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December 19th, 2003

Dr. Andrew Rawicz
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Re: ENSC 340 Project Small Heart EKG Progress Report

Dear Dr. Rawicz,

The attached document, *Small Heart Progress Report*, discusses the process Avrio Medical Inc. went through when designing and implementing the Small Heart EKG, which records electrical signals from a heart's surface to analyze irregular heart pulses in infants due to arrhythmias.

This document describes the notable device, deviations from our original design plans, and our future plans for the Small Heart EKG device. In addition, we outline some of the budgetary and time constraints we encountered and explain the inter-personal and technical experience gained from working on the project.

Avrio Medical Inc. consists of six experienced and hard working fourth-year and fifth-year engineering students who love to incorporate knowledge to aid people: Jeff Chang, Eric Chow, George Kwei, Seddrak Luu, Joe Ma and Kenny Pak. Please contact us if there are any questions or concerns via email, ensc340-wireless@sfu.ca or by phone through Seddrak Luu at 604-719-5929. Thank you.

Sincerely,

Seddrak Luu

Seddrak Luu
Chief Executive Officer
Avrio Medical Inc.

Enclosure: ENSC 340 Project Small Heart EKG Progress Report



Small Heart EKG Progress Report

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December 19th, 2003



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1. Introduction

For the past 13 weeks, the team of Avrio Medical Inc. – Jeff Chang, Eric Chow, George Kwei, Seddrak Luu, Joe Ma, Kenny Pak – has worked on the design and development of a *Small Heart EKG*. This report re-examines the process of design and implementation, reports on the current state of the device, any deviations from our original plans, and our future plans for the Small Heart EKG device. In addition, we outline some of the budgetary and, time constraints we encountered and explain the inter-personal and technical experience gained from working on the project.

2. Current State of the Device

The *Avrio Small Heart EKG* uses a custom built array of electrodes to effectively pick up weak electrical signals from a heart surface, and display an amplified, filtered, and analyzed version of these signals on a computer. A system overview diagram below outlines this process.

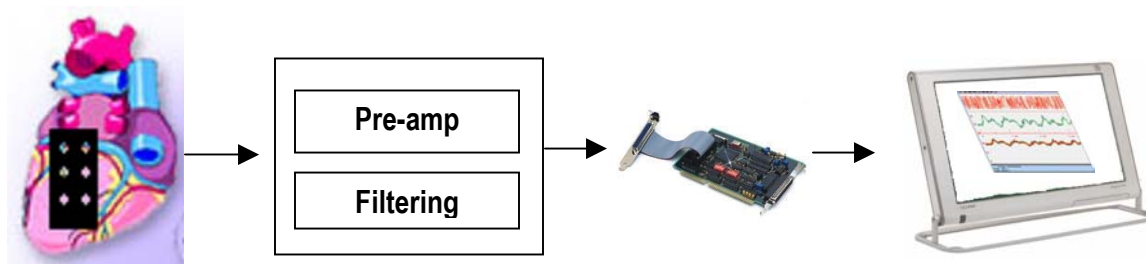


Figure 1: System Overview

There are four distinct components that make up the Small Heart EKG device: the signal retrieval phase, the signal transmission phase, the signal processing stage and the signal analysis stage.

To collect and record the electrical heart signals, a 1.0cm x 1.5cm (5-pin/channel) electrode array grid is placed onto the surface of the isolated rabbit heart. Each electrode on this array is composed of 35 gauge platinum wire insulated by Teflon. The end of the platinum wire which contacts the heart is stripped of its Teflon coating and coiled to form a contact point of ~3 mm in diameter. The other end of the platinum wire is wrapped around 25 gauge copper wire and shrink-wrapped to ensure proper contact and conduction. A total of four signal acquisition electrodes and one reference electrode is bundled together to form the electrode array grid. To minimize cross-talk between acquired signals, each length of copper wire is tightly braided together and further insulated with aluminum foil. With a complex apparatus of clips and clamps, this electrode array is placed to probe the heart following and recording the intensity of the electrical signal propagation traversing the heart.

The electrode array relays the heart's electrical signals to the Preamplifier and Filtering Module (PFM). The PFM is responsible for increasing the signal strength and cleaning up noise present. Each electrode channel is first fed through a differential amplifier (AD620) to eliminate noise and increase signal strength. The one electrode signal is feed in directly to the non-inverting input of the AD620 amplifier; the inverting input is used by the reference electrode. Next, to remove the unwanted 60Hz standard electrical background noise a third order low-pass filter with a -60dB per decade roll off is employed. The filtering consists of two stages. The first stage contains a -20dB roll off in cascade with a second stage consisting of a -40dB roll of to get the desired sharp roll off.

Considering that the major heart beat events are observed to be located in 3 – 5 Hz, the filters are designed with a roll off point at a 5Hz.

In order to eliminate any possible interference from conventional power supplies, 9V batteries are used to power the circuits. The noise from large power supplies gives a large ‘humming’ noise which will be easily detected by our platinum tipped electrodes. Therefore, two 9V batteries are used to provide a -9V to 9V power supply and an appropriate reference ground. This also aids in the portability issue for the circuit making it much easier to place the device in convenient places and without hauling a large power supply around.

Next, with a clean amplified signal, the rabbit heart’s electrical information is sent to a Digital Data Acquisition (DAQ) System. BNC cables are employed to transfer the electrical signals from the PFM into our Data Acquisition (DAQ) Card via a BNC-2090 connector by National Instruments. The DAQ is responsible for converting the analog signal to a digital medium and performing all the necessary signal processing. We use the NI AT-MIO-16E-10 which is PCI-BUS compatible,, allowing all our signals can be easily accessible using a standard PC computer.

Finally, a Data Display Unit outputs all the recorded and analyzed data into an easily interpretable graphical display. With the electrical signals fed into our computer operating under Windows 2000 on a PIII 800, we use Labview to relay this information. The first Labview interface is used to record, filter and perform initial analysis of the electrical signals. The second Labview interface is used to “play back” recorded data and perform further signal analysis. Screenshots of these two interfaces are in the figure below.

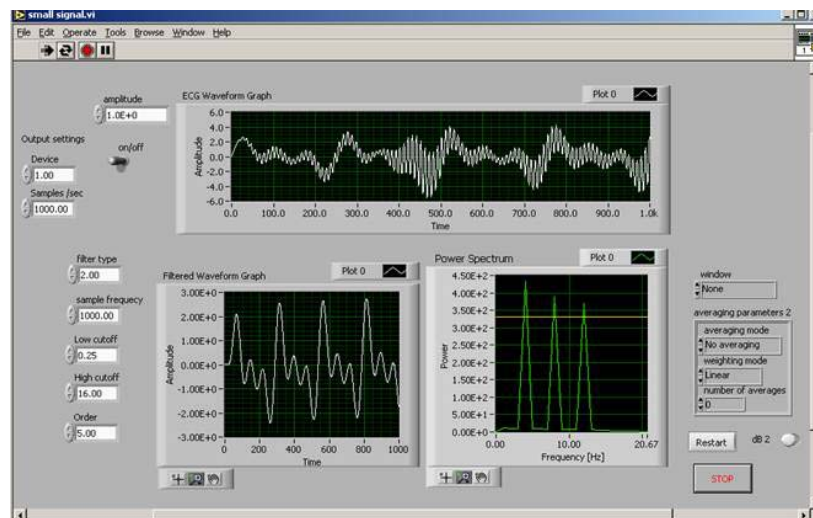


Figure 1: Labview Signal Acquisition Display

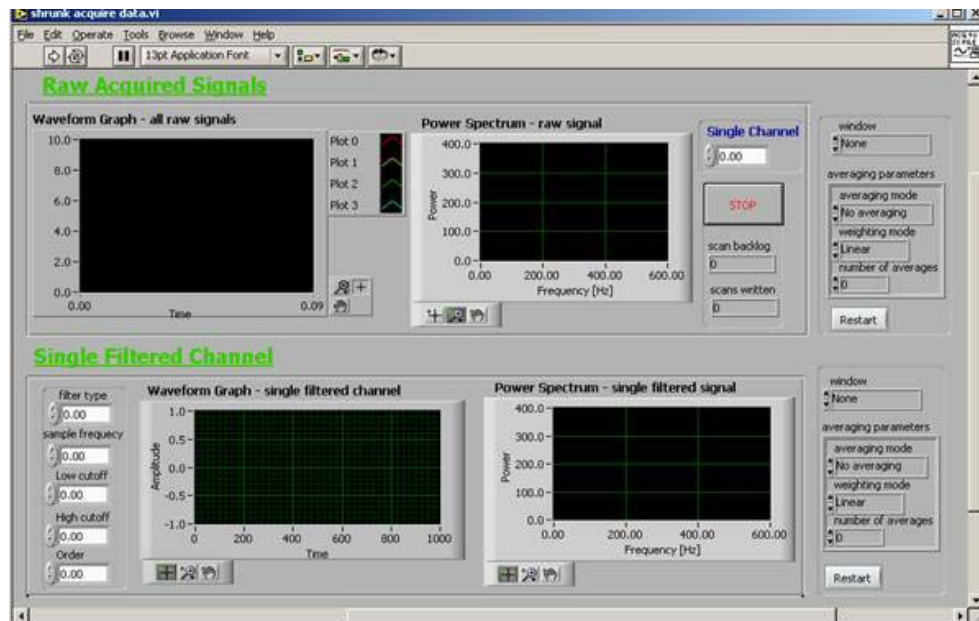


Figure 2: Labview Signal Presentation Display

The signal acquisition display shows all four acquired heart signals and records this data to file. In addition, the acquired signals are fed through a Fast Fourier Transform (FFT) and this information is used to display the power spectrum (frequency domain) of our signals. Another feature available is to further filter the acquired signals using a Butterworth Filter and being able to specify the filter type (low pass, high pass, band pass, band stop), cutoff frequencies, and order. This filtered signal is then again displayed and fed through a FFT again to see the new cleaned up frequency domain.

The signal presentation display reads in the recorded heart data from file displaying the data on three separate windows. The first window shows all the available signals. The second shows a single channel, and the last window shows the frequency domain of the signal. In addition, heart analysis information (such as heart beat rate) is interpreted from the data.



3. Deviation of the Device

Overall, the Small Heart EKG functions and has the features as planned and outlined in our project proposal and functional specification. The actual design has, however, evolved over the course of the project.

3.1 Probing Method

Initial design of the needle electrodes called for eight channels. The extremely small size of the rabbit heart was unanticipated. Due to this physical limitation, the needle electrode array now only contains four channels. The construction of the electrodes has also deviated from that of initial design. Original design called for the needle electrodes to be physically attached together in a rectangular mold. In practice, we found it is easier to position the electrodes if they are each free with a small amount of room to move. In addition, shrink wrap was used to provide a better connection between the platinum wires and regular copper wire. This is due to platinum being a very difficult material to solder.

3.2 Signal Acquisition

After the electrical heart signals are picked up by the electrodes, they are fed to our instrumentation amplifier as planned. This has not changed from original designs. At one point, an initial buffer was used to couple the incoming signal in order to reduce signal attenuation. It was later found that this buffer was unnecessary as the instrumentation amplifier has sufficient input impedance.

3.3 Filtering Technique

The filtering concept has not changed. However, the actual implementation of filters has. Initial designs called for only a -20db/dec roll off to filter off 60 Hz noise. We found 20db/dec to be an insufficiently sharp cutoff, and so a third order -60db/dec roll off low pass filter is used instead. Initial designs also included a final amplification stage to increase the acquired signal strength. It was found that this last stage was unnecessary as our instrumentation amplifier had already provided sufficient amplification and gain.

Furthermore, additional filtering is performed using Labview software. Instead of solely relying on hardware, using software gives us real-time flexibility in our designs and manipulation of signals. For example, using a Butterworth Filter we can easily change the filter type, cutoff frequencies, and order of the filter within seconds. This process has helped us speed up development of the Small Heart EKG prototype and has provided us with simulation results before applying designs to hardware.

Following is a schematic of our final signal acquisition and filtering circuitry.

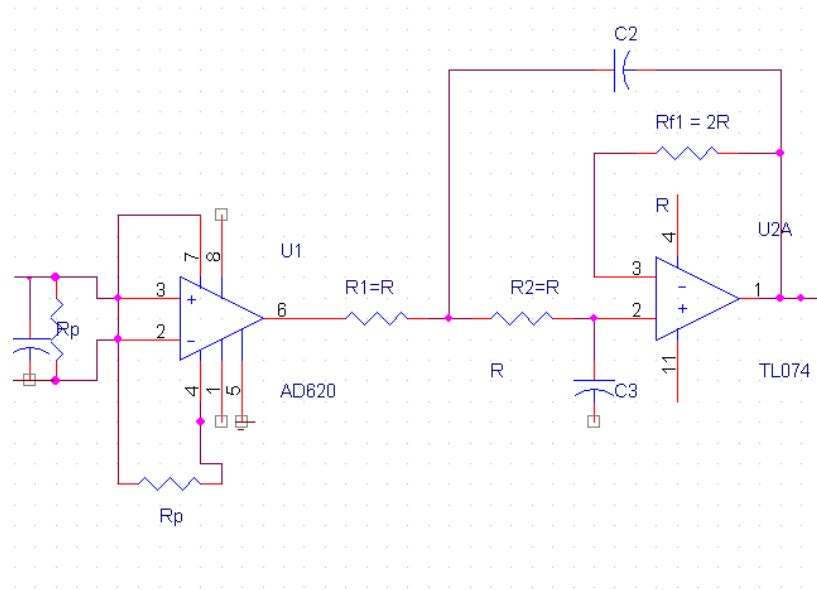


Figure 3: Modified schematic of electronics

3.4 Signal Processing and Analysis

After our signal is converted digitally and displayed. A new aspect of signal processing and analysis we employed is passing the acquired signal information to a Fast Fourier Transform. The obtained information allowed us to determine the frequency domain of our acquired signals and design hardware filtering around our chosen frequencies. This was essential in our testing and prototype designs.

Furthermore, as mentioned in the above section additional filtering is performed using Labview software.



4. Future plans

Small Heart EKG has great room of expansion. As we re-examine the development of the device, we have the following suggestions for future development.

4.1 Probing

- Use finer gauge wires to save space
- Reduce electrode contact tip size
- More electrodes involve during probing
- Design of mechanical device to hold probes in place

4.2 Signal Processing and Analysis

- Develop more sophisticated UI for better visualization of heart signal (for example, physical arrangement of probes)
- Interpret acquired data and measure PQRSST time differences.
- Labview interface can be developed as a sub-vi of the original programming at BCRI

4.3 Optical Fiber

- Possible alternative of the electrical system is the fiber systems.
- Optical fiber will eliminate the cross-talk and interruptions between wires.

5. Budgetary and Time Constraints

5.1 Budget

Overall, we are under budget for our project. This can be attributed to the high cost of the Rabbit Microprocessor which we did not need to purchase.

Table 1 contains the estimated cost and the cost of the project up to December 15th, 2003.

| Material | Estimated Cost | Actual Cost |
|------------------------------------|----------------|------------------|
| Electrodes/Platinum Wiring | \$100 | \$271.17 |
| Amplifier(s) | \$100 | \$ 42.00 |
| Electronics | \$100 | \$ 262.12 |
| Assorted Active Components | \$30 | \$ 52.12 |
| Assorted Passive Components | \$30 | \$ 28.26 |
| PCB boards / Bread Boards | \$30 | \$ 81.12 |
| Wiring/Misc. | \$10 | \$ 100.62 |
| Wireless transmitter/receiver pair | \$150 | \$0 |
| Rabbit Microprocessor/Board set | \$750 | \$0 |
| Analog/Digital Converter (PIC) | \$20 | \$0 |
| Subtotal | \$1220 | \$ 575.29 |
| Contingency Expenses (15%) | \$183 | N/A |
| Total | \$1403 | \$ 575.29 |
| Unanticipated Materials | | \$ 175.87 |
| | | |
| | | |
| | | |
| | | |
| | | |
| Total | \$1403 | \$ 751.16 |

Table 1: Estimated Cost vs. Actual Cost

5.2 Time

The biggest obstacle is the expensive and limited chemical buffer that is needed to keep the isolated rabbit heart working for us to test our circuits. This greatly reduces the time we can work on the heart, which was not expected. Also the size and condition of the heart was quite variable and we had a few times when did not obtain any useful signal even after many hours of attempts.

In terms of project timeline, we were on schedule has planned in our initial proposal. The below figure is a Gantt chart of the initial project timeline.

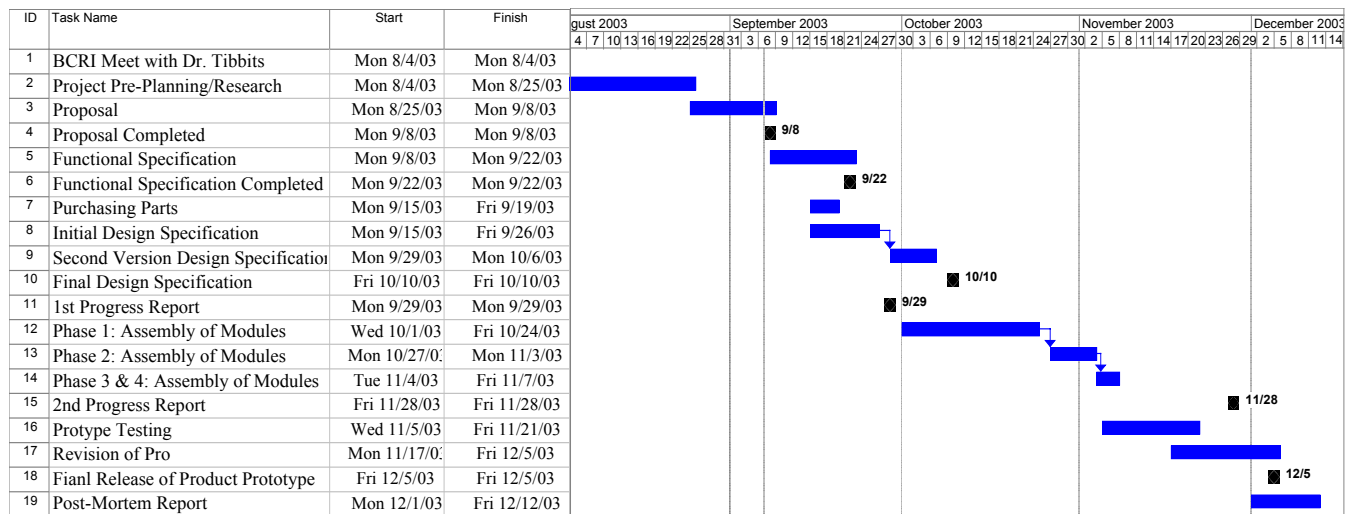


Figure 4: Gantt Chart of Initial Project Timeline



6. Inter-Personal and Technical Experiences

Jeff Chang

Looking back, it is safe to say that it has been one of the most stressful and yet most rewarding 6 months of my life. The project proves more challenging than expected due to integration between electronic and biological systems. This is one of the first tests for me personally to test myself to see if I am capable as an engineer. To see if I am capable to applying the knowledge I learned in previous engineering classes. Unlike co-op, the group members in the project has similar experiences and knowledge, so help must come from external sources, such as professors, TAs, and industry people. Talking to them makes one realize the lack of experience and knowledge a 4th year engineering student is. However, it becomes apparent to team very quickly, as the engineering education would not be able to prepare us for all possible challenges. It is good training to find out the necessary information through various sources.

Interactions between team members in such a large group are important. Harmony within the group is essential for team members to work long and late hours. With such a large group, there are major differences in personalities and work ethics. All in all, the group dynamics were great, and we had fun working together as the mood was light because constant jokes kept the group members in relatively good mood. It was a wonderful experience to work with others, and using the combined knowledge of everyone in pursuit of one ultimate goal.

Another important lesson we learned from the project is the importance of hands-on work. Theories and ideas seem good on paper, but often in reality it will not work. For example, the construction of the electrode seemed to be easy, but it actually requires much skill due to the miniature size of the electrode. Needless to say, many electrode tips broke off prematurely because of improper use of force.

The most satisfying part of the project is being able to apply the knowledge learned in previous courses because it was hard work to study for all those courses, but using it in this project makes one feel time wasn't wasted studying. The success of the project affirms the value of the years of hard being in engineering science.



Eric Chow

Overall, I had a positive learning experience throughout this semester. On the technical side, I have learnt the technique of DAQ (data acquisition) using National Instrument DAQ card, and interfacing the card with LabView. This is something I always wanted to learn, but never had a chance to throughout my education at SFU engineering. I was quite impressed with the capability of LabView, and the ease of creating custom user interface for data acquisition and analysis software. Such knowledge will be useful for any future work in lab setting.

The application of my knowledge in electronics and filter design is proved to be useful for this project. Circuitries learnt from ENSC225 and ENSC325 on active filters are applicable to this project. No longer are we only feeding in sine waves at certain frequencies and observe expected result as we do in course labs; we actually applied the filter to signals with noise at various frequencies, and able to extract useful signal by the use of filters. As well, the use high precision instrumentation amplifier in biological project such as these is extremely useful for any other biological data acquisition projects.

Perhaps the most interesting aspect of this project is the biology. With minimal knowledge on biology, I am glad that I have the privilege of learning from cardiologist about the working of the heart.

I also learnt that successful research project is a coordination of professionals from various fields. In our case, we had a mix of professionals from cardiology, kinesiology and engineering, as well as papers and publications from science journals. I learnt that regardless of any topic, there is always someone in this world already working on similar problem, and thus it is helpful to spend time on looking for such resources rather than designing from scratch.

Last but not least, I feel that our project has a positive contribution to the field of cardiology and could possibly help real patients in the future. This makes this project an extremely meaningful one and our time spent worthwhile.



George Kwei

From working on the Small Heart EKG Project, I have been able to apply my studies in past courses and have learned more than I expected. In this project, I was able to contribute and gain valuable experience working with biological systems, hardware circuit design, data acquisition, and Labview software.

At the onset of this project, I had little biology background. Most of what I now know about the functions of a heart and the circulatory system has been extracted from the project. The challenges involved with working with live specimens was more technical than I had anticipated.

Concepts I had learned in electric circuit design became very useful. Application to amplifying and filtering real signals was a challenging task. No longer was I working with ideal signals with minimal noise, but instead working with sometimes unknown signals with the challenge of eliminating noise. Furthermore, having the chance to practice PCB soldering was good to have.

Using data acquisition and Labview software was something new I was able to work with. Labview has proven to be very versatile and a very powerful application. I was astonished by all the different things Labview could do, and the relative ease of performing complex tasks using a GUI interface.

The skills and experience I have gained over the course of this project, is sure to be of great asset in my present future. Working within a medium sized group was also challenging to ensure everyone was coordinated and working efficiently. At the end, we have survived and I have made great friends amongst my team members. I would like to thank Dr. Glen Tibbits for the opportunity to undertake this project, and Eric Lin and Helen Sheng for their technical assistance. Without them, this project would not be possible.



Seddrak Luu

This project has been one the most rewarding experiences in my engineering career. From choosing the right group members, picking out a project to knowing Dr. Glen Tibbits from the BC Research Institute, the whole process is extremely valuable to my future career. There are several aspects of the project I learnt which I found beneficial.

On the technical side, I have applied my knowledge from the digital signal processing and electric circuitry courses. I was involved in finding the suitable circuitry for our pre-amplification stage while assigning the actual re-designing, building and testing of the circuitry to other group members. I was also involved in designing the electrodes at the initial stage, which applies my knowledge on engineering material. I enjoyed the process of improving the usability of the LabView software. Throughout the process, I have the valuable chance of learning the LabView software, which I believe this kind of experiences are difficult to discover in regular courses and laboratories.

On the other side, I have learnt a lot in the leadership side of the project. I was responsible for assigning different tasks to the group members, keep up-to-date to our schedule, decide on critical resolutions during emergency situations and hosting group meetings and contacts. I found myself as the “glue” of the company, which I believe, is very crucial to a company environment.

I recalled during the beginning of November, we still fail to observe a small signal from the rabbit heart. After a whole day of work, we all sit outside BCRI and yelled in pain. I admitted that when my group partner start asking me what we should do next since I am the group leader, I was confused. But then, I knew that I have to make rational decisions. In the end, I suggested we have to go back to the lab, and list out possible problems based on our observation. Also, I start contacting more people to get their advice. In the end, we are glad that we can slowly get a heart signal from the rabbit heart and eventually finish our product in a timely fashion.

I also believe group dynamics and group unity are the most important ingredients to a successful project. When people are feeling down and failure, we have to be there to motivate. As I was always saying to my group members, “not until the exact moment we are presenting, we still have time and we will not give up”. At the beginning we are good friends. At the end, we grow even closer. Although all the laughter and fun has passed, it will always be in my mind. I look forward in working with these people later on during my engineering career.

Last of all, the project is a very priceless experience for me since I am planning in pursuing my career in the biomedical engineering field, especially bio-equipment. Due to this project, I am going to continue with a similar project with Dr. Glen Tibbits, but this time with fiber optics. I will be working with a different group of people including a sub-group of people who will take Ensc 305 and Ensc 340 in 2004. I believe this will be another exciting project for my partners and me.



Joe Ma

This course provided a good opportunity to encapsulate and apply some of the knowledge acquired through the many engineering courses I have taken here at SFU. It also provided a setting resembling that of a real life corporation where I was able to take part in work together to accomplish an end goal. I am glad to be a part of this process where we started out with an idea in mind and ended up with a completion of our product. Through this completion, we faced many challenges and learned how to deal with and handle each of them as a group.

A real challenge in terms of the scope of the project is our inadequate biological background. Thankfully our associates at BCRI were patient and helpful with us. I realize the importance of understanding and learning about the project at an early stage. However, given the four month time frame of our course plus the additional course load we have, as opposed to an actual company dedicating full work hours, we have our limitations. It is also very important to find out about and talk to those who have previous background in the matter we are working with. They would be able to provide invaluable insight and help increase efficiency in our progress.

The last point I would like to stress is team cohesiveness. Our group had six members, efficient and adequate communication becomes challenging as group size increases. An effective distribution of tasks is necessary and so are the needs for meetings and group updates. Fortunately, we are all colleagues and a few of us have worked together previously to ease the process. This course has definitely been a great learning experience for me, and I shall now be able to apply this acquired experience in future endeavors.



Kenny Pak

From day one I knew that this project was going to be a fulfilling challenge in more ways than one. Being involved in this large group project let me understand what it could be possible be like in the outside work world.

On the technical side, I once again was part of the hardware design and implementation team. This was by far my favorite part of the project. I really did enjoy figuring out the implementation of the circuitry used to relay the analog signal into the A/D converter with as minimal signal loss as possible. I got a chance to work on my hands on skills for making breadboard setups and for laying out the PCB version of the circuit as a final step in our project.

Along side the hardware, we had both A/D conversion and software. I was less involved in this section of design but by keeping up with the project I found it easy to help with ideas when necessary. This was the great part of being part of a team because not everyone needs to know everything as long as everyone has a specialty in one area or another. That is the beauty of working in the team environment which I enjoy. Another enjoyable challenge during the duration of this project was to attempt to fully understand the biological parts of this project. As our project was limited in time, I found it difficult to fully comprehend all aspects of biological electrical conduction. I am very grateful that the helpful individuals at BCRI were always willing to lend us knowledge and advice in the situation of answering biological questions and concerns.

As my initial interest for this project was because it was related to the bio-medical field, it clearly gave me a strong determination to work extremely hard on this project to see its completion. This was a great experience for me as it was a first major step towards what I see myself doing as an engineer in today's society.

This project has taught me many basic ideas of how large and semi long term projects operate. First, it is crucial to sit down and have team meetings to discuss as much as possible. This such as what each individual is expected to do and when certain things should be done by to keep and straight and narrow timeline so that timely completion of the project will be achievable. Next, for any project background information is necessary to do the simplest of things such as ordering parts. Knowing the core information prior to designing the device will save a lot of time as I have learned.

Finally, I learned that team dynamics can make or break the team. Making sure that everyone is working when they are needed is crucial in a successful project. I learned also that everyone has a different work style to achieve the same goal. This requires understanding and patience which is a good skill to learn in the work world for everyone works very differently. There were certain rough spots during this long project but besides those we worked quite well together as we are also good friends in school and in this program which helped this situation and we still are good friends. In the end, we pulled through with our working project which was handed in on time which was a bonus. This was a great experience and I enjoyed every step along the way.