Bird Initiated Rubbish Disposal System (BIRDS)

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***Abstract* — The Bird Initiated Rubbish Disposal System (BIRDS) was designed to facilitate the training of birds for the purpose of keeping an environment free from litter. The BIRDS will accomplish this goal through the use of positive reinforcement. When a bird delivers a valid item (e.g. trash), the BIRDS will reward it with an edible reward. Since the system utilizes image detection software to discriminate between participating animals (currently only servicing birds) and submitted objects (currently cigarette buds), our system can be reprogramed to accept and reward any object small enough to fit into the analysis chamber without any changes to the hardware. This flexibility in choice is an unrivaled feature that differentiates the BIRDS from other bird conditioning projects, such as the *Crow Box*. Ultimately, the BIRDS strives to mitigate the environmental impact of littering and enhance overall cleanliness in public settings like campuses and cities.**

Index Terms* — *Conditioning Phases, Image Recognition, Bird Imaging, Trash Imaging, Laser-Break Motion Sensor, Housing Design

I. INTRODUCTION

Efforts to combat littering have included educational campaigns and legal enforcement; however, trash still accumulates due to convenience or neglect. Existing cleanup methods are energy-intensive, relying on volunteer, convict, or paid labor. Ideally, preventing littering through education and incentivizing reusable products would be most effective. Alternatively, leveraging birds' natural presence could aid in cleaning public spaces. The Bird Initiated Rubbish Disposal System (BIRDS) project proposes training birds to collect trash, employing classical conditioning to reward them for depositing waste.

This initiative presents an opportunity for interdisciplinary collaboration in fields such as Photonics Science and Engineering, Electrical Engineering, and Computer Engineering. Notably, previous attempts at a similar project faced challenges in implementing image processing software onto a small processing board, but lessons learned from past efforts inform the current project's design.

The project aims to create a device to incentivize birds to collect small trash items and deposit them into a temporary storage container for later human disposal. Drawing from operant conditioning principles, the device functions as a bird feeder, rewarding birds with food for depositing trash. Positive reinforcement, in the form of food pellets, is used to encourage birds to repeat the behavior. The device features two terminals, one for depositing trash into an analysis chamber and another for dispensing food rewards. Inspired by similar projects, the idea was originally proposed by sponsor Justin Phelps, who envisioned commercializing bird feeders that train birds to collect and deposit items.

The primary goal of the BIRDS is to ensure prompt feeding of birds that bring trash. This requires the system components to work quickly to reinforce stimuli to train birds effectively. Consistency in bird and trash detection is crucial to prevent other animals from interacting with the device and to maintain the conditioning process. Additionally, the device must be weatherproof to withstand outdoor conditions, particularly focusing on protecting food storage and internal components from rain and humidity.

II. SPECIFICATIONS

This section outlines the key component specifications and requirements we have set for our system. These specifications determined what we prioritized in the design process for both the optical and electrical components of the BIRDS, and they will ensure the smoothest operation of the system.

Figure 1 shows the optical specifications for the BIRDS. The key component specifications for this set are the fields of view (FOVs) created by the collimating lenses for each imaging system. The Bird Imaging System, as outlined later in Optical Systems Design, will require a wider angle of view than the Trash (Cigarette) Imaging System to capture images of birds approaching our system, so the acceptance angle of its collimating lens(es) will need to reflect that requirement. Further discussion on the design of the lens system is included later in this paper.

Figure 2 shows the electrical specifications for the BIRDS. The key component specifications for this set are the power draw from our PCBs, which should be low enough to share the common power supply with the Jetson. The response time for our image processor, which should deliver verdicts on the images taken of potential birds and cigarettes within 5 seconds of the images being taken.

	Component	Parameter	Specification
Optical	Collimating Lens (Trash)	FOV	25°
	Collimating Lens (Bird)	FOV	90°
	Focusing Lenses	Focal Length	10 – 20 cm
	CMOS Sensors	Resolution	640 x 480 pixels
	Red Laser Diode	Spot Size	6 mm (@ 5 m distance)
	Photodiode	Wavelength Range	400 – 1100 nm
	Mirror	Wavelength Range	400 – 700 nm

Fig. 1. Optical Component Specifications Table

	Component	Parameter	Specification
Electrical	Power Supply	Support Max Delivery	Up to 10 Watts
	PCB	Power Draw	Less than 5 Watts
	Motors	Reliability	Operate without fail 80% of the time
	Image Processor	Response Time	Deliver verdict within 5 seconds of taking image

Fig. 2. Electrical Component Specifications Table

III. General Hardware Design

This section outlines the overall design and implementation for the hardware in our system. Figure # helps to illustrate all of the subsystem's component parts, integration with the other subsystems, and general task distribution between our team.

The key features of the system shown in the diagram are the Jetson Nano for image processing, the Main PCB, the Trash & Bird Imaging Systems for their respective image recognition, the Trash Motion Sensor, and the motors controlling the mechanical processes for the various functions throughout the subsystems of the BIRDS.

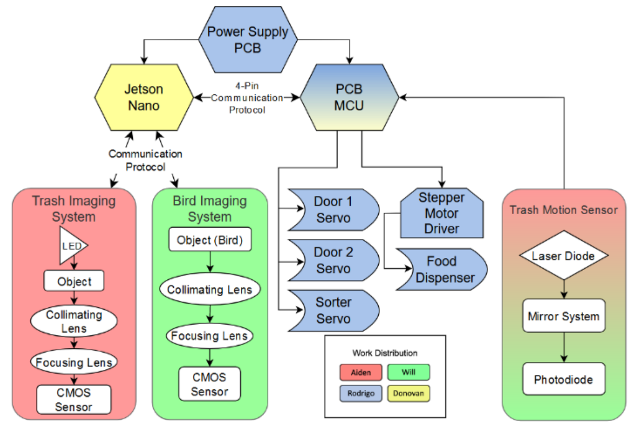

Fig. 3. Hardware Block Diagram for the BIRDS

A. The BIRDS House

The housing of the BIRDS provides a structure for all of the components, systems, and storage, all while remaining somewhat weatherproof, easy to take apart for maintenance, and aesthetically pleasing. There are two aluminum extrusions that serve as both structural support for the backplate and as guiding rails for the outer shell, bird platform, and trash storage. The housing system works by cutting rectangular slots in the backplate in order to slot in all of the subsystem platforms with ease. This approach allows for ease in attaching and removing platforms for maintenance and debugging. In hopes of attracting birds' attention through the sight of food, both the outer shell and food storage are transparent. In a final implementation, the user will be able to mount and secure the structure to a wall via metal fitting running down the back of the housing. Next, we will go more in depth on the specific subsystem platform implementations.

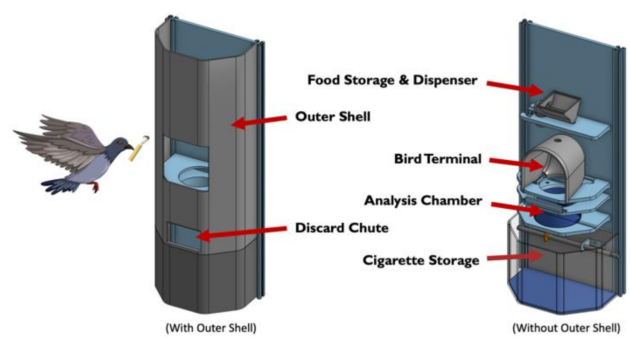

Fig. 4. BIRDS Housing Diagram, with and without outer shell

B. Subsystem Platforms

From top to bottom, first is the food storage and dispenser. A stepper motor is used to rotate a screw inside a food funnel. The rotational force applied by the stepper motor drives the screw, pushing the food pellets stored in the funnel towards a hole that drops into the food chute. The chute leads to the food receptacle outside the outer shell of the housing.

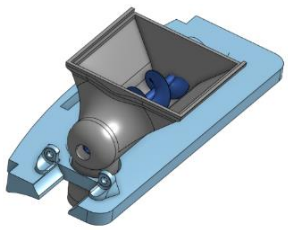

Fig. 5. Food Storage and Dispenser Platform

Next is the bird terminal platform (Fig. 6, top) where birds will deposit their items for evaluation. This platform contains a dome that serves as the inner lining separating the birds from the inside of the housing. This dome also serves to hold both the trash and bird cameras. Below the dome are two doors that are opened by two separate servo motors. When a bird is detected by the Jetson Nano, the doors will open, allowing access for the bird to drop an item into the analysis chamber.

Directly below the bird terminal platform is the laser-break motion sensor platform (Fig. 6, middle). The laser system will be explained in more detail in the Optical Systems Design section. Simply put, the platform makes use of two mirrors, a laser, and a photodiode to form a laser-beam break motion detector that will detect when an object is dropped into the analysis chamber below it.

Once an item has been deposited into the analysis chamber platform (Fig. 6, bottom), the analysis disk serves to hold the item while the trash analysis recognition software verifies it. While the optical structure and design choice will be more thoroughly discussed in the next section, the layout of the analysis chamber and trash camera allows for a clear, top view of the analysis disk and item. Cylindrical walls were designed to enclose the analysis chamber to prevent ambient light to affect the results.

Once the submitted item is verified by the Jetson Nano, the Main PCB drives a servo motor to rotate the analysis disk containing the sample to either of two directions. If the item is acceptable, the disk rotates towards the backplate, and the item falls into the trash storage container. If the item is not acceptable, the disk rotates away from the backplate, directing the item into the discard chute and out of the housing.

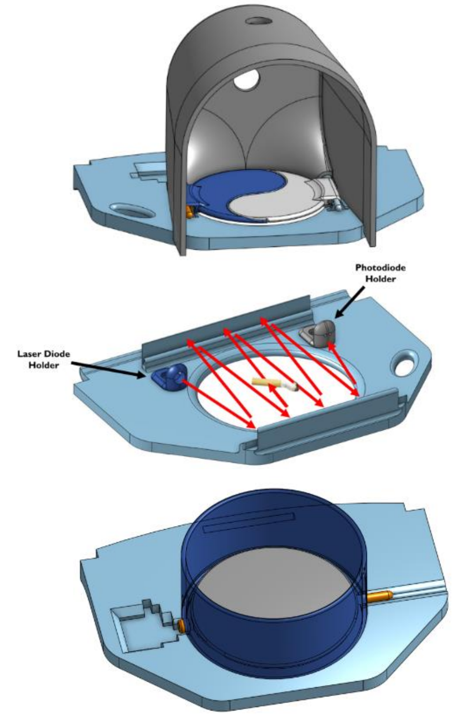

Fig. 6. Expanded view of Bird Terminal Platform (top), Laser Motion Sensor Platform (middle), and Analysis Chamber Platform (bottom)

Lastly, the trash storage container will collect the desired items for the disposal system. The container also supports the discard chute that leads discarded items outside of the housing. The container can be removed from the housing by removing the securing rod. Once removed, the trash storage can be emptied into a proper disposal. To return the storage to the housing, users simply insert it back and secure it with the securing rod.

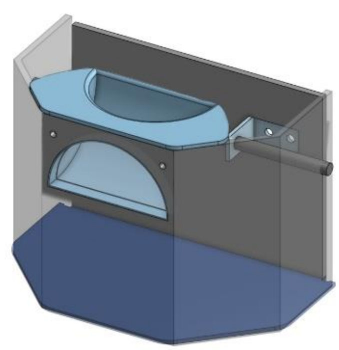

Fig. 7. Trash Storage Container and Discard Chute

IV. Optical Systems Design

For any lens system, there are two general equations that must be known, and they are as follows:

$$\frac{1}{s_1} + \frac{1}{s_2} = \frac{1}{f} \tag{1}$$

$$-\frac{s_2}{s_1} = M \tag{2}$$

where s_1 and s_2 are the distances between the object and lens and the focal point and lens, respectively, and f and M are the focal point and magnification, respectively. With these two equations, others can be derived for multi-lens systems.

A. Trash Imaging System

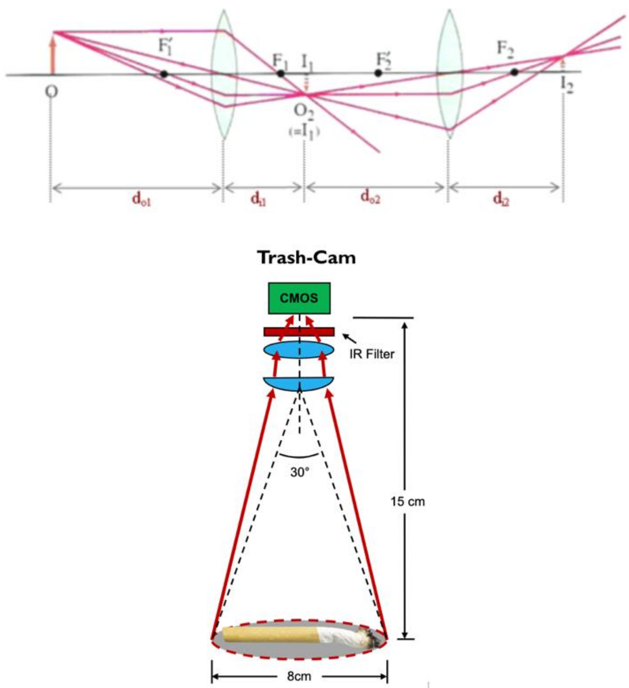

Fig. 8. Two-lens system diagram (top) and Trash Imaging System Schematic (bottom)

To capture images of the objects dropped by birds, a two-lens system was designed. The goal of this system is to determine if a cigarette has landed in the analysis chamber. The average length of a cigarette is 8cm long. The size of the CMOS sensor is 5.42mm x 3.02mm. The magnification of the overall lens system required to capture a complete image of the cigarette onto the sensor is $3.02mm/8cm = 0.0378$. The entire length of the lens system must be equal to or less than the distance from the cigarette to the CMOS sensor, 15cm.

$$s_1 + s_2 \leq 15cm \tag{3}$$

Therefore, using (2), $s_2 = 0.0378s_1$. Furthermore, from (3), $s_1 \leq 15/1.0378$. Plugging the new values of s_1 and s_2, we find $f = 5.26mm$. The double lens system must have an effective focal length (EFL) of 5.26mm or smaller. This means that the variables d_{o1} and d_{i2}, seen in Figure 8 (top) must inversely add in (1) to achieve a focal length of 5.26mm or less.

To calculate the focal lengths of each lens in the double lens system, we come up with seven equations and seven unknowns. The first four equations are taken from (1) and (2) for each respective lens shown in Figure 8 (top). The fifth equation uses (1) for the front and back of the two-lens system, values d_{o1} and d_{i2}. The sixth equation, (4), solves for the overall magnification of the two-lens system with

$$M_1 + M_2 = M \tag{4}$$

the first and second magnification of each lens.

The final equation, (5), is the height constraint of the entire lens system.

$$d_{o1} + d_{i1} + d_{o2} + d_{i2} = 15cm \tag{5}$$

Having already solved for the overall magnification, M, and the overall focal length, f, this leaves one variable to have a value arbitrarily selected. This value will be d_{o1} as we can design the length of the housed two-lens system to match the left-over height of the analysis chamber. The selected value is, d_{o1} = 125mm. Plugging the equations into a calculator gives us the values desired, the most important numbers being the focal length of the first and second lens, f1 and f2 respectively. These values are f1 = 8.4mm and f2 = 3.6mm.

B. Bird Imaging System

To capture images of birds approaching the system so that the doors of the bird terminal can be opened for access to the analysis chamber, a three-lens system was utilized. The Bird Imaging System, placed at the back of the bird terminal facing outwards to approaching birds, introduces a third wide-angle lens in addition to the two-lens system for the Trash Imaging System. This lens acts as another collimating lens that expands the field of view for the system so that birds, which are much larger than cigarettes at about 15 cm, can be sufficiently imaged and recognized. The same CMOS sensor is utilized for this system, but the total magnification of the bird onto the sensor is $3.02mm/25cm = 0.0201$. And the total length of the system must be around 20 cm for birds to be sufficiently imaged. The other known values for the three lens system are the effective focal length of the system, which was found to be 3.863mm after using (1), (2), and (3), the focal length of the second (smaller) plano-convex lens, approximated to be 10mm, the focal length of the third (biconvex) lens, approximated to be 7mm, and the object distance for the first (wide-angle) plano-convex lens, approximated to be 175mm. After introducing forms of (1) and (2) for the third lens added in this lens system scenario, there are nine total equations and nine total unknown values, which can be solved for in a linear equations system calculator. This outputs the new lens to have a focal length of 25mm.

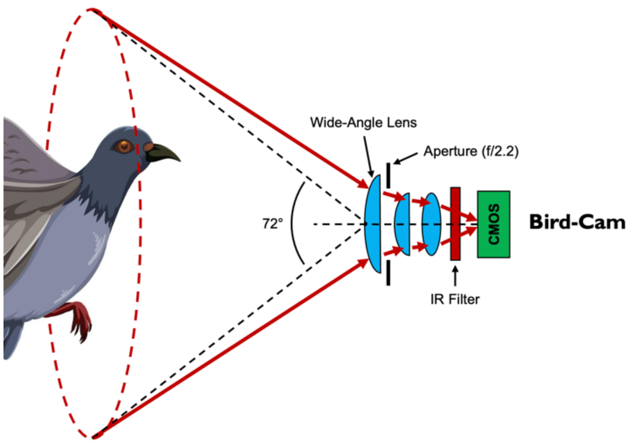

Fig. 9. *Bird Imaging System Schematic*

C. Laser Motion Sensor Design

The goal of this motion sensor is to create a laser grid in which any object that is dropped into the analysis chamber will break. To achieve this, the laser diode, the mirrors, and the photodiode must be positioned in such a way to send, reflect, and capture the laser light on a consistent plane. As seen in Figure 10, the components are placed so that when the laser is aligned, the light will be reflected anywhere from 7 to 9 times. Knowing typical cigarettes brought by birds will be anywhere from 4cm-8cm, the design attempts to not allow for spaces larger than 4cm that would allow trash to fall undetected.

As seen in Figure 10, there are some spaces in the laser grid design that an object could pass through without being detected. This is considered in the engineering specifications as this motion sensor must only work 80% of the time to accurately detect an object falling through. Another solution to this problem is to have the software communicate to the trash camera to always take a picture if the laser motion sensor fails.

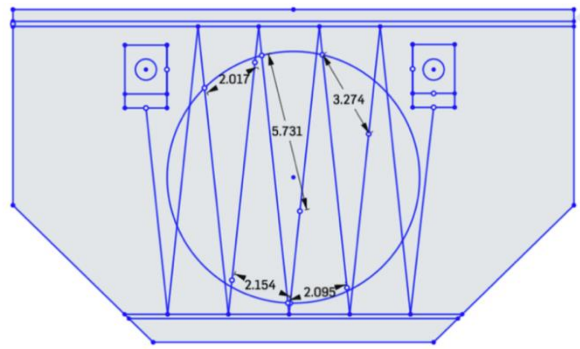

Fig. 10. Laser Motion Sensor Design Drawing

V. Electrical Systems Design

The brains of the BIRDS relies on electrical systems and processors. In this section the implementation of the electrical systems is discussed.

A. Image Processor

The image processing unit used is NVIDIA's Jetson Nano development board. This is a premade board by NVIDIA, and no modifications are required. A few of the given GPIO pins on the development board are utilized and the GPU accelerator will be doing all of the image processing. The Jetson Nano is powered at 5V using the USB connection as power. With the Jetson being a standalone system, it will be easy to interface in the future by anyone wanting to see the images taken or update the image recognition software in any way.

B. Actuators

This project requires moving parts; therefore, actuators are necessary. The first motor discussed is the stepper motor. The BIRDS utilizes one stepper motor to drive the food dispenser screw conveyer. A stepper motor was selected due to its strong torque and fine control of movement as opposed to a standard DC motor. Aside from the stepper motor, the BIRDS uses three servo motors to drive limited rotational functions. Two servo motors operate the doors in the bird terminal platform, and another drives the analysis disk sorter.

C. Main PCB

The Main PCB serves as a middleman between the actuators and the Jetson's verdicts. The board is powered by the ATmega328PB. It provides plenty of Pulse Width Modulation to drive the servo motors, pins to drive the stepper driver, and pins to read the laser-beam break detector. Along with the MCU is the stepper driver. It is a dedicated chip that utilizes 4 control pins from the MCU and dedicated 5 Volt and Ground pins.

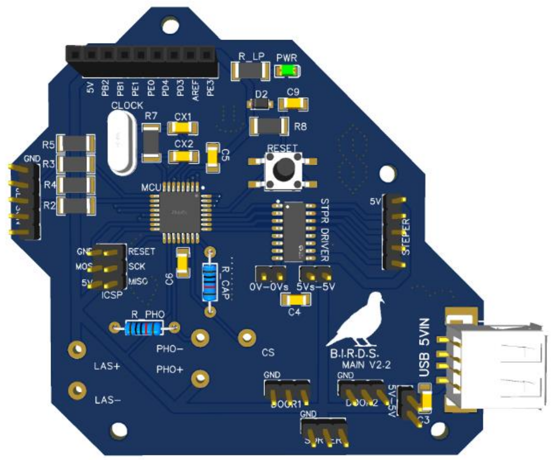

Fig. 11. Main PCB Schematic

A notable feature of both custom PCBs is the isolating of sections of the circuit using pin connectors. For example, the power for the stepper driver circuit can be isolated from the rest of the board using two jumper pins. This allows for flexibility and debugging. The stepper can be powered separately from the Main PCB, reducing current draws through the traces in the board.

Another feature on the Main PCB board is the Jetson communication terminal. A custom communication scheme was implemented by using 4 pins: two for the “is bird?” question and the other two for the “is trash?” question. One pin from each pair is dedicated to output into the Jetson. This allows the Main PCB to tell the Jetson when to activate the respective image detection software. For example, when the laser-break detector is activated, the Main PCB tells the Jetson to start analyzing the trash chamber. One notable feature in the output pin is that the Jetson can only read 3.3V from its pins. Therefore, it was necessary to step down the output voltage to match it. The other pin reads from the Jetson for a verdict response. If the Jetson detects something valid, the pin activates, and the Main PCB proceeds to the next phases. If the Jetson does not detect something, the pin remains LOW and the Main times out and returns to the IDLE condition.

The MCU was programmed using ICSP to avoid the need for a USB serial communication chip. The Main PCB has 6 pins where an external USB programmer is attached, and code is uploaded through it. All of the left-over pins that were not immediately used were placed into a “Leftovers” header pin in case of a future need. Finally, a power LED indicated whether there is power on the board.

D. Power Supply PCB

A stand-alone power supply board was built to power both the Jetson Nano and the Main PCB. This was to prevent damage to the more sensitive components on the processing boards when first testing and debugging the power supply. Originally, batteries were meant to power the BIRDS, but testing the power draw of the Jetson Nano revealed that a week of autonomously powering the unit would be unfeasible. Therefore, a wall adapter that turns 120 Volts AC into 9 Volts DC was utilized, and the Power PCB turned the 9 Volts down into 5 Volts for both the Jetson and Main PCB.

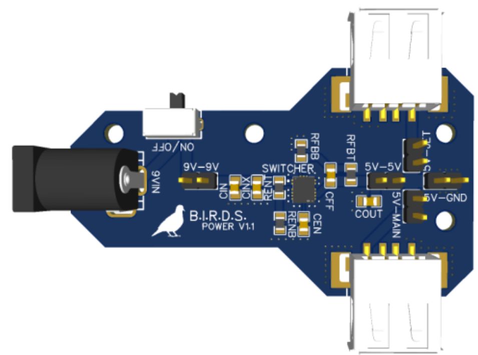

Fig. 12. Power Supply PCB Schematic

The Power PCB succeeds in powering both the Jetson and Main PCBs, even at peak current draws. Similar to the Main PCB, jumper pin sections were added to isolate different parts of the circuit. Specifically, 5 Volt and Ground pins were added in case of a need to power something directly from the Power PCB, such as a stepper driver.

IV. Software Design

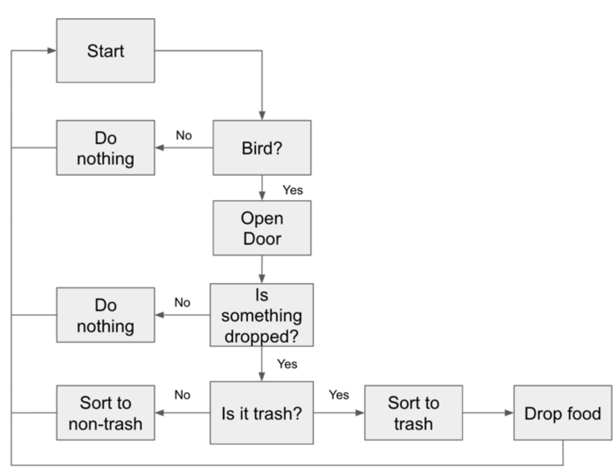

Fig. 13. Software Block Diagram for the BIRDS

The BIRDS has two main parts to the software. First, there is the microcontroller software reading all the sensors and sending small amounts of data to interface other components. Second, there is image recognition that is being run on our Jetson Nano that will classify the images as needed. These two systems will communicate with each other through the use of direct connections. Being that all we need are start and result bits this simplifies down to only a 4-wire design and reduces some of the extra overhead from communication protocols.

A. Overall Software Flow

The software is being thought of as 4 Conditioning phases which will be described as follows:

1) As seen in Figure #, the system will first be running the image recognition to detect birds flying up to the system. It will continuously do that until a bird was detected. After detecting a bird, the Jetson will send a digital high to the microcontroller, signifying that the system can move on. The microcontroller then opens the doors that allow the bird to drop in trash.

2) After the doors have been opened it turns on the laser that is shining back and forth on the mirrors into a photodiode to wait for something to fall. If nothing drops after an allocated amount of time, then the system will reset back to the start. When something breaks this plane, the logic goes from digital high to digital low signifying to move on to the next phase. The microcontroller then sends a start bit to the Jetson to start the cigarette camera.

3) The Jetson then detects if a cigarette was dropped or anything other than a cigarette. If no cigarette was found, then the system will time out, the trash sorter sorts back to the ground and the system restarts back to the beginning. If a cigarette is found, then a digital high is sent back to the microcontroller representing that it has found a cigarette, the trash sorter spins to store the trash, and can move on to the final phase.

4) The final phase only includes spinning a stepper motor to drop food for the bird and resets the system back to start.

To aid in the training process, there will be an easy way to switch to different training modes that will only do some of these phases in order to improve the bird's comfort with different things moving and the noises that might occur.

B. Bird Image Detection

The image recognition software, utilizing the GPU of the Jetson Nano to do calculations, will have two different networks. The first network is the detection of birds. This is using a prebuilt model from the jetson inference library. This can detect many different objects with birds being one of them. This is utilizing one hot encoding so the class we need is only one index in the array. This means that even though other objects are being detected the only thing that will matter is birds. This model has been tested using pictures of different kinds of birds, alongside small bird dolls in order to confirm its accuracy.

C. Cigarette Image Detection

This image detection was a bit harder to set up as it is very specific. There wasn't many pretrained models that could detect cigarettes. In order to train our image detection to detect cigarettes, we used an online platform named Edge Impulse. This still follows the usual training methods through normalization then training and testing. Since our camera will never be moving and the platform that it will be reading from will always be the same in every way, this makes our training application much more specific enhancing the accuracy a bit. We used a normalization on the images to create 160x160 images to pass through the network. It is then utilizing a prebuilt network weights based on FOMO (Faster Objects, More Objects) MobileNetv2 0.35 to adjust the weights in order to detect the cigarette. Any other objects such as a stick or leaf is not classified making it essentially background to the system. We used 135 images with bounding boxes drawn over the cigarettes manually with a train test split of 80% and 20% respectively. These are trained over 100 cycles using the FOMO model above using a training rate of .001. The validation set size is 20% and the batch size is 32. After training the model we classify everything in the testing dataset. The accuracy on the testing dataset is 81% which is above our goal with the misses mostly being if the cigarette is too close to the edge of the platform.

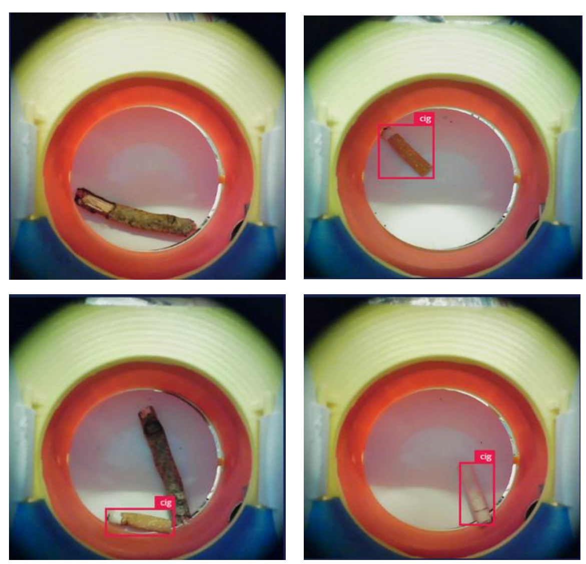

Fig. 14 Training Images with Bounding Boxes

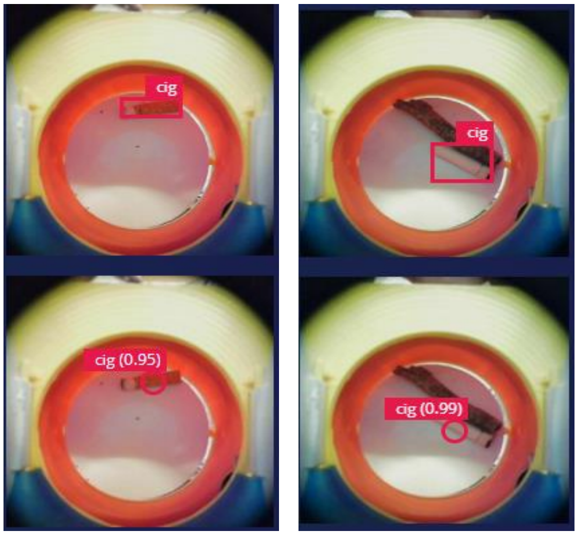

Fig. 15 Testing Images with Confidence

V. CONCLUSION

In conclusion, the BIRDS project represents an innovative and ambitious approach to address the persistent issue of improper waste disposal in public spaces. By capitalizing on the intelligence and adaptability of birds, this project aims to establish a mutually beneficial relationship between birds and humans.

The motivation behind BIRDS is rooted in the acknowledgment that despite various efforts to curb littering, significant challenges persist. Traditional clean-up methods often require substantial energy and resources. The project introduces a novel solution by harnessing the natural behaviors of birds through operant conditioning, utilizing positive stimuli like food to encourage them to collect and deposit small-sized trash. This approach not only offers a unique and sustainable method of waste disposal but also contributes to the overall well-being of public spaces. The project's goals emphasize the importance of timely and consistent reinforcement for bird behaviors, ensuring that the association between depositing trash and receiving food is effectively established. Both the electrical and optical designs were configured around the objective to reach these goals.

Exploring existing products in the market aimed at bird interaction and waste management provided valuable insights for the development of the BIRDS project. The comparison with products like the CrowBox, Birdbox, Smart Bird Feeder (UCF Senior Design), and Smart Bird Feeder by Bird Buddy has revealed distinct design philosophies, strengths, and limitations. This research has formed a well-rounded design strategy that incorporates the best elements while addressing specific challenges identified in existing solutions.

The BIRDS project not only addresses a pressing environmental concern but also provides a unique opportunity for collaboration across diverse fields, including Optical Engineering, Electrical Engineering, and Computer Engineering. As the project progresses through the research and design phases, it holds the potential to inspire a new generation of environmentally conscious individuals. By fostering healthy relationships between humans, birds, and the environment, the BIRDS embodies the spirit of cooperation and innovation needed to tackle complex global challenges. The documentation outlined in the report ensures a comprehensive understanding of the project's development, from its motivation to its ambitious goals and beyond. The BIRDS project stands as a testament to the transformative power of interdisciplinary collaboration and the boundless possibilities that emerge when humans and other species work together for the greater good.

ACKNOWLEDGEMENT

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