HUMAN TURNTABLE

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ECE445
Design Document
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1 Introduction

1.1 Objective

Ryan Corey, a graduate student, is working on binaural audio modeling in an order to develop audio signal processing for listening devices. An aspect of his research involves studying how sound interacts with the human body. Placing microphones all over the human body and playing sounds from different angles allows him to collect essential data. His experiments require that the subjects need to hear the sounds at different angles or locations [1]. This due to the tight space is most easily done using a mannequin on a turntable, but a live subject is the next step.

The current turntable is only capable of supporting around 20 pounds with limited functionality. Our task is to make a turntable for a human being. This will aid Ryan in his research with a device tailored to his needs.

To complete this request, we are planning on constructing a robust turntable which is capable of precise directional turns and supporting the weight of a human subject. The wooden turntable will be driven by a CNC grade stepper motor which will allow for precise turns in either direction. The gearing of the driveshaft to the motor allows for torque and accuracy refinement. We will drive the motor using a microcontroller and a stepper motor driver consisting of transistors and specialized ICs. A computer interface will allow the user to define parameters of rotation.

1.2 Background

With continuous advances in audio technology, hearing aids are becoming more advanced than ever. The development of low-power and low- footprint components allows for expansion in the technological abilities of a traditional hearing aid. Microphones can now be placed all over the body to provide a more realistic amplification of sound for the hard of hearing.

Binaural modeling in this application is the study of how acoustics interact with the human body. Incoming sounds are processed by the brain to decide location, position, intensity, and other aspects of sound. Having two ears allows for our brains to process these conditions depending on how they strike the ears differently. People who are hard of hearing cannot themselves distinguish many of these details. Through Ryan's research, he can make decisions on microphone placement and audio signal processing to produce a better hearing aid that results in a more natural amplification of sound.

Upon a quick search, no market solution exists. All turntables which can support a human being are unpowered or homemade. Those which do exist cannot execute precise rotation as needed.

1.3 High level requirements

- The turntable must be able to rotate clockwise and counter-clockwise with worst-case 5.0° +/- 5% accuracy.
- The turntable must be able to support a 300-pound human being
- safely with quiet +5dB ambient max operation.
  The turntable's operation must be programmable from the comfort of a desktop environment by Ryan through a GUI.
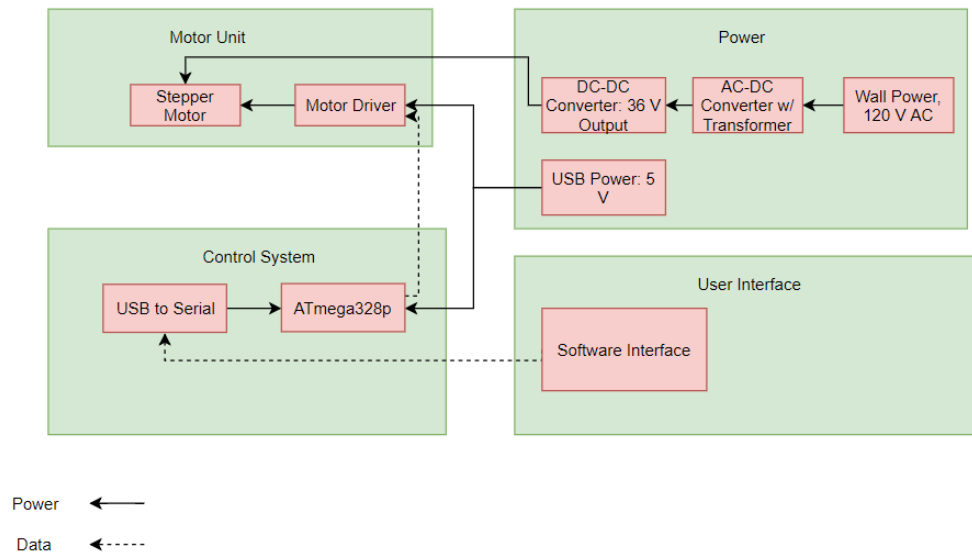
2 Design

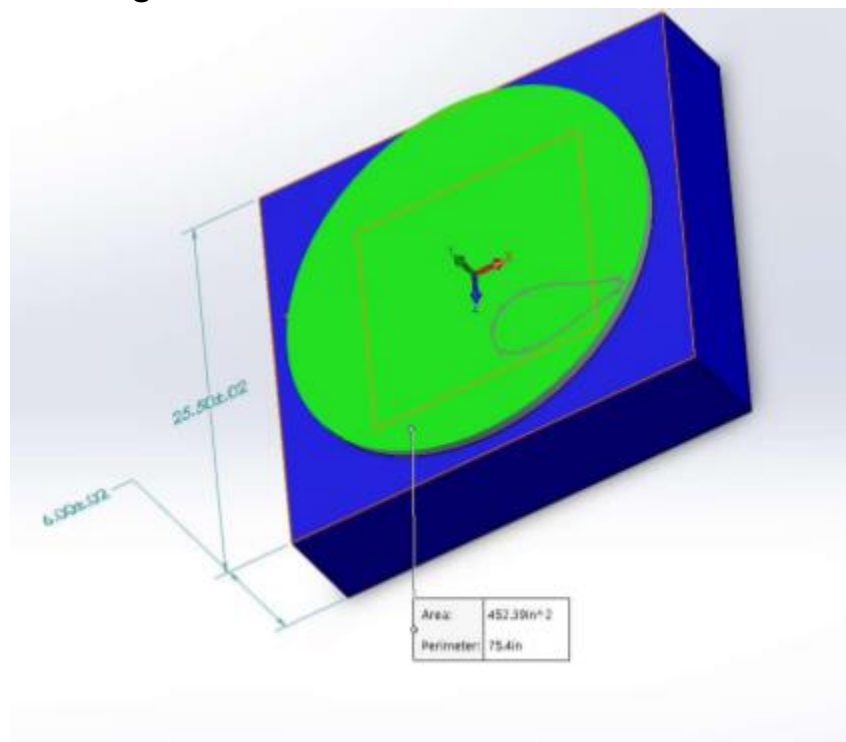## 2.1 Block diagram

Figure 1 Block diagram

2.2 Physical design

Figure 2 Physical Design

The physical turntable will be constructed from ¾ inch plywood and will be covered in carpet to absorb reflecting sound waves while also isolating the possible noise coming from the motor. The round (gray) platform will be the standing platform which will connect to the blue base with a lazy susan bearing. The driveshaft is attached to the platform and interfaces the ground with a housed ball bearing. This reduction in rotational friction allows for a relatively weak motor to rotate the loaded platform.

The NEMA 34 stepper motor (modeled in purple) will be fitted with a ~ 15 tooth sprocket gear. The driveshaft will have a ~ 60 tooth sprocket. They will be interconnected with a bicycle-like drive chain. This gives a 4:1 gear ratio allowing for even more precise movement and multiplied torque. The circuit boards will be mounted inside the base where they will not interfere with mechanical motion. The system will be connected to the wall using an C7 cord, this is also commonly known as a figure 8 cord.

2.3 Block Descriptions and Functional Overview

2.3.1 Control System

The control system is responsible for executing programs which in turn will send commands to the motor for turning.

Microcontroller (Atmega328P)

The control system in this project is centered around the Atmega328p microcontroller. This specific microcontroller was chosen as it is very popular and has wide support. It has an Arduino bootloader installed on the chip so that it can be programmed in the Arduino IDE. The microcontroller is then responsible for sending commands to the motor controller. Although

there is a plethora of other available controllers, this one offers ease of soldering and an acceptable quantity of I/O.

Inputs (5-pin header top right on schematic) : +5VDC power, RX, TX, GND (from programmer)

Outputs (12 pin header on bottom right of schematic) : +5VDC power, STEP, DIR, MS1, MS2, PFD1, PFD2, EN, RST, SR, GND

| Pin	Function	Connection
1	Reset, active high	from DTR of the FT232RL chip
2	RXD, serial receive	from RXO of FT232RL chip
3	TXD, serial send	To TXO of FT232RL chip
7	VCC, power	+5 VDC from FT232RL
8	GND	ground
9,10	XTAL, oscillator	To 16MHz crystal
4	PD2 digital OUT	STEP (all to A4989)
5	PD3 digital OUT	DIRECTION
6	PD4 digital OUT	MS1 (step select bit 1)
11	PD5 digital OUT	MS2 (step select bit 2)
12	PD6 digital OUT	EN (chip enable)
13	PD7 digital OUT	RST (chip reset)
14	PB0 digital OUT	PFD1 (decay 1)
15	PB1 digital OUT	PFD2 (decay 2)
16	PB2 digital OUT	SR (Synch. Rectification enable)
17	PB3 digital OUT	Buck Convertor

Table 1 MCU Pinout
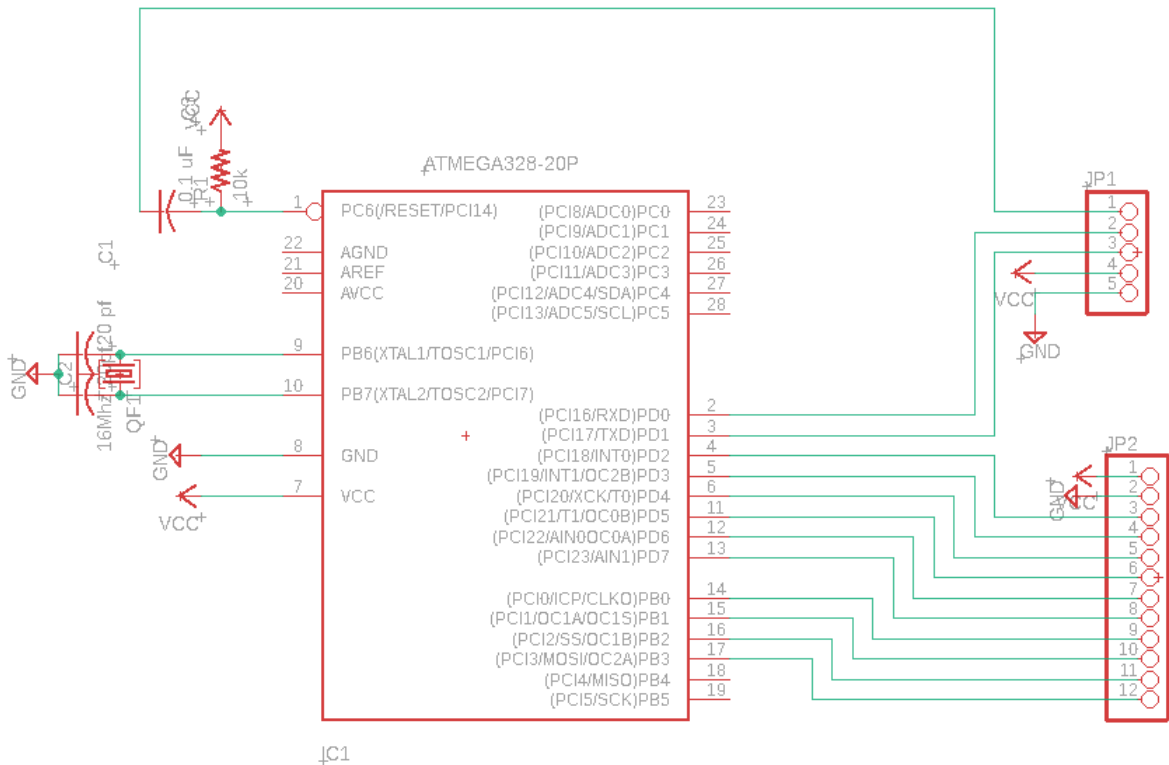
Figure 3 ATmega328p circuit

Programmer (SparkFun's FT232RL PCB)

To connect the microcontroller to a computer we need a serial connection. Modern computers today do not have an R232 port available for use. To remedy, we use a USB to Serial conversion IC produced by FTDI. This is a chip which converts D+ and D- on the USB to TX and RX R232 serial standard. The chip itself may be integrated into the final circuit, but as this project is not going into production, this step is optional. Below is a circuit diagram of the chip. This chip allows for easy programming of the microcontroller from Arduino IDE.
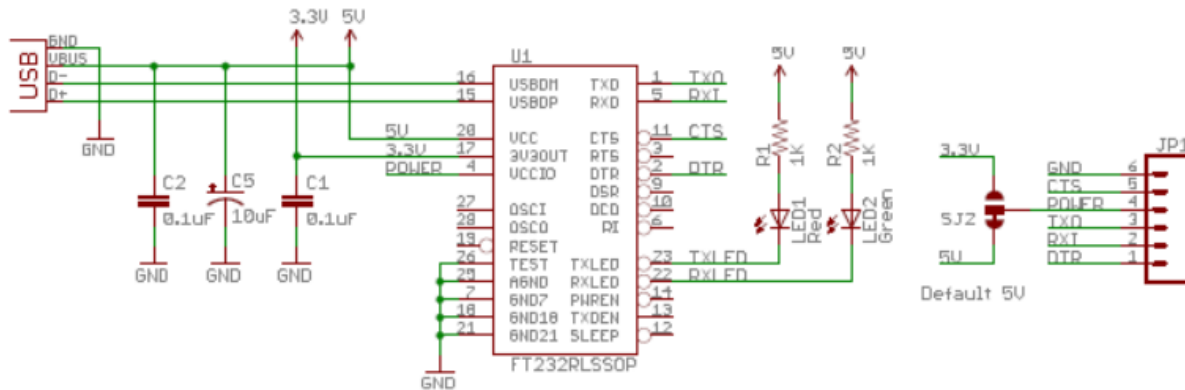
Figure 4: FT232Rl circuit

Inputs: USB micro (+5V, D+, D-, GND)
Outputs: GND, RX, TX, +5V, DTR

Requirements	Verification
Operates reliably with 5vdc supplied by USB	Probe USB supply and observe tolerance of +5VDC supplied. With a program running (such as LED blink) use a benchtop power supply to slowly decrease voltage until unreliable operation occurs.
Communicates with 5vdc +/- 20% logic.	Use oscilloscope to observe signals from I/O pins to ensure that valid +5VDC +/- 20% signals are sent
Can support a digital signal up to 100 Hz	Program controller to output at 100Hz signal and confirm by feeding output to oscilloscope.

Table 2 MCU RV

2.3.2 Motor Driver

The motor driver is responsible for translating the MCU's signals into powering the phases of the stepper motor.

Translator (Allegro Systems A4989 H-Bridge Translator)

While connecting a microcontroller directly into the MOSFETs which drive the motor phases is plausible, it requires a lot of code work and timing to execute correctly. This IC takes the legwork out of the equation as it controls the MOSFET bridges and has a lot of monitoring to ensure proper motor operation. In simple turns, it translates step execute, direction, and size into the control signals needed to drive each phase of the motor.

Inputs (12 pin header on bottom of schematic) : +5VDC power, STEP, DIR, MS1, MS2, PFD1, PFD2, EN, RST, SR, GND, VMOT
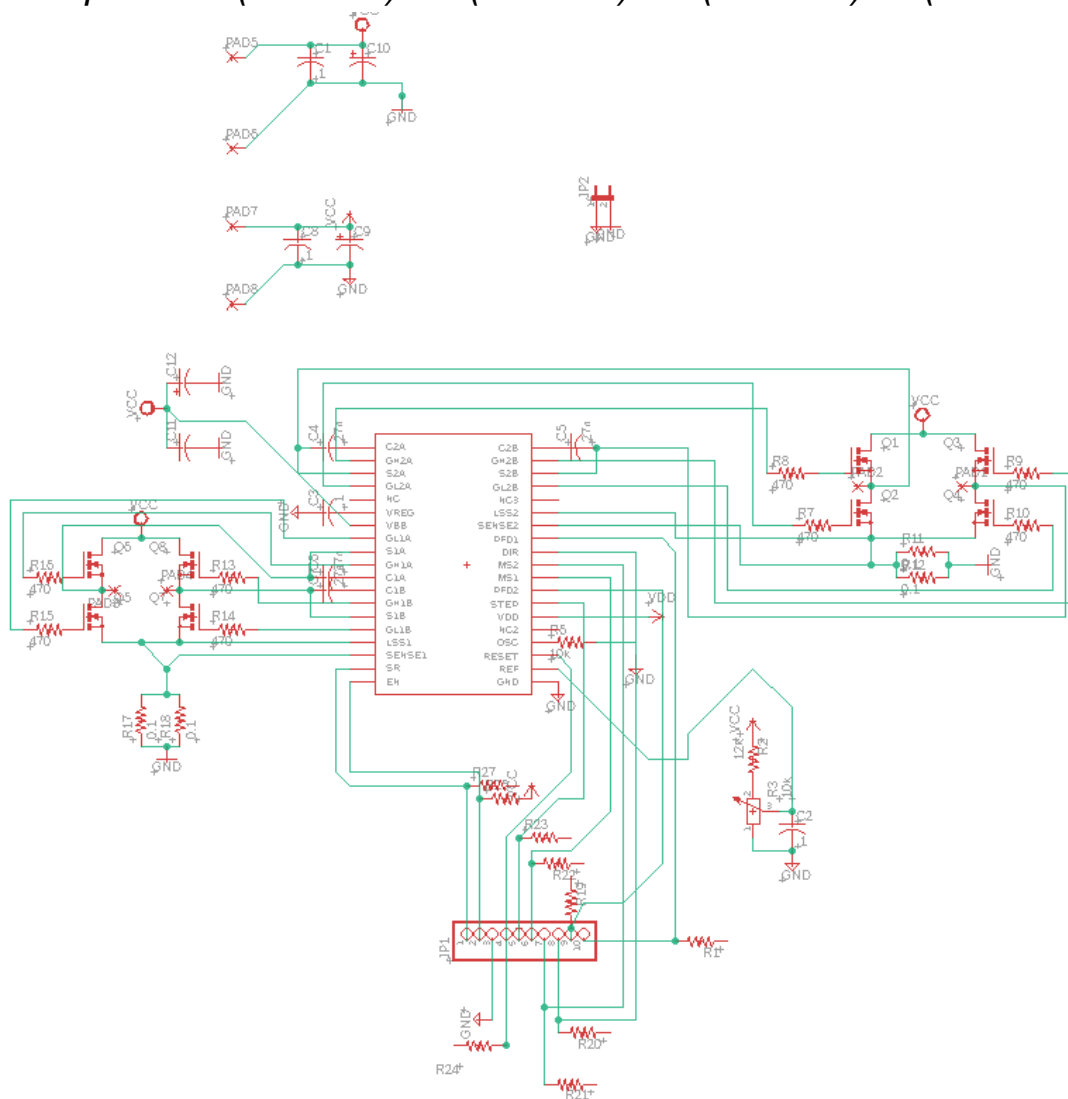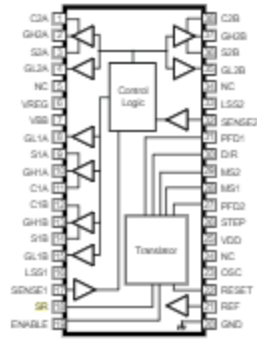*Outputs: Q5 (Phase 1) Q4 (Phase 2) Q6 (Phase 3) Q7(Phase 4)*

Figure 5 Motor Driver Circuit

Pin-out Diagram

Terminal List Table

Number	Name	Description
1	C2A	Phase 2 bootstrap capacitor drive A connection
2	GH2A	Phase 2 high-side gate drive A
3	S2A	Phase 2 motor connection A
4	GL2A	Phase 2 low-side gate drive A
5	NC	No internal connection
6	VREG	Regulator decoupling capacitor connection
7	VBB	Motor supply voltage
8	GL1A	Phase 1 low-side gate drive A
9	S1A	Phase 1 motor connection A
10	GH1A	Phase 1 high-side gate drive A
11	C1A	Phase 1 bootstrap capacitor drive A connection
12	C1B	Phase 1 bootstrap capacitor drive B connection
13	GH1B	Phase 1 high-side gate drive B
14	S1B	Phase 1 motor connection B
15	GL1B	Phase 1 low-side gate drive B
16	LSS1	Phase 1 low-side source connection
17	SENSE1	Phase 1 bridge current sense input
18	SR	Synchronous rectification enable
19	ENABLE	Output enable
20	GND	Ground
21	REF	Reference voltage
22	RESET	Reset input
23	OSC	Oscillator input, ROSC resistor connection
24	NC	No internal connection
25	VDD	Logic supply voltage
26	STEP	Step input
27	PFD2	Percent Fast Decay Input 2
28	MS1	Microstep Select Input 1
29	MS2	Microstep Select Input 2
30	DIR	Direction input
31	PFD1	Percent Fast Decay Input 1
32	SENSE2	Phase 2 bridge current sense input
33	LSS2	Phase 2 low-side source connection
34	NC	No internal connection
35	GL2B	Phase 2 low-side gate drive B
36	S2B	Phase 2 motor connection B
37	GH2B	Phase 2 high-side gate drive B
38	C2B	Phase 2 bootstrap capacitor drive B connection

Figure 6 A4989 Pinout

Source 1 : from [2]

MOSFETs (IRF540N)

The MOSFETs chosen for this project are IRF540N, which are a common power MOSFET capable of 100 V 36 A, which is more than necessary for our needs. Since we are not pushing the boundaries of the FETs, we are able to obtain a safer and cooler operation. The H-bridge allows for ease of direction change in the motor.

2.3.3 Motor

Motor (NEMA 34 standard Bipolar Stepper 1200 oz/in)

The motor chosen can deliver 1200 oz/in of torque to the shaft. Unaltered, the motor has a 1.8 degree per step resolution. Converting the torque value to something more common results in 6.3 ft-lbs. (1 foot pound = 192 inch ounces). However, with the gear ratio of 4, we multiply the torque value by 4 and divide the degree resolution by 4.

Inputs: Phase A, Phase A', Phase B, Phase B',
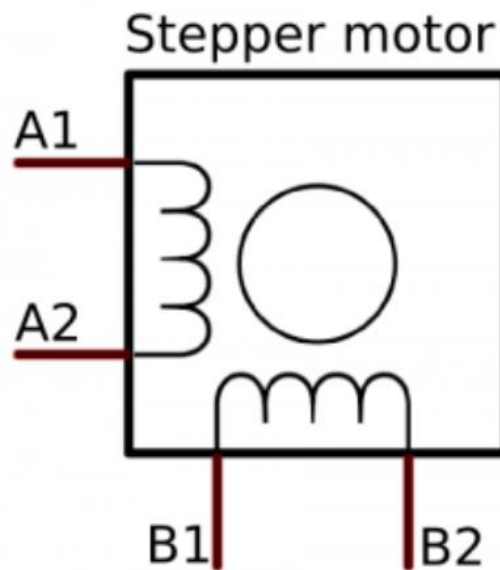*Output: mechanical torque*

Figure 7 Bipolar Stepper

Source 2 from [3]

Requirements	Verification
MOSFETs can support a 36VDC 5.5A load without reaching dangerous temperatures (Max 175°C)	Run the motor at continuous load and use IR thermometer to measure the temperature. Ensure temp does not exceed 175°C

Motor can rotate at 100Hz with only addition of max 5 dB to ambient noise	Use SPL meter to measure the acoustic intensity, in dB SPL. Compare to ambient noise, ensure motor not exceeding +5dB to ambient
A4989 translator IC successfully switches the MOSFETs in the correct stepping sequence from input step signal	Use oscilloscope to monitor signal of step input and compare to the gate signals of the MOSFET bridges. Find the time between step signal and phase activation to monitor delays

Table 3 Motor RV

2.3.3 Power Unit

The power unit is responsible for converting wall power at 120 V AC 60 Hz to a 36 V DC power for the motor. This is done using an AC-DC converter with an attached buck convertor. The overall circuit that will be used isshown in Figure 8.
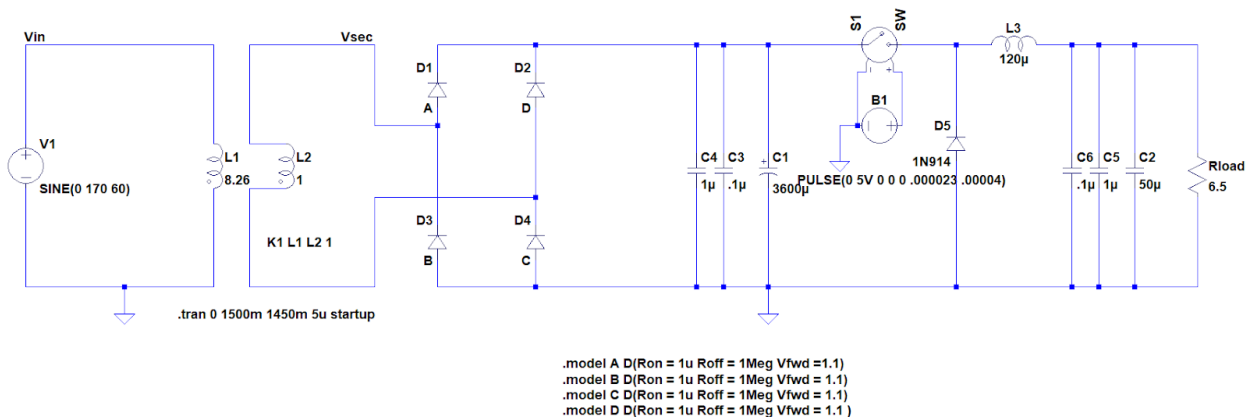

Figure 8 Power circuit

AC-DC Converter

The converter takes an input of 120 V AC and outputs a rectified voltage. The first component that was selected for this section was the transformer. A transformer with a primary voltage of 115 V and a secondary of 40 V. As the input is 120 V RMS this is equates to a sine wave with a peak of 169.7 V. This means the secondary voltage will have a peak of 59 V. This voltage is rectified using a full bridge rectifier. The rectifier that was chosen for this project is capable of handling 600 V and an average of 2 A. As the stepper motor never is continuously in use the current rating is never close to being met. Even if the motor was constantly on, simulations showed that the rectifier sees 1.5 A average allowing room for error. This is feed into 2 1800 µF capacitors in parallel with each other for a total of 3600 µF. This will smooth the voltage greatly. The simulated output of this system is shown below in Figure 9.
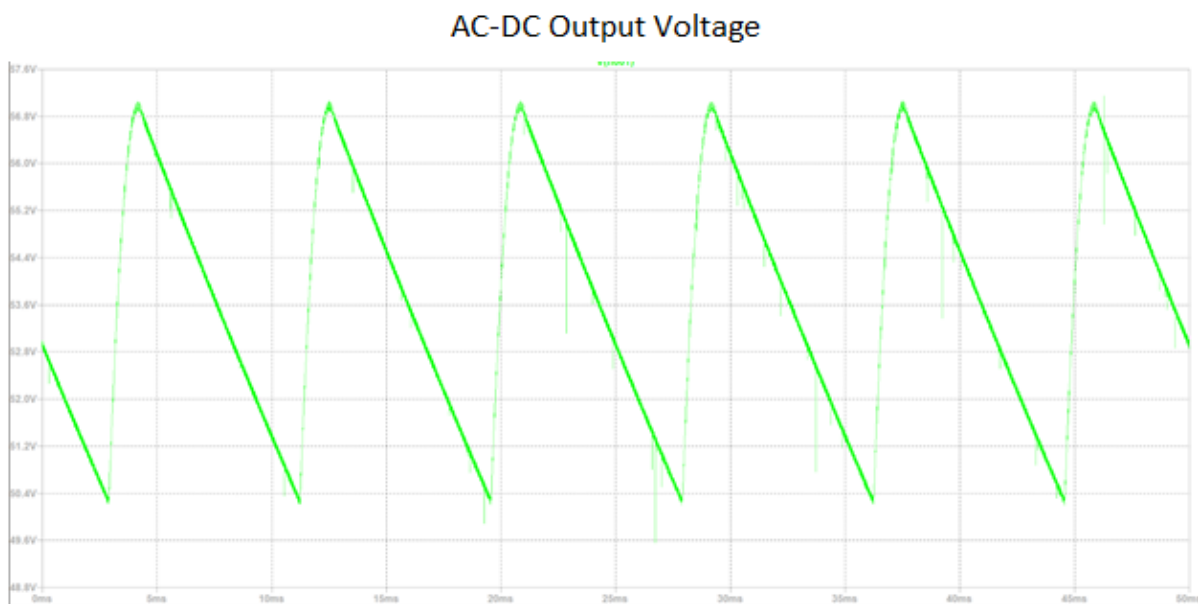

Figure 9 AC DC Converter Simulated Output

Buck Converter

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The converter takes an input as what was outputted from the AC-DC converter.   The output will be a DC voltage in the range of 31-37 V to power the motor. This will be done using a buck converter to bring done the voltage to the desired voltage. The same MOSFET's that were used for the motor driver are used in this section for the same reasoning. To set the duty ratio for the buck converter a pin will be used from the microcontroller. A sufficiently large inductor was chosen using calculations and simulations. This inductor must have a high enough current rating to take in 5.5 A from when the motor is in use. A capacitor is added to the output to help with ripple and create more gentle slopes in the waveform. The output voltage of the power unit is shown in Figure 10.
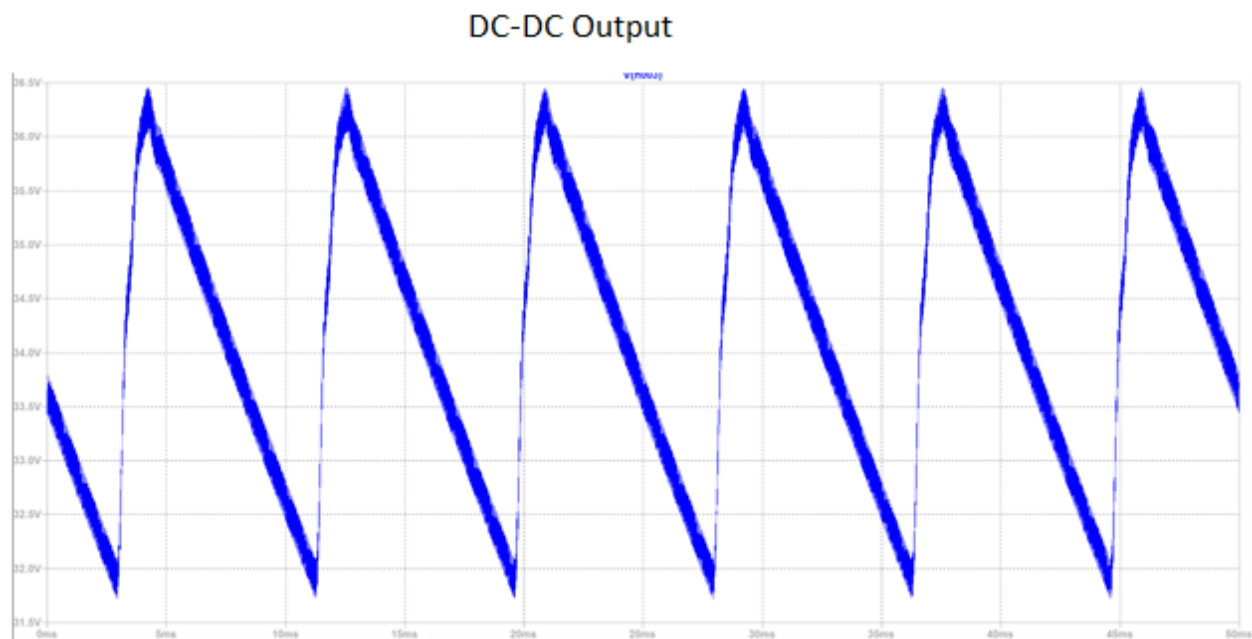
Figure 10 Simulated Output

Requirements	Verification
AC to DC converter circuit can output average value of >40VDC with =+/- 20% ripple	Isolate the converter from the rest of the circuit and use oscilloscope to monitor the voltage signal produced from rectification.

|	
Verify Buck Converter works as individual converter. Be able to see that voltage can be controlled. Verify that 50 V DC voltage can be converted to the range of 31-37 V. Show that both ends of the ranges can be met.	Connect Buck converter using components. Use function generator to set duty ratio and DC power supply at 50 V as input. Measure voltage across output of converter using oscilloscope. Change duty cycle of buck converter so that voltages in range of 31-37 V can be seen.
Buck Converter output with AC:DC converter connected has output of 31-37 V	Monitor input signal to converter and the output voltage for motor. Set duty cycle to appropriate setting. Confirm that it is in the 31-37 V range

Table 4 Power RV

2.3.4 Software
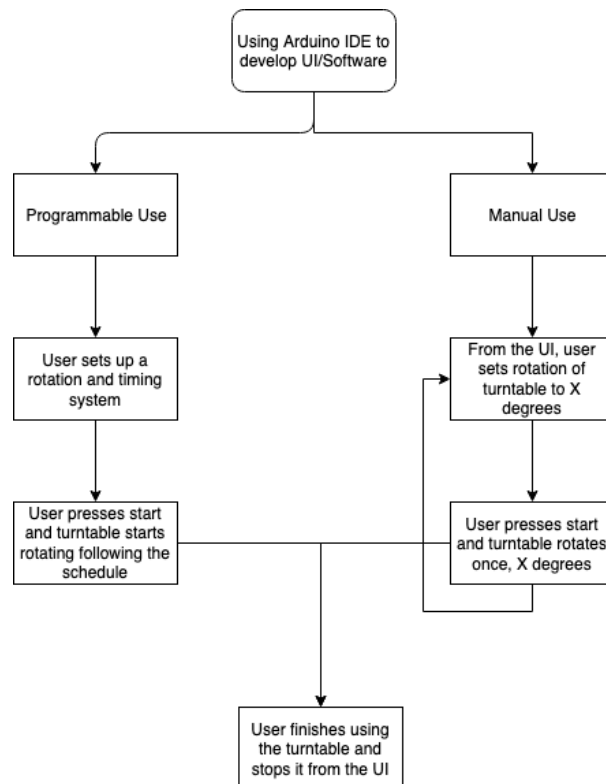
Figure 11 Human Software Interaction

For this diagram, this is more of a high-level flowchart for usage of our Human Turntable device. We're planning on using the Arduino IDE to develop the UI and the software behind the device. It'll have two usages,

one is the manual use and the other is the programmable use. For manual usage, the user will simply input in a degree value X, to a box on the UI and press play. This will lead to the device rotating the X amount of degrees then pausing for an unlimited amount of time. If the user wishes to change the degree of rotation, they can do so during this wait time. When they press play again, it'll rotate the new/same amount of degrees that's in the box on the UI. For the second usage, programmable use, the user will be able to schedule and create an overarching plan for how much they want to rotate and how long they wish to pause the rotation for the device. For example, if I wanted it to rotate 10 degrees, wait 30 seconds, repeated 10 times, I could do that. For the UI, it would probably be useful to have the units change as well, so that the user could specify seconds/minutes and degrees/radians.
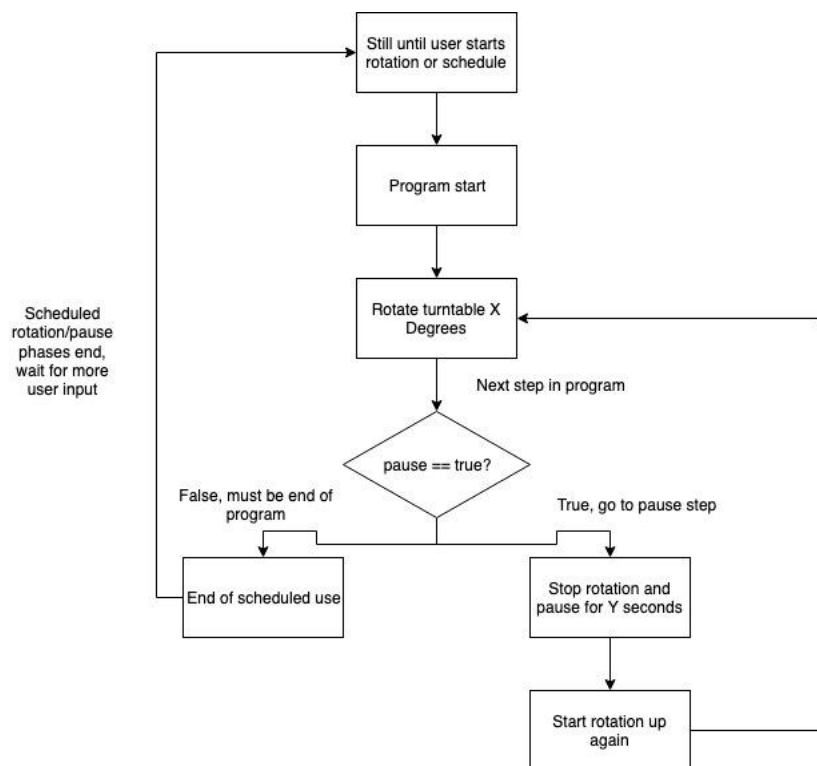

Figure 12 Software Flowchart

This is the more specific diagram for the programmable use of the software. Since the manual use only does one step at a time, we don't have to add much logic to it if the signals and timing is set up correctly.

However, there is some logic to be used for the programmable aspect. We were thinking of utilizing an array to store the scheduled program the user created. Since initially, the device starts in the paused state, the person standing on the turntable could get situated prior to the user starting the rotation. Using the array, all the even indices could represent rotation and the odd ones, the pause duration. The program would go through the array and run the schedule that the user set up and if it's at the end of the array, the rotation will stop, and the turntable will go back to the idle state. After that, the user will then be able to either change which program/schedule they wish to run, or swap back to manual mode if there was some issue with a certain part of the program.

Requirements	Verification
Device should be able to perform rotations of 5°,10°,90°,180°, and 360° +/- 5%	Input value from UI and give start command. Ensure the program translates degrees to appropriate signals for microcontroller to send to motor driver. Monitor rotation of table to be sure that each rotation is within 5% of that specified rotation. Use protractor to measure rotation.
Device should be able to have pauses at 10 seconds, 30 seconds, 60 seconds intervals with +/- .5 second precision.	Use a stop watch to time the programmed pause, make sure that each pause last 10 seconds, 30 seconds, and 60 seconds =/- .5 second. Do multiple trials as humans will be slightly off in their timing.
Ability to combine a series of rotations and pauses into a single command. For instance, set a run of ten 5° rotations with a 10 sec pause between each rotation.	Program a sequence from UI, compare to expected values. For example, have ten 10° turns with 10 second pause. Use protractor to ensure table rotates 100°. Measure that each pause lasts 10 seconds +/- .5 seconds.

Table 5 Software RV

2.4 Tolerance Analysis

2.4.1 Motor Accuracy analysis

The motor can step at 1.8° Full-Step with a 5% accuracy. Using the driver's capability of 1/16 steps, and the gear ratio of roughly 4:1.

$$Step\ Angle_{table} = 1.8 * \frac{1}{16} * \frac{1}{4} = 0.028 \overset{+}{\underset{-}{}} 5\%$$

Equation 1 Tolerance for Overall Rotation

2.4.2 Power Accuracy analysis

For our tolerance analysis we will look at the power unit. The power unit is chosen as without the power unit the motor will not be able to be powered. As the motor drives the turntable the project would fail if an adequate power unit is not designed. The overall requirement for the power unit as a whole is to create a DC voltage in the range of 31-37 V which is converted from a standard 120 V 60 Hz wall outlet. To do this each component will be looked at individually to make sure this spec is still meet. Then, all of the worst cast scenarios will be combined to see if the spec is still met. Additionally, all simulations will be done under the max anticipated load as this puts the most strain on the unit to meet the requirement.

The first component that will be examined is the transformer. The transformer that we are currently using is a 115/40 V transformer rated for 240 VA. The winding tolerance for a typical transformer is +/- .5% [4]. The nameplate turns ratio is 2.875:1. With this added tolerance the ratio can vary from 2.889:1 to 2.861:1. This will still meet the requirements. The output voltage of the AC-DC voltage will change slightly. The voltage in the worst case which is when the winding ratio is high has the voltage still well above 40 V which is the AC-DC converter requirement. The Buck Convertor duty ratio will need to be raised slightly to compensate for this tolerance, but the requirement is still met.
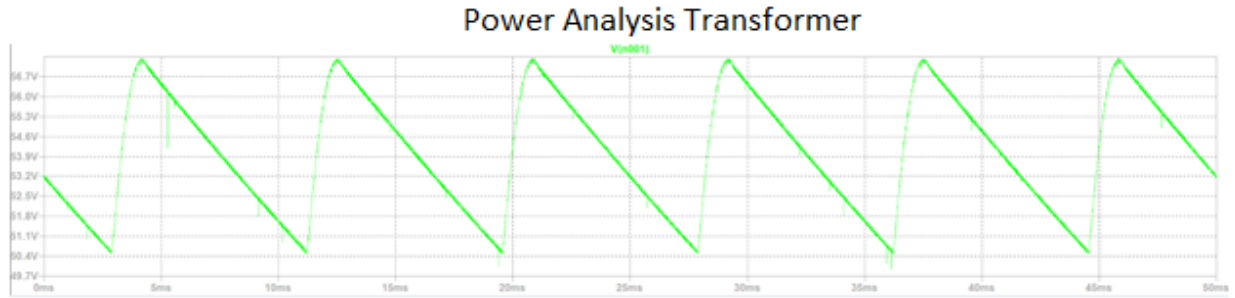
Figure 13 Power Tolerance Transformer

The next tolerance that will be looked at is the AC-DC capacitor tolerance. The capacitors chosen have a tolerance of +/- 20%. Increasing the capacitance will decrease the ripple voltage across the convertor. This will cause the DC-DC converter to have a smaller ripple and perform even tighter than the proposed requirement [5]. If the capacitance is lower than each capacitor would have a value of 1440 µF (1800-1800*.2). Simulating with this capacitor value leads to the result of the requirement is still met. This is shown in the Figure below.
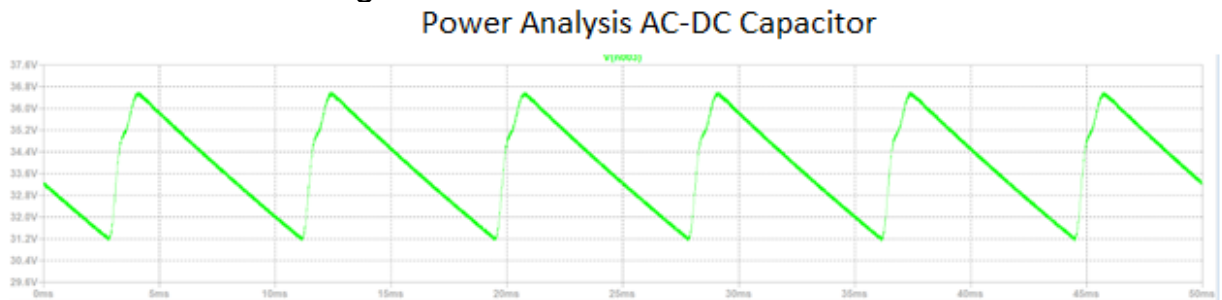

Figure 14 Power Tolerance AC-AC Capacitor

The next component looked at is the Buck Convertor inductor. This component has a value of 120 µH with a +/- 15% tolerance. As an increased inductor value will cause less ripple current only the worst case will be looked at in the case of the lowest possible valued inductor. This value would be 102 µH. This will still meet the requirements as shown in the Figure below.
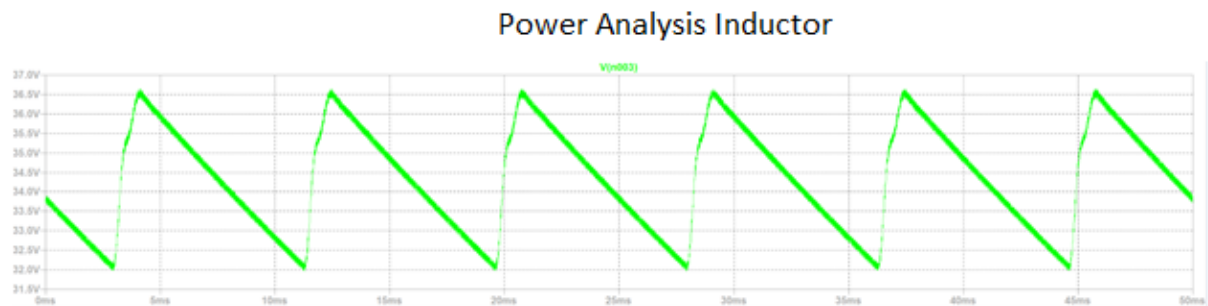

Figure 15 Power Tolerance Inductor

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Next, the output capacitor on the DC-DC convertor will be examined. The size of the capacitor. This capacitor is to smooth the small voltage peaks of the waveform. This is best explained as looking at the Figure above. The green line is rather thick, but this is not the line being thick, but small voltage changes. The capacitor size is 100 µF with a +/- 20%. Again, in the worst case this is 80 µF, as a higher capacitance would smooth the voltage more. As shown in the Figure below this meets the requirements.

Figure 16 Power Tolerance DC-DC Capacitor
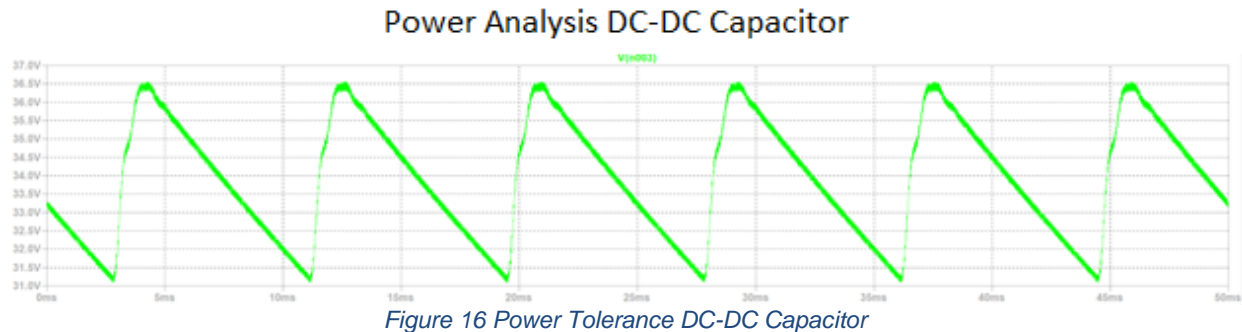
Now making all of the power unit's components the worst case. As shown in the following Figure the worst case still meets the requirements. The next Figure shows the circuit used to simulate this. LTSICE was used for all simulations. Through the tolerance analysis it was learned that even with parts that are not the exact parts we had in mind the power unit will still work.

Figure 17 Power Tolerance Combined
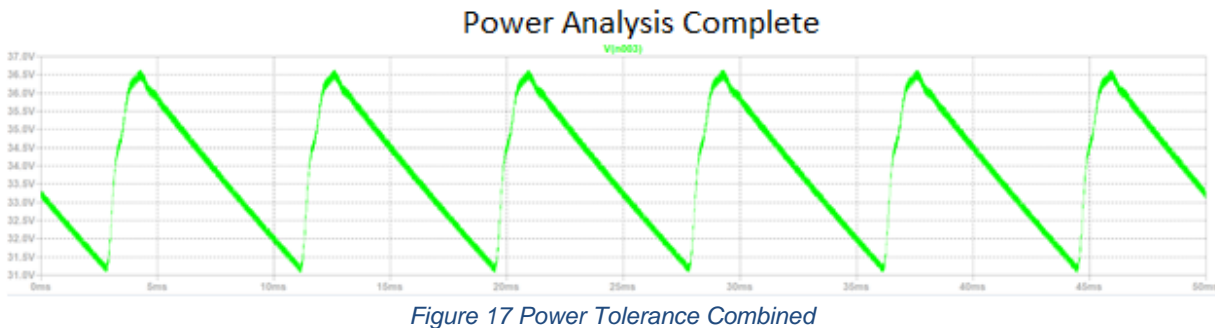
3 Costs and Schedule

4.1 Costs and Labor

The average ECE Illinois Electrical Engineer's starting salary was $67,000 and the Computer Engineering starting salary average was $84,250 [6].

Dividing these numbers by 2080 will get the corresponding hourly rate.

$67000/2080= $32.21/hour
$84,250/2080=$40.50/hour
Estimated Hours:

Daniel K: 20 hours/week = 80 hours/month = 200 hours/semester
Jacob: 20 hours/week = 80 hours/month = 200 hours/semester
Daniel Z: 20 hours/week = 80 hours/month = 200 hours/semester

This leads to 600 hours/semester total. Two students are Electrical Engineers and the other is a Computer engineer: (400*32.21) + (200*40.50)=$20,985 for the development labor costs rounded to the nearest dollar.

In Table 6 the estimated coats of parts are listed.

Part	Cost
Crystal 16MHz (COM-00536)	$0.95
SparkFun FTDI Basic Breakout - 5V	$14.95
ATmega328 with Arduino Optiboot (Uno)-Atmel	$5.50
20 pF Capicator 1kV Rated- 1265PH-ND- Vishay BC Components (2)	$.62
38 Pin IC Adapter- PA0039-ND- Chip Quik Inc.	$6.21
Motor Driver IC-620-1389-1-ND- Allegro Microsystems	$4.07
470 µF Capicator 63V- P5585-ND- Panasonic	$.86
220 µF Capicator 16V- 1189-1546- 1-ND-Rubycon	$.25
MOSFET 100V 36A- IRL540NPBF- ND-Infineon Technologies	$1.59
220 µF Capicator 63V493-1942-ND -Nichicon	$.57

Nema 34 Stepper Motor 36 V 5.5 A 8.5 Nm	$59.50
Transformer 115V/40V 250 VA-F-273U-Triad Magnetics	$30.91
1800 µF Capicator 100V- ECO-S2AP182BA-Panasonic (2)	$3.22
Full Bridge Rectifier 600 V 2A-KBP206G-Diodes Incorporated	$.60
120 µH Inductor 6.7 A- HCTI-120-6.7-Signal Transformer	$2.44
C7 6 foot cord	$2.49
C7 connector	$.36
1-6-4 Whitewood Board X 2	$9.36
1-12-4 Whitewood Board	$6.38
1-1/4-18 Stain Grade Round 24 in	$10.97
M6 Screw 1x30mm x4	$2.78
M5 Screw 30mm x4	$1.98
Wood Screw 2in 75Ct	$4.98
Nuts	$2.00
Lazy Susan Bearing 6in Dia	$6.97
Mounted Bearing ½ in Dia	$10.97
0.05 Ohm Resistors x4	$0.25
½ in ID sprocket, 14 teeth #25 chain	$11.50
#25 chain 60 tooth sprocket ½ in ID	$40.00
#25 chain 3 feet	$30.00
Various Passives (taken from lab)	$ <5.00
Carpet	$5.00
Total	$284.15

Table 6 Parts list

Combined with labor the total estimated cost of this project is $20,935+$284.45=$21,219.15.

4.2 Schedule

Week	Dan K	Daniel Z	Jacob Taylor

1/14	Meet with Ryan to discuss his needs and the scope of the project	Meet with Ryan to discuss his needs and the scope of the project	Meet with Ryan to discuss his needs and the scope of the project
1/21	Begin modeling of physical design, researching components and methods	Research the overall scope of the project	Research the overall scope of the project
1/28	Purchase materials for physical base	Continue to research, investigate specifics regarding UI development	Continue to research. Start to simulate power unit
2/4	Construct base without driveshaft	Work on project proposal	Work on proposal. Define power unit operation
2/11	Draw circuits and purchase electrical components	Continue to work on proposal	Draw circuits and simulate
2/18	Start prototyping circuits on breadboard	Assist team members on their tasks	Purchase power unit components
2/25	Layout PCBs if prototype is successful	Assist team members on their tasks	Start prototyping circuit on breadboard and protoboard
3/4	Purchase driveshaft components	Begin UI development for turntable	Design and route PCB in Eagle
3/11	PCBs ready for pcbway Mount motor and driveshaft	Basic functionality complete, able to send commands to MCU	Assemble and test PCB, adjust if necessary

3/18	Spring Break	Spring Break	Spring Break
3/25	Solder components to PCB	Troubleshoot UI and finalize	Connect power unit to motor driver and see if enough
4/1	Mount and wire PCB in table	Implement task scheduling feature	Mount PCB
4/8	Troubleshoot and assist teammates	Unit test and debug	Troubleshoot and assist teammates with work
4/15	Final adjustments and more troubleshooting	Debug and final touches	Final adjustments
4/22	Demonstrate	Demonstrate	Demonstrate
4/29	Present	Present	Present

Table 7Schedule

4 Safety and Ethics

For our project, we don't have too many hazards. Since someone must stand on our human turntable, there is a chance that the motor could spin out of control with someone on it. We will thoroughly test this to ensure this does not happen and will attach an emergency stop button as well on the off chance that something like this does happen. That way, if somehow the turntable were to spin too fast, the person standing on it still had a way to stop the rotation manually. Another issue is that people could have issues balancing on the platform. If the rotation is slightly jerky and inconsistent, a person standing on the turntable could potentially fall off. To solve this issue, we will first make the platform large enough for the user to stand on the turntable comfortably. It is also up to the observer to ensure that the unit is on flat and stable ground. We can also add a railing to the appliance

so that when the person is standing on the platform, they have something to hold on to. Since our project is going to be used by Ryan for audio testing, a large railing connected to the device might have some interference with his results. To remedy that, we could have the railing removable, that way it's up to the researcher and participants discretion as to whether they use it. These precautions are to adhere the IEEE Code of Ethics item 9 which states "to avoid injuring others …" [7]. By following these precautions, we will make sure that no injury occurs when using our project.

Since we are also using a 120 AC/60 Hz power supply unit, if someone were to use this elsewhere at a different current/voltage level, it could potentially overheat the motor. We must also be considerate about overheating when we are building and testing this device. The main concern here is that our device will be built out of wood, and as such, is flammable if the electronics were to overheat. By being mindful of these issues, as well as having a fire extinguisher on hand, especially when building and developing, we should be able to reduce the risk of harm.

 Additionally, per Zitzewitz currents in the range of .1 to .2 A are deadly. The motor can draw up to 5.5 A [8]. Safety precautions when testing and using the unit should be done. For instance, use standard lab precautions and double check circuits when prototyping. As the device can draw a large amount of power if rotations are continuously performed certain safety precautions should be managed. The device should not be plugged into an outlet with several other high-power devices, this could overload the outlet. Additionally, when testing the device each time the device is plugged in, the wall plug should be inspected for fraying and other defects [9].

Finally, per item 7 in the IEEE code of ethics as engineers, we should only undertake a task if we have knowledge and experience to do so [7]. For this project, we assembled a team with various skills in Electrical and Computer Engineering that has the necessary experience to successfully complete this project.

5 References

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