

Stepper Machine Power Generation

ECE 445 Design Document

Team 46:

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1 Introduction

1.1 Problem

Exercise in our era is difficult to fit into our busy schedules. Even when we can find the time to exercise, sometimes we are unmotivated or it comes at an opportunity cost. The pandemic also increased the amount of people working remotely from their desks at their homes. Sitting around is just as much of a killer as smoking is. It has been found that people who sit for more than 13 hours a day are actually at a 200% higher risk of death when compared to people who sit for only 11 hours or less per day[1]. However, we are forced to sit sometimes, and it would be helpful to get some exercise while sitting and doing work.

1.2 Solution

A sitting exercise step machine that could generate electricity by an up and down movement of the legs would be a viable exercise in an office setting, because it leaves the arms free by allowing you to use the machine without your hands. Also, the exercise is not intense, so you are not sweating while sitting or standing in an office. Finally this exercise machine can use the movement of legs in order to generate some electricity, giving users a sense of accomplishment.

The exercise machine we plan on creating is a step motion machine that can be used while sitting. The steps will be able to be converted into electrical energy by connecting to a DC motor. We plan on using this electrical energy to efficiently charge a portable (5V) battery. The idea of charging a portable charger made sense because then the user could still use their phone during the workout/day and after work be able to take the portable charger with them to charge their phone after. Charging a portable battery may not be enough incentive, so we also plan on connecting the machine to a computer to be able to remind the user to use the machine.

1.3 Visual Aid

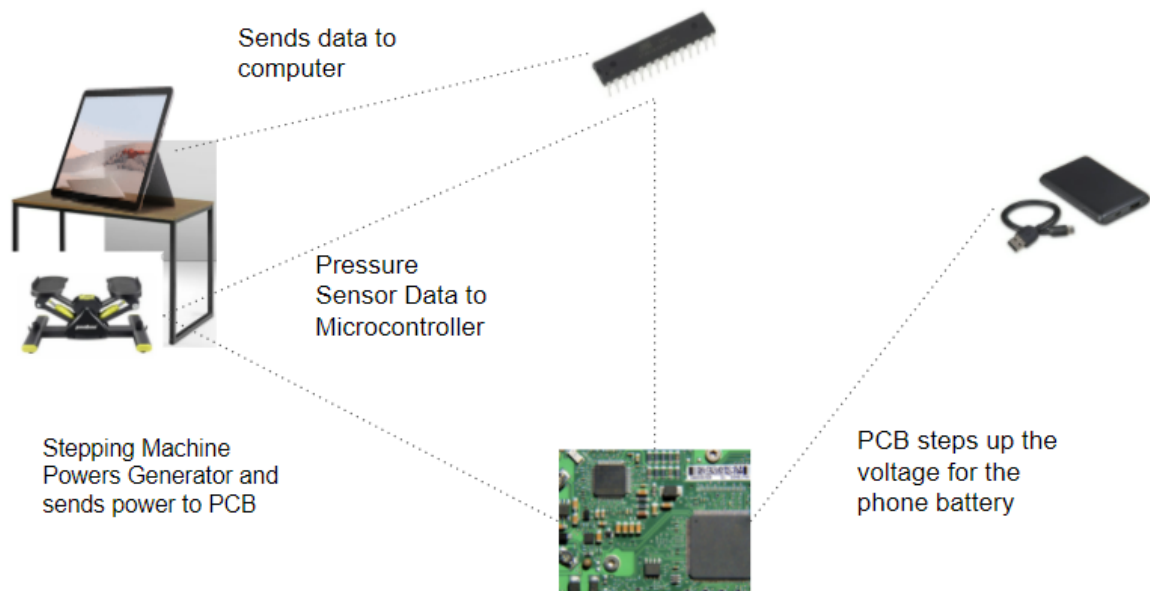


Figure 1: Visual aid of how the whole project is planned

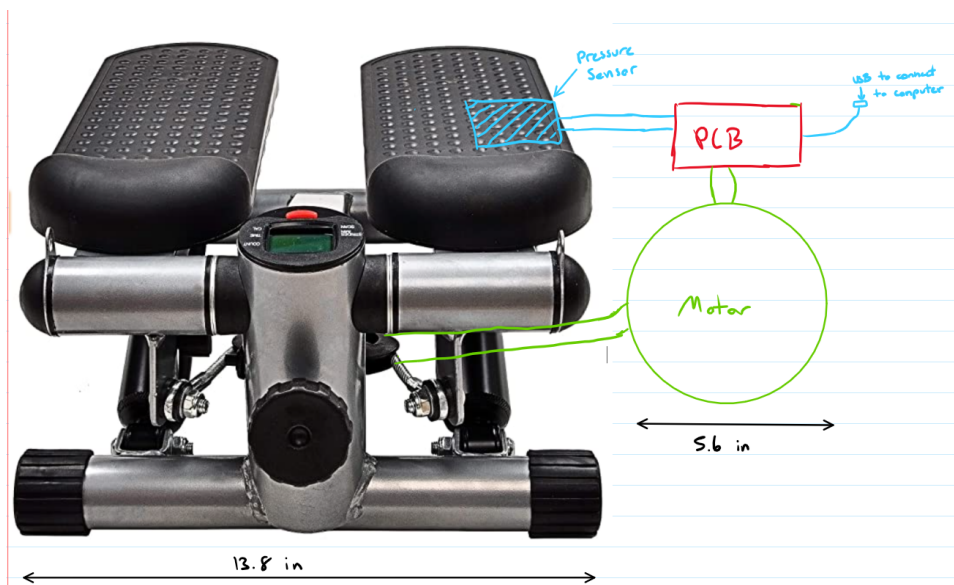


Figure 2 : Physical Sketch of the Design

1.4 High-level Requirements List

- 1) The power electronics, our DC-DC converter, needs to be able to convert the electrical energy generated from the motor and stepper into a constant 5V to supply the output to the portable charger within 5%.
- 2) Machine can be used while sitting, and small enough so that it can fit under a desk (About 36 inches deep, around 30 inches tall, and minimum width for a person of around 24 inches[2]).
- 3) The pressure sensor and computer program system is able to reinforce working out at least 8 times a day (Once every hour of an 8 hour workday).

2 Design

2.1 Block Diagram

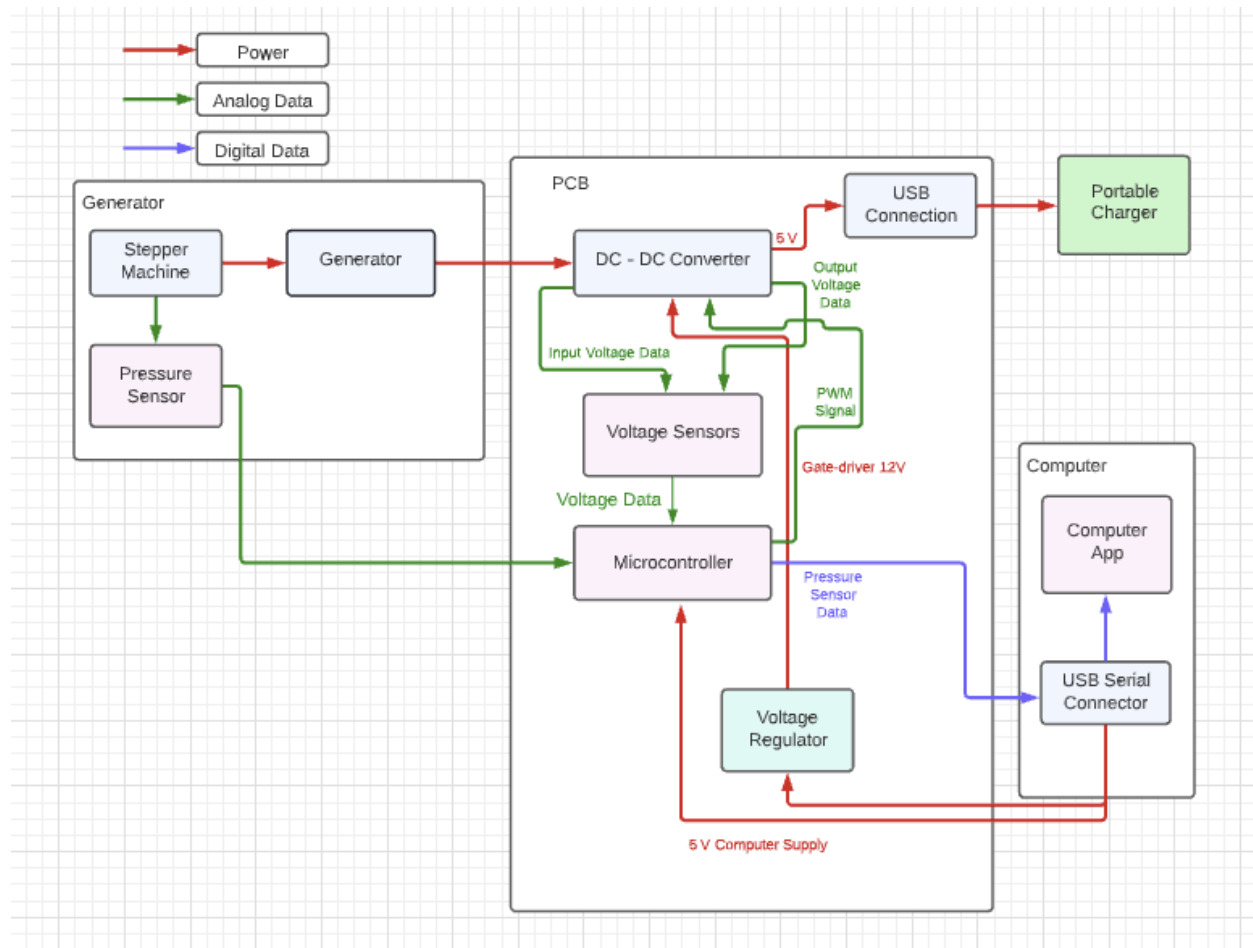


Figure 1: Block Diagram

2.2 Subsystem Overview:

2.2.1 Mechanical System (Generator)

Stepper Machine

To be a generator, we need a mechanical system that can convert the step motion into electrical energy. We plan to produce mechanical energy with a generator connected to the step machine. If the user creates mechanical energy by movements of legs, the motor will convert the mechanical energy to electricity. The electricity converted by the motor will be connected to the PCB board so that it can be converted to a voltage that can be safely put into the portable charger.

Table 1: RV Stepper Machine

Requirement	Verification
The stepper system needs to be able to fit under a desk.	<ol style="list-style-type: none">1. Measure the width and height of the machine.2. Verify that depth < 36 inches, height < 30 inches, width < 24 inches

Generator

We will be using a Minertia Motor P12-H in order to generate electricity. This is a relatively small motor which is perfect for our design as we are not going to be generating a lot of electricity and we are planning on making the whole thing fit under a desk. Because the exercise is not strenuous and the stepper design inefficient, we expect the output of the generator to be low. The output of the generator will be the input to the DC-DC converter. We have performed tests on the motor at low rpms to see what kind of voltages we should expect since the lower rpms are not included in the data sheet. In Figure 2 below a table for the speeds we tested at can be seen showing the voltages we were able to get at these lower rpms. We found that we will need to provide a minimum of 150 rpm so that we can produce a constant and reasonable voltage at the input of our converter circuit. By reasonable we mean that we can use common duty ratio values to step up the voltage to 5 V. The duty ratio would have to be on the extreme end if we tried to step up anything below 1 V.

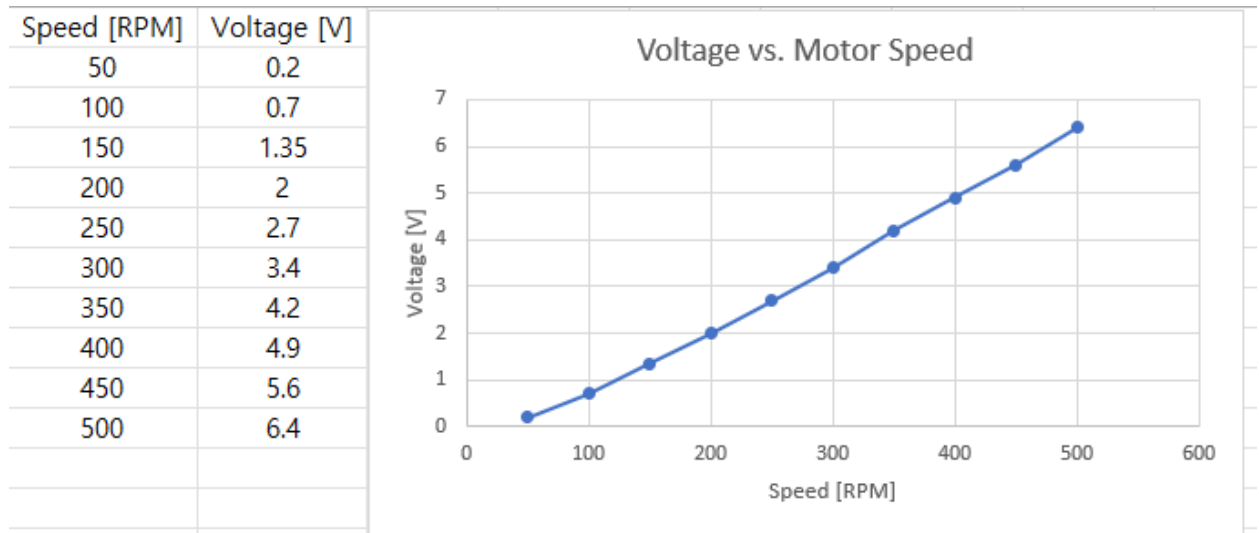


Figure 2. Testing generator at low rpm

Pressure Sensor (Force Sensitive Resistor)

We are going to have a pressure sensor on the step machine. In order for users to use the step machine, the user's weight will press down the pressure sensor and will send data to the user's computer. We are planning to use '406 FSR' as a pressure sensor which is a force sensitive resistor. The pressure sensor will use the voltage divider circuit seen below in Fig 3 to connect the sensor to the microcontroller[3]. When the user puts his foot on the machine the force sensitive resistor will be a low value so the microcontroller will read a high voltage. When there is no pressure on the sensor the resistance will be very high so the microcontroller will read no voltage. This is how we plan on being able to tell if the user is using the machine.

Table 2 : RV for Pressure Sensor

Requirement	Verification
Must be able to sense pressure of force above 10 kg.	<ol style="list-style-type: none"> 1. Without connecting to PCB first construct circuit below on testing breadboard. 2. Connect 5 V DC supply to the pressure sensor circuit. 3. Read voltage across the 3.3 ohm resistor 4. Apply pressure and make sure that voltage increases. 5. Apply weight of around 10 kg to ensure that the sensor can handle sitting person weight.

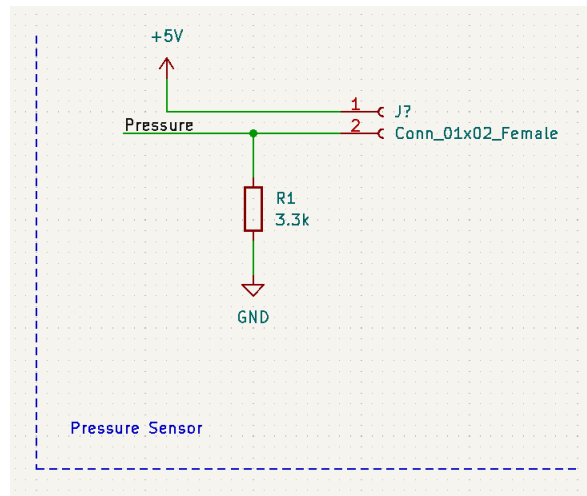


Figure 3 : Force Sensitive Resistor Schematic

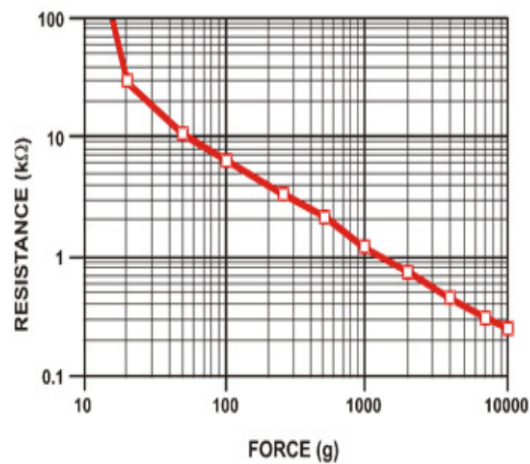


Figure 4 : Force vs. Resistance for FSR [3]

2.2.2 PCB

DC-DC Converter

We want to be able to charge a 5 V portable charger with this machine. To do this, we will need a PCB that can step up the voltage generated by the machine into a voltage that can be used to charge a portable charger. This will involve a DC-DC power converter that is able to handle low, inconsistent voltages. This will rely heavily on how much power we are actually able to create from our stepper generator as an input. The DC-DC converter's PWM will be supplied by the microcontroller. The output of the DC-DC controller will feed into a USB input so that the USB to charge the portable charger can be plugged into the PCB.

For our DC-DC converter we plan on designing a flyback converter. A flyback converter is a type of DC converter that can both step up and step down voltages based on the duty cycle. The flyback converter is able to step up and step down voltages through switches and transformer turns ratios.

$$\frac{V_{out}}{V_{in}} = \frac{nD}{1 - D} \quad (1)$$

From Equation 1 it can be seen that D, duty cycle, controls the input output relationship of the converter. Another beneficial aspect of the flyback converter that can be seen from equation 1 is that the input-output relationship is also dependent on n, the turns ratio of the transformer used in the flyback circuit. One of the main benefits of having this transformer in this circuit is that it naturally isolates the input of the circuit from the output of the circuit. Below in figure X the circuit design for the fly back converter can be seen. For the duty cycle/PWM control of our converter we will be using a generated output waveform from the microcontroller. The microcontroller will have a control scheme that will take in the input and output voltages to determine the duty cycle of the PWM signal that it will send out.

Due to the nature of our project and how it involves connecting a stepper machine to our motor we needed the machine shop to help connect the stepper motion to the generator. The machine shop is still working on figuring out how to connect the two so we don't know exactly how much rpm we should expect from our stepping motion. Due to this inconvenience we will have to wait on the specific parts for our converter design because it is impossible to design a converter without being able to plan for the exact voltages you expect at the input. For the purpose of this document and the tolerance analysis we plan on assuming that we are going to operate within the range of 150-300 rpm which the machine shop has said should be reasonable.

Table 3: RV DC-DC Converter

Requirement	Verification
Needs to output 5V with a tolerance of $\pm 2.5\%$.	<ol style="list-style-type: none"> 1. Use a variable DC voltage supply to the converter input. 2. Connect a 3ohm (10% tolerance), 30 ohm (10%), 100ohm (10%) to the output. 3. Measure the output with an oscilloscope 4. Change the values of the DC voltage supply from 1V to 10V. 5. Check that the output is $5V \pm 2.5\%$

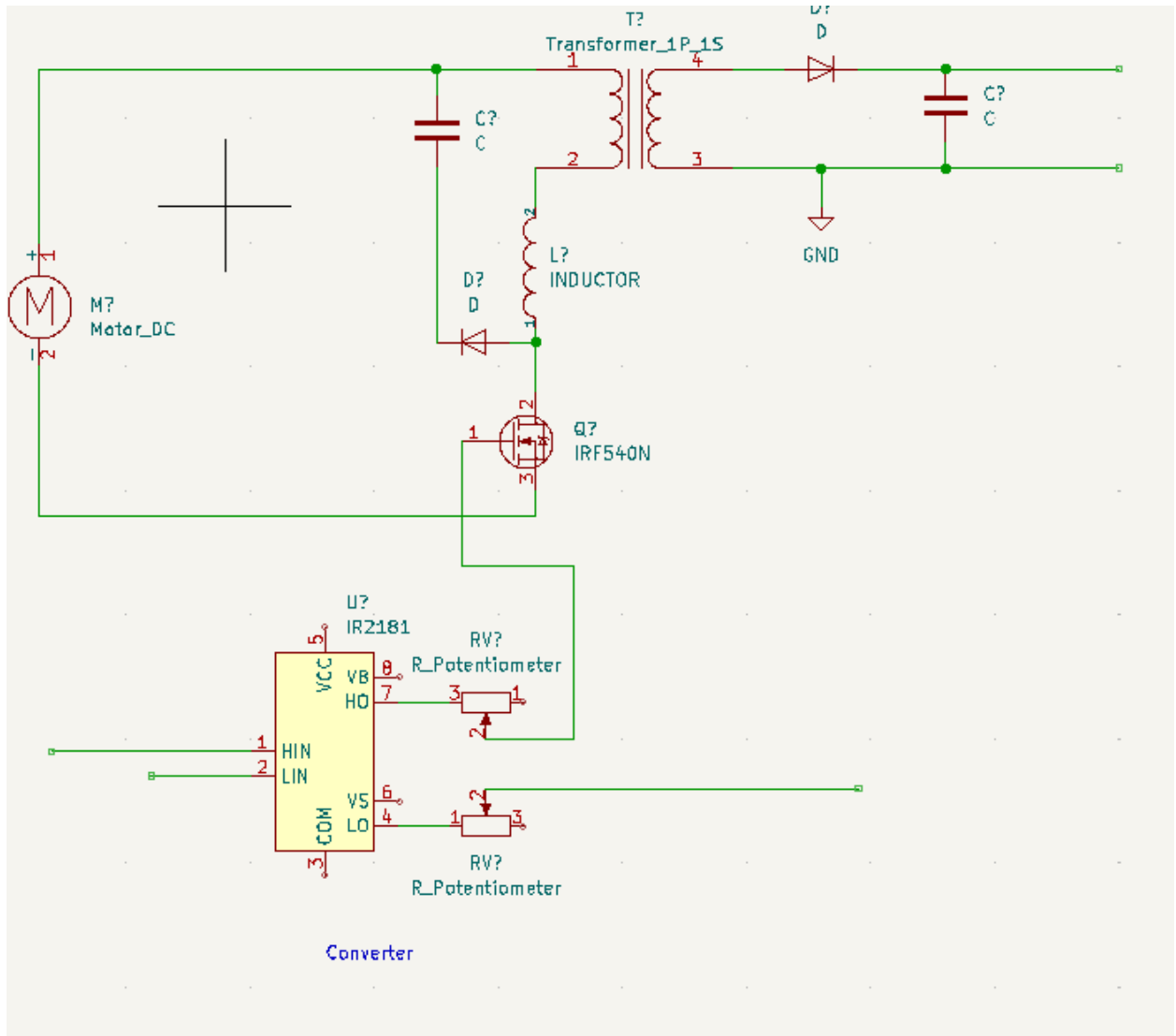


Figure 5: Flyback Converter Schematic

Voltage Sensors

The voltage sensors will need to be able to sense the output of the DC-DC converter as well as the input voltage from the generator.. The input voltage from the generator will be sent to the microcontroller so that the microcontroller can use the input voltage to determine the duty cycle that will be needed to convert the output voltage to 5 V. The output voltage of the converter needs to be sensed to get the error of the output when compared to 5 V. This is needed to be able to construct a better control scheme for the duty cycle. This output voltage sensor can also be used to know when the 5 V is stable enough to power the USB output for the portable charger.

In Figure 6 below the voltage sensor circuit we plan on using to sense the input and output voltages of the DC converter circuit. We plan on using .25W resistors that have a tolerance of plus or minus 1%. The resistors we will be using are 20k Ohm and 10k Ohm resistors. This will map our input and output ranges we expect to see from 0-8 V to 0-5.33 respectively so that the voltage sensing is within the operating range of our microcontroller [4].

Table 4: RV Voltage Sensors

Requirement	Verification
Needs to be able to sense voltage within plus or minus 2.5%.	<ol style="list-style-type: none">1) Attach a known DC supply to the voltage sensor circuit from 0 - 8 V.2) Probe the voltage going to the microcontroller to see what the true reading should be.3) Ensure with simple test code that the microcontroller is correctly sensing the voltage within the tolerance range.

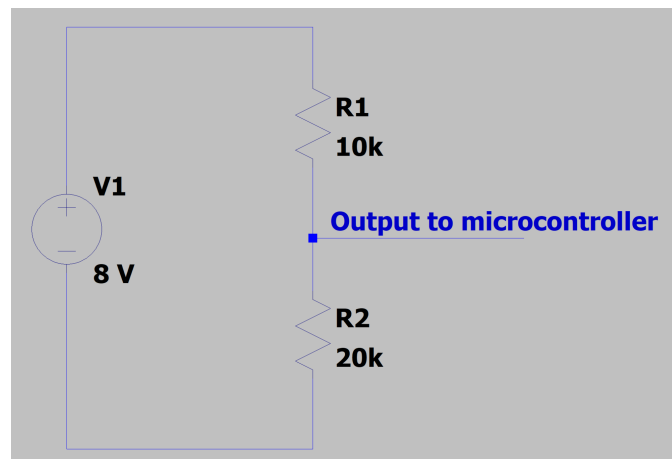


Figure 6 : Voltage Sensor Circuit

Voltage Regulator

The voltage regulators are to be used to supply power for the DC-DC converter. The voltage regulator will be taking a 5 V supply from a USB port from a computer to convert the voltages to 12V. We are planning to use ‘PDS1-S5-D12-M’ as our voltage regulator since it can take input from 4.5V to 5.5V and have voltage output of -12V or 12V.

Table 5: RV Voltage Regulator

Requirement	Verification
Must output a voltage of $12 \pm 0.3V$	<ol style="list-style-type: none">1. Connect the voltage regulator to the 5 V USB supply.2. Probe the output of the voltage regulator from the output pin.3. Ensure that the output is within the specified range.

Microcontroller (ATMega328)

The microcontroller we plan on using is the ATMEGA328. This device is being used to take information from the pressure sensor and the input/output voltage of the DC-DC converter. The information from the pressure sensor is sent to the computer software so that the computer knows when to turn off the notification to work out. The input voltage of the DC-DC converter needs to be used to determine how the duty cycle should change based on output of the converter to keep a constant 5 V. The output voltage sensor of the DC-DC converter will also be used as a part of the control scheme for the converter so the microcontroller will also be connected to the output of the converter.

Table 6: Microcontroller

Requirement	Verification
Must take in data from the pressure sensor and send a boolean value to the computer through the USB.	<ol style="list-style-type: none">1. Check that there is a voltage from the register output of the microcontroller.2. Run test code to ensure that the computer is receiving the data from the microcontroller about the pressure sensor.
Must take in voltage at the input and	<ol style="list-style-type: none">1. Connect an oscilloscope to the

output of the DC-DC converter and create the appropriate duty cycle for the converter. (PWM capability)

- gate drivers.
2. Produce a DC voltage at the inputs for the microcontroller (1V to 10V)
3. Run control code mode for the microcontroller.
4. Ensure that the microcontroller is producing correct PWM by probing the input to the gate driver circuit.
5. Change input DC voltage and ensure that microcontroller changes PWM signal correctly.

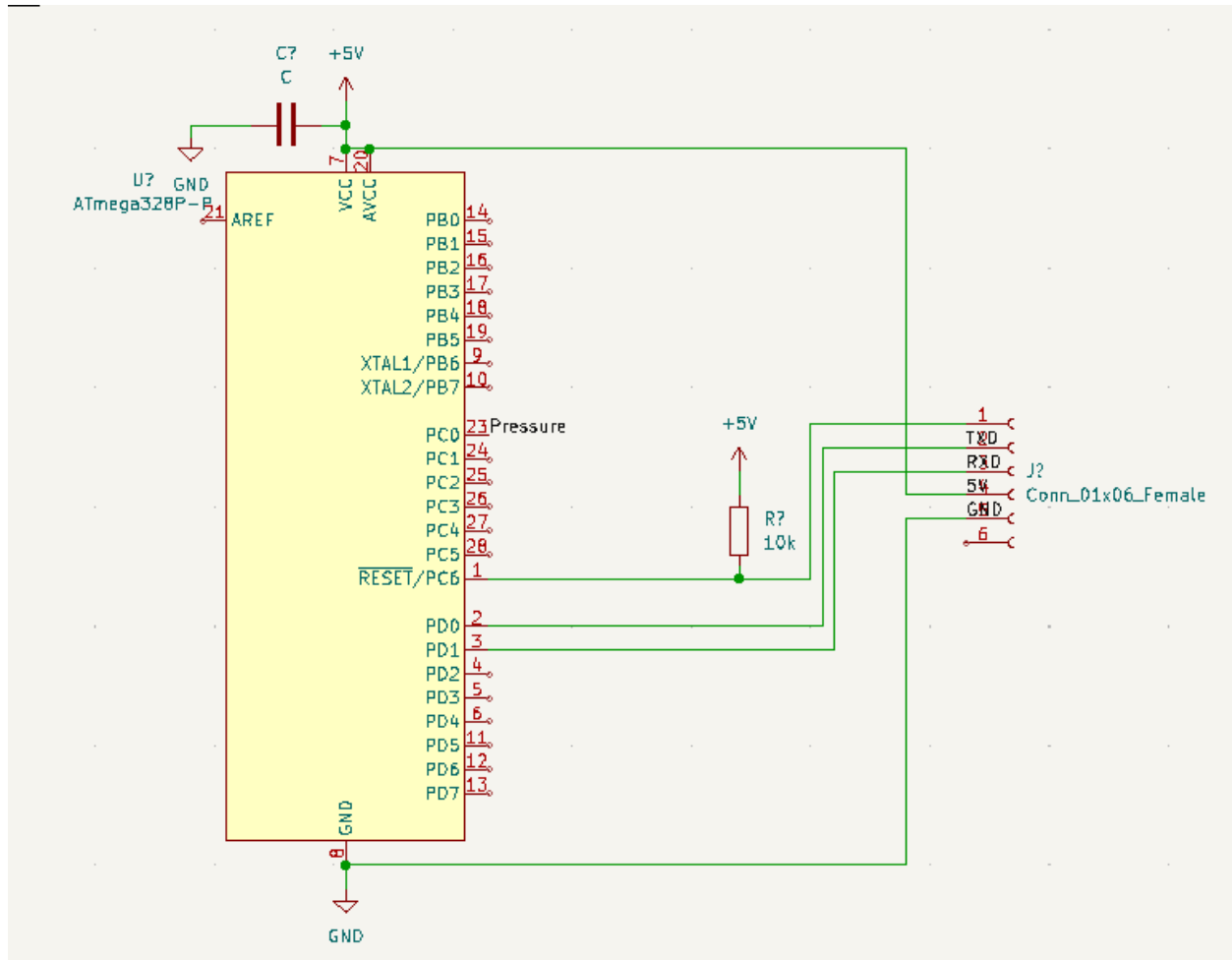


Figure 7: Microcontroller, Serial USB Connection

2.2.3 Computer Connection

Computer Application for Device

We want to demonstrate a step machine that can help users make goals and achieve them. Before the user starts to use the machine, he/she will be asked to put workout duration on the computer app. The computer will communicate with the pressure sensor on the step machine to do a countdown to zero as the user works on a machine. In addition, the app on the user's computer will also be used to notify when the users should start workout with step motion again. The notification will be sent an hour after the user finishes a workout to remind the user to work out again. The notification will be sent out 8 times. Figure 8 below is a simple flowchart for the computer application.

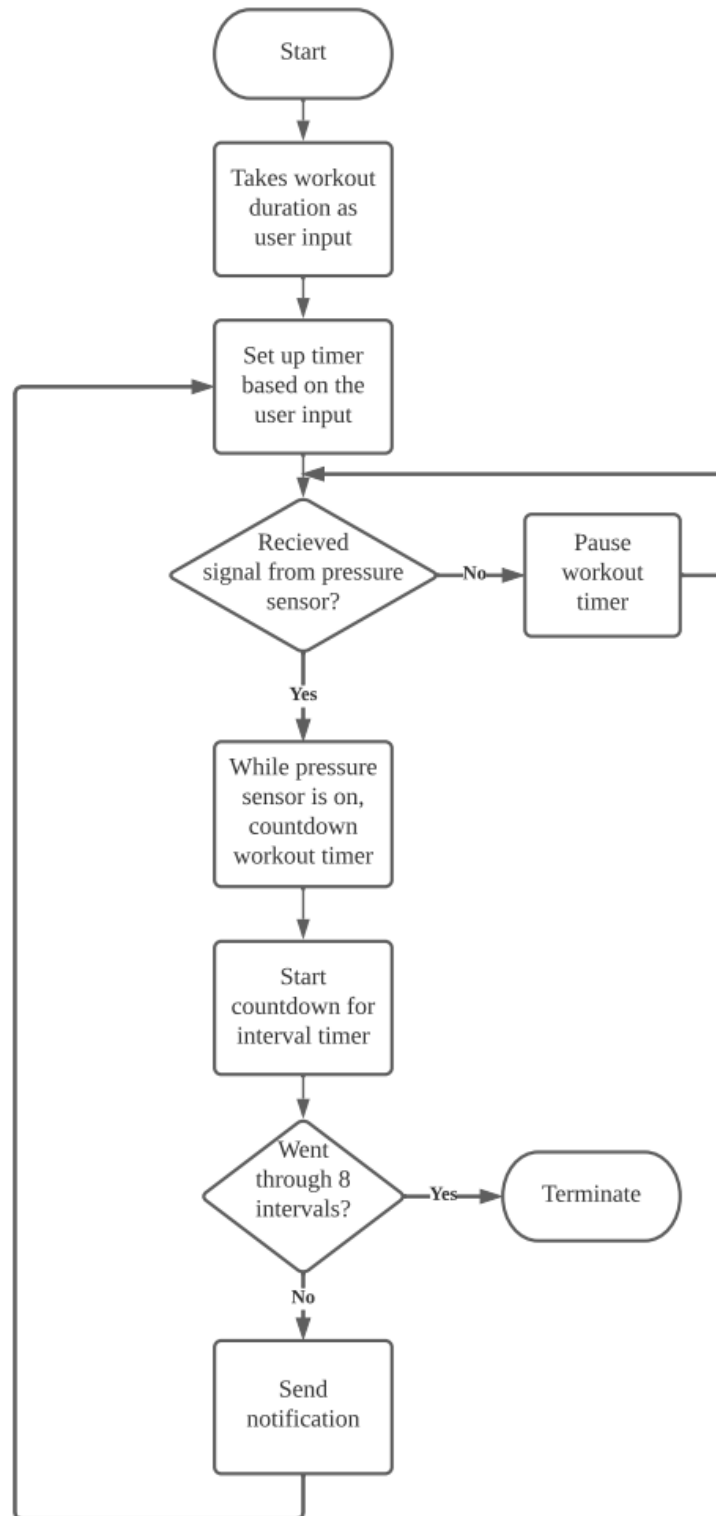


Fig 8: Computer Application Flowchart

Table 7: RV Computer Application

Requirement	Verification
When activated, the computer app must take in the amount of time the user wants to work out every hour	<ol style="list-style-type: none">1. The user inputs a workout duration.2. Verify that the application can display the amount of time the user imputed and have a countdown.
When the user touches the pressure sensor the computer app must start the timer.	<ol style="list-style-type: none">1. An artificial red flag variable will be created to represent the pressure sensor.2. Check that when the variable is turned on the timer is counting down.3. Check if when the variable is turned off the timer pauses.
Must be able to send notification to remind users to work out after an hour break.	<ol style="list-style-type: none">1. Verify that the interval counter appears after the duration timer is done.2. Verify that the app sends out notification when the interval timer hits 0.

USB Ports

The first USB port will be used to supply 5V to our voltage regulators to power our PCB elements and to be able to send information between the computer application and the microcontroller. This USB port will be connected to the board and the computer. We will be using a serial converter for the programming and data transfer of our board [5]. This USB Connector has a 5V source and GND pin as well as D+ and D- pins for information as well as pins that help program the microcontroller. The second USB port will be used as a connection to our portable charger from the output of our DC-DC converter. This will be a simple USB A connector that we will supply 5 V with so that the portable charger can be plugged in to charge.

Table 8: RV USB Port

Requirement	Verification
Must be able to supply $5 \pm 0.5V$.	<ol style="list-style-type: none"> 1. Measure the differential voltage of the USB pins from Vcc to GND (This is the voltage the USB will be supplying to the PCB). 2. Verify that the output is within our tolerance of $\pm 0.5V$.
USB must transmit information from the microcontroller to the computer.	<ol style="list-style-type: none"> 1. Write and apply dummy code with LED circuit to the microcontroller that won't hurt the system. 2. Test the code to ensure that the microcontroller is able to send data to the computer through the USB data pins and that a simple LED can blink.

2.4 Tolerance Analysis

The most important part of this project is in the DC-DC converter. The output voltage of the converter needs to be within a 5% tolerance range. In the DC-DC converter the output capacitor will be an important factor in reducing the ripple voltages in the converter. This is because the capacitor at the output will take the ripple voltages while sending the main voltage to the battery. This value can be calculated with the following equation.

$$C \geq \frac{P_{out}D}{V_{out}\Delta V f_{sw}} \quad (2)$$

This equation represents that the capacitor must be greater than or equal to the output power times the duty ratio over the voltage out times the ripple voltage times the switching frequency. Using this equation and values found in the generator, we can find out that the capacitor must be at least 2.56uF. That means that our capacitor must be at least that large in order to find the ripple voltages that are acceptable in the output. However, because of variables from various sources such as heat and internal resistances, inductances, and capacitances, in order to be safe the capacitors must be larger than that by a bit. The tradeoffs would be money and space, so we will need to find a capacitor that fits our design while still being reasonable and not overengineered. The 3.3uF seems to be the capacitor that fits our circuit the best. The capacitor could technically be larger and reduce the voltage ripple even further. However, there is a tradeoff between a very low ripple and the cost and size of the capacitor. We decided that we want to meet the

threshold we need based on the equation, but not make it too much larger to reduce size and cost of the capacitor.

3 Cost and Schedule

3.1 Cost

Table 9: Part Cost Table

Part	Link	Part Number	Quantity	Unit Cost
Force Sensitive Resistor	https://www.sparkfun.com/products/9376?_ga=2.112622916.1334350071.1645290147-2111583577.1644187093 (Sparkfun)	FSR 406	1x	\$11.25
Female Connector for Pressure Sensor	https://www.mouser.com/ProductDetail/SparkFun/COM-14194?qs=YCa%2FAAYMW02cJ%2FAnvxA%2FCA%3D%3D (Mouser)	474-COM-14194	1x	\$1.95
Std USBType A Connector	https://tinyurl.com/yeur43tb (TE connectivity)	6364372-2	1x	\$1.10
USB 3.0 Cable Type A Male to Male	https://www.walmart.com/ip/3-ft-USB-3-0-Cable-Type-A-Male-to-Male/678450801	N/A	1x	\$3.96
5V to 12V DC DC Converter	https://tinyurl.com/2e3yhcr3 (Digi-Key)	PDS1-S5-D12-M	1x	\$5.67
Microcontroller	ECEB supply shop	ATMega328-P	1x	\$6.40
USB Serial Connector	https://www.jaycar.com.au/arduino-compatible-usb-to-serial-adaptor-module/p/XC4464	Serial Connector Module	1x	\$19.95
USB A to USB-B	Link	0887328702	1x	\$3.35

16MHz Crystal	https://www.adafruit.com/product/215?gclid=CjwKCAiA9tyQBhAIEiwA6tdCrIaC_1GCnof2ENb_2qEpTNv0J1iyEGUYe7XXMIXZVvEU244ARah_aBoCEI_gQAvD_BwE	16 Mhz crystal and 20 pF caps	1x	\$.75
Portable charger	https://www.walmart.com/ip/onnn-Portable-Battery-4k-mAh-Pink/254815878?wmlspartner=wlp&selectedSellerId=0&w13=5403&adid=2222222277254815878_11775502866912420145346&wmlspartner=wmtlbs&w10=&w11=g&w12=c&w13=501107745824&w14=pla-293946777986&w15=9022185&w16=&w17=&w18=&w19=pla&w110=8175035&w111=local&w112=254815878&w113=5403&veh=sem_LIA&gclid=CjwKCAiApfeQBhAUEiwA7K_UH11rpPkH9dvnmo0IJIIs0PaEM8YjVSSm_xt-5YaUCsGAwbe5qLcZqexoCa8AQAvD_BwE&gclsrc=aw.ds			\$6.00
Stepper Machine	N/A	N/A	1x	\$50.00
Motor	Yaskawa Electronics	P12H-DB11	1x	About \$45
Approximate	N/A	N/A	1x	About \$45

Flyback Cost (diodes, MOSFETS, Caps, resistors, gate driver, transformer)				
Rough Total Cost for Parts				\$194.38

We expect our total cost for parts to be lower than this for the course because we were able to get the motor from the power lab and will be able to get other parts from the ECEB supply center.

Labor Cost:

Average Starting Salaries of Electrical Engineering graduates is \$79,714 at year 18-19[6].

Full-Time job works 1920 hours per year assuming that a person works 8 hours a day, from Monday to Friday, and gets 8 holidays a year and 12 vacation days[7].

Average hourly wage = $\$79,714 / 1920\text{hr} = \$41.52/\text{hr}$

$\$41.52/\text{hr} \times 2.5 \times 100\text{ hr} = \$10,379$ per person

Total Labor Cost: $\$10,379 \times 3 = \$31,138$

Machine Shop:

SCS Machine Shop has construction and repair cost as \$36.65/hr + materials[8].

Assuming machine shop works on our project for 15 hours, the total machine shop cost is

$\$36.65/\text{hr} \times 15\text{hr} = \549.75

Total Cost of Project = \$31,882.13

3.2 Schedule

Table 10: Schedule

Week	Zach Deardorff	Jooseung Kim	Jayden Cho
2/21	Finish Design Document (PCB Schematic)	Finish Design Document (Schematics)	Finish Design Document (Schematics)
2/28	Design Review and Finalize PCB (Converter)	Design, Review, and Finalize PCB (Converter)	Design Review and order parts we need.
3/7	Submit PCB for first round order, and hopefully test mechanical portion.	Submit PCB design, if mechanical portion is finished, begin testing and collect data	Start working on coding computer applications and data communication, test out data if the mechanical portion is done.
3/14	Spring Break	Spring Break Start Final Paper	Spring Break Learn how to use LaTeX and Overleaf
3/21	Begin Soldering parts onto PCB, Test Pressure Sensor.	Start writing code for microcontroller (duty ratio for converter)	Start writing code for microcontroller, computer application code
3/28	Test and Debug Converter Circuit	Test and Debug Converter, Microcontroller, and Pressure Sensor	Start testing out code on the PCB with microcontroller and debug
4/4	Debugging PCB together	Debugging PCB together	Start working on comput
4/11	Test generator with PCB converter circuit	Test PCB with the mechanical portion	Test computer application to ensure proper functionality with pressure sensor
4/18	Test Complete PCB and complete system, Mock Demo	Test Complete System	Test complete system
4/25	Demo Project and work on presentation	Demo Project and work on final presentation	Work on final presentation
5/2	Presentation and Final Paper	Finish Presentation and Paper	Work on final paper

4 Ethics and Safety

Our biggest safety concern is our battery usage in our project. Since we plan on charging a portable charger battery through the use of our converter, there is an inherent risk of overcharging the battery. Overcharging can cause the cathode of the battery to become unstable, producing carbon dioxide, eventually leading to a failure and possible fire [9]. One way we plan on preventing this from happening is by having a switch to the USB connector that will open if the microcontroller senses the output of the DC-DC converter is above our wanted tolerance. Also, a flyback converter is inherently isolated from its input and output. This means that the generator is isolated completely from our battery so if something goes wrong on either end it will not affect either side. Finally, since we plan on simply connecting the USB charger to the actual portable charger itself the portable charger will also have safety mechanisms inside it to prevent overcharging of the portable charger battery.

Inherently in using a generator there could be a danger of connecting the generator to the converter with the wrong polarity. This could put people in danger because it could cause our circuit to short and overheat. Luckily there is a simple solution to this danger. We will simply input a diode at the input of our converter. This will make it so that whenever the cathode voltage is higher than the anode voltage the diode will act as a switch and separate the power supply from the rest of our circuit [10]

In addition to battery, converter, and generator safety, there also are ethical issues we have to keep in mind for this project. It is important for us to follow 7.8 IEEE Code of Ethics. Especially, since the project is worked as a team size, team members must ‘hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment’, and ‘to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, to be honest and realistic in stating claims or estimates based on available data, and to credit properly the contributions of others’[11]. All the team members should have responsible behavior, and will respect each other and treat everyone fairly. Also, we will not engage in any kind of harassment and discriminate against each other[12].

5 References

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