

ROBOTIC MICROPHONE STAND FOR POGO STUDIOS

By

Alejandro Gomez

Dennis Yuan

Final Report for ECE 445, Senior Design, Fall 2012

TA: Igor Fedorov

12 December 2012

Project Group No. 24

Abstract

We design, construct, and demonstrate a robotic microphone stand. Stepper motors drive three linear actuators to provide motion along the x, y, and z axis. Instructions are provided by the user over Bluetooth by a laptop using a PuTTY terminal interface. Instructions are then relayed to the ATmega328 microcontroller and used to control the speed and direction of rotation of each motor. Bump switches are placed at the ends of the movement range for signaling back to the microcontroller. Two voltage regulator circuits are designed to power the motors and the microcontroller. All circuit elements are laid out on two printed circuit boards. Testing shows that stepper motors are appropriate for this application, and we achieve the ability to transmit instructions wirelessly over sufficient distances for its intended purpose.

Contents

1. Introduction	1
2 Design.....	2
2.1 Structural Overview	2
2.2 Hardware Design Overview	2
2.2.1 Block Diagram	2
2.2.2 Power Supply and Voltage Regulation.....	3
2.2.3 Stepper Motors and Linear Actuators.....	5
2.2.4 Motor Control Circuit.....	6
2.2.5 Bluetooth RX	7
2.2.6 Bump Sensors.....	8
2.2.7 Microcontroller	9
2.2.8 Computer and Control Interface.....	10
2.2.9 PCB and Layout Considerations	10
3. Design Verification	12
3.1 Power Supply and Voltage Regulation.....	12
3.1.1 AC-DC 5V Power Supply	12
3.1.2 5V to 3.3V Step Down Voltage Regulator	12
3.1.1 5V to 12V Step Up Voltage Regulator	12
3.2 Stepper Motors, Motor Controllers, and Linear Actuators	13
3.2.1 Stepper Motors and Motor Controllers.....	13
3.2.2 Linear Actuators.....	13
3.3 Bluetooth RX	13
3.4 Bump Sensors.....	14
3.5 Microcontroller	14
3.6 Computer and Control Interface.....	14
4. Costs.....	15
4.1 Parts	15
4.2 Labor	16
5. Conclusion.....	17
5.1 Accomplishments.....	17
5.2 Uncertainties.....	17
5.3 Ethical Considerations.....	17
5.4 Future Work.....	17
References	18
Appendix A Requirement and Verification Table.....	19
Appendix B Circuit Simulation	21
Appendix C Arduino Code	22

1. Introduction

Mark Rubel, a music producer at Pogo Studios located in Champaign, Illinois and Audio Director for Eastern Illinois University's Doudna Fine Arts Center, desired a robotic microphone stand for use in his studio.[1] His primary motivation for requiring such stand is to find a reliable way to position a microphone from outside the recording booth in his studio for optimal recording characteristics.

The position of the microphone relative to a speaker or performer is crucial to how the recording ultimately sounds. Finding this optimal microphone location is difficult due to the short audio of the average person. This makes it hard to directly compare the sounds of two relative microphone positions, since by the time a producer walks into the booth, adjusts the microphone, and walks back out, his memory of what the previous sound was is no longer accurate. This remote control will allow for quicker audio feedback and proper microphone positioning. A secondary motivation Mark has is to use this stand to attract clients and enhance the recording environment. Almost anyone can record and produce their own music at home and upload it to YouTube for mass distribution on the internet. Professional studios must offer services or recording environments that cannot be achieved in a home studio setting, and such a robotic microphone stand would give Pogo studios such a service. An additional benefit of using this stand is that it provides protection of studio personnel from potentially harmful audio environments. Finally, similar products currently on the market are quite expensive and do not meet all of his requirements. Mark is looking for a low cost solution.

Our design has several features that Mark is looking for. It can move two feet along both the x and y axis, and three feet along the vertical axis. Movement can either be in preset increments or by providing a desired location. It is wirelessly controlled, and is controlled by a laptop using open source software. Movement is provided by three stepper motors that each drive a linear actuator. We have programmed the ability to store up to ten microphone positions and load them at any time. These stored positions are saved even when the system is powered down. It uses an external power source, a wall outlet, separate from that which supplies power to the microphone.

2 Design

2.1 Structural Overview

The stationary base of the stand is made of a single wooden board that measures 2ft. by 2ft. The first linear actuator is mounted directly onto the wooden base along tracks for stability. We label the axis of movement for the first linear actuator the y axis. The second linear actuator is then mounted to the first set of tracks and provides movement along a direction perpendicular to the first actuator. We label this second axis of movement the x axis. The third linear actuator is mounted vertically, 1 ft. above where it is mounted, providing movement along the z axis. A rod to mount the microphone to is attached to the third actuator.

Wires are strung from the three motors to the base of the stand for interfacing with the control hardware. Four wires are required for each motor, two for each coil. Three wires are strung from the bump sensors attached at the ends of the linear actuators to the base of the stand for interfacing with the control hardware. The control hardware consists of two printed circuit boards attached to the base of the platform. The microcontroller, Bluetooth chip, motor controller chips, and power regulators are all distributed between these two PCBs.

2.2 Hardware Design Overview

2.2.1 Block Diagram

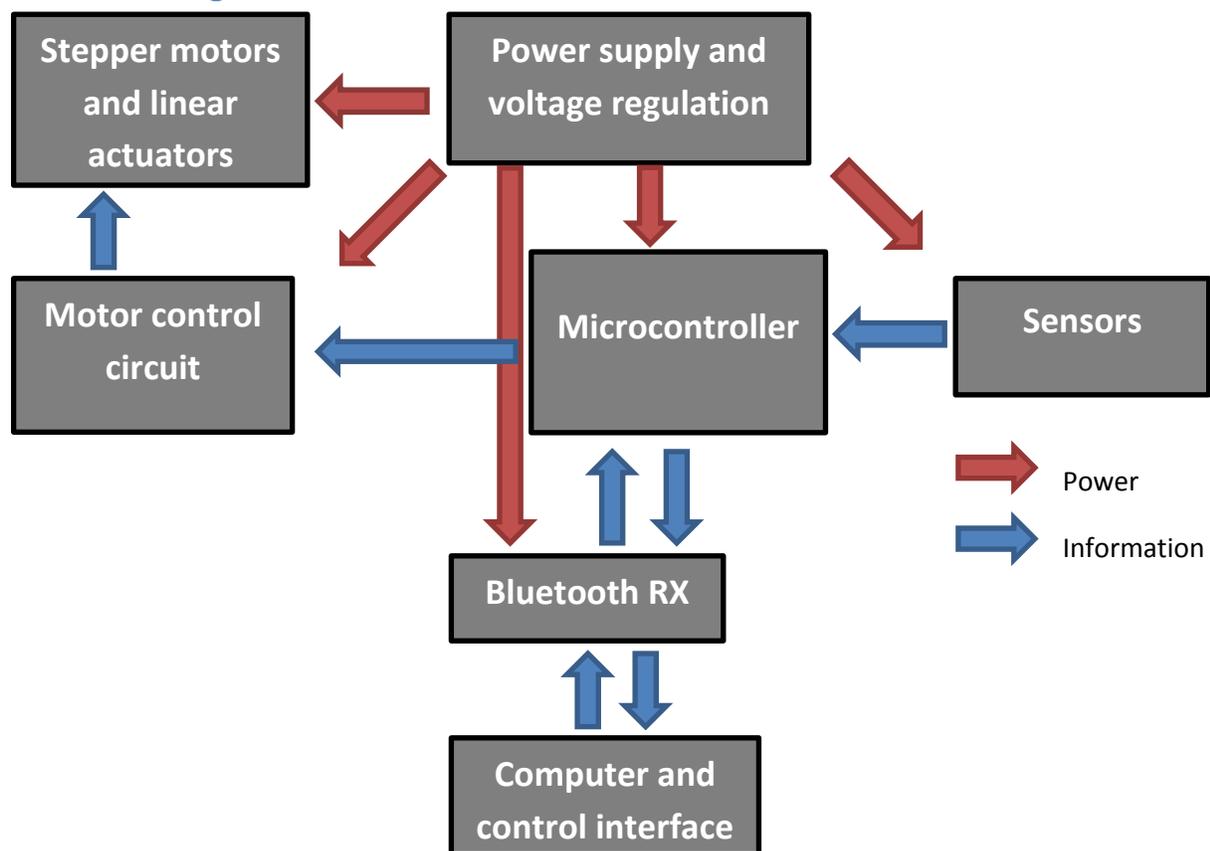


Figure 1 The high level block diagram of our robotic microphone stand

Table 1 Table of upper estimate for total power draw

Component	Rated Voltage (V)	Maximum Current (mA)	Max Power Draw (W)
Microcontroller[2]	5	250	1.25
Motor controllers[3]	5	0.02	0.0001 (x3)
Bump sensors	5	5	0.025 (x6)
Bluetooth[4]	3.3	100	0.33
Motor[5]	2.7	2000	5.4 (x3)
Total			17.93

2.2.2 Power Supply and Voltage Regulation

The three components of the power supply and voltage regulation block are the commercial AC to DC commercial power supply which outputs 5V DC, a step down voltage regulator to convert 5V DC to 3.3V DC, and a step up voltage regulator to convert 5V DC to 12V DC.

2.2.2.1 AD-DC 5V Power Supply

We are using a commercial power supply to convert AC voltage to a 5V DC output. The manufacturer is TKD-Lambda Americas, Inc. The specific model is the LS35-5, which is rated for up to 35W.[6] An upper estimate for the power required is shown in Table 1. We purchased a power supply that can handle up to 90 percent more power as a precaution to account for future design changes and possible inefficiencies not taken into consideration during the initial design phase, like voltage regulator efficiencies.

2.2.2.2 5V to 3.3V Step Down Voltage Regulator

The Bluetooth module we are using takes a 3.3V DC input, requiring us to convert the 5V DC we receive from the commercial power supply using a voltage regulator. One possibility would be to use an adjustable linear regulator, like the TI LM117/LM317 series, but using linear regulators create thermal concerns. The regulation is facilitated by burning off the rest of the power as heat. Switching regulators are more efficient, and may not require many extra components. Instead, we use the TI PL497A Switching Voltage Regulator in a step-down configuration. The design equations, as taken from the application information, are

$$I_{PK} = 2I_{Omax} \quad (2.1)$$

$$L(\mu H) = \frac{V_I - V_O}{I_{PK}} t_{on}(\mu s) \quad (2.2)$$

$$C_T(pF) \approx 12t_{on}(\mu s) \quad (2.3)$$

$$R1 = (V_O - 1.2V)k\Omega \quad (2.4)$$

$$R_{CL} = \frac{0.5V}{I_{PK}} \quad (2.5)$$

$$C_O(\mu F) \approx \frac{t_{on}(\mu s) \left[\frac{V_I - V_O}{V_O} I_{PK} + I_O \right]}{V_{ripple}(PK)} \quad (2.6)$$

where I_{PK} is the peak input current, I_O is the desired output current, t_{on} is the switch-on time, $V_{ripple}(PK)$ is the maximum desired ripple voltage, V_I is the expected input voltage, and V_O is the desired output voltage.[7] L , C_T , R_1 , R_{CK} , and C_O are all component values of the surrounding circuit elements as shown in Figure 2. The Bluetooth chip has a maximum current draw of 100 mA, so we set $I_{Omax} = 100mA$ and $I_{PK} = 200mA$ in Equation (2.1). V_I and V_O are set to 5V and 3.3V, respectively, in Equation (2.2). We pick a convenient L of $68\mu H$, since Coilcraft provided inductor samples at this inductance, for a t_{on} of $8\mu s$. C_T is chosen to be 100pF, again a convenient value, from Equation (2.3). $R_1 = 2.1k\Omega$ from Equation (2.4). $R_{CK} = 2.5\Omega$ from Equation (2.5). C_O should be at least $50\mu F$ for a maximum $V_{ripple}(PK)$ of 1 percent of the output voltage. A larger C_O will simply provide a smaller ripple voltage, so we are using a $100\mu F$. We are also using a $470\mu F$ bypass capacitor, labeled C_{IN} in Figure 2, at the input voltage to protect the chip from any voltage spikes or transients.

2.2.2.3 5V to 12V Step Up Voltage Regulator

While the motors are rated for 2.7V, the motor control IC we are using requires a motor voltage of 8V-35V for proper operation, and then uses active current limiting to make sure the current through the stepper motors is not higher than what is rated. We are using the TI LM2585 3A Flyback Regulator in a boost configuration, as taken from the application notes.[8] The use of a linear regulator here is not possible, since we need to step the voltage up. While there are no design equations, TI does have the Simple Switcher design software for picking component values. However, the level of current we want to draw from this particular regulator is not supported by the application (the software suggests another part for higher efficiency). Instead, we base our component values on the sample circuits in the application notes. $C_{IN2} = .1\mu F$, $R_C = 3k\Omega$, and $C_C = .39\mu F$. We use the same $68\mu H$ Coilcraft inductor that we used in the step down regulator for convenience. A 1N5822 schottky diode is used since it is rated for 3A

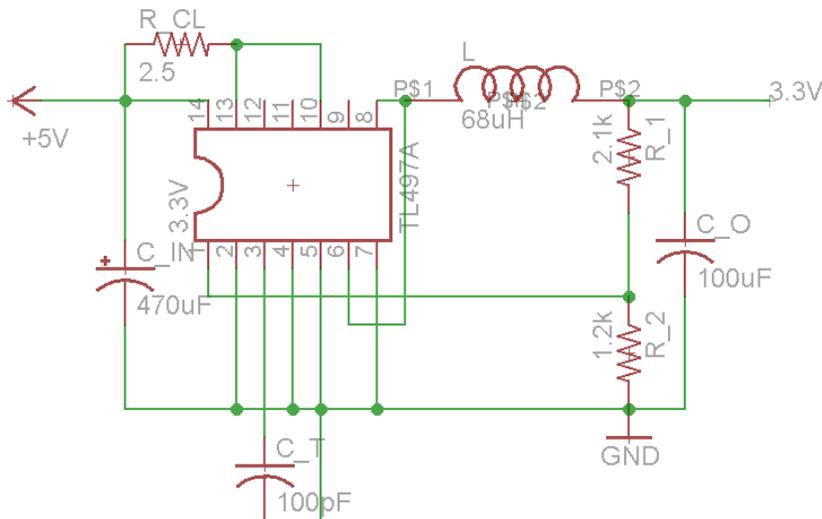


Figure 2 Schematic of step-down voltage regulator to power Bluetooth chip. Converts 5V DC to 3.3V DC.

and a maximum reverse voltage of 40V, both less than the 2A and 12V that it will be operating at.[9] Capacitor C_{OUT1} is used to store energy to be discharged when the regulator is switched off. The capacitor must be sufficiently large, and an $1800\mu\text{F}$ is used. C_{OUT2} is added to filter out transients and voltage spikes to protect the motor control board that is powered by this regulator. Again a $470\mu\text{F}$ capacitor is used for C_{IN} to protect the chip from voltage transients. The full schematic is shown in Figure 3. There are three copies of this circuit, one for each motor. This is for added modularity, simplifying testing, and also allows us to use a lower power regulator instead of a large regulator that must handle up to 6A of current.

2.2.3 Stepper Motors and Linear Actuators

We are using three stepper motors to each spin a screw rod that moves a platform along the screw rod. This use of screw rods is called a linear actuator.

2.2.3.1 Stepper Motors

We are using stepper motors to drive the linear actuators. We decided on stepper motors over other motors for the precision that this motor type provides over other DC motors. With stepper motors, we can dictate exactly how many steps we want the motor to rotate. The specific motor we are using is the Pololu Stepper Motor rated for 2.7V and 1000mA.[5] Each motor contains two coils that work to spin the motor in discrete steps. There are 200 steps per revolution, and each motor is controlled independently of the others.

2.2.3.1 Linear Actuators

Each linear actuator is comprised of a motor attached to a screw rod with a nut that is threaded onto the rod. The orientation of the nut is held constant so that spinning the rod moves the nut, or anything attached to it, along the rod. Depending on the incline of the threads, a faster or slower linear speed can be achieved given a constant motor speed. We choose a rod that moves 1in per revolution for movement along all three axes. This scheme of movement provides with a constant linear speed, whereas using another scheme with pivoting arms might not provide a constant relationship between motor speed and linear speed. For each step of the motor, we can expect to move $1/200$ in = 5 mils. This is our minimal linear resolution.

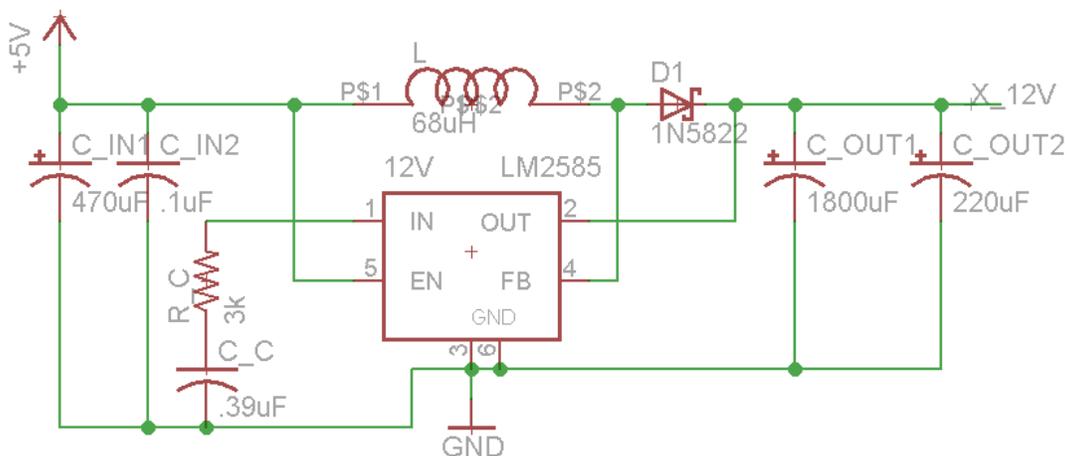


Figure 3 Schematic of step-up voltage regulator to power motors. Converts 5V DC to 12V DC.

2.2.4 Motor Control Circuit

The microcontroller cannot directly power the motors, since the motor currents would be too much for the microcontroller to source. Instead, we are using the Pololu Stepper Motor Driver Carrier. It uses the Allegro A4988 stepper motor controller IC, and simplifies our control scheme. It not only translates the control signals from the microcontroller into the appropriate high power waveforms to power the motors, it also has active current limiting so that we can use almost any stepper motor with it. This controller has many features, including sleep mode, reset, enable, and the ability to drive the stepper motors microsteps as small as a sixteenth step. The motors are always enabled and are never reset or put into sleep mode in our design.[3]

We are using the controller in full step mode, since we feel that the 5 mil resolution is more than adequate for this application. Using the controller in this way also reduces the number of components required, since many of the inputs are internally pulled to default values. MS1, MS2, MS3, and NOT_EN are pulled low, meaning the motors are always enabled and are in full step mode by default. NOT_SLP is pulled up by default, so connecting NOT_RST to it means the motors are never put to sleep or reset. No external components are required in our schematic, as shown in Figure 4. Each of the three controllers control one motor and is powered by a single 12V regulator.

The motors are rated for 2.7V, but this controller only takes motor voltages of 8V-35V. To make our motor compatible, we provide a 12V input as the motor voltage and the use the active current limiting feature on the board to keep the current below 1A per phase to not overheat the controller board and also stay within the rated current of the motors.

The only signals we have to provide are the STEP and DIR. When a rising edge is provided to STEP, the motor will spin one step. DIR controls whether the motor spins clockwise or counter-clockwise.

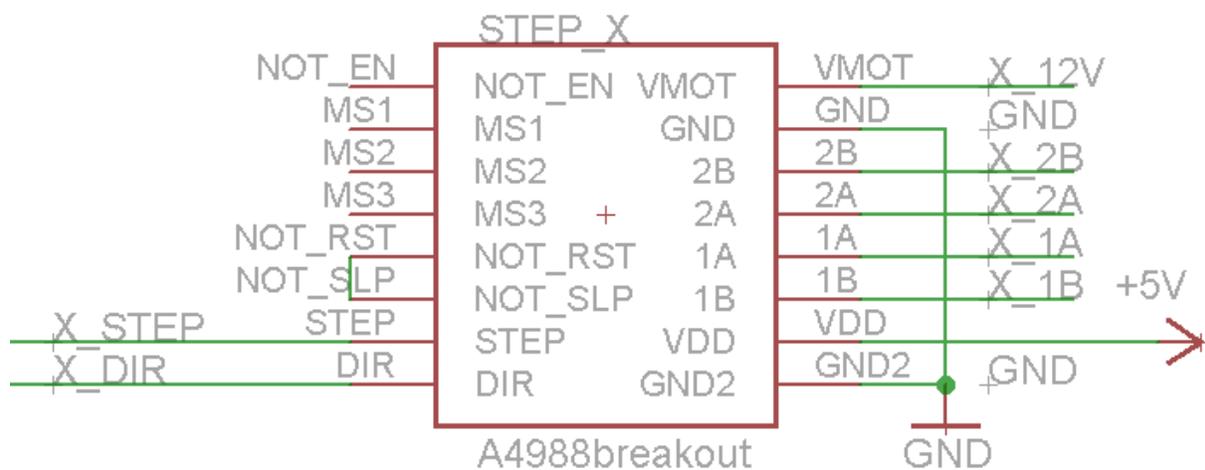


Figure 4 Schematic of Pololu Stepper Motor Drive Carrier using the Allegro A4988 stepper motor controller IC. One of three used to control the stepper motors.

2.2.5 Bluetooth RX

We are using Bluetooth to wirelessly control the stand. The specific profile being used is the Serial Port Profile, which exactly simulates a serial cable between the laptop and the output of the Bluetooth receiver.[10] The specific chip we are using is the Roving Networks RN-41 Bluetooth chip on a breakout board provided by Sparkfun. All the specifics of the communication software stack are encapsulated between the RN-41 and the laptop, greatly simplifying its usage. The chip requires a 3.3V input, making necessary the 3.3V voltage regulator. Our circuit includes a reset button, an LED for pairing status, an LED for incoming data, and a circuit to convert the 5V input the chip is receiving from the microcontroller to 3.3V. Table 2 shows the list of IO pins, their functions, and their settings in our implementation.[11]

The circuit to convert the 5V input to 3.3V can be seen in the schematic in Figure 5. If the incoming signal is low, the diode will be forward biased and the voltage seen at the input of the Bluetooth RX pin will be low. If the incoming signal is high, the diode will be reverse biased and the voltage seen will be 3.3V. Note that the RX pin of the RN-41 is connected to the TX pin, digital pin 0, of the microcontroller and the TX pin of the RN-41 is connected to the RX pin, digital pin 1, of the microcontroller. A simulation of this circuit is shown in Appendix B.

The actual data is received one byte at a time, with an initial start bit of 0 and then data pushed in from lowest significant bit to highest significant bit.

Table 2 Table of RN-41 IO pin functions and settings

IO pin	Functionality	setting
RESET	Resets chip (active low)	Connected to button switch
CLK	Used for SPI protocol	Not used
MOSI	Used for SPI protocol	Not used
RTS	Request to send	Shorted to CTS
CTS	Clear to send	Shorted to RTS
CS	Used for SPI protocol	Not used
MISO	Used for SPI protocol	Not used
PIO2	Connection status (high = connected)	Connected to LED
PIO3	Auto discovery = high	Pulled down for no auto discovery
PIO4	Reset to factory default	Pulled down for no reset capability
PIO5	Data status	Not used
PIO6	Set Bluetooth master (high = auto master mode)	Pulled down
PIO7	Baud rate (high = force 9600, low = 115k or firmware setting)	Pulled up for baud rate of 9600
PIO10	Incorrectly labeled by Sparkfun; actually PIO9, provides extra IO pin	Pulled down/not used
PIO11	Incorrectly labeled by Sparkfun; actually PIO8 provides RF data	Connected to LED

In our circuit, we connect the common leads directly as an input to the microcontroller, shown in Figure 6, labeled as BUMP_X/Y/Z_MIN/MAX. Each NO lead is grounded and each NC lead is pulled up to 5V. In this way, the signal coming from the sensor will change from high to low whenever the level on the sensor is pushed.

2.2.7 Microcontroller

The microcontroller interprets the instructions sent by the user and sensor information into control signals to send to the motor controller block. It also sends data back to the user via Bluetooth. The specific microcontroller we are using is the ATmega328, the same one that is used in the very popular Arduino series of hobbyist microcontroller boards. It is programmed in Arduino language and has standard libraries to support serial communication. Another added benefit is that an external programmer is not required. We can upload sketches, Arduino code programs, to the microcontroller through the Arduino board over USB and then pop out the microcontroller from the headers.

Reset functionality and an external oscillator are provided on the PCB for proper operation, as described by the tutorial for building a breadboard compatible Arduino.[12] The inclusion of a 16MHz oscillator The microcontroller is powered directly by the 5V supply, without need any further voltage regulation. Inputs come from the bump sensors and the Bluetooth transceiver while outputs go back to the Bluetooth transceiver and to the motor controllers.

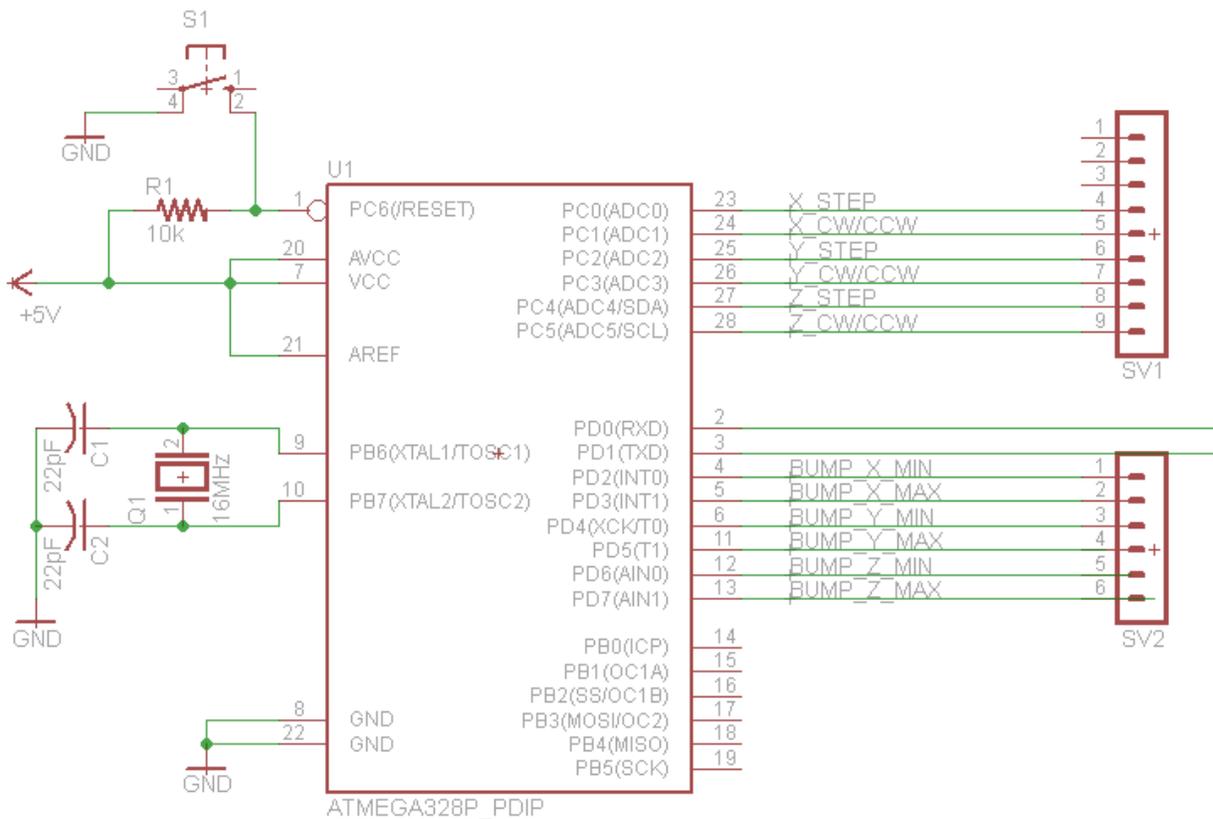


Figure 6 Schematic for the ATmega328 microcontroller. It interfaces with the Bluetooth, sensor, and motor control blocks.

2.2.8 Computer and Control Interface

We are using a laptop to control the microphone stand. It is assumed the laptop has Bluetooth capabilities, either through an integrated radio or an external dongle. The only software required is PuTTY, an open source terminal software. Under its license, anyone is granted permission to do anything with it and its documentation except for removing the license itself.[13]

Once paired with the Bluetooth transceiver, commands are sent with the keyboard. The user can move the microphone position, one direction at a time. The user can also store the current location in one of ten memory slots and then recall those positions at any time to force the stand to move to a preset location. Another feature is the ability to input a microphone position and force the stand to move to it. Finally, there is a reset button to move the microphone back to the origin of the coordinate space. The full list of commands is listed in Table 3. An example of the control interface is shown in Figure 7.

2.2.9 PCB and Layout Considerations

All the components except for the bump sensors and laptop are placed on PCBs. We use two separate PCBs due to the size limitations of the free version of EagleCAD used. The first PCB, design shown in Figure 8 contains the 3.3V step down regulator, the Bluetooth chip, and the microcontroller. The second PCB, design shown in Figure 9, contains the 12V step up regulators and the motor controllers.

Both PCBs are two layered, top and bottom, and designed to accommodate the fabrication restrictions of the UIUC ECE Service Shop.[14] Vias are used sparingly, since they are not plated through. Trace isolation of 60 mils is used per request of the Service Shop. Traces were made as short as possible to reduce noise and interference effects. All bypass capacitors are placed as close to the input of the ICs as possible. The 220 μ F capacitors at the output of the 12V regulator are actually placed under the motor controllers to save space. All ICs except for the 12V step up regulator are placed on headers which are soldered onto the PCBs. This allows us to easily remove the ICs for testing or replacement. Another consideration was to make sure the ceramic chip antenna of the Bluetooth chip was not over any copper, as specified by the application notes.[11]

Table 3 Keyboard commands for controlling the microphone stand from a laptop

Keyboard input	functionality
J/L	Step in the +/- X direction
I/K	Step in the +/- Y direction
Q/A	Step in the +/- Z direction
C + (0-9)	Save current location at memory location (0-9)
(0-9)	Return to stored location (0-9)
G + (input number A) + space + (input number B) + space + (input number C) + space	Move microphone stand to (A,B,C)
R	Move microphone stand to (0,0,0)

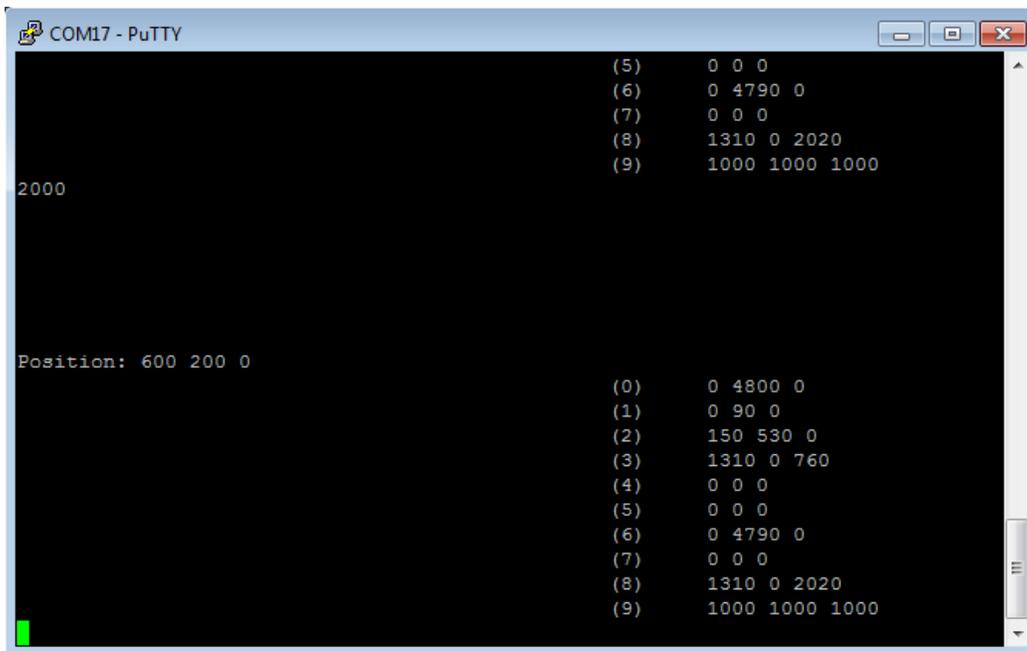


Figure 7 Screenshot of control interface via PuTTY terminal.

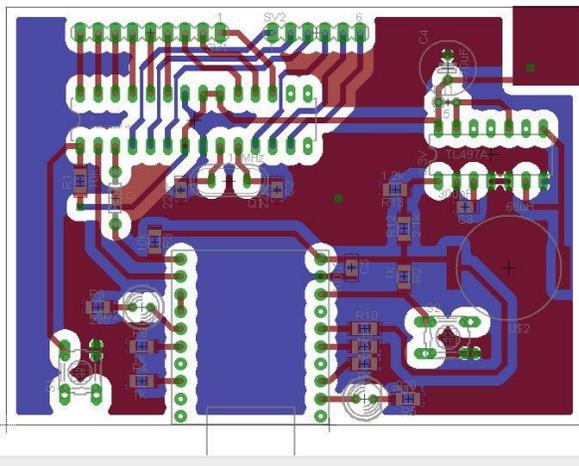


Figure 8 PCB design containing the 3.3V step down regulator, Bluetooth chip, and microcontroller

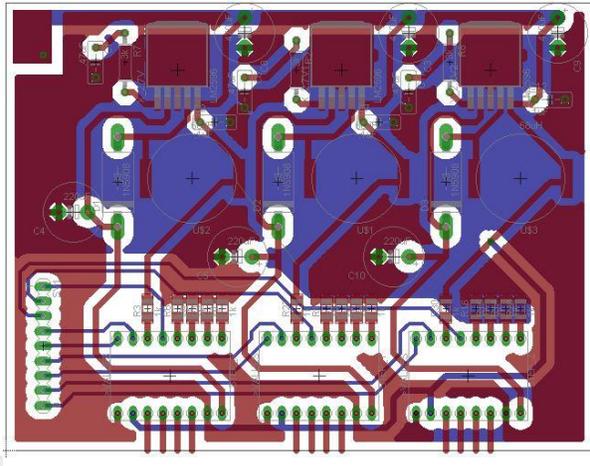


Figure 9 PCB design containing the 12V step up regulators and motor controllers.

3. Design Verification

See Appendix A for full requirement and verification table.

3.1 Power Supply and Voltage Regulation

Testing took place in two stages. The first stage was on a breadboard to verify out design, and the second was on PCB.

3.1.1 AC-DC 5V Power Supply

Testing and verification consisted of measuring the 5V output on an oscilloscope. Worked as advertised.

3.1.2 5V to 3.3V Step Down Voltage Regulator

This circuit was bread-boarded as in Figure 2 with the output measured on an oscilloscope, as shown in Figure 10. After transferring the design to PCB, however, the regulator output was around 4V. Loading the output with the Bluetooth chip lowered the output to around 3.8V, but would periodically drop below 3.3V. This dropping would cause the laptop to lose pairing with the Bluetooth device. We did not have time to find the problem, but we suspect that the capacitor C_T has something to do with it, as it controls the switching frequency. The quick fix for the demonstration was to instead use the 3.3V output from the Arduino board to power the Bluetooth chip.

3.1.1 5V to 12V Step Up Voltage Regulator

Originally this part was a 5V to 2.7V step down voltage regulator using a different chip, because we overlooked the fact that the motor controllers could only take 8v-35V as the motor voltage. Testing with the 2.7V regulator proved problematic in itself, because a necessary diode was not included in the design. Loading the incorrect design would pull down the voltage of other components connected to the 5V power supply being used at the time. Adding the diode remedied this issue, but we soon realized that we needed an entirely new regulator circuit to step the voltage up above 8V.

Testing this new regulator circuit using the LM2585-12 on a breadboard did not go smoothly at first. The C_{OUT1} capacitor was not large enough, less than $1000\mu F$, and turning on the regulator resulted in the chip

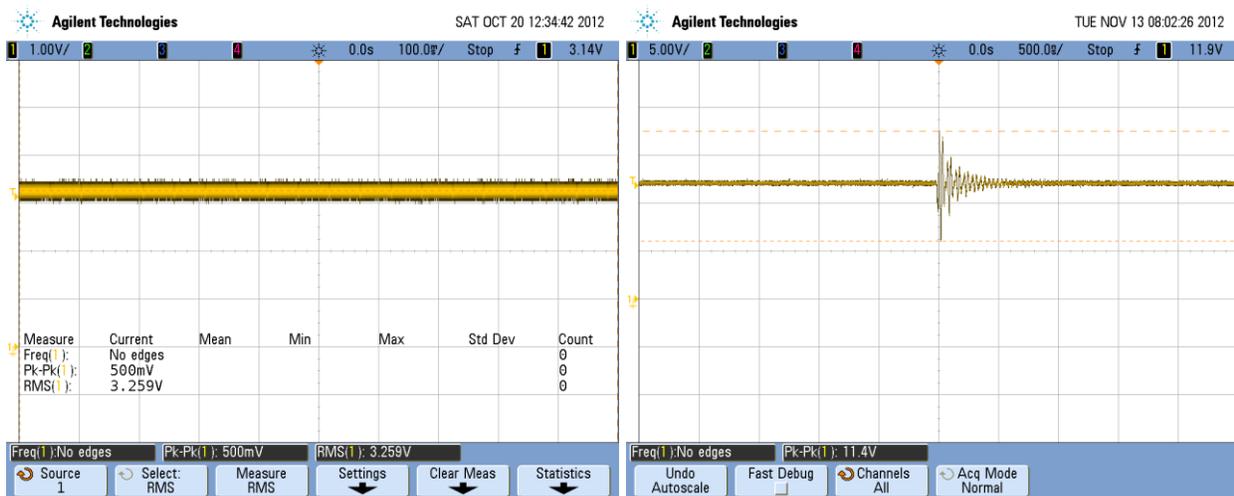


Figure 10 Output of 3.3V regulator during breadboard testing Figure 11 Output of 12V regulator during breadboard testing

being burned out. After increasing the C_{OUT1} to over $1000\mu\text{F}$, the output voltage became stable, with measured output shown in Figure 11, and the design was quickly laid out on PCB. The somewhat high voltage transient signaled to us that the bypass capacitor might need to be increase to protect the motor controller, causing us to increase C_{OUT1} further to $1800\mu\text{F}$ and add an extra $220\mu\text{F}$ bypass capacitor, C_{OUT2} to the design.

3.2 Stepper Motors, Motor Controllers, and Linear Actuators

While we had to wait until the UIUC ECE Machine Shop finished fabricating the stand and the linear actuators, we were able to test the motors independently. A lot of the motor testing was done using the motor controllers, since we otherwise would have had to provide two relatively high power sine waves 90 degrees out of phase with each other.

3.2.1 Stepper Motors and Motor Controllers

With the motor controllers bread-boarded, according to Figure 4, we were able to use the function generator to spin the motors. The function generator was set to output a $5V_{p-p}$ square wave with DC offset $+2.5V$ at 1Hz . The output of the function generator acted as the STEP input. The DIR input was either grounded or pulled to $5V$, and switched between the two to make sure the motor could be driven both clockwise and counterclockwise.

We did have some problems causing us to burn out three motor controllers. We believe the problem was a short circuit caused by a mistake in pulling up the SLEEP and RESET inputs in combination with incorrectly pulling down the ENABLE input. The short caused a large current to be drawn, signaling to us that the controller was burned out. The solution to this was to simply not externally pull up or down any of the inputs. As previously mentioned, all of the inputs except for RESET are internally pulled up or down. While the PCBs were designed with pull down and pull up resistors, we opted not to solder them onto the board.

3.2.2 Linear Actuators

Testing the linear actuators was largely finding a sufficient current from the active current limiting feature of the motor controller to spin the screw rods without risking damage to the controllers or motors. The potentiometer on each motor controller had to be adjusted individually, since the mechanical load on each motor is different.

3.3 Bluetooth RX

The original design had the QFN version of the chip soldered to the final PCB, and the Sparkfun breakout board used for testing purposes only. We decided to replace the QFN packaged chip directly with the Sparkfun board after having success during the bread-boarding phase. Testing the Bluetooth chip involved several steps. We had to figure out how to pair the device with a laptop, learn what kind of software was required to communicate, write test code to verify operation, and then redo everything after the circuit was placed on PCB. Testing was successful, and we were able to view the data streaming in on an oscilloscope, with an example shown in Figure 12.

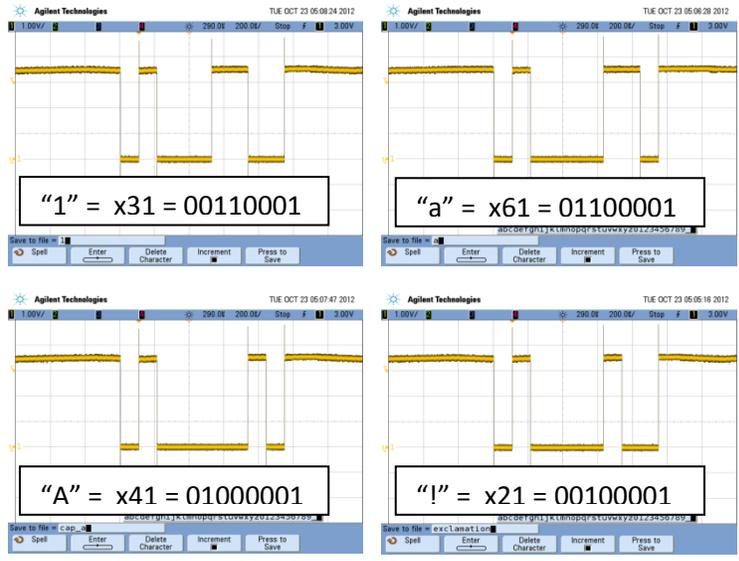


Figure 12 Test data from the TX pin of the Bluetooth chip. Note that bits are received lowest significant bit first.

3.4 Bump Sensors

Bump sensor testing was very simple. All that is required is an ohm meter to measure whether the impedance between the common lead and the other two is high or low.

3.5 Microcontroller

Testing the microcontroller was also very simple. Since the microcontroller is from the Arduino Uno board, running the provided example sketches was an easy way to test the functionality of the microcontroller. We did have an Arduino Uno board burn out for an unknown reason over the Thanksgiving holidays, but purchased a replacement quickly to continue testing.

3.6 Computer and Control Interface

Little testing was required to verify the operation of the laptop used to send instructions. Testing the use of the PuTTY interface was required for testing the Bluetooth module, so they were basically tested simultaneously.

4. Costs

Total cost is \$17500 (labor) + \$537.14 (prototype parts) = \$18037.14

Total cost of production model as design is currently = \$244.81

4.1 Parts

Table 4 Cost of Parts

Part	Manufacturer	# Purchased (or acquired by other means)	# Used in final design	Retail Cost	Bulk Cost	Cost of prototype	Cost of production model
Stepper Motor	Pololu	3	3	\$15.95	\$15.95	\$47.85	\$47.85
A4988 stepper motor controller	Pololu	6	3	\$12.95	\$12.95	\$77.70	\$38.85
Snap-Action Switch	Pololu	8	6	\$0.75	\$0.75	\$6.00	\$4.50
35W, 5V power supply	TDK Lambda Americas Inc.	1	1	\$19.00	\$19.00	\$0.00	\$0.00
LM2585-12 switching regulator	Texas Instruments	6 (samples)	3	\$6.75	\$3.51	\$40.50	\$10.53
LM2596 buck regulator	Texas Instruments	4	0	\$1.78		\$7.12	\$0.00
1N5819 Schottky Diode	Vishay Semiconductor	2 (service shop)	1	\$0.15	\$0.06	\$0.30	\$0.06
1N5822 Schottky Diode	Vishay Semiconductor	4	3	\$0.46	\$0.11	\$1.84	\$0.34
1800uF capacitor	United Chemi-Con	5	3	\$0.95	\$0.30	\$4.75	\$0.90
470uF capacitor	Panasonic	4	4	\$0.41	\$0.09	\$1.64	\$0.36
220uF capacitor	Panasonic	4	3	\$0.44	\$0.10	\$1.76	\$0.30
100uF capacitor	Panasonic	3	0	\$0.33		\$0.99	\$0.00
150uF capacitor	Panasonic	3	0	\$0.51		\$1.53	\$0.00
TL497A regulator	Texas Instruments	2	1	\$2.02	\$0.94	\$4.04	\$0.94
ATMega328	Atmel	2	1	\$2.88	\$1.60	\$5.76	\$1.60
1k surface mt resistor	Panasonic	20	6	\$0.10	\$0.01	\$2.00	\$0.06
10k surface mt resistor	Panasonic	22	2	\$0.10	\$0.01	\$2.20	\$0.02
1.2k surface mt resistor	Panasonic	6	1	\$0.10	\$0.01	\$0.60	\$0.01
2.1k surface my resistor	Panasonic	5	1	\$0.10	\$0.01	\$0.50	\$0.01
220ohm surface mt resistor	Panasonic	4	2	\$0.10	\$0.01	\$0.40	\$0.02
200uH SMD inductor	Signal Transformer	2	0	\$1.11		\$2.22	\$0.00
2.5ohm resistor	Bourns Inc.	2	0	\$3.64		\$7.28	\$0.00
RN-41 on breakout	Sparkfun	1	1	\$59.95	\$59.95	\$59.95	\$59.95
TO-263-5 to DIP-10 SMT adapter	Proto Advantage	3	0	\$4.49		\$13.47	\$0.00
ATMega328 with bootloader	Sparkfun	2	0	\$5.50		\$11.00	\$0.00
RN-41 QFN	Sparkfun	2	0	\$24.95		\$49.90	\$0.00
33uH inductor	Coilcraft	5 (samples)	0	\$1.62		\$8.10	\$0.00
47uH inductor	Coilcraft	5 (samples)	0	\$1.62		\$8.10	\$0.00
68uH inductor	Coilcraft	5 (samples)	4	\$1.62	\$0.67	\$8.10	\$2.68
100uH inductor	Coilcraft	2 (samples)	0	\$1.62		\$4.86	\$0.00
333uH inductor	Coilcraft	2 (samples)	0	\$1.62		\$4.86	\$0.00
200ohm resistor	Vishay	3 (service shop)	3	\$0.23	\$0.01	\$0.69	\$0.03

.1uF capacitor	Vishay	3 (service shop)	3	\$0.44	\$0.03	\$1.32	\$0.09
.39uF capacitor	AVC Corporation	3 (service shop)	3	\$0.40	\$0.40	\$1.20	\$1.20
2.3ohm resistor	Tageo	1 (service shop)	1	\$0.33	\$0.04	\$0.33	\$0.04
22pF capacitor	Vishay	2 (service shop)	2	\$0.34	\$0.03	\$0.68	\$0.06
100pF capacitor	Vishay	1 (service shop)	1	\$0.34	\$0.03	\$0.34	\$0.03
white LED	Everlight Electronics	8 (IEEE Lab)	2	\$0.59	\$0.16	\$4.72	\$0.32
16MHz Crystal	ECS Inc	1 (service shop)	1	\$0.70	\$0.70	\$0.70	\$0.70
Sub-Mini pushbutton	All Electronics Corp	2	2	\$0.33	\$0.18	\$0.66	\$0.36
Arduino Uno	Arduino	1	0	\$27.18		\$27.18	\$0.00
female headers	Sparkfun	6 (IEEE lab)	2	\$1.50	\$1.50	\$9.00	\$3.00
PCB fabrication	ECE service shop	3 (service shop)	2	\$35.00	\$35.00	\$105.00	\$70.00
Parts total						\$537.14	\$244.81

4.2 Labor

Table 5 Cost of Labor

Labor	wage	time	Total
Alejandro Gomez	\$35/hr	100hr	$\$3500 * 2.5 = \8750
Dennis Yuan	\$35/hr	100hr	$\$3500 * 2.5 = \8750
Labor Total			\$17500

5. Conclusion

5.1 Accomplishments

Our demonstration was a great success. We were able to demo the full functionality of the project we set out to build, and even had a bonus in the form of stepper motor music. We both feel like we learned a lot throughout this process. At the start, neither of us were familiar with really any of the hardware components we successfully designed. Implementing Bluetooth seemed overwhelming, learning about using motors in practice was new, and figuring out exactly what we could do with a microcontroller were all things that seemed daunting at first. As we read the documentation and gained more understanding of what was actually required, we realized elements that used to seem overwhelming are actually straight forward. We both feel much more confident jumping into a project now than when we started the semester.

5.2 Uncertainties

Since we were unable to perform testing inside Pogo Studios, the recording environment might not support our Bluetooth implementation. While the Class 1 Bluetooth module has a large range, the actual range is probably limited by the Bluetooth radio in the laptop. Unless the Bluetooth radio in the laptop is also Class 1, the range will drop significantly. Soundproof walls also tend to attenuate electromagnetic radiation as well, further degrading the signal.

5.3 Ethical Considerations

to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment;

All wireless communications devices we use in this project, the Class 1 Bluetooth module in particular, are certified by the FCC.[11]

to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;

Designs based off datasheets and application notes are properly credit. The use of PuTTY software in our project is also ethical under the open source license that explicitly gives us permission to use it.

5.4 Future Work

Immediate work to be finished include fixing the 3.3V step down regulator circuit and getting the JavaScript code to work over Bluetooth. Fixing the voltage regulator would eliminate the need for using the entire Arduino board, and the microcontroller would be placed on the PCB. Getting the JavaScript code to work would improve the look and utility of the control interface, giving it more of a “cool” factor that Mark desires.

Other potential improvements include enclosing the hardware components in some kind of box, adding pan or tilt capability, and writing a program to take any MIDI file and automatically play it using the stepper motors.

References

- [1] *About Pogo*, Pogo Studio. [Online]. Available at: <http://www.pogostudio.net/aboutpogo.htm>
- [2] 8-bit AVR® Microcontroller with 4/8/16/32k Bytes In-System Programmable Flash, datasheet, Atmel. [Online]. Available at: <http://www.atmel.com/Images/doc8161.pdf>
- [3] A4988 DMOS Microstepping Driver with Translator and Overcurrent Protection, datasheet, Allegro Microsystems, Inc. [Online]. Available: <http://www.allegromicro.com/Products/Motor-Driver-And-Interface-ICs/Bipolar-Stepper-Motor-Drivers/~media/Files/Datasheets/A4988-Datasheet.ashx>
- [4] RN-41/RN041-N Class 1 Bluetooth Module, datasheet, Roving Networks. [Online]. Available: <http://dlnmh9ip6v2uc.cloudfront.net/datasheets/Wireless/Bluetooth/rn-41-ds-v3.3r.pdf>
- [5] Pololu Robotics and Electronics, Stepper Motor: Bipolar, 200 Steps/Rev, 35x36mm, 2.7V, 1000mA. [Online]. Available: <http://www.pololu.com/catalog/product/1209/specs>
- [6] LS Series Single Output General Purpose Power Supplies, datasheet, TDK-Lambda. [Online]. Available at: <http://us.tdk-lambda.com/lp/ftp/Specs/ls.pdf>
- [7] TL297A 500-mA Peak Step-up, Step-down, Inverting Switching Voltage Regulator, datasheet, Texas Instruments. [Online]. Available at: <http://www.ti.com/lit/ds/symlink/tl497a.pdf>
- [8] LM2585 Simple Switcher® 3A Flyback Regulator, datasheet, Texas Instruments. [Online]. Available at: <http://www.ti.com/lit/ds/symlink/lm2585.pdf>
- [9] 1N5820-1N5822, datasheet, Fairchild Semiconductor. [Online]. Available at: <http://www.fairchildsemi.com/ds/1N/1N5822.pdf>
- [10] Bluetooth Special Interest Group, Serial Port Profile (SPP). [Online]. Available: <https://www.bluetooth.org/Building/HowTechnologyWorks/ProfilesAndProtocols/SPP.htm>
- [11] RN-41/RN041-N Class 1 Bluetooth Module, datasheet, Roving Networks. [Online]. Available at: <http://dlnmh9ip6v2uc.cloudfront.net/datasheets/Wireless/Bluetooth/rn-41-ds-v3.3r.pdf>
- [12] Building an Arduino on a Breadboard, Arduino. [Online]. Available at: <http://arduino.cc/en/Main/Standalone>
- [13] Simon Tatham, *PuTTY Licence*. [Online]. Last modified Jan 27, 2012. Available at: <http://www.chiark.greenend.org.uk/~sgtatham/putty/licence.html>
- [14] Design Requirements For Our Milled PCBs, ECE Electronics Service Shop. [Online]. Available at: <http://www.ece.illinois.edu/eshop/pcbdesign/DesignReq.htm>

Appendix A Requirement and Verification Table

Table 6 System Requirements and Verifications

Requirement	Verification	Verification status (Y or N)
<p>Power Supply and Voltage Regulation</p> <ol style="list-style-type: none"> 1) Commercial power supply will deliver 5V 2) Output of switching regulator to power Bluetooth will deliver 3.3V at up to 100mA 3) Output of individual switching regulator to power stepper motors will deliver 12V at up to 2A 	<ol style="list-style-type: none"> 1) Hook up oscilloscope to output of the commercial supply. Plug in commercial supply to wall socket and turn on supply. <ol style="list-style-type: none"> a) Measure 5V output on scope. 2) Use the bench DC generator as a 5 Volt input voltage for 3.3V step down circuit. Output should be 3.3V. <ol style="list-style-type: none"> a) Load the 3.3V output with a 33 ohm load and measure that the current is 100 mA b) Repeat after parts laid out on PCB 3) Use the bench DC generator as a 5 Volt input voltage for 12V step up circuit. Output should be 12 Volts <ol style="list-style-type: none"> a) Load the 12V output with a 1.3 ohm load and measure that the current is 2 Amps b) Repeat for each of the three 12V regulator circuits c) Repeat after parts laid out on PCB 	<p>Y</p> <p>Y</p> <p>Y</p> <p>Y</p> <p>N</p> <p>Y</p> <p>Y</p> <p>Y</p> <p>Y</p> <p>Y</p>
<p>Motor Controller</p> <ol style="list-style-type: none"> 1) Control motor movement step by step 2) Must turn both clockwise and counter clockwise 	<ol style="list-style-type: none"> 1) Set DIR to high. Connect output leads to oscilloscope OUT1A with OUT1B to one channel and OUT2A with OUT2B to a second channel, with B's being grounds. Connect STEP lead to a debounced switch so that you can toggle the input to STEP. <ol style="list-style-type: none"> a) Toggle switch on and off manually and observe the output on the oscilloscope to verify that each step corresponds with a rising edge. Repeat 20 times 2) Set DIR to high. Connect the output leads to an oscilloscope OUT1A with OUT1B to one channel and OUT2A with OUT2B to a second channel, with B's being grounds. Connect the STEP lead to a function generator and send a square pulse with a frequency of 100Hz. <ol style="list-style-type: none"> a) Observe that the output signals are 2 square waves with OUT2 having a 90 degree phase lag. b) Connect DIR to ground. Observe that the output signals are 2 square waves with OUT1 having a 90 degree phase lag. 	<p>Y</p> <p>Y</p> <p>Y</p> <p>Y</p> <p>Y</p>
<p>Stepper Motors</p> <ol style="list-style-type: none"> 1) Motor should not skip steps, should give a step every time it's instructed to 2) One revolution should match lead screw spec for linear motion 3) Move both clockwise and counterclockwise 	<ol style="list-style-type: none"> 1) Set DIR to high. Run test program from microcontroller to give a square wave of period 5us with 1600 cycles as an input to the STEP pin of the motor drivers so the motor will give 200 steps. <ol style="list-style-type: none"> a) The motor should move one revolution. 2) Move a full revolution using test program from above <ol style="list-style-type: none"> a) Measure the linear distance traveled on the lead screw with ruler. it should be 1" 3) Repeat above tests, but set DIR low for opposite direction of rotation. 	<p>Y</p> <p>Y</p> <p>Y</p> <p>Y</p> <p>Y</p>

<p>Bluetooth RX</p> <ol style="list-style-type: none"> 1) Needs to establish connection with computer 2) Needs to be able to receive data to computer 3) Needs to be able to send data back to computer 4) Data transfer should be accurate 5) Should communicate through a wall from at least 5 meters away 	<ol style="list-style-type: none"> 1) Establish connection with computer. Connection status LED indicator should light up, showing that connection has been made 2) After establishing connection with computer, send characters in the terminal interface. Data status LED indicator should be flashing, showing that data has been received by the Bluetooth module 3) Program the microcontroller to send arbitrary location data to the computer, and echo the received data to the screen. Compare for correctness and repeat 20 times 4) See verification for Computer and Control Interface block 5) Place computer at least 5 meters away through a wall and repeat all above test procedures 	<p>Y</p> <p>Y</p> <p>Y</p> <p>Y</p> <p>Y</p>
<p>Computer and Control Interface</p> <ol style="list-style-type: none"> 1) Send accurate serial data to the microcontroller over Bluetooth 	<ol style="list-style-type: none"> 1) After receiving inputs keyboard, echo transmitted data on the screen before they're sent through Bluetooth to make sure they are read correctly <ol style="list-style-type: none"> a) Verify data is sent by checking connection and data status LEDs on Bluetooth RX module b) Verify data is correctly sent by reading output of Bluetooth RX module on oscilloscope 	<p>Y</p> <p>Y</p> <p>Y</p>
<p>Sensor Elements</p> <ol style="list-style-type: none"> 1) Pushing down the lever on the pumper switch should change the output from low to high. 	<ol style="list-style-type: none"> 1) Construct the circuit as shown in the schematic and supply a voltage to the pull up resistors. The voltage should show high. <ol style="list-style-type: none"> a) Press and hold the lever down. The voltage should now show low on the oscilloscope. b) Let go of the lever. The voltage should now again read high on the oscilloscope 	<p>Y</p> <p>Y</p> <p>Y</p>
<p>Microcontroller</p> <ol style="list-style-type: none"> 1) Properly send and receive signals from the Bluetooth RX block 2) Properly send signals to motor control block 3) Properly receiving signals from sensor block 	<ol style="list-style-type: none"> 1) See verification for Computer and Control interface block 2) Place microcontroller in Arduino development board. Use LEDs to read I/O pins corresponding to motor control outputs. Run test program that sends a square wave of period 1 second to STEP output, checks for clockwise and counterclockwise operation, and phase reset functionality. <ol style="list-style-type: none"> a) Verify for each set of motor controls for x,y and z axis motor control outputs 3) Connect bumpers to microcontroller and run microcontroller test program. <ol style="list-style-type: none"> a) Motor control output signals should indicate position reset when they receive a signal from their respective bumpers 	<p>Y</p> <p>Y</p> <p>Y</p> <p>Y</p> <p>Y</p>

Appendix B Circuit Simulation

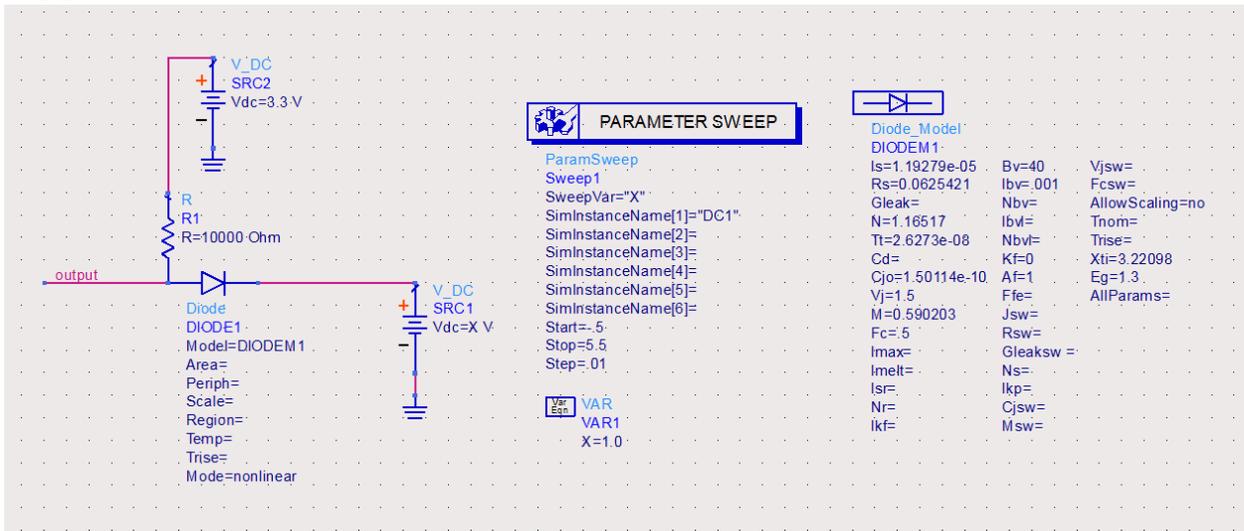


Figure B.1 Schematic and diode parameters of circuit to convert 5V logic input into 3.3V

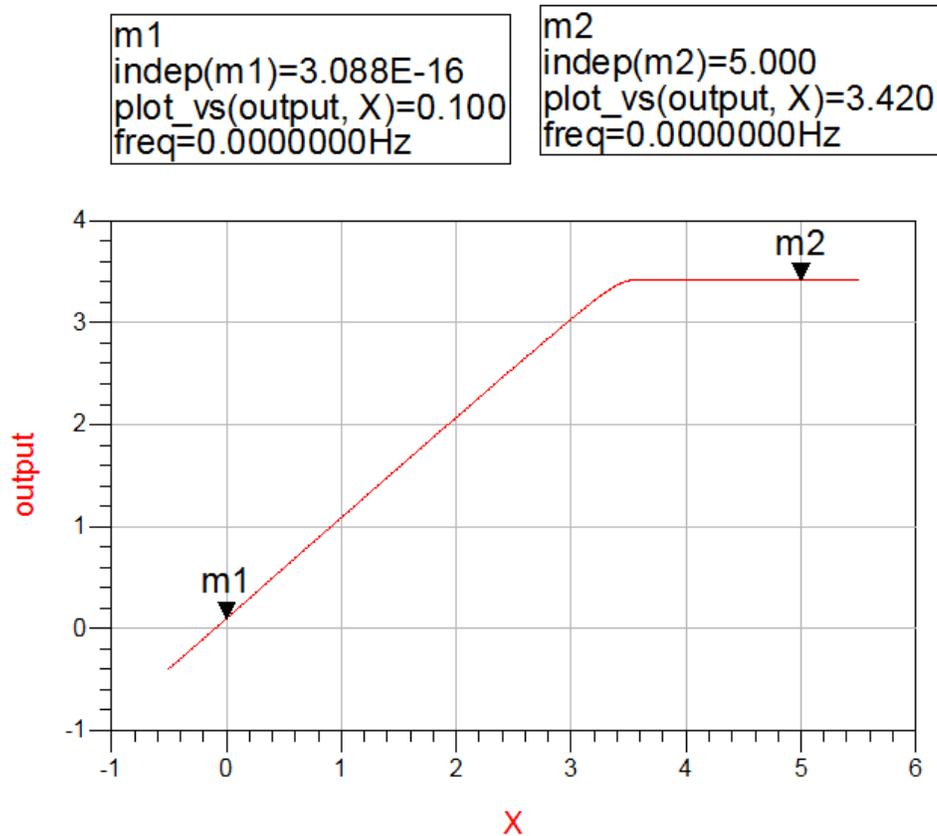
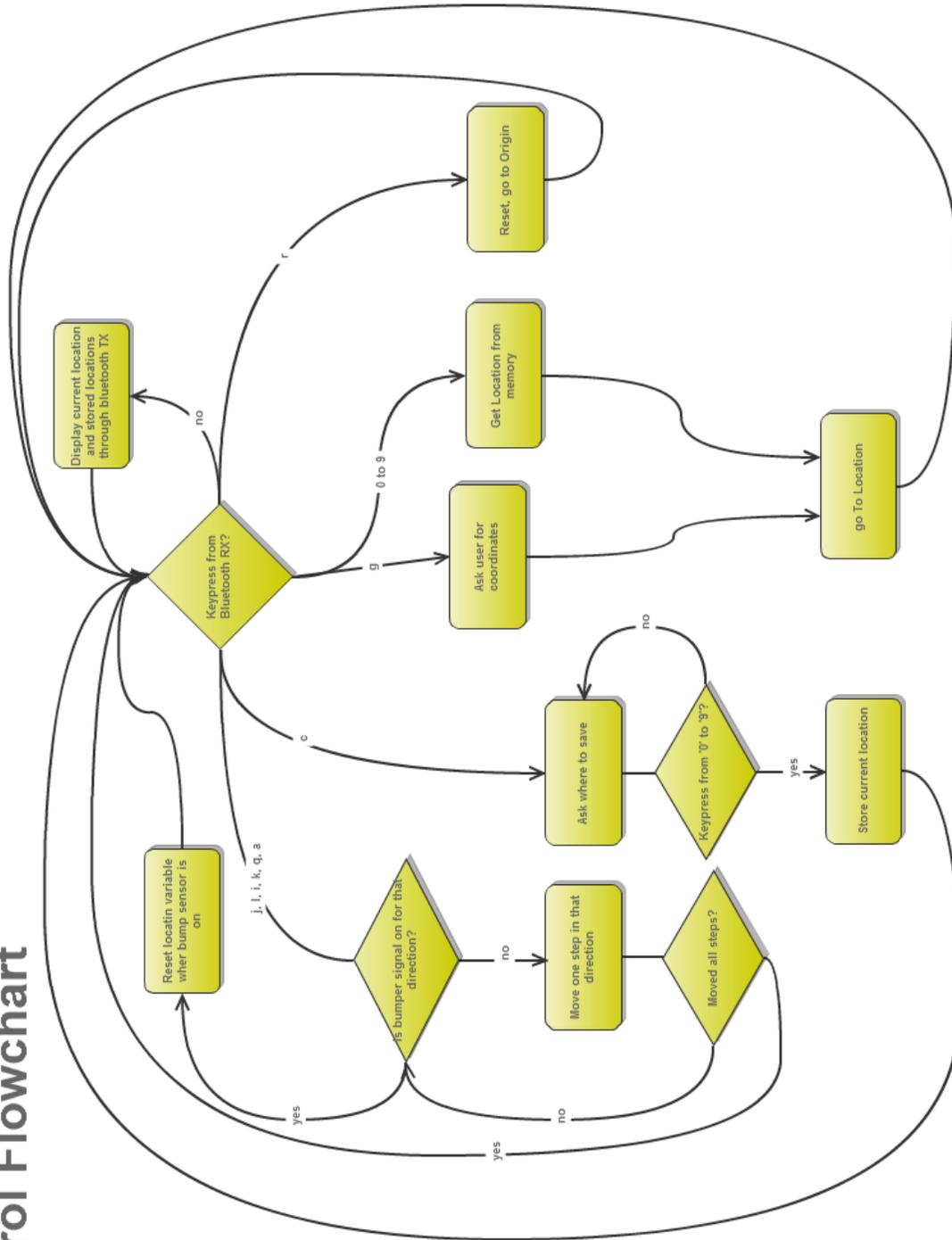


Figure B.2 Simulation results of circuit to convert 5V logic input into 3.3V

Control Flowchart



Code

```
#include <EEPROM.h>
int stepSignalX = A0;//12;
int stepSignalY = A2;//11;
int stepSignalZ = A4;//10;
int dirX= A1;//9;
int dirY= A3;//8;
int dirZ= A5;//7;
int bumperX1=2;
int bumperX2=3;
int bumperY1=4;
int bumperY2=5;
int bumperZ1=6;
int bumperZ2=7;
int countX=0;
int countY=0;
int countZ=0;
int limX=4800;
int limY=4800;
int limZ=7200;
int display = 1;
int key=0;
int gdelay=2000;

int vcount=1;

void setup(){
    Serial.begin(9600);
    pinMode(bumperX1,INPUT);
    pinMode(bumperX2,INPUT);
    pinMode(bumperY1,INPUT);
    pinMode(bumperY2,INPUT);
    pinMode(bumperZ1,INPUT);
    pinMode(bumperZ2,INPUT);
    pinMode(stepSignalX,OUTPUT);
    pinMode(stepSignalY,OUTPUT);
    pinMode(stepSignalZ,OUTPUT);
    pinMode(dirX,OUTPUT);
    pinMode(dirY,OUTPUT);
    pinMode(dirZ,OUTPUT);
    //goToOrigin();
    displayPosition();
}

void note(int length, int note){
    if (vcount==1)vcount=-1;
    if (vcount==1)vcount=-1;
        int delay;
        int x=1;
        int y=1;
        int z=0;
        if(note =='c'){ delay = 500000/130.81;}
        if(note =='C'){ delay = 500000/138.59;}
        if(note =='d'){ delay = 500000/146.83;}
        if(note =='D'){ delay = 500000/155.56;}
        if(note =='e'){ delay = 500000/164.81;}
        if(note =='f'){ delay = 500000/174.61;}
        if(note =='F'){ delay = 500000/185;}
        if(note =='g'){ delay = 500000/196;}
        if(note =='G'){ delay = 500000/207.65;}
}
```

```

if(note == 'a'){ delay = 500000/220;}
if(note == 'A'){ delay = 500000/233;}
if(note == 'b'){ delay = 500000/246;}
if(note == 'c'+1000){ delay = 500000/261;}
if(note == 'C'+1000){ delay = 500000/277;}
if(note == 'd'+1000){ delay = 500000/293;}
if(note == 'D'+1000){ delay = 500000/311;}
if(note == 'e'+1000){ delay = 500000/329;}
if(note == 'f'+1000){ delay = 500000/349;}
if(note == 'F'+1000){ delay = 500000/369;}
if(note == 'g'+1000){ delay = 500000/392;}
if(note == 'G'+1000){ delay = 500000/415;}

//if(countX+countY>0) x=-1;
//if(countX-countY>0) y=-1;
motorSteps(length,delay, 1,vcount,vcount,0);
}

void loop(){
  int steps=100;

  if (Serial.available() >0){
    display=1;
    key=Serial.read();
    if(key=='=') gdelay+=200;
    if(key=='-') gdelay-=200;
    int delay=gdelay;
    steps=200;

    if(key=='j') motorSteps(steps,delay ,1,-1, 0, 0);
    if(key=='l') motorSteps(steps,delay ,1, 1, 0, 0);
    if(key=='q') motorSteps(steps,delay*2,1, 0, 0, 1);
    if(key=='a') motorSteps(steps,delay ,1, 0, 0,-1);
    if(key=='k') motorSteps(steps,delay ,1, 0,-1, 0);
    if(key=='i') motorSteps(steps,delay ,1, 0, 1, 0);
    if(key=='c') {storeLocation();};
    if(key=='g') {goToInputLocation();};
    if(key>='0' && key <='9') goToLocation( getX(key),getY(key),getZ(key));
    if(key=='r') goToOrigin();
    //while(Serial.available(>0){Serial.read();}
    Serial.flush();

  }
  else{
    if(display){
      Serial.println(gdelay);
      displayPositionAndStored();
      display=0;
    }
  }
}

```

int motorSteps(int steps, int revs, int secs , int x , int y , int z){ // speed of revs/sec, fraction with revs being the numerator and secs being the denominator

```
/*      int loops=floor(steps/revs);
```

```

int rem= steps%revs;
int moving=0;
for(int i=0;i<loops;i++){
    moving = step(revs,x,y,z); //200*revs
    // if(moving==1) delay(5*secs); //1000*secs
}
moving = step(rem,x,y,z);
// if(moving==1) delay(5*secs);
//displayPosition();
*/
step(steps,revs,x,y,z);
}

int step( int steps , int delay, int x,int y,int z){
int count=0;
for(int i=0;i<steps;i++){ // move loops*revs steps
int bumperX1r = digitalRead(bumperX1);
int bumperX2r = digitalRead(bumperX2);
int bumperY1r = digitalRead(bumperY1);
int bumperY2r = digitalRead(bumperY2);
int bumperZ1r = digitalRead(bumperZ1);
int bumperZ2r = digitalRead(bumperZ2);

if(bumperX2r && x== 1){ countX = limX;}
if(bumperX1r && x== -1){ countX = 0;}
if(bumperY2r && y== 1){ countY = limY;}
if(bumperY1r && y== -1){ countY = 0;}
if(bumperZ2r && z== 1){ countZ = limZ;}
if(bumperZ1r && z== -1){ countZ = 0;}
int moving = 0;
if(x==1 && !bumperX2r) { //&& countX<limX
digitalWrite(dirX, HIGH);
countX++;
digitalWrite(stepSignalX, HIGH);
moving=1;
}else if(x== -1 && !bumperX1r){ //&& countX>0
digitalWrite(dirX, LOW);
countX--;
digitalWrite(stepSignalX, HIGH);
moving=1;
}

if(y==1 && !bumperY2r) { //&& countY<limY
digitalWrite(dirY, HIGH);
countY++;
digitalWrite(stepSignalY, HIGH);
moving=1;
}else if(y== -1 && !bumperY1r){ //&& countY>0
digitalWrite(dirY, LOW);
countY--;
digitalWrite(stepSignalY, HIGH);
moving=1;
}

if(z==1 && !bumperZ2r) { //&& countZ<limZ
digitalWrite(dirZ, HIGH);
countZ++;
digitalWrite(stepSignalZ, HIGH);
moving=1;
}
}
}

```

```

}else if(z== -1 && !bumperZ1r){ // countZ > 0
    digitalWrite(dirZ, LOW);
    countZ--;
    digitalWrite(stepSignalZ, HIGH);
    moving=1;
}

if( moving==0 ){
    return 0; //stopped moving so stop delaying
}
delayMicroseconds(delay);
digitalWrite(stepSignalX, LOW); // turn the LED off by making the voltage LOW
digitalWrite(stepSignalY, LOW); // turn the LED off by making the voltage LOW
digitalWrite(stepSignalZ, LOW); // turn the LED off by making the voltage LOW
delayMicroseconds(delay);
//if(count++==10){displayPosition();count=0;}
}
return 1;
};

int getX(int location){
    if( EEPROM.read(location*7) == 255 ) return countX;
    return EEPROM.read(location*7+1)*100+EEPROM.read(location*7+2);
}
int getY(int location){
    if( EEPROM.read(location*7) == 255 ) return countY;
    return EEPROM.read(location*7+3)*100+EEPROM.read(location*7+4);
}
int getZ(int location){
    if( EEPROM.read(location*7) == 255 ) return countZ;
    return EEPROM.read(location*7+5)*100+EEPROM.read(location*7+6);
}

int goToInputLocation(){
    int temp;
    int x=0;
    int y=0;
    int z=0;
    int count=0;
    int xcounter=0;
    int ycounter=0;
    int zcounter=0;
    Serial.println("");
    delay(1);

    while(Serial.available()==0){ if(count==0){Serial.println("Enter coordinates");count++;}delay(1); }
    delay(1);

    for(xcounter;xcounter<4;xcounter++){
        while(Serial.available()==0){ delay(100); }
        temp=Serial.read();
        if(temp>='0' && temp <='9'){
            Serial.write(temp);
            x=x*10+(temp-48);
        }
        if(temp == ' '){
            Serial.write(temp);
            break;

```

```

        }
        else{
            xcounter--;
        }
//      if(xcounter==3) Serial.print(' ');
}
for(ycounter;ycounter<4;ycounter++){
    while(Serial.available()==0){ delay(100);    }
    temp=Serial.read();
    if(temp>='0' && temp <='9'){
        Serial.write(temp);
        y=y*10+(temp-48);
    }
    if(temp == ' '){
        Serial.write(temp);
        break;
    }
    else{
        ycounter--;
    }
//      if(ycounter==3) Serial.print(' ');
}
for(zcounter;zcounter<4;zcounter++){
    while(Serial.available()==0){ delay(100);    }
    temp=Serial.read();
    if(temp>='0' && temp <='9'){
        Serial.write(temp);
        z=z*10+(temp-48);
    }
    if(temp == ' '){
        Serial.write(temp);
        break;
    }
    else{
        zcounter--;
    }
//      if(zcounter==3) Serial.print(' ');
}
if(x>4800) x=4800;
if(y>4800) y=4800;
if(z>7200) z=7200;

Serial.println();
Serial.print("Going to ");
Serial.print(x);
Serial.print(' ');
Serial.print(y);
Serial.print(' ');
Serial.println(z);
goToLocation(x,y,z);

}

int goToLocation(int x,int y,int z){
    int stepsX = x - countX;
    int stepsY = y - countY;
    int stepsZ = z - countZ;

```

```

int signX = stepsX > 0 ? 1 : stepsX == 0 ? 0 : -1; //m
int signY = stepsY > 0 ? 1 : stepsY == 0 ? 0 : -1;
int signZ = stepsZ > 0 ? 1 : stepsZ == 0 ? 0 : -1;

stepsX = abs(stepsX);
stepsY = abs(stepsY);
stepsZ = abs(stepsZ);
int speed=2000;

if( stepsX <= stepsY && stepsX <= stepsZ){
    motorSteps( stepsX, speed, 1, signX, signY, signZ); //m
    if(stepsY <= stepsZ){
        motorSteps( stepsY-stepsX, speed, 1, 0, signY, signZ); //m
        motorSteps( stepsZ-stepsY,speed,1,0,0,signZ);
    }
    else{
        motorSteps( stepsZ-stepsX, speed, 1, 0, signY, signZ); //m
        motorSteps( stepsY-stepsZ,speed,1,0,signY,0);
    }
}
else if(stepsY<=stepsX && stepsY<=stepsZ){
    motorSteps( stepsY, speed, 1, signX, signY, signZ); //m
    if(stepsX <= stepsZ){
        motorSteps( stepsX-stepsY, speed, 1, signX, 0, signZ); //m
        motorSteps( stepsZ-stepsX,speed,1,0,0,signZ);
    }
    else{
        motorSteps( stepsZ-stepsY, speed, 1, signX, 0, signZ); //m
        motorSteps( stepsX-stepsZ,speed,1,signX,0,0);
    }
}
else{
    motorSteps( stepsZ, speed, 1, signX, signY, signZ); //m
    if(stepsY <= stepsX){
        motorSteps( stepsY-stepsZ, speed, 1, signX, signY, 0); //m
        motorSteps( stepsX-stepsY,speed,1,signX,0,0);
    }
    else{
        motorSteps( stepsX-stepsZ, speed, 1, signX, signY, 0); //m
        motorSteps( stepsY-stepsX,speed,1,0,signY,0);
    }
}
};
/*
int abs(int n){
    return n<0?-n:n;
}*/

void displayPosition(){
    Serial.print("\n\n\n\n\n\n\nPosition: ");
    Serial.print(countX);
    Serial.print(" ");
    Serial.print(countY);
    Serial.print(" ");
    Serial.println(countZ);
}

```

```

};
void displayPositionAndStored(){
    displayPosition();
    for( int i='0';i<='9';i++){
        if( EEPROM.read(i*7) != 255 ){
            Serial.print("\t\t\t\t\t");
            Serial.print("");
            Serial.write(i);
            Serial.print("");
            Serial.print("\t");
            Serial.print(EEPROM.read(i*7+1)*100+EEPROM.read(i*7+2)) ;
            Serial.print(" ");
            Serial.print(EEPROM.read(i*7+3)*100+EEPROM.read(i*7+4)) ;
            Serial.print(" ");
            Serial.print(EEPROM.read(i*7+5)*100+EEPROM.read(i*7+6)) ;
            Serial.println("");
        }
    }
};

int storeLocation(){
    int location;
    int count=0;
    Serial.println("");
    delay(1);

    while(Serial.available()==0){ if(count==0){Serial.println("Enter a number from 0 to 9");count++;}delay(1);

    delay(1);
    Serial.write(location=Serial.read());

    if(location<'0' || location>'9') return -1;

    EEPROM.write(location*7, 1);
    EEPROM.write(location*7+1, floor(countX / 100) );
    EEPROM.write(location*7+2, countX % 100);
    EEPROM.write(location*7+3, floor(countY / 100) );
    EEPROM.write(location*7+4, countY % 100);
    EEPROM.write(location*7+5, floor(countZ / 100) );
    EEPROM.write(location*7+6, countZ % 100);

    displayPosition();

    return location;
};

void goToOrigin(){
    countX=0;
    countY=0;
    countZ=0;
    digitalWrite(dirX,LOW);
    digitalWrite(dirY,LOW);
    digitalWrite(dirZ,LOW);
    if( digitalRead(bumperX1)==1 && digitalRead(bumperY1)==1 && digitalRead(bumperZ1) == 1) return;
    if(digitalRead(bumperX1)==0) digitalWrite(stepSignalX,HIGH);
    if(digitalRead(bumperY1)==0) digitalWrite(stepSignalY,HIGH);
    if(digitalRead(bumperZ1)==0) digitalWrite(stepSignalZ,HIGH);
    delay(1);
}

```

```
digitalWrite(stepSignalX,LOW);  
digitalWrite(stepSignalY,LOW);  
digitalWrite(stepSignalZ,LOW);  
delay(1);  
goToOrigin();  
}
```