# Bird-Friendly Electrochromic Windows

ECE 445 Design Document – Spring 2023

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Project # 48

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# Contents

# Introduction

## 1.1 Problem

Each year, roughly one billion birds in the U.S. die due to collisions with windows [1]. Even birds that are only temporarily stunned and fly away often die later due to bruising and internal bleeding in the brain or other vital organs. For some species such as the ovenbird, window collisions cause more fatalities than any natural predator [2]. During the day, windows often reflect the sky and outdoor foliage which can seem inviting to birds. Birds that see through the glass are frequently attracted to houseplants or other vegetation within the home. In the evenings the glass of windows becomes invisible to birds. Making matters worse, many nocturnal migrants (including most songbirds) are attracted to the artificial light in homes, pulling them off course, causing confusion, and significantly heightening their risk of a fatal window collision. For this reason nocturnal migrants have the highest rates of window collision fatalities. In the Spring months collision rates also rise due to territorial behavior in many species that can cause them to attack their own reflection in the glass.

Organizations like The BirdCast Project, the Fatal Light Awareness Program, and the American Bird Conservancy recommend several low cost solutions: installing netting or mosquito screens, one-way transparent film, tightly spaced decals or masking tape (the grid can be no larger than 4 x 2 inches with lines no smaller than ¼ inch), or tempera paint to the outside of your windows, while solutions such as hawk or owl silhouettes do little to deter bird-window collisions [3]. Unfortunately all of these solutions involve a significant and semi-permanent change to the aesthetic appeal of a building. Despite the benefits to local wildlife, many homeowners and architects are unwilling to make this compromise. Hence, a new solution is

needed to prevent bird-window collisions while maintaining the aesthetic appeal of large windows.

## 1.2 Solution

In response to this problem, we intend to make bird-friendly windows that prevent bird-window collisions while maintaining the aesthetic appeal of large windows. The essential concept is to make birds aware of the presence of a hazard before a collision occurs, giving the birds time to react and change course. Our design relies on electrochromic glass, a material that can transition between transparent and opaque depending on the voltage applied across it. At rest, the electrochromic panels will be in a transparent state. Our system is designed to detect a bird's approach using ultrasonic sensors and image processing. The ultrasonic sensors are attached to a frame, which extends a sufficient distance from the window to detect and react to a bird early enough to allow a direction change. When a bird is detected by either the ultrasonic sensors or the image processing, the electrochromic panels will transition to or remain in an opaque state, making the birds aware of the hazard in front of them. This system should allow birds to respond to windows as a hazard and avoid potentially fatal collisions.

### 1.3 Visual Aid

To detect birds approaching the windows, we will be using ultrasonic sensors. The ultrasonic sensors have a 15 degree angle of detection and are pointed across the sides and front of the frame, such that any bird entering the area in front of the window must pass through one of the areas read by the ultrasonic sensor. The ultrasonic sensors are connected to the microcontroller, which times the delay between sending out a pulse and receiving the echo. By dividing the time it takes the ultrasonic sensor to return an echo by the speed of the ultrasonic wave, our microcontroller can determine the distance from the ultrasonic sensor to the object immediately in front of it. Our threshold distance will be the distance from the side of the frame where the electrochromic panels are mounted to the side of the frame where two ultrasonic sensors are mounted pointing vertically down. If the microcontroller computes a distance from one of the ultrasonic sensors that is less than the threshold distance, it follows that another object entered the area immediately in front of the window. The microcontroller then tells the Raspberry Pi to initiate image processing using the thermal camera to determine whether the object detected by the ultrasonic sensors is a bird. If the object detected is a bird, the Raspberry Pi will continue to track the object's location relative to the frame and tell the microcontroller to turn the correct electrochromic panel opaque based on the bird's location. If the object detected is determined not to be a bird or the bird leaves the area, the system will return to a rest state (all electrochromic panels will be transparent). The frame holds four electrochromic panels in a square arrangement, and an ultrasonic sensor is mounted in the center of each side of the square. There are also two additional ultrasonic sensors directed downwards across the front of the frame as mentioned previously. The thermal camera is mounted at the center of the electrochromic panel configuration as shown below.xxs

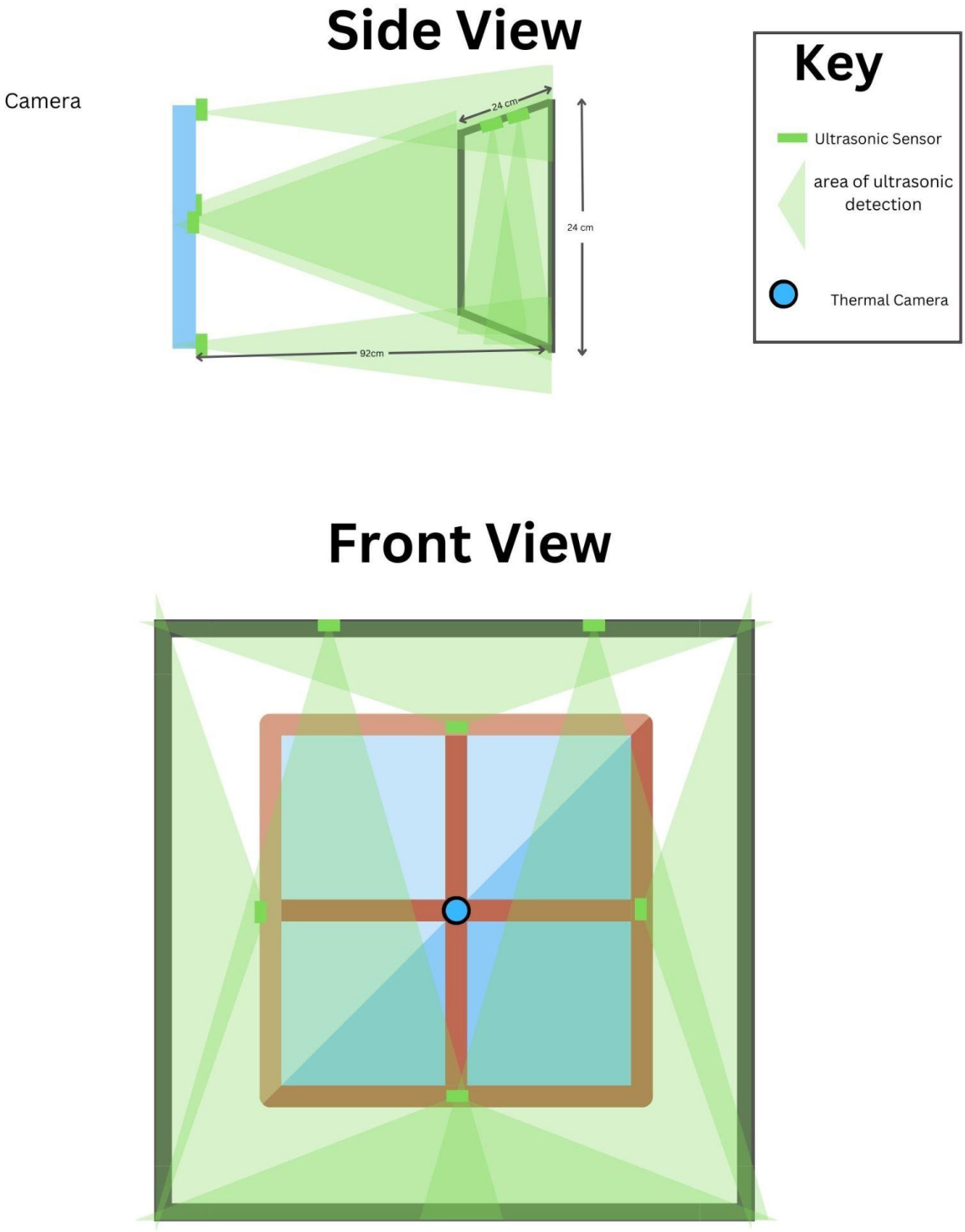


Figure 1: Our proposed arrangement of panels and sensors to avoid bird-window collisions

### 1.4 High Level Requirements

To consider our project successful, our window system must fulfill the following:

- When the system is at rest, the panels must be kept in their transparent state. The system is considered at rest before a bird is detected or after a bird has exited.
- The system must be able to successfully detect an object of length ≥ 11 cm and width ≥ 19 cm (minimum length and wingspan of the seven birds with the highest rates of window collisions) entering or exiting through the front of the 24 cm x 24 cm x 58 cm rectangular prism encompassed by the frame traveling at 7.6 m/s or less in ≥ 80% of trials.
- When the system determines that an object has been detected entering the frame-encompassed area, it must successfully transition one or more of the electrochromic panels from transparent to opaque.

These requirements are based on several key assumptions based on our research:

1. The majority of fatal bird-window collisions are head-on.
2. The system will only have to consider one bird entering or exiting the system at a time.
3. Our system is designed to protect the seven species most likely to experience fatal bird-window collisions, not every shape, speed, and variety of bird. According to our research, the bird species at highest risk cannot fly upside down or perpendicular to the ground.

While these assumptions are slight simplifications of the system, we believe they are reasonable given the context and size of our proposed application.

# Design

## 2.1 Physical Design

Each of our electrochromic panels is 10 cm by 10 cm. The model we ordered is an easy to apply “peel and stick” with an adhesive on one side which we can attach to the frame. To ensure that there is sufficient overlap between the electrochromic panels and the frame we will make each opening of Frame Part 1 8 cm by 8 cm so that 1 cm of adhesive can be used to attach the panels to the frame along each side. The central beams in the horizontal and vertical direction of Frame Part 1 are each 2 cm wide, and the outer beams of Frame Part 1 are 3 cm wide. Frame Part 2 is a simple rectangular frame with a width of 3 cm. The four ultrasonic sensors attached to Frame Part 1 are mounted such that they face forward and align with the center of each side of the square. The ultrasonic sensors attached to Frame Part 2 are centered 6 cm away from the inner edge of the frame and each other.

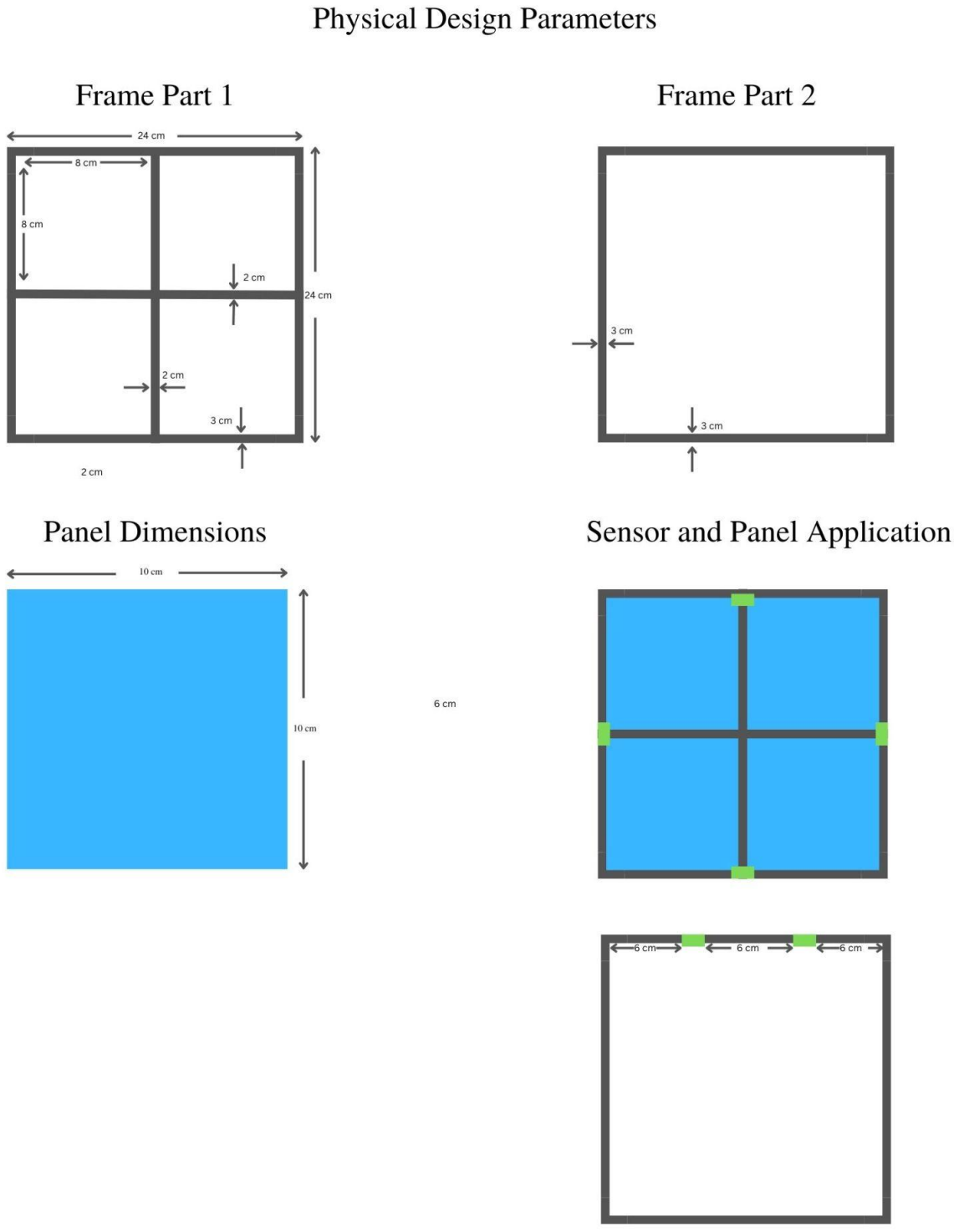


Figure 2: The physical dimensions of our system

## 2.2 Block Diagram

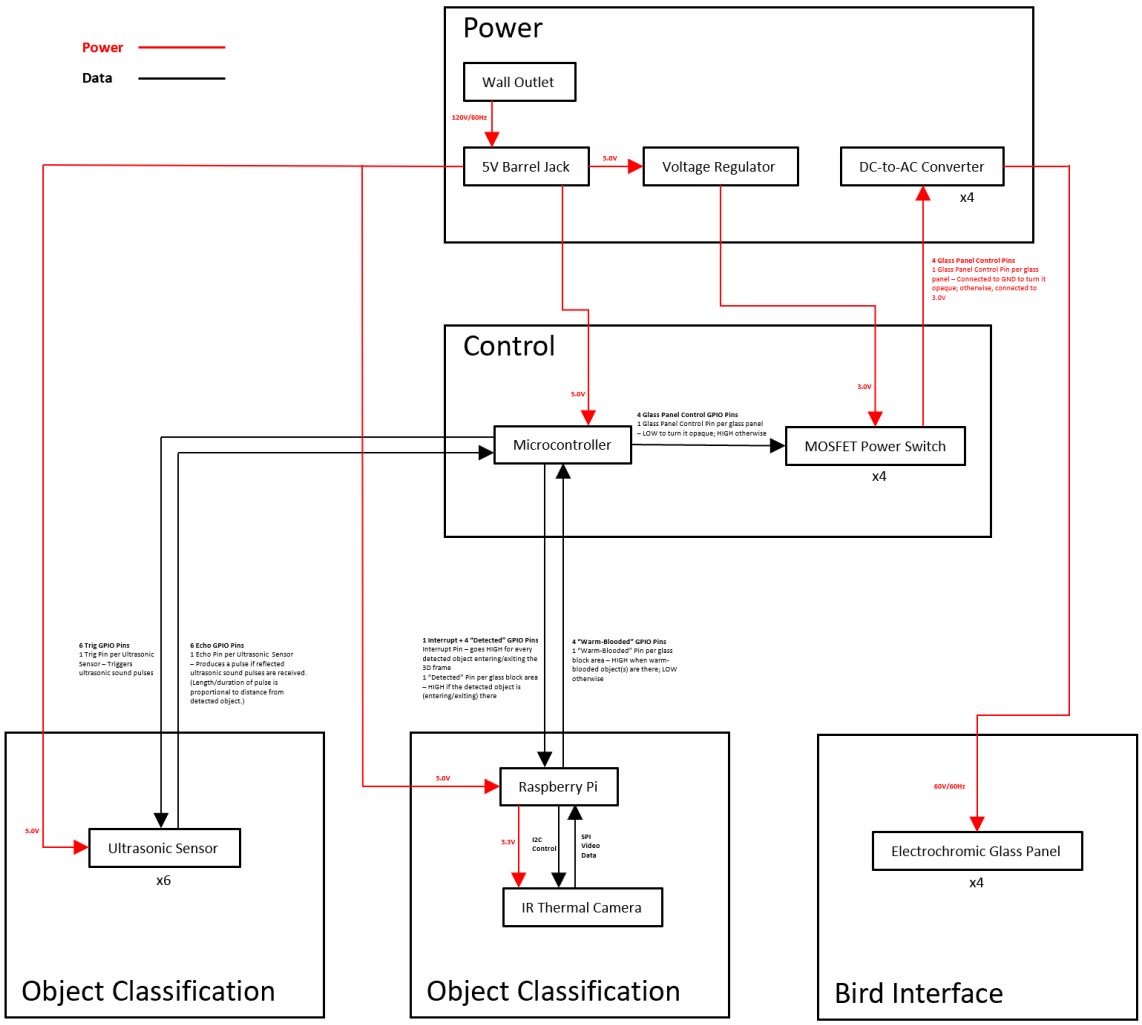


Figure 3: Block Diagram

## 2.3 Functional Overview and Block Diagram Requirements

### 2.3.1 Control Subsystem

The Control System is responsible for interacting with the ultrasonic sensors in the Object Detection Subsystem, the Raspberry Pi in the Object Classification Subsystem, and the electrochromic panels in the Bird Interface Subsystem. It controls the trigger input to each of the ultrasonic sensors and calculates the distance detected by each ultrasonic sensor based on the echo output. If an object is detected going into the 3D frame, the microcontroller signals the

Object Classification System to turn on the IR Thermal Camera, with a focus on the block(s) where the object was detected as entering. Making the control system responsible for initiating our image processing helps determine whether we need our IR thermal camera and real-time video processing to be running at any given time. Since the Control System also supplies the Image Processing System with information on which ultrasonic sensor detected a change in distance, this setup also helps more specifically identify where the entering object should be within the 2D thermal frames of our IR camera. The Control Subsystem also receives information from the Object Classification Subsystem on which electrochromic panels have warm-blooded objects in front of them. Based on this classification information, the Control Subsystem can signal the Bird Interface Subsystem about which electrochromic panels should be opaque. The Control Subsystem consists of the ATMega32U4-MU microcontroller.

| Requirement | Verification |
| --- | --- |
| The control subsystem must be able to calculate distances correctly based on input from the ultrasonic sensors. For measured distances below 20 cm, the accuracy of the calculated distances should be within 5 cm. For measured distances between 20-60 cm, the accuracy of the calculated distances should be within 10 cm. These standards should be met in 90% of trials. | We will place objects at known distances from the ultrasonic sensors and compare the calculated distance with the distance measured in the lab. |

| | |
|---|---|
| The control subsystem must be able to signal to the electrochromic panels to change opacity once an object is detected. I/O pins controlling the opacity should transition to a high voltage (2.7-5.5 V) and low voltage (0-2.75 V) correctly in 90% of trials. | The changes in opacity can be observed visually by the experimenter.<br>I/O pin values will be measured using one of the multimeters provided in lab |
| The control system must be able to initiate image processing in the Raspberry Pi. The interrupt pin of the microcontroller feeding into the Raspberry Pi must go high (2.7-5.5 V) when an object is detected in 90% of trials. | The voltage output by the interrupt pin of the microcontroller feeding into the Raspberry Pi will be measured using either one of the multimeters or oscilloscopes provided in the Senior Design Laboratory, depending on the speed of the system's response. |

### 2.3.2 Object Detection Subsystem

The Object Detection Subsystem is responsible for detecting where warm-blooded animals have entered or exited the 3D frame in front of the electrochromic panels. This subsystem consists of 6 ultrasonic sensors which communicate with the Control Subsystem via the trigger-echo protocol. (See Figure 1 for where the ultrasonic sensors are placed along the 3D frame). When the Control Subsystem sets the trigger pin to HIGH, the corresponding ultrasonic sensor would send out 8 ultrasonic pulses. The ultrasonic sensor would then utilize its echo pin to signal to the Control Subsystem how long it took for the pulse signals to be reflected back from (detected) objects within their (2-400 cm) beam range. Using the time between when the ultrasonic sensors emitted their pulse and the time the pulse was reflected back, we can divide by

the known speed (343 m/s) at which the pulse traveled, to determine the distance between the sensor and the closest object in front of it.

| Requirement | Verification |
|---|---|
| For measured distances below 20 cm, the accuracy of the calculated distances should be within 5 cm of the of the measured distance in ≥ 90% of trials. For measured distances between 20-60 cm, the accuracy of the calculated distances should be within 10 cm in ≥ 90% of trials. | We will place objects at known distances from the ultrasonic sensors and compare the calculated distance with the distance measured in the lab. |
| The ultrasonic sensors must be mounted on the frame in such a way that they can accurately determine which electrochromic panel zones the detected objects are entering/exiting within the 3D frame area in ≥ 90% of trials. | For each 24 cm x 58 cm side of the 3D frame, we will place objects in the unique plane of the given sensor's area of detection and confirm that no other sensors have detected a distance below their programmed threshold. For the 24 cm x 24 cm side, we will place objects in each of the 9 electrochromic panel combinations (4 for each panel individually, 4 potential pairs along each side of the frame, 1 combination for when an object is detected in |

| | |
|---|---|
| | the center of the frame with overlap across all four panels) and confirm that each of these combinations can be identified uniquely. |

### 2.3.3 Object Classification Subsystem

The Object Classification Subsystem is used to determine whether a detected object has entered or exited the 3D frame and whether the objects that entered the 3D frame are warm-blooded or not. It receives signals from the Control Subsystem on where objects have entered or exited the 3D frame, in terms of the 2 x 2 electrochromic panel grid. It then keeps track of which electrochromic panels the warm-blooded objects are in front of, and sends this information to the Control Subsystem. The subsystem includes an IR Thermal Camera and a Raspberry Pi. The Raspberry Pi controls the IR Thermal Camera via the I2C communication protocol, and receives video data through the SPI communication protocol, for video processing/warm-blooded object classification.

For the object classifications subsystem, we have two components: the Raspberry Pi 3 Model B+ processor and the IR camera. The current B+ model that we are using requires 5 V and 3A DC for a power supply. This translates to 15 W of DC Power. For the thermal camera model we are using from the provided ECE 445 parts inventory, the operating power is 150mW [4].

| Requirement | Verification |
|---|---|
| The image processing can correctly identify warm blooded objects within the 24 cm x 24 | During the debugging phase, we will use the LED on the Raspberry Pi to determine when |

| | |
|---|---|
| cm x 58 cm frame space in ≥ 80% of trials. | the system believes it has identified a warm-blooded object in the frame space, and can verify whether such an object is actually present via inspection. |

### 2.3.4 Bird Interface Subsystem

The bird interface subsystem consists of four 10 x 10 cm panels of electrochromic glass. This translates to 0.4303 square feet, which is approximately 160 mW. The electrochromic glass will turn opaque given a 60V/60Hz AC voltage, which will be driven by the control subsystem.

| Requirement | Verification |
|---|---|
| The opacity must visibly transition between transparent and opaque in response to the microcontroller. | Opacity changes can be easily confirmed via visual inspection. |

### 2.3.5 Power Subsystem

Our power system contains two primary components. The first is a barrel jack power supply connecting our PCB to a wall outlet and supplying a constant 5V to the microcontroller, Raspberry Pi, ultrasonic sensors, and voltage regulator. The second primary component is the voltage regulator we use to step down from 5V to 3V. The DC to AC converters feeding our

electrochromic panels take the 3V output of the regulator. There is an additional voltage regulator within the Raspberry Pi that supplies our IR camera with 3.3V.

| Requirement | Verification |
|---|---|
| The barrel jack power supply must provide a steady 4.5-5.5 voltage at all times the system is operating. | We can confirm that the output of our barrel jack is within the acceptable range using a multimeter. |
| The voltage regulator must supply a DC input voltage 2.5-3.5V to the DC to AC converters feeding into the electrochromic panels at all times the system is operating. | We can confirm the output of our voltage regulator is within the acceptable range using a multimeter. |

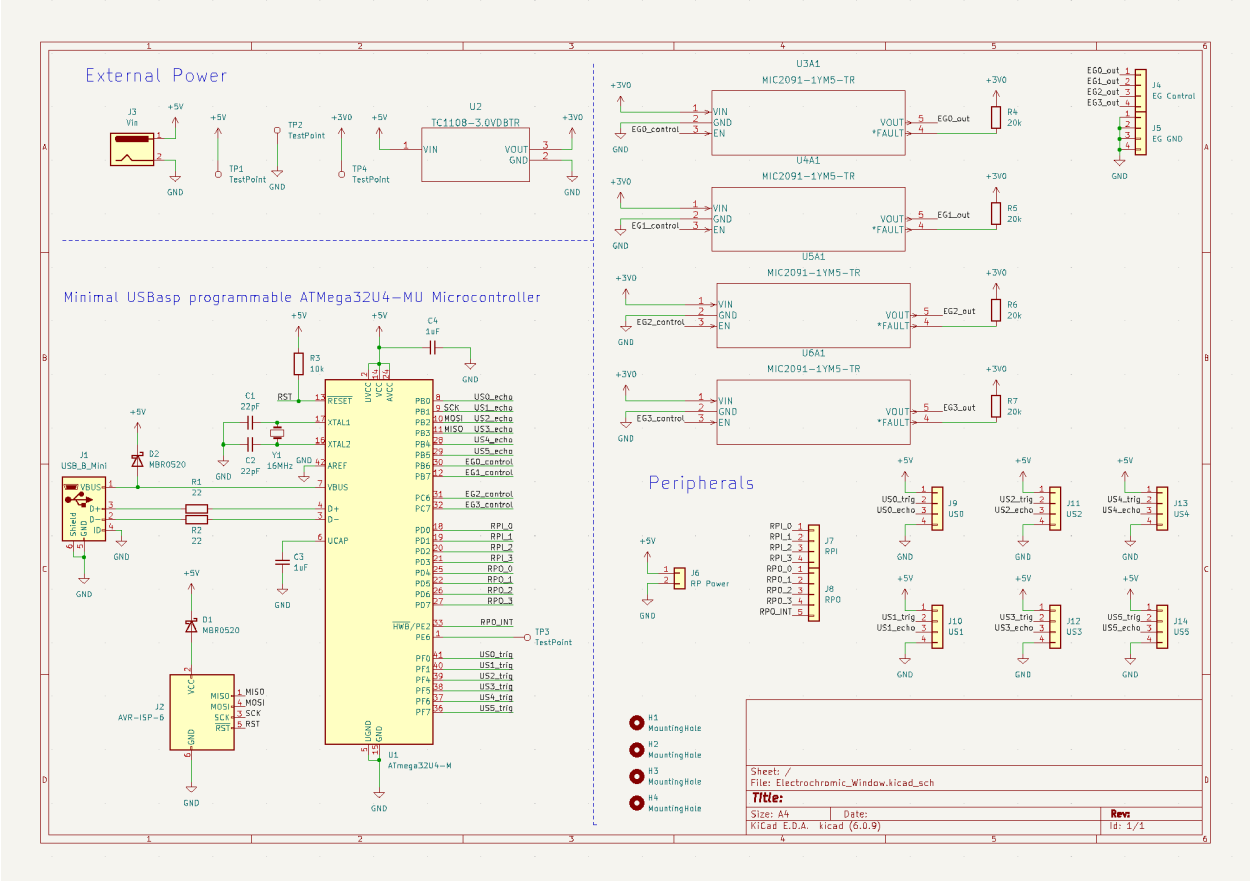


Figure 4: PCB Schematic

## 2.4 Tolerance Analysis

It is important that the system not only responds to the presence of approaching birds but also allows sufficient time for the birds to react and change course. In a study involving starlings (Sturnus vulgaris), researchers found that the mean reaction time of the birds to light stimuli was 76.38 ms [7]. Since starlings are nocturnal migrants of approximately the same size and speed as the seven bird species with the highest rates of window collisions, this reaction time offers a good approximation for our purposes. The most common victim of window collisions is the white-throated sparrow [2]. While there is little available data on the flight speed of white-throated sparrows, the flight speed of Song Sparrows, a close relative [8], was measured at

17 mph (7.6 m/s) [9]. These numbers indicate that in the time it takes a bird to recognize a hazard it will continue traveling forward another 0.58 m. Researchers studying bird flocking behavior have observed that birds are able to make fast, hairpin turns in less time than it takes for them to travel the length of their own body [10]. Our system must therefore be able to detect an approaching bird from 58 cm away in order to effectively prevent collisions.

### 2.5 Cost Analysis

Since we are seniors in electrical and computer engineering at UIUC, we believe a realistic estimated approximate cost per hour of labor is $45/labor. Including the soldering of components, the programming of communication between the microcontroller and Raspberry Pi, the image processing of the thermal camera images, the integration of the UV sensors and electrochromic panels, we believe that the total amount of labor will be 150 hours. This comes out to $6750 for labor and an additional $143.98 for materials (excluding the Lepton Thermal Camera Breakout) as detailed in the table below.

| **Description** | **Manufacturer** | **Quantity** | **Total Price** | **Links** |
|---|---|---|---|---|
| 22pF Capacitor | KYOCERA AVX | 2 | $0.20 | https://www.digikey.com/en/products/detail/kyocera-avx/06035A220JAT2A/563277 |

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| 1uF Capacitor | TAIYO YUDEN | 2 | $0.30 | https://www.mouser.com/ProductDetail/TAIYO-YUDEN/EMK107B7105MA8T?qs=DPoM0jnrROXUU71CJc1ypA%3D%3D |
| MBR0520 Diodes | Micro Commercial Co | 2 | $0.40 | https://www.digikey.com/en/products/detail/micro-commercial-co/MBR0520-TP/717250 |
| USB Mini-B Connector | Tensility International Corp | 1 | $1.32 | https://www.digikey.com/en/products/detail/tensility-international-corp/54-00023/6056085 |
| IDC Connector Header for AVR-ISP-6 | Wurth Elektronik | 1 | $0.48 | https://www.digikey.com/en/products/detail/612000621621/732-5394-ND/4846913?itemSeq=363606694 |
| Barrel Jack Connector | Wurth Elektronik | 1 | $1.02 | https://www.digikey.com/en/products/detail/w%C3%BCrth-elektronik/694106301002/5047522 |

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|---|---|---|---|---|
| 1x4 Molex Connectors (EG Control, EG Gnd, RPI, US0…5) | Molex | 9 | $3.15 | https://www.digikey.com/en/products/detail/molex/0022232041/26671 |
| 1x2 Molex Connector (RP Power) | Molex | 1 | $0.21 | https://www.digikey.com/en/products/detail/molex/0022232021/26667 |
| 1x5 Molex Connector (RPO) | Molex | 1 | $0.41 | https://www.digikey.com/en/products/detail/molex/0022232051/26673 |
| 22Ohm Resistors | Bourns Inc | 2 | $0.20 | https://www.digikey.com/en/products/detail/bourns-inc/CR0805-JW-220ELF/3785269 |
| 10k Resistor | YAGEO | 1 | $0.10 | https://www.digikey.com/en/products/detail/yageo/RC0603JR-0710KL/726700 |
| Atmega-32u4-m | MICROCHIP | 1 | $4.92 | https://www.microchipdirect.com/product/ATMEGA32U4-MU |

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| TC1108-3.0VDBTR | Microchip Technology | 1 | $0.70 | https://www.mouser.com/ProductDetail/Microchip-Technology/TC1108-3.0VDBTR?qs=3huTxzs8ogpmjE9g347POQ%3D%3D |
| MIC2091-1YM5-TR Power Distribution Switches | Microchip Technology | 4 | $1.04 | https://www.digikey.com/en/products/detail/microchip-technology/MIC2091-1YM5-TR/2650461 |
| 20kOhm Resistors | YAGEO | 4 | $0.40 | https://www.digikey.com/en/products/detail/yageo/RC0603JR-0720KL/726740 |

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|---|---|---|---|---|
| 16MHz Crystal | Abracon LLC | 1 | $0.36 | https://www.digikey.com/en/products/detail/abracon-llc/ABLS7M2-16.000MHZ-D2Y-T/5135076?utm_adgroup=Crystals%2C%20Oscillators%2C%20Resonators&utm_source=google&utm_medium=cpc&utm_campaign=Shopping_Supplier_Abracon_8154_Co-op&utm_term=&utm_content=Crystals%2C%20Oscillators%2C%20Resonators&gclid=Cj0KCQiAgaGgBhC8ARIsAAAyLfF1LtZbe1qPwJ52YWdBHE8G4wsnlL2s_J8pNc23KzpcZjPKDCo49WMaAt2KEALw_wcB |

| **Description** | **Manufacturer** | **Quantity** | **Total Price** | **Links** |
|---|---|---|---|---|
| Ultrasonic Distance Sensor - HC-SR04 | Adafruit Industries LLC | 6 | $23.70 | ECE Supply Center |

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|---|---|---|---|---|
| 32 GB SD Card (for Raspberry Pi) | SanDisk | 1 | $7.49 | ECE Supply Center |
| Thermal Camera (Lepton Thermal Camera Breakout) - KIT-13233 ROHS | FLiR | 1 | (Retired Product) | https://www.sparkfun.com/products/retired/13233?_ga=2.27298555.634401702.1599046628-470002576.1598427502 |
| Raspberry Pi - Raspberry Pi 3 Model B+ | Raspberry Pi | 1 | $35 | https://www.raspberrypi.com/products/raspberry-pi-3-model-b-plus/ |
| Raspberry Pi Power Supply | Raspberry Pi | 1 | $19.99 | https://www.raspberrypi.com/products/raspberry-pi-universal-power-supply/ |

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| Electrochromic Windows - HOHOFILM 10cmx10cm Smart Film PDLC Magic Switchable Transparent Color Film | HOHOFILM | 4 | $34.44 | https://campaign.aliexpress.com/wow/gcp/tesla-pc-new/index?UTABTest=aliabtest375881_486351&src=google&aff_fcid=9ccae7f5b2c74900b3bf7519ed3d0b8c-1676434714495-09614-UneMJZVf&aff_fsk=UneMJZVf&aff_platform=aaf&sk=UneMJZVf&aff_trace_key=9ccae7f5b2c74900b3bf7519ed3d0b8c-1676434714495-09614-UneMJZVf&terminal_id=373facf98a2a44648c3e707e85341d01&wh_weex=true&wx_navbar_hidden=true&wx_navbar_transparent=true&ignoreNavigationBar=true&wx_statusbar_hidden=true&bt_src=ppc_direct_lp&scenario=pcBridgePPC&productId=2255800182531405&OLP=1084300508_f_group2&o_s_id=1084300508 |

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| MTA-100 2 Pin Connector | TE Connectivity AMP Connectors | 2 | $0.44 | https://www.digikey.com/en/products/detail/3-640440-2/A31080-ND/698278?itemSeq=373904068 |
| MTA-100 4 Pin Connector | TE Connectivity AMP Connectors | 18 | $4.86 | https://www.digikey.com/en/products/detail/te-connectivity-amp-connectors/3-640440-4/698280 |
| MTA-100 5 Pin Connector | TE Connectivity AMP Connectors | 2 | $0.78 | https://www.digikey.com/en/products/detail/te-connectivity-amp-connectors/3-640440-5/698281 |
| Barrel USB Power cable | Grid Connect Inc | 1 | $14.95 | https://www.gridconnect.com/products/usb-power-cable?variant=8999272480804&utm_term=&utm_campaign=Shopping+-+Desktop&utm_source=adwords&utm_medium=ppc&hsa_acc=7986939350&hsa_cam=18566303751&hsa_grp=147887861968&hsa_ad=6 |

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| USBASP Programmer with Adaptor | SparkFun Electronics | 1 | $18.50 | https://www.digikey.com/en/products/detail/sparkfun-electronics/PGM-09825/5230949?utm_adgroup=Programmers%2C%20Emulators%2C%20and%20Debuggers&utm_source=google&utm_medium=cpc&utm_campaign=Shopping_Product_Development%20Boards%2C%20Kits%2C%20Programmers_NEW&utm_term=&utm_content=Programmers%2C%20Emulators%2C%20and%20Debuggers&gclid=Cj0KCQiAutyfBhCMARIsAMgcRJRPpAemAkRxwASHy6gMGvCSvEiDH6yz1RgAQpy34L_QsDvdpn-9uA4aAq6_EALw_wcB |
| USB A to USB Mini-B Cable | Monoprice | 1 | $1.49 | https://www.monoprice.com/product?p_id=107&utm_term=&utm_campaign=PMax:+Smart+Shopping+-+Monoprice+-+Cables&utm_source=googl |

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| Lux Meter | Cheffort | 1 | $19.95 | https://www.amazon.com/dp/B0824HBV3G?psc=1&ref=ppx_yo2ov_dt_b_product_details |

## 2.6 Schedule

| **Weeks** | **Actions** |
|---|---|
| **February 26th - March 4th** | Mary Rose: Submit final documentation to the Machine Shop |

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|---|---|
| | Phoebe: Algorithm and Image Processing Library Research<br>Owen Thamban: Raspberry Pi/Microcontroller communication protocol research |
| **March 5th - March 11th** | Owen: Submit PCB Order |
| **March 12th - March 18th** | Mary Rose: Pick up Electrochromic Panels and attach to frame<br>Mary Rose and Phoebe: Draft Initial Version of Bird Recognition Software<br>Owen: set up communication between microcontroller and Electrochromic glass |
| **March 19th - March 25th** | Owen: Frame Assembly<br>Mary Rose and Phoebe: Test and Debug Bird recognition software with other objects of similar temperature |
| **March 26th - April 1st** | Mary Rose and Owen : Solder microcontroller and other components onto PCB<br>Phoebe: Test and debug bird recognitions software, optimize |
| **April 2nd - April 8th** | Initial Unit Testing:<br>Mary Rose: Object Detection, Bird Interface Subsystem |

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| | Phoebe: Bird Recognition Testing<br>Owen: Initial Total System Testing |
| **April 9th - April 15th** | Final System Testing:<br>Mary Rose: Ultrasonic Sensors and Response Time of Ultrasonic Sensors<br>Owen: Electrochromic Panel Response Time<br>Phoebe: Image Processing can distinguish between birds and other similar sized objects within adequate time window |
| **April 16th - April 22nd** | Mock Demo (all members) and Final Revisions based on TA feedback |

## 2.7 Risk Analysis

The primary goal of our system is to preserve and protect wildlife to the greatest extent possible by balancing efficacy with ease of adoption. While our research indicates that the strategy behind our system (making the bird aware of the presence of a hazard) is likely to be effective, we believe at the very least it should pose no significant additional safety risks to wildlife or humans. In order to remain effective, our system must respond within a sufficiently small amount of time to give the bird time to respond. The greatest challenge in mitigating our response time is processing the images that are captured by the thermal camera efficiently. To decrease this risk, we will turn the corresponding electrochromic panels opaque upon detection of an object by the ultrasonic sensor and return the electrochromic panels to their transparent

state only after our Image Classification Subsystem has confirmed that there is not a bird present in a given area of the system. This way, our system is still able to distinguish between birds and other objects but the response time is significantly reduced.

# 3 Ethics and Safety

Overall, our proposed solution poses minimal safety concerns to humans or wildlife. There are no moving parts to cause injury and all voltage and current levels are well below the lethal range (100-200 mA) and below the level that would cause electrocution (50 mA). Since any field applications of the system would be installed outdoors, the components used in our prototyping of the product would need to be replaced with waterproof equivalents (i.e. the ultrasonic sensors) or thoroughly insulated from the environment in a field installation.

One possible safety risk is the emission of infrared radiation from our thermal camera. Although there are always some health risks associated with radiation exposure, the limited time and intensity of exposure make the health risks minimal.

Another concern is the safety of potential test subjects. Should we choose to test the system with real birds by encouraging them to approach the window and then observing whether they are appropriately repelled, any system failure could lead to injury or death. Consequently it is vital the system is thoroughly tested beforehand in the lab prior to any field applications or testing.

To protect the privacy of others as mandated by the IEEE Code of Ethics [1], the images of pedestrians or other persons whose image may be captured by the thermal camera will not be stored in the system after the cycle of image processing for the current image is complete. Images will not be exported or extracted from the system to any secondary device or database.

All data collected during the testing of the system will be recorded in at least one group member's lab notebook and marked with the time and date of collection in order to accurately represent the efficacy of our system throughout the development process. We believe this method will ensure that any claims or estimates we make concerning our system are honest and accurate.

While all new technologies are always vulnerable to misuse and abuse, the applications in which this technology could be used to cause individual, societal, or environmental harm are, to the best of our knowledge, little to none. Should any possible misuses of our design come to light, we would greatly appreciate being made aware of the problem and will revise our design accordingly.

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