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April 29, 1999

Dr. Andrew Rawicz
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Re: ENSC 370 Remote Transcranial Doppler Ultrasound Orientation Device Process Report

Dear Dr. Rawicz,

We are submitting the document entitled, *Remote Transcranial Doppler Ultrasound Orientation Device Process Report*. This report explains the process that our team went through to design an electromechanical device to orient a Transcranial Doppler (TCD) Ultrasound transducer from a remote location.

This document describes the current status of the device, deviations from the original specifications, and future plans for the device. We have also included as section defining some the challenges encountered throughout the project, and the technical and personal experiences gained by each group member.

KineTech Solutions consists of four engineering science students at Simon Fraser University: Cyrus Sy, Carmel Cinco, Kevin Ko, and Michael Ilich – each with an interest in electronics as well as in the field of Kinesiology. If you have any questions or concerns, please contact Michael at (604) 944-6302 or via email at ilich@sfu.ca. Contact *KineTech Solutions* directly by email at kcmc-ensc370@sfu.ca. Please visit our website at www.sfu.ca/~kkoa/three70/Kinetech.html.

Sincerely,
Michael Ilich
KineTech Solutions

Enclosure: *Remote Transcranial Doppler Ultrasound Orientation Device Functional Process Report*

Process Report

Submitted by
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Date
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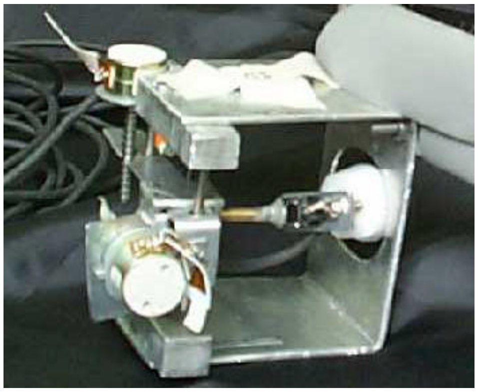
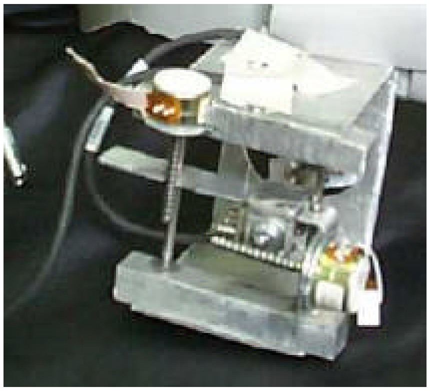
1.0 Introduction

The road to developing the KineTech Solutions Remote Transcranial Doppler Ultrasound Orientation Device (RCTDUOD) was as bumpy as it was smooth. We took on a project that was simple on paper, yet posed some serious mechanical challenges. This report details the trials and tribulations experienced during the development of the RTCDUOD.

2.0 Current State of Device

As described in the project proposal RTCDUOD begins with an input from the test operator via some suitable input device. The operator input is processed and control signals are sent to the sensor actuating mechanism to move the Doppler sensor to the desired position. The angular movement of the TCD sensor is accomplished using a dual-axis planar link mechanism (illustrated in the photos below)





Based on the audible feedback from the TCD ultrasound monitoring system (already provided), the operator will adjust his/her input as needed in order to find the optimal audio signal. The RTCDUOD also incorporates position feedback sensors which help verify movement of the sensor and ensure accurate positioning. The system process is depicted in Figure 1.

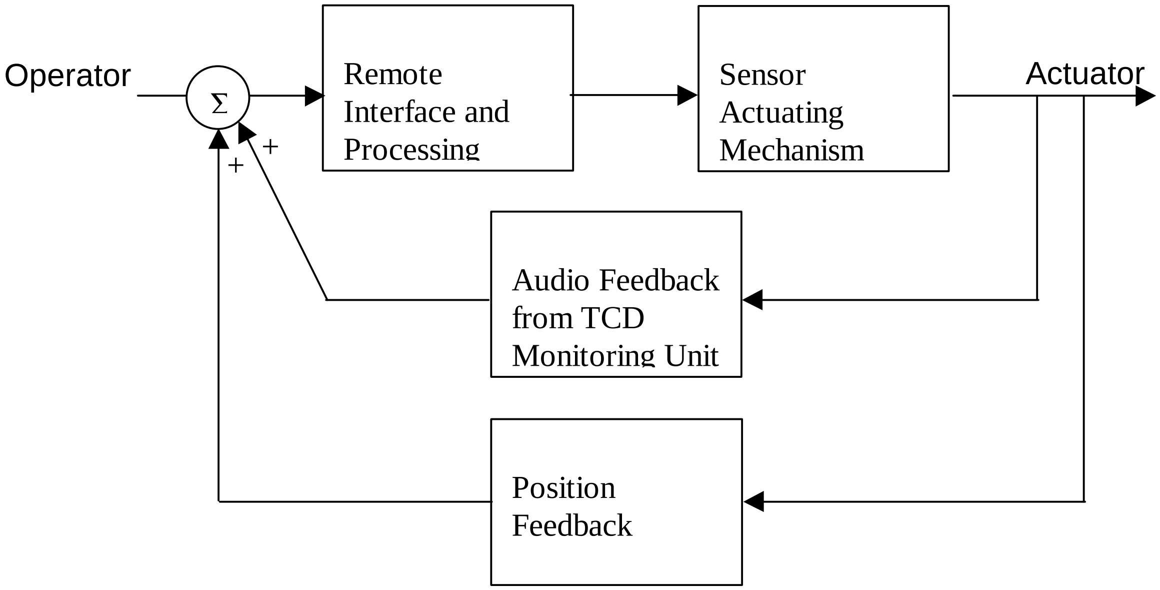


Figure 1: System Diagram

In our prototype system, the Remote Interface and Processing Unit (RIP) consists of a hand-held controller unit connected by wire to a motor control module. The hand-held unit consists of two rotary-type potentiometers for each axis of movement, and a series of status and warning LEDS. The motor control module contains a Motorola MC68HC11E2 micro-controller to process the input signals from the test operator and send appropriate motor command signals to a pair of stepper motor controller IC's. The stepper motor controllers and two dual H-bridge drivers generate the required signals necessary to drive the stepper motors of the Sensor Actuating Mechanism. In addition to the processing electronics the motor control module contains a push button switch to reset the system if necessary.

The Sensor Actuating Mechanism is connected to the motor control module of the RIP via shielded cable. The mechanical design of the Sensor Actuating Mechanism was much more time consuming than expected. However, we believe that the current mechanical structure is a suitable "proof of concept" which can be improved upon in the future. Position feedback is accomplished using a pair of sliding-type potentiometers. However, difficulties were encountered in mechanically linking the potentiometers to the sensor actuating mechanism. As a result, position feedback is not fully implemented.

3.0 Deviation of the Device and Design Issues

3.1 Overall System

Functionally, our device meets most of the requirements that we had planned. Time and cost constraints prevented us from conducting thorough testing in the hyper-hypobaric chamber in the EPU. The mechanical and electrical materials used in the construction of the Sensor Actuating Mechanism may not be suitable for use in the harsh environment of the hyper-hypobaric chamber. However, our prototype system demonstrates that a electro-mechanical means of remotely positioning the TCD sensor is feasible. From this point, a new mechanical system can be created using less pressure sensitive materials.

Due to mechanical constraints the range of sensor motion was restricted to within a small area of approximately 1.5cm x 2.0cm. The RTCDUOD is capable of a maximum 0.136 degree physical resolution using the stepper motors we currently have.

Instead of the using a PC interface, the Remote Interface and Processing Module (RIP) uses a microcontroller-based control unit which reads the test operator's input, converts the signal appropriately, and sends control signals to the Sensor Actuator Module. Instead of a graphical user display as a series of status LEDs and dial knobs were used.

3.2 Remote Processing Unit Hardware

The Remote Interface and Processing Unit (RIP) consists of a hand-held controller unit connected by wire to a motor control module.

3.2.1 Choice of Input Device

Our original functional specifications called for an input device which closely mimics the present method of orienting the Transcranial Doppler Ultrasound Sensor manually. Rotary potentiometers were chosen because they could represent the current position visually (using tick marks) and by touch (you can feel limits of motion). Two rotary pots were used where each pot represented the movement on a single axis (X or Y). Using software, the range of motion of one rotary pot should represent the full range of angular motion of the actual sensor.

3.2.2 Motor Drive Electronics

The rotary input potentiometers generate a voltage between 0 and 5V that is processed by the A/D converter of the MC68HC11 micro-controller. Motor control command signals are generated and sent to a pair of L297 stepper motor controller chips which in turn send appropriate signals to dual H-Bridge drivers necessary to drive the stepper motor. A 555 timer circuit generates an adjustable pulse width modulated signal required by the L297 motor control chips. The speed (torque) of the motor can be adjusted by turning a trim pot on the circuit board.

The current prototype does not fully exploit the processing capabilities of the HC11. Since considerable time and resources were put into the mechanical design we decided to implement very rudimentary position control. In the future the expandability and interfacing capabilities of the HC11 may be used in conjunction with DSP hardware to implement feedback control using the ultrasound output of the TCDUOD (see future plans).

3.2.3 Position Feedback

Although stepper motors are capable of being used with open-loop control, more precise and predictable movement of the ultrasound sensor can be accomplished by using some form of position feedback. We attempted to implement position feedback by using sliding potentiometers that are mechanically coupled to each axis of movement. However, because of mechanical difficulties, the sliding pots are not connected on the Sensor Actuating Mechanism (SAM).

Sliding potentiometers are simple to use; however, we found that they posed some serious problems:

1. Severe Mechanical Loading
The motors chosen could not generate the amount of torque necessary to move the mechanical link AND to overcome the resistance of the sliding pot.

2. Non-Linear Operation
The sliding potentiometers acquired were non-linear.

3. Susceptibility to Severe Environmental Effects.
In addition to the mechanical loading effects, we soon realized that the mechanical contacts in the sliding pot would most likely be sensitive to extreme conditions such as high humidity, pressure and particles – similar to what might be present in a hyperbaric chamber.

3.2.4 Cabling

The prototype could not be fully tested in the hyper/hypobaric chamber using the appropriate BNC cables. However, our design minimizes the amount of wires entering the chamber by placing as much of the control circuitry outside the chamber. The only wires going into the chamber are the 8 wires need to control two motors, 2 lines for the position feedback pots, and a +5V and Ground line, for a total of 12 wires.

3.2 Remote Interface Processing Software

Controlling the stepper motors requires a fair amount of real-time processing. A microcontroller-based system written in assembly code was found to be more suitable than the PC system that was originally proposed in the functional specifications.

3.2.1 Motor Control

By knowing the current position of the feedback pots and receiving the desired position of the rotary pots, the motors move in the necessary direction until both the feedback pots and rotary pots show the same voltage. By placing the feedback pots in their middle position (i.e. 2.5V) and detaching them from the motors, we can implement open loop control of the motors.

During the span of the project, the code experienced a drastic change in how the stepper motors would be enabled. Both the original version and the improved version had the same base algorithm for determining when the motors should move and in what direction. The two versions differed in the manner in which the stepper motors were turned on. The original version of code did not involve a 555 timer. Originally, the microcontroller was programmed to send a high pulse followed by a low pulse in order to cause a step in the stepper motors. Unfortunately, the resulting motion was very jittery. Inconsistency of the step frequency caused inconsistent motion of the motor. An alternative method was necessary. By using a 555 timer, the output of the timer could be connected to the clocks of each of the stepper motor controller chips. As a result, just a simple enable command to the stepper motor controller chips would allow for smooth running of the motors and a simple disable command would stop the motors.

3.2.2 Boundary Sensing

In order to prevent the motors from moving the transducer beyond the limits of the desired workspace, boundary limits have been implemented. Therefore, the motors cannot move any less than the minimum positions or more than the maximum positions of the x and y axes. For example, if the minimum position is reached, but the desired position is less than the actual position, the motor will not be signaled to move to the desired position. The actual position of the motors is indicated via the feedback pots.

3.2.3 Detection of Motor Mobility Problems

Since the product will eventually be used in a hypo/hyperbaric chamber, the operator outside the chamber will not be able to see if the motors are moving as he/she is directing them. A problem light on the operator's hand control unit indicates whether or not the motors are behaving properly. There are two cases in which a motor mobility problem is detected:

- The motor is suppose to move but doesn't move
  Before the motor is told to move, the actual position of the motor is saved. Once the motor is told to move, it is allowed some time to move, if the new actual position is equal to the old actual position then the motor hasn't moved and there is a problem

- The motor is supposed to stop but doesn't stop
  Once the motor is told to stop, the actual position of the motor is saved. A brief time period is given to allow the motor to come to a stop. If the new actual position is not equal to the old actual position, then the motor hasn't stopped and there is a problem.

4.0 Sensor Actuating Mechanism

4.1 Stepper Motors

The bi-polar stepper motors used in our prototype were salvaged from 3.5” floppy disk drives. These motors were quite easy to find from used drives. In addition to there availability, they were small and inexpensive.

4.2 Mechanical Structure

The mechanical structure consists of a plastic headband with aluminum enclosure mounted on the right side. The enclosure contains aluminum bars that hold the stainless steel tracks in place along with a mobile bridge between the rods that has folded metal carrier that connects directly to the sensor via a telescopic shaft arm and universal ball and socket joint. The metal carrier is moved back and forth by the horizontal motor, which is mounted on the sliding bridge as well. The horizontal motor is able to move the carrier a total distance of approximately 1.5cm before obstruction occurs, due to the rods and spring later added to the carrier to keep it straight. The vertical motion of the bridge along the stainless steel rods is extremely stiff and cannot be controlled by the vertical motor at this time.

4.3 Mechanical Challenges

Many challenges faced us in the design of the mechanical system. Initially we were unsure of what material would provide as little friction as possible. Originally, our design involved folded aluminum bars with brass tracks to slide on. With a little grease, the system appeared to work reasonably well, but not quite to our satisfaction. With the added weight of the motor and a sliding piece on the middle bar (to drive the motor in the horizontal direction), we found the system sluggish and were unsure whether the motors would eventually function in such a system.

Eventually we re-built the mechanical frame with solid aluminum bars and replaced the brass rods with the same stainless steel rods used in the worm drive mechanism in most disk drives. Careful drilling and milling were required to align the stainless steel rods with the aluminum bars to ensure a perfectly orthogonal system. An initial concern was the sluggish movement of the middle aluminum bar, meant to carry the horizontal stepper motor (X). We tried fitting the rods with sleeves from the disc drive and re-aligning them, however the torque was still to great to be driven by a stepper motor shaft. We decided to cut the weight of the middle bar down by cutting a new piece of metal less than a millimeter in width. By fitting the hole nearest the vertical motor notch and leaving the other hole a bit wider, we were able to move the middle bar smoothly along the stainless steel rods. One requirement we observed was that the motor (and notch on the middle piece) must not be more than a few millimeters away from the stainless steel rod. The motor shaft should be mounted perpendicular to the middle bar to compensate for the extreme torque imposed on the middle bar by metal friction and the imperfect alignment of the two rods.

The other major challenge in the mechanical system involved the metal carrier that slides across the middle aluminum bar and controls the horizontal position of the sensor. Initially, we simply glued a sleeve onto a folded piece of metal with a notch for the horizontal motor mounted at 90 degrees to the middle bar. When the width of the carrier was fitted to the middle bar, the friction was too great to slide across it. When the width of the carrier was left slightly larger, the side opposite the motor would catch against the middle bar. Our solution was to mount a spring mechanism that kept the carrier against one side of the middle bar, keeping it straight at all times and allowing the horizontal motor to slide it evenly.

Despite our mechanical difficulties theoretical resolution of approximately 0.1 degrees per step can be achieved and the physical size of the mechanical structure falls within our functional requirements.

5.0 Future Plans

After four months of researching and creating a working prototype, the development of the KineTech Solutions' Remote Transcranial Doppler Ultrasound Orientation Device is still in its infancy. Many adjustments and improvements are necessary in this long arduous process. Here are some of the things to look forward to:

5.1 A Better Product Name

The Remote Transcranial Doppler Ultrasound Orientation Device possesses a name that, although clearly explains its application, is annoyingly hard to remember and breath-takingly long to mention. In the future, this product will have a shorter (but fancier) name that will grasp the attention of all mammals within ears' range.

5.2 Motor selection

The motors are an integral part of the RTCDUOD system. Due to budgetary restrictions and size limitations, small motors taken from 3.5" disk drives were used. Although these motors offered a desirable size and weight, the torque available was not enough. These motors also tend to draw a large amount of current and heat up quite quickly. Given a larger budget, we can expect to get more accurate motors (i.e. higher resolution) with higher torque. Possible motors we can use can be purchased from Shinano (a company in the United States). Their motors have high torque and very high resolution (500 steps/revolution).

5.3 Feedback Sensors

The feedback potentiometer was accidentally chosen as a non-linear pot, as opposed to a linear pot. The effect of this is that the resolution of the feedback voltage from the sliding pots is poor for low values of feedback voltage. If we could do this again, we would use linear potentiometers for a more balanced resolution.

Furthermore, the use of a subtracter (negative adder) would be a better way of determining where the position of the system is relative to the desired position.

5.4 Packaging

Our electronic system is packaged in a simple metal casing with the user controls (rotary potentiometers) and LEDs extruding from the box. Future plans include having all necessary electronics in one box, and having a smaller, but stable, wired “remote control” connected to the main box. The remote control will include any input or output signals (again, potentiometers and LEDs). The remote control will allow the user to move around conveniently while operating the RTCDUOD. The remote control enclosure was attempted for our prototype; however long wires caused problem with noise affecting the motors’ performance.

5.5 Mechanical System

The mechanical system was completely handcrafted in KineTech Solutions’ limited machine shop. Manufacturing a miniature system, as mentioned earlier, gives rise to many new problems. As it is obviously necessary to keep the size of the orientation device small, more attention needs to be focused on the construction of the mechanical system. Given more time and money, a professionally manufactured mechanical system would have smoother running sliding shafts, and an infinitely more accurate worm drive control. A good mechanical construction would result in a more precise RTCDUOD.

5.6 Translation Routine

Currently, we are treating the relationship between the desired position and the actual position to be linear. Unfortunately, the linear movement caused by the motors result in a spherical movement on the transducer. Therefore, the relationship between the desired position and the actual position of the transducer is not linear. Either a lookup table or calculations will be required to compensate for the fact that as we approach the extremes of the transducer’s reachable workspace the relative amount of movement from the motors differs. Referring to the Figure 2 on the following page, you can see that even though the $\Delta\theta$’s are the same, the ΔY’s are not.

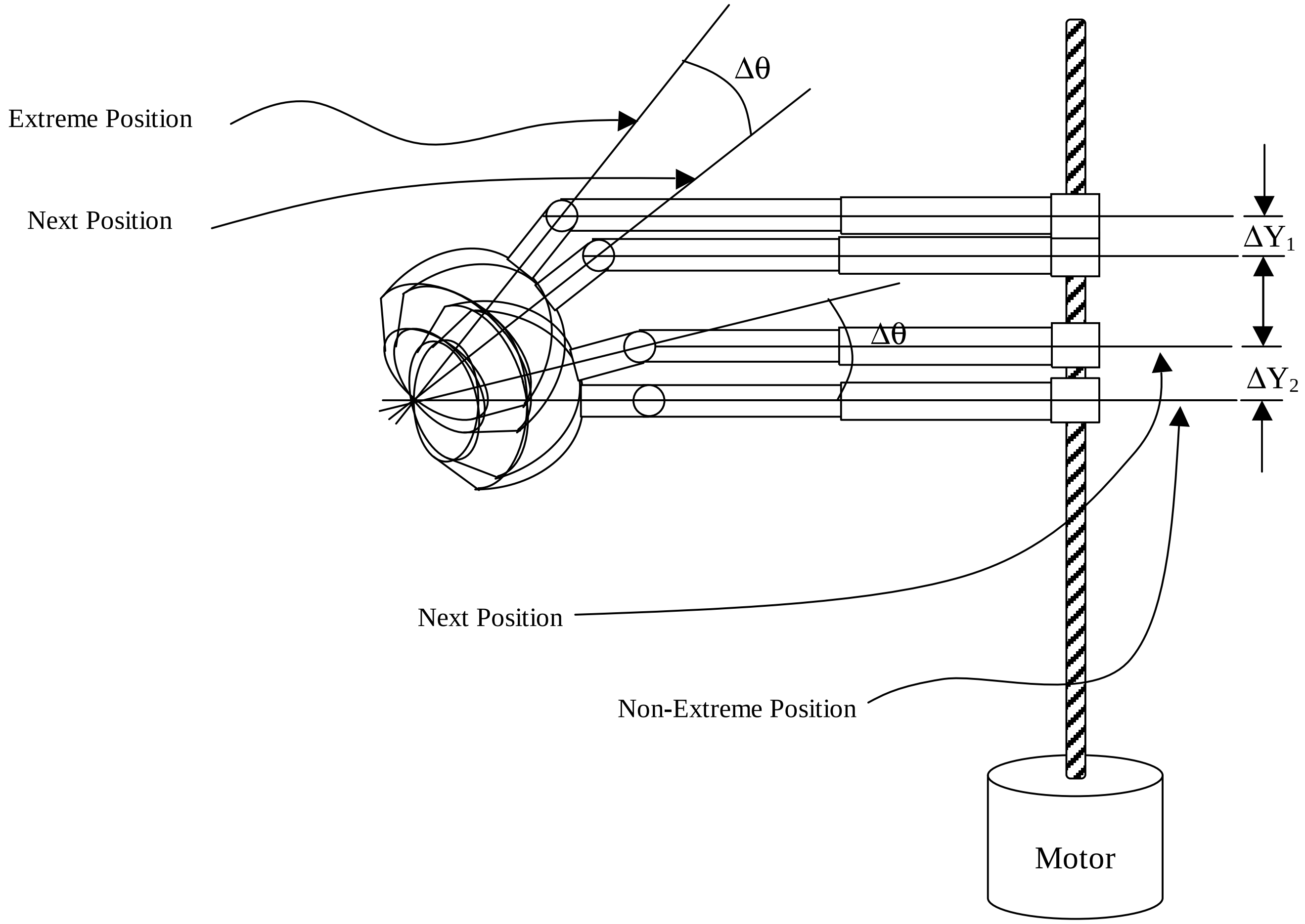


Figure 2: How the Change in Distance Differs as the Extreme Position is Reached

5.7 Intelligent Optimization Routine

In addition to the manual mode of operation currently implemented, we would like to add an autonomous operation mode. This would require processing the audible output from the TCD monitoring unit into a manageable digital form. The object of the algorithm would then be to move the transducer until the processed sound waves are at its clearest and loudest. This could be implemented with using the processing capabilities of the HC11 and the perhaps DSP hardware.

6.0 Personal Experiences and Lessons Learned

6.1 Carmel T. Cinco

The past four months have definitely been a whirlwind experience for me. I've felt frustration, fatigue, panic, and exhilaration. As my participation in ENSC 370 comes to a close, I have earned valuable lessons in both technical ability and team work skills.

Being one of the major code contributors, I substantially increased my knowledge of stepper motor control and HC11 assembly programming. I was also able to fine-tune my layout and commenting skills in order to provide maximum code readability. As the major software tester, I sharpened my testing skills by outlining my own test procedure and all the cases I needed to test. Working with a portion of the hardware planning and assembly also helped ease some of my hardware phobias.

As for my team work skills, I have a greater understanding of the importance of communication between the software and hardware developers. The software developer must always be clear about which ports, pins, types of sensors, and types of indicators he/she requires in order for the software to work. Although communication is very important to team dynamics, I am sure my teammates will agree with me that time management is just, if not more, important. When we took on this specific topic for our project, we did not realize how difficult and time consuming the mechanical portion would be. From this experience, I think it would be better in the future to at least start each section of the project early on in order to realize the full scope of the time and energy required. Luckily for us, we contained enough energy, determination, and stamina in order to complete a working version of the project.

I also enjoyed going through the design process; from research to brainstorming to implementation and finally to testing. Working for Dr. Andrew Blaber also made the project more exciting since it provided the professional experience of creating and tailoring a specific product for a client's needs.

6.2 Michael Ilich

In the four months we spent developing the Remote Trans-cranial Doppler Orientation Device, I learned that, above all, teamwork and an equal effort constitute the foundation for any successful project. Without the dedication and enthusiasm of all four group members, this project would certainly not have been possible in such a short period. A well thought out functional specification is an extremely important guide for all team members to follow, however each team member must remain flexible to apply changes when necessary. Although our group was very familiar with programming the HC11 and preparing a circuit, we were all very unfamiliar with controlling stepper motors and machining small mechanical parts. Hence, our controller circuitry and mechanical system faced many revisions before a final design was agreed upon.

I learned that my brief exposure to industrial education in high school wasn't a complete waste as it was extremely useful when it came to building the mechanical system to house the motors. Textbooks were useful for reference in many cases, however advice from experienced individuals (engineers and hobbyists) proved most valuable for the major areas of uncertainty. For example, we realized very early that the shaft guiding the sensor would have to be flexible yet rigid. Upon investigation, a mechanism similar to a constant velocity joint was suggested, however a universal ball and socket joint was finally chosen (for full freedom in all directions).

Finally, I learned that a little thought and a little resourcefulness can go a long way, both in efficiently solving a problem and in doing it affordably. Our first notion in the design of the RTCDUOD was to find a device that functioned similarly, in a mechanical fashion. As a result, we discovered striking similarities in the operation of a computer disk drive, from which we obtained many parts including the stepper motors, the slider rods, screws and springs. With these parts, the basis for the RTCDUOD was established.

6.3 Kevin Ko

During these past four months of discussing, designing, building, and testing, the most important things I have learned are that it pays to start early on a large project as the given. Many problems were encountered too late in the development process, not allowing us to overcome them and finish as planned.

In the discussion stages, communication with my group members and with Dr. Andrew Blaber provided me with more interpersonal experience, experience in working in a group and with other people on a large project. Knowing sources through which funds can be acquired is also useful information acquired in working on this project.

From a technical point of view, I learned more about researching and acquiring electronic parts, how to use these parts in a circuit, and parameter issues to consider when working with a particular part (e.g. current consumption). At the same time, complications with simple devices such as potentiometers can and will also arise unexplainably. In order to build the mechanical structure of the RTCDUOD, I improved my skills in the machine shop – working with some of the machines more effectively and effectively. A number of the machine shop machines I had never had a chance to work with before. Now I feel confident in using them all.

6.4 J. Cyrus Sy

Something I was constantly reminded of over the last13 weeks is that design is an inherently iterative process. Good design requires one to break down a problem into a set of smaller problems, analyze them, come up with a solution, test the solution, identifying what works, what doesn't work, and then starting the whole process over again to make improvements. My group went through several mechanical and electrical design changes, each change leading to something that worked better than the previous method.

Technically, I came away with a deeper understanding of stepper motor control and electronic design. I learned a lot of the 'nitty-gritty' details of configuring an HC11 microcontroller for use in a real-time control application. The project was an even more relevant and valuable experience because I was able to apply the theory learned from courses I was taking at the same time – one course on robotics and another on sensors and actuators.

As with all projects, time management proved to be another important lesson. We found that we could have avoided a lot of grief (and sleepless nights) had we resolved several basic issues earlier. I also learned that its sometimes easy to get too frustrated or caught up with one particular problem while working alone. As a result valuable time can be wasted. Consequently, I found that a lot time can be saved by asking others (ie. The lab engineers, profs and other students) for advice.

Finally, the most challenging aspect about our project was the mechanical design. I found that my mechanical design skills are far from stellar. This project made me realize how mechanics is such an important part of any engineering design (even for electronics engineers) and has motivated me to learn more about mechanical design.