Ambient Light Detection and Auto Dimming Smart Switch

ECE445 Final Report

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Spring 2023

Abstract

The Ambient Light Detection and Auto Dimming Smart Switch is a light switch that detects the ambient light level in the room, and adjusts the power sent to a light bulb based on a user set desired light level. The system includes a sensor subsystem, power subsystem, and control subsystem. These systems combine to smoothly adjust the power sent to lights as the ambient light changes in a room.

Contents

1 Introduction **1**
- 1.1 Problem . . . 1
- 1.2 Solution . . . 1
- 1.3 High-level Requirements . . . 1
- 1.4 Design Changes . . . 1

2 Design **2**
- 2.1 Block Diagram . . . 2
- 2.2 Power Subsystem . . . 2
  - 2.2.1 Rectifier . . . 3
  - 2.2.2 DC/DC Flyback Converter . . . 4
  - 2.2.3 Light Power Control . . . 5
- 2.3 Sensor Subsystem . . . 6
  - 2.3.1 Ultrasonic Sensor . . . 6
  - 2.3.2 Luminosity Sensor . . . 6
- 2.4 Control Subsystem . . . 7
  - 2.4.1 User Interface . . . 7
  - 2.4.2 Microcontroller . . . 7

3 Verification **9**

4 Costs **10**
- 4.1 Cost Analysis . . . 10
  - 4.1.1 Parts . . . 10
  - 4.1.2 Labor . . . 11
  - 4.1.3 Total Cost . . . 12

5 Conclusion **13**
- 5.1 Accomplishments . . . 13
- 5.2 Shortcomings . . . 13
- 5.3 Future Work . . . 13
- 5.4 Ethics and Safety . . . 14

Appendix A Requirements and Verification Tables **17**

Appendix B Microcontroller Control Flow **20**

Appendix C Microcontroller Serial Outputs **21**

Appendix D PCB Design **22**

Appendix E Flyback Breadboard **23**

Appendix F Control and Sensors Breadboard **24**

Appendix G Safety Warnings **25**

1 Introduction

1.1 Problem

Most light switches are binary switches and do not have brightness control. There are dimmer switches that allow the user to control brightness, but they do not automatically adjust if the ambient light changes. Users may need to adjust the light if they are in the same room for a long period of time and do not want large changes in light level. There are existing smart no-neutral switches, and lights that detect ambient light (like the BenQ e-Reading Desk Lamp), but there are no existing solutions that combine the two. We are seeking to make users' lives more convenient by introducing this brightness adjusting smart switch.

1.2 Solution

To solve this problem, we created a smart switch that can intelligently control light level based on the ambient lighting. This includes user set light level, a manual control switch, and sensors to detect the light level and any possible obstructions.

1.3 High-level Requirements

Our project intended to achieve the goals listed below. We were able to meet requirements two, three, and four, but were unable to meet requirement one. We were unable to implement the power siphoning circuit for this requirement. This will be discussed in more detail later in the report.

1. Be able to connected to existing light fixtures and switches, even those without a neutral wire.
2. Maintain a constant light level for the room at the user set brightness.
3. Prevent unintended fluctuations in light level due to obstructions in front of the switch.
4. Have an override switch that allows for absolute control of the lights.

1.4 Design Changes

Originally, we intended for our project to source power directly from the AC mains using a no-neutral power siphoning circuit and a triac to pass the AC waveform to the light. Unfortunately, we faced some difficulties implementing these features and were unable to complete these portions.

2 Design

2.1 Block Diagram

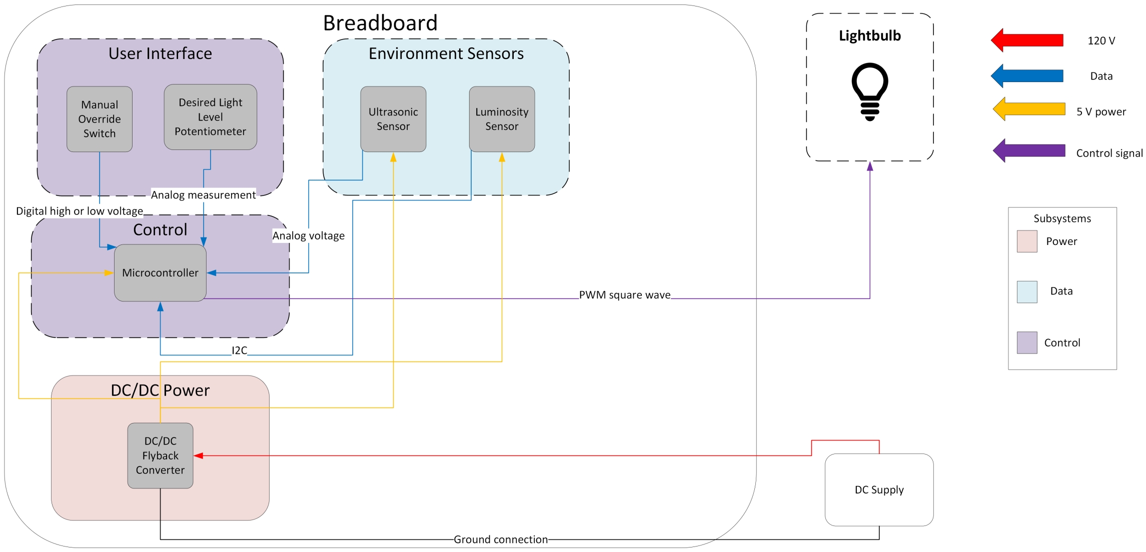

Figure 1: Updated block diagram

The block diagram in figure 1 outlines our three subsystems, and the power/data signals between the different subsystems. The power system takes in a DC voltage and down-converts it to 5 V. The control and sensor subsystems are powered using a 5 V signal. The user interface portion of the control system is how the user inputs the desired function. There is a switch to determine manual or smart mode. In manual mode, the user is able to directly the level of the lights using the potentiometer on the user interface. In smart mode, the user is able to set the desired light level. The control system then takes in data from the sensors, and outputs a PWM square wave to vary the power sent to the light to adjust the brightness level. The duty cycle of the PWM square wave output is varied to change the brightness of the LED array.

2.2 Power Subsystem

Since we are designing a smart switch with no neutral connection, the smart switch has to obtain power and stay in standby mode. It will have a power harvesting circuit that allows a small amount of power to the light bulb even when the switch is not turned on to complete the circuit. When the switch is turned on, enough power will be sent to the light bulb to light it up. The power supply should be able to extract power from the open circuit over a wide voltage range.

In order to power the switch, we are sourcing power from the 120V 60Hz AC source existing in the wall circuit on the neutral side, and then rectifying the AC line voltage with a bulk capacitor to create a DC voltage. From there, we chose to implement a flyback converter to allow a switching buck-boost topology that would be able to power 5VDC into the control system. Flyback converters offer an isolated buck-boost topology that is isolated by using a transformer, acting as the storage inductor. The transformer has separate grounding which provides additional safety, has variability in the turns ratio, and is most optimal for low-power applications. [11] [4] [9] [6] [2].

The circuit design also consists of a triac optocoupler to control the power passing to the bulb, chopping up the waveform into the desired trigger angle from a microcontroller PWM signal [8] [15]. We chose to use a triac optocoupler for its electrical ability to provide electrical and physical isolation from the control output and the high voltage AC mains.

2.2.1 Rectifier

The selected single phase bridge rectifier will take the AC mains voltage and output a DC voltage to feed into the flyback converter as can be seen in figure 3. A full bridge rectifier is more advantageous to use in our application over a using a center tapped full wave rectifier as it requires more size and cost. The expected output waveform is attached as shown in figure 2.

The following equation determines the expected DC voltage from our maximum AC input.

$$V_{dc} = \frac{2V_{max}}{pi} = 0.637V_{max} = 0.9V_{rms}$$
$$V_{dc,max} = 0.9V_{rms} = 0.9 * 120 = 108V$$

To improve the average DC output and reduce the AC variation from the rectified output, a smoothing capacitor is essential. The bulk capacitor sizing was determined based on the maximum load current and voltage ripple expected as can be from the equation below. [14]

$$V_{ripple} = \frac{I_{DC}}{2fC}$$
$$C_{estimate} = \frac{I_{DC}}{2fV_{ripple}} = \frac{0.02}{2 * 60 * 75} = 2.2uF$$

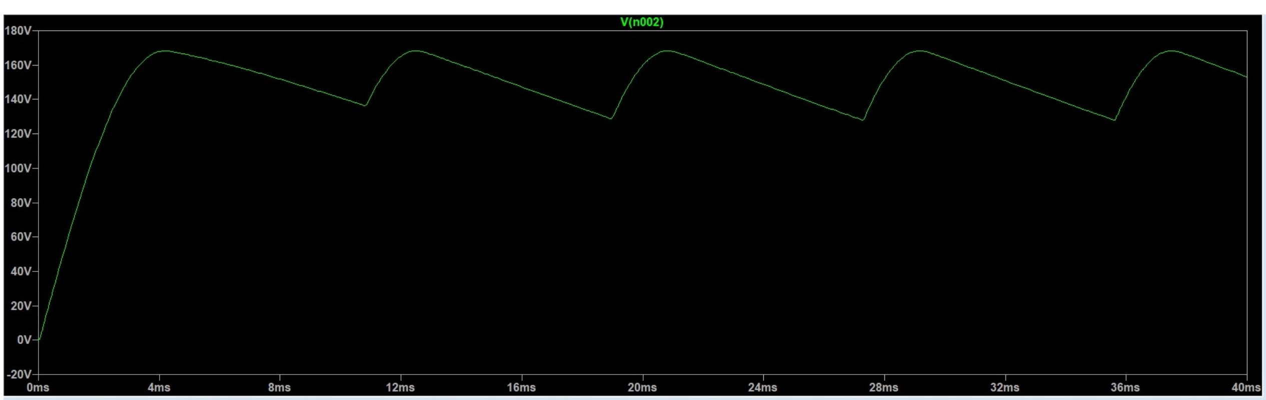

Figure 2: Simulated Rectifier Output

2.2.2 DC/DC Flyback Converter

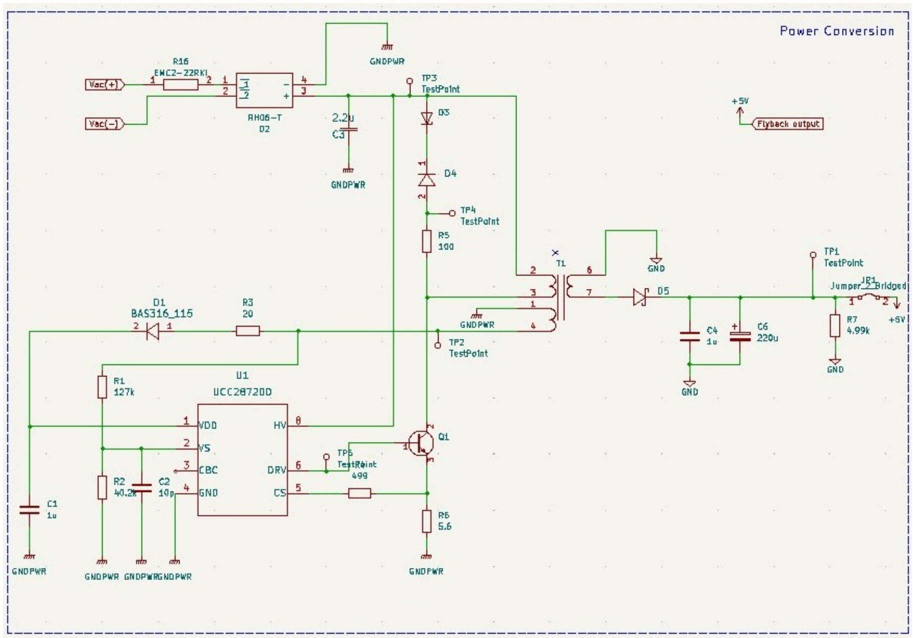

Figure 3: AC/DC and DC/DC Circuit

The flyback converter will then receive input power from the full bridge rectifier and output a 5V signal. This 5V signal will be the basis for all the DC electronics included on the PCB such as the microcontroller and the ultrasonic sensor. Due to the nature of the no neutral power harvesting circuit, the converter must be able to function over a wide voltage range and maintain the 5V output. The transformer selected, T1 - 750314178, is a 2.50mH power transformer with a primary winding, an auxiliary winding, and a secondary winding. Unlike ordinary transformers, the primary winding steps down into the auxiliary winding, which is used for the flyback controller. The turns ratio for each winding is listed below.

$$\frac{V_{pri}}{V_{aux}} = \frac{4}{1}$$

$$\frac{V_{pri}}{V_{sec}} = \frac{12}{1}$$

The fundamental conversion equation for a basic flyback topology is listed below. Essentially,the output voltage is determined by the switching duty ratio and the primary to secondary turns ratio.

$$\frac{V_{out}}{V_{in}} = \frac{D}{1-D}\frac{N_{sec}}{N_{pri}}$$

Since the key highlight of a flyback converter is its switching topology, we selected a built-in flyback power supply controller, U1 - UCC28720, for reliable control. The controller provides an isolated constant-voltage and constant-current output regulation without the need for an optical coupler, and it processes information from the power switch and the auxiliary winding for precise control of output voltage and current. With the controller, it contains control algorithms that monitors the peak primary current in the transformer to avoid core saturation and drives the bipolar transistor power switch, Q1, as needed. [13]

With flyback converters, due to its switching operation, it introduces unwanted voltage spikes with high frequency noise harmonic disruptions and stress on the power switch. Our design includes a zener diode clamping circuit that was selected based on the expected voltage spikes. Based on the reflected voltage, the voltage reflected on the secondary when the primary switch is turned off, and the leakage inductance, the zener diode selected, is rated at 82V. [1]

2.2.3 Light Power Control

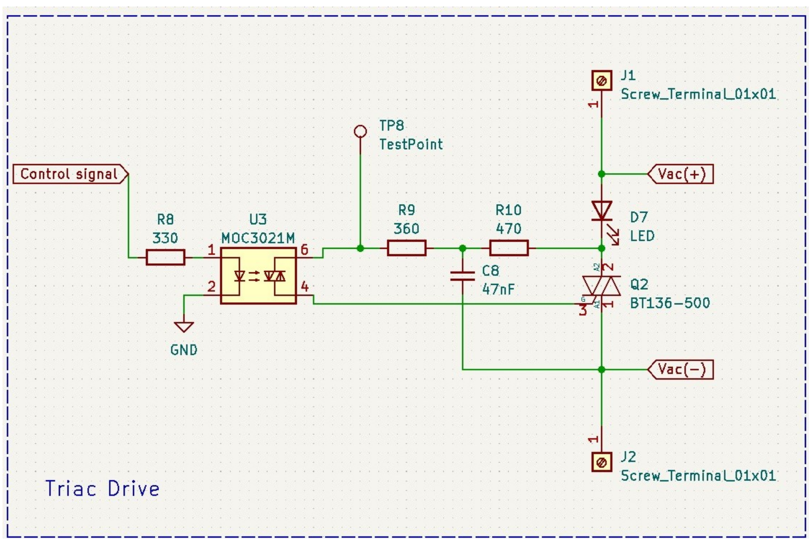

Figure 4: Triac Dimming Circuit

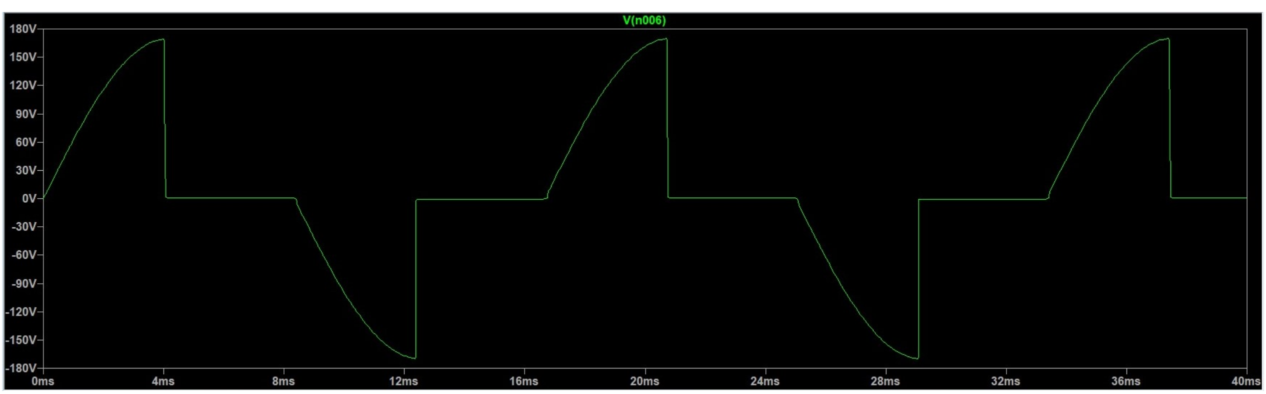

Figure 5: Simulated Triac Dimming Waveform

Conduction to the light will be managed by a triac dimming circuit as picture in figure 4. The microcontroller will send a signal to trigger into the MOC3021, a triac driven optoisolator, which is an ideal choice when controlling high voltage AC loads through digital control. The optocoupler cannot directly drive loads due to its limited current rating, so it is connected to another triac to act as a power switch to provide enough current to drive the loads. When we trigger the control to turn the LED on with our microcontroller, we adjust the time delay to cut the waveform to our desired preference. Since we are sourcing from the 120V/60Hz AC wall source, we have the period of the desired output signal at 16.66ms, which is calculated by computing the inverse of 60Hz. Our lightbulb is modeled as D7, so the lightbulb will receive the chopped waveform (pictured in figure 5) coming out of the triac on the AC mains.

2.3 Sensor Subsystem

The sensor subsystem of our project is comprised of two sensors: the ultrasonic sensor and the luminosity sensor. The ultrasonic sensor is used to detect if there is an obstruction in front of the switch. The luminosity sensor is used to detect the general light level of the room. The microcontroller outputs a control signal using a PWM square wave. The duty cycle of this square wave is varied to change the light level. The breadboard for the sensor subsystem can be seen in figure 15 in appendix F. This is a combined breadboard for the sensor and control subsystems. The ultrasonic sensor can be seen in the upper left of the image as the component with two speakers on it. The luminosity sensor is directly below it.

2.3.1 Ultrasonic Sensor

If an object is detected within 20 cm of the system for three consecutive polling intervals, the system is marked as obstructed. While obstructed in smart mode, the system does not make any changes to the light level. This is to prevent any fluctuations in light level from a momentary obstruction. After the obstruction is removed, the switch will continue smart operation and adjust the light level as needed. In manual mode, the light level changes as the user turns the user interface potentiometer, without regard for whether the switch is obstructed or not. This sensor outputs an analog voltage which is then converted to a digital value by the integrated analog-to-digital converter in the microcontroller.

The threshold for an obstruction is 20 cm. After an object is within 20 cm for three polling periods, the switch is marked as obstructed. Some example output can be seen in figure 10 in appendix C.

2.3.2 Luminosity Sensor

The second sensor in this subsystem in the luminosity sensor. This sensor measures the light level of the room in lux. In smart mode, if the light level of the room is higher than the desired light level, the power sent to the lights is reduced. If the light level of the room is lower than the desired light level, the power sent to the light is increased. The sensor communicates with the microcontroller using a digital signal over the I2C protocol. Some example output can be seen in figure 10 in appendix C.

2.4 Control Subsystem

The control subsystem of the project consists of two parts: the user interface where the light level and manual mode/smart mode function can be selected, and the microcontroller that varies the power sent to the LED array. The microcontroller takes input from the sensors and user interface, and combines these inputs to output a PWM square wave signal to the lights. The breadboard for the control subsystem can be seen in figure 15 in appendix F. As mentioned previously, this is a combined breadboard for the sensor and control subsystems. The microcontroller can be seen as the IC chip in the middle channel of the breadbroad. The LED array can be seen on the right side.

2.4.1 User Interface

Using a potentiometer, the user can raise or lower the desired light level and the microcontroller adjusts power to the lights to match. Using the manual mode/smart mode switch, the user can change between smart mode, where the microcontroller determines the light level, and manual mode, where the user can directly control the light level.

2.4.2 Microcontroller

The microcontroller used in our project is an ATmega328P. We chose this specific microcontroller because it has an integrated I2C interface and an integrated 10 bit analog-to-digital converter (ADC), while also having a low power consumption. The I2C interface communicates with the luminosity sensor, and the ADC converts the analog voltage from the ultrasonic sensor to a digital value.

The microcontroller is responsible for handling the inputs from the user interface and sensor subsystem and controlling the power to the light. It first sets the operation mode based on the user override switch and whether an obstruction is detected by the ultrasonic sensor. As mentioned previously, the microcontroller interfaces with the ultrasonic sensor using the integrated analog-to-digital converter. If manual mode in on, the user can directly set the light level using the potentiometer. If manual mode in off but there is an obstruction, the system holds the current light power level until the obstruction clears. In normal operation, the microcontroller utilizes inputs of the luminosity sensor and the desired light level switch to run a control loop that adjusts the power sent to the light to approach the desired light level received by the luminosity sensor. The light control continues to adjust to reach the desired level unless it reaches a limit by the minimum or maximum power levels available to the light. The power level of the lights is varied by using a PWM control signal output by the microcontroller. By varying the duty cycle of this PWM signal, the power sent to the lights is adjusted. A more detailed description of the control flow can be seen in figure 9 in appendix B. A schematic showing the connections can be seen in figure

The feedback loop is implemented with a PID (proportional, integral, derivative) algorithm. At each time step, an error is calculated between the target brightness level and the current brightness measured by the luminosity sensor. The proportional term adjust the output proportionally to the error. This is the simplest and most important term as it directly brightens or dulls the bulb in order to reach the target brightness. The integral term adjusts based on the cumulative error and helps remove any residual error. The derivative term accounts for the rate of change of the error and can help prevent the control loop from overshooting the target. A diagram illustrating this can be seen in figure 7. An example of the algorithm output values can be seen in figure 11 in appendix C.

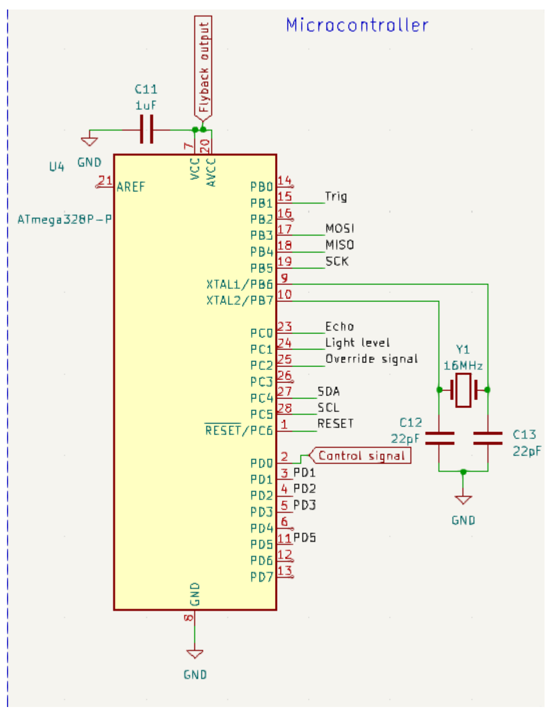

Figure 6: Microcontroller schematic

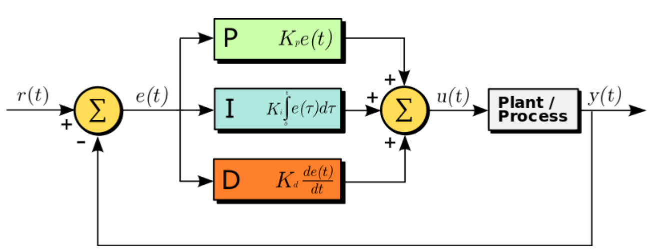

Figure 7: PID Algorithm[3]

3 Verification

Our requirements and verification tables can be seen in detail in appendix A. The basic requirements of our system included that the ultrasonic sensor needed to be able to detect an obstruction within 20 cm, the luminosity sensor needed to be able to detect the typical brightness of a room, including when lights and direct sunlight were shining on it. Some readouts taken from the sensors can be seen in figure 10 in appendix C. A readout from the control subsystem can be seen in figure 11, also in appendix C. From these outputs, you can see that the ultrasonic sensor is successfully able to detect an obstruction with 20 cm, and the luminosity sensor is able to detect the general light level of the room. These tests were done using an Arduino and reading from the included serial monitor in the Arduino IDE.

We were also able to sucessfully output a 5 V signal from the flyback converter. This can be seen in figure 8. In figure 8, channel 1 is the output voltage of the converter (4.94 V), channel 2 is input voltage of the converter (82.0 V), and channel 3 is the voltage across the auxillary winding (17.2 V) powering the flyback controller. The value of 4.92 V is within the 5 V ±5% specified in our requirements. We were also able to partially satifies the input voltage requirements. Since our circuit did not pull a single-phase 120 V AC waveform directly from the wall, we were only able to test up to 80 V DC using the Keithly DC power supply in the power lab. So, our converter functions at 80 V DC, but we were unable to test above this voltage.

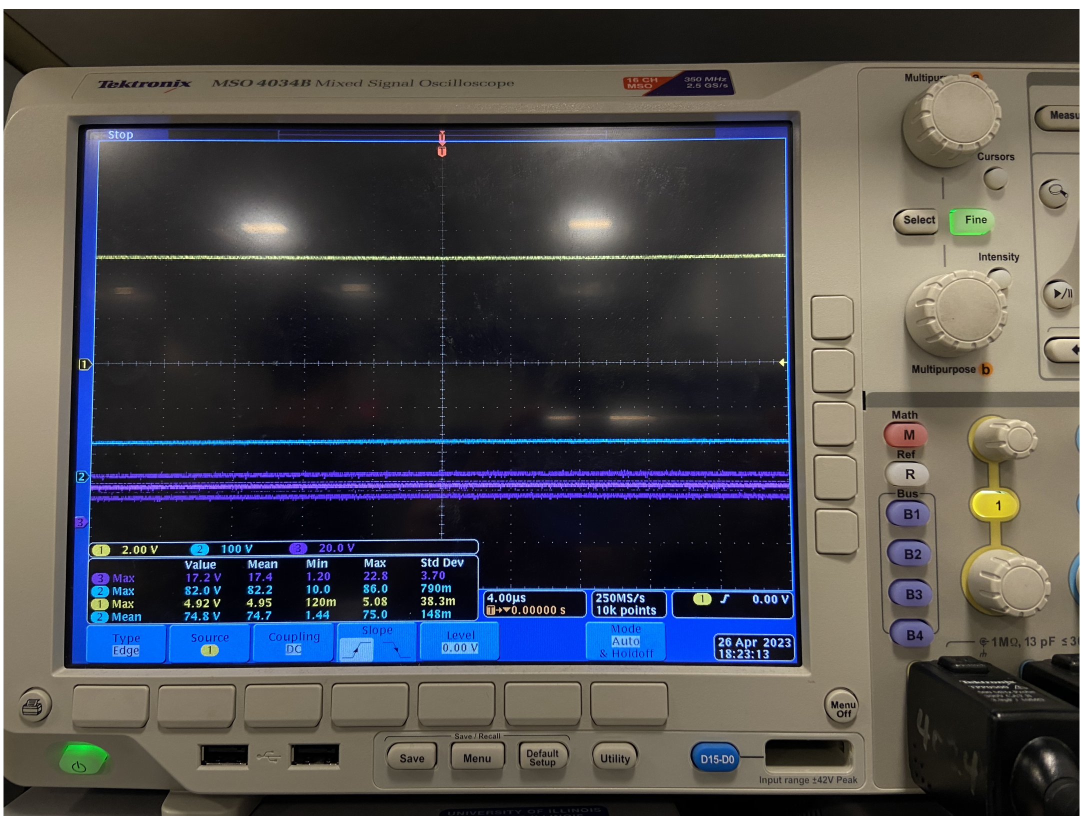

Figure 8: Waveform of flyback converter

4 Costs

4.1 Cost Analysis

4.1.1 Parts

This is our parts lists that we purchased to assemble our project.

Table 1: Parts list

Description	Part Number	Unit Cost ($)	Quantity	Total Cost ($)
Microcontroller	ATMEGA328P	7.70	1	7.70
Override switch	SW-T3-1A-A-A3-S1	0.88	1	0.88
Analog to digital converter	MCP3021A2T-E/OT	1.42	1	1.42
Diode	ES2CA-13-F	0.73	5	3.85
Triac optoisolator	MOC3021	0.54	1	0.54
Triac	583-BT136	0.67	1	0.67
Ultrasonic sensor	3942	3.95	1	3.95
Ambient light sensor	VEML7700	4.95	1	4.95
1 uF cap	CL05A105KP5NNNC	0.10	3	0.30
16 MHz crystal	16M20P2/49SMT	0.16	1	0.16
330 Ω resistor	RC0603JR-07330RL	0.10	1	0.10
360 Ω resistor	RC0603JR-07360RL	0.10	1	0.10
470 Ω resistor	ERA-3AEB471V	0.35	1	0.35
47 nF capacitor	C0603C473K4-RECAUTO	0.18	1	0.18
22 Ω fuse resistor	EMC2-22RKI	0.65	1	0.65
Diode switching bridge	RH06-T	0.18	1	0.18
Transformer	750314178	10.65	1	10.65
Flyback controller	UCC28720	0.53	1	0.53
Schottky diode	SS110-TP	0.35	1	0.35
Diode	BAS316,115	0.15	1	0.15
Test point (red)	5000	0.42	4	1.68
Test point (black)	5001	0.42	4	1.68
100 Ω resistor	RC0805FR-07100RL	0.10	1	0.10
4.99 kΩ resistor	CPF0603F4K99C1	0.20	1	0.20

Table 1: Parts list continued

20 Ω resistor	CPF0603F20RC1	0.19	1	0.19
127 kΩ resistor	RC0402FR-07127KL	0.10	1	0.10
499 Ω resistor	CPF0603F499RC1	0.20	1	0.20
40.2 kΩ resistor	CPF0603F40K2C1	0.20	1	0.20
5.6 Ω resistor	RC0805JR-075R6L	0.10	1	0.10
2.2 uF capacitor	CKG57NX7T2W-225M500JH	3.79	1	3.79
1 uF capacitor	CL10A105KO8NNNC	0.10	3	0.30
10 pF capacitor	06033C100KAT2A	0.20	1	0.20
1 uF capacitor	CL21B105KBFNNNE	0.11	1	0.11
220 uF capacitor	10TPE220ML	2.37	1	2.37
Diode	CGRM4007-G	0.37	1	0.37
82 V zener diode	MMSZ5268BT1G	0.24	1	0.25
Banana plugs	CT2230-0	1.40	2	2.80
0 Ω jumper	RMCF0603ZT0R00	0.10	1	0.10
22 pF capacitor	06035A220JAT2A	0.10	1	0.10
1 kΩ resistor	ESR03EZPF1001	0.15	2	0.30
10 kΩ resistor	ESR03EZPJ103	0.14	2	0.28
Potentiometer	P120PK-Y25BR10K	0.93	1	0.93

4.1.2 Labor

According to the Grainger College of Engineering, the average salary for an electrical engineering graduate is $80,296 [10]. This translates to an hourly rate of about $38/hour. Given that each member worked the number of hours specified in the labor breakdown in table 2 the labor cost can be calculated as shown in equation 1. The total comes out to a labor cost of $29545.

Table 2: Labor breakdown

Labor Category	Spencer	Michael	Christine
Circuit Design	25	25	45
Board Design	20	15	20
Software Design	8	15	3
Assembly & Soldering	5	5	5
Test, Verification, Troubleshooting	40	40	40
Total	**98**	**100**	**113**

$$\$38/hr * 2.5\ (overhead) * (98 + 100 + 113)\ (hours) = \$29545 \tag{1}$$

4.1.3 Total Cost

Totaling up table 1 the total parts cost is \$59.58. Adding this cost to the labor costs results in a total project cost of \$29604.58.

5 Conclusion

5.1 Accomplishments

Overall, we were successful in creating a smart light switch that controls light level based on ambient lighting. We were able to meet three of four high level requirements and integrated the control and sensor subsystems while also having a working DC/DC power converter. The user is able to select a wide range of target brightnesses, and the control loop is able to adjust smoothly to meet user demands. This does not mean that the device is perfect, but it does carry out the intended functionality.

We learned a great deal about desigining and testing power circuits, especially at high voltage. Along those same lines, we learned a lot about PCB design and debugging. Planning and executing a project with various subsystems and design phases was also a big learning experience.

5.2 Shortcomings

The largest shortcoming with our project is that we were unable to fulfill the no-neutral high level requirement due to issues integrating the rectifier. Additionally, we were unable to implement the triac portion of the circuit. These two pieces are would be needed to replace a normal light switch with our project. Without the triac to pass the AC waveform, our circuit would have a much larger current input than it could handle. Additionally, due to not meeting the no-neutral requirement, our project would require additional wiring to be run to be installed in an existing light switch. If we redesigned our project, we would adjust the timeline to allow more time for PCB debugging and reordering. Though we were able to test high voltages on the PCB as can be seen in appendix D that integrated high power components and control, certain issues such as improper grounding limited us to model our circuitry on a breadboard instead.

5.3 Future Work

The basic functionality for our device is completed, but the main point to build on for future work would be to get the no-neutral and triac circuit portions working. As mentioned in the shortcomings, once these items are implemented, the switch could replace an ordinary light switch. However, this would also require fitting the final project onto a PCB and packaging the whole device into a smaller form factor that would fit in the same space as a normal light switch. It is possible that the parts could be chosen specifically to reduce the size of the circuit. Once this is accomplished, the product would be ready for wider adoption and use by the general public.

5.4 Ethics and Safety

We followed the IEEE Code of Ethics in the development of our project. Section I.1 specifies to hold safety in the highest regard [7]. The goal of our project is to make users' lives more convenient. We want to ensure that our project does not injure users in the process of installing it. We have included warnings in appendix G.

The primary source of danger in our project is the power system, specifically the connection to DC power supply. As little as 50 to 150 mA could cause death [12], so it is paramount that the user understands safe protocol for installing our project. While developing the project, we will always ensure that the power is off before connecting or disconnecting any components. Our project will also include safety documentation for the user very clearly list these steps to ensure their safety.

Another possible danger is the circuit shorting and causing an electrical fire. From 2015-2019 there were an average of 46,700 home electrical fires [5]. To protect our users we decided to use a flyback converter for our AC-DC power converter system. The flyback converter provides galvanic isolation between the AC mains input and the circuit output. Due to this topology, the output side of the transformer is isolated from high current [9]. The input side of the power system will be protected by the usual circuit breakers that are included in home circuits.

As our project is a light switch, we do not believe that there are major ethical concerns beyond the power system being as safe as possible. The device is entirely self-contained, and no data from the user is stored or shared.

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Appendix A Requirements and Verification Tables

Table 3: Sensor subsystem requirements and verification

Requirements	Verification	Results
• Flyback converter should output 5V $\pm 10\%$	• Connect a differential probe across flyback voltage output • Connect the circuit to the 120V AC mains • Monitor the output voltage for 5 minutes and ensure that the value is between 4.5-5.5V	Satisfied. The flyback converter was successful in outputting a 5V signal that varied within our tolerance range when supplied an input up to 80V.
• Flyback converter should function from 5V-120V input	• Connect an oscilloscope differential voltage probe across the output terminals • Connect the circuit to a single phase AC variable voltage source • Vary the voltage on the voltage source from 5-120V in 5V increments for 3 minutes each • Monitor the output voltage and ensure that the value is between 4.5-5.5V	Mostly satisfied. Due to the limitations of the power source in the lab, we were only able to test up from 5V-80 V DC.

Table 4: Sensor subsystem requirements and verification

Requirements	Verification	Results
• The ultrasonic sensor must be able to accurately detect a person between the heights of 5' and 6' within 1 m.	• Connect the Arduino 5V to the VCC pin, analog out to trig pin, analog in to echo pin, and ground to ground pin. • Start the custom Arduino module. Check the console to ensure that there is a connection. • Have a person stand in front of the sensor at distances ranging between 5-50cm in 10cm increments. • Verify that the distance calculated from the output of the ultrasonic sensor is accurate to the actual distance of the person.	Satisfied. We validated the accuracy of our ultrasonic sensor reading through Arduino unit tests and hand measurements. Our software was able to properly detect various obstructions such as a chair or a person's hand or body.
• The luminosity sensor must be able to detect the typical brightness in a room from 100-4000 lumens.	• Connect the Arduino 5V to the VCC pin, ground to GND pin, and I^2C data and clock pins to the corresponding ports on the Arduino • Cover the sensor and verify that close to 0 lumens is measured. • Gradually increase the light level and verify that the lumens measured increases as the intensity of light shined on the sensor inscreases.	Satisfied. In our Arduino unit tests, we calculated a lux value of around 0 from the luminosity sensor output when in a dark room, and a lux value of around 300 in a fully lit room. This is an accurate range and sufficient for the operation of our control subsystem.

Table 5: Control subsystem requirements and verification

Requirements	Verification	Results
• Microcontroller must be able to interface with user interface and light bulb simultaneously	• Connect jumper wires to triac to connect to a power meter • Vary luminosity sensor input from 100-4000 lumens and set ultrasonic sensor readings between 5 and 100 cm. • Manually test each combination of user input and environment sensor possibilities through unit tests through Arduino. Check Arduino console at each combination to verify sensors are reading. • The output should be verified by measuring the power delivered to the light bulb.	Satisfied. When we moved from sensor unit tests to the Arduino testing of the entire control flow, we got valid input data from all sensors and user controls, verified the correct operation of our control algorithm, and outputted varying power levels to the lights.
• Microcontroller must allow the triac to conduct to allow for power siphoning, while ensuring the light stays off	• Connect a voltage probe across the microcontroller and another voltage probe across the light bulb connection to view waveforms throughout the operation of the light bulb. • Vary the light bulb dimming output from the lowest (2 W) to highest setting (9 W) to ensure the entire range behaves properly and power is always delivered back to the control circuit.	Failed. Unable to implement triac circuit

Appendix B Microcontroller Control Flow

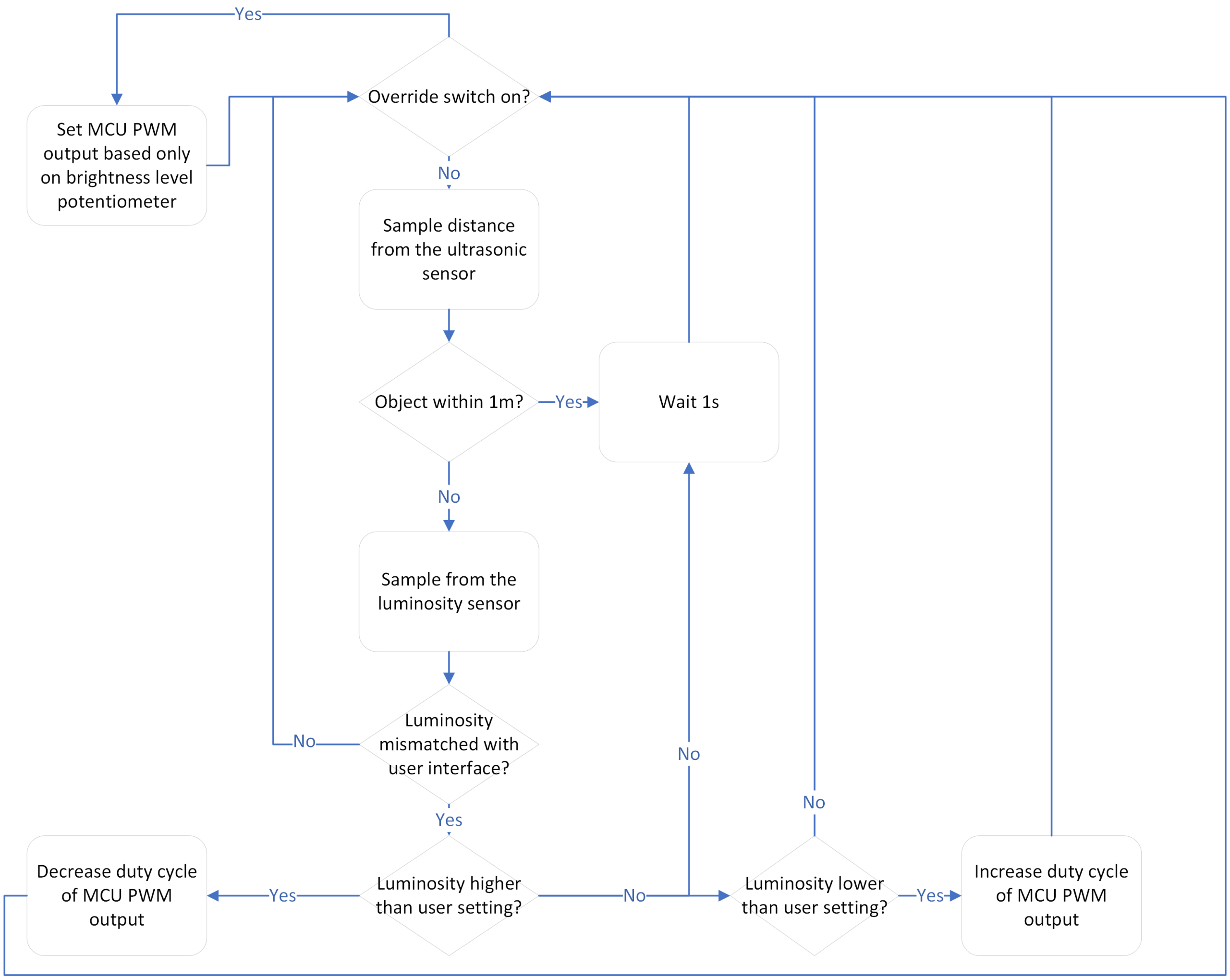
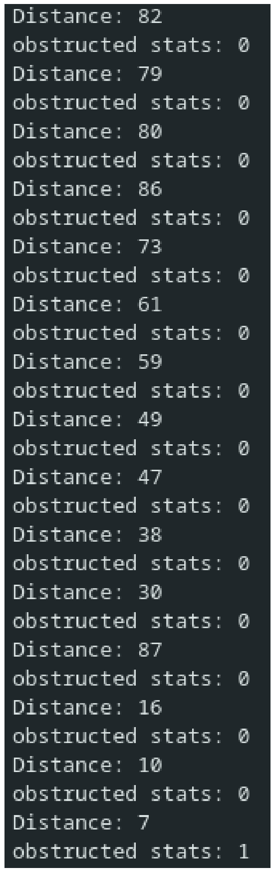


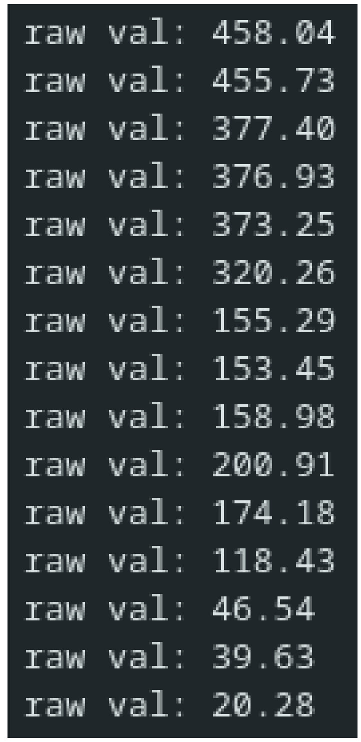
Figure 9: Control Flowchart

Appendix C Microcontroller Serial Outputs



```
Distance: 82
obstructed stats: 0
Distance: 79
obstructed stats: 0
Distance: 80
obstructed stats: 0
Distance: 86
obstructed stats: 0
Distance: 73
obstructed stats: 0
Distance: 61
obstructed stats: 0
Distance: 59
obstructed stats: 0
Distance: 49
obstructed stats: 0
Distance: 47
obstructed stats: 0
Distance: 38
obstructed stats: 0
Distance: 30
obstructed stats: 0
Distance: 87
obstructed stats: 0
Distance: 16
obstructed stats: 0
Distance: 10
obstructed stats: 0
Distance: 7
obstructed stats: 1
```

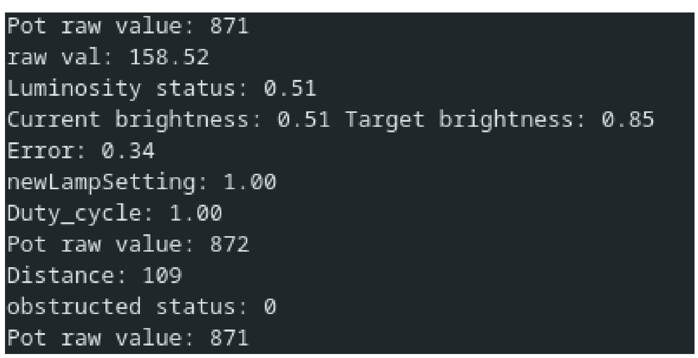
(a) Ultrasonic serial output



```
raw val: 458.04
raw val: 455.73
raw val: 377.40
raw val: 376.93
raw val: 373.25
raw val: 320.26
raw val: 155.29
raw val: 153.45
raw val: 158.98
raw val: 200.91
raw val: 174.18
raw val: 118.43
raw val: 46.54
raw val: 39.63
raw val: 20.28
```

(b) Luminosity sensor serial output

Figure 10: Sensor serial output in Arduino IDE



```
Pot raw value: 871
raw val: 158.52
Luminosity status: 0.51
Current brightness: 0.51 Target brightness: 0.85
Error: 0.34
newLampSetting: 1.00
Duty_cycle: 1.00
Pot raw value: 872
Distance: 109
obstructed status: 0
Pot raw value: 871
```

Figure 11: Control serial output

Appendix D PCB Design

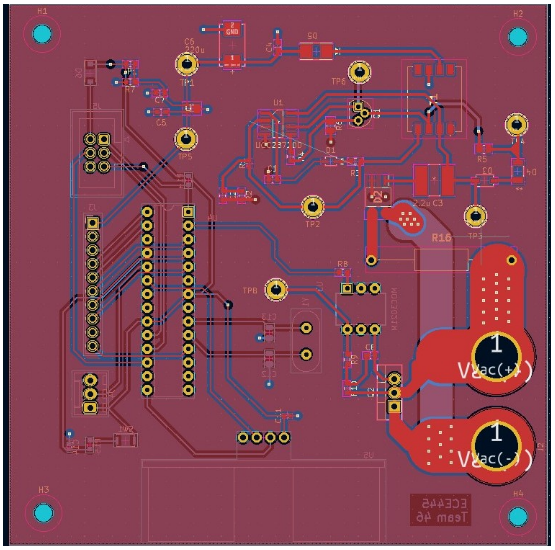


Figure 12: PCB Design: Front

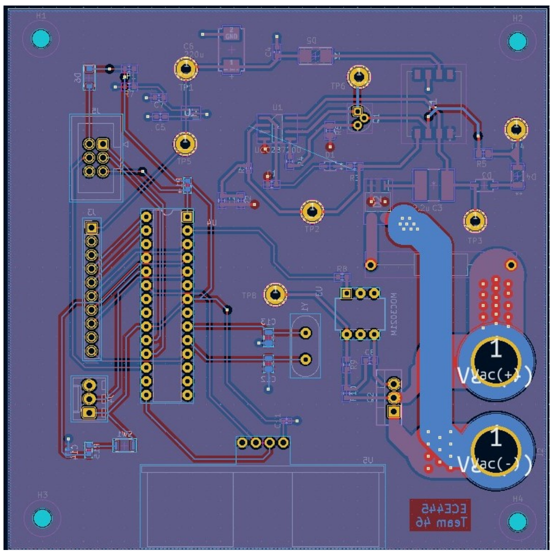


Figure 13: PCB Design: Back

Appendix E Flyback Breadboard

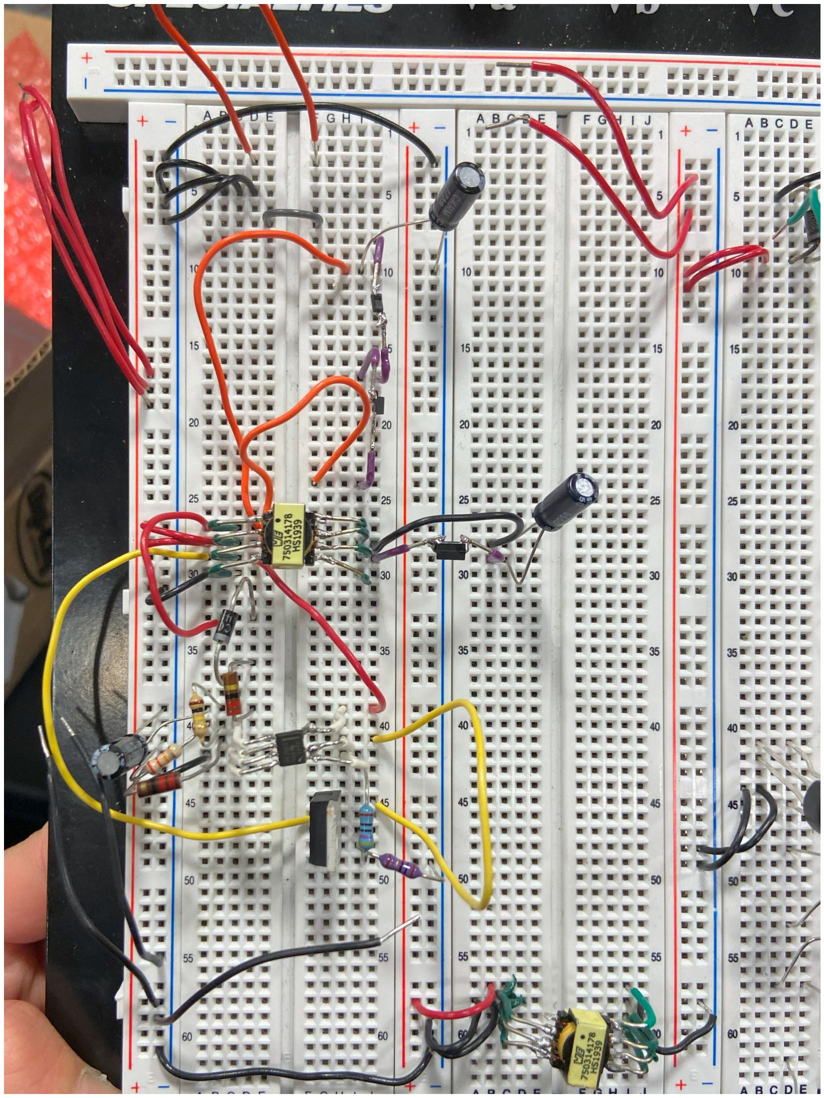


Figure 14: Resulting Flyback Converter

Appendix F Control and Sensors Breadboard

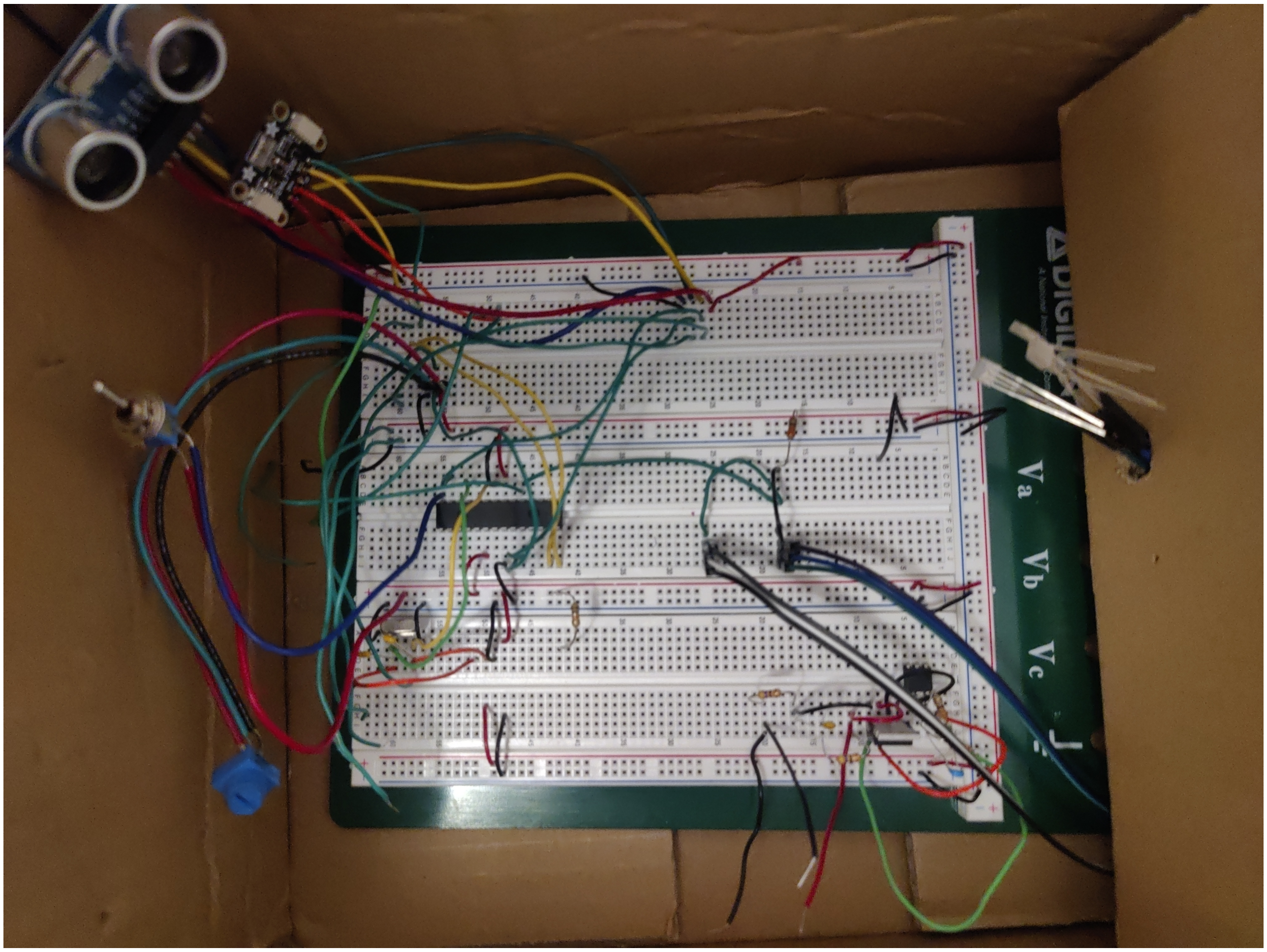


Figure 15: Breadboard for sensors and control

Appendix G Safety Warnings

If connecting this device to a high voltage DC supply, it is extremely important to be careful. Accidentally touching a live circuit could result in permanent damage or even death. Before connecting any wires, make sure that the supply output is off. Even after connecting the circuit, do not touch any exposed metal wires or plugs while the supply is on. This could create a path for high current to travel through your body and possibly cause death. Additionally, if at any point there is a large amount of heat radiating from the switch, turn the supply off immediately. The components used in this system are very low power consumption, so a large amount of heat means that the circuit is somehow shorted. If not addressed, this could result in a fire.