HUMAN TURNTABLE

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Abstract

We are tasked with creating a motorized turntable capable of supporting a human being. The device is built as to cater to Ryan Corey's audio research needs. The team members pool together knowledge in various fields of electrical engineering to present a working prototype. Our device is capable of omnidirectional precision rotation which is safe and quiet. This prototype is fully functional but leaves room for improvement for future versions.

Contents

1. Introduction

Ryan Corey, a graduate student and former 445 TA, is working on binaural audio modeling in an order to develop advanced audio signal processing for listening devices. The current methodologies which Ryan uses involve a stationary speaker and a turntable. 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].

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 develop a robust turntable which is capable of precise directional turns while supporting the weight of a human subject. The wooden turntable is driven by a CNC grade stepper motor which will allow for precise turns in either direction. We power the turntable with a power supply and control it via microcontroller.

A computer interface allows for programming through our included UI or optionally via the serial port. The interface should be able to control rotational direction (clockwise or counter-clockwise), specify a rotational amount either in radians or degrees, and be able to save and load schedule rotations. The software connects with the device through USB and the data is sent through the serial port.

While our turntable is purpose built, it can be used for other applications where ever a large load is needed to be rotated accurately and autonomously. An example would be 3D scanning.

The block diagram for the project is shown in Figure 1. The power unit is what supplies power to the entire system. The power unit takes in power from a 120 V AC wall outlet and converts it to 36 V DC. This voltage is applied to the motor driver. The motor unit contains the motor driver and the stepper motor. The motor driver is an off the shelf stepper motor driver. The stepper motor is what physically rotates the motor. The motor gets power from the motor driver. The control system is what controls the turntable. Using a microcontroller the motor is controlled to move a certain amount of steps for a certain rotation. The longer the rotation the more steps the motor moves. The software subsystem communicates with the microcontroller to do this. Using a USB to serial chip from the control system the software subsystem can communicate with the microcontroller. The software subsystem contains a GUI. In the GUI is where the user can set the length of rotations. The user may also create a series of rotations with pauses between each rotation.

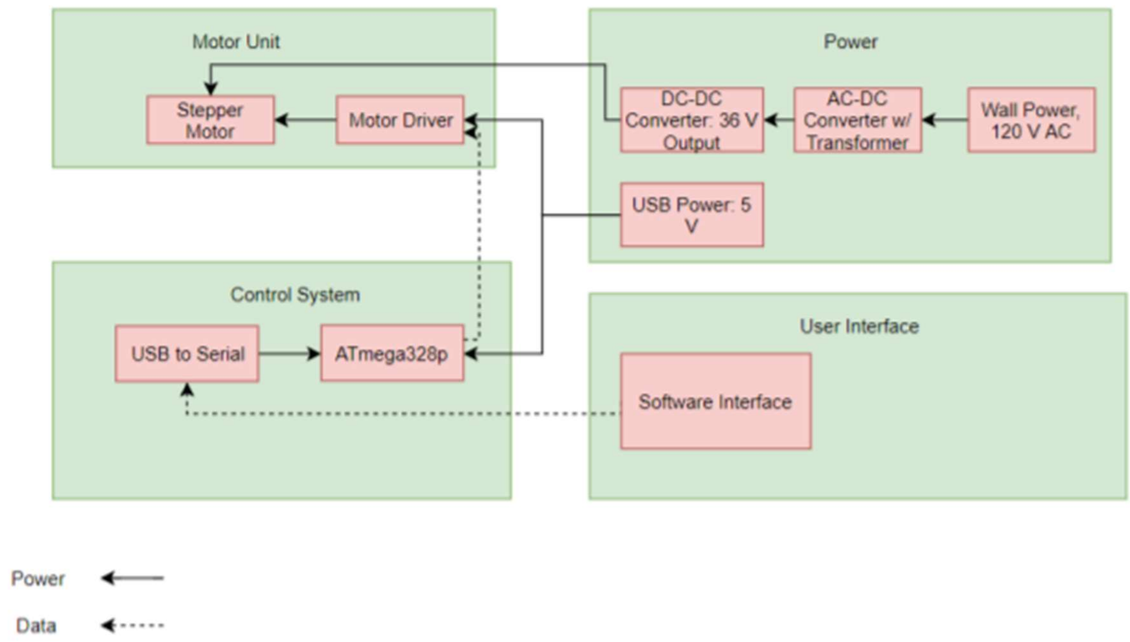

Figure 1 Block Diagram

The remained of the paper will delve into our design process, our iterations, our results, and an insight into our shortcomings.

2 Design

2.1 Design Procedure

To design our prototype, several considerations had to be taken. This section talks about how we came up with the designs that we did and why. We break up all the subsystems into their own physical piece such that if any one component fails, they are easily replaceable by like off-the-shelf counterparts.

2.1.1 Control System

Due to the relative size of our project, we did not have any real constraints on our choice of a controller unit. However, due to having little to no knowledge of microcontrollers prior to this project, we had to go with something simple. Our goal was to find a way to interface a computer to 5 volt TTL logic. The Senior Design lab supported the use of ATmega328p microcontrollers as they had a stock of ICs and supporting hardware. This chip is also the heart of an Arduino Uno which lends itself to the whole suite of software and online support revolving the popular product. This allowed for a sure-fire way that was not going to leave us overwhelmed. We tailor the microprocessor to our needs by including only essential supporting hardware and cutting out the rest as shown in sFigure 2.

The controller serves as a digital signal generator for our stepper motor driver running only a portion of the code. The main task was to interface the microcontroller with a computer from where Ryan would control the table.

While there were several ways of accomplishing this task, we found that we can use the serial UART interface provided by the ATmega's TX and RX pins. This port was also useful for programming the microcontroller, so it would cut down complexity. However, modern computers tend to lack the RS232 serial port of the past. To remedy this problem, we included an FTDI IC dedicated to translating from USB to UART serial. This IC has native plug and play drivers from Windows which would make it easy for the end user.

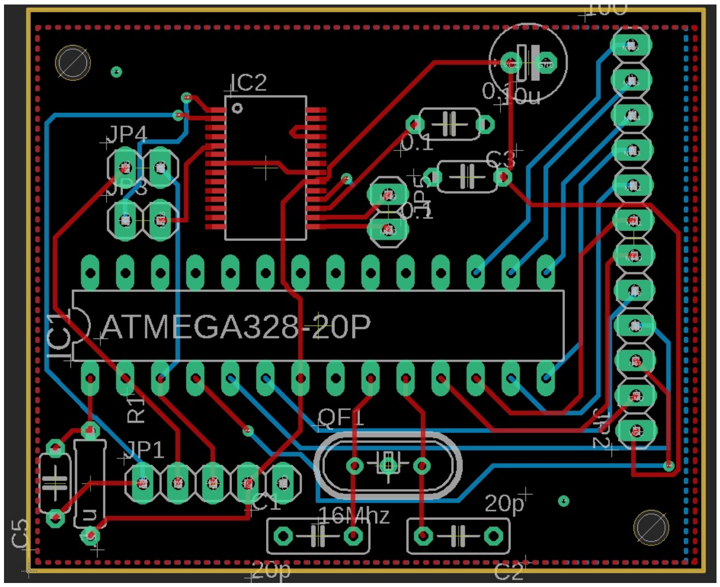

Figure 2 MCU PCB

2.1.2 Motoring

The next hurdle was to figure out how to mechanize the turntable's rotation. There were a few options which we considered before ultimately coming to our current design.

While there are a variety of motors out on market, we narrowed our options to DC motors. This gave use two choices, either an encoded brushless DC motor or a stepper motor. The encoder would have required a lot of extra work as we would need to learn how to interpret an encoder and then implement an inverter circuit to drive the motor. We settled with stepper motors as they have open-loop control operation. Also, the stepper motor is a true DC motor as the motor phases receive direct current.

We found a NEMA 34 standard motor which can handle up to 6 amps and provides a torque of around 8 Nm.

Normally, stepper motors are controlled through simple transistor circuits. However, when driving a motor of such power, the circuitry to drive the motor would need to be sophisticated.

2.1.3 Motor Driver

The heart of controlling the current to the motor's phases lies in MOSFET full bridges. A FET bridge allows for omnidirectional current flow which is controllable via the gate signal. The omnidirectional flow allows us to rotate the motor in either direction. Each time a phase is powered the motor's rotor teeth align with the induced magnetic field. Sequencing the phases allows for rotation of the motor.

To drive these full bridges, one for each motor phase, specialized IC's exist. These ICs can control the gate signals of the full bridges allowing for constant current, timing, and a variety of inputs. The ICs convert simple 5 V logic inputs to high voltages and current required for the motor.

With this information and a lot of online research, we attempted making our own home-brew stepper motor driver. With several attempts we kept burning up chips, fets, and other components which only resulted in the motor vibrating at best.

Accepting our failure, we turned to an off-the-shelf solution. As planned, we divided our subsystems such as that if any design process failed, we can replace it with a manufactured part. We found a driver which turned out to be cheaper than the cost of the components for our homemade driver. The purchased driver also included a multitude of features we would never even thought of including such as opto-isolated inputs, reverse polarity protection, adjustable current, overheat protection, and a metal heatsinked enclosure which dissipates heat. All in all, this driver provided a safer end-product at a reduced price.

2.1.4 Power Supply

The power supply takes in 120 V AC at 60 Hz from a standard wall outlet and supplies 31-37 V DC at up to 3 A to the motor driver. The power supply is made up of two power convertors. There is an AC-DC convertor in a full bridge rectifier and a DC-DC convertor in the form of a buck convertor.

For the AC-DC convertor a full bridge rectifier was chosen over a half-bridge rectifier as a full bridge has a power factor of 1. The part selection for the AC-DC convertor was done using LTSPICE. The convertor was simulated, and parts were chosen from there. The first part selected was a 115/40 V transformer. The transformer is rated for 240 VA. This transformer easily meets the power requirement for the power unit. This calculation is done using the standard power formula shown in Equation 1.

$$P = VI = 37 * 3 = 111\ W \tag{1}$$

The next component selected was the bridge rectifier chip which was rated for 600 V and 2 A of continuous use. This is enough as the average current of the rectifier is much lower than 2 A. Lastly, smoothing capacitors were chosen to make the voltage a constant DC value on the output of the convertor. Using the simulation 3600 µF capacitance value was chosen as this value was easily found in online parts catalogs. The figure below of the AC-DC convertor meets the requirement from Appendix A that the AC-DC convertor should have an output greater than 40 V and a ripple less than 20%.

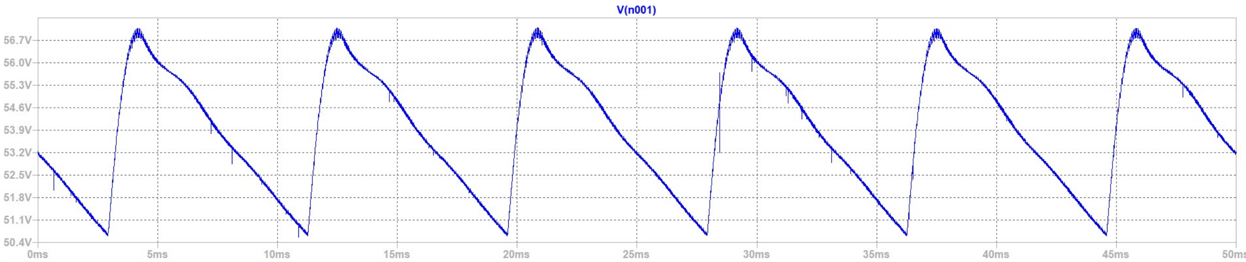

Figure 3 AC-DC Converter

The other converter that comprises the power supply is the DC-DC convertor in the form of a buck convertor. A buck convertor was chosen as it is a simple power electronics circuit that can be easily made. It offers simplicity while still providing good performance. For the Design of the buck convertor the main component is a switching regulator. The LM2576HVT chip was chosen. This chip can take in an input voltage up to 60 V and output a voltage up to 57 V. This output voltage is controllable by changing two feedback resistors on the output of the buck convertor. Capacitors and inductors were selected for the chip using the Texas Instrument datasheet [2]. This circuit was simulated to verify that the components selected would meet the requirements for the power supply. The simulation results are shown in the figure below. The voltage falls within the 31-37 V range. This test was conducted at 3 A proving that the current is high enough as well.

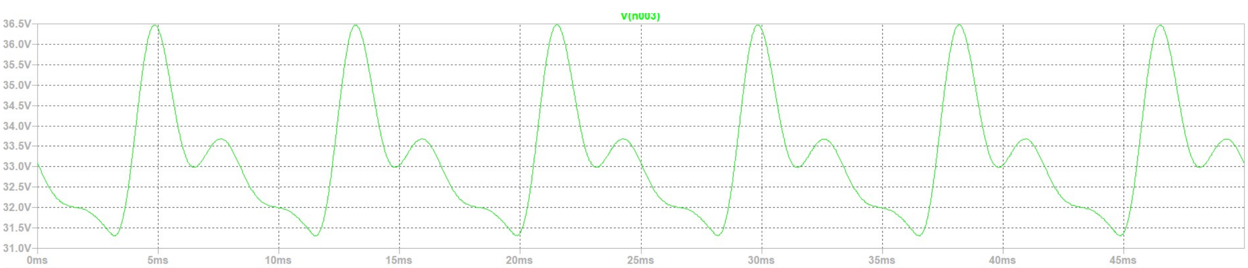

Figure 4 Power Supply Output

A PCB was designed for the power supply. It is shown in Figure 5. It has various test points to test intermediate values that were used during the verification.

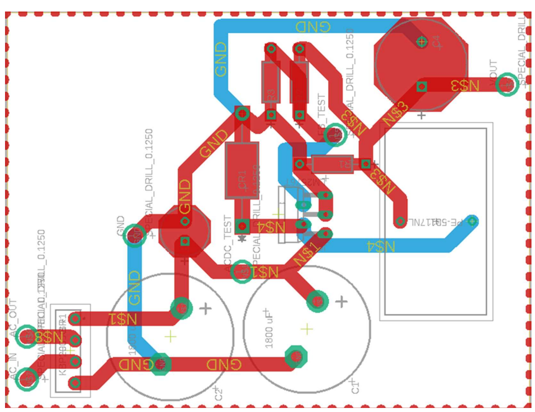

Figure 5 PSU PCB

2.1.5 Software

For the software component of our system, we had multiple requirements. Ryan wanted a UI that he could interact with to easily rotate the turntable (Figure 6). These rotations had to be within 5-degree accuracy as well. We added some other features ourselves such as being able to rotate in both directions and being able to schedule rotations. Scheduling rotations is critical as that way the user wouldn't have to constantly manage the rotation of the device and could simple run a routine/schedule created beforehand.

The code was mostly done in Processing, but there was also some simple Arduino code as well. Processing was the best choice for this project since it allowed us to integrate with the Arduino and the ATmega328P chip seamlessly. It also had many packages that were useful in communicating through the serial port, string parsing, and UI development. Since we wanted our application to be flexible, Processing also allowed us to generate executables that were able to run on both Windows and Mac, allowing the user flexibility in choosing which device they wanted it to run on.

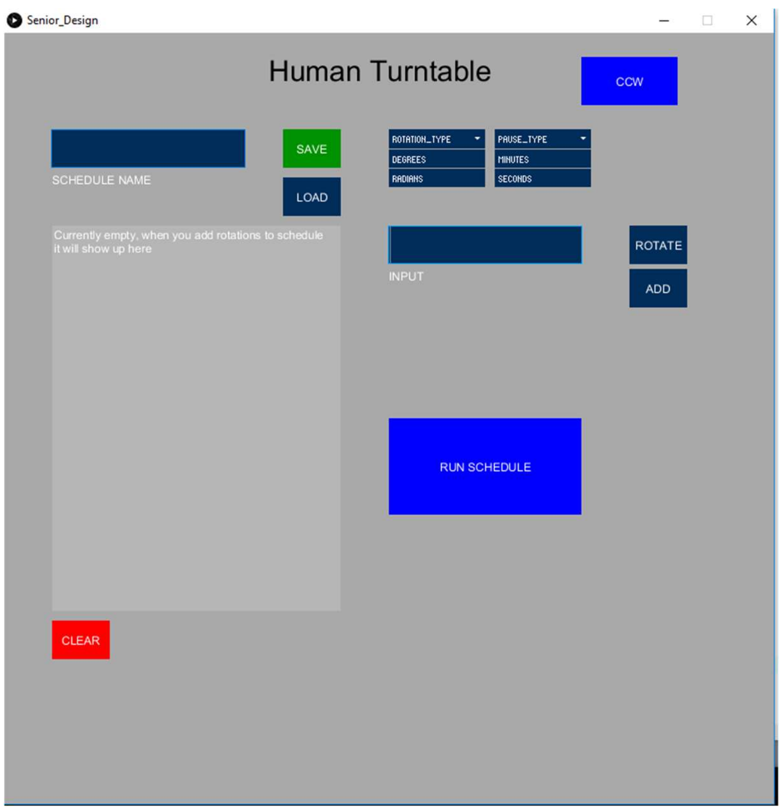

Figure 6 User Interface

Some problems we faced with the software were sending the serial data through the Arduino, ensuring that saving and loading schedules would load with the correct units, and specifying which direction the rotation should be done in. The main issue we had was sending the data through serial is that the

Arduino serial read function would read in the integer as ASCII which would lead to it rotating an undefined amount of times. These issues were resolved, and the UI functions as intended.

An improvement that could be made would be a better UI design. None of us were designers and the UI looks a bit rough. A quick discussion with a UI designer would be enough to improve the interface. If given more time, we could have also added some features like toggling the rotation speed, when saving the schedule, we could also save the direction of the rotation, an adding an interactive graphic for the rotation rather than the simple text box.

2.1.6 Physical Design

One of the most challenging subsystems for our project this semester had to be the physical design of the table structure. While this task would have been rather trivial for a mechanical engineer, we ran into some troubles. This subsystem is easily the weak point of our entire project.

The design procedure for the table relied on the choice of bearings. The rotation of the load had to be supported by an appropriate bearing. A class of large load-bearing ball bearings nicknamed “lazy-susan” bearings were used. The inner diameter of the bearing also provided suitable for clearance the motor.

The idea started in SolidWorks where the table was drafted as shown in Figure 7.

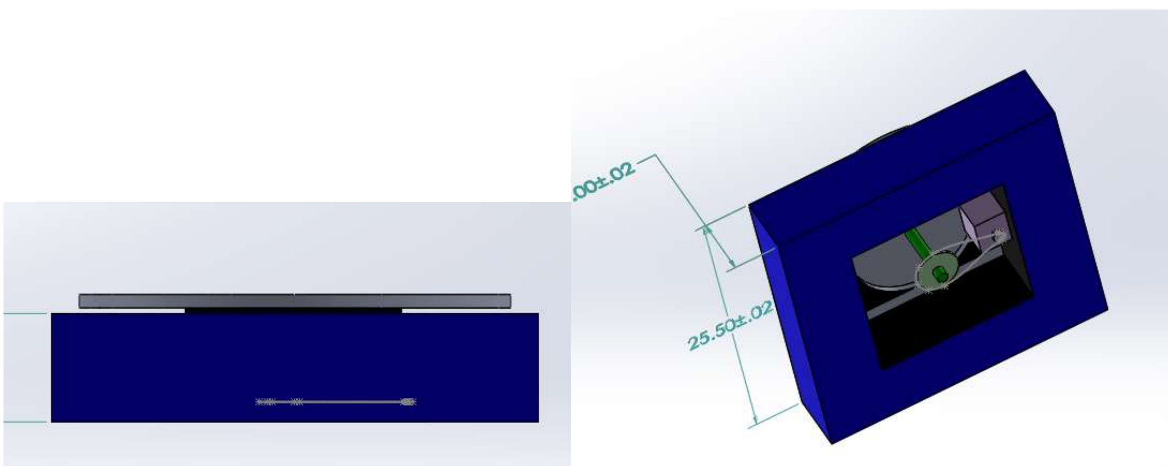

Figure 7 Turntable Design

To increase the motor torque, the original idea was to use a gearing system based on chain and sprockets with the motor mounted off-axis. However, as the semester went on and our budget was slowly getting used, we opted for a less mechanically complex design. In the current prototype, the motor acts as the driveshaft for the rotation.

Upon construction of the table, some problems were encountered and dealt with. The first problem revolves around the rotational friction and balance of the main bearing. This bearing which was purchased for a few dollars from a department store was more than enough for the weight we were trying to support but lacked the smoothness and build quality desired. It was made from cheap sheet metal and had missing balls in the races. This caused friction in the table's rotation and a see-saw effect when standing on the table.

To remedy this, the first solution was to include additional support bearings which can be utilized if the person was off-balance. The load transfer ball bearings in this role can only support 30 pounds each but are only used as back up. This idea worked to an extent, but effectively did not resolve all our problems.

The largest problem with the table itself is the wooden round disk. Wood is an imperfect material for such precision mechanical projects as it tends to warp and is soft. We found that the transfer bearings can dig into the wood as a lot of weight shifted on a small ball-bearing causes the wood to deform and the bearing to dig in. This may result in stall during rotation. For future iterations of the table, we would need a machined metal disk to stand on as it would provide a more rigid, nondeformable structure.

The resulting prototype works if the person is balanced on it. Problems such as skipped motor steps may occur if the load is unevenly distributed due to rotational friction in parts of the revolution.

3. Design Verification

3.1 Power Supply

The requirements for the power supply were done using the equipment on one of the benches designed for power work. The standard test procedure was to connect our system to a Variac and connect the output of the convertor to an adjustable electronic load. The electronic load was originally set to 1000 Ω. This is low power and would not stress the components. The Variac started at 0 V and was ramped up to 120 V AC. This test was first done with the AC-DC Convertor. As the tests were successful the electronic load resistance was decreased. This allows the system to test higher power conditions. The AC-DC Results are shown in Table 1. The requirement is that the output voltage is greater than 40 V and that the ripple is less than 20%. From the results that is clearly met.

Load(Ω)	Output Voltage	Ripple(%)
1000	63.5 V	0
40.2	59-61V	3.3
20.0	58-62V	6.7

Table 1 AC-DC Convertor Results

The next requirement that was tested was that the buck convertor output voltage was able to be adjusted. This was done using a breadboard. The circuit was setup using the circuit given in the switching regulator data sheet. This is shown in the figure below.

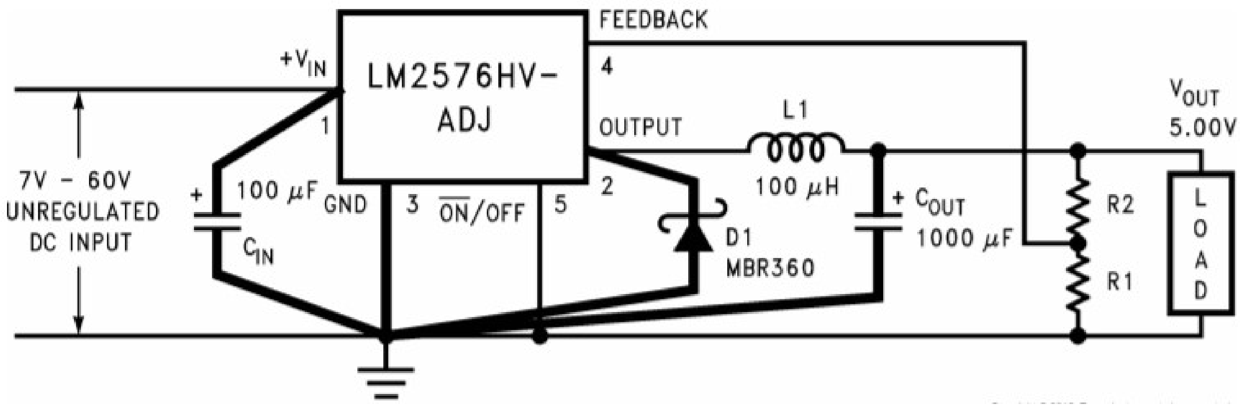

Figure 8 Buck Converter

The resistors were set using the formula given in the data sheet. This is shown in Equation 2.

$$R_2 = R_1(\frac{V_{OUT}}{1.23} - 1) \quad (2)$$

For this test the only requirement is that the buck convertor voltage changes by changing the feedback resistances. The input voltage was a DC voltage source at 16 V. The load was a large resistance. The Results are shown in Table 2.

R_1 (Ω)	R_2 (Ω)	Expected Voltage (V)	Actual Voltage (V)
982	3291	5.36	5.37
982	9950	13.69	13.68 V

Table 2 Low Power Buck Convertor Results

The last test was the combined power supply circuit with both convertors. The same setup as in the AC-DC test was used. The only exception was that the test was also done without the Variac to ensure that the circuit worked when directly plugged in the outlet. The circuit was also plugged into the motor driver to verify that the systems integrated correctly. The results from these tests are shown in Table 3. The requirement is that the voltage must be in the range of 31-37 V and support up to 3 A. From the data the requirement is met.

Load(Ω)	Load(Ω)
Output Voltage	Output Voltage
1000	1000
36.59	36.59
40.2 w/ Variac	40.2 w/ Variac

Table 3 Full Convertor Results

3.2 Controls Verification

Verification of the controls system was much less in depth. The goal of the control system was the ability to receive serial bytes over the COM port. To verify that this communication worked. We used the serial monitor included in the Arduino IDE to echo back sent information.

To verify the logic levels the included multimeter was used to monitor the states and voltage of the outputs.

To ensure that the control circuit was sufficiently powered with 5 V from USB, a multimeter was connected to measure the current. The current was less than 500 mA, which is the standard minimum computer USB 2.0 output.

3.3 Software Verification

Testing was an integral part of determining whether our device worked. We had to ensure that our input rotation and schedule rotations were accurate and our pauses in our scheduled rotations were accurate as well (specifics found in the RV table in the appendix). We tested rotation by utilizing the iPhone compass as our measurement tool, and manually timing the pauses with a stopwatch. For testing the rotations, all we did was simply input a degree of rotation and measure the rotation. For the pauses, we tested it by creating a short rotation-pause-rotation schedule and measuring the pause in between the rotation. Finally, for testing the schedule, we simply input in a schedule, and tested to see if the schedule would run with the right number of pauses and the if it would end up at the right angle. All these tests were done by hand and aren't 100% accurate due to innate human error. However, they're accurate enough for the data to verify our functionality. Our data for these tests are found in Appendix B.

3.4 Overall Verification

To deliver a complete product, we must verify on what we set out to do for Ryan. We verified the weight handling capabilities of the turntable by having a multitude of subjects all weighing above 200 pounds to test the table during rotation.

The ability of movement of the table is also verified using an iPhone compass app which tells relative direction in degrees. This was of enough accuracy for our needs.

The table was also silent when not in rotation and therefore did not require further analysis.

4. Costs

4.1 Parts

In Table 4 the parts list used for the final product is shown.

Parts Costs

Part	Manufacturer	Retail Cost ($)	Bulk Purchase Cost ($)	Actual Cost ($)
Stepper Motor	Value Hobby	60.00	60.00	60.00
Cw250 Driver	Unknown	50.00	34.00	30.00
Lazy Susan Bearing	Richelieu	4.88	4.88	4.88
Ball Transfer	KangTeer	8.39	8.39	8.39
Wood Round	Lowes	9.50	9.50	9.50
¾ in hobby planks	Lowes	15.00	15.00	15.00
Various Hardware	Lowes	20.00	20.00	20.00
USB cable	Amazon Basics	4.50	4.50	4.50
Atmega328p	Microchip	2.14	1.78	3.00
FTDI RL232	FTDI	4.50	2.65	4.50
16Mhz Oscillator	Txc	0.30	0.15	1.00
Various Passives	n/a	5.00	5.00	5.00
LM2576HVT	Texas Instruments	6.20	3.06	6.20
Transformer	Triad Magnetics	30.91	22.72	30.91
Inductor (330 µH)	Pulse	4.20	2.03	4.20
1800 µF Capacitor (2)	Panasonic	1.61	1.61	1.61
Bridge Rectifier	Diodes Inc.	.55	.23	.55
Total		227.70	195.50	209.24

Table 4 Parts Cost

4.2 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. The calculation of labor costs is shown in Equation 3. So, the total labor costs are $20,985. With the costs of parts, the total cost of this project was $21,212.70.

$$400 * 32.21 + 200 * 40.50 = \$20{,}985$$

4.3 Labor 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(theoretically)	Waited for PCB. Redesign DC-DC Convertor
3/18	Spring Break	Spring Break	Spring Break
3/25	Solder components to PCB	Troubleshoot UI and finalize	Test Buck Convertor at Low Power
4/1	Mount and wire PCB in table	Implement task scheduling feature	PCB Arrived

4/8	Troubleshoot and assist teammates	Testing and debugging	Tested PCB
4/15	Final adjustments and more troubleshooting	Debug and final touches	Connect Power Unit to rest of Project
4/22	Demonstrate	Demonstrate	Demonstrate
4/29	Present	Present	Present

Table 5 Schedule

5. Conclusion

5.1 Accomplishments

The project met all the high-level requirements that were determined at the beginning of the project. The table can rotate when controlled from a computer. The turntable can rotate in both the counter and clockwise directions. The user can set the rotation length in both degrees and radians from an easy to understand GUI. The user can set a schedule. This allows the user to set a series of rotations and pause to aid their research. The accuracy of the turntable is within 1 degree of the desired rotation. All the various requirements that were originally made in the design document for the RV table were met. The project overall was very successful.

5.2 Uncertainties

There are a couple of uncertainties with the project. The turn table is not completely ready for Ryan Corey to use for research as it needs to be approved for use by human subjects. However, Ryan Corey told us at the beginning that he would take care of this after the project was delivered. The turntable requires the person being rotated to balance on the turntable. The table itself has a slight wobble. Therefore, the person needs to be standing in a certain way for the rotations to be accurate. This is a small cause for concern, but the turntable still does work.

There is also some concern about the accuracy of the rotations as the rotation lengths are not perfect. From the data in Appendix B it is shown that the rotations are typically off by 1-2 degrees. This can leave an amount of uncertainty in Ryan Corey's data. Currently, he has said to have rotations with sub 5 degree accuracy. However, if he were to perform experiments with greater accuracy needed the table would need to be improved.

5.3 Ethical considerations

There were some concerns with our device as it was to be used for research with an actual human being. Some issues being, it could spin out of control with someone standing on it, the device could burn up if an issue occurred with the electrical components and balancing on the device could be an issue with someone with less mobility were to stand on it. We did not implement an emergency stop in the user interface, however given that the device is rotating only if the serial read is available, we recommend simply just unplugging the device from the computer to get it to stop rotating. We addressed the balancing issue by finding a speed at which the rotation of the device is smooth and consistent and adding a wide platform to make it easier to stand on. Balancing on the platform isn't difficult, and by adding some tape to indicate where the user where to place their feet allows the turntable to be used with relative ease. We were considering adding a bar for the user to hold onto, but it could cause interference with the Ryan's research results. We did not add a bar for that reason but if needed, installing a short railing would be quick and painless given the space available on our device. These precautions are to adhere the IEEE Code of Ethics item 9 which states "to avoid injuring others …" [4]. By following these precautions, we made sure that no injury occurs when using our project.

Since our device is built out of wood and we're using a 120 AC/60 Hz power supply unity, if the user uses this device at a different current/voltage level, our motor could overheat, and the device could burn up. However, by having a fire extinguisher on hand, and ensuring the user knows which voltage and current the device is supposed to be used at, we should be able to reduce the risk of harm. And 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 [4]. For this project, we were able to assemble a competent team with skills and knowledge in various areas of Electrical and Computer Engineering. This allowed us to tackle the problem head on and successfully deliver on our proposed project.

5.4 Future work

The project is complete and was successful. The project was mainly a one-off product build. Ryan Corey was the only one who wanted this made. Additional turntables will not be made as there is not a market for human turntables in the economy. However, the design of the turntable could be improved if Ryan wants a better turntable. The table itself could be made with machined metal. This would create a perfectly round turn table for the subject to stand on. This would decrease the error that certain rotations had. It would also make it so the subject does not need to balance on the turntable. As for future work that will be performed. A user manual for the turntable is being developed. This manual and the turntable itself will be delivered to Ryan in the coming week. That will complete the project.

References

[1] Ryan M. Corey, Naoki Tsuda, and Andrew C. Singer, " ACOUSTIC IMPULSE RESPONSES FOR WEARABLE AUDIO DEVICES," International Conference on Acoustics, Speech, and Signal Processing, Brighton, United Kingdom, May 2019.

[2] Texas Instruments, "LM2576xx Series SIMPLE SWITCHER® 3-A Step-Down Voltage Regulator," LM2576xx datasheet, Jun. 1999 [Revised May 2016].

[3] USB.org, "USB 2.0 Specifications", Specification Datasheet, April 2000 [Revised Jan. 2018].

[4] Ieee.org, "IEEE Code of Ethics", 2016. [Online]. Available: http://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 25- Mar- 2019].

Appendix A Requirement and Verification Table

Requirements	Verification	Successful?
Table can support an average human being	Have a person of 200 pounds test the table by standing on it	Yes
Electronics are silent when not in rotation	Monitor the audible output, if present, use SPL app to see what noise pollution is.	Yes
GUI only program needed for manipulation of table	Verify the GUI is can communicate on COM ports by sending bytes and verifying with serial monitor	Yes

Table 1 Overall R/V

Requirements	Verification	Successful?
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.	Yes
Communicates with 5vdc +/- 20% logic.	Use oscilloscope to observe signals from I/O pins to ensure that valid +5VDC +/- 20% signals are sent	Yes
Can communicate through serial UART	Send bytes and verify with Arduino's serial monitor	Yes

Table 2 Controls R/V

Requirements	Verification	Successful?
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.	Yes
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.	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.	Yes

Show that both ends of the ranges can be met.	Change feedback resistor values for output voltage in range of 31-37 V.	
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 feedback resistors to correct values. Confirm that it is in the 31-37 V range	Yes

Table 3 Power R/V

Requirements	Verification	Successful?
Device should be able to perform rotations of 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.	Yes
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.	Yes
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.	Yes

Table 4 Software R/V

Appendix B Testing Data

Rotation Testing

Input Angle (Degrees)	Initial Angle (Degrees)	Final Angle (Degrees)	Difference (Degrees)	Accurate
20	201	221	20	Yes
20	221	241	20	Yes
30	308	337	29	Yes
60	206	266	60	Yes
90	100	189	89	Yes
180	180	361	181	Yes
360	0	359	359	Yes
360	170	171	361	Yes
360	171	174	364	Yes

Pause Testing

Input Pause (seconds)	Initial (seconds)	Final (seconds)	Accurate?
10	0	9.85	Yes
10	0	10.03	Yes
10	0	10.14	Yes
30	0	29.63	Yes
30	0	30.10	Yes
30	0	29.88	Yes
60	0	59.98	Yes
60	0	59.68	Yes
60	0	60.32	Yes

Schedule Testing

Schedule 1: 30 degree, 5 sec, 30 degree, 5 sec, 30 degree, 5 sec, 30 degree

Total Rotation: 120 degrees, ending angle 120 degrees

Schedule 2: 30 degree, 5 sec, 60 degree, 5 sec, 90 degree, 5 sec, 180 degree

Total Rotation: 360 degree, ending angle 360 degrees

Schedule 3: 180 degree, 5 sec, 270 degree, 5 sec, 360 degree

Total Rotation: 810 degree, ending angle 90 degrees

Schedule Type	Attempt	Initial (degrees)	Final (degrees)
1	1	0	124
	2	0	122
	3	0	118
2	1	0	364
	2	0	361
	3	0	357
3	1	0	92
	2	0	93
	3	0	89