Smart Trap

Team 63

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March 2nd, 2021

ECE 445

1. Introduction

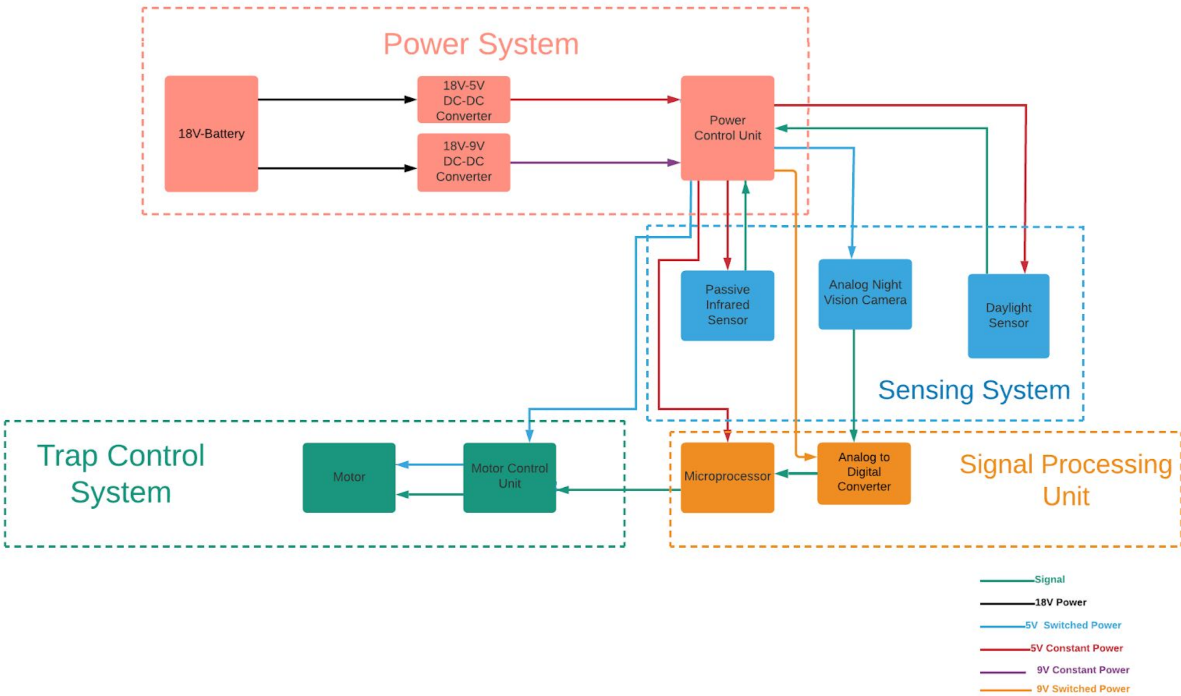
Animals like raccoons and foxes have been a problem facing homeowners since the dawn of time. While these animals seem harmless, they actually are responsible for a large amount of property damage, as well harming pets like cats. While there exist traditional traps in the market meant to capture these animals, they have the major problem of accidentally capturing other animals like rabbits, or even worse your own pet. This problem is particularly amplified in the case that the trap setter is inexperienced [1]. This is where the Smart Trap comes in. The Smart Trap will take your existing trap, and prevent it from capturing the wrong animal, so you don't have to worry about Spike going into the trap. This is done by implementing a camera and object detection to identify if an animal is a targeted animal, and to allow the trap to be set if it is. Our goal is to ensure our customers can live a pest free life without their animals getting harmed.

2. High-level Requirements

- Our trap should capture the targeted animal at least 95% of the time that a target animal enters the cage.
- The trap should fail safely: it is more desirable to let the target animal leave untrapped than to capture the wrong animal.
- Our trap should run on an 18V battery and have a minimum of twelve hours of battery life.
- Our device should make a decision and enable the trap within five seconds of the animal entering the cage.

3. Design

3.1. Block Diagram



3.2. Subsystem Descriptions and Requirements

3.2.1. Signal Processing Unit:

The signal processing unit consists of the ARM Cortex-A53 processor on the Raspberry Pi, which processes the image and implements an object detection machine learning algorithm for detecting a creature. The signal processing unit also consists of a digital signal processor to convert the analog RCA video jack to a digital USB.

- Analog to Digital Converter:

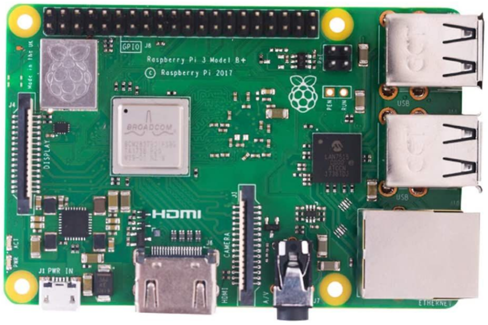
The Analog to Digital Converter takes in the analog signal via the RCA video cable and digitizes it through the USB 2.0 cable. The converter has a video resolution of 720x480 pixels at 30 fps.

- Microprocessor:

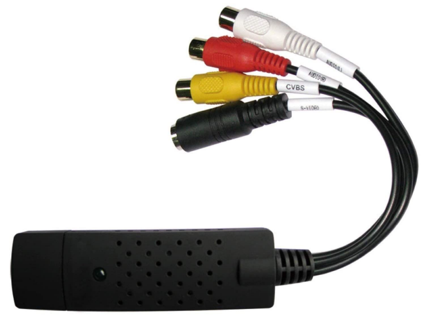
The microprocessor which in this case is a Raspberry Pi 3 B+, has a ARM Cortex-A53 quad core processor clocked at 1.4GHz with 4 × USB 2.0 ports and Extended 40-pin GPIO header. The Raspberry Pi handles the image processing from the camera by taking in the data through the USB 2.0 port, implementing the object detection algorithm on the image, and applying a 3.3V signal output to the motor control unit via the GPIO pins. This output merely communicates with the mtor control circuitry; it does not supply power. [2]

Signal Processing Unit Requirements:

1) The sample rate of the analog video input used by the Raspberry Pi should be at least one frame every two seconds.
2) The Raspberry Pi should boot up and run the object detection program immediately.
3) Subsequent boots and shutdowns should not compromise the functionality of the program.
4) The program must handle the case where there is no input from the camera.
5) The Raspberry Pi should consume at most an average of 4.5W. This number should be minimized as much as possible, perhaps by implementing an interrupt signal that tells the Raspberry Pi when to idle and cease computations.



Above: The Raspberry Pi 3 Model B+



Above: RCA to USB 2.0 converter

3.2.2. Trap Control System:

Trap Control System consists of a motor and motor control unit. The motor control unit receives a boolean signal from the Raspberry Pi to control the motor's position. Power to the motor and its controller are provided from the power control unit. The motor will be a 90 degree servo motor with the default state preventing the pressure plate from activating.

Trap Control System Requirements:

1) The motor/solenoid arrangement must be subtle enough to not scare an animal away. This includes any noise from gears. This can be quantitatively accounted for when testing the trap, as this will affect the overall efficacy.
2) The motor control unit should not consume any power at idle while still effectively blocking the pressure plate.
3) The motor control unit should not consume any power in steady state while an animal is in the trap. The only use of power should be momentarily opening and closing the pressure-plate disable mechanism.

3.2.3. Power System and Power Control Unit:

The power system consists of an 18V battery, a DC-DC converter, and a power control unit. The 18 volt input must be converted to several different voltage levels, including 3.3 and 5 volts in a self-built DC-DC converter. The power control unit is able to switch power to all systems based on need parameters which include time of day and the proximity of an animal. The 18V battery is charged by whatever charger is supplied by the battery manufacturer. The charger is not a part of our device. This is desirable because our device does not rely on incompatible, proprietary technology. It is instead able to be used with commonly available consumer battery technology.

- DC-DC converter:

The 18 volt input must be converted to 5V and 7.5V. Most devices in our project run on 5V, with the exception of the camera, which runs on 7.5V. We will use a buck converter to reduce the voltage. The converter also serves as a voltage controller, outputting fixed voltages.

- Power Control Unit:

The power control unit takes the reduced voltage signal from the DC-DC converters and distributes it to the different components in the project. The power control unit distributes power to the PIR sensor, Analog night vision camera, daylight sensor, motor control unit, the A/D converter, and the Raspberry Pi. The power control unit will also incorporate TTL circuits to offload computation power from the raspberry pi.

Power Supply and Control Requirements:

1) The input to the entire system must be a commonly available 18V-20V tool battery. Brands of such batteries include Ryobi, Dewalt, and Milwaukee.
2) The power supply must be able to output the DC voltages needed by the Raspberry Pi (4.5W , the analog camera, and the sensors used. The logic will be run from the lowest of these voltages.
3) The power control system must switch power to the camera and the motor controller. This switching is controlled by the passive infrared sensor.

Above:
Example of a common 18V tool battery

3.2.4. Sensing System:

Our sensing system consists of three parts: a daylight sensor, a PIR sensor, and a night vision camera. The daylight sensor detects the ambient light. This is used to turn the device off during the day if desired. This function will conserve battery life when trying to catch nocturnal animals. The PIR sensor allows the camera and Raspberry Pi to idle when no animal is present near the trap. Once movement is detected, signals will be sent back to the power control unit to activate the night vision camera and to take the Raspberry Pi out of idle. Note that the state of the door does not have to be sensed. The door can only close if the pressure plate is triggered. This can only happen if the target animal is detected which unblocks the pressure plate.

- Security Camera:

A 300 x 380 analog pixel camera which outputs video to the RCA cable, the RCA cable is then hooked up to the RCA to USB converter which allows the image to be processed by the Raspberry Pi. The camera is weatherproof and contains low light infrared LEDs that allow the camera to work during the night. [4]

- Photocell Resistor:

For our sensor, we will use a CdS photoresistor. As the squiggly face is exposed to light, the resistance goes down. When the ambient light is brightest, the resistance is about 1kΩ. When there is little ambient light, the resistance is about 10kΩ. It will be connected to the power control unit. As shown in the simulations, our circuit model is able to tell the difference between night and day and therefore turn the entire system on or off. [5]

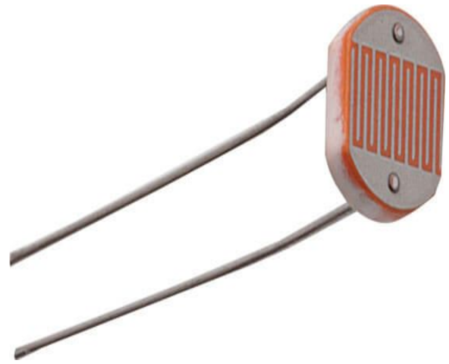
- Passive Infrared Sensor:

The PIR sensor is used to detect if a creature approaches the cage, and is connected to the power control unit to turn the system into a low power state whenever there are no creatures in the vicinity. The sensor works by detecting the infrared light emitted by the heat of animals or people passing through the detection area. The sensor outputs a pulse whenever movement is detected. The PIR sensor takes in a 5V input from the power control unit and outputs a signal back to the power control unit. [6]

Sensing System Requirements:

1) The passive infrared sensor should consume no more than 2mW. Preferably, it should consume less than 0.5mW. Operating voltage for the PIR sensor should be between 3.5V-5V.
2) A simple photocell will be used for daylight detection. The daylight sensing circuit should consume as little power as possible such that the main battery life goal can be achieved.
3) The analog night vision camera must only be turned on when the PIR sensor detects movement.
4) The analog night vision camera must have a minimum resolution of 240 pixels in any direction. The camera will likely have a square image because we intend to use one meant for security applications.

Above:
Example of a security type, low light, analog camera



Above:
Example of a photoresistor, to be used in the daylight sensing circuit

Above:
Example of a passive infrared sensor

4. Requirements & Verification Tables

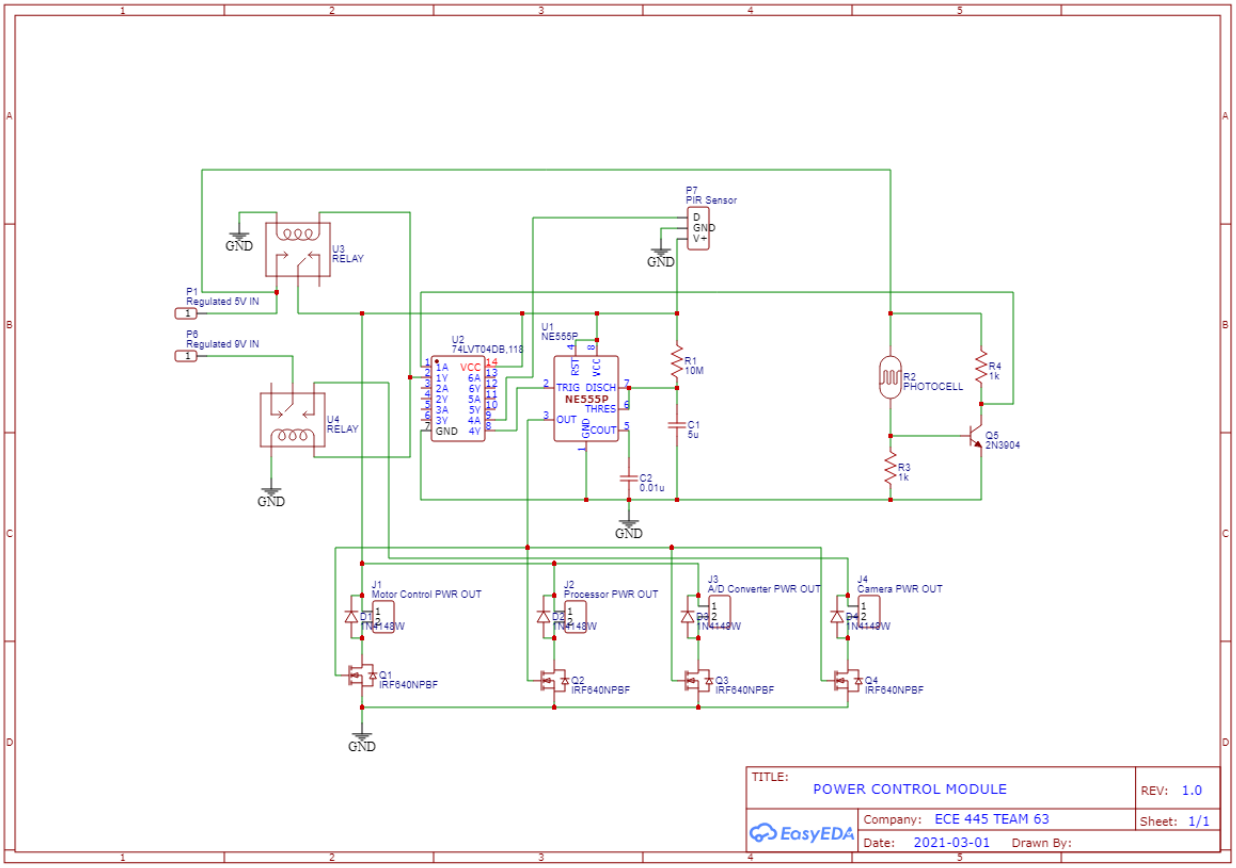
Requirements	Verifications
Trap should have a minimum of twelve hours of battery life.	1. Make sure the device has been optimized not to waste too much power on components like resistors by testing the circuit with different values. 2. Set the system on a low power state whenever it is daytime, and only have components like the daylight sensor draw power. 3. When it is nighttime, minimize power consumption by shutting down the camera unless the PIR sensor detects a creature. 4. Minimize power by having the camera shut down after 30 seconds if the detected creature was not a targeted creature.
The trap should make a decision within ten seconds of the animal entering the cage.	1. Optimize time it takes for the camera to turn on and start sending the image data when a creature is detected via the PIR sensor. 2. Optimize the machine learning algorithm to perform object detection in about 1-2 seconds per frame. 3. Optimize the machine learning algorithm to only take more frames from the image if the algorithm isn’t at least 90% certain that it is the targeted creature. 4. Minimize time it takes for the microprocessor to send the control signal to the motor control unit, thereby increasing the speed with which the trap can be activated. 5. Ensure that the servo motor used can rotate quickly.

The Motor Control Unit must be able to rotate the servo through its full range of motion (D roughly less than 10% and greater than 90%).	1. Verify ideal resistor values using LTSpice 2. Ensure that the pulse waveforms fall within the specifications of the servo motor 3. Test servo motor with a function generator to see which duty cycle and frequency will create the desired rotation 4. Compare the simulated waveforms and lab results and modify the simulated circuit as needed 5. Build the circuit on a breadboard and test with an oscilloscope to ensure that the proper outputs are achieved in hardware 6. Test the physical circuit with the servo to ensure full movement
The Power Control Module must be capable of switching power on to other components for one minute after receiving a pulse from the PIR sensor.	1. Simulate the circuit design in LTSpice and verify that the preliminary design can create a boolean true signal with a duration of one minute when an input pulse is received. 2. Record the resistor and capacitor values necessary for this behavior and source them for building the physical circuit. 3. Obtain the PIR sensor and measure the real output waveform. 4. Return to simulation and emulate the output from the PIR sensor. Ensure that the circuit still functions. 5. Build the circuit on a breadboard. Use the function generator as an input and measure the output. 6. Use the PIR sensor as an input to the circuit. Control the sensing environment with a box and excite the sensor. Ensure that the measured output pulse lasts for one minute.

The entire system should turn off during the day.	1. Simulate the light detecting circuit using LTSpice. Ensure that the sensing circuit can output a different boolean value when the light sensor is at its minimum and maximum resistance values. 2. Obtain the photoresistor and measure its actual resistance values during a typical night and typical day. 3. Return to simulation and adjust the circuit now knowing the real world values. Include a proper tolerance with reference to the measure values obtained in step two. 4. Build the circuit on a breadboard. Test the output using a resistor to emulate the photoresistor. 5. Now use the photoresistor. Use a battery to power the circuit, connect the output to an LED, and test it in outdoor environments. Ensure proper functionality. 6. Test the circuit to make sure that it can adequately power the relays which switch the main power to the device. If this approach consumes ample power, consider using MOSFETs instead.
The Power Control Module should control current to its child devices.	1. Find proper N-channel power MOSFETS that are capable of handling the required current at the rated voltage with a safety factor of at least two. Because the children devices are comparable, order a set of the same devices where the device is suitable for the highest current child. 2. The highest current child is the Raspberry Pi. Our initial choice for a throughhole MOSFET can handle 60 volts at 50 amps. It has a threshold voltage of 2 volts. This rating has a large safety factor, but the next smallest rating may not

	suffice for the Raspberry Pi. Adjustments can be made here, but due to low unit cost and likely durability, we will use these devices. 3. Create a circuit on a breadboard to bias the transistor into saturation. Verify the voltage between the gate and the source. 4. Now bias the device with 5V at the gate and ensure that the device functions as intended. If not, return to the schematic and add a resistor network to pull the voltage down. 5. Add a 0.5A load to switch. Test the circuit and ensure proper switching behavior. 6. Test the circuit using the analog camera as the load. Ensure functionality of the camera and the switching circuit. 7. Use the output of the power control module to switch the circuit, but use a dummy load. Ensure proper functionality. 8. Now use the power control unit as the input and the camera as the load. Ensure proper functionality. Continue steps 6-8 for each child device. 9. Finally, add switching circuits in parallel. Add them one by one and ensure proper functionality.

5. Schematics

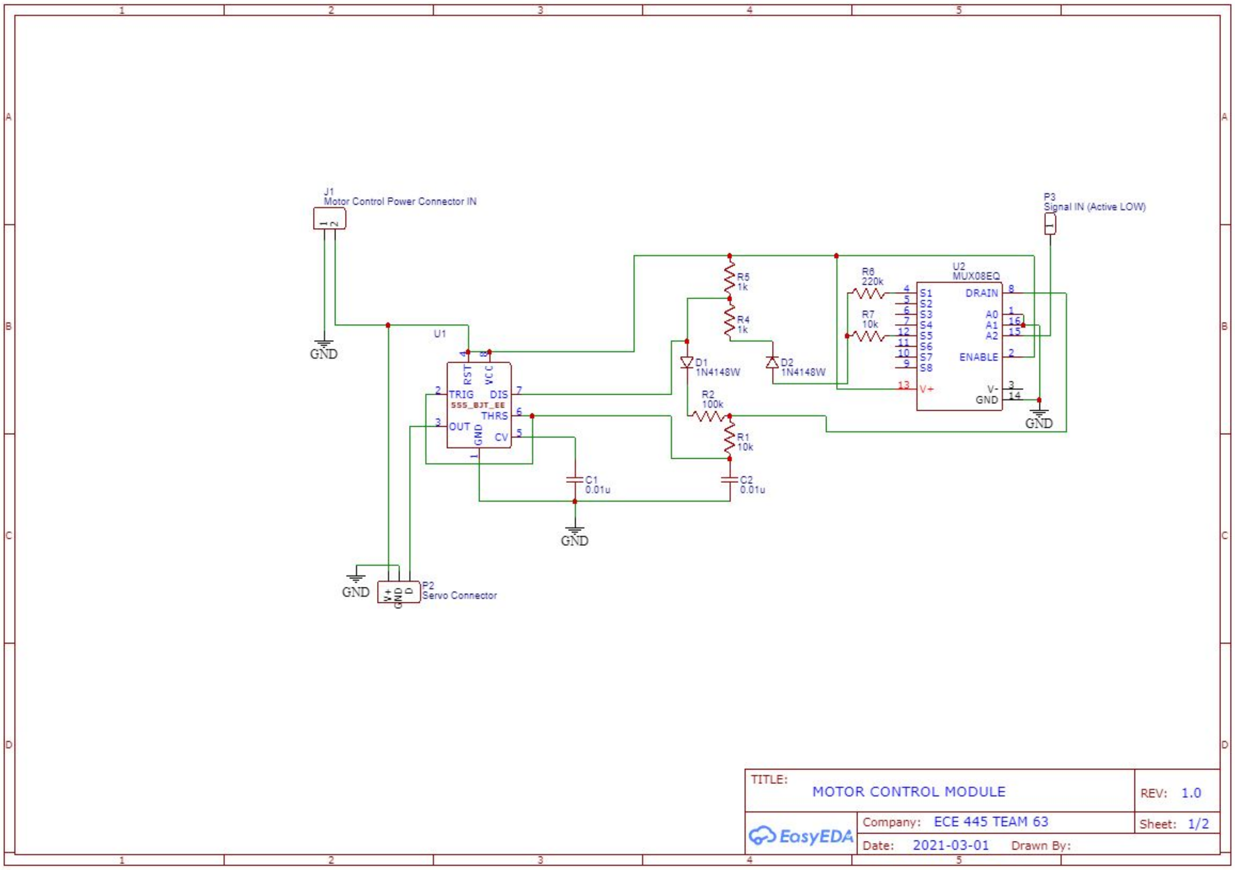


5.1. Power Control Schematic Explanation (Pictured Above)

The power control system has two main parts. One part is responsible for switching all power to the device depending on the time of day, which is measured by ambient light. The other part switches power to specific subsystems when the presence of an animal is detected. In the center of the schematic above, a 555 timer is used to extend the pulse length from the PIR sensor. In simulation, output pulse was measured at about 55 seconds. An inverter is used to change the positive pulse from the PIR sensor to a negative one.

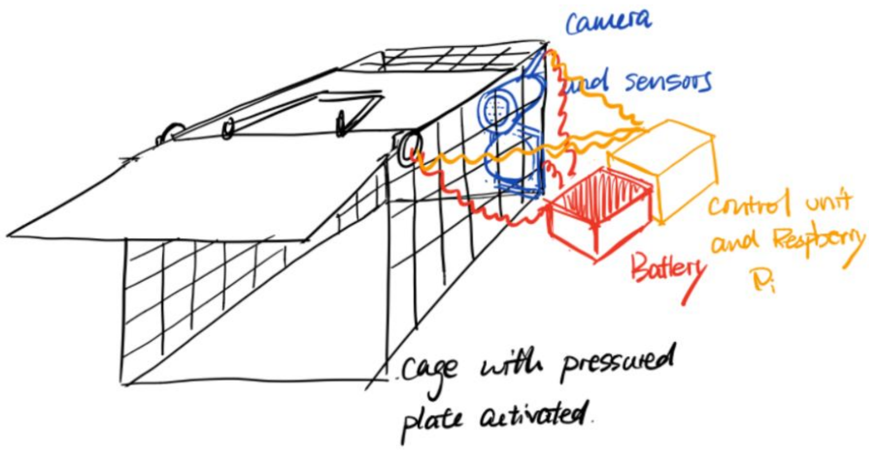
On the right hand side of the schematic, the arrangement can be seen for our light detector. We have not yet decided whether a BJT or MOSFET will be used, although simulations have been done with both. The output of this circuit is routed to the relays through the inverter.

At the bottom of the schematic, the arrangement of our power switching MOSFETs can be seen. The diode is placed across the power output in each case so that any residual current flow due to inductance can be dissipated in the devices and avoid harming the MOSFET.



5.2. Motor Control Schematic Explanation (Pictured Above)

The motor control system must move the position of the motor when the target animal is detected. On the top of the schematic, you can see the motor control power-in connector and the input from the Raspberry Pi. The Raspberry Pi selects which resistor will be used to control the duty cycle of the pulse waveform that is sent to the servo motor. A 555 timer is used to create a square wave, however the arrangement of resistors and diodes allows for controlling the length of each pulse. R6 and R7 should be thought of as a single variable resistor. All passive components in the network have an affect on the duty cycle and the frequency. So far, we have done many simulations to come up with this choice of values, but bench testing must be done to confirm that they will work in practice.



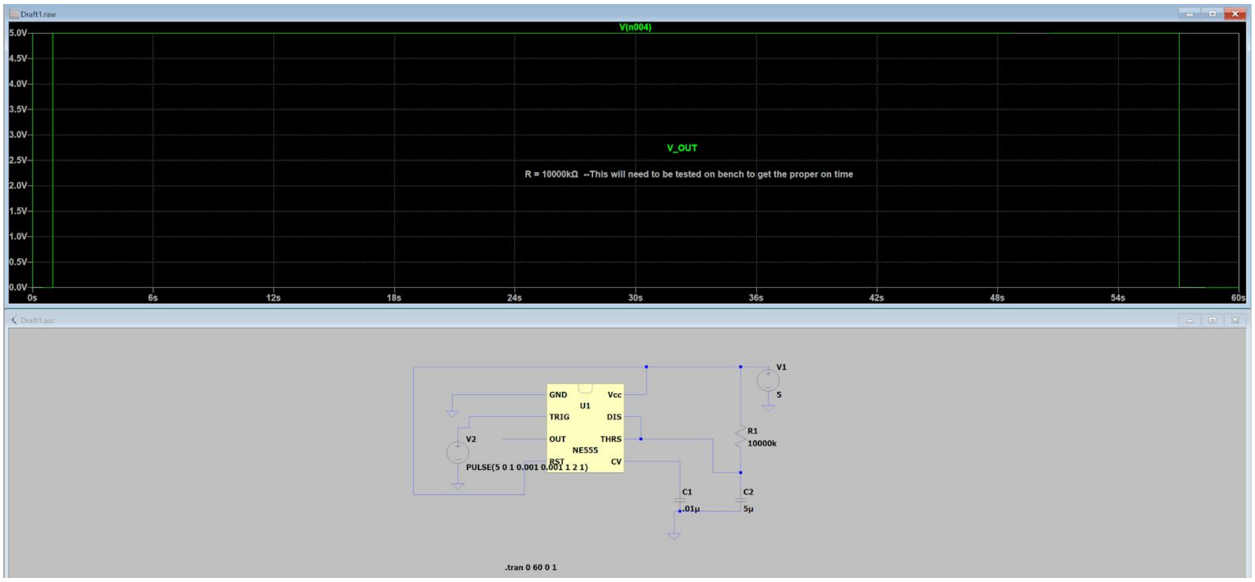
Above: Image of Smart Trap with Cage

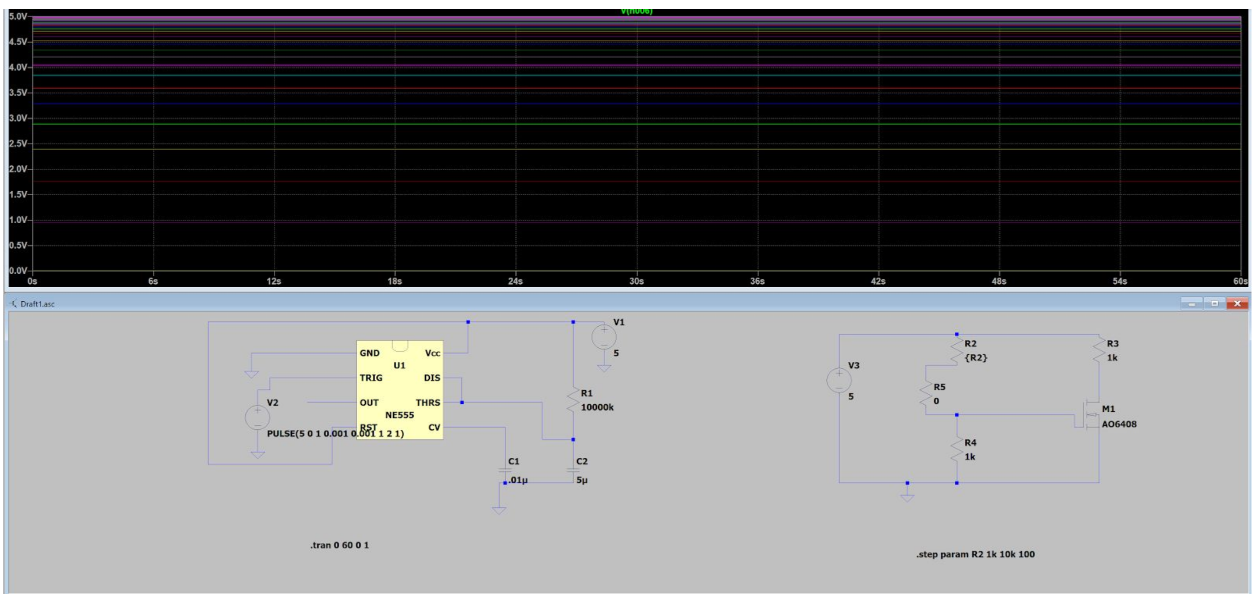
6. Calculations and Simulations

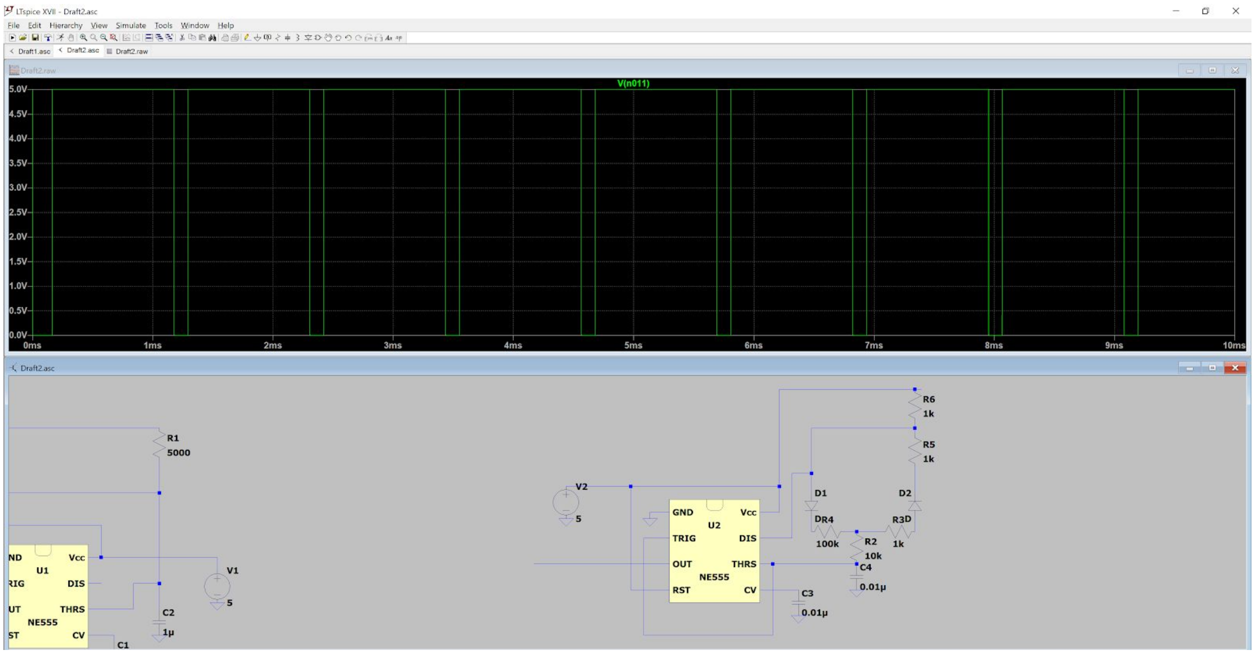
Below are two simulations of the power control module followed by two simulations of the motor control module. The topmost simulation shows that when the PIR sensor sends out a pulse, a logic one is output by the 555 timer for about 55 seconds. In practice, we will need to test this circuit on a bench to get the RC time constant correct. We should also take into consideration the non-idealities introduced by temperature since this product is designed to be used outdoors.

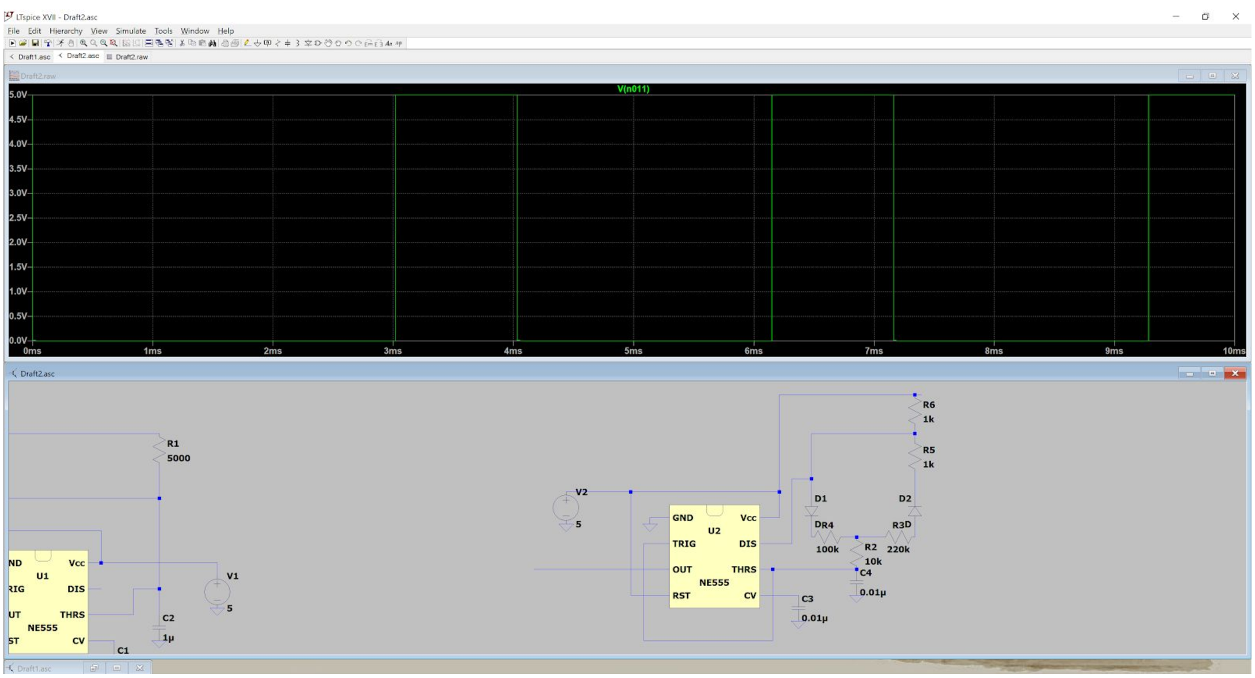
The second simulation shows that the light sensor sub-circuit can control main power to the entire device. The pull-down resistor may need adjustment depending on exactly which light conditions we desire for the on state, but we can find this by testing the photocell when it has arrived.

The third and fourth simulations show that the motor control circuit can create a pulse signal with adjustable duty cycle. One drawback of this circuit is that duty cycle adjustment also affects the frequency of the waveform. Real testing with our servo must be done to ensure that we get enough range of motion. The duty cycle of the waveform will be controlled by selecting between two resistors. The circuit that we use to select the resistor must be used when testing the servo angle. Semiconductor devices will likely affect the RC time constant which dictates the duty cycle of the output waveform. In our current schematic, we use a mux to choose between resistors. This may not work in practice, so a MOSFET arrangement may be better suited for resistor selection.

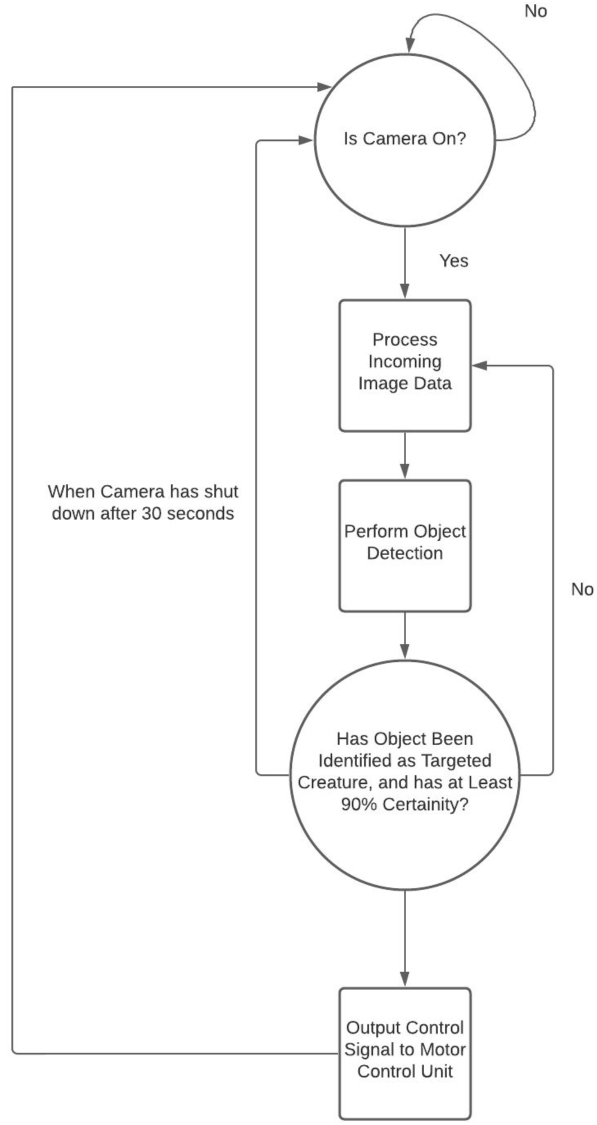

Draft1.raw
V(n004)
V_OUT
R = 10000kΩ --This will need to be tested on bench to get the proper on time
5.0V
4.5V
4.0V
3.5V
3.0V
2.5V
2.0V
1.5V
1.0V
0.5V
0.0V
0s
6s
12s
18s
24s
30s
36s
42s
48s
54s
60s
Draft1.asc
GND
U1
Vcc
TRIG
DIS
V2
OUT
THRS
NE555
RST
CV
PULSE(5 0 1 0.001 0.001 1 2 1)
V1
5
R1
10000k
C1
.01µ
C2
5µ
.tran 0 60 0 1


5.0V
4.5V
4.0V
3.5V
3.0V
2.5V
2.0V
1.5V
1.0V
0.5V
0.0V
0s
6s
12s
18s
24s
30s
36s
42s
48s
54s
60s
Draft1.asc
GND
U1
Vcc
TRIG
DIS
V2
OUT
THRS
NE555
RST
CV
PULSE(5 0 1 0.001 0.001 1 2 1)
V1
5
R1
10000k
C1
.01µ
C2
5µ
.tran 0 60 0 1
V3
5
R2
{R2}
R5
0
R4
1k
R3
1k
M1
AO6408
.step param R2 1k 10k 100


LTspice XVII - Draft2.asc
V(n011)
R1
5000
V2
R6
1k
R5
1k
D1
D2
R4
R3
100k
1k
R2
10k
C4
0.01µ
U2
NE555
C3
0.01µ
V1
5
C2
1µ
C1
U1
NE555


LTspice XVII - Draft2.asc
V(n011)
R1
5000
V2
R6
1k
R5
1k
D1
D2
R4
R3
100k
220k
R2
10k
C4
0.01µ
U2
NE555
C3
0.01µ
V1
5
C2
1µ
C1
U1
NE555

Software Flowchart For Raspberry Pi



7. Cost Analysis

Part #	MFT	Description	For	Price	Qty	Cost (total)
SC0073	Raspberry Pi Foundation	Raspberry Pi 3 B+	Microprocessor	$38.75	1	$38.75
95914	Bunker Hill Security	Weatherproof Color Security Camera With Night Vision	Analog Night Vision Camera	$29.99	1	$29.99
189	Adafruit	PIR Sensor	PIR Sensor	$9.95	1	$9.95
161	Adafruit	Photocell Resistor	Daylight Sensor (Sensing System)	$0.95	1	$0.95
1000012	DIGITNOW	RCA to USB 2.0	Analog to Digital Converter	$12.99	1	$12.99
1143	Adafruit	90 degree Servo Motor	Motor Control Unit	$9.95	1	$9.95
p197	Ryobi	18V battery	18V Battery	$42.95	1	$42.95
IPS-DTD12S510	IDEALPLUSING Technology	18V to 5V DC converter	18V-5V DC-DC Converter	$5.12	1	$5.12
LM317DCYR	Texas Instrument	18V to 9V DC converter	18V-9V DC-DC Converter	$0.64	1	$0.64
COM-16473 ROHS	Texas Instrument	555 Timer	Power Control Unit and	$0.95	2	$1.90

			Motor Control Unit			
IRFZ44PBF	Vishay/Siliconix	N-Channel Mosfet with 60V-50A rating	Power Control Unit	$1.61	5	$8.05
ALZN1F05W	Panasonic	5V DC Relay	Power Control Unit	$2.81	1	$2.81
ALZN1B09W	Panasonic	9V DC Relay	Power Control Unit	$2.69	1	$2.69
VR68000001005JAC00	Vishay/BC Components	10M Ohm resistor (plus or minus 5%)	Power Control Unit	$0.52	1	$0.52
MOS1CT528R102J	KOA Speer	1k Ohm resistor (plus or minus 5%)	Power Control Unit and Motor Control Unit	$0.10	4	$0.40
SF100JB-73-0K	Yageo	10k Ohm resistor (plus or minus 5%)	Motor Control Unit	$0.34	2	$0.68
HV-50FR-52-00K	Yageo	100k Ohm resistor (plus or minus 1%)	Motor Control Unit	$0.48	1	$0.48
SF100JB-73-20K	Yageo	220k Ohm resistor (plus or minus 5%)	Motor Control Unit	$0.34	1	$0.34
4GADUC450A0J	Kemet	5uF capacitor (plus or minus 5%)	Power Control Unit	$4.06	1	$4.06
100J15C0GFTL2	Vishay/BC Components	10pF capacitor (plus or	Power Control Unit and	$0.31	3	$0.93

		minus 5%)	Motor Control Unit			
B07KWY M922	HomGarde n	Animal Cage (Pressure Plate Activated)	All Systems	$38.99	1	$38.99
Total						$213.14

Total cost of the parts used is $213.14, with an estimated labor cost of 34$ an hour per person. For an average of 2.5 hours per week for 7 weeks (week7-week14) comes out to 595$ per person or $1785 for the three employees leading to a final cost of 1998.14$ total with the salary and cost of parts included.

8. Schedule

Week	Goals
Week 6 (2/28-3/6)	• Complete Design Document Draft for Design Check *(Whole Group)* • Complete Design Document Final Draft by 3/4 *(Whole Group)* • Order Parts *(Whole Group)*
Week 7 (3/7-3/13)	• Design Review on 3/9 *(Whole Group)* • Start implementing machine learning algorithm on laptop *(Vicky)* • Test circuit schematic for the DC-DC converter *(Christian)* • Test circuit schematic for the Power Control Unit *(Jonathan)* • Test circuit schematic for the photoresistor *(Jonathan)* • Test circuit schematic for the motor driver circuit *(Jonathan & Christian)* • Test circuit schematic for the passive infrared sensor *(Jonathan &Christian)* • Test circuit schematic for the camera/Digital Signal Processor *(Christian)*
Week 8 (3/14-3/20)	• Complete Eagle PCB designs of different circuits by 3/17 *(Whole Group)* • Teamwork evaluation due on 3/17 *(Whole Group)* • First PCB order due on 3/19 *(Whole Group)* • Simulation/Soldering assignment due on 3/20 *(Whole Group --Soldering)*
Week 9 (3/21-3/27)	• Begin to transfer machine learning algorithm onto Raspberry Pi *(Vicky)* • Interface the Raspberry Pi with video camera to begin machine learning trials *(Vicky)* • Second PCB order due on 3/26 *(Whole Group)*
Week 10 (3/28-4/3)	• Continue running machine learning trials *(Whole Group)* • Solder circuit schematic for the DC-DC converter *(Christian)* • Solder circuit schematic for the Power Control Unit *(Jonathan)* • Solder circuit schematic for the photoresistor *(Jonathan)* • Solder circuit schematic for the motor driver circuit *(Christian)*

	• Solder circuit schematic for the passive infrared sensor *(Christian)* • Solder circuit schematic for the camera/Digital Signal Processor *(Vicky)* • Start testing motor component on a pressure plate *(Whole Group)*
Week 11 (4/4-4/10)	• Individual progress report by ⅘ *(Whole Group)* • Third PCB order due on 4/6 *(Whole Group)* • Start testing on cat/RC car *(Whole Group)*
Week 12 (4/11-4/17)	• Make any last minute additions *(Whole Group)*
Week 13 (4/18-4/24)	• Mock demo *(Whole Group)*
Week 14 (4/25-5/1)	• Final demo *(Whole Group)*
Week 15 (5/2-5/6)	• Final paper due on 5/5 *(Whole Group)* • Lab checkout on 5/6 from 3:00-4:30pm • *(Whole Group)* • Lab notebook due on 5/6 *(Whole Group)* • 2nd teamwork evaluation due on 5/6 *(Whole Group)*

9. Tolerance Analysis

An important tolerance for this product is the time it takes for the animal to be detected and the trap to be set. Assuming the detection algorithm takes on average 2 seconds to process a frame, and there has to be a positive result with 90% accuracy in at least 2 frames to prevent a false flag, this means that it can take 4 seconds to 30 seconds to successfully detect the animal (camera shuts off after 30 seconds). This may or may not be acceptable depending on how long the animal stays in the cage. If there is bait, it seems more likely that the animal will be in the cage for 30 seconds. While things like propagation delays from the circuits also contribute towards the time delay, the detection algorithm is the bottleneck of the project. We aim to make this time ten seconds. It should be noted that the actual time to trap readiness is less important than our measured trap accuracy. The standard deviation of trap detection time might be large, and depending on the animal's behavior, the realized behavior of the trap may suffice. Optimizations can be made if the trap has often failures or a generally slow reaction time.

10. Ethics and Safety

A primary safety concern we have with our product is potential damage to the components from either animals or the weather, causing the circuit components to be exposed. We wish to address this by reinforcing the components to minimize likelihood of damage occurring. We may include the use of weatherproof connectors and enclosures.

Another safety concern is the safe handling of animals tested and trapped within the cage, and we will follow the USDA Animal Welfare Act and the NIH Public Health Service Policy as stated by Illinois Institutional Animal Care and Use Committee.

To prevent any kind of dangerous reactions occuring in our product and harming the customer, we decided not to incorporate hazardous or volatile materials in our project. All components we will use are consumer grade and can be purchased legally online.

Concerns regarding lab safety such as knowing what different warning symbols stand for is paramount for the success of our group constructing the product, so all group members have completed lab safety training according to the safety guidelines of UIUC.

11. Citations and References

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