April 09th, 2008

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

Re: ENSC 305/440 Post-Mortem for Heart Rate and Motion Monitoring System

Dear Mr. Leung:

The attached document below presents the Post-Mortem 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 Post-Mortem below presents the current state of our device and any deviations compare to our proposal, probable future expansions of this project, and finishing off with a section describing problems encountered during our device implementation along with our solutions.

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, Corazon Engineering Inc.

Enclosure: Post-Mortem for Heart Rate and Motion Monitoring System

# Post-Mortem

## 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 |



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| Date Issued: | April 09, 2008 |
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# 1 Introduction

The ability to detect heart rate with respect to user's physical position can provide important information regarding to the subject heart's state of health. Corazon's solution, a heart rate and motion monitoring system (HRMMS) has completed its prototype stage. In this document, the HRMMS's current state will be discussed. Additional information such as changes applied that is different than the proposal, problems encountered during implementation, and the product's future expansion options are described in detail below.

# 2 Current State

As proposed, the heart rate and motion monitoring system (HRMMS) consists of the building blocks as shown in Figure 2-1.

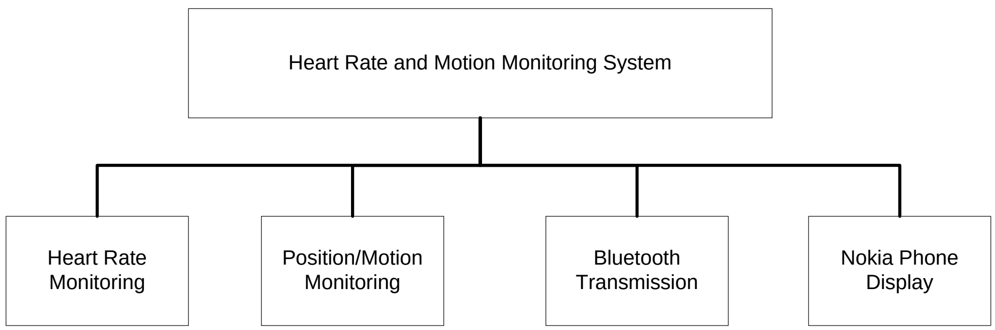


**Figure 2-1: Current System Overview**

In general, the whole system consists of heart rate and position/motion monitoring modules as the input to the system. The microcontroller handles the calculation of heart rate, position analysis, motion activity level analysis, and then transmits these information through the on board Bluetooth module to any Bluetooth enabled Symbian based mobile handset. The current detail of the functional blocks is described as follows.

## 2.1 Heart Rate Module

As described in the design specification, in order to extract full heartbeat information, the bandwidth of 0.5 to 100 Hz is favored for ECG.

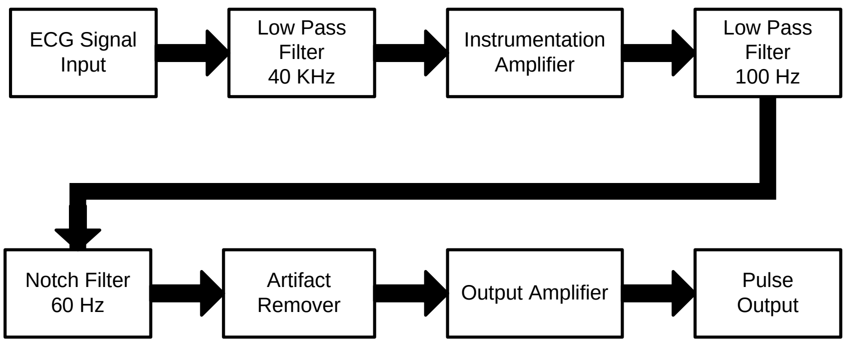


**Figure 2-2: Design for Heart Rate Module**

As shown in the above figure, based on the bandwidth selected to extract the heartbeat signal, several filters and amplifiers are implemented through additional stages in order to enhance the signal's clarity and to shape and amplify the signal into a 3.3V pulse in order to meet the criteria of the microcontroller's heartbeat detection algorithm. The major design consideration for this system is the noise removal and reduction. Radio frequency interference, electromagnetic interferences, and the AC power supply noise at 60Hz all contribute to the distortion of the heart beat signal. To reduce any interference effect, a high order 40 kHz low pass filter and a high order 60 Hz notch filter are applied. Additional filters are also applied to remove the signal artifact cause by the skin and electrode contact during movement.

## 2.2 Position and Motion Monitoring

The position and motion monitoring module incorporates two 3-axis accelerometers, placed on the upper torso and the left thigh. The voltage output from the accelerometers is proportional to the amount of gravity force (G force) it has experienced on a certain orientation at any time. Analyzing the voltage output of each axis on LabVIEW instrument device allows us to apply statistic analysis algorithm for both position and motion detection.

The positions and the motion levels that we can determined are shown in the following table:

| Position | Motion Level |
|---|---|
| Standing | Level 1 |
| Sitting | Level 2 |
| Lying on left side | Level 3 |
| Lying supine (face up) | |
| Lying on right side | |
| Lying prone (face down) | |

**Table 2-1: Position and Motion Determination**

Several static positions can be determined with the calculation of the average of the sample data.  The motion activity level is determined with the calculation of the variance of the sample data. The larger the variance, the higher the activity intensity.

## 2.3 Bluetooth Transmission

The Bluetooth transceiver module used for HMMRS is LinkMatik 2.0. It acts as a slave device that waits to be connected by any nearby Bluetooth devices. As mentioned earlier, this Bluetooth module transmits the instantaneous heart rate and position/motion information to the mobile device of interest. The signal strength of this module is set to 20dBm and allows the line-of -sight signal coverage up to 60 meters in open field.

## 2.4 Symbian Application

Nokia phone acts generally as a communication and display device in HRMMS system. It provides human interface that displays real-time heart rate and position/motion information. A data logging function is also implemented to keep the time stamp of any abnormal occurrence of heart rate.

# 3 Deviation from Proposal

## 3.1 Heart Rate Module:

In general heart rate monitoring module is designed as proposed and it functions as desired. The only deviation is the hardware implementation. This module initially was planned to be constructed purely on breadboard. However, for noise reduction and reliability purposes, the final design on breadboard is transferred to PCB. The breadboard and PBC design are both illustrated as below:

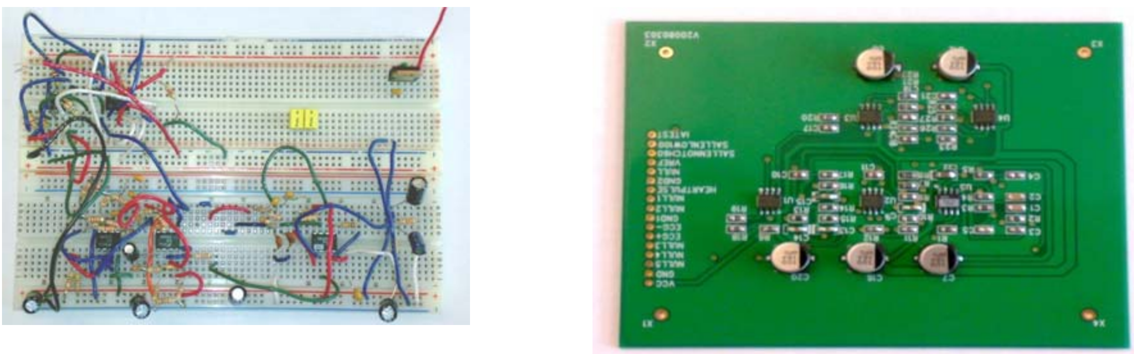

**Figure 3-1: Heart Rate Module Breadboard and PCB**

## 3.2 Position and Motion Monitoring

Initially, all three axes of the accelerometer output were planned to be used for the position/motion detection in our design. However, during our implementation, the Z-axis on the upper torso and Y and Z axes on left thigh can be ignored. In addition, we are also able to determine the motion level by calculating the statistic variance for the sampling data.

## 3.3 Bluetooth Transmission

The functionality of the Bluetooth module is conducted and performed as proposed. The overall transmitting range is only 60m in open field as compare to 100m in our proposal. This deviation is due to the Bluetooth device in the N73 handset. The Bluetooth receiver in the Nokia N73 handset is a class II device, which supports only 10m of transmission range. And, the LinkMatik Bluetooth transceiver in our system is a Class I device, which support up to 100m of transmission range.

### 3.4 Symbian Application

Data logging capability is added due to its importance for keeping track of any abnormal heart activity. The file that keeps the data logging is also transferable to any personal computer. These data can be used for further analysis on the healthiness of user's heart.

### 3.5 Budget

The table below shows the costs differences between our estimated and actual budget for developing our prototype system:

| Components | Estimated Cost | Actual Cost |
|---|---|---|
| Accelerometer | 10.00 | 20.00 |
| ADC | 20.00 | - |
| Battery Power System | 20.00 | 10.00 |
| Bluetooth Module | 50.00 | 97.00 |
| Cables | 20.00 | 5.00 |
| Case | 20.00 | 10.00 |
| Electrode | 20.00 | 8.85 |
| Heart Rate Monitor Module | 80.00 | 38.00 |
| Microcontroller | 100.00 | 60.00 |
| PCB | 10.00 | - |
| Miscellaneous | 50.00 | 50.00 |
| PCB Fabrication from Hong Kong | - | 400.00 |
| **Total Cost** | **400.00** | **698.85** |

**Table 3-1: Budget Analysis**

From the budgeting point of view, a major difference between our estimation and the actual cost is the 3rd-party fabrication costs. We did not take this into consideration in our estimation since we planned to construct our own circuits. Most of the other costs of the estimated and actual are very similar.

### 3.6 Project Timeline

The actual progress timeline of our system implementation are very similar to our proposed schedule. As can be seen in figure 3-4 below, the actual progress timeline, highlighted in red is a lot longer than our initial schedule. However, we did manage to finish the project within our pre-defined time frame since many stages of our implementation actually started earlier than our schedule (highlighted in blue).

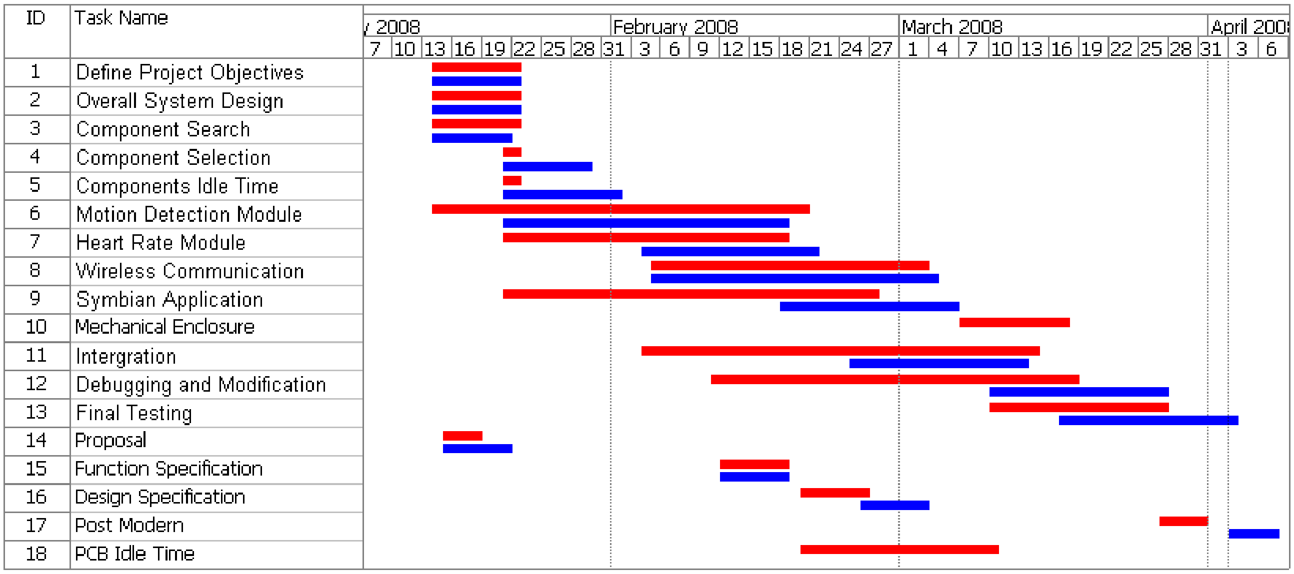


**Figure 3-2: Initial Schedule (Blue) and Actual Progress (Red)**

We also have two additional tasks in our actual timeline, Mechanical Enclosure design task and the PCB fabrication task. We manage to accomplish the mechanical enclosure design after all of the sub modules has been tested and verified. The idle time for waiting on the PCB fabrication, including the shipping time are also accounted for. We manage to handle this idle time by writing our design specification one week earlier than our original schedule.

# 4 Problems Encountered

The following lists some of the major problems encountered during the development stages of HRMMS. These problems are shown in the following:

## 4.1 Signal Artifacts

Since we are detecting dynamic activities, skin contact artifacts and muscle movements causes interference with our heart rate detection circuit. HRMMS heart rate detection module is based on the ECG signal, which detects the electrical potential across the heart. When the test subject is moving, the electrical potential of the body changes due to electrical potential created from muscle movement. Therefore, these two potentials will interfere with each other. Using FFT analysis, we noticed that the muscle movement artifacts are close to the ECG signal frequency range. Since we only want to detect the heart beat from the ECG signal, we apply band pass filters to isolate the artifacts while maintaining the necessary ECG signal frequency for detecting heart beat.

We tested the accuracy of our heart rate module for calculating heart beat along with a commercial heartbeat detection watch. The result of this comparison test is shown below:

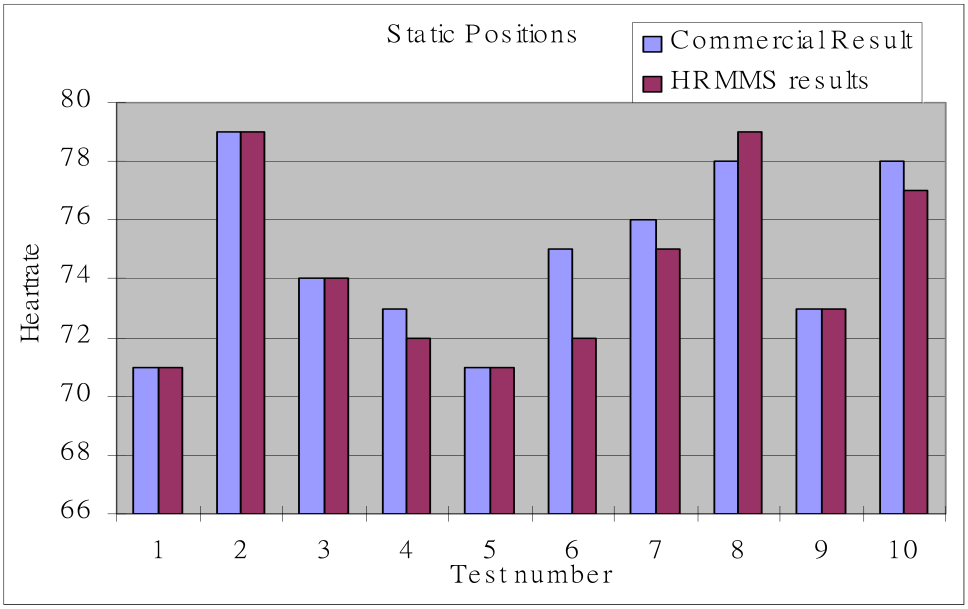


**Figure 4-1: Heart Rate Detection Results for Static Positions**

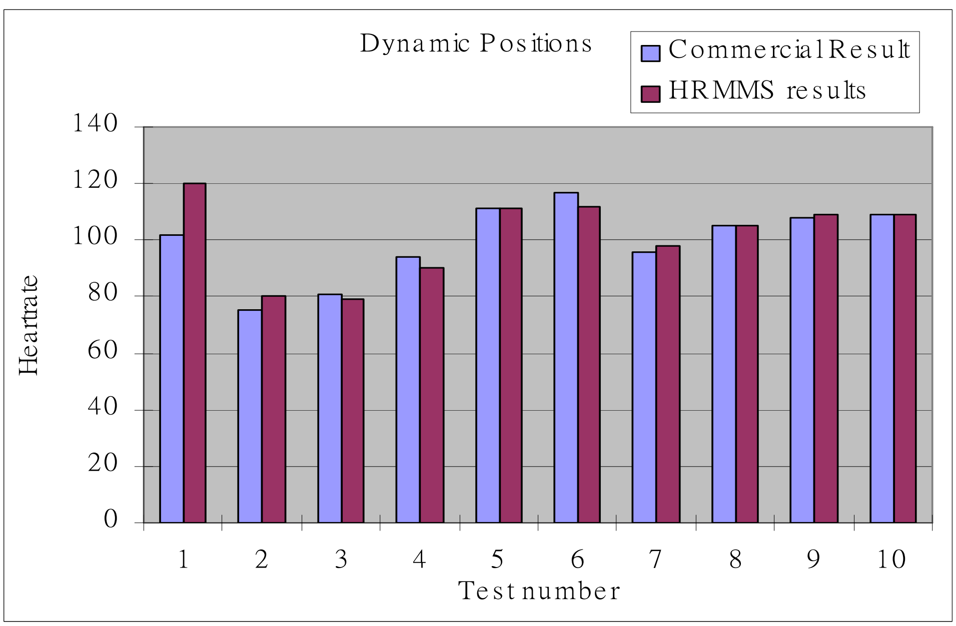


**Figure 4-2: Heart Rate Detection Results for Dynamic Activities**

It can be seen from figure 4-1 and 4-2 that the heart rate detection in our system is very close to the commercial heart rate detectors.

## 4.2 Power Supply Circuit

During implantation of our power supply circuit, the regulator chip shown below did not mount onto our “in-house” power supply PCB. This is mainly due to the small pin size of the surface-mount regulator chip and the lack of precise soldering equipments. Our solution to this problem is to send the power supply circuit PCB design and circuit components to a 3rd party company for fabrication. Figures below show the “in-house” power supply circuit board and the 3rd party fabricated board.


**Figure 4-3: “In-house” Board and 3rd-Party Fabricated Board**

## 4.3 Microcontroller and Bluetooth Communication

Writing the firmware on the Taxes Instruments MSP430F1611 microcontroller has problem such as improper setting to the register for input capture function. As a result, we have spent much more time on debugging, and system integration. There were also problems with configuring the serial port communication format to connect the microcontroller unit to the LinkMatik Bluetooth module for data transferring.

## 4.4 Symbian Application

Many problems were encountered during the Symbian application development. One of the major problems encountered was the version conflict between the SDK and Nokia’s IDE Carbide C++. Apparently Carbide C++ required a specific version of active perl (which is not the latest version) installed in order to work with the SDK. Another difficulty in dealing with Symbian application was the setting of the application UID. Each application must have a specific UID in order to be installable on a phone. And there is a set of complicated rule regarding UID selection, for example some are protected and some are only for 3rd party signed application and so on. It took at least a week of trial and error to get the application installed on the phone. Last but not least, the clean up stack mismanagement caused most of the instability problems. Adding on top of that Symbian error message are not helpful at all so debugging the application was at best frustrating.

# 5 Future Expansion

The completed HRMMS device is the first prototype designed by Corazon members. There are a few future expansion ideas Corazon has in mind that can be added to our device for future models. Each possible future extension is discussed below:

## 5.1 Determining Distinct Dynamic Positions

In our prototype design, dynamic activity levels, ranging from 1 to 3 are detected based on the movement intensity level. However, we cannot yet determine the exact activity of the user. In order to determine activities such as running or jumping, a more detailed test procedure needs to be defined.

## 5.2 Determining of Heart Disease Symptoms

The detection of signs of atrial fibrillation [1], a type of abnormal heart rhythm can be determined from results detected with HRMMS. This has not been confirmed by a licensed medical doctor yet, it is only based on research done by Corazon team members. Working together with licensed medical practitioners undergoing a series of in-depth test and analysis on a wide range of population can fully utilize HRMMS's potential in the medical device area.

## 5.3 Additional Bio-sensor Integration

Another way of utilizing the portability features of the HRMMS is with additional bio-sensors for detecting blood pressure, glucose level, and cholesterol level. Corazon believes the additional heart health information can further analyze the healthiness of the heart for both training and medical purposes.

# 6 Group Member Reviews

## 6.1 Benny Hung [Chief Executive Officer]

As the CEO of Corazon Engineering Inc., my main role is to plan our project schedule, executive, and revision of our work progress. It is one of the most valuable experiences I learned aside from all the technical courses offers by the undergraduate engineering program. I will like to thank every member of the Corazon Engineering Inc. Each of them showed their great contribution throughout our project development cycle.

From the technical aspect, I have learned a lot during these past 3 months on research and development. I was responsible for programming the microcontroller, MSP430F1611, in C language. In the earlier phrase of our project, I spent a lot of time on evaluating the functionalities of the microcontroller and designing the interface for our multi-sensors system. For example, the heart rate sensor interface with MCU with digital pulse, motion sensor interface with MCU with ADC channels, and Bluetooth communication module interface with MCU with UART serial communication format. It is very amazing that these interfaces turn well together in an overall system. In the later phrase of our project, I was also responsible for developing our own algorithm on position/motion detection from motion sensor output signal. Sufficient knowledge from previous statistic course and signal analysis courses helped me understanding the signal behavior of the motion sensor. I was able to apply the mean and variance concept to develop a reliable algorithm on position/motion detection base on the available resource on the microcontroller unit.

Aside from all of this, I will like to share some more about this course. During the development period, we have encounter many problems relate to hardware failure, programming bug, and unpredictable error comes from out of nowhere. These are what most people call the “nightmare” from previous students who took 440 before. I have three suggestions to students who will take this course in the future in the following:

- Start working on your project earlier than your schedule
- Still, start working on your project earlier than your schedule
- Again, start working on your project earlier than your schedule

## 6.1 Thomas Cho [Chief Technology Officer]

This project course really allows us to use what we have learnt in the past in a practical way. Throughout my undergraduate studies, I have often questioned the usefulness of some of the course that I have taken. But after this project I come to realize that all the engineering courses in the past are very useful. Not only did we get to build something cool, it also strengthened our friendship among each other.

As the CTO of our company, I was primary responsible for the Symbian application and ECG extraction circuit development. Throughout these three months I have learnt a great deal about Symbian development and circuit design. But most important of all, working on the project gave me better insight into design and planning techniques.

For anyone who plans to take this course in the future, please do not ignore the importance of proper design and planning techniques. Before you even start to build anything everything should be written down and discussed with all your group members. And if you are dealing with software, have a state diagram or flow chart ready before you start to write any code. This will save you a lot of time when you have to the piece together later on. Many of you have probably heard a lot of scary things about this course. But let me tell you, the proper planning and design technique save me from pulling any all nighters and I hope it will work for you too!

## 6.2 Michael Mao [Chief Financial Officer]

The engineering project course in my opinion is the most valuable course in the entire undergraduate engineering problem at Simon Fraser. Utilizing the knowledge from many different areas of engineering, this project simulates a real life design situation that will be experienced by many of us in the near future. Not only did this course give our group an impression of starting a start-up engineering company, but most importantly, it helped us in improving interpersonal skills such as teamwork, leadership, time management, and utilizing specialists in a company to achieve a common goal.

As the CFO of Corazon, I am in charge of handling all the financial related issues such as budget analysis, organizing sponsors, and market research. On the technical side, my main responsibility is implementing the position detection module using accelerometers. From sensor creation to final implementation of assembling all the modules together, I have learned many useful skills in the areas of sensor circuit design, accelerometer position detection, and methods of analyzing statistical information for dynamic movement detection.

This project course has also motivated me to continue graduate studies in the biomedical engineering field, more specifically in the cardiovascular area. In conclusion, I would like to give a few words of advice for future students who are going to be taking this project course, these are:

- Do not take too many courses when taking ENSC 440
- Do not start your project half way through the semester
- Order multiple sets of components if possible
- Maintain good relationship with all group members

### 6.3 Philip Lin [Vice Presidents of Engineering]:

ENSC 440 is a practical course that allows everyone to make good use of all the software and hardware knowledge and apply them to building something that works or even sells. HRMMS device is the monitoring device that incorporates analog filter and amplifier design. For the software portion, it requires C language for microcontroller programming and C++ for Symbian OS programming.

My role in this project is implementing the heart rate monitoring module. This circuit consists of several analog filters such as low pass and notch filters for noise reduction. Also, it contains voltage amplifiers such as instrumentation and non-inverting amplifiers to amplifier the signal level to 3.3V for microcontroller to trigger on heart beat signal's rising edge. All the filter and amplifier design theory are learned from ENSC220 and ENSC320. These two courses have established a strong foundation for designing all the necessary functional blocks for the heart rate monitoring module.

For future students taking this course, time management is the most important thing to take into consideration, because every group is only allowed such a stringent schedule to complete the project. It is definitely crucial to follow the agenda that the team sets forth and allow sufficient time before the demo for debugging the final work.

# 7 Conclusion

This post-mortem document presents a conclusion to Corazon's HRMMS prototype design phase. Even though Corazon group members encountered numerous problems during our product implementation, with friendly teamwork, attitude, and high enthusiasm, our prototype device implementation is a success. Future developments for the HRMMS will be carried out by Corazon members in the following semesters.

# 8 References

[1] Wikipedia, "Atrial Fibrillation", [Online Document], March 28 2008, [2008 March 28], Available at http://en.wikipedia.org/wiki/Atrial_Fibrillation