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March 12, 1999

Re: ENSC 370 Remote Transcranial Doppler Ultrasound Orientation Device Design Specifications

Dear Dr. Rawicz,

We are submitting the document entitled, *Remote Transcranial Doppler Ultrasound Orientation Device Design Specifications*. Our intention is to design an electromechanical means of adjusting a Transcranial Doppler Ultrasound transducer used in measuring blood velocity in a cranial artery. Remote adjustment will allow the operator to find an optimal signal without having to be at the subject's side. The attached document outlines the design specifications of our system. The main components of our system are the remote interface and processor and the sensor-actuator mechanism.

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.

Sincerely,

Michael Ilich
KineTech Solutions

Enclosure: *Remote Transcranial Doppler Ultrasound Orientation Device Design Specifications*

Remote Transcranial Doppler Ultrasound Orientation Device Design Specifications

Submitted by KineTech Solutions
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Date March 12, 1999

Executive Summary

Over the last 20 years, the development of Transcranial Doppler (TCD) sonography has allowed researchers, such as those at Simon Fraser University's Aerospace Physiology Lab, to use noninvasive techniques to assess intracranial circulation. Data collected from TCD can help researchers understand the physiological effects of extreme environments such as high and low altitudes. Within the rest of the medical community, TCD has proven to be useful in helping to predict strokes.

The problem with the existing TCD ultrasound systems is that the ultrasound sensor must be manually positioned by hand. Each time the transducer needs to be repositioned, someone must be present at the side of the test subject to make the appropriate adjustment. The problem is exacerbated when experiments need to be done in a hypo-hyperbaric chamber, which simulates high and low altitudes. The data-analyzing computer must remain outside of the chamber — for safety purposes. It would be inconvenient and even dangerous to always have the test operator and test equipment inside the pressurized chamber to adjust the position of the sensor.

KineTech Solutions has decided to design and prototype an electro-mechanical system which can alter the position and orientation of the transducer from a remote location. Our primary goal is to create a remote control system that would provide the same level of accuracy and user intuitiveness as the current manual positioning system. Additionally, our remote system will be designed to withstand the extreme environmental conditions inside hypo-hyperbaric chambers.

Table of Contents

Executive Summary i

Table of Contents ii

List of Figures iii

List of Tables iii

1.0 Introduction 1

2.0 Background 2

3.0 System Overview 3

4.0 Remote Interface and Processing (RIP) 4

4.1 Microcontroller Selection 6

5.0 Sensor-Actuator Mechanism (SAM) 7

5.1 Mechanical Structure 7

5.2 Motor Requirements 8

5.3 Sliding Block 9

5.4 Transducer Block 9

5.5 Transducer Arm 9

5.6 Materials 10

5.7 Choice of motor 11

5.8 Driving the Stepper Motor 12

6.0 Electronic Hardware Overview 12

6.1 User Interface 13

6.2 Stepper Motor Interface 13

Hardware Precautions 15

6.0 Testing 16

6.1 Resolution Testing 16

6.2 Pressure Testing 17

List of Figures

Figure 1: Ultrasound Monitoring Unit ____ *2*
Figure 2: System Block Diagram ____ *3*
Figure 4: Movement Actuators (drawn to scale) ____ *7*
Figure 5: Movement Actuators - Profile (drawn to scale) ____ *8*
Figure 6: Transducer Arm ____ *9*
Figure 7: Motor Circuitry ____ *12*
Figure 8: Schematic of HC11 and Motor Drive Circuit ____ *13*
Figure 9: Components for Calculating Resolution ____ *16*

List of Tables

Table 1 : Half-Step Excitations ____ *14*
Table 2: Full-Step Excitations ____ *14*

1.0 Introduction

The Transcranial Doppler (TCD) ultrasound is a noninvasive technique used to measure blood flow velocity in cranial arteries. In this system, a crystal transducer emits ultrasound pulses towards the target artery and measures the reflected ultrasound. The velocity of blood is then calculated using the Doppler shift in the reflected waves. The TCD ultrasound is used widely in the medical community and in human physiology laboratories. Knowing the speed at which blood is traveling through intracranial arteries can help detect signs of stress, as well as prevent deaths due to stroke and anemia.

In its current state, a trained operator must manually position and orient the TCD transducer such that it points precisely at the artery to be observed. This not only calls for a steady hand and experience in finding the artery, but most importantly, it requires the presence of an operator at the side of the subject when repositioning and reorienting is necessary.

KineTech Solutions Remote Transcranial Doppler Ultrasound Orientation Device will allow test operators and researchers a way to remotely orient the transcranial Doppler transducer. Its uses become obvious when trying to measure intracranial blood flow of subjects in a hypo-hyperbaric chamber (where test subjects are exposed to very low or extremely high atmospheric pressures).

This document provides the design specifications of our proposed Remote Transcranial Doppler Ultrasound Orientation Device. The intended audience for this paper is Dr. Andrew Blaber, Dr. Andrew Rawicz, Mr. Steve Whitmore, and the team at KineTech Solutions.

2.0 Background

Extensive research is currently being conducting in the Environmental Physiology Unit (EPU, est. 1981) at SFU to examine human physiological response to extreme environmental conditions. Components of the research apparatus include a climatic chamber, hot and cold immersion tanks and an altitude/diving chamber. The EPU allows simulation of a variety of temperatures and pressures under wet and dry conditions, below and above sea level.

The component that most concerns our project at hand is the altitude/diving chamber. It consists of an entrance lock, wet chamber and living chamber. The living chamber can accommodate up to four divers and includes four beds, a table, and systems for communication and fire detection/suppression as well as breathing masks. The chamber is rated to a pressure of 305 meters below sea level and an altitude of 12,000 meters. Internal and external doors allow separate pressurization or evacuation of either the wet chamber or living chamber. Each chamber is controlled from a central console that monitors air purity, temperature and water filtration. The altitude/diving chamber will also be referred to as the hypo-hyperbaric chamber.

Dr. Andrew Blaber, the Kinesiology professor who we approached for this project, is concerned with the analysis of blood cell velocity through the major cranial arteries when humans are subjected to extreme depths and altitudes. His analysis is achieved using DWL Electronic Systems, MultiFlow® TCD Ultrasound Monitoring System (see Figure 1). MultiFlow consists of a Doppler Ultrasound sensor connected to a dedicated 486-based computer. The MultiFlow computer has a built in display, stereo-loudspeakers and FFT (Fast-Fourier-Transform) for signal analysis. Test operators monitor pulses received from the ultrasound probe at the terminal. The operator can adjust the probe by hand while looking at a graphical and audible representation of the signal from the terminal to find the optimal signal.

Figure 1: Ultrasound Monitoring Unit[1]

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[1] Photo taken from DWL Electronic Systems website http://www.dwl.de/home_e.html

3.0 System Overview

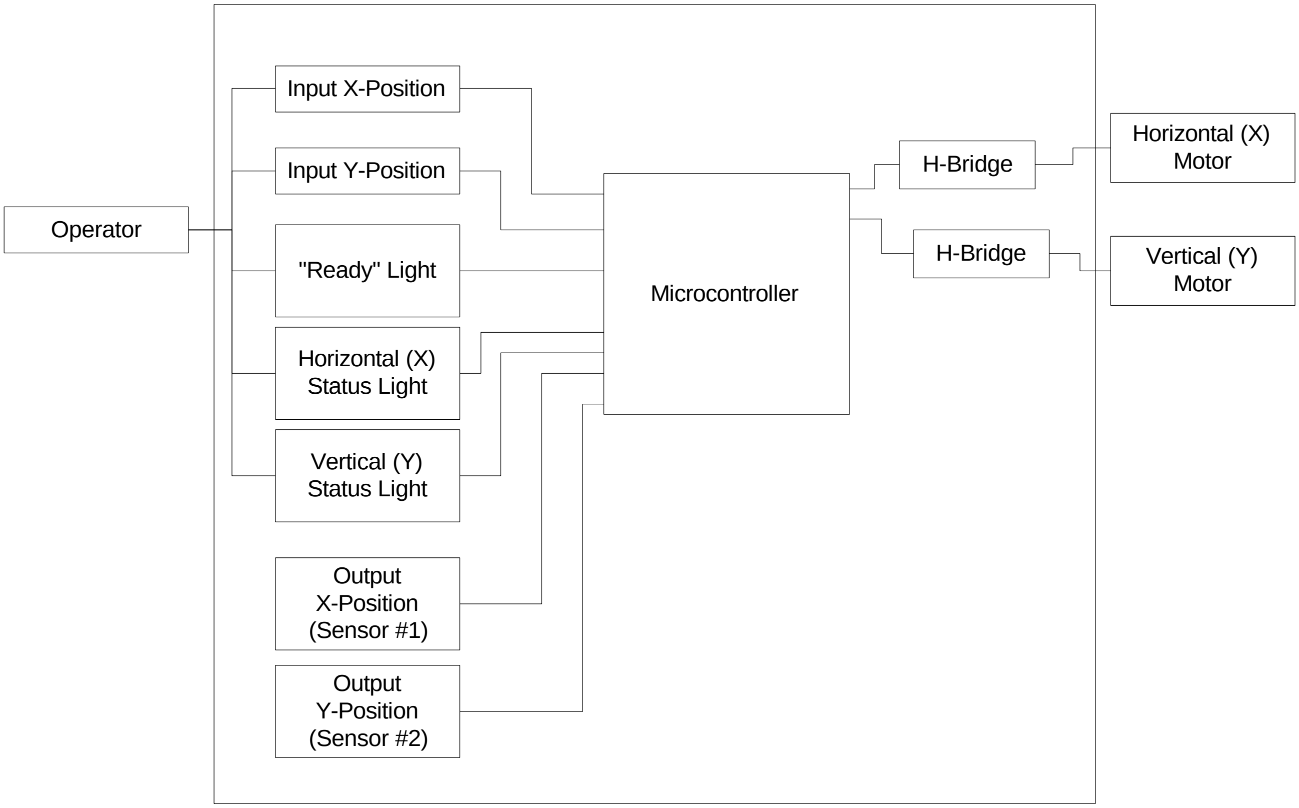


Figure 2: System Block Diagram

Figure 2 shows the general components of how the operator input will be translated into motor movement. The operator is able to input his/her desired x-y position which is fed into the microcontroller and communicated to the motors. Status lights, such as the “Ready” Light, Horizontal Status Light, and Vertical Status Light, are used to indicated when the system is operational and when each motor is moving. Sensors #1 and #2 are used to feedback the position of each motor to the microcontroller.

4.0 Remote Interface and Processing (RIP)

The Remote Interface and Processing Module (RIP) will consist of a suitable input device, and a PC or microcontroller based control unit which reads the test operator's input. The RIP will convert the signal appropriately, and send control signals to the Sensor-Actuator Mechanism.

The flowchart on the following page illustrates how the operator input will be interpreted into motor movement.

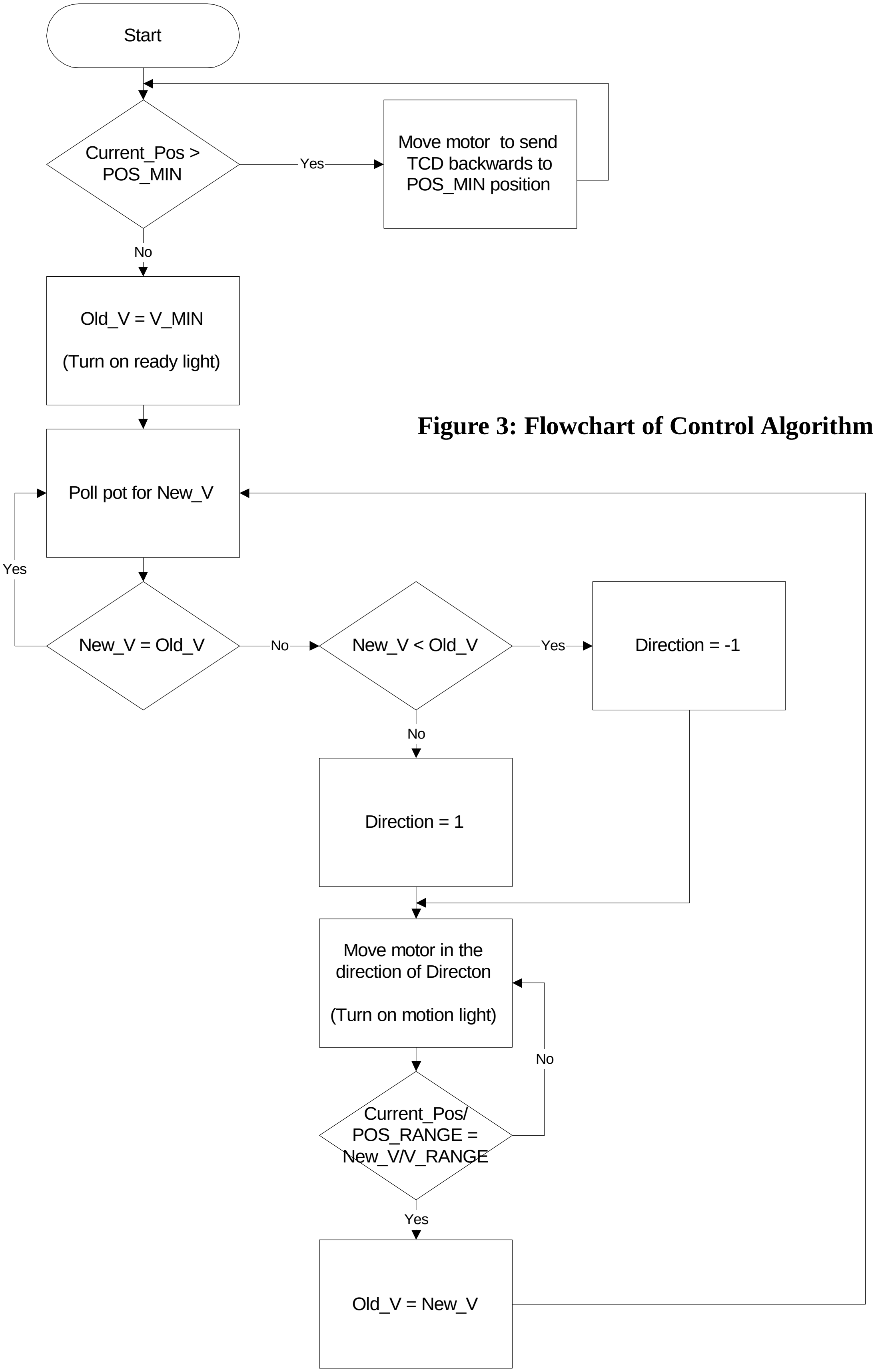


Figure 3: Flowchart of Control Algorithm

4.1 Microcontroller Selection

Some of the microcontrollers that we have considered were the Microchip PIC, Atmel AVR, and Motorola's MC68HC11. We decided to use the MC68HC11 because of our group's considerable experience with the HC11 for a very similar application, its 2 Kilobyte of on-board EEPROM, and the wide availability of resources and support for the chip.

We will use the M68HC811E2, which is an advanced 8-bit micro-controller unit (MCU) with highly sophisticated on-chip capabilities. The on-chip memory system include 8K bytes of read-only memory (ROM), 256 bytes of random-access memory (RAM) and 2K bytes of electrically erasable programmable ROM (EEPROM).

Major peripheral functions are provided on-chip. An eight-channel analog-to-digital (A/D) converter with eight-bit resolution is included. An asynchronous serial communications interface (SCI) and a separate synchronous serial peripheral interface (SPI) are included. The main 16-bit, free-running timer system has three input-capture lines, five output-compare lines, and a real-time interrupt function. An 8-bit pulse accumulator subsystem can count external events or measure external periods. The micro-controller is the board core: it manages all the inputs/outputs (I/O) with other elements and host and compute all the operations.

A prototype board will be built to run the HC11 in single-chip mode. The board will contain a serial interface (RS232) for connection to a Windows based PC for programming.

5.0 Sensor-Actuator Mechanism (SAM)

The Sensor-Actuator Mechanism Module (SAM) consists of the actuating mechanism used to control the TCD transducer and all other necessary mechanical components and packaging. The dimensions of this unit will fall within approximately 5.25 cm × 7.8 cm × 6.0 cm – which may change as needed.

5.1 Mechanical Structure

The sensor-actuator mechanism design is illustrated in Figure 6. The structure of the device is held by two supporting blocks with two smooth cylindrical supporting shafts running between them. The shafts are solid rods with a diameter of either 3/32 or 1/8 inch embedded into the supporting blocks via holes drilled into the blocks. This gives a sturdy backbone to the actuating mechanisms.

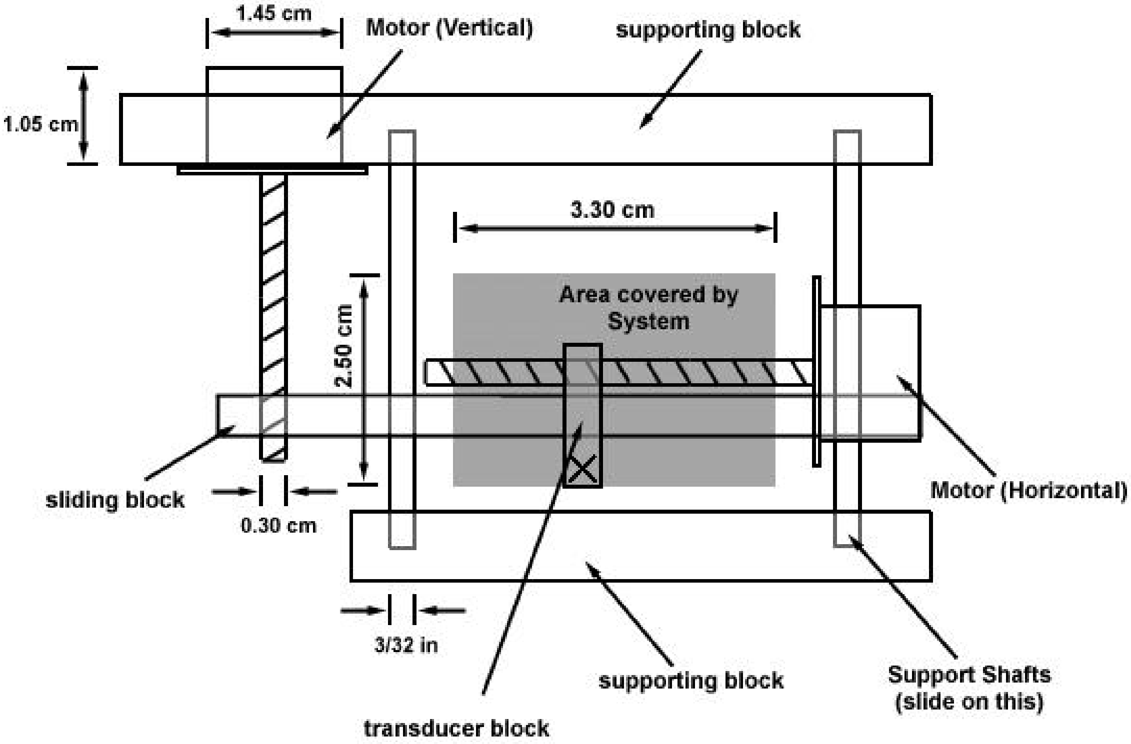


Figure 4: Movement Actuators (drawn to scale)

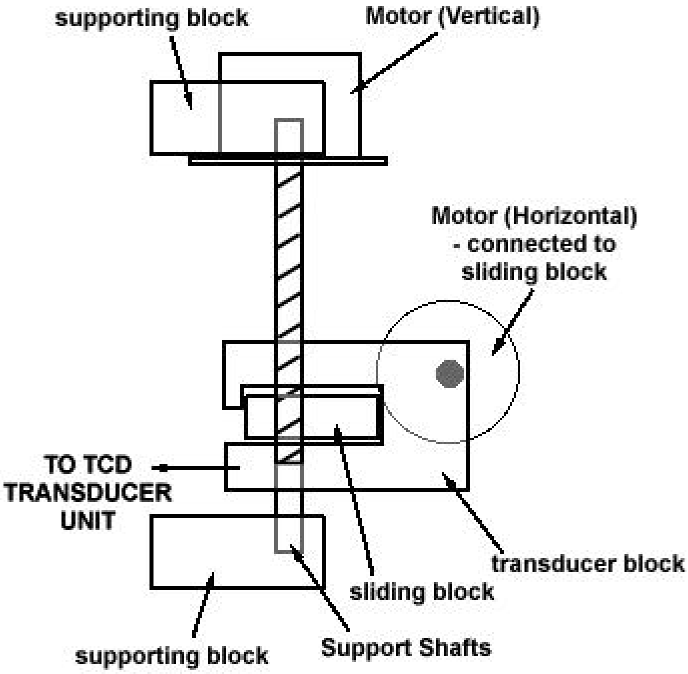


Figure 5: Movement Actuators - Profile (drawn to scale)

5.2 Motor Requirements

Two motors will be used to achieve coverage of a full area of motion (one motor for vertical movement, and the other for horizontal). Both motors are taken from 3.5" disk drives. The vertical motor will be mounted into a groove in the top supporting block and will a drive-shaft length of 2.5 cm. The horizontal motor will be mounted on top of a sliding block which will move vertically with the vertical motor acting as a worm-drive. In other words, the horizontal motor itself is not fixed, but will move as the vertical position of the transducer changes. For more detailed information about the stepper motors, refer to Section 5.7.

5.3 Sliding Block

The sliding block is a machined piece of metal that will have two through-holes for the supporting shafts to run through, and a threaded hole through which the motor-shaft threads insert. Its dimensions are undetermined as yet, as there is necessary testing for stability and durability. As mentioned above, as the vertical motor turns, the sliding block will move up or down accordingly.

5.4 Transducer Block

The transducer block (Figure 4) is a block connected to the transducer-moving arm (Figure 6) that will move horizontally as the horizontal worm-drive rotates.

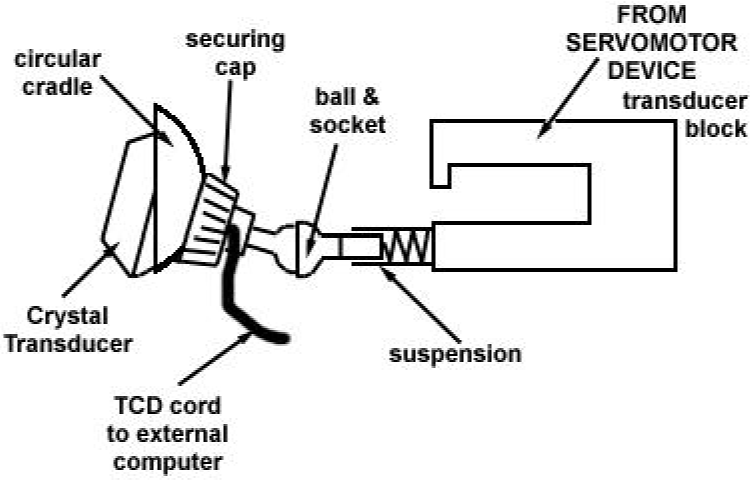


Figure 6: Transducer Arm

5.5 Transducer Arm

The transducer arm consists of three parts: a suspension, a ball and socket, and a metal prong. The cradle of the TCD transducer will be fixed to the supporting block (Figure 6). From the securing cap, a metal prong will protrude, allowing room for the TCD data cord. Because the transducer block will move according to the motor rotations, and the transducer cradle sitting fixed, as the transducer block moves, the angle and distance at which the transducer arm connects to the metal prong will vary. For orienting the transducer to point straight ahead, the suspension is compressed, and the ball and socket is straight. If there is vertical or horizontal movement of the transducer block, the suspension will extend, and the ball and socket will adjust its angle as necessary.

5.6 Materials

For this unit, all blocks and shafts will be metallic. The primary choices of metals are aluminum and brass. Aluminum offers an attractive weight/volume ratio; however it is not as easy to use in bonding (i.e. soldering will not hold). Brass can be soldered onto easily, but is heavier than aluminum. Both metals can be easily bought, and are both resistant to temperature and pressure changes. For our application, the supporting shafts will be the shafts used in 3.5” disk drives. The supporting blocks, the sliding block, and the transducer block will be either aluminum or brass depending on the volume needed (i.e. the supporting blocks should be made of aluminum because they are the largest pieces of the unit) and the necessity to weld or solder other pieces to it.

5.7 Choice of motor

Of all the actuating mechanisms that were available, we decided to use the stepper motor. The stepper motor is essentially a DC motor without the commutator. The windings are part of the stator and the rotor is made of a permanent magnet (PM) or in the case of a Variable Reluctance motor, some magentically soft material.

The stepper motor was chosen over DC servomotors for several reasons:

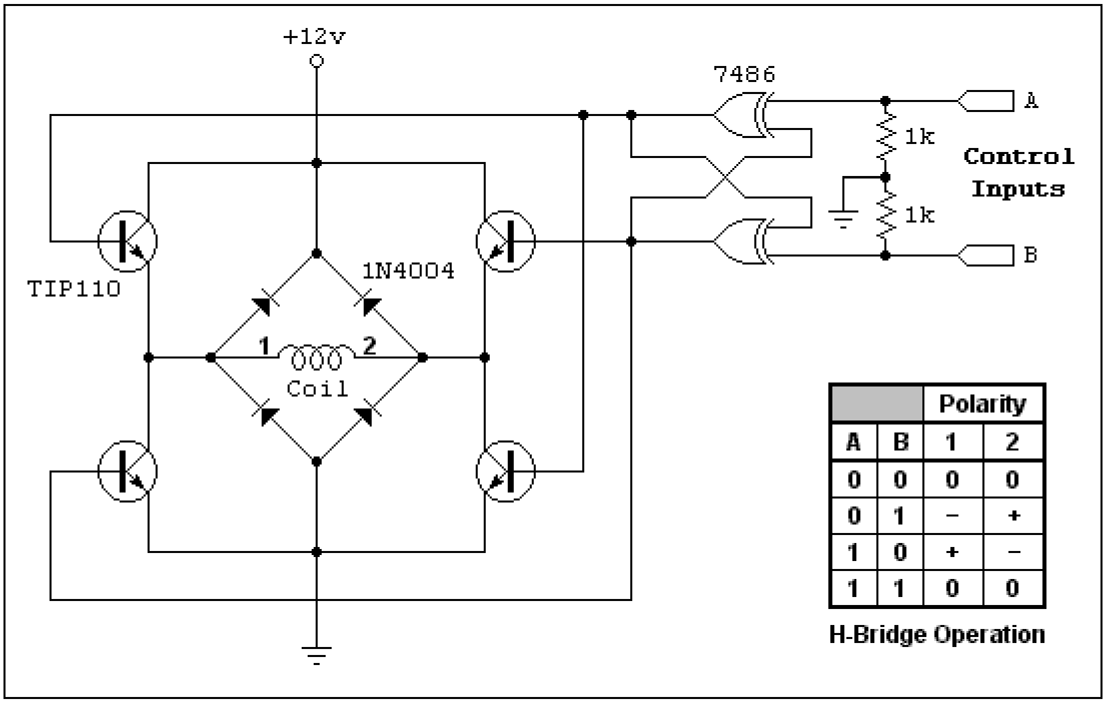
- rotation of the angle of the motor is proportional to the input pulse
- the motor has full torque at standstill (as long as the windings are energized)
- stepper motors generally have very precise positioning and repeatability
- response time is very good
- very reliable in harsher environments because there are less moving parts such as brushes
- motor can be controlled by digital inputs, therefore it is more easy to control using a microcontroller
- ability to achieve very low synchronous rotation with a load directly coupled to the shaft
- a wide range of speeds can be attained since the speed is proportional to the frequency of the input pulses

One of the other significant advantages of a stepper motor is the fact that they can be run in open loop. Expensive sensing and feedback devices such as optical encoders are not necessary.

As mentioned earlier, we will be using two bipolar permanent magnet stepper motors from salvaged 3.5” floppy disk drives. The 3.5” floppy drive motor runs on 5V DC, and has a resolution of approximately 18 degrees of motion.

5.8 Driving the Stepper Motor

The stepper motor from the floppy drives have two separate windings -- two wires per each winding. The windings have to be energized in a particular fashion in order to drive the motor. An H-Bridge circuit is required to drive each coil or winding in a bipolar permanent magnet motor. Figure 7 illustrates the basic energization sequence of the coils and the basic circuit for a single H-Bridge.



		Polarity	
A	B	1	2
0	0	0	0
0	1	–	+
1	0	+	–
1	1	0	0

H-Bridge Operation

Figure 7: Motor Circuitry

6.0 Electronic Hardware Overview

As stated previously, hardware for the TCD Orientation Device will consist of an M68HC11 microprocessor mounted on a prototype board to receive input data from the user interface, process the data, and then transmit control signals to the SAM (Sensor-Actuator Mechanism). Assembly code will be written to outline the semantics of data processing and downloaded from a PC via RS232 serial connection to the HC11's on-board EEPROM. Two input lines will be provided for the user interface and 4 output data lines will be provided for each stepper motor. Figure 8 depicts this.

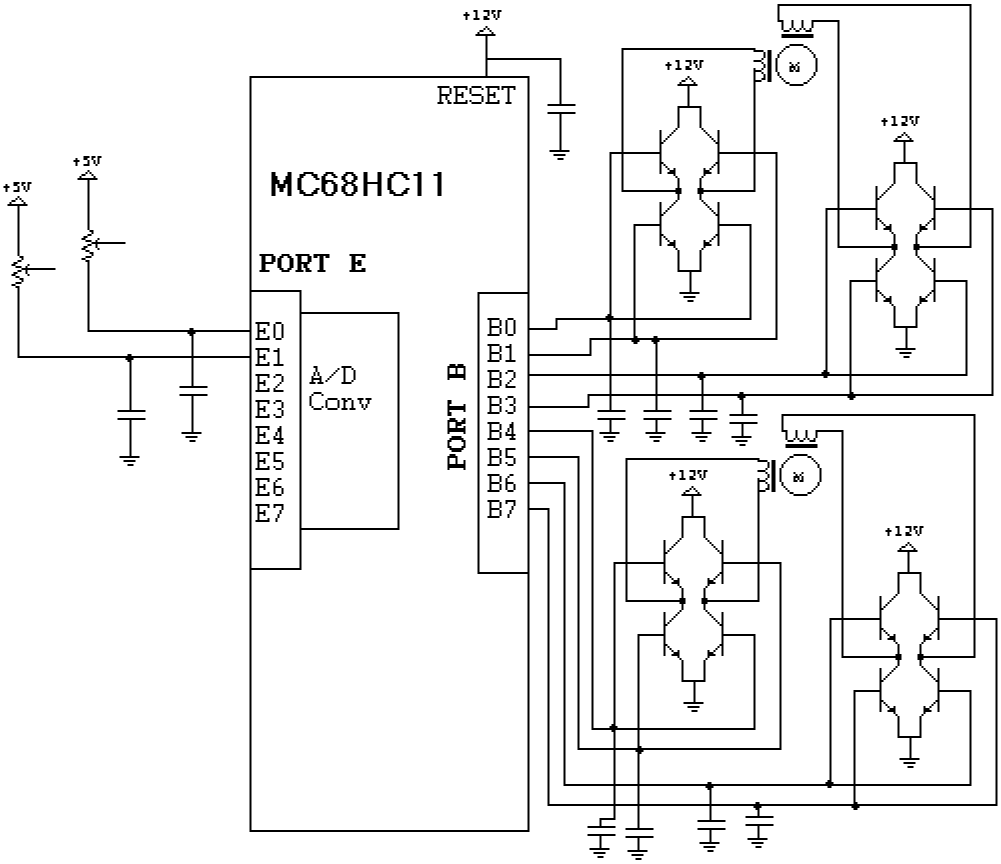


Figure 8: Schematic of HC11 and Motor Drive Circuit

6.1 User Interface

The user interface will consist of a pair of large potentiometers, one to control the rotation of each stepper motor. Each pot will have one pin connected to Vcc (expected to be 5V for input and all analog components), and the other pin connected to one input pin on Port E. Port E was chosen to accommodate the input controls, as these HC11 pins are connected to an internal A/D Converter –this eliminates the need for additional hardware such as a DAC chip.

6.2 Stepper Motor Interface

Four output pins will be require per stepper motor from the HC11 (2 per coil), hence the 8 data lines will be provided by Port B, PB0-PB3 controlling the first stepper motor and PB4-PB7 controlling the second. These pins were chosen for convenience of grouping and ease as well as consistency of coding.

Each of the sets of four data lines will connect to an H-bridge, which we chose for the moderate current and low power dissipation of the stepper motors. Data lines are paired such that PB0 will connect to the bases of two diagonal transistors while PB1 connects to the bases of the other diagonal pair. This circuit is duplicated for each coil on each stepper motor. The Emitter-Collector Junction of each vertical transistor pair is the output that must connect to a pin on the stepper motor. As the data pins become asserted in sequence, the corresponding transistors will activate and cutoff to polarize the coils of the stepper motor and force it to rotate in a direction determined by the assertion sequence of the data lines. It was suggested that a 1K resistance be placed between each HC11 output data line and the corresponding transistor base terminal, however we don't expect to need these, as their application pertains to damping.

The power voltage for each H-bridge will be 12V DC, drawing a current of no more than 1-3A. For these characteristics, we have chosen National Semiconductor's LMD18201T H-bridge IC. The LMD18200 is a 3A H-Bridge designed for motion control applications.

Stepper Motor rotational speed is expected to be slow, however compensation will be implemented through the use of full and half step assertion sequences on the Port B output lines. This is demonstrated in the tables below.

Table 1 : Half-Step Excitations

D0	D1	D2	D3
1	1	0	0
0	1	0	0
0	1	1	0
0	0	1	0
0	0	1	1
0	0	0	1
1	0	0	1
1	0	0	0

Table 2: Full-Step Excitations

D0	D1	D2	D3
1	0	0	0
0	1	0	0
0	0	1	0
0	0	0	1

Hardware Precautions

For the sake of obtaining clean DC signals at the two input terminals of the HC11 and the eight output terminals, we will be including by-pass capacitors to ground to filter out any high frequency resonance.

Also, we intend to assert the Active Load Reset pin on the HC11 to VCC and include a bypass capacitor at this junction also.

6.0 Testing

6.1 Resolution Testing

Since our motors cause motion in a linear direction and the actual motion of the TCD is spherical, resolution of the orientation device will vary at each position. Therefore, resolution testing will occur where the resolution will be the worst, that is, at the extremes of the reachable area.

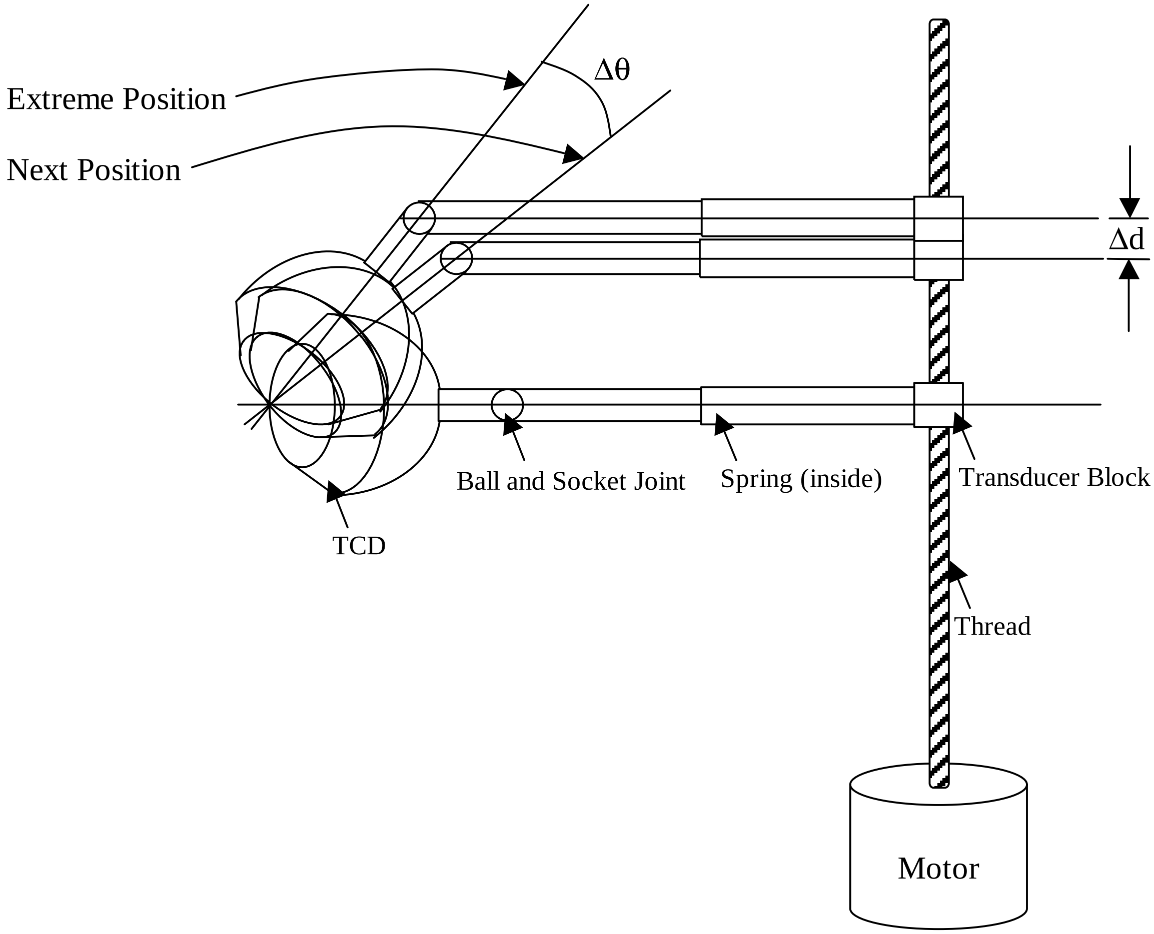


Figure 9: Components for Calculating Resolution

Referring to Figure 9, Δd depends on the resolution of the motor and the thread on the motor shaft. Δd can be expressed as:

$$\frac{\text{Displacement}}{\text{Smallest angular increment of the motor}}$$

Δθ is dependent on Δd and must be ≤ 2° as indicated in the Functional Specifications. This requirement can be verified using Vernier calipers.

6.2 Pressure Testing

Pressure robustness tests will be carried out on the electrical components to be used in the hypo-hyperbaric chamber. This involves observing the behavior of each electric component when subjected to the pressures created in the chamber. The current SFU TCD engineer has carried out pressure robustness tests and has offered to aid us in conducting our own pressure tests within the hypo-hyperbaric chamber.