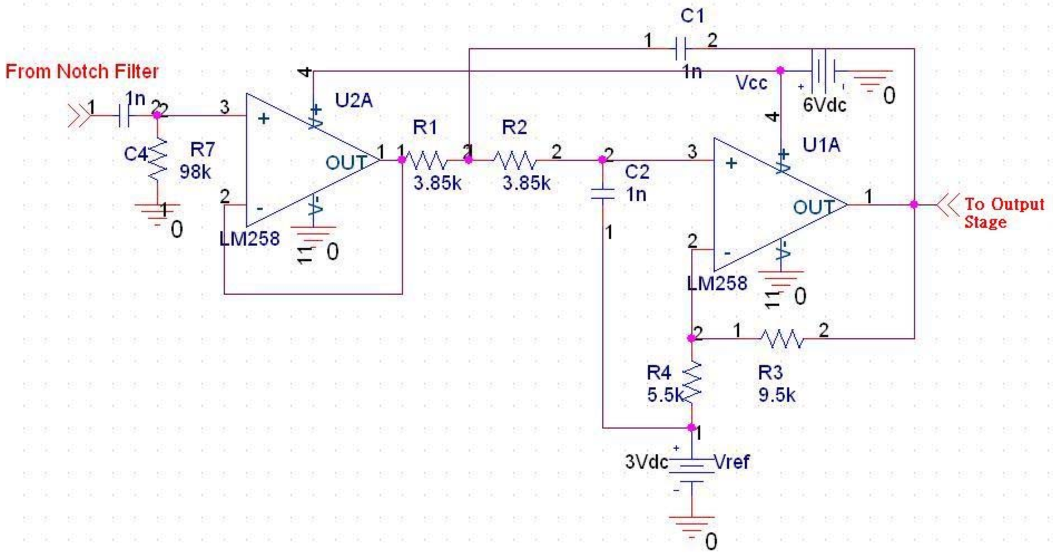


**Figure 3-10 Artifact Remover**

This artifact occurs at low frequencies less than 1 Hz and higher than 40 Hz. With the frequency band above, sufficient ECG information can still be accurately interpreted. The high-pass filter is designed to have a $F_c$ of 1 Hz. The low pass filter with a cut-off frequency at around 40 Hz is connected in cascade. This artifact remover will turn the ECG signal into a series of heart rate pulses.

The heart rate pulses are then amplified at the output stage to have a magnitude of 3.3V with an amplifier and a buffer. The finalized signal will be used for the MCU to detect and digitally process the signal.

### 3.4 Electrode Placement

The electrocardiogram (ECG) records the electrical activity of the heart over time. Since our heart rate detection is based on this technique, the electrodes will need to be placed across the subject's heart. The general accepted practice of ECG electrode placement location is very specific. This is because medical practitioners need to evaluate the morphology of the ECG signal, but for our device the details of the morphology is not needed to detect the heartbeat pulse. As long as the electrodes are placed across the heart, the activity detected is sufficient enough to calculate the heartbeat.

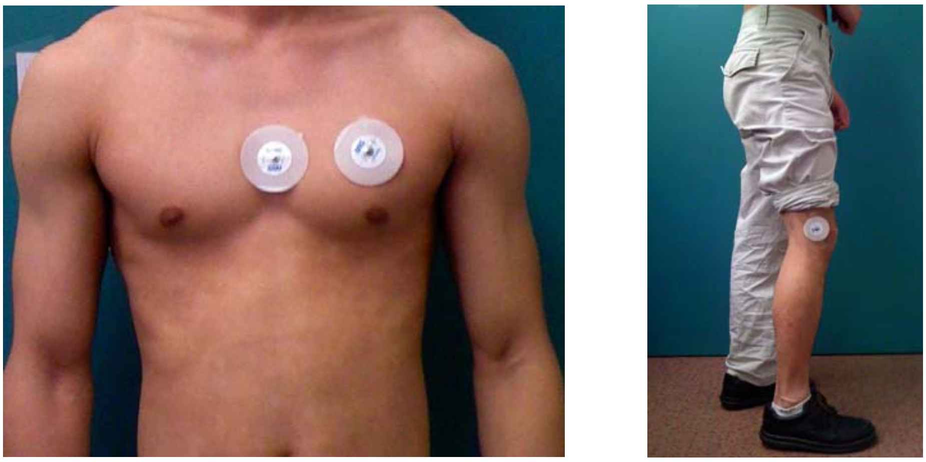

**Figure 3-11 Electrode Placement Diagram**

# 4 Motion Sensor

The motion sensor is used to determine the physical position of the body through the use of accelerometers. Body position assessment, utilizing the static acceleration due to gravity has been used with relatively high accuracy results for years now. The position detection technique using the above technology is simple to implement, accurate, and provides low power consumption.

## *4.1 General Design*

The accelerometer of choice for our design is: LIS3L02AL low-power 3-axis linear capacitive accelerometer from STMicroelectronics. Some of the important characteristics are listed below (all parameters below are specified at Vdd = 3.3V):

- Acceleration range (typical) : ± 2.0g
- Sensitivity (typical): Vdd/5
- [1]Zero-g level output : Vdd/2 ± 6%
- Supply current (max): 1.5mA
- Operational temperature range: -40 to +85 $^{o}$C

Below is the electrical connection of the accelerometer sensor, taken from the component data sheet [4]:

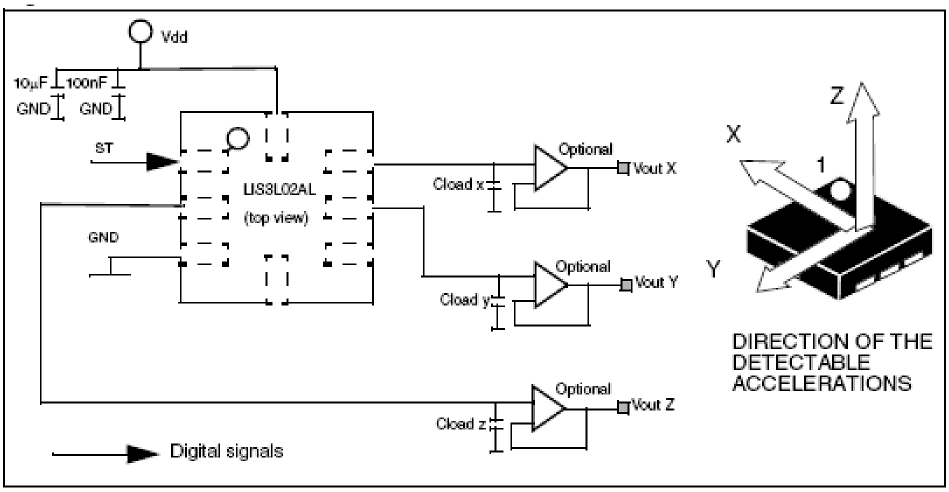


**Figure 4-1 Accelerometer Electrical Connection for Typical Application [4]**

[1] Zero-g level describes the actual output signal if there is no acceleration present. For example, a sensor in a steady state on a horizontal surface will measure 0g in X axis and 0g in Y axis.

From figure 4-1 above, the outputs of the accelerometers, namely Vout X, Vout Y, and Vout Z displays voltage offsets which corresponds to g-force values acting against the sensor. G-force is a measurement of an object's acceleration expressed in g's. The "g" is a non-SI unit that is equal to the nominal acceleration due to gravity on Earth's sea level, defined as $9.80 m/s^2$.

### 4.2 Power Supply

The recommended supply voltage to be used is 3.3V, according to the component data sheet. This supply voltage is supplied from a voltage regulator on the microcontroller. Referring from figure 4-1 above, the 10µF and 100nF capacitors are used for power supply decoupling.

### 4.3 Filtering Design

There are three external capacitors that can be places at the Cload x, y, and z locations to limit the frequency range.

The equation for the cut-off frequency of the external filters is:

$$f_t = \frac{1}{2\pi R_{Out} C_{load}(x, y, z)} \quad \textbf{Eq. 4-1}$$

Taking into consideration that the nominal value of 110kΩ, the simplified equation is:

$$f_t = \frac{1.45\mu F}{C_{load}(x, y, z)} \quad \textbf{Eq. 4-2}$$

Since the motion sensor detects static acceleration from g-force value outputs, which is close to DC, our sensor cut-off frequency is designed to be at 10Hz. The corresponding capacitor value for 10Hz cut-off frequency is 150nF.

### 4.4 Position Sensing

Detecting static position, such as standing, sitting, and lying can be done by determining the orientation of the sensors. We are using two sensors, sensor 1 and sensor 2 attached to the upper torso and thigh respectively. Utilizing all three axes on the accelerometer enables an accurate result of the sensor orientation in a three-dimensional space.

Example below shows how the orientation of the sensor is determined:

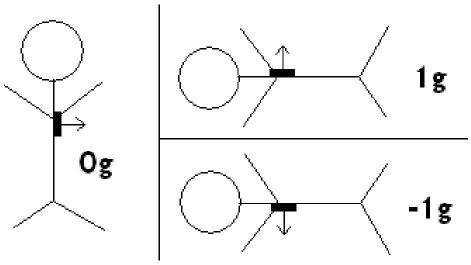


**Figure 4-2 Diagram for Sensor Orientation**

Figure 4-2 above shows the possible orientations of one axis. When the axis is pointing up, an acceleration of 1g is detected since the sensor will sense the gravitational force acting against the sensor. When the axis is pointing in the horizontal direction, the vertical gravitation force will not affect it, resulting in 0g. Similar to the 1g, a -1g acceleration is detected when the axis is facing down. Therefore, each sensor is able will display three g-force values, at one time since there are 3 axes on each sensors.

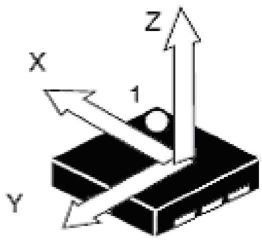


**Figure 4-3 Diagram for Accelerometer Axes**

The corresponding output values for each of the axis that will be used are determined experimentally and results are shown below:

| G-force | Sensor 1 X | Sensor 1 Y | Sensor 1 Z | Sensor 2 X |
|---|---|---|---|---|
| -1 | 1.05 V | 0.97 V | 1.11 V | 1.06 V |
| 0 | 1.65 V | 1.59 V | 1.70 V | 1.67 V |
| 1 | 2.31 V | 2.27 V | 2.36 V | 2.35 V |

**Table 4-1 Accelerometer output values of corresponding g-force values**

We can see from table 4-1 above that the output for each of the axes is a little different, but they are all within a small range that can be differentiated.

The expected g-force values acting on each of the axis for different body positions are shown below:

| Positions | Expected g-force values | | | |
|---|---|---|---|---|
| | Sensor 1 X | Sensor 1 Y | Sensor 1 Z | Sensor 2 X |
| Standing | 1 | 0 | 0 | 0 |
| Sitting | 1 | 0 | 0 | 1 |
| Lying on left side | 0 | -1 | 0 | 0 |
| Lying supine (face up) | 0 | 0 | -1 | 1 |
| Lying on right side | 0 | 1 | 0 | 0 |
| Lying prone (face down) | 0 | 0 | 1 | -1 |

**Table 4-2 Expected g-force Values of Corresponding Body Positions**

With the information provided in table 4-1 and 4-2, algorithms for position detection can be implemented the output the corresponding positions based on the sensor output readings. The detailed algorithm will be presented in the microcontroller section.

## *4.5 Motion Sensing*

The detection of motion, such as jogging and other exercises are more difficult to implement compare to detection of static positions. Since while the subject is moving, the accelerometer output varies, we cannot determine the motion using the sensor output values of one point in time. An analysis of a specified time interval needs to be considered.

For our solution, the use of variance calculation is used to determine the movements of the subject. The detailed design algorithm will be discussed in the microcontroller section.

## 4.6 Schematic

Figure 4-4 on the following shows the finalized sensor schematic taken from screen capture of EagleCAD:

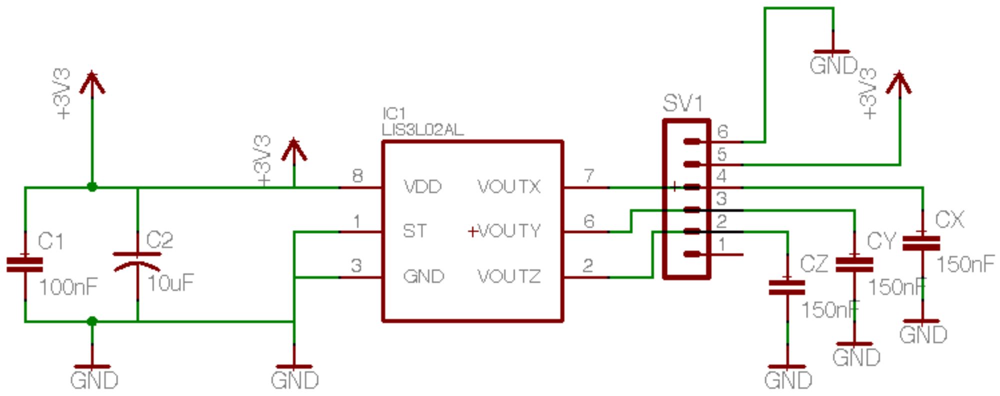


**Figure 4-4 Schematic for Motion Sensor**

## 4.7 PCB Layout

Due to the fact that the accelerometer's pins are underneath the chip (refer back to figure 4-1), it is impossible to check the connectivity after the accelerometer is mounted onto the PCB. The solution to ensure the connectivity is to place the accelerometer up-side-down and manually connect the pins (facing up) to the board with wires. This is done by reversing the accelerometer's layout on the PCB design in EagleCAD. The final PCB design is shown in figure 4-5.

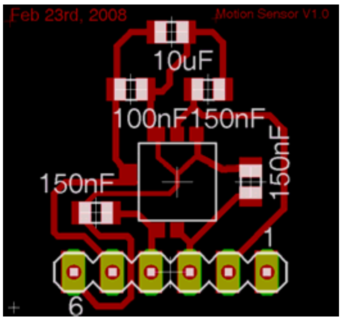


**Figure 4-5 PCB for Motion Sensor**

It can be seen that there are metal surfaces on the side of the accelerometer chip (White Square). The accelerometer will be mounted onto the board with pins facing up. The metal surfaces around the outside edge of the board can connect to the accelerometer pins manually with thin wires.

# 5 Microcontroller Unit

The microcontroller unit acts as a signal processing unit for the Heart rate sensor and the motion sensors. It is also a communication server that prepares data for the host cellular phone through Bluetooth. This section is dedicated to the design approach regarding the microcontroller unit based on functional specification requirement [R64] to [R75].

## *5.1 General*

The Texas Instrument MSP430F1611 Low-Power Mixed Signal Microcontroller is chosen to be used in our design. The core of the MSP430F1611 is a 16-bit RSIC architecture processor. The peripherals of the MSP430F1611 that meet our design requirements are the following [1]:

- 48 Configurable I/O pins act as general purpose I/O or peripheral I/O functions.
- 3 Timers that support Input Capture/Output comparison
- 8 Channels of ADC with 12-bit resolution and less than 10 µs conversion time.
- 2 Serial Communication Interfaces, USART, that can be configured as UART or SPI function.

The functional block diagram of the MSP430F1611 is the following:

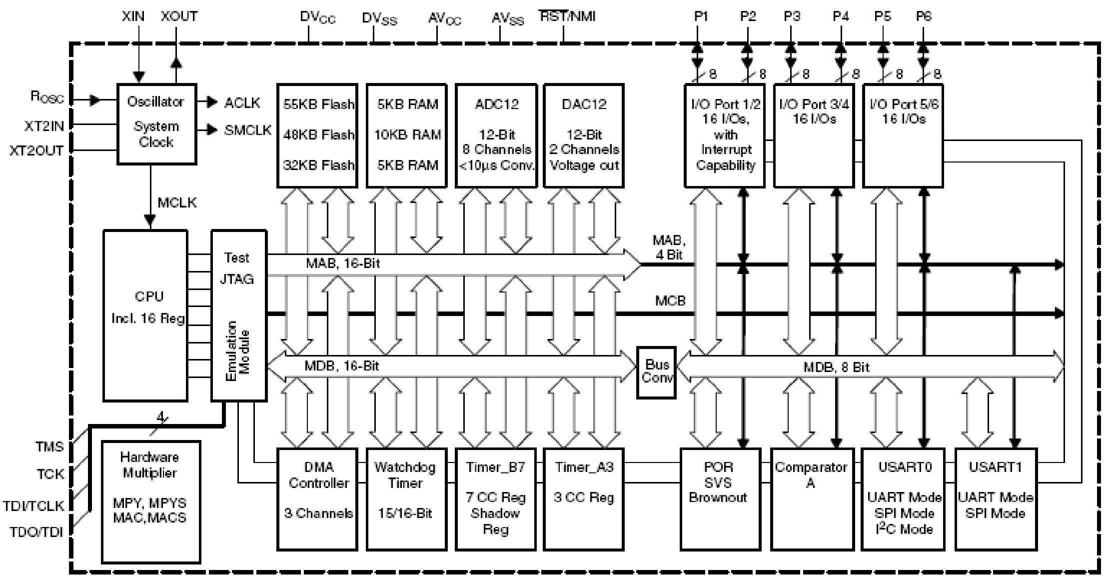


**Figure 5-1 Functional Block Diagram for MSP430F1611 [1]**

### *5.2 Microcontroller Operation*

The main algorithm of the microcontroller for the HRMMS is illustrated in the flowchart below:

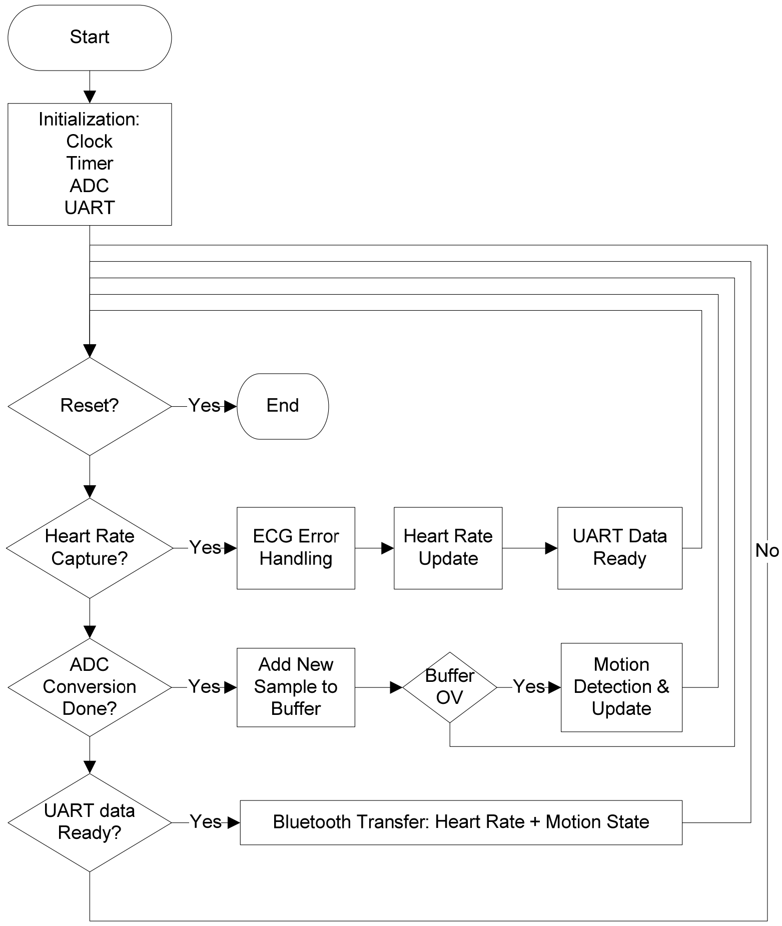


**Figure 5-2 Overall Flow Chart for MCU**

The heart rate sensor outputs a pulse for every heart beat detected from the sensor's signal output. This output pulse will be connected to one of the input capture pins in the MCU. The role of the MCU is to measure the period between these pulses and calculate the heart rate.

The motion sensors' outputs will be connected to the ADC channels in the MCU. MCU samples the ADC channels at a predefined frequency and inserts the current samples into the motion detection buffer. The MCU will then make decisions on the motion of the user when the buffer overflows.

The Bluetooth module connects to one of the UART port in the MCU. Heart rate and motion data will be transferred to the Bluetooth module for every heart beat that have been successfully captured.

### *5.3 Clock Source and Configuration*

The clocks for the MSP430F1611 can be sourced from two external crystal oscillators, or an internal digital oscillator. The three clock signals are: ACLK, MCLK and SMCLK. MCLK is the clock signal for CPU operation. ACLK and SMCLK are low frequency and high frequency clock signal for peripheral functions respectively. The frequencies for these clock signals and their support peripherals are listed in the following table.

| Clock Signal | Frequency | Support Peripherals |
|---|---|---|
| ACLK | 32 KHz | Timer Capture/Compare |
| MCLK | 3.2 MHz | CPU |
| SMCLK | 3.2 MHZ | UART baud rate setting |

**Table 5-1 Clock Sources and Configuration**

### *5.4* Heart Rate Measurement

The 32 kHz ACLK clock is used as a timer to keep track of the heart rate pulse. Since the frequency of the normal heart rate will not be more than 4Hz, we can divide the ACLK clock to a lower value for avoiding large data operations. ACLK is divided by 8 to form a 4096 Hz clock signal in order to minimize the counter steps. The smaller the counter size the less multiplication will be needed. The heart rate measurement is calculated using the equation below:

$$HeartRate = \frac{Clock}{Count_{Diff}} \times 60 \qquad \textbf{Eq. 5-1}$$

where $Count_{Diff}$ is the counter difference from a consecutive pair of pulses captured. *Clock* is the frequency of the counter, which is 4096 Hz. A constant integer value of 60 is used to convert the heart rate to beats per minute (BPM).

Due to the noise generated from body movements, the heart rate sensor output will contain high frequency noise. We will implement a software low pass filter to block off high frequency noise. We will also use some error handling algorithm to guarantee that results are within 10% accuracy.

### 5.5 Motion Detection

The ADC on the MSP430F1611 MCU has 12 bits of precision. The internal clock running on the ADC is 5 MHz. The conversion for each sample will take approximately 10µs. The digital value of the ADC output is calculated using the following equation:

$$ADC\_output = 4096 \times \frac{Vin - V^{-}_{\mathrm{Re}\,f}}{V^{+}_{\mathrm{Re}\,f} - V^{-}_{\mathrm{Re}\,f}} \qquad \textbf{Eq. 5-2 [2]}$$

Where $V^{-}_{ref}$ is connected to the ground and $V^{+}_{ref}$ is 3.3V.

Using this equation, the g-force value table (table 4-1) then becomes:

| G force | Sensor 1 X | Sensor 1 Y | Sensor 1 Z | Sensor 2 X |
|---|---|---|---|---|
| -1 | 1303 | 1204 | 1378 | 1316 |
| 0 | 2048 | 1974 | 2110 | 2073 |
| 1 | 2867 | 2818 | 2929 | 2917 |

**Table 5-2 Digitalized ADC Output Values Representing g-forces**

These digitalized values will be used for the static body position detection, by setting threshold numbers between the -1g to 0g region and the 0g to 1 g region.

After analyzing the outputs of the motion sensors on LabVIEW with a sampling frequency of 10 Hz, it can be concluded that the statistical mean of the sampling data that corresponds to the g-force value does not change much. It has also been noted that the variance of the sampling data is very sensitive to the change of the orientations of the accelerometers. Therefore, we can determine when the test subject is moving by setting the threshold variance value to compare with the actual variance of the sampling data.

The flowchart for the algorithm of motion detection is shown in the following diagram:

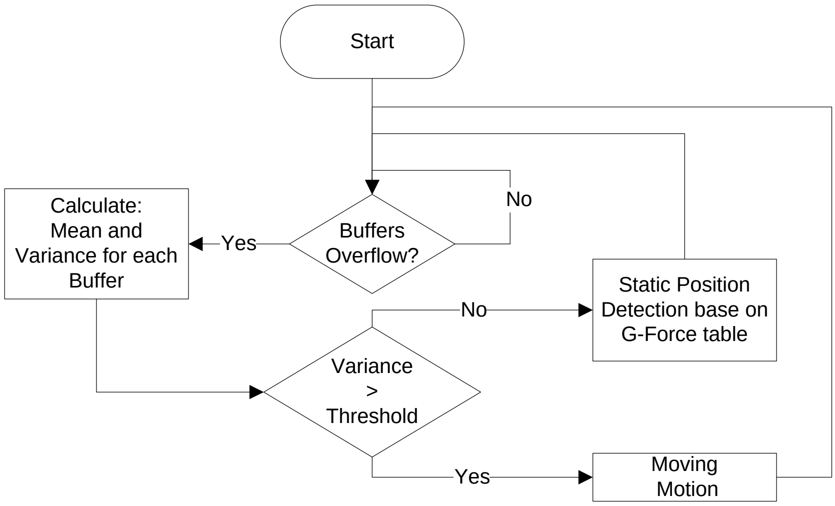


**Figure 5-3 Motion Detection Algorithm Flow Chart**

## *5.6 Bluetooth Communication Module*

LinkMatik 2.0 ™ Bluetooth transceiver is the product of choice used in our design [3]. UART communication interface is used for transmitting data between the Bluetooth module and the MCU. The I/O pins for the LinkMatik 2.0 ™ Bluetooth transceiver in shown in the following:

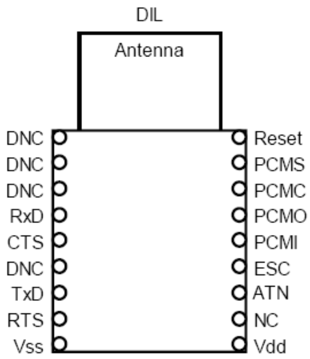


**Figure 5-4 I/O for the LinkMatik 2.0 Connection [3]**

The Serial Communication Interface configuration is shown below:

| Baud Rate | Date bits | Parity | # of Stop bit | Flow Control |
|---|---|---|---|---|
| 115,200 | 8 | None | 1 | None |

**Table 5-3 UART Communication Configuration**

# 6 Symbian Application

The Symbian Application will be the user interface for the HRMMS. Its main function will be to receive the heart rate and motion data from the microcontroller unit. The application will also be able to give warnings and to keep a record of all the data collected.

## *6.1 General*

A Symbian application is an application that is written to work on the Symbian operating system platform. All major brands of cellular phones today run on some version of the Symbian OS. For the prototype, the Symbian application will be using Nokia's S60 version of the Symbian OS. Therefore any Nokia phones with Symbian S60 will be compatible with our application.

## *6.2 Programming Language and Development Tool*

Any Symbian application can be written in Java or C++ programming languages. For our application, C++ is chosen to be the main programming language because this will allow us to access the S60 API natively, which contains many GUI and Bluetooth related resources.

The application will be developed using Nokia's official S60 IDE Carbide C++ v1.2 Express Edition.

## 6.3 User Interface

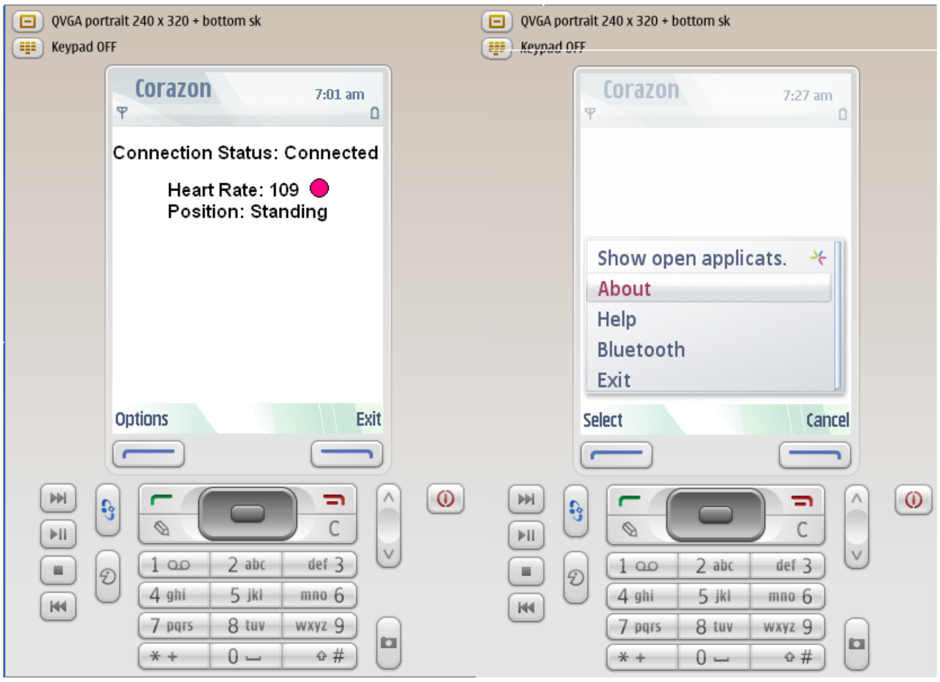


**Figure 6-1 User Interface for Symbian Application**

The above picture shows the proposed UI design of the Symbian program. The user can access the options menu, which contains all the settings and Bluetooth connection options. The heart rate and body position data will be displayed at the center of the screen.

When the application is successfully connected to the MCU, the connection status should read “connected”. If the connection is lost or failed, the connection status will read “disconnected”. Also, when the heart rate reaches the warning level, a flashing red dot will appear and the phone will ring.

### 6.4 Basic Program Flow

Figure below shows the flow chart for the Symbian application:

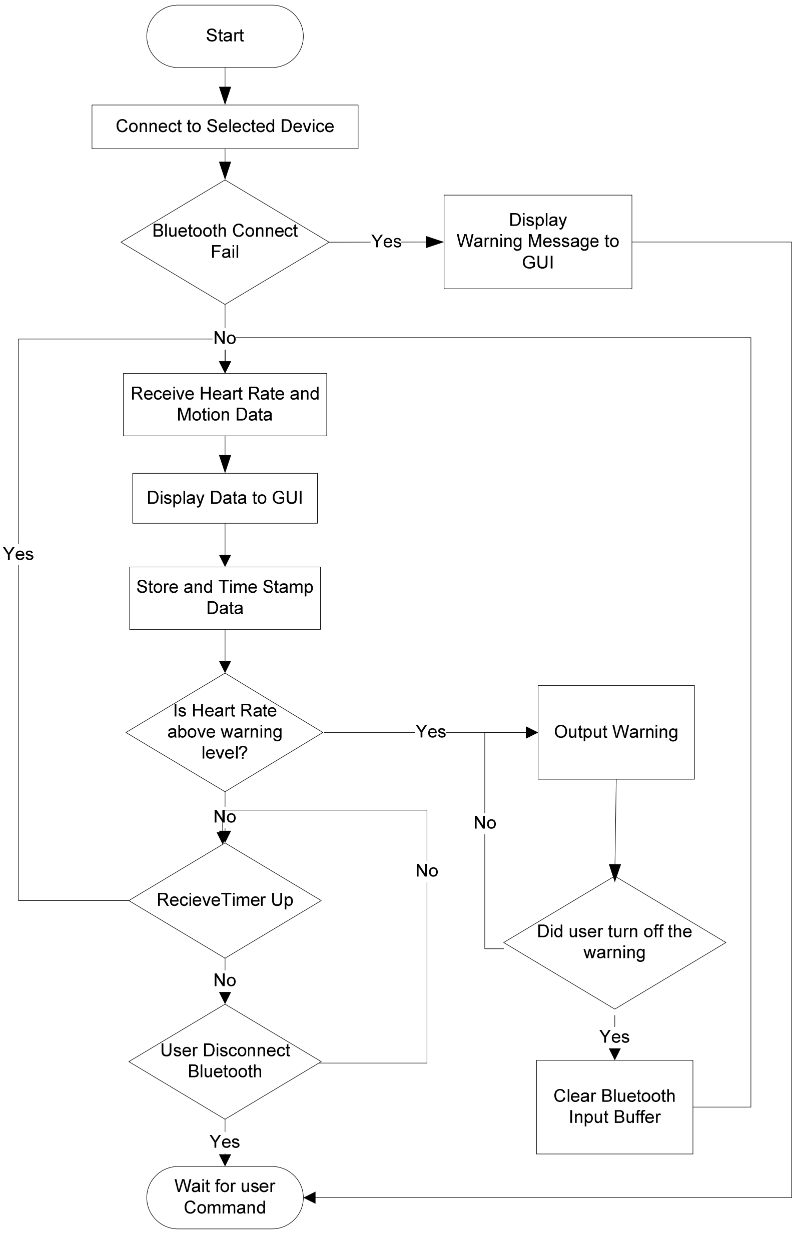


**Figure 6-2 Flow Chart for Symbian Application**

When the user has found the Corazon MCU Bluetooth device and successfully connected to it, the MCU will start to transmit heart rate and motion data to the Symbian application. The application will then display the data to the GUI. Then, the data will be given a time stamp and be stored in a text file which will act as the data logging system. If the heart rate is above the warning level, a warning message will be displayed to the GUI and the phone will ring. The phone will continue ringing until the user turns off the warning, which will bring the application back to receiving data from the MCU. If the heart rate is below the warning level, it will wait for preset time before checking the input buffer for new data. If the user disconnects the Bluetooth connection, then the application will wait for a user command.

## 6.5 Bluetooth Communication

As with any wireless channel, Bluetooth occasionally receives transmission errors. A CRC checksum will be used to check if the incoming data is sent correctly or not. If the data received is corrupted, then a re-transmission request will be sent back to the MCU. If the data is sent correctly, it will be stored in the input buffer.

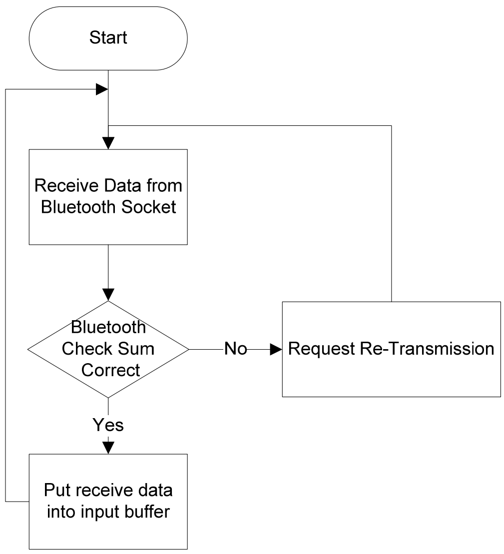


**Figure 6-3 Flow Chart for Bluetooth Transmission**

## 6.6 Class Implementation

The application will be separated into five major classes as in the following:

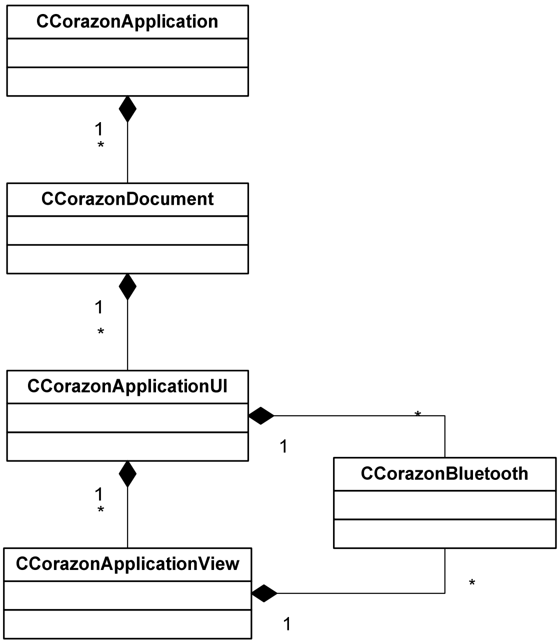


**Figure 6-4 Class Diagram for Symbian Application**

The following table will give a brief description to what these classes are responsible for. All the base classes listed in the table are part of the S60 API.

| Class Name | Base Class | Description |
|---|---|---|
| **CCorazonApplication** | **CAknApplication** | The Application class is the class that holds the whole application. It also provides an entry point for our application. |
| **CCorazonDocument** | **CAknDocument** | The S60 API is base on the Document View Architecture. The document class is responsible for holding all the data. |
| **CCorazonApplicationUI** | **CAknAppUi** | The Application UI class is responsible for handling all the GUI events. |
| **CCorazonApplicationView** | **CCoecontrol** | The Application View is the class that holds all the actual controls. This is what the users see when they are using the application. |
| **CCorazonBluetooth** | **No Base Class** | This is responsible for the Bluetooth transmission. This class will work with the Bluetooth socket contained in the S60 API. |

**Table 6-1 Class Description**

# 7 Test Plan

Our test plan below is designed for the prototype device:

| Test Plan | Test Purpose |
|---|---|
| **Power Supply Test** | -To ensure our power supply circuit board output 6V from a 9V battery.<br>-Operation safety level must be achieved |
| **Heart Rate Sensor Testing** | - Ensure that the output pulse has an amplitude at least 3.3V<br>- No major artifacts when test subject is in motion<br>- Ensures that the heart rate detection algorithm is accurate for expected operations |
| **Motion Sensor Testing** | -Ensure that all of the axis outputs the correct range of values corresponding the appropriate g-forces<br>-The combination results need to trigger the motion detection algorithm with correct position results, within the predefined error range. |
| **Symbian Application Testing** | -To ensure that normal phone operations will not be affected when the application is running<br>- The ability for controlling the on-board Bluetooth resources and performing data transmission will be tested<br>- Various crash tests for the application will also be implemented in order to ensure reliability |
| **Bluetooth Communication Testing** | - To ensure the validity and accuracy of signals transmitted through Bluetooth<br>- To ensure the Bluetooth can operation within the recommended range |
| **Overall Device Testing** | - Upon the completion of the prototype device, a combination of heart rate and motion state, transmitted through Bluetooth needs to be verified, including testing of data accuracy and data response time. |

**Table 7-1 HRMMS Prototype Test Plan**

# 8 Conclusion

This design specification document listed out all the design approach and reasons of design for both our proof of concept prototype model. The prototype model will be completed by the end of the spring 2008 semester. No major design changes will be implemented unless normal operational functionalities listed above cannot be met or if more efficient methods can be used. Both the design specification and the functional specification will act as a reference and will be check listed weekly through out our product development cycle.

# 9 Reference

[1] Taxes Instruments, “Mixed Signal Controller”, [Online Document], Aug. 2006, [2008 Feb 25], Available at http://focus.ti.com/lit/ds/symlink/msp430f1611.pdf

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