ECE 445 Project Proposal:
Bird-Friendly Electrochromic Windows

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I. Introduction

A. Problem

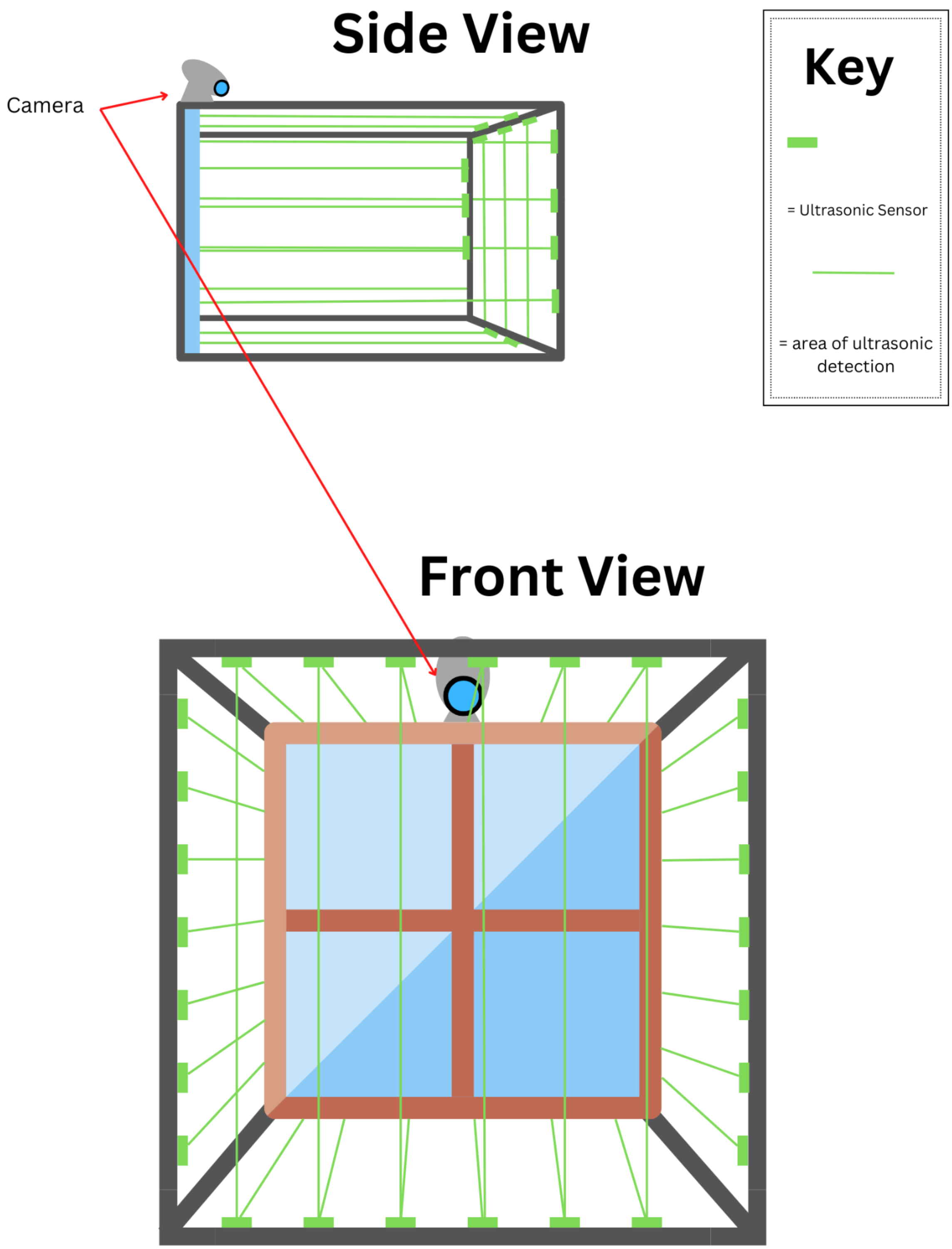
Each year, roughly one billion birds in the U.S. die due to collisions with windows [1]. Even birds that are only temporarily stunned and fly away often die later due to bruising and internal bleeding in the brain or other vital organs. For some species such as the ovenbird, window collisions cause more 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.

B. 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 glass 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.

C. Visual Aid: A Sketch of the Frame, Camera, and Sensor Orientations



D. High-Level Requirements List

- The system must be able to detect an approaching bird from 92 cm away (see the Tolerance Analysis for further details on how this number was determined).
- In order to allow sufficient response time, the voltage applied to the electrochromic panels to control opacity must change within 20 ms of a bird being detected by an ultrasonic sensor. This is the amount of time it takes for a bird to travel the distance of our “pad” mentioned in the Tolerance Analysis.
- Finally, the system must turn the correct electrochromatic panel opaque based on either the panels’ proximity to the triggered ultrasonic sensor which detected the bird or the image processing.

II. Design and Requirement

A. Block Diagram

B. Subsystem Overview

a. Object Detection Subsystem

The Object Detection Subsystem includes ultrasonic sensors that are used to detect the entry and exit points of objects into and out of the rectangular prism area in front of the glass window. Each sensor is connected to the microcontroller in the Controls Subsystem. Changes in detected distance will indicate that an object has entered or exited the space immediately surrounding the window.

b. Object Classification Subsystem

The Object Classification Subsystem is used to determine whether or not the object entering the rectangular prism area in front of the glass window is warm-blooded or not. It includes a IR Thermal Camera and a Raspberry Pi, which communicates with the microcontroller in the Controls Subsystem. Based on the entry point of the object, which is given by the microcontroller, the Raspberry Pi will process the corresponding part of the thermal camera's image, to determine whether or not the object is a mammal, and then track it's movement within the rectangular prism area if it is a mammal. The Raspberry Pi will be indicating to the microcontroller which glass block(s) should turn opaque.

c. Power Subsystem

The Power Subsystem is relatively simple as it consists of only one component (the power supply in the laboratory). It provides 5 V and a universal ground to the microcontroller and Raspberry Pi, each ultrasonic sensor, and to the IR camera which is used in the image processing.

d. Control Subsystem

The control system consists of the microcontroller, which serves several important functions. The microcontroller reads the output of each ultrasonic sensor. When a distance is detected below a certain threshold (there is a base number equal to the distance from one side of the metal frame to the other. When the distance drops significantly below this (a difference of several centimeters) we will consider the distance as "below the threshold"), it sends a signal to the Raspberry Pi to begin image processing and a signal to the electrochromic glass to increase opacity. Once the image processing has determined that there is no longer a bird present, the microcontroller changes the electrochromic panels back to a low opacity.

C. Subsystem Requirements

a. **Object Detection Subsystem**

For object detection, a UV sensor requires 75mW. Since we are using 4 sensors for each panel of electrochromic glass this totals to 300mW.

1. **Ultrasonic Sensor**

   Each sensor is connected to the microcontroller in the Controls Subsystem through a trigger and echo pin. When the trig pin is set to HIGH, the sensor starts transmitting ultrasonic sound pulses. The echo pin also goes HIGH. If no pulses are reflected back, the echo signal will time out. Otherwise, (if the pulses are reflected back) it means that the sensor has detected an object, and it will set the echo pin to low. (The microcontroller will be using the width of the echo pin's pulse to calculate the distance of the detected object from the sensor).

b. **Object Classification Subsystem**

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 which we will use from the provided ECE 445 parts inventory, the operating power is 150mW [4].

1. **IR Thermal Camera**

   When an object is detected, the Raspberry Pi will turn the camera on (through the I2C interface). The camera sends the captured images through the SPI interface.

   Requirement 1: The IR Thermal Camera should be able to have a view of the entire rectangular prism area.

   Requirement 2: The IR Thermal Camera should maintain a frame rate of at least 2 frames per second.

   Requirement 3: The IR Thermal Camera should be able to distinguish between warm-blooded animals and their surrounding environment.

2. **Raspberry Pi**

   The microcontroller will let the Raspberry Pi know of any objects detected by the Object Detection Subsystem, and their corresponding electrochromic panel. The Raspberry Pi will then turn on the thermal camera through the I2C interface, receive video frames through the SPI interface, and then process them. If the first received frame has warm-blooded animal(s) in the grid block(s) indicated by the microcontroller, the Raspberry Pi will let the microcontroller know to turn those corresponding glass blocks opaque. Otherwise, if the first frame does not contain warm-blooded animal(s), it means either a non-warm-blooded object has entered the rectangular prism area, or a previously tracked warm-blooded object has left the rectangular prism area. If a non-warm-blooded object has entered the rectangular prism area, the Raspberry Pi can turn off the thermal camera. If a previously tracked warm-blooded object has left the rectangular prism area, then the Raspberry Pi will tell the microcontroller to make the corresponding electrochromic panel clear again, and, depending on whether or not there are any more warm-blooded objects in the rectangular prism area, turn off the thermal camera.

In addition to processing the first frame after an object is detected, if the object is warm-blooded and determined as entering the rectangular prism area, the Raspberry Pi will track the object moving around the area, and update the microcontroller on which glass blocks to turn clear or opaque.

Requirement 1: If an object directly heading towards the glass has entered the rectangular prism area, it has (4.000 - 1.366 - bird's turn radius m) / (17.8816 m/s) = 0.1473 seconds - (bird's turn radius m) / (17.8816 m/s) to determine whether or not the object is warm-blooded. (In the case of a Japanese White-Eye, which has a turn radius of 0.015 +- 0.008 m, the Raspberry Pi will have 0.1473 seconds - (0.023 m) / (17.8816 m/s) = 0.1460 s to process the first frame.)

Requirement 2: Should be able to process the frames (coming at a frequency of at least 2 Hz) and track the movement of warm-blooded objects within the rectangular prism area in (near) real-time.

c. Power Subsystem

The power subsystem will be the power supply which will be connected through every other subsystem with 5V and a universal ground. It needs to supply a steady 5 V to all other subsystems. Current, voltage, and power calculations are provided in each relevant subsystem requirement section.

d. Control Subsystem

For our control subsystem we will be using a microcontroller. The typical power consumption for a microcontroller is around 3.3 V and 5-50mA[5], so the power will range from 16.5 to 150 mW based on the model we select.

e. 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 [6].

- Requirement 1: The sensors must be able to accurately detect the entry and exit points of any object into and out of the rectangular prism area in terms of which glass window block the object is in front of. (This should not be a problem, since the ultrasonic sensors have an accuracy of 3 mm, while each glass block is 10 cm x 10 cm.)

D. 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]. While the largest species to commonly collide with windows (Hermit Thrush) has a maximum length of 18 cm, we will pad this number with an additional 16 cm to ensure that approaching birds have a sufficient amount of time after recognizing a hazard to respond. Our system must therefore be able to detect an approaching bird from 92 cm away in order to effectively prevent collisions.

III. 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 [11], 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 [11].

While all new technologies are 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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