Bird Initiated Rubbish Disposal System

Healing the World Through Bird Power

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1. Executive Summary

Many of the world's advancements in both innovation and entertainment have come about as a result of humans learning how to cooperate with other species. There is a long history of human cooperation with other species and relationships that are mutually beneficial. Domestication of animals, which began thousands of years ago, helped humanity transition from the primitive hunter-gatherer life to the more-modern settled and agricultural life. Domesticated animals were nourished and cared for well by their human owners, and in return humans were provided companionship, labor, and other resources. The results of this process of domestication are seen very clearly today, in a society where dogs now assist responders in the search and retrieval of harmful objects and substances, and bees create honey for beekeepers and provide pollination for an incredibly large part of the world's food and crop supply. If such advancement in solving the world's problems has come from humans cooperating with animals up until now, what more must the future hold if we continue to press into new ways of cooperating with our friends here on earth? What new innovations could unfold, and what new avenues of research and development could open up if we pursue a deeper relationship with the world and environment around us?

Birds are a significant example of a species that humans have cooperated with over the years for the benefit of each other. Birds have been used as messengers, hunters, and pets as they are adored by many. Birdwatching has become a popular form of entertainment and hobby for many consumers, and bird houses and feeders have brought the entertainment even closer to humans than before. Bird houses and feeders, which are mutually beneficial in that they provide birds with a place to be nourished, and they provide humans with the enjoyment of viewing, observing, and learning about birds, have bridged the gap between the natural habitats of birds, many of which have been deforested, and the new homes and neighborhoods of humans, many of which have replaced these natural habitats. Bird feeders on the market now even feature cameras that have brought our friends of the air even closer, with mobile applications for avid birdwatchers to collect unique images of birds that pay a visit.

Some hobbyists have taken a curiosity in bird feeding behavior, and they have introduced some interesting new ideas to the concept of the bird feeder. The ideas are centered on the notion that birds are intelligent creatures, and that they have the ability to pick up on patterns for how they can receive food. These hobbyists have developed electrical and mechanical systems within bird feeders, along with different operational phases of acclamation, for birds to be conditioned to perform tasks that ultimately reward them with food. These systems have been designed with the goal of training and conditioning birds to bring items to the bird feeder in exchange for food, and they have shown proof that in a controlled environment, along with multiple phases that help a bird slowly adjust and learn how the feeder works, birds slowly pick up on the pattern performed by the mechanics of the system. Experimentation must continue to take place to determine the differences

in cognitive ability between species, but the signs of learned behavior in bird species like crows, as a result of these experiments, have given great promise within advancing the capability of human cooperation with birds. One of the most significant ways that humanity has not developed a good relationship with the environment is by polluting the earth. Much of this pollution has come from the improper disposal of human waste. Wrongfully accepted practices in waste management and the careless decisions of countless organizations and individuals have led to the pollution of the land and water of the earth. The dumping of plastics, hazardous materials, and other waste into our oceans, due to the runoff from land into rivers, has introduced some significant challenges for our environment, and has endangered multiple species of animals in the process. As the initiators of this damage to the environment, it is our responsibility to take the initiative to fix it. While directly changing consumer behavior is the most effective way of creating sustainability and promoting care for the health of the environment, our project aims to take advantage of a potentially mutually beneficial relationship between humans and animals that has the potential to negate some of the effects of human waste pollution.

This project aims to approach the problem of improper waste disposal with these promising discoveries about cooperation between humans and birds in mind. The Bird-Initiated Rubbish Disposal System (BIRDS) aims to provide a reward-based bird feeder system that will reward birds with food when they bring trash, or rubbish, to the system. As a side note, we must say that no one on our team is British, but we must confess that the use of the word rubbish in our project's title, rather than trash or waste, gave us the unique opportunity to title our project with the convenient acronym it now possesses. We simply felt the need to fully confess our intentions in naming the BIRDS. The BIRDS should be able to image and recognize birds approaching, prevent other animal species like squirrels from invading the feeder, accept items that the bird brings, image and recognize items that are considered trash or waste, reward birds that bring trash by dispensing food, sort between items that are trash and items that are not, and collect trash for waste retrieval. The waste items that will be targeted by our system will be relatively small, not like large plastic bottles, as birds are limited in what they can easily pick up and bring. The trash analysis chamber will also only be catered to these smaller items, like cigarettes, to provide a simple image recognition approach for trash that would serve as the foundation for other and potentially bigger waste items to be targeted in other research. The idea for our system is to have the BIRDS be used in settings like campuses to help reduce the effects of littering and improve the quality of the environment. We aim to inspire a new generation of people that desire healthy relationships with the animals and the environment around them.

The following report documents the research and design for the BIRDS, during the first semester of Senior Design. The report will begin with a detailed description of the motivation, an introduction, and the goals and objectives for our project. It will then give a detailed section on products, technology, and other information that has been researched as a foundation for the efficient and innovative development

of the project. It will also provide specific details about requirements and specifications for our designed system. The report will provide a detailed section on parts and components that have been selected to build the sub-systems of the BIRDS, along with why they were selected. Then, extensive descriptions of the design for all of the hardware that is used and all of the software that is developed and integrated will be included. And finally, an explanation of fabrication methods and testing results of all included sub-systems will be given, along with an administrative section on how our group interacted and performed the various research, communication, design, decision-making, and testing of our project.

2. Project Description

In this section, we present a deeper dive into the motivation for and introduction to our project. This section explains our initial thoughts and plans and how they connect to our planned design and order of business. We also outline some important goals for the sub-systems of our project, along with some key objectives for reaching each individual goal. This description section then finishes with casting a clearer and more tangible vision for the project via our hardware and software block diagrams and a component table that includes the engineering specifications and requirements that make our project unique.

2.1 Motivation

For decades, governments and societies around the world have attempted to discourage the act of littering. Some have implemented educational programs to educate the public and others enforce it by law and threat of force. In the United States, public programs to incentivize proper waste disposal have mostly worked, at least for younger generations. However, a non-negligible amount of trash is still generated in public spaces, whether due to inconvenience or neglect.

All current solutions for public clean up involve extensive energy cost. Whether using volunteers, convict labor, or salaried street cleaners, they all require active effort to keep streets clean. The most optimum solution for this issue is to ensure that people themselves stop littering, either by increasing accessibility to and educating the public about proper waste disposal or incentivizing products to be reusable and non-disposable. In the absence of that, we believe that harnessing the omnipresence of birds would be beneficial for the health of our public spaces.

The BIRDS project will be a device that can be used to train birds to pick up trash. Birds are very smart creatures and there have been many occasions where they have been trained with enough consistency. Since birds have such free access to many locations, they would be great candidates for picking up different bits of trash. The birds will bring in trash and be rewarded as long as they bring the right things in. This is a classical conditioning for birds to show them that depositing trash to the BIRDS is beneficial for them.

This will be a great project to take on as this could very heavily benefit areas that are littered with trash around the world. Along with trash pickup there are many different fields of expertise that can come together in this project. This makes it the perfect opportunity to learn more about our respective fields of Photonics Science and Engineering, Electrical Engineering, and Computer Engineering. This also helps us learn to learn more about finding the experts and getting help from all different fields to come together.

A small disclaimer, the concept of the BIRDS was previously attempted to be implemented a few semesters prior to our BIRDS. That previous attempt was originally proposed by our current sponsor, Justin Phelps, as an extracurricular activity that could help participants practice for their Senior Desing projects. However, as is evident by our current possession of the BIRDS project, the original attempt was unsuccessful in implementing a fully functional project. We believe it was due to an issue with transferring an image processing software into a small processing board. To maintain transparency, one of our current team members, Rodrigo Guerra, was involved in that original attempt. He designed and built a functioning trash sorting prototype. We will most likely implement a similar design as the previously built prototype, but not that exact replica. Aside from that specific influence of the trash sorting mechanism, the systems and approaches of the BIRDS are independent from the previous attempt.

2.2 Introduction

This project consists of designing and building a device that will reward avian creatures to collect small sized trash from the environment around them into a temporary storage container for humans to collect and properly dispose of.

Using the theories on operant conditioning, we will design a bird feeder that will attempt to train birds to collect and submit trash in the housing for later collection. Operant conditioning refers to a psychological theory that proposes that behaviors can be learned through the use of and association with stimuli that either reinforce or discourage behavior. In our project we plan to use positive stimuli, such as food, to incentivize birds to repeat the behavior of submitting valid trash items into a designated terminal. In a sense, we are simply building a skinner box that rewards trash disposal for birds.

The birds will interact with the BIRDS through two terminals. One allows them to deposit items into the analysis chamber and the another will deliver a food pellet as a positive reward to associate trash in the BIRDS with food in the birds.

This project was originally proposed by our sponsor Justin Phelps. He saw a video of someone building a bird feeder that trained crows to collect and deposit coins into it. We of course have been influenced by similar projects, but to our knowledge, no one has tried to commercialize or mass produce such bird feeders.

2.3 Goals

Core Goals

Our main goal is to promptly feed birds that bring trash. For a conditioning machine to have a chance at training birds, the most critical element is quick and decisive activation of the reinforcing stimuli. The BIRDS must be able to respond to a trash submission within a short period of time in order for the bird to associate the action of submitting trash with receiving food.

Another critical goal is for consistent bird and trash detection verdicts. Other animals, such as squirrels, must not be able to interact with the BIRDS; otherwise, any chance of birds reaching the unit would be slim. Similarly, it would be disastrous for bird conditioning for a valid trash item to not be rewarded or the opposite of a non-valid object being rewarded. Such cases could ruin the conditioning or form unanticipated behaviors.

Since the BIRDS is meant to be placed outside in public spaces, the BIRDS should be as weatherproof as possible. To the bare minimum, it should be able to survive rain and humid conditions. The most critical sections for weatherproofing are the food storage, so the food does not spoil, and the internal circuitry and mechanical actuators.

Advanced Goals

With the core goal of timely and consistent delivery of food secured, adding supplementary stimuli when the food is dispensed should help associate the BIRDS with food, which in turn, associates food with trash delivery. Auditory and optical stimuli could easily be added to the system, such as bells or LED lights. However, the vibrations from the mechanical trash sorter and food dispenser should provide enough complementary stimuli.

For further reliability, the BIRDS should be rated for extreme weather such as hurricanes and flooding. We do not expect the systems to operate during such conditions, but it should be able to withstand adverse weather.

Since the BIRDS is meant to operate outside for long stretches of time, the BIRDS would benefit from being able to autonomously service birds for around a week. This would involve a power supply that is able to power all systems with a moderate amount of service for a week. Applying solar cells could alleviate the power demand during the day. And the last aspect for autonomous operation is that the storage units are large enough to hold a moderate amount of trash and enough food for such volume accepted.

Stretch Goals

Since training the image recognition software is challenging enough, we believe that for testing the performance of this project, the BIRDS will be trained only to detect cigarette buds for their simple shape and consistency.

The Stretch Goal then is to design the BIRDS to accept and detect multiple types of trash. That maybe pieces of plastic, bottle caps, plastic wrappers, etc. However, opening up to such a broad selection of items may prove challenging because of the different optical properties, not to mention increasing the chance for birds to submit something that may get stuck inside the housing or analysis chamber.

Another stretch goal is to be able to classify what kind of bird is in front of the housing. This seems like a task that might be too big to accomplish. Since we are developing on a smaller embedded device and not a big desktop system, classifying something like this might take too much processing power. It would be a nice addition if when saving images, we could say what kind of bird was being trained.

As with any ordinary bird feeder, aesthetics matter. If we have time, it would be nice to design the housing and external components to look visually appealing.

2.4 Objectives

In this section, we will discuss our objectives as they relate to our goals stated above. Our objectives are divided into different sections of the project and describe how these components of the BIRDS will assist in accomplishing the goals.

Housing

The housing of the BIRDS will be designed to keep the inner compartments safe from the weather. A typical housing-like form with four walls and a slanted roof will be utilized. The length, width, and height of the housing will be carefully configured to allow for enough volume within the structure to store food, trash, and system compartments.

The birds will interact with the device via two terminals. One terminal allows the bird to drop items into a trash analysis chamber to validate whether it is a valid trash item. The other terminal allows food pellets to drop from a storage container to reward the bird upon successful submission of valid pieces of trash. However, the BIRDS will need a way to discard not disapproved items separate from the approved storage. The BIRDS will have at least two storage containers for the accepted trash and food storage respectively. The BIRDS is being designed for weekly maintenance for trash removal, food replenishments, and battery life without recharging.

Sensing

The BIRDS will make use of a capacitive motion sensor and an optically designed imaging system to detect and exclusively service birds. Another imaging system will validate whether the submitted item is trash, and a laser motion sensor will activate the BIRDS from a power efficient sleep mode.

To give timely and consistent responses for the birds, we need to design sensor systems for image processing of trash and birds in the trash analysis chamber and outside the terminals respectively. The capacitive bird motion sensor will be weatherproof and disregard natural movements in the surrounding environment such as wind, leaves falling, insects, etc. This is a more rudimentary motion sensor that will enable the more energy intensive image recognition sensor to save power. The laser motion sensor will detect if an object falls into the analysis and will communicate with the trash imaging system to take a picture of the fallen object. The imaging system will be able to view the entirety of the chamber and be calibrated for the mostly constant image conditions inside the device.

Preferably, both imaging systems will consume as little power as possible, but the low energy motion sensors will be used to turn on the imaging systems only if they detect motion. This will prove sufficient for the BIRDS to use minimal power.

Identification

As a natural extension of the previous objective, the BIRDS will need an image recognition software that can approve or disapprove a submitted item in an accurate and quick fashion. The software being used will be trained models on their respective systems for birds and for trash. These models will be run on a separate machine learning system that will be discussed later in more detail. In order to achieve our goal of rapidly rewarding birds if they bring trash, we must ensure we minimize a false negative occurrence.

Confusion Matrix

In any sort of statistics-based approach there is an important aspect that goes into the prediction that is not just the probability of guessing right. There is something called a confusion table or sometimes referred to as a confusion matrix. This is a table that can show extra details about how the data is being picked accurately or inaccurately. In machine learning this is used the same exact way.

A confusion matrix using a binary classification such as ours is a 2 by 2 table that consists of the rows being the actual condition or the label, and the columns being the predicted condition or the prediction. When filled in properly this makes a confusion matrix with the 4 squares inside being labeled as follows, true positive, false negative, false positive, and finally true negative. Let us take the example of our bird classifier, a true positive is when both the label and the prediction match the expected value of both being the same and both being saying that a bird is front of our system. A false negative is where the actual classification a positive

value, but the predicted value was negative, so there was a bird in front of the system, but the classifier said that it was not a bird. A false positive where the actual classification is false, but the predicted value was true, so there was not a bird in front of our system and the classifier thinks there was. The final one being a true negative where both the actual classification and the predicted classification agree that both are negative, so this is when there is not a bird in front of our system and the classifier also agrees that there is no bird in front of our system.

Final Confusion Matrix Choices

With both of our systems it is important that we do our best to minimize one of these outcomes while trying to maximize the correct responses. For the bird system it would be best to minimize a false positive. Our reasoning for this is that the most common animal to try to take down bird houses are squirrels. Because of squirrels always being destructive to bird houses, we must limit the access of squirrels at all costs. With our housing being tamper proof and our image classifier minimizing the chance of guessing a bird when a squirrel is in front of our housing, this will limit the destructive nature that the squirrels always tend to have in bird feeders.

In the trash system minimizing one particular part of the matrix becomes a bit more challenging. The question to ask is to either be okay with rewarding birds for bringing something that is not trash like a stick, or to be okay with not rewarding birds when they bring trash. Both of these options would have a negative effect on training of the birds. With the first option, there might be times where the bird associates stick with the correct object to bring. This means that the bird just associated bring a stick, which is everywhere for birds, with being rewarded with food. This leads to the bird learning that sticks give you food which is not the intention. On the other hand, the opposite option begins to not reward birds with proper objects being brought. This leads to birds associating trash with nothing at all. This will cause birds to not want to go out their way to bring anything to our system. In the beginning it felt hard to select which option was best for our means of training. After giving it more thought we concluded that rewarding negative behavior, the bird bringing a stick, would be worse than not rewarding positive behavior. This is similar to how training any animal works that you never want to reward negative behavior if you want it to stop. This makes our final option to minimize the false positive where the bird brings something that isn't trash and gets rewarded for it.

Actuators

The objects brought by birds and food dispensed to birds must get to where they are designed to go. For this to occur with minimal time and energy, we need to design mechanical and electrical systems to dispense a certain amount of food and collect or disregard submitted items from the trash analysis chamber. Simple mechanical systems will be employed to avoid wear, maintenance, and to function in most weather conditions.

Lastly, a mechanical and electrical system to close and open the terminals for use. Such doors should be designed to optimize weather proofness.

Power

For the BIRDS to operate autonomously for weeks, we need to design a power system that will supply all the subsystems on battery alone for at least a week. And to integrate a solar array for continuous charging of the battery.

As much as we would love a totally independent power source, the BIRDS will need charging ports and access to power functions from the outside.

In order to achieve long-lasting independent operation, the BIRDS will initiate a sleep mode when not in use. Then, through the use of low power motion sensors, the BIRDS will awake for higher level processing.

Embedded Processing

We will design the control and processing units to coordinate and operate all the subsystems. The BIRDS will be designed for ease of maintenance and should include a battery charge indicator, activity log, and perhaps a recorded image log. For further ease of use, the BIRDS should have externally accessible data ports to interphase with the processor for activity logs or error messages.

Along with battery charge indicators, there should be some indicator for food running low and trash being full. This could easily be accomplished with a transparent section on the storage units or with a more complex electrical sensor and display.

To be able to handle the heavy computational cost of image recognition software, the BIRDS will operate using two sets of processors. One energy efficient central processor that will manage and control all subsystems and a higher power processor for the image recognition.

2.4.1 System Block Diagrams

In this section, diagrams representing the parts our system are presented for helpful visualization of the scope of our project. In the two figures below are the developed hardware and software diagrams for the BIRDS.
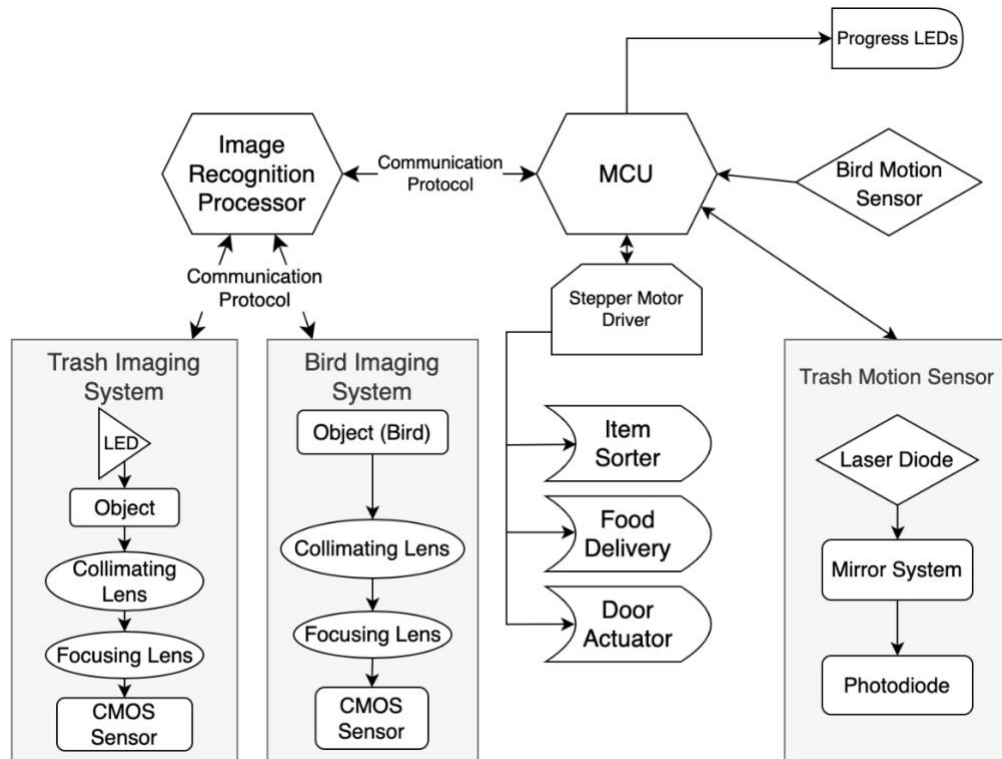
Figure 2.4.1.1. Hardware Flow Diagram
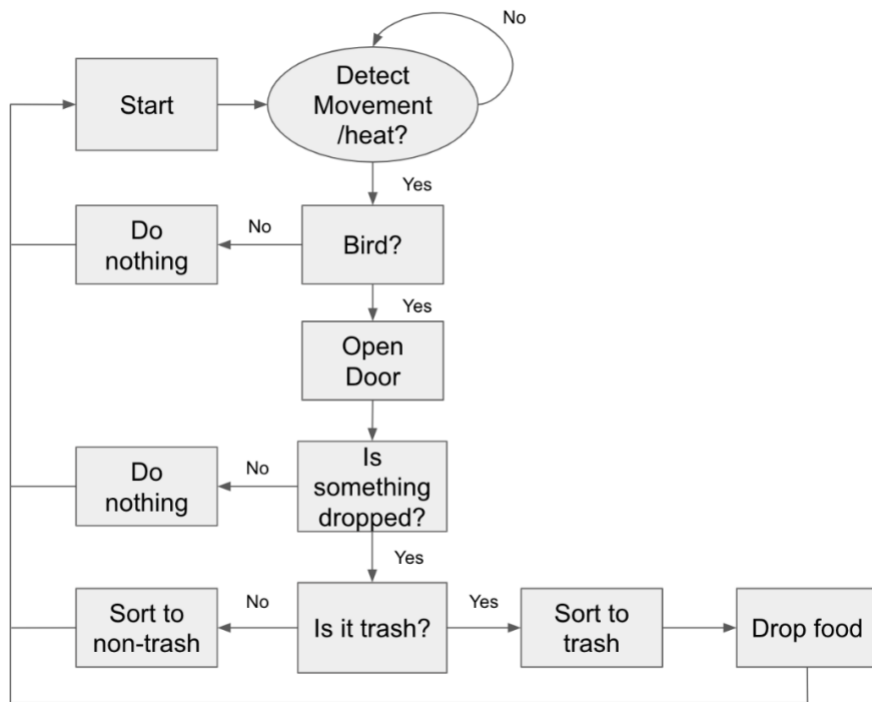
Figure 2.4.1.2. Software Flow Diagram

2.5 Required Components

This section of our report provides the key component specifications and engineering requirements that make our project unique. These specifications and requirements will be the driving forces for our design process, as they will create our best possible design. The primary consumer of the BIRDS is intended to be local governments, large universities, and environmental companies in a densely populated area. To meet the needs of the consumer, part specifications are given. The overall housing unit is still in the design phase; however, the electrical and optical hardware constraints are shown.

Table 2.5.1. Component Specifications

Type	Component	Parameter	Specification
Electrical	Power Supply	Charge Density	Power all functions for a week
	PCB	Central Control	Low power draw
	Solar Cell	Charge Amount	Enough to charge the sleep draw
	Motors	Reliability	Operate without fail 95% of the time
	Image Processor	Computational Power	Deliver a verdict within 2 seconds of taking the image.
	Status Displays	Human Interface	Simple, cheap, and weatherproof
Optical	Focusing Lens (Trash)	Focal Length	4mm
	Collimating Lens (Trash)	Field of view	80°
	Red Laser Module	Spot Size	6mm @ 5m distance
	Photodiode	Wavelength Range	400-1100nm
	CMOS Sensor (Trash Cam)	Resolution	640 x 480
	Mirror	Wavelength Range	400-700nm

	CMOS Sensor (Bird)	Sensor Size, Resolution	640 x 480
	Focusing Lens (Bird)	Focal Length	~5 mm or less
	Collimating Lens (Bird)	Field of View	120°
	Aperture (Bird)	Aperture Size	f/2.8 or higher

Table 2.5.2. Engineering Requirements

System	Specification
Accuracy of the Bird Image Recognition	≥ 60%
Accuracy of the Trash Image Recognition	≥ 90%
Accuracy of the Bird Motion Sensor	≥ 50%
Accuracy of the Trash Motion Sensor	≥ 95%
Time duration of Input Door from Bird Detection	≤ 3 sec
Time duration of Trash Sorter verdict	≤ 3 sec
Time duration of Food Dispenser from Trash approval	≤ 2 sec
Solar Cells/Power System ability to power BIRDS for	≥ 1 week

2.5.1 House of Quality Analysis

The figure below shows our House of Quality for the BIRDS. The House of Quality characterizes the relationships between the customer requirements and the function requirements of our system, showing which relationships and characteristics must be considered most in our development and design.

Figure 2.5.1.1. BIRDS House of Quality

Legend

Symbol	Meaning	
Θ	Strong Relationship	
O	Moderate Relationship	3
▲	Weak Relationship	1
╫	Strong Positive Correlation	
+	Positive Correlation	
—	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
X	Objective Is To Hit Target	

Column #				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)				▲	▲	▲	▲	X	▲	▲	▲	X	▲	▲	X	▲	X	▲
Row # / Max Rel / Rel Wt / Wt Imp / Demanded Quality				Fast Image Processing	Low Power Modes	Sealed Compartments	Easy Access to Components	Human Interfaces	Enjoyable Terminals for birds	Supplementary Visual Stimuli	Supplementary Additive Stimuli	"Loading" Feedback	Larger Trash Data Sets	Strong Image Recognition Software	Well Lit Analysis Chamber	Low Power Components	Communication Port to Processors	Large Storage Compartments

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality	Dir	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	9	13.9	5.0	Fast Trash Submitting Response	▲	Θ	O			▲				▲	Θ	Θ	O	Θ		
2	9	11.1	4.0	Long Lasting Autonomous Operation	▲	Θ	Θ	O	▲	O	▲	▲	▲	▲				Θ		Θ
3	9	13.9	5.0	Weatherproof	▲			Θ	Θ		Θ									O
4	9	8.3	3.0	Ease of Maintenance	X	▲	▲	Θ	Θ	O	O			▲				▲	Θ	Θ
5	9	11.1	4.0	Ease of Bird Use	X	▲	Θ				Θ	▲	▲	▲						
6	9	13.9	5.0	Effective Action Feedback	X		▲				▲	O	O	O		Θ				
7	9	2.8	1.0	Pleasing Aesthetic	▲			O	O	Θ	Θ	Θ	Θ	Θ				▲		Θ
8	9	8.3	3.0	Broad Trash Categories	▲										Θ	O	O			
9	9	13.9	5.0	Consistent Dependable Results	X	Θ			▲						O	Θ	Θ			
10	9	2.8	1.0	Activity Log	X	▲				Θ							O		Θ	

Target or Limit Value	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Too Power Hungry	Too Slow to Boot			Power Indicator				Display Current State		Clear and Consistent View			Access to Activity Log	Food and Trash
Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	7	8	6	6	4	6	0	0	0	9	9	0	4	1	3
Max Relationship Value in Column	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Weight / Importance	372.2	263.9	255.6	219.4	122.2	300.0	88.9	88.9	111.1	241.7	400.0	200.0	236.1	100.0	241.7
Relative Weight	11.5	8.1	7.9	6.8	3.8	9.3	2.7	2.7	3.4	7.5	12.3	6.2	7.3	3.1	7.5

3. Research

In this section, numerous technologies and current products that have been thoroughly investigated by our team are discussed and compared with the technology we wish to implement for the BIRDS. The components that will be implemented into the BIRDS were investigated and discussed below, along with part selections for the key components of the system.

3.1 The Bird Training Process

It is crucial for our team to research and understand the basics of bird psychology and behavioral characteristics; otherwise, the BIRDS may become another post

for birds to rest on without enjoying the full functionalities. However, it is important to note that this project seeks to achieve the core goal of designing and building an apparatus that will carry out all the necessary tasks should a bird bring trash to the unit. Our goal is not having birds fully trained with the BIRDS to bring trash in exchange for food by the end of our project. Our hope is that teams down the road will take on the task of assisting in training birds to use this system.

One key feature of birds is their intelligence compared to other animals, including primates. Some birds are especially known for their brilliant minds, like corvids and psittacines. They are considered among the most intelligent animals, and crows, specifically, have almost identical proportions of brain mass to body mass when compared with chimpanzees. [1] The brains of parrots and songbirds contain on average twice as many neurons as primate brains of the same mass, indicating that avian brains have higher neuron packing densities than mammalian brains. Additionally, corvids and parrots have much higher proportions of brain neurons located in the pallial telencephalon compared with primates or other mammals and birds. [2] Birds are beautiful creatures that we believe should be studied further to find more ways of mutually benefiting them and humans.

3.1.1 Feeding Behavior

Understanding their intelligence, we can easily see why birds exhibit remarkable problem-solving abilities related to obtaining food. They can navigate complex obstacles and puzzles to access food rewards, and some bird species exhibit tool usage in their foraging behaviors. For example, New Caledonian crows are one of only a handful of birds that forage with tools. They utilize hook-shaped sticks that they fashion from twigs to fish out grubs and other bugs from hard-to-reach places, like trees. [3] Other birds have demonstrated this behavior in a closed environment. [4]

In some cases, birds learn about food sources and foraging techniques from other birds and species. This can involve observing the feeding habits of more experienced individuals and imitating their behavior. The reason this is important is due to the hypothesis, termed "behavioral drive", about behavioral innovation and social transmission, referring to the non-genetic spreading of a new skill among a species. [5] When animals show both frequent innovation and fast social learning, new behaviors can spread more rapidly through populations. [6] On a university campus in Japan, Carrion crows have been observed dropping nuts in the road. While cars are stopped at a red light, the birds hop in the road and place walnuts in the middle of the street. After the lights turn green, the birds fly away and vehicles drive over the nuts, cracking them open. Finally, the crows fly back to the road when it is safe and eat their food. The crows have been observed doing this since the 1990s, and today, more and more crows have joined in on the walnut cracking. [7] In a study done in 2007, random, wild pigeons were put to four different tests. Two of these tests involved innovation and social learning. The results showed a strong correlation between innovation and social learning as the majority of the birds that passed the innovative test also passed the social test.

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These researchers believe the co-occurrence of innovativeness and social learning is a pre-requisite for the potentially accelerating effect of cognition on evolutionary rate. [6]

As research is discovering more ways that birds are innovating and sharing behaviors, we hope this strengthens our goal of birds learning how to use the BIRDS very rapidly and efficiently in groups.

Another important factor in the feeding behavior of birds is what they like to eat. The type of food used in the BIRDS will attract different species of birds. Based on research shown above, corvids, psittacines, and columbidaes have been found to be the more intelligent birds and are the specific families of birds we are looking to attract; however, the BIRDS will be designed to accommodate any birds that bring trash.

Food enjoyed by the corvid, psittacines, and columbidaes are typically seeds, fruits and cracked corn. Specifically, corn is desired by larger birds, and it can be fed in small amounts, mixed with white proso millet, on platform feeders. However, with millet, this food can attract unwelcome species which is accounted for with our bird imaging system. [8]

3.2 Current Market Offerings

In this section, we will discuss relevant market offerings available to the public. The design philosophy and performance characteristics of each will be compared to the BIRDS in a detailed discussion below.

3.2.1 The CrowBox

One of the previous products that was foundational to our motivation behind the BIRDS is the CrowBox. Joshua Klein invented the CrowBox after an intensive study of corvid behavior. His idea was to create a housing unit that would entice crows to collect coins found in nature and bring them in exchange for food. The motivation behind the CrowBox was to work with synanthropic species, like crows, rather than continuing to live in frustration with them. Klein wanted to find a way to live mutualistically with crows. His end goals of the CrowBox are to eventually train crows to pick up trash after large events, find reusable components in discarded electronics, or even assist with search and rescue operations. Finding an equilibrium with crows and other synanthropic species may improve our lives more than we may think.

The CrowBox was specifically designed to be easily shipped and assembled by the customers themselves in an inexpensive way. This differs from our BIRDS, where the complexities and fragility of some of the components, such as the camera and mirrors, do not lend themselves to be easily assembled by the user.

They utilize a very simple and inexpensive system to achieve the same goal, of training birds to deposit a desired object. However, currently, the crow box is only designed to train birds to deposit coins into it. This differs from the BIRDS. The BIRDS is meant to train birds to deposit trash for a food reward. And the BIRDS is able to change which object it will accept though a simple software update. While much more expensive than the Crow Box, a single BIRDS housing can be utilized to train birds to pick up multiple types of objects.

Due to the simplistic design of the CrowBox, their response times are very fast. When a bird arrives, they have a pressure sensitive pad that enables the CrowBox's functions. Once a bird deposits a coin, the coin is maneuvered in such a way that it bridges the connection of two conductors, therefore signaling a coin deposit. Since they are simply reading a voltage drop, their response time is almost immediate. However, the time it takes for the birds to gain access to the food reward was around 2 seconds after trash detection.

Due to the simplicity of their design, any conductive material, small enough to fit through the deposit terminal will activate the reward. Not to mention, their design seems very hopeful that birds will not deposit any foreign objects that may clog up their narrow coin detector. While the BIRDS is much slower than the CrowBox, the added flexibility and robustness may be a worthwhile compromise that only the BIRDS seems to offer.

3.2.2 The Birdbox

Made and designed by Hans Forsberg, the Birdbox was started as an amateur hobbyist project for Forsberg to see if he could train his local birds to pick up bottle caps. He recorded his progress in a YouTube channel by his own name. His ultimate design utilized a simple metal detector that would trigger a motor to release food.

Because of the simplicity of their detection system, the trash detection is almost immediate, however, due to the way he designed the food delivery system, the food takes about 3 seconds to arrive from the initial trigger. This 3 second delay, nonetheless, seemed to be sufficient for his test birds to make the association between trash submittal and food reward.

Similar to the CrowBox, the Birdbox does not discriminate between trash types. As long as it is conductive, in the case of the CrowBox, or able to interact with magnetic fields, in the case of the Birdbox, the trash will trigger a food reward. Additionally, both the CrowBox and Birdbox seem to have narrow detection chutes that are liable to clog.

As stated with the CrowBox, the BIRDS is different from these examples because of the unique trash discrimination system, that through the use of image recognition, is able to distinguish between a variety of trash types and is able to reward which everyone through software, instead of hardware.

3.2.3 The Smart Bird Feeder

Another similar product to the BIRDS is a past Senior Design project at the University of Central Florida entitled the Smart Bird Feeder. This team of young engineers wanted to create a bird feeder that would deter squirrels and allow users to easily take care of the feeder. They utilized a computer vision machine learning model to identify between squirrels and birds as well as the species of birds. The students designed a user-friendly interface via a phone application for consumers to see what type of birds come across their feeder, and a notification system was designed to alert users when more food needed to be added to the Smart Bird Feeder.

Very similar to our own BIRDS in that the Smart Bird Feeder utilizes image recognition to detect birds and act accordingly. However, unlike the Smart Bird Feeder, who was more focused on user experience with their own mobile application, the BIRDS is designed to train birds to submit a certain object in the hopes of a food reward. The approaches are similar, but the goals are vastly different. The Smart Bird Feeder was more focused on capturing images with a higher quality for species recognition, while our system will be more focused on quickly identifying the resemblance of a bird without the need for high image quality.

3.2.4 Smart Bird Feeder by Bird Buddy

The final existing product we investigated was the Smart Bird Feeder by Bird Buddy, which is currently offered on the market. This bird feeder features an AI-powered camera that captures high-quality photos of birds as they feed. Like the feeder developed as a part of the Smart Bird Feeder Senior Design project described in the previous section, Bird Buddy's Smart Bird Feeder connects to an app that features what they call postcards of images that are sent to the user's phone when the camera captures the birds in action. Their product is catered towards birdwatchers and bird lovers that desire the entertainment of having a closer look at their avian friends.

Unique characteristics of Bird Buddy's Smart Bird Feeder, when compared with the other investigated products in this market comparison section, include the high-resolution camera module, solar panel integration option, and other features across a lineup of bundles with additional accessories. The base model of the Smart Feeder offered by Bird Buddy online starts at $239, with occasional dips in pricing due to seasonal discounts that have been observed by our team. This base model features the bird feeder housing unit, with a built-in 5MP camera module for capturing high-resolution photos. The camera boasts a built-in laser motion detector for activating Bird Biddy's so-called postcard process of image capturing, which saves power since the system isn't always running at full capacity. The camera also boasts an expansive 120° wide angle field of view. For charging, the system comes with a USB-C to USB-C cable, which takes about 2-4 hours to

charge for the feeder to then last for 5-15 days, depending on various usage factors, like the amount of activity the feeder gets, with more activity having a negative effect on battery life.

The second option for the Smart Bird Feeder sold online features a solar roof, a solar panel add-on for the roof of the housing, which has shown to improve the battery life of the camera module so manual charging of the battery isn't needed as often. This option runs at a price of $299, and the solar panel add-on is also sold separately, but for a steeper additional cost of $89, when compared with the solar panel bundle. Bird Buddy's lineup of features for their Smart Bird Feeder even includes enhancements for feeding. These features include an extended perch attachment for the landing pad of the feeder and a so-called nutrition set featuring a holder for pieces of fruit to entice birds even more.

Another key feature we found on the Smart Bird Feeder is what Bird Buddy calls the deep sleep mode for the feeder. According to the specifications on their website's support page, this deep sleep mode is a power-saving feature that automatically activates an hour after sunset and deactivates an hour before sunset as an overnight lower-power mode. Battery life for the camera module is just about doubled when this mode is activated. In addition to this deep sleep mode, the camera module also has an LED that lights up in various ways, with different colors and blinking patterns, for different system alerts. This could be a useful feature to integrate into the system for our project, as it would provide a user-friendly experience by easily alerting users of different processes, statuses, or needs for the feeder.

Lastly, the feeder housing and seed container specifications are outlined in the same support information location as the camera module information on the Bird Buddy website. The Smart Bird Feeder seed container has an easy access point and comes with an easy-to-use scoop that cooperates with the opening hatch of the seed container. The ease of use when refilling the feeder, which is an important consumer-friendly feature, will be yet another key point of consideration for our design of the BIRDS.

3.2.5 Comparison with BIRDS

These existing products that have been outlined provide a basis for how we will design our system. The CrowBox, the Birdbox, the Smart Bird Feeder Senior Design project, and the Smart Bird Feeder by Bird Buddy each have their own pros and cons, and we hope to apply a combination of the pros from each to our own design the BIRDS. Knowing the downfalls of these products on the market will allow us to learn from these projects and designs so that we can build a structure with the ability to train birds to pick up trash.

Below is a comparison of all the relevant technologies that were investigated as a part of our research into existing products. Table 3.2.1 compares the products to

our planned design for the BIRDS, with points of comparison including generic features the products possess.

Table 3.2.1. Bird Feeder Market Offering Comparison

Bird Feeder Features	Smart Bird Feeder (SD G7, 2021)	Smart Bird Feeder (Bird Buddy)	The CrowBox	The Birdbox	Our System (BIRDS)
Bird recognition (imaging system)	X	X			X
Birdhouse aesthetics	X	X			X
Food easily refillable	X	X	X	X	X
Food protection (defense feature)	X		X	X	X
Solar-powered option		X			X
Food given as reward for item			X	X	X
Trash collected by system				X	X

To highlight some of the key compared features, attention should be drawn to the upper and lower parts of the comparison table. Overall, our goal for BIRDS is to integrate the bird recognition capabilities, shown by both Smart Bird Feeders, with the motivation for birds to bring items, specifically trash in our case, to the feeder, exemplified in the CrowBox and Birdbox. Our design aims to implement the advantages of each existing product into a new singular product.

3.3 Relevant Technologies

Described below are some relevant technologies researched in order to better understand how to design the best product possible. This section includes research on technologies available for the optical, electronic, computer, and mechanical applications we wish to perform with the BIRDS.

3.3.1 Bird Housing Architecture

This section covers current general decisions about the use of technology for the BIRDS housing architecture. The knowledge gained from this investigation will assist us in designing the most attractive structure possible for birds to enjoy using the BIRDS.

<u>**Landing Pad Appeal**</u>

To attract birds to the BIRDS, we must design the housing so that it is suitable and enjoyable for birds to land on. An appealing and advantageous landing area for birds that gives them an optimal and comfortable experience will prove to be key in the progression of our goals and objectives for the BIRDS. In the Smart Bird Feeder Senior Design project, the landing area for birds was a rod positioned directly in front of the feeder, which made it natural and easy for birds to have something to grip onto when feeding. As another design example we referred to, the commercial Smart Bird Feeder made by Bird Buddy utilizes a brightly colored, visually appealing, and grippy landing pad for birds to land on when feeding. For our project, we anticipate designing an appealing and comfortable landing area for birds to come and both dispose of trash and feed from the bird feeder. Therefore, we decided that a platform positioned in front of the dispenser for birds to land on and have sufficient space seems to be the most natural and appealing design.

There are many different structures that make up the whole system of our bird feeder. Due to the many electronic and optical systems that need to be housed, we have chosen a typical house-like design that will act as a platform dispenser. Most of the physical structure will be housing and aesthetics, which are areas that will not be captured by the bird camera, and then the area where the action will be happening will be a platform attached to the front of the feeder. The bird imaging system will only image birds that land on this front platform of the structure, which will be the landing pad. To prevent birds from landing on other parts of their structures, some designers created products that utilize bird deterrents on their feeders in the form of physical structures on these specific parts of the feeder that they don't want the birds to get distracted by and land on. Spikes and sharp corners prevent the birds from landing on surfaces of the feeder that the designers don't want the birds landing on, like the roof of the house structure, for example. We will design a housing unit that does not have these obstacles out of a desire to encourage birds to land on the BIRDS and to promote safety for our avian friends.

3.3.2 Motion Sensors

In order to the detect the presence of birds and trash, the BIRDS will make use of peripheral devices needed for our design is the sensors that will be used to communicate with the central control unit on when to turn on the bird and trash camera systems. The cameras within our system will resort to a sleep mode in which power is conserved, and the sensors will serve as the means by which the cameras will be turned on for imaging. These sensors will need to be fast enough to provide minimal delay between detecting the bird and rewarding the bird. They will also need to be cheap and operate at a low power so that their use is worth the time and cost of implementation.

First, there will be a sensor for activating the bird camera system. The sensor for activating this imaging system will need to operate quickly enough for the controller to be notified, activate the camera, and take a picture, ideally of the bird on the

landing pad. It will need to operate at a low power that makes its addition to the system and assistance in lowering overall power consumption worth the extra cost and commitment. Options including a motion sensor and a touch sensor were considered and are outlined in the following sections. In addition to a sensor for bird imaging, a sensor for activating the camera for the trash imaging system will be needed to conserve the power consumed by the camera of the trash subsystem running. This sensor will need to operate quick enough to minimize the time it takes for food to be dispensed to reward the bird before it leaves. Decreasing this time delay will be a crucial part of our system's design. Research of the optical and electronic capabilities of various options for bird and trash sensing was done, and the following sections outline the options we considered in our project development and design of the sensors for our optical subsystems. Research and development of the optical subsystems controlled by these sensors is detailed in 3.4.5.

<u>Infrared Motion Sensor</u>

Knowing that power consumption would be too high if the external camera system for bird detection was always running, we anticipated the need for a low-power activation system for the camera. This section outlines the thought process and research conducted on the possibility for a passive motion sensor to be implemented so that problems with battery consumption could be minimized.

The idea was to have a motion sensor, placed at a similar vantage point to the camera, that would activate the camera upon sensing a movement in the proximity of the landing pad. The idea was to use a passive infrared (PIR) motion sensor, typically used to detect human body heat signatures, and tune it to detect the unique heat signatures of birds. Another idea was to use an ultrasonic sensor, serving the same purpose as the motion sensor of activating the imaging upon detection of movement near the landing pad. The sensors would be adjusted to specifically detect the area surrounding and including the landing pad for the birds, in attempt to isolate birds in our detection.

A PIR motion sensor has two slots that are sensitive to IR radiation, and when a warm body like a human, or a bird in our case, passes between the two sensing paths from each slot, a differential is detected upon the body leaving one of the paths. Like the creators of the Smart Bird Feeder mentioned in their motion sensor selection and comparison for their senior design project in 2021, using a simple line-of-sight laser sensor with a photodiode would create too much sensitivity and, therefore, too many false positives for our system. Since the laser trips when obstructed or when it is moved itself in any way, we would run the risk of the camera activating for too many movement detections that aren't birds. Even movement of the system itself because of wind or another animal interacting with the system would cause the sensor to trip. Therefore, this laser sensor system will be exclusive to just the trash chamber, detailed in 3.2.5.3, because the trash chamber will be less prone to unwanted activations from movement. The trash laser sensor will be fixed to the trash chamber it will be imaging, and so it will not run much of a risk of false positive activations from the entire system moving

around. Using an external laser sensor, on the other hand, would make the activation system very prone to movements in its field of view of the immediate environment.

When researching applicable motion sensors, we struggled finding a solution capable of isolating only birds before turning on the camera for image recognition. Because of factors including sensitivity, accuracy, and feasibility, we scrapped the motion sensor for a capacitive touch sensor built into the landing pad of the feeder. This alternative camera activation is detailed in the following section.

Capacitive Motion Sensor

The magic behind the technology that is utilized today in touch screens and sensors is the capacitive sensor. Capacitive sensors work by charging and reading the length of time it takes to discharge the energy stored in the parasitic capacitance when something that can retain charge touches the reading node. This node can be extended as long as desired, therefore making it a great option for a sensing pad for our bird detection system.

For the BIRDS, we will utilize a large, one-bit, capacitive sensor to detect if something has landed on the landing pad of the BIRDS. A change in charge will indicate a subject of interest as landed on the landing pad and wake the bird analysis camera system. The simplicity of this approach for camera activation gives it a great advantage over the motion sensor, and the images captured upon sensing will have a much higher probability of being clear.

Bird Motion Sensor Comparison

The two options for the bird sensor to activate the bird camera were the PIR motion sensor and the capacitive touch sensor. Logically, a motion sensor would activate upon a bird approaching in the air. Taking this situation into careful consideration, we would run the risk of an image that is either motion blurred or just not clear enough because of the lack of control we have over where the bird is in relation to the camera sensor. Since we will be working with a fixed focal length camera, the object of interest, the bird, must be relatively close to a distance equal to the focal length away from the camera sensor where the image will be formed. Without control over where and when the bird will be sensed, the motion sensor option is at a serious disadvantage.

The second option we had was the capacitive sensor. With a touch-based sensor that senses upon a bird having landed on the landing pad of the feeder, we would have more of an ability to control the working distance of the imaging system. A fixed size landing pad along with a sensor built into that landing pad would make the bird sensing happen and the image be taken at a relatively fixed distance, depending on how far apart we design the camera and landing area to be. As long as the focal length of the designed bird lens system is matched with this distance that the bird will be on the landing pad from the camera, the image that is taken

will be of sufficient resolution. It is because of this ease of control over where and when the bird is sensed that we decided to select and implement the capacitive sensor as the sensing for the bird detection system of the BIRDS.

It's also worth noting that this capacitive touch sensor will be useful if we perform the same second stage of bird training and acclamation that the creator of the Crow Box used in development. The second acclamation stage for the Crow Box is a system that opens the food for the bird to feed on when the bird lands on the feeder. This stage slowly gives a bird the awareness of the system opening when it lands, as birds that have landed on the feeder for the first time will most likely be scared by the sudden movement of the door covering the food. This is yet another reason why the capacitive sensor was a cool and beneficial selection for the bird sensor of the BIRDS.

Laser Motion Sensor

In order to accurately detect if an object falls into the trash chamber, we will design a laser sensor system. If any object breaks the plane of the laser grid, a signal will be sent to the trash imaging sensor to take a picture of what has landed in the chute. This allows for a passive mode of the imaging sensor to use less power.

The Baumer retro-reflective sensor was researched and compared with the BIRDS laser motion sensor design. This sensor is designed to change its state when the object breaks the light beam, or when the photosensor receives no light for a brief period of time. Its response time is less than 100µs and the emitter and receiver components are located within the same housing. The reflectors can be used in close range without signal breakdown. This specification would be useful to the BIRDS as the laser motion sensor will be implemented in the tight space of the trash analysis chamber. There is also a mounting option with this technology which would allow for less mechanical design to build it onto the chamber.

However, Baumer's retro-reflective sensor is bulkier than we would like, tending towards more mechanical design needed for adding the component. It is rather expensive compared to buying three separate components: laser diode, mirrors, and a photodiode. Additionally, it draws a lot of power requiring an 11V DC input. [9] Very little power would be needed for a low power laser and photodiode designed for the BIRDS.

Table 3.3.2.1. Laser Motion Sensor Technology Comparison

Technology	Price	Power	Size (l x w x h, cm)	Response Time
Baumer	$300	11V	2 x 3 x 3	< 1us
BIRDS Laser Grid	< $50	5V	1 x 2 x 2	50us

3.3.3 Image Detection

The image detection capabilities of the BIRDS is paramount to the overall design as accurate determination of birds and trash enables the BIRDS to move into higher order functions to reach the end goal of feeding birds that brought trash.

Hardware

The specific hardware needed to properly image birds and trash are a lens system, an imaging sensor, and an interface. Research into each of these components will be delved into in further sections. Here, we seek to compare presently available imaging technology, specifically bird imaging and trash imaging, with the BIRDS two imaging systems.

Specim is a well-known hyperspectral imaging company specializing in imaging systems to capture data on trash, food, minerals, medicine, etc. Hyperspectral imaging is a powerful technology combining spectroscopy with imaging capability. It enables gathering detailed information about the composition and characteristics of objects and surfaces in a way that is impossible with conventional imaging systems.

[10] most advanced trash imaging technology is the FX17. This camera is designed to collect hyperspectral data in the near-infrared (NIR) region (900 to 1700 nm). It is best suited for determining food and feed quality, waste sorting, and recycling. The FX17 is a line-scan camera with a push broom feature allowing for a full spectrum for each spatial position to be measured simultaneously. It detects different plastic types and measures hundreds of color bands rather than just red, green, and blue like most cameras. On the other hand, this technology is very expensive with the many features it contains. Its size is much too big to efficiently fit within the BIRDS and it draws a lot of power.

Another imaging technology dealing more specifically with birds is the AXIS F2105-RE Standard Sensor. A specific example of this technology in use is in the case of the west Texas hummingbird feeders. The feeding sites are monitored using an AXIS F2105-RE Sensor Unit paired with an AXIS F41 Main Unit. The smaller-sized technology captures activity in high-definition resolution and high-quality audio and streams the live footage at 30 frames per second. [11] The audio aspect is an additional feature that the BIRDS will not offer. This imager offers up to 1080p at 30 fps with a 108° horizontal field of view, and good low-light performance in color. The AXIS F2105-RE Standard Sensor is ideal for installation outdoors. It uses cables with connectors to withstand vibrations and ensure a ruggedized installation. It can be installed practically anywhere, and it is reliable under rough conditions, withstanding temperatures as low as -40 °C and as high as 70°C intermittently. [12]

Table 3.3.3.1. Trash Imaging System Technology Comparison

Technology	Price	Power	Size (l x w x h, cm)	Imaging Type	Video Rate
Specim FX17	$15,000	12V	85 x 150 x 75	Hyperspectral Image	527 fps
AXIS	Inquired	5V	4.6 x 2.9 x 10	High Definition	30 fps
BIRDS CMOS	$50-$100	2.5V	5 x 6 x 8	Object Shape/ Outline	100 fps

Software

With the emergence of convolutional neural networks and the rise of processing power image detection has become very popular. Something that could once only be done on the most powerful of computers can now be done on edge computing devices. Some of the most popular image detection software that is used are things like OpenCV, YOLO (You Only Look Once), and Region-based Convolutional Neural Networks. All of these are very similar in the sense that they require some neural network to be trained and through the clever use of filtering and convolutions we can detect objects in an image. In the upcoming sections we will discuss how we plan on using this technology and compare some different frameworks for machine learning that we will employ in order to achieve our goals.

3.3.4 Autonomous Charging

For our advanced goal of prolonged autonomous operations, implementing some type of self-charging mechanism seems like an appealing technology to implement into the BIRDS.

However, implementing a self-charging system is always appealing, it requires additional complexity in the power circuit. It requires voltage regulators and then a mechanism to charge the batteries while in use, which can be challenging.

Solar Cells

"Solar cells operate on the principle of converting sunlight into electricity through the photovoltaic effect. At a high level, solar cells consist of semiconductor materials, commonly silicon, designed to absorb photons from sunlight. When photons strike the semiconductor material, they transfer their energy to electrons, causing them to become mobile and generate an electric current.

The semiconductor material in a solar cell is intentionally doped with specific impurities to create a p-n junction. This junction is a crucial element that facilitates the separation and movement of charge carriers. The energized electrons move through the semiconductor material, creating a flow of electricity. Metal contacts

placed on the cell's surface then capture this electric current, allowing it to be harnessed for practical use.

Essentially, solar cells transform sunlight into electrical power through a direct conversion process. This clean and renewable energy source has gained prominence in addressing global energy challenges, contributing significantly to the pursuit of sustainable and environmentally friendly power generation." [13]

Starting off with the most versatile and likely, the solar cell technology allows for access to at least some power directly off the sun. This unprecedented technology is able to provide power or charge the BIRDS' batteries during the day, greatly increasing the autonomous operations, now only limited by food and trash storage.

If we want to implement a solar charging system, we will require power converters to collect, convert, and provide a smooth voltage to either charge the battery or power the sleep mode of the BIRDS. However, implementing a power supply system that switches from different sources might be more challenging than continuously changing the battery. While implementing solar charging means that we will also need to implement additional power circuits, the generally stable amount of sunlight makes solar cells more manageable to regulate.

Wind Generator

Just like conventional power plants, wind generators produce AC current by spinning a generator by some kinetic force, however, in this case, the kinetic energy is captured from the wind by propellers.

To implement this, it would require us to design the entire housing around a aerodynamic and structural sound design to aid in wind capture. Not to mention the additional need for not only voltage regulation, but also AC to DC conversion that will further reduce whatever inconsistent power surges the wind turbine is able to capture. Also, the need for air flow will place a heavy restriction on where customers are able to place their BIRDS. And would probably require the BIRDS to abandon the mounted housing idea due to decreased wind flow.

In conclusion, we will not implement a Wind Generator to power the BIRDS.

Hydro-Electric Generation

Again, just like the wind generator, Hydro-Electric power would require us to place heavy design constrictions. Implementing a power generator that can generate useful amounts of power from rain would be a Senior Design project on its own right. The BIRDS does not need this added complexity.

3.3.5 Food Dispensers

In order to get the food reward from storage to the bird, the BIRDS will need to utilize some type of transportation technology. In this section, we will discuss some of the more practical dispensing mechanisms available.

Revolving Door

Figure 3.3.5.1. Revolving Door Mechanism Sketch

Popular with consumer pet dispensers, what we call Revolving Door dispensers deliver a certain amount of food by a revolving a plate with a hole that when it lines up with an opening on the floor, allows food to flow from storage to the destination.

The Revolving Door mechanism only requires one rotational actuator to rotate the plate from one position to another. While simple to implement, when food reserves run low, it is almost certain that there will be food left over, inaccessible for the birds, unless the plate and hole were at an angle. But nevertheless, this is a very well-known and simple mechanism we could implement.

Screw Conveyer

Another wildly popular transportation system for industrial settings, the Screw Conveyer mechanism utilizes a simple rotational actuator to push materials through piping. This is the same technology that vending machines utilize to dispense their items. By applying a rotational force, items on the screw experience a linear translational force. Unlike the Revolving Door mechanism, the Screw Conveyer seems to be more likely to dispense more food items before it is unable to further dispense items.
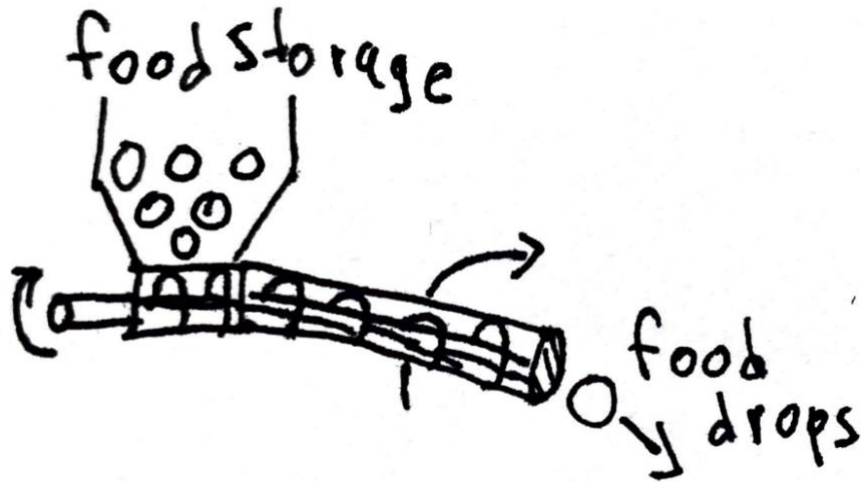
Figure 3.3.5.2. Screw Conveyer Mechanism Sketch

Vibrating Storage

Utilized by the Birdbox design, a Vibrating Storage mechanism delivers food by shaking the specifically designed storage until food drops. Because this mechanism is not as reliable and consistent in vibration duration, it is often paired with additional sensors to ensure that the motor will not stop until some food has been dropped.

Because of the unreliability and need for additional sensor, the BIRDS will not be using a Vibrating Storage mechanism.

Direct Food Storage Access

One of, if not the simplest way to get food to the birds, is to simply make an opening to the food storage that can be opened or closed. The previous Senior Design Smart Bird Feeder implemented a version of Direct Food Access for their birds that utilized a latch for bird vs squirl discrimination.

Figure 3.3.5.3. Direct Food Storage Access Sketch

While very simple to implement, we believe that it looks amateurish and causes some concerns for extended autonomous operation. Because the food storage is easily exposed, water or moisture could leak in, possibly spoiling the food before it is able to be dispensed. And since the BIRDS is intended to operate for long periods of time without maintenance, it is a liability. So, the BIRDS will probably nor utilize a Direct Food Access mechanism.

3.4 Core Components

In this section, we will unpack the research process leading to the selection of different components. Each part was chosen to best suit the BIRDS in accomplishing the goals previously stated.

The BIRDS will make use of several components for Low-Power Mode optimization and to enact the required behaviors to accomplish our goals.

The BIRDS will need at least two low-power sensors: one to activate the bird detection camera and one to activate the trash detection camera. These cameras and their image detection software will most likely be the most energy intensive systems in the BIRDS. Therefore, we want to minimize their utilization as much as possible.

Once a bird is detected and verified, the BIRDS will need an actuator to at least open the trash submittal terminal. Then, when the trash is detected and verified, it will use an actuator to sort the trash item into their storage container and another to dispense food to the bird.

3.4.1 Actuators

The moving parts of the BIRDS will make use of motors and actuators to open the trash submittal terminal, open the food delivery terminal, and rotate the trash sorter mechanism.

The following subsections will discuss all the available actuator technologies and discuss their compatibility with the BIRDS's goals.

DC Motor

"A DC (direct current) motor is an electric motor that converts electrical energy into mechanical motion. It operates on the principles of electromagnetic induction and the Lorentz force. The motor consists of an armature (a coil of wire), a stationary stator (containing magnets or field windings), and a commutator (a split ring attached to the armature).

When an electric current flows through the coil in the armature, it generates a magnetic field. This magnetic field interacts with the fixed stator magnetic field, resulting in the Lorentz force, which creates a torque, causing the armature to rotate. The commutator is responsible for reversing the direction of the current flow in the coil, ensuring continuous rotation of the motor.

There are various types of DC motors, including brushed and brushless varieties, which differ in commutation methods and efficiency. Brushed DC motors use physical brushes and a commutator, while brushless DC motors employ electronic control and sensors for commutation, offering improved efficiency and reliability." [13]

To control the speed, you can implement a pulse width modulating signal into the input port, or you can get a dedicated DC motor driver board that controls its speed and rotational direction. There are a few variations of DC motors, the first is whether its brushed or brushless (brushed are generally cheaper but create more heat from friction, and therefore are less efficient; brushless can reach higher speeds and are more efficient, that being, more expensive), and the second is whether it provides rotary or linear motion.

For the BIRDS, we were considering DC motors to serve as a rotary actuator to drive the trash sorter and food dispenser. However, while being very simple to operate, the lack of fine positioning, precise torque application, and possible need for a dedicated driver board discourages us to utilize DC motors into the BIRDS.

Stepper Motor

One step higher in complexity, a stepper motor builds upon the simpler DC motor technology. A stepper motor uses direct current to induce a magnetic field that interacts with fixed magnetic fields in the body of the motor. Unlike DC motors, as

described by its name, a stepper motor takes steps that jumps to discrete ridges in the fixed magnetic field, almost acting like magnetic gears.

"A stepper motor consists of two key components: the stator and the rotor. The stator comprises coils or windings, while the rotor is equipped with teeth or magnetic areas that interact with the stator's magnetic poles.

Stepper motors are categorized by the number of phases they possess, typically two or four. Each phase involves a coil that can be electrically energized in a particular sequence to induce rotation.

To initiate movement, a specific phase is energized, and the magnetic field generated by that phase draws the rotor's teeth or magnetic regions towards it. These motors operate in discrete steps, with common sequences being "full step" and "half step." In full-step mode, each phase is energized sequentially, while in half-step mode, two phases can be energized simultaneously at varying levels to achieve smaller steps." [13]

These fixed steps allow for great control on positioning and torque. However, this technique requires a lot more complexity to operate than a simple DC motor. Stepper motors also operate with pulse width modulation signals, but since there are multiple phases to coordinate for one rotation, stepper motors need dedicated driver boards to operate. This complexity requires Stepper Motors to operate with a dedicated Stepper Driver board. This driver board requires several controller pins, 4 pins for the motor we were looking at, and a dedicated power source. We are interested in this technology for the precise control of rotation for possible application on the trash sorter and food dispenser. However, the increased complexity of operation and the need for at least 4 pins to control still remains a possible option but we would prefer for a simpler motor.

Servo Motor

Even more complex that stepper motors, servos work by a combination of sensors and actuators to achieve a desired position.

"The servo motor's precision arises from its closed-loop control system. This system employs the position feedback device to continually monitor the motor's current shaft position. This real-time feedback ensures that the motor is always aware of its exact position.

To guide the servo motor's movement, a target position, also known as the setpoint, is specified. The control circuit calculates the error, which represents the variance between the desired position and the motor's actual position.

A control signal, often in the form of a pulse-width-modulated (PWM) signal, is computed by the control circuit based on the error calculation. This signal regulates the voltage or current supplied to the motor, influencing its movement.

The motor responds to the control signal and initiates motion, adjusting itself until the feedback system confirms alignment with the desired position.

The servo motor continually fine-tunes its position by assessing the feedback against the target position, enabling it to respond quickly to any deviations. This adaptability makes servo motors well-suited for applications demanding precise and real-time control.

In addition to position control, servo motors also manage speed and acceleration. By modulating the control signal, they deliver smooth and controlled motion profiles. Furthermore, servo motors offer substantial torque output, even at low speeds, catering to applications that require both accuracy and strength." [13]

As a closed-loop control system, a servo motor uses sensors to provide feedback to its control system about its current position. Based on its feedback, a servo utilizes its actuator, that can be a DC or AC motor, to drive its position to a desired state. While having the most complex motor system, since it already includes its feedback and control system, servo motors have very simple interface. Servos usually only need one control pin and dedicated power supply. They are controlled by pulse width modulation to control speed and direction. For the BIRDS, this versatile motor could be implemented for trash analysis chamber and terminal door system. However, because of the nature of a closed-loop system, a servo motor has to constantly check and confirm its position, this means that even if it is not in use, it continues to draw current. This could be detrimental to the goal of energy efficiency, but we could simply divert power away from them until they are needed, but that adds complexity to the power circuit.

Solenoid Actuator

Probably the simplest actuator technology, a solenoid actuator has two states, extended and retracted. By running a current across a coil, it forms a magnetic field that then attracts or repels from a fixed magnetic core creating linear motion along an axis. This could be an interesting option for driving a rudimentary extending door. While simple, the extent of the linear motion varies, but most are very limited as to a few centimeters. This limited range, in addition with the substantial draw to maintain the piston activated for long periods of time makes the solenoid actuator an unsuitable choice for the BIRDS.

3.4.2 Light Emitters

Preferably, the BIRDS will use light emitters to supply additional stimulus for bird training and association. We believe that some type of display that illustrates the current stage of the BIRDS would be beneficial for the birds and for us to debug. In addition to training elements, the BIRDS will need a light emitting device to illuminate the trash analysis chamber for the camera to take a clear picture of any introduced item and to measure if an item is submitted to the trash analysis chamber.

LEDs

The easiest, most versatile, and cheapest in cost and power is the light emitting diode. We are most likely going to depend on LEDs for all illumination needs. Light emitting diodes work because of a specific PN semiconductor boundary configuration. By applying voltage across an LED, electrons are forced to move across that semiconductor boundary layer that because of electrons passing through, they go from a high energy state and release light of a specific wavelength as they cross the boundary layers. LEDs are by far the most energy efficient light emitting device out there. For the current-stage display, we can have an LED light up for each new stage progressed.

Incandescent Bulb

The oldest and lest efficient light emitter. Incandescent light bulbs runs current trough a special filament, that essentially works as a resistor, that is specially designed to emit as much visible light when heated to a certain temperature. Because of specific conditions are required for the filament to work, incandescent bulbs require… bulbs. These bulbs serve to keep the filament in a vacuum as for it to not ignite with oxygen. This vacuum requirement makes bulbs limited in how small they can physically be. Since much of the energy is wasted in heating the filament and emits heat and useless wavelengths, the incandescent bulb is not a very energy efficient device, and therefore, does not comply without energy efficiency goal.

Fluorescent Bulb

Similar to Incandescent Bulbs, fluorescent bulbs emit visible light when a voltage is applied to it. However, instead of running current through a filament, fluorescent bulbs emit light by ionizing a gas contained in the bulb. This makes fluorescent bulbs more efficient to incandescent because there is not as much wasted heat energy. But fluorescent bulbs are more constrained in shape and size, as well as the need for large voltage difference for ionization. These constraints are hard to reconcile with our energy and size constraints.

Laser Diode

A laser diode is a semiconductor device that emits coherent light, which is light with a consistent phase and wavelength. It is used in various applications due to its compact size, efficiency, and ability to emit light in a narrow and well-defined wavelength. Laser diodes operate on the principle of stimulated emission. Essentially, when current flows through the diode, it excites electrons in the semiconductor material. These excited electrons release energy in the form of photons. The emitted photons stimulate other excited electrons to release more photons with the same energy and direction. This process leads to the amplification of light through optical feedback. Repeated stimulation of emission results in the production of coherent light, where the photons have the same

frequency and phase. Overall, the versatility and efficiency of laser diodes have made them indispensable in numerous technological applications across different industries.

3.4.3 Acoustic Emitters

If we wanted to implement additional auditory stimulation, the BIRDS will need some type of audio component. We are thinking of adding auditive stimulation when the capacitor sensor wakes the BIRDS, another when a trash item was validated, and another when food is dispensed. It would be useful if we implemented a failure or invalid item stimulus as well.

Buzzer

A simple oscillating object that can vibrate at a certain frequency. Some allows for selected and changing frequency. Such buzzer would allow us to utilize only one buzzer for all the possible tones we could need.

Bell

Bells are simple metal objects in a shape that creates a distinct sound when struck with another metal object. The only reason why we even consider this is because of the historical usage of bells in skinners conditioning experiments and because they are fun to listen to.

In order to implement a bell into an autonomous system, we would also have to add some type of actuator to ring the bell. Current commercial bell controllers are quite expensive, and building our own would be too much trouble for something so frivolous.

Speakers

Speakers work by oscillating a membrane, usually with magnetic pulses, to certain wave signals. They are the most widely used audio system because of their versatility in producing an immense variety of sounds. However, this versatility is due to sound drivers and dedicated sound boards to drive the speakers by converting digital signals into analog, then amplifying them to drive a speaker. This is way too complex for a simple auditory stimulator and therefore out of scope.

3.4.4 Human Interface

In the same spirit of providing supplementary stimuli for the birds, it would be useful to implement some type of human interface for maintenance and debugging purposes. We think that at the very least, the BIRDS should have a battery charge indicator. Other human interface features may be added in future design decisions.

Battery Charge Indicator

For a battery charge indicator, we could use any type of display from OLED, LCD, or simply add a row of LEDs.

OLEDs, or organic light emitting diodes, are too expensive and require drivers and communication ports to operate. They are too complex for a simple battery indicator. This is the same case with an LCD screen, so neither are good options.

Most likely, if we implement a charge indicator, it would be a row of 4 cheap LEDs that represent the charge of the system. This design would be simple enough to not consume much power yet sufficient enough for users to maintain power for their BIRDS system and know when it needs to charge.

3.4.5 Optical Components

To accurately detect and image animals to determine if they are birds and to effectively identify if birds bring introduce trash to the BIRDS, we must build an optical design that gives our machine learning processor board sufficient images to determine what animals are activating the system and what objects they bring to it. The ultimate goal for our design is to only have our system advance in its processes with two conditions, the first of which being if a bird is detected, and the second being that the bird deposits trash into the container. To achieve this, two different lens systems will be built to focus light into their respective sensors and image: one for the exterior of the system, positioned on the front of the feeder facing the landing pad, for imaging birds that land, and one for the interior of the trash chamber, positioned above the chamber and facing down, for detecting whether objects brought by the birds are trash. The sensors will be hooked up to the processing units for image recognition to take place. A third optical system in the form of a laser motion sensor will also be designed to detect movement of an object dropped by birds into the analysis chamber. Below is a discussion of the parts and components to be implemented in the designs for these optical systems.

Laser Motion Sensor

A system of mirrors will be designed to reflect the light from a laser source in different angles, ensuring that no trash can fall without breaking the path of light. The exact number of mirrors and at what angles they are to be placed will be determined during the design process. The laser source will be reflected onto a photo-detecting sensor. This sensor will either be a solar cell or a photodiode. Both convert photons into electrons, but there are pros and cons to each that will determine our final selection.

The laser source will need to be cost-effective and run at a low power to not drain power necessary for other functions of the BIRDS. A low power laser will also remove the dangers laser light could pose to users and animals alike. However, the power of the laser must be large enough selected sensor to convert the light

into a signal. It must also produce visible light to correctly align the mirrors designed to create a laser grid.

One option for the photo-detecting sensor is the solar cell. Solar cells are designed to convert sunlight into electricity. They are optimized for capturing solar energy and typically have larger surface areas compared to other photodetectors. Usually, there is no voltage applied to the solar cell as its main attraction is the voltage it creates for power usage. This means there is only one operation for a solar cell to operate in: photovoltaic mode. A typical solar cell design can be seen in the figure below. Studies have shown that solar cells can be used to extract a high-speed data signal in an optical wireless communication link. Data speeds of 34Mbps have been observed while still generating maximum power in the cell. [14] This data speed is important for the BIRDS as a one-bit system will be designed to determine if an object breaks the laser grid and enables the sensor to go under a certain voltage. This drop of voltage would communicate to the MCU to take a picture of the trash chute for analysis.

Another option for the laser sensor is the photodiode. Commercially available photodiodes typically run at data speeds of 2Gbps with rise times anywhere from 400ns-10µs. [15] [16] Research has pushed data speeds to 25-50Gbps. [14] Their rapid response time makes them ideal for applications that require real-time detection, such as optical communication and laser detection. A photodiode's high sensitivity makes them suitable for low-light sensing. They are also very compact and fit very well into any environment, and they are relatively cheap. The temperature sensitivity of photodiodes may cause their response to fluctuate. A third and final option to act as a laser sensor is the photoresistor. They are typically used in night lights where the light will turn on when the room light shuts off. Photoresistors operate by changing resistance depending upon incident light levels. They are also cheap components and are very simple to use. The spectral bandwidth of a photoresistor is very wide, usually spanning from visible to infrared light. They also draw very little power. However, photoresistors typically have a response time of 2-50ms, much slower than photodiodes. [17] Additionally, they do not last as long as other photo sensors, and they have very low sensitivity. A third and final option to act as a laser sensor is the photoresistor. They are typically used in night lights where the light will turn on when the room light shuts off. Photoresistors operate by changing resistance depending upon incident light levels. They are also cheap components and are very simple to use. The spectral bandwidth of a photoresistor is very wide, usually spanning from visible to infrared light. They also draw very little power. However, photoresistors typically have a response time of 2-50ms, much slower than photodiodes. [17] Additionally, they do not last as long as other photo sensors, and they have very low sensitivity.

Laser Sensor Comparison

After this comparison, we decided to use a photodiode for our laser detector. It is the fastest responding detector for the most optimal price. It can be seen in the table above that solar cells are not typically used for communication systems and

therefore, data sheets do not provide rise times. Additionally, photoresistors are also not usually used in communication systems and most data sheets do not provide data rates for them.

We will design the layout of the laser and mirrors to shine the laser light onto a photodiode so that any object breaking the laser plane will cause a voltage drop in the diode. This drop in voltage will signal the camera to take a picture of the trash that was dropped into the chute.

Table 3.4.5.1. Laser Sensor Comparison

	Solar Cell	Photodiode	Photoresistor
Data Rate	34.2 Mbps	2 Gbps	N/A
Rise Time	N/A	1 µs	10 ms
Spectral Bandwidth	400nm - 700nm	800nm - 1100nm	400nm - 900nm
Cost	$15.50	$0.40	$0.20

Image Sensors

To determine the best sensor to be used in both of our optical systems, we researched CMOS (Complementary Metal-Oxide-Semiconductor) and CCD (Charge-Coupled Device) sensors. Both CCD and CMOS image sensors convert light into electrons by capturing photons with thousands of light-capturing wells called photosites. When an image is being taken, the photosites are uncovered to collect photons and store them as an electrical signal. [18] Each sensor is discussed in detail below.

CMOS Sensor

CMOS sensors are designed similar to most integrated circuits, almost 90% identical to computer chips. [19] Each pixel in these sensors has its own amplifier and readout circuitry allowing for parallel reading of pixel values. This means that CMOS sensors are capable of faster readout speeds and lower power consumption compared to CCD sensors. There are also no complex time clocks used. They are known for their lower power consumption, which makes them suitable for battery-operated devices like the BIRDS CMOS sensors can achieve high frame rates and are used in applications that require rapid image capture. This is mainly due to parallel reading previously discussed. The image quality of CMOS sensors has been improving over time, but they do not have the same

capabilities as CCD sensors in this area. CMOS sensors also tend to be more cost-effective to manufacture. Because of this, they tend to be the preferred choice for consumer electronics and many different applications. Additionally, CMOS sensors allow for more compact designs. [20]

CCD Sensor

In a CCD device, the charge is transported across the chip and read at one corner of the array, and an analog-to-digital converter turns each photosite's charge into a digital value. [17]**Error! Bookmark not defined.** CCD sensors send the electrical signals through a series of capacitors and registers before being read out sequentially. This serial readout process results in slower readout speeds and higher power consumption. CCD sensors are therefore less suitable for battery-powered applications but still valuable in scenarios where power efficiency is not a primary concern. They typically consume 100 times more power than CMOS sensors. The slow readout speeds limit their use in high-speed applications. When dealing with image quality, CCD sensors are preferred in applications where the best resolution is needed, such as scientific imaging and astronomy. These sensors are typically more expensive to manufacture, making them more common in specialized industrial imaging applications.

Image Sensor Comparison

The figure below shows a comparison between the data acquisition of CMOS and CCD sensors, as a structural schematic.
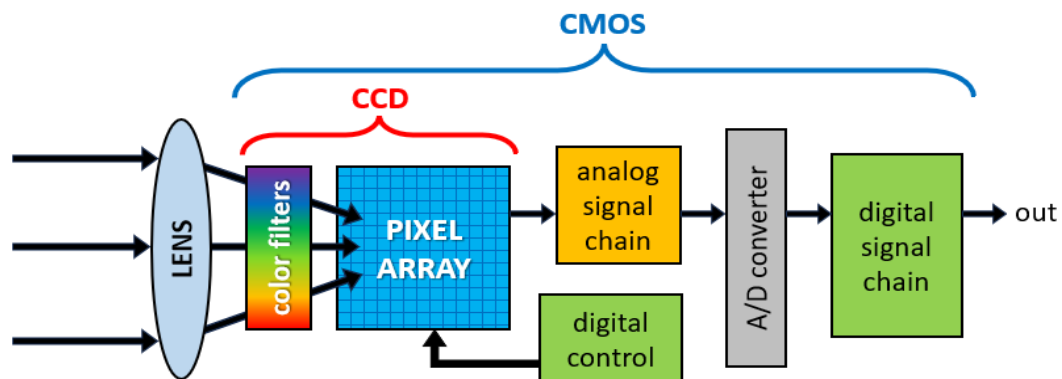

Figure 3.4.5.1. Comparative Schematic of CMOS and CCD Data Acquisition. Reproduction permission requested from OPI.

After conducting a thorough investigation on CMOS and CCD sensors, we decided to choose CMOS sensors to implement into our imaging systems because of cost and power constraints. It can be seen in the chart below that CMOS sensors draw less power than CCD sensors, which is a vital capability for the BIRDS. CMOS

sensors are also typically cheaper and more user-friendly. The figure above gives a brief synopsis of the main hardware differences within the two sensors. As said before, the ability for the CMOS sensor to pixel values in parallel leads to its faster readout time.

Table 3.4.5.2. CMOS & CCD Sensor Comparison

	CMOS	CCD
Readout Noise	5 e$^-$	3 e$^-$
Power Consumption	2.5V	12V
Readout Time	10ms	500ms
Price	$50	$200

Infrared Filter

To form the clearest picture possible for the CMOS sensor, an infrared (IR) filter will be implemented onto both trash and bird lens system designs. The biggest reasoning for this is that the IR-cut filter helps to produce accurate color images with color CMOS cameras. The filter blocks the transmission of IR light while passing visible light. It can be performed by absorption or reflection optical techniques. [21] Invisible to the human eye, IR light can cause significant image quality issues, such as color distortion and reduced contrast. These issues can be particularly pronounced in low-light conditions, where the camera may rely on the IR light to see. By blocking IR light, the IR cut filter helps to improve the color accuracy and contrast of the images captured by the camera.

In general, IR light leads to color distortion during the day. To solve this issue, an IR-cut filter is used to keep the IR light disturbance out of the image sensor during the day. When the light falls below a certain level, the filter automatically swivels out of the way so that the IR light does hit the image sensor. Also, cameras can switch to a black-and-white mode to use the IR light optimally. [22]

Another reason for the usage of an IR filter is to achieve realistic colors. The IR-cut filter in a color camera can achieve realistic colors in white light. [21] The color spectrum viewed by the human eye is very narrow compared to the bandwidth of frequencies seen by a CMOS sensor. The sensitivity of these sensors is significant in the near IR region of the spectrum. If an IR-cut filter is not used, an overflow of infrared light will appear leading to unnatural images.

Furthermore, IR filters help achieve color correction in lens systems. It is difficult to design imaging optics covering both the visible spectrum and the near IR spectrum. [21] Because of this reason, lenses are designed with different depths of focus for the visible and the IR spectrum. With these designs, the IR filter removes a significant amount of the near IR light and executes color correction.

As stated previously, there are two different types of filters: absorptive and reflective. Absorbing filters are designed with special optical glass to absorb IR radiation. Reflection type filters are short-pass interference filters that reflect IR light with high efficiency. [21]

Image Sensor Interfacing

The optical systems of the B.I.R.D.S. must interface with the electronic systems in order to process the data and activate higher order functions in the B.I.R.D.S. To effectively connect the CMOS sensors to the Jetson Nano for image processing, we must select the proper interfacing cable to transfer data of high resolutions at high speeds.

MIPI CSI-2 Interface

MIPI (Mobile Industry Processor Interface) sensor interfaces are a popular choice for applications where high data throughput, power efficiency, compact design, and standardization are essential. The MIPI CSI-2 (Camera Serial Interface 2nd Generation) standard is a high-performance, cost-effective, and simple-to-use interface. [23] It offers a bandwidth of 10 Gb/s and faster speeds than USB 3.0. There are four image data lanes with each lane capable of transferring data up to 2.5 Gb/s. However, MIPI cameras rely on extra drivers to work. [20]

USB 2.0 Interface

The USB interface is well-known for its plug-and-play capabilities. The simplicity and cost-effectiveness of it speaks for itself. Still, USB 2.0 is an older version, and there are technical limitations. This specific interface is beginning to dwindle, and several of the components involved are now incompatible. [20]

USB 3.0 Interface

USB 3.0 has now begun to replace USB 2.0. The industrial standard of vision embedded systems, USB 3.0, also improves its ability to capture images of high-resolution at high speeds. [20] It is one of the most cost-effective interfaces for machine vision. The latest CMOS image sensors, commonly used in compact cameras with high data throughput, make good use of the high bandwidth, up to 5 Gb/s. [19]

Image Sensor Interfacing Comparison

Features	USB 3.0	MIPI CSI-2
Availability on SoC	On high -end SoCs	Many (Typically 6 lanes available)
Bandwidth	400 MB/s	320 MB/s/lane 1280 MB/s (with 4 lanes)*
Cable Length	< 5 meters	<30 cm
Space Requirements	High	Low
Plug-and-play	Supported	Not supported
Development Costs	Low	Medium to High

Figure 3.4.5.2. Interfacing Comparison Chart. Reproduced with the permission of e-con Systems.

We chose a USB 3.0 interface as it is the cheapest option yet still reliable to accomplish our objectives. The extra drivers for the MIPI interface would draw more power and cost more to process our images. The simplicity and easy use of the USB 3.0 interface makes it the best selection. There also wasn't a significant need for extremely high-quality images, and the USB 3.0 interface gives sufficient resolution for image processing.

Trash System Lenses

Creating a clear enough picture for the software to determine if an object dropped into the trash chamber is indeed trash, a lens system will need to be designed to focus light into the sensor. Our basic goal is to be able to detect cigarette butts from other objects. Once an image is taken, the data will be transmitted to the Jetson Nano through a USB 3.0 cable to run the image through a neural network for machine learning.

Capturing a picture in the trash chamber will require a few elements: the object itself, an LED to illuminate the object, a double lens system, and a CMOS sensor. Typical trash imaging and sorting cameras are designed to gather hyperspectral data on trash. These systems identify and separate different materials, such as plastics, textiles, metals, glass, paper, and cardboard, based on their chemical structure. [10]

Many companies have built and are designing imaging systems that can automate the waste sorting process. This reduces errors and decreases the time of sorting. For example, Specim is a company devoted to building hyperspectral imaging solutions. The way their cameras work is using a line scan push broom design. In

it, a small slit is utilized to measure accurate spectra of the object. [23] Their systems also display images with numerous color bands compared with the three band RGB cameras most used today. Our design will not include these additional components and features as we are simply attempting to read the outline of objects, namely a cigarette butt. There are many different types of lenses to use in a lens system. Specifically, lenses can be classified into two main categories, converging (positive) and diverging (negative). In general, positive lenses collimate light to a focused point called the focal point, and negative lenses cause the light to spread behind the lens. [24] Tied with lenses is what is called the conjugate ratio. It is defined as the ratio between the distance from the object to the lens and the distance from the lens to the projected image. [10] Our design, if assumed as a single lens system, will deal with an infinite conjugate ratio as the distance of the objects we will image will be orders of magnitude greater than the focal length. Because our design is really a double lens system, we will deal with the collimating with an infinite conjugate ratio and a focusing lens with a 1:1 conjugate ratio. As seen below in Figure 3.4.5.3., we will use a plano-convex lens for the collimating lens because it is the best positive lens to deal with an infinite ratio. The asymmetry of the plano-convex lens minimizes spherical aberration in situations where the object and image are located at unequal distances from the lens. The optimum reduction of spherical aberration is the object placed at infinity and the final image is a focused point. [25] The focusing lens will be biconvex lens as they deal better with smaller ratios.

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When multiple lenses are added to any design, more factors are added into the configuration of the system. Exit pupils must match entrance pupils, or put simply, light out of one lens must all converge into the next lens. Magnification of the desired images is also increased, and certain aberrations can be fixed with a specific ordering of lenses.

Lens shape	Ideal conjugate ratio
Biconvex	< 5:1
Plano-convex	All
Plano-concave	Infinite, larger finite (> 5:1)
Biconcave	< 5:1
Meniscus	Varies; dependent upon curvature and polarity

Figure 3.4.5.3. Ideal Conjugate Ratio for Lens Shape. Reproduction permission requested from MKS Newport.

As seen in Figure 3.4.5.4., our design will consist of a double lens system to mitigate complexities and best image the trash.
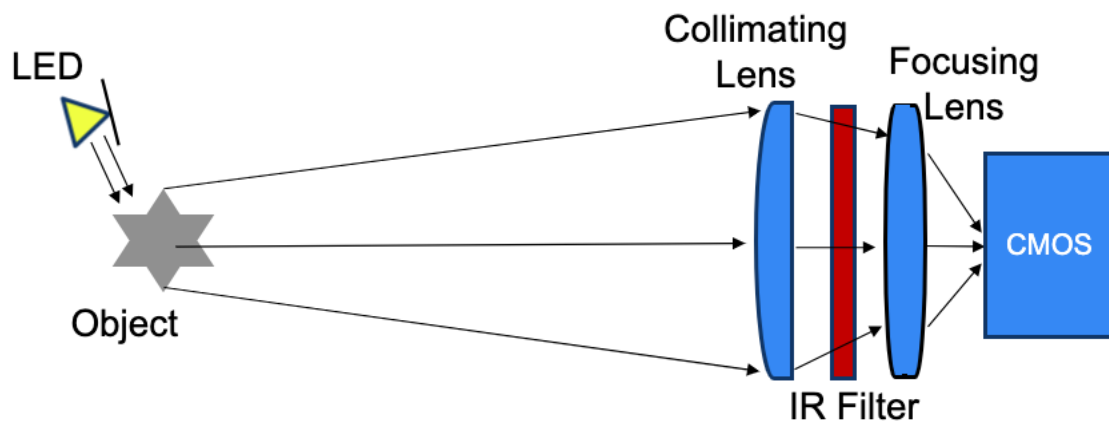

Figure 3.4.5.4. Diagram of Trash Lens System

Bird Camera Lenses

In order to pass off an image with sufficient resolution and dimensions to the image recognition software via the CMOS sensor, a lens system for the camera to image birds that interact with the feeder must be designed. This section goes into detail on some research and idea development for the design of said system.

To capture an image of a bird on the landing pad of the feeder, a camera, composed of a CMOS sensor, a double lens system, and housing to mount the lens system to the sensor and keep it secure. Since we are designing the optical systems of our project to meet the needs of the specific distances and circumstances for our imaging systems, research on how to design this lens system for our purpose will be necessary.

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Much like the trash lens system, the bird lens system will be set up so as to have a distance from the object to the front lens of the system that is pretty significantly larger than the distance from the front lens of the lens system to the image produced by the front lens, which will be in between the two lenses. Because of this, like the trash lens system, the ratio between the two can be considered infinite, which is an approximation, but a relatively accurate one. And because of this being the ratio, when referring to the lens types in Figure 3.4.5.3, it can be seen that the plano-convex lens type matches this infinite ratio. Therefore, a plano-convex lens will be used, as it is best used for collimating a point source of light, which will benefit the imaging of the bird with regards to our system. Then, similar to the trash lens system, the ratio between the distance from the object for the second lens to the second lens and the distance from the second lens to the image of the second lens will be closer to one-to-one. The object for the second lens is the same as the image of the first lens within the double lens imaging setup. The image of the second lens will be the final image that is cast onto the CMOS sensor, and it will need to be small enough to fit within the sensor, so a smaller magnification than expected would be better than a larger one, as a larger one could cause the sensor to not capture the whole image. Since this ratio for the second lens of the setup is closer to an even ratio and needs to be one that provides a demagnification, the biconvex lens will be used in its place, as it will converge the light traveling through the system and provide a smaller image magnification. The setup will also utilize an IR filter as detailed in the previous section. Figure 3.4.5.5 shows a general diagram of the bird lens system concept.
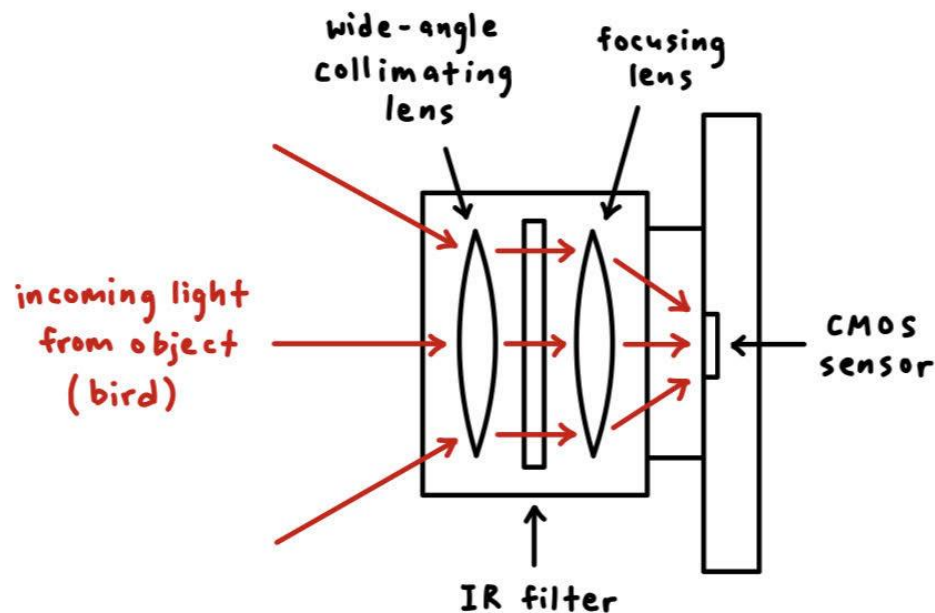

Figure 3.4.5.5. Diagram of Bird Lens System

Image Size and Lens Optical Format

After understanding how to best collimate the light from an object into a lens, the light must now be focused onto an imaging sensor. A lens produces images in the form of a circle, called the image circle or optical format. [26] An imaging sensor, specifically a CMOS sensor, has a rectangular sensor area that detects the image focused by the lens. In order to have the best possible image of the desired object, the lens optical format should coincide with the imaging sensor as seen in the left most image in Figure 3.3.5.4. If the image circle and sensor size do not match, the data may still be useful, but not as beneficial. For example, when the optical format is bigger than imaging sensor, the lens field of view will be reduced. Furthermore, if the lens optical format is smaller than sensor size, there will be dark areas in the produced image, and some portions of the sensor area is not used. The design of the lens system must include calculations that create an image circle coinciding with the CMOS sensor. This will be further discussed in the design section.
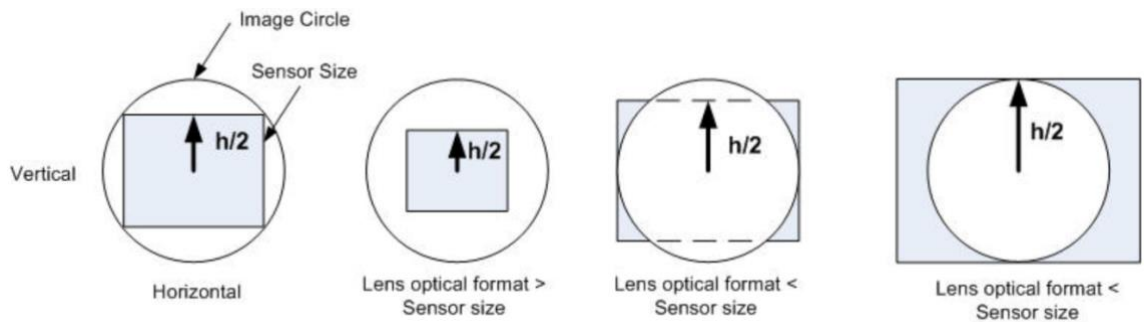

Figure 3.4.5.4. Image Circle and Sensor Size. Reproduction permission requested from ArduCam.

Minimum Object Distance

The minimum object distance denotes the closest proximity at which the lens can be positioned to the subject for capturing an image. This measurement is taken from the front lens's vertex. While it's possible to manually focus the lens on a very close object, there's a trade-off involved. Achieving sharp focus on one end might result in blurriness at the other. To address this, the minimum object distance parameter is defined to optimize focusing for both close and distant objects. This will be further discussed in our lens calculations.

Back Focal Length

The distance from the rear element lens vertex to the image sensor is crucial. In instances where a lens has an exceptionally short focal length, as is our case, it becomes necessary to use an appropriate lens holder that aligns with the lenses' back focal length. For instance, a fisheye lens requires a specific, dedicated lens holder, as it cannot be used with any other lens holders due to its unique design. The design we come up with for the lens systems will determine the lens holders he use.

Field of View

The field of view, also known as the angle of view, is the range that can be imaged by the lens given a specified image size. This value is normally conveyed in degrees or radians. The field of view is measured with a lens focused on and infinite distance. This number can be calculated if the focal length and image size are known. [26]

3.4.6 PCB Components

The BIRDS brain and central management unit will be a printed circuit board that will interact with the peripheral devices, such as the capacitive sensor, laser break sensor, and all the actuators directly and coordinate with the image processing computer. For this, the PCB will require a dedicated microcontroller unit to process and run the required code.

External Communications

The relevant purposes for communication with foreign entities is if we implement a log system that records a list of activities with possibly a snapshot from the cameras and to notify someone when food or trash are empty or full respectively. However, the trash and food notification system would require additional sensors which is a stretch goal that most likely won't be realized.

Bluetooth

"At a high level, Bluetooth is a wireless communication technology designed for short-range data exchange between electronic devices. The Bluetooth protocol operates in the 2.4 GHz ISM (Industrial, Scientific, and Medical) frequency band and uses a frequency-hopping spread spectrum to reduce interference from other devices in the same frequency range.

Bluetooth devices communicate through a master-slave architecture. In a network, one device serves as the master, while the others act as slaves. The communication involves the exchange of packets of data between devices, and the devices take turns transmitting and receiving information.

When two Bluetooth devices want to communicate, they initiate a process known as "pairing." During pairing, the devices establish a secure connection and exchange encryption keys, ensuring the confidentiality and integrity of the data being transmitted. Pairing may involve entering a PIN or using more modern methods, such as Near Field Communication (NFC) or Bluetooth Low Energy (BLE) pairing without a PIN.

Once paired, devices can establish a connection and exchange data. Bluetooth supports various profiles that define the types of applications and services it can

provide, such as the Hands-Free Profile (HFP) for hands-free calling or the Advanced Audio Distribution Profile (A2DP) for streaming audio.

Bluetooth operates in different modes, including the traditional Bluetooth Classic and the more energy-efficient Bluetooth Low Energy (BLE). Bluetooth Classic is suitable for applications requiring higher data transfer rates, while BLE is optimized for low power consumption, making it ideal for devices with limited energy resources." [13]

The concept of "short-range" data communication is somewhat antithetical to the goals of the BIRDS, that you set it and forget about it, for a week of course. Unless you installed your BIRDS on the side of your home, it would not make a lot of sense to implement a shot-range communication technology in the BIRDS.

Data Port

Since we only want to implement logging system with camera snapshots, it would be much easier to connect directly to a built in USB port to the image processing unit. The customer visits the BIRDS once a week to refill the food and empty the trash. Then, if they wish to, can connect to the BIRDS data port to receive an activity log with accompanying snapshots.

While not entirely user-friendly, the BIRDS is primarily designed to train birds. The communication and logs are an added feature.

Additionally, since the Jetson Nano will contain the detected images, it might be easier to use the Jetson for the user interface rather than the PCB itself.

Wi-Fi Module

One possibility of keeping the user informed on the device is to add Wi-Fi capability to the Jetson nano to upload different activity or error logs. This could also give some extra information like food levels and trash levels or if something is stuck in the chamber. The Jetson does not come with Wi-Fi on the development board itself meaning that this would need an extra component to be added to work with full functionality. Having a Wi-Fi enabled system would allow for some extra features, but then this also restricts placement of where the system goes. Since we want this to be an outdoor system where birds can easily get to, needing Wi-Fi makes it required to be close enough to a signal to be able to interface with any website or server that we make. This also adds a lot of extra work as it will then need to have a server that it can update to in order to send push notifications. With the placement being restricted Wi-Fi is a possibility to be looked into but will most likely not make it to the final product.

Board Programing Port

The development boards have everything on it allowing the user to go straight from programming to automatically writing to the flash memory through just a USB. The

microcontroller itself does not have such a feature. In order to write memory for the microcontroller to read from, there needs to be some kind of communication protocol to write to it. The ATmega1280 that we are using has a few different ways of being able to flash the memory to write the program to it. In these upcoming sections we will talk about some of the benefits of using one over the other and decide which will best suit our needs.

Parallel Programming

The Parallel Programmer is the most complex of the three with 16 different connections not including any power connectors or ground. This method is unique in the fact that it uses a 12-volt pulse to start the programming. This has the benefit of being able to program the fuses as well as the flash memory. The biggest strength of using the Parallel Programmer is that it can overcome any issue with any of its fuse that may come up later on. An example of one of these issues could be caused by programming a reset fuse bit to the incorrect value. This would cause the device to stop working and then render it completely useless as a microcontroller. That is just one example of how a software bug can cause something like that to happen, but there is many more that could also occur. A parallel programmer is essentially a key to any software lock that may occur. This interfacing method is great for fixing problems, however it is not practical when it comes to just programming the board. Because of the issue of practicality this will not be implemented into our board and will be left as a tool for possible connections later.

Serial Downloading

Serial Downloading is the simplest of the 3 interfaces as it just uses serial data to write to the flash memory. This is included in the ATmega1280 as it has something named ICSP which stands for in circuit serial programming. This is just taking information and writing it through an SPI interface to the microcontroller flash memory. In using this method, we would use the Arduino development pack that could connect to the circuit board. This would use another board that has the capability to transmit data through a serial connection. The Arduino IDE allows for direct programming of taking a specific program and writing serially to a certain microcontroller. This would then require a 6-pin connection header that we can connect to the Arduino Mega.

While using another Arduino would be very easy to setup, it can be very prone to error. Instead of using an Arduino, a product such as the Atmel ICE is an alternative that gives the same thing but is less prone to error. This device is not very cheap starting at $200 which is unreasonable for what we plan on using it for. There is another device that is called the AVR ISP Mk2 that does a very similar thing at much more reasonable prices starting around $20. Going with this option provides us the ability to program the microcontroller in circuit very easily by just connecting USB to the device and the device to the 6-pin header properly routed.

JTAG

JTAG is a great debugging interface that stands for Joint Test Action Group. JTAG is mainly used for programming and debugging for microcontrollers. JTAG is best used for more complex systems as it can be connected to many different devices in a daisy-chain fashion helping to test many systems at once. JTAG allows for hardware breakpoints throughout code giving more power to the debugger. This would significantly speed up software development for the microcontroller because having breakpoints like this cut down on the bug fixing part of programming by a significant margin.

Programming Port Conclusion

For our application, it makes the most sense to go with something that allows us to program in a reasonable amount of time in a simple way. What is nice about all of these options is that they can all be available later to choose from if we need to change for any reason. We plan on using the serial downloading method. This method seems to be widely used for projects such as these with little overhead and easy adapters to connect to. The parallel programmer will be a good fallback should we ever need to reset certain fuses because of any sort of program that goes wrong in production.

3.4.7 Power Circuit

To power all the systems for the BIRDS, we will need a power system able to supply operations for at least a week. Now calculation how much capacity we will need is a challenge, because since we don't have a prototype, we can not test power draw for normal operations. This is why the capacity amount of the batteries might be one of the last things we decide on. However, we can still choose and compare battery technologies. In addition to battery power, the nature of where a BIRDS might be located (out in the open, probably under direct sunlight), it might be fun and useful to implement some type of solar charging system.

Battery Power

Since we want autonomous operations, we will need some type of battery technology to supply the power when isolated. The battery will supply small amounts of power when in sleep mode (from the capacitive sensor) and large amounts of power when running the image recognition software. Not to mention the solar cells that may charge the batteries when in sleep mode. Our chosen battery will have to be able to constantly deliver power and be able to recharge while in use.

Lithium Ion Battery

"Lithium-ion (Li-ion) batteries are rechargeable power sources found in a wide range of portable devices, including smartphones, laptops, and electric vehicles.

The fundamental operation of these batteries relies on the movement of lithium ions between two critical components within the battery structure. Here's a simplified breakdown of how lithium-ion batteries work:

A typical Li-ion battery comprises three key elements: a positive electrode (cathode) made of a lithium-based compound, a negative electrode (anode) usually composed of carbon (graphite), and an electrolyte solution containing a lithium salt in a solvent. The interplay of these components is central to the battery's functioning.

During the charging process, an external voltage source, like a charger, applies a voltage across the battery's terminals. This voltage drives lithium ions from the cathode to the anode, where they become embedded within the carbon structure of the anode, effectively storing electrical energy.

In contrast, during discharge, when the battery powers a device, the stored lithium ions begin their journey back to the cathode through the electrolyte. This movement of lithium ions generates an electric current, which is harnessed to operate the device. The movement of ions is closely associated with the flow of electrons in the external circuit, resulting in the production of electrical energy.

The transfer of lithium ions between the cathode and anode is facilitated by chemical reactions at the electrode surfaces. These reactions involve the exchange of electrons, and they are entirely reversible, enabling the battery to be charged and discharged repeatedly." [13]

It is easy to see how Li-ion came to dominate personal electric devices with their impressive energy density and ability to recharge. However, for safe use, Li-ion batteries require some type of management system that protect it from overcharging and overcurrent, especially if using multiple Li-ion packs. For the BIRDS, it is a good fit for all the reasons above. We will only need to implement some type of battery management system or buy a battery pack with it included.

Lithium-Polymer Battery

"Lithium-polymer (LiPo) batteries, like their lithium-ion counterparts, are rechargeable power sources found in numerous electronic devices, particularly in applications where a flat and lightweight design is essential. The operational principles of LiPo batteries share commonalities with lithium-ion batteries, yet they exhibit distinctive characteristics. Here's an overview of how LiPo batteries function:

LiPo batteries are constructed with multiple layers of a flexible, porous polymer separator embedded with an electrolyte. These layers encompass positive and negative electrodes, with the positive electrode often containing lithium cobalt oxide ($LiCoO_2$) and the negative electrode frequently including graphite.

What sets LiPo batteries apart is their utilization of a solid or gel-like electrolyte as opposed to the liquid electrolyte found in conventional lithium-ion batteries. This polymer-based electrolyte not only enhances safety by reducing the risk of leakage but also allows for a pliable packaging approach.

The operation of LiPo batteries revolves around the movement of lithium ions within the solid or gel-like electrolyte. During charging, an external power source applies voltage across the battery's terminals. This voltage initiates the migration of lithium ions from the positive electrode (cathode) to the negative electrode (anode) via the polymer electrolyte. The energy is stored in the form of chemical potential.

Subsequently, when the battery is employed to power a device, the lithium ions undertake a return journey from the anode to the cathode via the solid or gel-like electrolyte. In this process, the stored energy is liberated, generating an electric current that powers the device." [13]

While the increased flexibility and lighter batteries are interesting, the increase in price does not justify the minute differences of LiPo batteries over Li-ion.

Nickel-Metal Hydride Battery

"Nickel-Metal Hydride (NiMH) batteries are rechargeable power sources widely utilized in various consumer electronics like cordless phones, digital cameras, and handheld tools. These batteries operate by enabling the movement of electrically charged ions within their structure. Here's a simplified account of how NiMH batteries work:

A standard NiMH battery consists of three primary constituents: a positive electrode known as the cathode, which is made from a compound containing nickel oxyhydroxide ($NiOOH$); a negative electrode, referred to as the anode, composed of a hydrogen-absorbing alloy, often featuring a blend of metals including rare earth metals and nickel; and an electrolyte, typically a potassium hydroxide (KOH) solution that facilitates the flow of ions between the anode and cathode.

During the charging process, when you connect a NiMH battery to an external voltage source, like a charger, a voltage is applied across the battery terminals. This voltage prompts the oxidation of nickel ions (Ni^{2+}) from the cathode, resulting in the formation of nickel oxide ($NiOOH$). Concurrently, hydrogen ions (H^+) are liberated at the anode.

When the battery is deployed to power a device, the inverse of the charging process unfolds. Hydrogen ions (H^+) at the anode engage with the metal hydride alloy, leading to the release of electrons, thus generating an electric current. Meanwhile, nickel oxide at the cathode accepts electrons and releases nickel ions (Ni^{2+}).

Throughout both charging and discharging phases, charged ions, encompassing nickel ions and hydrogen ions, journey back and forth between the anode and cathode via the electrolyte. This reciprocal ion movement is the basis for storing and discharging electrical energy.

The beauty of NiMH batteries lies in their ability to recharge and discharge multiple times owing to the reversibility of chemical reactions occurring at the anode and cathode. NiMH batteries typically provide 1.2 volts per cell, which is slightly lower than the 1.5 volts of alkaline batteries, yet they compensate for this with higher capacity and the reusability factor. It's worth noting that NiMH batteries experience somewhat higher self-discharge rates compared to some other rechargeable batteries, which implies they may gradually lose stored energy over time, even when not in active use. Regular full discharge and recharge cycles help maintain their performance and longevity." [13]

While NiMH batteries might be safer to use, they lack the energy density of lithium batteries. I doubt the BIRDS will run on AAA batteries.

Lead-Acid Battery

From its name, lead-acid battery creates power by submerging lead into some type of acid, most often sulfuric acid.

"Lead-acid batteries, known for their durability and long history of use, are prominent as rechargeable energy storage devices in various applications, including vehicles and uninterruptible power supplies. The core of a lead-acid battery's operation hinges on electrochemical reactions taking place between lead dioxide (PbO_2) and sponge lead (Pb) immersed in a sulfuric acid (H_2SO_4) electrolyte. Here's a simplified elucidation of how lead-acid batteries function:

A standard lead-acid battery is composed of crucial components, including the positive plate (made of lead dioxide), the negative plate (consisting of sponge lead), a separator to prevent short-circuits between these plates, and the electrolyte, a dilute sulfuric acid solution that enables ion flow between the plates.

During discharge, when the battery is employed to power a device, the lead dioxide at the positive plate (anode) reacts with the sulfuric acid (H_2SO_4) in the electrolyte, leading to the formation of lead sulfate ($PbSO_4$) at the positive plate. Simultaneously, electrons are released at the anode, setting in motion an electric current that provides power to the connected device.

Conversely, when the battery is being charged, a reverse chemical process unfolds. Lead sulfate at the positive plate undergoes conversion back into lead dioxide, while sulfuric acid is regenerated in the electrolyte. During this operation, electrons are consumed, effectively reversing the direction of the electric current. Electrons flow from the negative plate (cathode) to the positive plate via an external circuit, constituting the electrical energy.

In both the charging and discharging phases, sulfate ions (SO_4^{2-}) traverse between the plates through the electrolyte, ensuring a balanced electrochemical environment." [13]

Since the chemicals are always in contact, slow degradation of charge happens constantly and eventually the battery needs to be replaced. This, plus the severe limit on battery drain to prevent battery damage, makes Lead-acid batteries unsuitable for the BIRDS.

Wired Power Supply

The most common, and simplest way to power a system is to connect it to preexisting electrical grids. The only consideration for choosing what type of wire is to choose a wire that will be able to supply the maximum possible current draw. If the wire is not rated to handle a certain current, the wire becomes a fire hazard that could melt or even ignite the insulation.

Since the BIRDS is battery powered, it requires some way to charge said batteries. We will have to implement a charging system.

Voltage Regulators

If we decide to implement battery packs with voltages higher than the operating voltage for the MCU and peripheral devices, we will need to implement voltage regulators to step down power source voltage.

Buck Converters

"A buck converter, also known as a step-down converter, is a type of DC-DC power converter widely used to efficiently reduce a higher input voltage to a lower output voltage.

The buck converter consists of several key components: an input voltage (Vin), a semiconductor switch (usually a MOSFET), an inductor (L), a diode (D), and an output capacitor (C). When the switch is closed, current flows from the input source through the inductor into the load, storing energy in the inductor. During this phase, the diode blocks the current. When the switch is opened, the inductor releases its stored energy, transferring it to the output capacitor and load, with the diode allowing this energy flow.

This switching process occurs rapidly at a controlled frequency, thanks to pulse-width modulation (PWM). By adjusting the duty cycle (the time the switch is on relative to the total switching period), the output voltage can be precisely regulated." [13]

Probably the most widely used and efficient DC-DC step down converter. Compared to other ways to step down voltage such as, a simple voltage divider or the similar Low Dropout Regulator, the buck converter does not rely on simply

burning off excess power. Instead, it stores and regulates power through magnetic and electric fields. If the need for a step-down converter arises, we most definitely will implement a buck converter.

Boost Converters

"A boost converter, also referred to as a step-up converter, is a type of DC-DC power conversion device with the primary function of raising a lower input voltage to a higher desired output voltage.

The essential components of a boost converter include an input voltage (Vin), a semiconductor switch (usually a MOSFET) responsible for controlling current flow, an inductor (L), a diode (D), and an output capacitor (C). When the switch is closed, current flows from the input source through the inductor, and this phase results in the storage of energy in the inductor. Simultaneously, the diode blocks current flow in the reverse direction.

When the switch is opened, the stored energy in the inductor is released. What distinguishes the boost converter is the way in which this energy is transferred to the output. Rather than simply passing it along, the boost converter adds this energy to the input voltage, consequently increasing the output voltage.

The operation of a boost converter is managed through pulse-width modulation (PWM), where the duty cycle of the switch is adjusted to control the output voltage level." [13]

Closely related to Buck Converters, Boost Converters are the only decent way to step up voltage. And just like with Buck Converters, we will make use of Boost Converters in the BIRDS

Low Dropout Regulators

"Low Dropout Regulators (LDOs) are essential electronic components used to ensure a stable and precise output voltage, even when the input voltage is only slightly higher than the desired output voltage. They play a crucial role in various electronic devices, providing a reliable power supply for sensitive components like microcontrollers, sensors, and RF circuits. Here's a closer look at how LDOs work

At the core of an LDO is the pass transistor, typically a MOSFET, which serves as a valve controlling the flow of current from the input voltage to the output. The key challenge for LDOs is to maintain a stable output voltage when the input voltage drops, and this is where their low dropout feature comes into play.

LDOs employ a feedback mechanism to continuously monitor and adjust the output voltage. They have an internal voltage reference, often implemented as a bandgap voltage reference, that establishes the desired output voltage level. An error amplifier continuously compares the actual output voltage with the reference

voltage. When any deviation is detected, the error amplifier generates an error signal.

This error signal guides the pass transistor's operation. If the output voltage falls below the desired level, the pass transistor opens up, allowing more current to flow and thus increasing the output voltage. Conversely, when the output voltage exceeds the desired level, the pass transistor reduces current flow to lower the output voltage. This continuous feedback loop ensures that the output voltage remains regulated, even when the input voltage is close to the output voltage.

To further stabilize the output voltage and reduce voltage fluctuations, LDOs are often equipped with an output capacitor. This capacitor helps mitigate transient voltage changes and provides additional filtering to ensure a clean and steady power supply." [13]

While not as efficient as Buck converters, LODs can serve a critical role in providing stable voltage. If we are to implement some type of self changing, such as solar cells, receiving a constant and reliable voltage would be critical. We would use LODs for smoothing out small fluctuations of solar power, in addition to its dedicated solar power management system.

3.4.8 Machine Learning Processor Boards

With our project, BIRDS, we will have to use a sensor to detect motion to then turn on higher computing devices that are machine learning enabled. The main use of machine learning in our case is the use of image recognition. This means we will use computer vision and machine learning to correctly identify birds and trash. We will have to be able to detect if a bird has arrived in front of the housing, or some other kind of animal. After seeing that a bird has arrived, we must then see what the bird has dropped into the trash chamber and classify it as trash or not trash.

The core challenge we face lies in the real-time processing of images to make quick decisions. We require a device capable of giving a classification quickly and accurately after being presented with the image. Additionally, because we plan to run our device on battery, we must employ a device that is power efficient and has low-power or sleep technologies integrated into it. With these technologies all working together they must be able to give a classification of the image within less than a second to meet the 3 second starting input to finish output. For quick processing to happen, the image needs to be able to reach the processor quickly meaning it must be CMOS compatible.

With all this in mind, we investigated devices that support artificial intelligence, machine learning, and computer vision. These devices come in a range of different specs with how popular machine learning enabled devices are currently. Because of this there are many different things to take into consideration because there are so many different devices to choose from.

Options for products

In the following sections, we present some of the products that we have evaluated for their performances, weaknesses, and compatibility with machine learning applications. Each of these products use libraries specific to the device to support machine learning or computer vision in some way. These options all contain strengths and weaknesses that will be compared including cost, power, software, performance, and lead time. With chip shortages being more and more of a problem as time goes on, we may find the perfect device that meets all the requirements we want, but the lead time is just too long, and it is not feasible to acquire in time. To provide deeper understanding, we will be giving all the boards individual spotlights and then narrow them down to just a few boards that align with the requirements we are looking for.

Raspberry Pi 4

The first system that came to mind when it comes to small computing devices was the Raspberry Pi 4. The Raspberry Pi has been known for its low-cost computing for many years that can be used in many different applications of robotics, engineering, and computer science. With the Raspberry Pi being such a widely used system, there is tons of documentation on it with many open-source materials and tutorials on how to set up. The Raspberry Pi comes equipped with a Quad core 64-bit ARM-Cortex A 72, options of ram from 1 to 4 Gigabytes of LPDDR4 RAM, Bluetooth 5.0, and 28 GPIO pins. The board idles at somewhere around 540 mA and there is not any low power or sleep mode to this device. You can save power by shutting off certain peripherals that are not being used since we will not be using every piece of hardware on it. Disabling the USB Controller saves about 100 mA, the HDMI saves about 30 mA, and the CPU can be clocked down to save power depending on the speed. [27] With all this put together the power should not be too much of an issue to this device when combined with external solar power to charge while its clock is slowed down. The Raspberry Pi uses the Raspberry Pi OS which is based on a Debian Linux distribution which some members of our team are already familiar with. This makes it much easier to write programs directly on the device rather than needing something to interface to it. Putting all this together at a starting price of $35 USD sounds like it would be a great fit for our project. One of the biggest issues is that all the lower RAM models are sold out from most retailers leaving the only options to be the 8GB models at $75 USD. The Raspberry Pi also has a weaker GPU compared to some of the other comparisons on here, which is the bulk of where the processing needs to come from in our machine learning model.

Coral USB Accelerator

In researching for the Raspberry Pi, we came across something called the Coral USB Accelerator. This is a device that can link through USB as a coprocessor to the system. This enables high-speed machine learning on any device that can link through USB. The Accelerator has an on-board Edge TPU coprocessor that is

capable of performing 4 trillion operations per second. This device uses 1 watt of power for every trillion operations that it does. [28] This device supports all major platforms that are using an operating system such as Windows, Debian Linux, or macOS. This would be a good attachment to the weaker GPU of the Raspberry Pi to give it the boost in computation that is needed to run a trained machine learning model. The price for this Accelerator starts at $59.99. This, along with the Raspberry Pi together, would work very well in processing but leaves the pricing to be quite high.

Coral Dev Board

Along with the Coral USB Accelerator we found a board that is another Google product named the Coral Dev Board. This is another one of Google's devices found under Coral.Ai which has many distinct products and documentation to go along with.

The Dev Board comes with an on-board Edge TPU coprocessor that is comparable to the Coral USB Accelerator. This coprocessor offers 2 TOPS, which means it can perform 4 trillion operations a second and again at 1 watt per 2 trillion operations. The CPU is an NPX i.MX 8M SoC (System on Chip), a graphics processing unit, a video processing unit, 2 USB modules, 16 GPIO lines, and a machine learning accelerator as mentioned earlier. [29] Putting the processor and coprocessor together you get a computing powerhouse. This board gives some of the best performance for its power across all the devices. The Dev Board is also using a complete Linux system using a Debian derivative called Mendel. The coprocessor is made specifically to accelerate TensorFlow Lite models which could potentially limit our use of pretrained models because they would need to be made using only TensorFlow lite. This all comes at a price starting at $129.99 for the 1 GB version of this board. This is a decently high starting price, but due to it having such a powerful arsenal of machine learning hardware this will be kept in for consideration.

Nvidia Jetson Nano

Next up to compare is the Nvidia Jetson Nano. Nvidia is a company that has been known for its high standing in artificial intelligence for many years. The Jetson Nano does not shy away from this with its very powerful performance in machine learning. The Jetson Nano contains a 128-core Maxwell GPU. Maxwell is the name of the microarchitecture that Nvidia uses that allows for very good efficiency of its processors. The Jetson contains a 1.43 GHz Quad-core ARM processor which is very high performance for a small device such as this. It allows for a microSD slot for extra storage to be added. There are 2 models between the Jetson Nano that is a 2 GB of ram, and another model that is 4 GB of RAM. There is a header allowing for GPIO pins to be connected to other devices such as sensors and external hardware. There is no on-board wireless connection, however there is an extension for it to be added easily. The power consumption is between 5 and 10 Watts, which is a little on the higher end of devices. The Jetson Nano does have

a sleep mode that it can enter that quickly resumes operations. This low power is just enough to power devices connected to it and keeps all the logic for its pins rather than setting them to 0 Volts. [30] The Jetson Nano runs a desktop environment named LXDE which is a lightweight operating system that requires very little resources to run. The Jetson Nano has support for many different deep learning frameworks such as TensorFlow, PyTorch, Caffe, Keras, and many more. This allows for a very smooth programming experience as we will not be limited to one framework. Very similarly there is very good library support, so this device really shines with its versatility. The Jetson Nano 4 GB version comes in around $150 USD. This is very widely available and not sold out everywhere like some of the competitor boards. While the 2 GB version is advertised on Nvidia's website for support, finding a seller was a bit more challenging. With a very low starting price of $59 USD, it seems all the sellers are sold out making this version not an option.

Arduino Nano 33 BLE Sense Rev 2

With microcontrollers Arduino was another one to come to mind very quickly. Our team has some experience with using Arduino for some smaller projects in the past, just with a less powerful microcontroller in their brand. This is why we thought to see if Arduino had some more powerful microcontrollers, and this is where we found the Arduino Nano 33 BLE Sense Rev 2. While it may not be as powerful as some of its competitors above it still has some key features to investigate. The Arduino Nano 33 BLE contains a 32-bit ARM Cortex CPU running at 64 MHz. It has 1 MB of flash and 256 kB of RAM, which is very small compared to other boards. The processor comes with Bluetooth pairing and ultra-low power consumption modes. The Arduino has the possibility of running Edge Computing application using TinyML. This uses the TensorFlow Lite framework which again limits it to only one framework making software a little bit harder to develop and maintain. Arduino has its own IDE that it uses to program its boards called Arduino IDE. There is a web version and a software version of this making it very easy to move between devices. Our team is familiar with this IDE, and it is a very high-level programming language with a lot of abstraction, making the software very easy to make. Arduino is very beginner friendly and has many different resources to get started and libraries to evolve the software to a more powerful state. The very appealing factors of the Nano that made it a very interesting choice is its low power applications. The Nano at maximum computing power with all its peripherals on and working draws a current on average of 6.3 mA. On the low end of the typical current consumption in low power mode, it draws only .95 uA. [31] The Nano has a very low cost of $40.50 USD and is in stock straight from Arduinos website. With its very low price and easy access this looks like a great product, however from its computational standpoint it will not be able to achieve the performance we are looking for. This means that the Nano will not be making it into the final product consideration.

Sipeed MAIX GO Suit

In our search for machine learning microcontrollers our team came across the Sipeed MAIX GO Suit. This is a product and brand that our team is unfamiliar with, however it does offer some good features that suit our needs well. The MAIX contains a dual-core RISC-V 64-bit processor. This is the first competitive processor that doesn't use an ARM instruction set. The RISC-V instruction set is an open-source instruction set architecture rather than the ARM proprietary architecture. The board also contains a KPU which is a general-purpose neural network processor. It offers the ability to use any activation functions, allowing for more versatility when it comes to the neural network framework. This KPU also has the ability to overclock to 800 MHz offering .5 TOPS. [32]The MAIX supports the use of micropython allowing access to many different libraries to use as well as using python to program the board. MAIX supports tiny-yolo, mobilenet-v1, and TensorFlow lite which are all frameworks to make neural networks. This allows for some more options in software when it comes to picking the network to train with. All its software is open source which means there will be tons of access to documentation. It has a very small footprint which makes it easy to integrate anywhere. Starting at $40 USD it again looks like a very good option. All sellers appear to be sold out of this board at this time. With no access to buy this option is not able to make it into our final product consideration.

Product Comparisons

After carefully considering all our machine learning products above we have narrowed down our results to just three main options. These options consist of Google's Coral Dev Board, Nvidia's Jetson Nano, and finally the Raspberry Pi 4 with the Coral Accelerator as an extra attachment. These 3 options appear to be the most qualified and suited for the kind of processing we need in our project. The following sections offer a comparison of these 3 boards and where they do very well or fall short to the others.

Processing Power

In the table below we have the comparison of the CPU, Clock Rate of the CPU, GPU or TPU, and processor cache. Because of the nature of machine learning, the most important component in this will be the GPU or TPU as these are the best at performing matrix multiplications necessary for the network. These details will help provide the necessary details to choose which processor will have the best performance for what we are looking for.

The memory of each board is another important component to be able to determine if it is qualified to run many tasks in parallel and not need to wait on memory to free up. In the table below there is a comparison between the same 3 boards as above. This time we are comparing the memory on the system, to see which one will fit

our machine learning needs. We also need enough memory to store the program on the system after the model has been trained. Another bonus would be if there is expandable memory so we can store things like images and data logs.

Table 3.4.8.1. Processing Comparison

	Coral Dev Board	NVIDIA Jetson Nano Developer Kit	Raspberry Pi 4 Model B + Coral USB Accelerator
CPU	Quad Cortex-A53, Cortex-M4F	Quad-core ARM A57	Quad core Cortex-A72
Clock Rate	1.5 GHz	1.43 GHz	1.8 GHz
GPU	Integrated GC7000 Lite Graphics + Google Edge TPU coprocessor	128-core Maxwell @ 921 MHz	Google Edge TPU coprocessor
Cache	32KB L1 instruction and data cache, 1MB unified L2	48 KB L1 instruction cache and 32 KB L1 data cache, 2 MB of L2 Unified Cache	48 KB L1 instruction cache and 32KB of L1 data cache, 1MB of L2 Shared Cache
RAM	1 or 4 GB LPDDR4 Memory	2 or 4 LPDDR4 Memory	1, 2, 4, or 8 GB LPDDR4 Memory
Flash	8 GB eMMC, with a MicroSD slot for expandable storage	16 GB eMMC, with a MicroSD slot for expandable storage	Expandable MicroSD slot for program and Operating system

The table above shows that the most qualified CPU for the task is the Raspberry Pi 4 Model B with its A72 processor. This is a newer generation of processor when looking at its predecessors that both the Coral Dev Board and the Jetson Nano both have. At 1.8 GHz, this processor seems to be the best in the CPU and Clock Rate for these categories. In the GPU category while the Raspberry Pi standalone doesn't have a mentionable GPU the coral accelerator gives it the edge with the same TPU as the Coral Dev Board. This makes the Raspberry Pi come out on top for the GPU category as well, with the only contingency that the TensorFlow Lite framework is used. The Jetson Nano gives a more versatile performance allowing for more frameworks than just one. In the final category of cache, the Jetson Nano takes it with 2 MB of L2 cache with the Raspberry Pi shortly behind it with only 1. In terms of raw computational power, the Raspberry Pi 4 with the Coral Accelerator comes out on top.

All these options have comparable memory and flash. Since they all have expandable MicroSD slots all of these are great options for the flash memory that we need. In terms of RAM the only one that has an advantage is the Raspberry Pi 4, as it has an 8 GB option for memory unlike the other 2 that only go up to 4. When looking for these different products many retailers were sold out of their lower RAM options, leaving only their higher versions of RAM devices to choose from. This means that the Raspberry Pi 4 has a slight edge on the others in terms of memory as well, making it the best choice for our needs in this category.

Pricing

Like with every engineering process, there is always a trade-off between performance and price. This principle also applies when selecting a machine learning controller. We must try to keep everything as cheap as possible so that we can meet our funding provided by our sponsor. Our primary objective is to maintain cost-effectiveness to align with the funding provided by our sponsor. Simultaneously, we must ensure that the product we procure fulfills our processing requirements both effectively and efficiently.

As a collective we have chosen a philosophy that functionality must come first over price. This means that while price is important, we must make sure that every requirement is met properly. With this understanding the pricing is important, however it is valued a little bit less than functionality and versatility.

With these things taken into consideration, we have the prices as found at their minimum on seller websites. The Coral Dev Board starts at $129.99 with the 1 GB version and $149.99 for the 4 GB version. The NVIDIA Jetson Nano comes out to be $149 for the 4 GB version and the 2 GB version doesn't exist on seller websites anymore. The Raspberry Pi 4 at 1 GB of RAM comes out to be $35 all the way up to $75 for the 8 GB version. The Coral Accelerator starts at $59.99. This paired with the Raspberry Pi 4 can range from $95 to $135. This makes the Raspberry Pi option the best priced even with the added expense of the Coral Accelerator.

Product Software and Setup

Hardware is a very import topic going through each of these small devices, however another important thing to note is that each of these devices uses its own special software with it. Either the initializing of all the operating system for the first time or how to program the board itself. This section will cover different features and drawbacks on these three boards.

For the Jetson Nano Developer Kit there is a great tutorial that gives an Introduction, Preparation for setup, how to Write an Image to the SD card, Setup and First Boot, Next Steps, and Troubleshooting all on one page with a getting started guide. In starting off it is very simple for the first boot of the Jetson Nano. First the microSD card that is being used just needs to have the Jetson Nano Developer Kit SD Card Image formatted to it. This is as simple as just downloading

the software from NVIDA's website and then using another piece of software to format the microSD. From here just connect keyboard, mouse, and display to see the boot and all the initial options to choose from. Since there is a Linux operating system running on the device, programming it will be very easy as we can write the software directly on the device itself. The JetPack SDK is said to be NVIDIA's solution for building accelerated AI applications. This comes with a complete set of libraries for acceleration of GPU computing and computer vision which is perfect for the application we are using it for. Some of the key features of this SDK include TensorRT, cuDNN, CUDA, Computer Vision, CUDA Toolkit. With this many libraries it will be very easy to find something that fits our need rather than having to tailor specific things to our specific needs. There is a whole library of Jetson Community Projects that will have some examples and some software that can help us achieve what we are trying to do with our object recognition.

The Coral Dev Board also has a great getting started tutorial right through their website. This has all the same steps as the Jetson Nano on their site starting with requirements all the way down to the next steps. Unlike the Jetson Nano that runs the operating system straight from the microSD card, the Coral Dev Board takes the microSD and writes it to the flash memory after its first use. This is also as simple as downloading the required software onto the microSD chip, then bootup the device with the microSD in the board and it will flash to the chip itself. The tutorial has a few extra steps to setup once booted as the operating system is not a graphical user interface system like the Jetson nano. This adds a bit of difficulty to the setup because most devices we are used to working with aren't only command line interfaces. The Coral Dev Board works with PyCoral API that utilizes its Tensor Processing Unit built into the board. This hardware only works properly with TensorFlow Models that are specifically meant for the Edge TPU. Because of this our choice of framework is limited, which in turn could limit some of our software to be forced into a box that we will not be able to adjust.

With the Raspberry Pi alongside the Coral Accelerator, we are introducing multiple things to have to worry about in software. We will be having to setup and properly initialize 2 different pieces of hardware to work together. The Raspberry Pi itself has a beginner's guide that is very comprehensive, but also a bit overwhelming at first with it having close to 250 pages. Similarly, to the other boards the microSD has to be loaded with the operating system that is going to be used then written to the Raspberry Pi on its first boot. The operating system used by Raspberry Pi that is heavily supported is the Raspbian Operating System. This is another Debian-based operating system that has a graphical user interface making setup a bit easier. The Thonny Python IDE is already on the system allowing for easy development of Python applications. Setting up the Coral Accelerator to run alongside the Raspberry Pi actually isn't very hard to do at all. All that is needed is to make sure that it is in a USB 3.0 to utilize the higher data rate than the other USB slots. There isn't a setup for the device it is just plug it in and when the script is going to be run just add --edgetpu to the script argument and it will utilize the TPU. Since this is using the same TPU as the Coral Dev Board this again limits us to using only TensorFlow Lite models as that is what the hardware is for.

When it comes to programming and training different machine learning models, the actual device itself will not vary too much. With Google having a cloud-based programming service named Google Collaboratory, every program can be written and computed in the cloud. This service uses Jupyter notebooks to further simplify and organize Python Code. This gives us easy access to programming from any device, with free access to a Google GPU or TPU that can train models in reasonable amounts of time. This GPU does have a limit on how long you can use it, so there is a small premium to pay to extend the time with the GPU. After writing everything being done running and testing it can be downloaded as a Python script making it easy to access from any device. Google Collaboratory comes with many libraries already installed making it as simple as just importing whatever library is needed. For any library that isn't already installed, there is a simple command to install the library to Collaboratory. This will be our main source of programming when it comes to all of the machine learning applications.

Our machine learning applications will most likely use a pretrained model in some way, as these are generally very powerful and very accurate. We will go into more detail in a later chapter, but this is done through something called feature extraction. A very popular computer vision model that is open sourced by Google is called MobileNet. MobileNet is very powerful, but it is also a bit more computationally intensive so we need to make sure that the board can handle these speeds. As shown in the table below, the performance of these boards all meets the requirements. Some are faster than others, but since these are all rendering videos, they should more than meet the requirements of our project.

Table 3.4.8.2. Benchmarking for Machine Learning Frameworks

Model	Framework	NVIDIA Jetson Nano	Raspberry Pi 4 B + Coral Accelerator	Coral Dev Board
MobileNet V1	TensorFlow	61.6	14.9	15.7
MobileNet V2	TensorFlow	72.3	18.2	20.9
ResNet-50 V2	PyTorch	27.7	52	56
ResNet-18	PyTorch	200	DNR	DNR
YOLOv3-320	Darknet	40	DNR	DNR
VGG – 19	MXNet	100	200	DNR
Unet	Caffe	55.5	200	DNR

This is the amount of time per inference in milliseconds. The lower the number the better.

These results are all based on taking a very big test image at 3888x2915 pixels. This image was taken and preprocessed down to a 300x300 pixel image, then passed into the model. [33] [34] With these times we see that the Raspberry Pi 4B with the Coral Accelerator is the fastest of all of the boards when using the MobileNet models. This is very apparent when looking at the MobileNet models because these are TensorFlow models that the Google TPU is specifically meant to perform so highly on. This would restrict us to using TensorFlow to get the most out of the hardware we have which could cause some problems in the future.

Product Availability and Miscellaneous Features

In addition to all of the different processing features there is some things that sway us to some boards over the other. This section will highlight a few of these features here that allow us to come to our final decision.

We will be using a USB interface to be able to communicate with the CMOS, so it is important for our device to have enough ports to support the 2 cameras. With this in mind in order to make sure that the device gets the data as fast as possible to process, USB 3.0 speeds will do better to give the data over. Since we have 2 cameras, we would like there to be at least 2 USB 3.0 ports and at least 1 USB port of any kind to be able to interface a device to see diagnostics, and food levels. The Jetson Nano has access to 1 USB 3.0 and 3 USB 2.0 ports totaling to 4. The Raspberry Pi 4 B has access to 2 USB 2.0 ports and 2 USB 3.0 ports. This is deceiving because it also needs a USB 3.0 port in order to properly interface the Coral accelerator, allowing for only 3 USB ports in total to use. The Coral Dev board is a little less straightforward with its interfacing hardware. There is a USB 3.0 Type C, USB 3.0 Type A and USB 2.0 Micro-B. This means the Coral Dev board would require a USB hub to properly work with our cameras.

Wireless technology such as Wi-Fi or Bluetooth might also be useful in interfacing devices. The Jetson Nano does not come with built in Wi-Fi but has a peripheral that can be added in the future should we choose to need Wi-Fi. The Jetson Nano does however have an ethernet port so it can still be connected to the internet. Similarly, there is no Bluetooth support on the Jetson Nano without an add on. If we need either of these wireless connections in the future it is as simple as adding one thing to give both Wi-Fi and Bluetooth access. The Raspberry Pi 4 comes integrated with both Wi-Fi and Bluetooth already on the device. This means that there would be no extra need for added peripherals to connect any devices wirelessly. The Coral Dev Board comes with both Wi-Fi and Bluetooth as well. This means that in terms of wireless connections both the Coral Dev Board and the Raspberry Pi 4 come out on top.

3.4.9 Machine Learning Product Choice

After careful consideration of our options, our team decided to move forward with NVIDIA's Jetson Nano. In terms of performance, it is slightly lacking behind the other two, but it makes up for its versatility. We don't know what issues may arise in the later times of testing, so versatility goes a long way in making this decision. The Jetson Nano is more than capable of holding its own to the competition. This system comes in at $150 USD and will be used in all of the machine learning applications with the image recognition of both the birds, and the trash. The NVIDIA TensorRT SDK that uses CUDA packages so many different components together all in one making it very easy to work with and open to many different applications. Another very big reason in making this decision is at the time of purchasing there is no sellers that have any other options in stock. To avoid having very little time to work with and debug our project, we wanted a board that could get here in a reasonable time. In order to achieve this the Jetson Nano was the only one that could fit that description. Every other board was unavailable or had incredibly long lead times making it impossible to choose given our circumstances.

Development Boards

Along with the microcontroller choice, it is also important to have a development board capable of easy testing and prototyping. These development boards have access to many different features that help the process before putting everything on to a printed circuit board. These boards have features like access to on board LEDs, an on board lcd displays that are very easy to use with the module of choice, and they come with pin headers already on the board for easy access to different functions of microcontroller. With the proper selection of development board, the prototyping phase will be much faster to test and work out different functions and make sure that all the sensors and devices properly interface with the microcontroller choice that we make. The correct selection of development board will also influence the selection of our microcontroller as we want to test all of our devices with the same microcontroller that is being used in the development board as well as the one, we choose for our printed circuit board.

Arduino Mega 2560

The Arduino Mega 2560 is a microcontroller sitting under the Arduino branding. Arduino is used very commonly used among many electronics systems with it having access to many different libraries using the Arduino IDE. The Arduino IDE is open source and very easy to perform logical operations as there is high levels of abstraction. This development board has access to 54 digital input and output pins that operate at 5 volts with a 20-mA recommended current rating. These pins have a 20 to 50 kiloohm pull-up resistor that have a maximum rating of 40mA so that no permanent damage happens. The 2560 board also supports all the major communication protocols between microcontrollers such as UART, I2C, and SPI. The board supports both a hardware reset button as well as an automatic software reset that will force the program to start back at the beginning of the bootloader.

The Arduino Mega 2560 comes with 54 general purpose input/output pins that can be used for many different functions. Of the 54 of these pins, there are special pins that support serial data input and output, external interrupts, PWM (pulse width modulation) which allows for digital output to look like an AC signal, SPI, and a built in LED. This development board comes with 256 Kilobytes of flash memory of which 8 KB is used for the bootloader, 8 Kilobytes of SRAM, and 4 Kilobytes of EEPROM memory. The on-board clock runs at 16 MHz driving the main microprocessor. The input voltage range is from 6 to 20 volts with a recommended of 7 to 12 volts so that everything functions properly as expected. This development board supports different varieties of sleep modes which turn off certain peripherals as well as turning off the processor. Once the processor is off it can be woken up by different types of interrupts that can all be interfaced through the Arduino libraries. [35]

Arduino Uno

The Arduino Uno is in the same microcontroller family as the Arduino Mega so it will share a lot of the same specifications between them. The Arduino uno is generally used for an introductory system into robotics are programming embedded systems. It is using the Arduino IDE as its development environment with all of the same access to the different Arduino libraries. This development board uses the ATmega328P. This is a much smaller microcontroller with 14 general purpose input/output pins that 6 of these can be used with a pulse width modulation which makes a digital signal turn into a square wave that modulates the duty cycle to create a kind of AC signal. This board is also running with a 16 MHz clock on the development board that drives the main processor. This board supports USB connection as well as ICSP header, a reset button to allow the program to start from the beginning of boot. The Arduino Uno is the very first revision in the USB versions of Arduino as "Uno" stands for one. The Uno board also supports all the major communication protocols between microcontrollers such as UART, I2C, and SPI. The Uno also supports Automatic software resets just as the Mega above does. The Uno has 32 KB of flash memory, and .5 KB is being used by the bootloader. The Uno contains 2 KB of SRAM and 1 KB of EEPROM memory. All of these are smaller than the Mega, but the board is also cheaper, as it is more of an introduction to robotics. The input voltage range is from 6 to 20 volts with a recommended of 7 to 12 volts so that everything functions properly as expected. This development board supports different varieties of sleep modes which turn off certain peripherals as well as turning off the processor. Once the processor is off it can be woken up by different types of interrupts that can all be interfaced through the Arduino libraries. The Arduino Uno operates at 5V making it very easy to interface as with most electronics, a lot of devices like to use 5V. [36]

MSP430FR6989

The MSP430FR6989 is a very popular and very powerful microcontroller dev board in the MSP430 series. This is a system that we have a good bit of experience with

because of a previous class on "Embedded Systems" where we learned how to use the MSP430FR6989. This microcontroller is also being driven by a 16 MHz clock on the development board. This board also has access to a 32K crystal that can be used to time different aspects at a slower frequency to allow for timing without having to count rapidly with a fast crystal. The MSP430 supports 128 KB of flash memory alongside 2 KB of RAM. The MSP430 has a ton of general-purpose input/output pins with 83 different pins available. The MSP430 can be programmed using Code-Composer Studio. This is an IDE that allows for debugging, programming, and writing code for a variety of TI related projects. This IDE uses C as its main programming language.

The C standard is not made for embedded systems such as these so particular libraries need to be implemented in order to access memory mapped modules. The pro to using C as the main programming language is that it allows us to program much closer to what the hardware is actually doing. This means that we know exactly what the microcontroller is doing at all times since we are the ones manipulating the memory without much abstraction. This means with the proper development it would require much less instructions to run the same code in C than it would in higher level programming languages. The downside is that this makes software development much harder as we would have to work with harder concepts like using bitwise operators, dynamic memory allocation, and other lower-level programming methods. While our team has a good bit of experience programming in lower-level languages like C, because our image recognition software will be using Python, we would like to keep another higher-level language for our microcontroller if possible. The MSP430 also supports all of the common methods of communication methods such as UART, I2C, and SPI. This development board supports the use of both 5 volts as well as 3.3 volts. To program and debug this microcontroller it has a dedicated section of the board that has JTAG on it that can interface with the microcontroller as well as the other pieces of hardware. [37]

MSP430G2553

The MSP430G2553 is another development board in the MSP430 series that is meant for low power processing. This system is a much lighter weight and cheaper than the competitor above with the FR6989. This microcontroller is again very similar to what we have studied as a team in embedded systems, but this board we have also used in another course with junior design and actually making a printed circuit board using it.

This board can also be programmed using Code-Composer Studio since it is another TI branded product. This development board is driven by a 16 MHz clock just as the FR6989. The G2553 has 16 KB of flash memory with all of it being available to the programmer. There is .5 KB of RAM which is a very small amount, but it would still get what we need done as we wouldn't be using a ton of RAM on our low processing unit. This development board has a 10-bit ADC which is about 4 times lower resolution than what is on the other development boards. This could

limit our range of reading from analog signals which we plan on using to detect a break in a light sensor. This development board has 24 general purpose input/output pins to be used for different features. This board also supports the major communication protocols like UART, I2C, and SPI just as the other boards. This development board comes with 2 real time timers with a 32 KHz clock speed. This has very similar pros and cons to the MSP430FR6989. This version is a bit cheaper with a slightly smaller number of features so this can still be a good candidate for testing and use of its microprocessor in the final design. [38]

ESP32-DevKitC

The ESP32 is a different series of low-cost and low-power system on chip microcontrollers that has integrated Wi-Fi and Bluetooth. Having Wi-Fi and Bluetooth, while not super pertinent in our final design not requiring any wireless connection, may have a good benefit when trying to test and properly design our system. The ESP32-DevKitC comes with a hardware reset button on the module and a boot button that allows for firmware downloading. It comes with a USB to UART Bridge for writing code to the board through USB making it easy to flash a new program onto the board which is a big requirement for easy testing of the system.

This development board comes with 39 different general-purpose input/output pins. The ESP32 has 448 KB of ROM for booting, 520 KB of SRAM. This board uses a 40 MHz to drive the CPU which is faster than the other boards that we are comparing. This board also supports major communication methods such as UART, I2C, SPI, Wi-Fi, and Bluetooth. This board comes with a lot of new features on it that would help for debugging purposes, however the datasheet comes saying that it is not recommended for new designs. This is because there are newer products that come with more features even though this board is still in production. We are designing a new product so we do not want any of our hardware to be deprecated in any way, this means that we are not allowing the ESP32-DevKitC in our final comparison of development boards that we will be using to test our designs. [39]

Development Board Choice

Between all of these different development boards a lot of them have very similar features for what we are needing. Since this development board will also influence what microprocessor, we choose to go on our PCB this is an important choice to be made. Below we have a table summarizing the different development boards along with some of their main features that we are choosing to look out for.

Table 3.4.9.1. Development Board Comparison

Device	Flash	RAM	GPIO Pins	Programming Language	Price
Arduino Mega 2560	256 KB	8 KB	54	Arduino IDE	Already Own
Arduino Uno	32 KB	2 KB	14	Arduino IDE	Already Own
MSP430FR6989	128 KB	2 KB	83	C	$26.59
MSP430G2553	16 KB	.5 KB	24	C	Already Own

After careful consideration of the table above we have decided to move forward with the Arduino Mega 2560. This comes with some very great features that will help us test and debug as well as it will make programming a lot easier. The high level of abstraction will allow us to development software without much need or worry of our low-level memory accesses. This has large amounts of overkill when it comes to read and write memory as well as the number of general-purpose pins on the board which is a great feature to have when testing this way, we can determine how many pins will be needed in the final product. This is much better than having a development board with too little, then having to upgrade it to something with a larger amount. One of the most redeeming features of using this board for testing is that we already own this board so there will be no need to buy an extra component that will be used purely for testing that will not go into the final product.

Microcontroller Unit

In the paragraphs above we have discussed which development board we are going to use to test all of our code and part selection. To keep consistency of microcontrollers we will be using the same microcontroller family of that on development board in order to ensure that everything can transfer over nicely. The SOC (System On Chip) is the ATmega2560. Knowing that we are using a microcontroller of the ATmega series we will make sure to keep our part selecting there.

3.5 Part Selection

In this section, we will mention which technology we will use for each component type. Afterwards we will discuss and compare the currently available market

offerings and then choose which component we bought and is being used in the BIRDS.

Motion Sensors

We will use a capacitive sensor and a laser-break sensor. The capacitive sensor will detect whether something with dielectric properties (ie. almost everything) is present on the serving platform to then trigger the bird image detection. And the laser-break sensor will detect when something has been dropped into the trash analysis chamber and to then trigger the trash analysis image detection.

Since the capacitor sensor is just a big conductor connected to a resistor, we will manufacture our own 1 by 1 bit resolution capacitive sensor.

In order to construct a laser-break sensor, we require two components. The laser produces a steady and continuous light signal that hits a photodiode, allowing current to flow through it. The most important specifications to have both of these components meet are a small and consistent spot size and a fast response time for the laser diode and photodiode respectively. After finding the components that met these specifications along with our economic and safety constraints of the project, we purchased and tested them.

Autonomous Charging Technology

We will attempt to implement a solar battery charging system. There are two types of solar cell material options, monocrystalline and polycrystalline. Monocrystalline is supposed to be more efficient than polycrystalline, but for our application, it does not make a difference. What does make somewhat of a difference is the produced voltage. Since our highest voltage components will run at 5V, we were planning to utilize a 5V battery pack. If the solar cells output around 5V, that simplifies the charging circuit a bit.

Looking at the current available options, three solar panels caught our interest:

Table 3.5.1. Solar Cell Product Comparison

Product	Voltage	Wattage	Size	Pieces	Voltage Regulated	Price
FellDen Micro	5 V	1 W	110 mm x 60 mm	5 Pcs	NO	$14.99
ALLPOWERS	5 V	2.5 W	130 mm x 150 mm	2 Pcs	NO	$12.99
Soshine Mini	5 V	6 W	176 mm x 270 mm	1 Pc	YES	$11.99

Due to the sensitivity of dealing with battery packs, I do not wish to play around with it myself. That is why finding a solar panel with included voltage and current regulation would be best. Therefore, the BIRDS will be charged by the Soshine Mini Solar Panel due to the integrated voltage regulation and high wattage output for the lowest price.

Food Dispensing Mechanism

We will design and implement a screw conveyer to deliver food to the birds. We will have to design our own food storage and screw conveyer ourselves.

Actuators

We will use two servo motors. One for driving the trash insert latch and the other to drive the trash sorter. In addition to the servo motors, we will use one stepper motor to drive the screw food conveyer mechanism.

Table 3.5.2. Servo Motor Product Comparison

Product	Turn Range	Operating Voltage	Stall Torque	Gear Materials	Pieces	Price
Smraza SG90 9g	180°	4.8 V to 6 V	1 kg/cm	Plastic Gears	4 Pcs	$7.99
TIANKONGRC MG90S 9g	180°	4.8 V to 6 V	2 kg/cm	Metal Gears	4 Pcs	$13.99
Deegoo MG996R 55g	180°	6 V to 7.2 V	12 kg/cm	Metal Gears	4 Pcs	$20.99

We will use the Smraza 9G servo motor because we already had some lying around and after testing, it was strong enough to drive the trash sorter or a door latch.

PCB Micro Controller Unit

Because we want a continuity between our prototyping board and out final prototype, we the same microcontroller family as the one on the Arduino MEGA2560. Below is a table summarizing some of the main features of the different ATmega series microcontrollers.

Table 3.5.3. 8-bit Atmel Microcontroller Comparison

Device	Flash KB	EEPROM KB	RAM KB	I/O Pins	16-bit resolution PWM channels	Serial UARTs	ADC Channels	Price
ATmega640	64	4	8	86	12	4	16	$5.7
ATmega1280	128	4	8	86	12	4	16	$16.2
ATmega1281	128	4	8	54	6	2	8	$13.6
ATmega2560	256	4	8	86	12	4	16	N/A
ATmega2561	256	4	8	54	6	2	8	$25.4

Out of these microcontroller options, the ATmega1281 fits our proposes well. It is most definitely overkill for what we require, but it is easier to have leftovers than to lack the flexibility.

Supplementary Stimulus

Supplementary visual stimulation will be provided by LEDs and auditory stimulation by a buzzer.

We already have multiple LED components and a passive buzzer.

Power Supply

We have not decided on the exact battery technology nor the capacity because it will all depend on what the actual load of the complete system will be. Since both Lithium-Ion and Lithium-Polymer are practically identical, at least on the needs of the BIRDS, we would choose the cheaper one of them. The only thing we are certain about is that because of the danger of playing with batteries when inexperienced, we want to stay away from building our own battery pack system and instead buy a prepackaged and regulated battery.

Nevertheless, Table 3.5.4 shows some batteries that are somewhat like what we are looking for.

Table 3.5.4. Battery Product Comparison

Product	Output Voltage	Input Voltage	Amp Hours	Battery Type	Pieces	Price
Kakashi Heat Glove Batteries	5 V	5 V	5 Ah	Li-Ion	2 Pcs	$29.99
INIU Portable Charger	5 V	?	10 Ah	Li-Ion	1 Pc	$17.99

4. Standards and Design Constraints

In this section, we will discuss, in depth, the standards and constraints of the design process for the BIRDS. This segment will cover how the BIRDS will assist in advancing our society and how we will ensure no harm to the intended audiences. Assessing the limitations of our circumstances and surroundings, along with many other factors, will prove necessary in executing our design process effectively.

4.1 Standards

Standards are an inescapable fact of life that everyone has to deal with at all times. Standards can appear in the clothes we wear on our back all the way to the electronics we use. It is important that we follow these standards so that we can keep everything in place. To keep our project in high regard, we have to make sure that our project can stay inside of these standards. It is important to be aware of these set of standards, so in the following sections we will be listing some of these standards in which we will be abiding by.

Electrical Safety

Our products involve electronic systems, so this means that we have to abide by the UL67 standard. The UL67 standard is a standard for making sure that the cover panelboard for the electronics is properly used with the primary function of control and protection of electrical circuits. We need to make sure that all of our electrical circuits are blocked so that no accidental contact can be made. The UL67 standard is not only applicable to high-power applications, but it also applies to any electrical enclosure regardless of power distribution. We must make sure that even though our system is a low power system we abide by these regulations.

To follow in accordance with this electrical standard we will be taking the following steps. We will make sure that all of the electronics are in an individual box cover so that no accidental exposure to live electrical components can happen. This includes but is not limited to our printed circuit board, our image processing system the Jetson Nano, and any connections to external sensors or devices. This box needs to be extremely tamper proof on the off chance that any animal could possibly encounter it. We are building the outer housing to be tamper proof, but on the off chance that somehow an animal gets through that, there needs to be no chance that any live electronics could be touched by them. Not only animals might be able to come in contact with these components, but also people who are performing maintenance on any of the physical systems as well. So, this box needs to be clearly labeled and marked so that no accidental touches can be made.

Laser Safety

The BIRDS consists of a single laser diode along with a few LEDs. The main concern of laser safety will have to do with the diode, but the LEDs must also be taken into consideration. The laser used is a class 3R laser meaning it produces an optical power between 1mW and 5mW at one visible wavelength according to ANSI standards. A Class 3R laser normally would not harm eyes during a momentary exposure of less than ¼ second. This is within the aversion response, where a person turns away and/or blinks to avoid bright light. Therefore, one should not deliberately look or stare into the laser beam. Laser protective eyewear is not necessary, and a Class 3R laser is not a skin or materials burn hazard. [40]

The team was provided with comprehensive training on laser safety practices before interacting with the system. This includes information on the potential hazards associated with laser exposure, proper usage procedures, and the importance of wearing appropriate protective eyewear if necessary. The only necessary time for protective eyewear would be when aligning the laser properly. During this procedure, the laser may become at eye level for a longer period of time than anticipated. The laser is encased in an analysis chamber as discussed later. This physical barrier was implemented to contain trash and prevent direct exposure to laser beam. These barriers are designed to withstand accidental reflections and scattered radiation, ensuring that users are shielded from any potential harm.

The main users of this product are the team building it as well as the birds and other animals that come into contact with the BIRDS. Thus, all of the above safety features are designed for both humans and animals.

Environmental Standards

Our device will be working with birds, meaning that our device must also meet certain environmental safety standards. The main intention is to deploy this outdoors, meaning that our housing must be weatherproof enough to survive the elements. This means that we need to make sure that our housing we choose has

a high enough IP rating to survive the constant stream of different elements that it may run into.

In an IP rating there is 2 numbers that represent the protection that it provides. The first number is for solid particle protection. This is for protection against things like dust, dirt, or something bigger like tools and wires. This scale goes from 0 all the way up to 6 where 0 is the least effective and has no protection against contact and ingress of objects, where 6 represents being dust-tight where no ingress of dust. The second digit is for protection against liquids. This scale ranges from 0 to 9K. In this scale 0 is the lowest with it being effective against no form of water, whereas 9K represents protection against powerful high-temperature water jets. There are also some extra letters that can be added on to add some levels of detail. These additional letters are as follows. For protection against oil the letter f is added. For protection against high voltage the letter H is added. M is for monitoring during water test, S is for standing still during water test, and finally W is for weather conditions.

For our system a reasonable IP would be IP64 which means that it is completely dust and dirt resistant and that it can resist water splashing from any direction. This would be a good choice because the system being outside it will be windy and often times dirt and dust will get kicked up. Not only that but the times that it rains it will be windy with water downpouring meaning that we will want water protection from all angles.

IEC 61215

The IEC 61215 standard is on design qualification and type approval for terrestrial photovoltaic modules. This is essentially how to implement solar panels into a design. This includes indoor and outdoor designs in open air. This standard defines qualification tests that modules should undergo to verify their durability in different environments. This means that the panels have also been tested in different environments and can withstand things without significant degradation. In order to use solar panels that can hold up in the environment we need to make sure that the solar panels we use have gone through testing to meet this standard.

Battery Standards

In our choice of battery, we need to make sure that it can meet all standards on batteries appropriately to be able to incorporate in our design. Our plan is to use a lithium-ion battery in our design to be able to meet our constraints. The IEEE 1625 is a standard relating to the design and manufacture of these lithium-ion batteries. To make sure that we have proper batteries that comply to these standards we must make sure that they are rated as such.

4.2 Design Constraints

Our team must be able to balance between feature of development as well as cost of the components and boards. It is very common that the more expensive option has enough more processing power, but it increases heavily with its cost. For our system we need to have something that meets all of our design philosophies without giving up too much in any one particular field. In the upcoming sections we will discuss some of the different constraints that we decided how we are going to approach as well as some problems that may arise.

<u>Economic Constraints</u>

In designing our system, a big factor to take into consideration is the economic constraints. As we are in college we would like to spend as little money on this as possible while trying to keep all of our requirements met. Luckily, we do have a sponsor for this project that will be supporting us as we pick out devices and electronics for developing. Because we have a sponsor for the project that also means that we need to keep our project within budget, or we will have to start paying for things out of pocket. Even with a sponsor we want to try to keep options as affordable as possible so that this project would be reasonably priced if it went to market. This means we need to make sure that we spend enough time in the researching phase to guarantee that we can stay under our budget requirement while also meeting the specification requirements. This is sometimes known as getting the most bang for its buck, basically meaning you are getting performance for every dollar. Keeping all of these things in mind as we move along will be pertinent to make sure that we meet our goals without upsetting our sponsor or having to spend too much money ourselves.

<u>Time Constraints</u>

The time constraints put upon us are probably among the most stressful for this project. Because this is our senior design project in the course, we need to make sure that all of our goals are met on time. Failure to do so can result in one or all of us retaking senior design from the start again. This would severely delay our graduation. In order to make sure that this doesn't happen we as a team need to ensure that we have a working prototype by the end of senior design 1 and the device is working and fully functional by the end of senior design 2. This only leaves us with about 4 months to get a working prototype and then another 4 months to get it fully functional. This on top of other classes will be one of the hardest constraints to follow, but also the most important. There are some things that might become a hurdle in meeting this time constraint that we will discuss further.

One of the main hurdles that our group will most likely run into is with the printed circuit board design. No one in our group has any real experience with this kind of work so this will be starting from scratch for all of us. First, we need to make sure that we have all of our components picked out and they all properly work together. This adds some extra delay to actually designing our PCB because we don't yet

know what components to include in our design. Then finally after the PCB is designed in software, we then need to wait for it to actually be manufactured. This process can typically take anywhere from 3-15 business days. All of this time adds up and this is still before we even have the board to test in our possession. After receiving it there will definitely be things that don't work the first time, meaning there will be fixing of the board. This will involve desoldering and resoldering items on to it which add to development time. Because of all of this information, we need to make sure that we order our PCB with time to spare to meet the requirement for time.

Another section that can affect time it takes to develop is the fact that some of our team members live a bit far away from campus. This means that meeting up can sometimes be a bit hard to coordinate as the commute just takes too long. Not only the commute but many of us have jobs or internships that we also have to try to balance along with the commute. This makes in person meetings very hard and generally can only happen around once a week with our very busy schedules. We are fortunate enough to be able to use things that allow us to meet online named Discord. We will discuss Discord further later in the paper.

Environmental Constraints

As mentioned, the potential environmental impact our project could create, as it will be interacting with birds and potentially other animals, gives significant reason for environmental safety precautions. This means we need to consider our surroundings and make sure that our device is as economically friendly as possible. On the flip side we still need to make sure that all of our specifications are being met while keeping this goal true. We cannot afford to give up too much while trying to be economically friendly. One of the best ways we plan on keeping this environmentally friendly is through the use of solar panels. These solar panels will be hooked up to our rechargeable battery. This means that it is using renewable energy in order to give the battery extra charge and longer battery life. This limits us with the placement of the system. We need to make sure that our system when placed has easy and plentiful access to sunlight to make sure that it is being charged adequately.

While keeping a battery charged through the use of solar is great and helps limit the use of charging the battery through other means, this isn't the only thing that we need to worry about. We need to ensure that no wildlife can be harmed from our system at all. To do this we need to think about the kind of food that the system should be filled with, the possible noises that it may make, and just any possibilities of malfunctions that may potentially arise in the future with no one around to fix right away. One way of helping with this is by keeping the system closed until a bird comes, this way no other animals have the possibility of getting trapped in any sort of housing or having something closed on top of them. We also need to make sure that any LEDs that we add or any noises that may play for positive reinforcement are not at all detrimental to any kind of animals that may approach our system.

In keeping all these things in mind this allows our placement of BIRDS to be more versatile and thus covering more ground. Keeping the environment safe is a very important task for us considering that we are building something that can be used to help clean the environment. If this were to create more waste than it does help it would render our project useless. This also makes our project more marketable as we can be presenting a topic that can help the environment as well as clean up the world.

Social and Political Constraints

The main objective of BIRDS is to provide a service in which to train birds by. This system will mainly be for the use of people who are willing to train the birds. This will act as a helper to their training as they will need to introduce them to the system first. This means that we will be aiming towards bird trainers with our product. Once one or two birds are trained it will spread to more birds realizing what is happening and then more birds will begin to come to exchange trash for food. While this product could very much go to the general population as a product, the intention is more so for the use of cleaning up particular areas that birds can access. This means that we need to aim to please bird trainers in the way the system works in order to properly meet the goals that we are shooting for. We want this device to be easy to install as well as easy to handle and access. The reason for this is that we do not intend for people who are well versed in electronics to be handling this device. We want to make it as user friendly as possible so that it does not matter who buys and uses this device, even if they may have no idea how the electronics work.

As for political constraints that we must abide by, not too many come to mind. The only real thought we had that could cause some political problems could be if the device is placed in a location where birds should not be fed. This does not have too much impact on our design. As a team we have decided as long as everything is up to standard, and we do not use anything that could possibly be illegal in any way then this constraint poses no threat to our project.

Ethical Constraints

As we develop our project further and progress in our research, we plan on keeping our standards of safety very high. We need to always keep this in mind as we will be making a system that will not only be useable by people but also by birds. This makes the talk of ethics come very largely into play as these birds will be interacting with our system and we need to make sure that we do not put them in any sort of danger or cause stress or harm to any of these animals. These sorts of conversations have come up already in our research when we were discussing the design of how the bird would deposit trash in the first place. Our original thought was to have a housing that is closed off to all other animals and to open up only for a bird and allow the bird inside of the house. With great intentions we had planned on birds coming inside to drop off trash. This introduces a lot of extra variables and things to worry about. Now the question becomes what precautions

we can take to make sure that no bird gets stuck or harmed inside of our housing. This is why we changed the design to only open a portion that the bird can drop things inside rather than having an entire location for them to come inside. If we were to allow birds inside, we would need to add so many extra layers of precautions to absolutely ensure that no bird could ever nest inside, or potentially unwillingly get stuck inside. This was one of our first steps to ensuring that our project stays ethical with no risk to any people or birds that may come into contact with our system.

Another very important aspect, on the topic of ethics, is the material that we make our device out of. There will of course be the need of protective layers inside to house the electronics away from reach of any animal or accidental contact. This box needs to be strong enough so that no animal could slip through and try to chew on or even eat any electronics. This is very important as wild animals will not know what it is they are trying to get to, but they will try anyway as their curiosity will get the better of them. The first way of properly making sure that this does not happen is to make sure the outer housing cannot be penetrated in any way and is safe to animals. This means that there should not be any sharp edges or possible material that could harm the ecosystem or any animal to come into contact. This means that we will have to make sure that all of our corners are rounded and there is no possibility of anyone getting hurt. This should also be material that is sturdy enough to withstand any battering from an animal that might try to break inside. The source of the material is also important. This material cannot be anything that may be detrimental to the animal's environment. This could be anything from the color to the scent of the material. All these things are important to take into consideration when we are making a product designed for the purpose of working with animals.

Manufacturing Constraints

Another set of constraints will be placed on the production and manufacturing of the BIRDS, specifically the physical housing and waterproofing and the mechanical parts of the system. There will be limitations on what can be done when building and the materials that can be used for the exterior housing, for example, based on our desires for the system to be lightweight, durable, and waterproof. The construction of our system will also be heavily dependent on the building skills and resources we have. A lack of experience in typical manufacturing procedures like soldering or 3D printing would cause a fairly significant constraint on the structures we can produce. These limitations, however, can be overcome with resources, whether those be other people who are more familiar with these manufacturing processes, or tutorial videos we might use to learn how to do them ourselves. Time and cost constraints will go hand in hand with these manufacturing constraints.

Another future manufacturing constraint to consider if the BIRDS is to be made available and produced as a commercial product down the line is the efficiency of production and ease of replication in building the system. If we even want to consider making the system readily available for campuses, governments, or other

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potential customers to use, making the system efficiently produced and manufactured in a way that makes it worth the time and cost, both for us in producing and for customers in purchasing, is another constraint to consider.

Sustainability Constraints

When the factors of environmental and animal hazards are considered, a high importance is placed upon the sustainability of our system. Since the BIRDS will be placed outside, where it will be exposed to the elements and to wildlife, efforts to give the system a suitable durability that will sustain it without frequent maintenance will prove to be important.

Weatherproofing will need to be implemented on the surfaces of the housing for our optical and electronic components, since these components do not mix well with water or any type of excessive moisture. We will attempt to encase all of these non-weatherproof components inside of the housing to ensure they will not be susceptible to water or moisture damage. This, however, will impact and constrain various parts of our system's design, including where components will be able to be placed and how big sections of the housing will need to be. Though this may pose problems, there is a high importance placed on the sustainability of our system, given the goal of the system operating on its own for extended periods of time, possibly for a week at a time, without the manual maintenance of cleaning or drying. A robust and waterproof physcial design will be a key part of the BIRDS.

Another significant reason for why the BIRDS will need to be robust is that it will be exposed to contact with wildlife. While the wildlife the system will come into contact with will mainly be birds that the system will be able to support without it moving too much or being damaged, other wildlife like squirrels or even cases where larger birds could compromise the integrity of the system. This needs to be heavily considered in the structural design and materials used for the housing. A robust and weighted structure for the housing of the optics and electronics or the BIRDS will be necessary to protect against any threats against the sustainability of the system. This necessity will also pose constraints and important requirements for the design of the subsystems and their integration.

Health and Safety Constraints

When research for BIRDS, safety is our number one concern. Just as mentioned in our constraints for ethics we must make sure that our device is safe for all. This from the people who may do maintenance or change out any trash or food devices, all the way to the birds and any other animal that tries to use it. In order to ensure safety is preserved we will make sure to abide by the electrical standard of having all possible electronic contacts properly covered. This will guarantee that there is no accidental touches to any electronics by human and animal alike. We need to make sure that our materials all meet the correct standards to ensure no one is harmed in any situation.

To keep up with UL67 electrical standard, we must ensure that all devices and connections are covered appropriately. This is a little bit extra concerning with wild animals as there is much more possibility for contact unexpectedly. In a project working explicitly for humans it would be labeled as well as guarded. When working with birds, the labels will not go very far, and they will be more interested in getting inside. This means we will have to use extra sturdy material on the housing to guarantee that no animal can break inside. This will properly protect the electronics as a first line of defense. That being said it will still be important to clearly label anything for any human interaction with the system for maintenance or any other reason. We plan to have extra precautions should this outer housing ever be broken through or slipped between. This will include covering all electronics and wires together and making sure that no device, such as a camera or sensor, could possibly be eaten or interacted with by any animal in any way.

In keeping up safety the material of use is also of great importance. We must make sure that this material is properly sourced with no detriment to the environment whatsoever. This material must guarantee all animals safety, even if used in an unintended way. We must make sure that this can properly hide away any potentially hazardous materials such as a lithium-ion battery. Having a battery in our design is without question as we plan on our device being able to run wirelessly in the wild. This means that there is not any way around such a component. With research we have found that lithium-ion batteries are generally safe and unlikely to fail. Due to this fact and that it is so widely used, we determined that this would be a good way to keep our health standard high as it is unlikely to fail. With that being said, if anything does go wrong with the battery if it gets damaged or fails to operate safely anymore it does pose a potential fire and explosion hazard. To make sure that we account for this, we will be making sure that the battery used is fully up to standard and high quality as this could be potentially very dangerous should we get the wrong device.

5. Hardware Design

This section defines our design for the main body and housing for the optical and electrical components of the BIRDS. Without hardware, we would be left with a grand assortment of wires, motors, and laser beams. The hardware is what will define and give purpose for the motors and position the sensors in order to define what they may detect.

In this section we will discuss the hardware systems and their respective design considerations. While not strongly focused on developing the hardware in Senior Design 1, we have come to some conclusions of what the hardware must accomplish and how we may approach them.

5.1 Housing

Being the home in which all the subsystems will live, the housing will have to accommodate for all the actuators, electronics, storage units, and the innards of the BIRDS, such as the position of the trash analysis chamber and how to route the chute to it. Therefore, we believe that housing will be a topic that will be more thoroughly developed during Senior Design 2 next semester. However, there are some characteristics that we are quite sure we will implement. The following sub-sections will discuss them in general detail.

5.1.1 Terminals

The main way birds will interact with the BIRDS is through the terminal area. We are currently thinking of creating a moderately sized landing pad that will contain the capacitor sensor's conductor to detect when something is present on the pad. The conductor will obviously have to be isolated from direct contact, however, isolated in a way that minimizes the sensitivity drop of the sensor.

Once the capacitor sensor triggers the bird recognition camera and receives bird validation, an actuator must grant access to the terminals.

The design of the terminals is inexorably interlinked with the design of the door mechanism. While we have not decided on a definitive approach, we have design objectives.

- There will be two distinct terminals, one for trash submittal, and the other for food delivery.
- The terminals should be distinct enough from each other as to prevent confusing the birds as for their function.
- The trash submittal terminal should be designed to facilitate the bird training procedure. Therefore, when trash is on the platform, trash can be easily thrown into the trash terminal by accident.
- They should both, preferably, be designed to assist in weatherproofing the BIRDS, especially the food terminal.

From these design considerations, two general design philosophies arose. The first was to have the terminals open at all times, but control access to the terminal wall, for example, a garage door controlling access to the inner-house doorway. We will call this approach the Garage Door approach. The second approach was to individually control access to the terminals, for example, automatic doors, we will call this approach Selective Access.

Garage Door

The most eye-catching and complicated approach. The garage door would require an actuator to move a large door to allow birds to access both the trash submittal and food reward. The benefits of this approach is that you only need one door to

cover both and prevents provides a lot of weatherproofing. Now from this design philosophy, two new branches were made. To have a recessed wall for birds to walk in to, very similar to a garage and garage door, or to have the door simply cover holes in the wall.

Out of the two, the recessed wall sounds very interesting and aesthetically complex. However, a recessed wall would decrease the available space for other systems such as trash analysis chamber.

And ironically enough, the exterior terminal door creates even more design challenges, for example, where do you place the motors to drive the door.

The following are some Garage Door concept door mechanisms that we came up with:
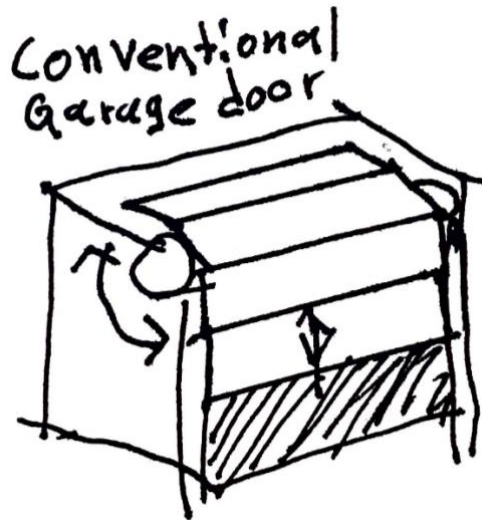
Figure 5.1.1.1. Conventional Garage Door Sketch

The conventional garage door mechanism would require the implementation of the recessed wall in order to accommodate the garage door when open. The downside is that because of the mechanical complexity of the door, it may be prone to mechanical malfunction, and as a largely autonomous bird feeder, we want to ensure reliability.
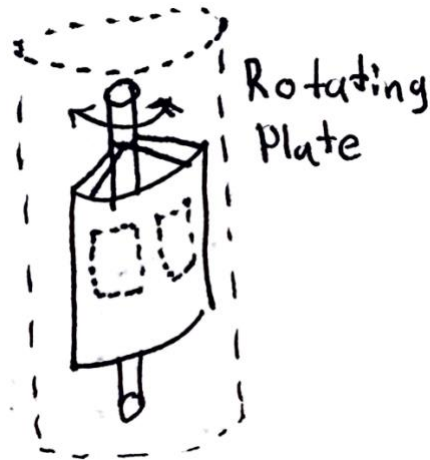
Figure 5.1.1.2. Rotating Plate Door

At some point in development, we realized that we had an affinity towards a cylindrical housing concept. It was appealing and visually distinct from any bird feeders we have seen. However, implementing a round design requires specialized door mechanism. The Rotating Plate door was our first guess as to how one would work. The main concept is that there is a curved plate with the same curve as the outer cylindrical shell. To open the door, you simply rotate the plate out of the way into its storage compartment behind the outer shell. To drive the door, we imagine a rotational actuator driving the main shaft at the epicenter of the plate's curvature to reduce the required torque. However, the need for an intrusive support shaft, right in the middle of the housing was impractical at best and impossible when we need a trash analysis chamber and its require camera under the trash terminal.

Figure 5.1.1.3. Gear Driven Rotating Door

An alternative implementation of the Rotating Plate door is to add gear threading in the inner side of the plate and drive the rotational motion trough the gears.

However, to hold the plate while it rotates, it would need some type of guiding rails. This design heavily reduces the space needed for the door, even allowing for non-recessed door access. However, the need for support and guiding rails prevents a clean seal for weather proofing.

Selective Access

Since the garage door design was very visually appealing, we believe that the added complexity of operation is not worth it. Therefore, we will most likely implement some type of Selective Access system.

Originally, we were thinking of adding access door to both the trash submittal and food delivery terminals. However, we now think that the door on the food delivery door only adds needless complexity, and most importantly, wastes precious time, adding unnecessary wait for birds to receive their food. Therefore, we will most likely only implement an automatic door to the trash submittal terminal.

Since we now only need one door mechanism, it simplifies some of the design constraints, however, the easily trainable constrain requires a bit of thought. In order to facilitate the accidental submittal of trash on the training phase, the trash submittal terminal will most likely be on the floor. The terminal door will then simply, block or open it as needed. While not as waterproof as we would like, we can simply design the platform and internals to deal with leakage water.
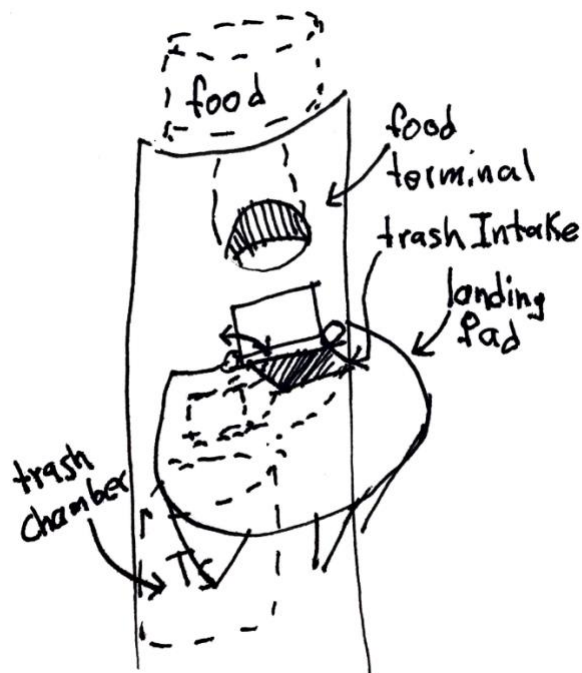

Figure 5.1.1.4. Terminal Placement Option

Our first attempt to arrange everything together. While we like the idea of a cylindrical design, it became more apparent that it would be harder to drive the

trash intake door unobtrusively. We have thought about adding gears to the door hinge and drive it through there, with the motor right behind the outer housing shell, but we could not figure out how to weatherproof that.

Eventually we proposed to implement a form of recessed wall design to fit the motor inside the wall.
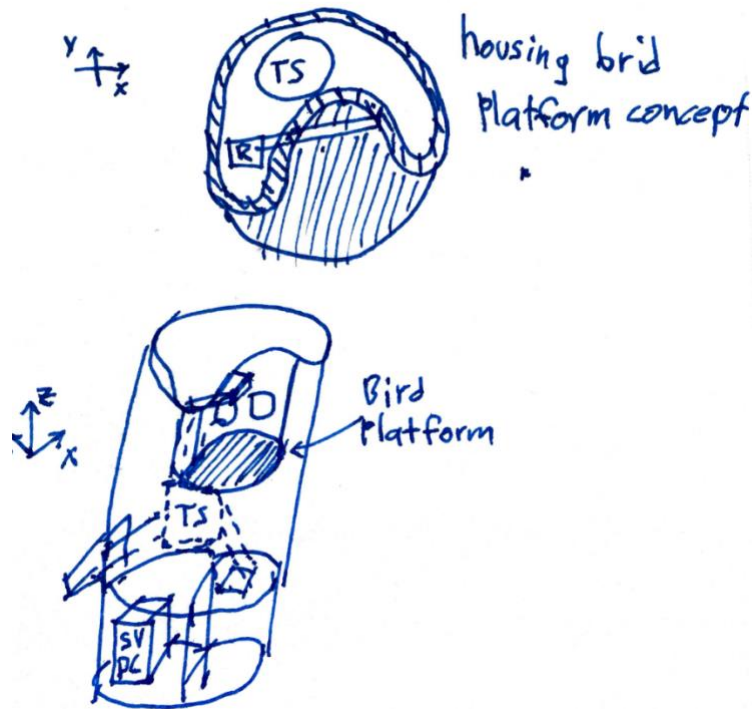

Figure 5.1.1.5. Horseshoe Terminal Concept

Implementing a horseshoe shaped intrusion into the housing would provide enough space for a servo motor to drive the trash intake latch directly. In addition, we realized that we could still fit the trash analysis chamber underneath the intrusion. It looks better and it should also provide more space for birds to rest when the external platform is added.

We will probably implement a horseshoe terminal/platform design, with the trash intake on the floor, leading directly to the trash analysis chamber.

5.1.2 Storage

The main attraction and whole point of this project, collecting scattered trash into one defined place for ease of collection. The storage systems require different design objectives from the other. The star of the show, the trash storage should be easily cleaned and easy to empty. And just like the trash storage, the food storage should be easily refillable, easy to clean, and optimally, well-sealed for food preservation.

Food Storage

To achieve the design objectives stated above, the food storage will need to have some type of food refilling system. The easiest option is to simply add a well-sealed, refill latch. It is opened to fill up the food storage and then closed and sealed tight. This should not prove too challenging, hopefully. And to aid in food storage cleaning, we can simply make the refill latch large enough to reach in and clean it manually.

The only other requirement is to design the food storage in such a way that it maximizes the efficiency of the confirmed screw conveyer system. This will most likely take the form of a funnel shape collecting towards the screw channel.

The only other confirmed aspect of the food storage is that it will be located above the terminals. This configuration will allow gravity to aid in the food delivery system. It should also reduce the length of the screw conveyer.

The materials of the storage does not entirely matter, as long as food stays safe and insulated from the elements. We could implement either an opaque material or a transparent material for the food storage. The opaque material would aid in preventing the food from heating up as much as direct sunlight would. However, the difference would be negligible, probably. And a transparent material would allow anyone to see how much food is left in reserves. Our only concern with a fully transparent food storage would be that it might attract unwanted attention from other animals and/or confuse new birds as to how to access that food. A compromise can be achieved by making the storage mostly opaque except in a small area that allows people and birds to see how much food is left in reserves.

And lastly, the storage should contain as much food reserves as to operate continuously for at least a week. As to how much food we would need, we won't know until we test the prototype on the field.

Trash Storage

The trash storage went through the same discussion about whether it should be transparent or opaque. However, much of the downsides of a transparent storage disappeared when thinking about trash. It would be desirable to build the trash storage in a transparent material because it allows anyone to see if it needs to be emptied, plus, it may aid birds to see what type of trash the BIRDS will accept, and therefore reward. So, we will most likely implement a transparent trash storage device.

Since the whole point of the BIRDS is to collect trash, the trash storage will need to be easily emptied in an intuitive manner. The simplest way to accomplish this is to make the entire trash storage floor a latch that can be opened and closed. This way, a user can just place a trash can underneath the BIRDS and proudly say, "bombs away" (not necessarily that exact statement, but something in that spirit).

Another approach to design a trash storage emptying procedure is to design for the entire trash storage to be removed from the rest of the housing and then emptied somewhere else. This approach also makes it easier to clean. However, this will require the need for some type of locking mechanism to secure the storage to the rest of the housing. All things considered, we believe that a fully removable trash storage would be most advantageous. Additionally, this approach could allow us to experiment with trash storage sizes on the go. We would only need to standardize the locking mechanism and then we can modularize the trash storages.

5.1.3 Internals

The organs of the BIRDS, without them, there would be no BIRDS. We will need to allocate all electronics, motors, and mechanism into the outer housing shell.

In the following sub sections, we will discuss what we will need to consider when designing the housing's internals.

Electronics

The brains of the BIRDS. The processing boards, motors, and batteries to power it all. Since the Jetson Nano and the coordinating PCB will not move or physically change, it would be easy and beneficial to seal them in some type of weatherproof container. While we may not be able to fully weatherproof the entire internal housing, we can at least protect what matters most and is most vulnerable. This includes the battery, however, because of the weight, the batteries will most likely be located at the bottom of the housing. The only downside to sealing the electronic components is that it would make maintenance much harder to accomplish. On the other hand, when things fail, they are most likely going to be mechanical components, like the motors, which are not going to be as inaccessible. Nevertheless, we can fix this maintenance problem by simply placing the electronics in a openable, but sealed, container.

The general location of the processing boards does not make a meaningful difference because all their peripherals will be connected through wires anyway. As a general idea, we think the electronics will probably be placed above the terminals next to the food storage.

Because the peripheral devices, such as motors, LEDs, and lasers, will not be protected in a sealable container, we ill most likely waterproof them by sealing their exposed conductor pins with some type of isolator, probably hot glue.

Water Drain

Because we will most likely not be able to fully weatherproof the housing, we will need to implement some type of draining system. This could range in complexity from simply adding drain holes throughout the housing to designing dedicated

water drain pipeage. We think the final design will be somewhere in the middle. Adding drain holes through the housing is not optimal because humidity can just permeate throughout the housing. If we are able implement a simple drainage system, we could allow water to flow cleanly through the housing in a controlled matter while maintaining some insulation inside the housing.

The most likely place for water to leak inside the housing is through the trash intake terminal. While the trash intake door may protect most of the water from entering the housing, the seal may not be perfect. We can further reduce the chances of water leakage by angling the bird platform slightly sloping towards the ground. That way, if water does reach the intake door, it will not pool around the hatch and instead flow off the platform.

Another way to prevent water from entering through the trash intake terminal is to add a roofing above the recessed wall containing the trash intake latch. This would reduce the chance of water even reaching the intake terminal seal.

Worst case scenario, water reaches the trash intake terminal and it breaker the hatch seal. We could design the trash chute going toward the trash analysis chamber with a small grove for water to flow in a controlled matter. It would be best if the water would then diverge away from the trash analysis chamber all together, but if not, water can flow through the trash analysis chamber. We should just ensure that that water flows into the discard chute instead of the trash storage.

Unwanted Discard Chute

In the same vein as the water draining system, the trash discard chute will have to direct unwanted objects thrown into the trash analysis chamber outside the housing. The design of the discard chute will be inexorably linked with the design of the trash analysis chamber. However, there is one objective we would like the discard chute to accomplish:

The discard chute should be designed in such a way that objects can fall out of the housing, but animals cannot climb inside the housing.

5.1.4 Externals

This section will discuss the external features of the housing of the BIRDS. The main feature of focus for the external part of our project will be the landing pad for the feeder, where the birds will have their first point of contact with our system. The external discussion also includes the positioning of the solar panel on the roof of the feeder's housing.

The landing pad will arguably be the most crucial part of our project's design, as designing it to be the most appealing, developing it at the proper dimensions, and creating it to be characterized by durability and consistency will be some very crucial aspects. In short, the landing pad will be suspended in front of the feeder,

supported underneath, and centered with the bird imaging system mounted to the front of the feeder. This will ensure for the most consistency in the location of the birds, forcing them to land within the field of view of the lens system. The landing pad will feature two openings where it meets the main body of the feeder. These are the terminals for food and trash. Figure 5.1.4.1 shows some concept sketches for the side view and front view of the external housing for the BIRDS. These sketches are not a final design, but rather some food for thought about the future prototypes for our system. They serve as promising bases for the development and decision-making of our project. More on the position and placement of the bird camera will be included in section 5.3.2.

To save battery power, we will implement and mount a solar panel on the top of the housing of the BIRDS. We will design a panel mount and the structural support it requires. Since we are currently in the northern hemisphere, we should ensure that either people mount the BIRDS with the solar panel pointing south, to receive the most amount of sunlight, or that we design a pivoting system for users to manually position the angle of the solar panel and therefore the direction that it faces. The latter option could allow our consumers to further cater their system for their surroundings and optimize performance.
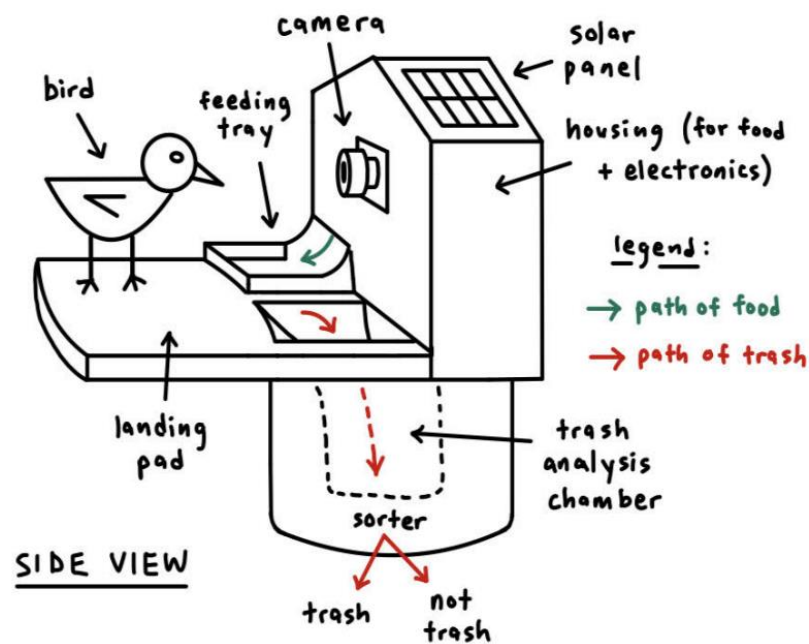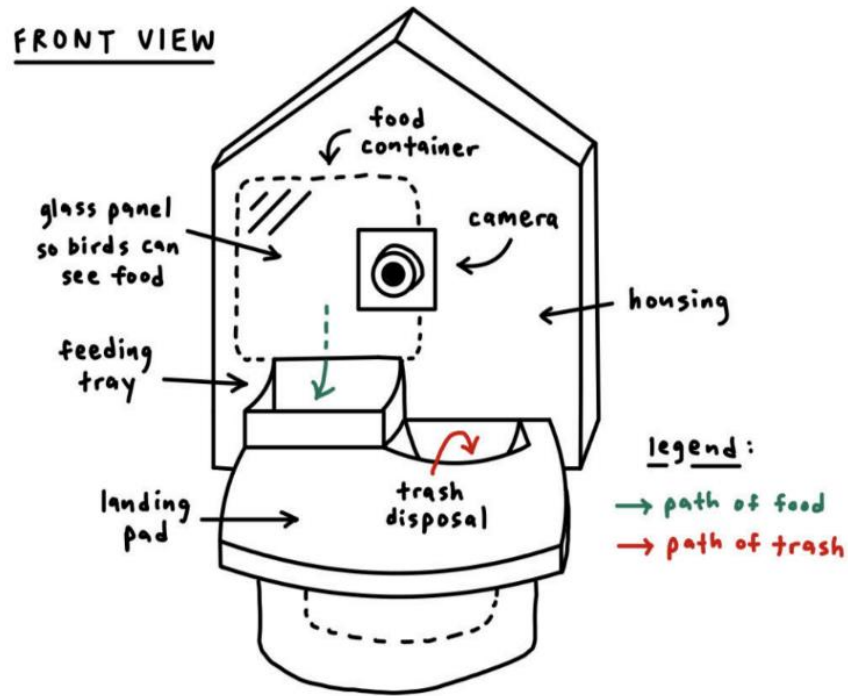
Figure 5.1.4.1. Alternative Concept Sketches for External Housing

For the solar panel electronics, we will also need to design some type of through hole for the wires from the solar panel to enter inside the housing. It will have to be sealed so that the system can still stand up to the elements. Since the solar panel is not likely going to move much, the through hole may be permanently sealed. This would provide the most weatherproofing.

5.2 Trash Analysis Chamber

And finally, the bowels of the BIRDS. The system that decides whether to accept and reward our participant birds, or to discard the object out of the housing. Being the most critical system of the BIRDS, the trash analysis chamber must accomplish some core objectives for successful operations. Following are the design objectives for the trash analysis chamber:

- Must provide a clear area for the submitted trash to be easily analyzed by the trash recognition camera.
- Must reliably catch and hold any submitted object from the trash intake chute.
- Must be able to sort the direction of the submitted object to either trash storage or the discard chute that leads outside the housing.
- If water does for some reason reach the chamber, it should be able to drain leakage water away from the storage chamber.
- It should, optimally, be simple enough to drive with a single actuator component.

As previously stated in the abstract of the paper. Our team member, Rodrigo Guerra, already had experience designing a successful concept for the trash analysis chamber. Because he was the model author and the prototype worked flawlessly, the BIRDS will implement a trash analysis chamber based on the previous design.

5.2.1 Trash Imaging System

The components that make up the trash imaging system are the LED, the lenses, and the CMOS sensor. The LED will illuminate a fallen object, the lenses will capture and focus light, and the CMOS sensor will take a picture and send the data to the Jetson Nano for processing.

The LED will be a white light source to properly irradiate the trash that birds drop into the analysis chamber. It will be placed at a specific location in the chamber to best light up the object and not interfere with any other systems, specifically the photodiode in the laser sensor. To avoid crosstalk between the laser and LED, the LED will be placed below the photodiode.

Properly designing the lens system required knowledge of the Thin Lens Equation, shown in Equation 1, and the linear magnification relationship, shown in Equation 2.

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

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

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. We can use these equations if we approximate the lens system to be a single lens system.

These equations had to be correctly integrated with the mechanical design of the analysis chamber to form a focused image onto the sensor. The chamber is a cylindrical-like shape with a height of 20cm. The lens design we will implement into the chamber is a double lens system. Approximated as a single lens system, s_1 will be set at infinity and s_2 will be roughly the focal length. This design allows for plenty of space for the trash to fall into the chamber and to also install the laser sensor below the lens.

Moving forward with this design, the magnification of the lens system is a crucial component of the design to focus the best image possible onto the CMOS sensor. To determine the optimal magnification of the image, we had to consider the

average size of the trash being imaged, the size of the CMOS sensor, and the height of our chamber. With these three values known, we were able to find the right focal length to design our lens system.

Our main goal is to be able to properly determine if a cigarette has landed in the analysis chamber. The average length of a cigarette is 8cm long. [41] The size of our CMOS sensor is 5.42mm x 3.02mm. The magnification of the lens system required to capture a complete image of the cigarette onto the sensor is $\frac{3.02mm}{8cm} =$ 0.0378. The entire length of the lens system must be less than the height of the system:

$$s_1 + s_2 \leq 20cm \tag{3}$$

Using Equation 2, $s_2 = 0.0378s_1$. Therefore, from Equation 3, $s_1 \leq 20/1.0378$. Plugging the new values of s_1 and s_2, we find $f = 7.02mm$. The double lens system must have an effective focal length (EFL) of 7.02mm or smaller. This means that the variables d_{o1} and d_{i2}, seen in Figure 5.2.1.1 must inversely add in Equation 1 to get a focal length of 7.02mm or less.
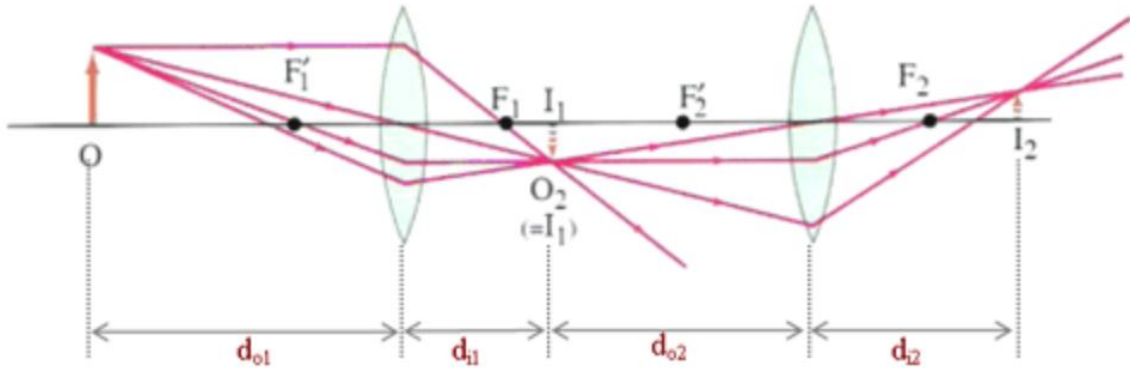

Figure 5.2.1.1. Two Lens System Schematic Diagram. Reproduction permission requested from Physics Live.

If we no longer approximate the lens system to have one lens and 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 Equation 1 and Equation 2 for each respective lens shown in Figure 5.2.1.1. The fifth equation uses Equation 1 for the front and back of the two-lens system, values d_{o1} and d_{i2}. The sixth equation, Equation 4, solves for the overall magnification of the two-lens system with the first and second magnification of each lens.

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

The final equation is the height constraint of the entire lens system.

$$d_{o1} + d_{i1} + d_{o2} + d_{i2} = 20cm \tag{5}$$

We have 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. We set d_{o1} = 175mm. 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 = 8mm and f2 = 4mm.

5.2.3 Laser Motion Sensor

Also within the waste analysis chamber is the object detection laser motion sensor. This design will utilize a red laser source, a potential system of mirrors, and a photodiode. The laser source will be used to create a laser grid from which, if broken by a falling object, will cause higher order functions within the BIRDS. The mirrors will be placed in specific locations around the chamber walls to reflect the laser beam at calculated angles to form a laser grid where every object that falls into the chamber must break this plane. This mirror system will eventually reflect the laser light onto a photodiode which will sense when and object breaks the created light path.

The goal of this motion sensor is to create a laser grid which any object that is dropped into the analysis chamber will break. To achieve this, the laser diodes, the mirrors, and the photodiodes must be positioned around the cylindrical-shaped chamber, all at the same height, to send, reflect, and capture the laser light. As seen in Figure 5.2.3.1, Figure 5.2.3.2, and Figure 5.2.3.3, the components will be placed so that when the laser is aligned, the light will be reflected anywhere from 7 to 13 times depending on the design chosen. Knowing typical cigarettes brought by birds will be anywhere from 4cm-8cm, we want to design a grid without any spaces larger than 4cm that would allow trash to fall undetected. To plan for even smaller trash brought by a bird, we will aim to design the largest spaces to be around 3cm.

One method to cover significant area is simply by reflecting the laser through the center of the circle over and over from the different mirrors. Solving for the constraint of the largest spacing to be about 3cm, we must understand how to calculate arc length. Arc length is typically defined by an angle from the center of the circle and the circle's radius:

$$s = r\theta \tag{6}$$

However, we will multiply Equation 6 by two (i.e., use the circle's diameter) in our case because we are dealing arc lengths defined by angles on the opposite side of the circle. Given we design the chamber with a diameter of 12cm, the maximum angle the laser can form at the mirrors is found solving for θ in Equation 6 with $\theta = 14.3°$. To give some room for error and to create a more symmetrical grid, we designed the laser grid with $\theta = 13°$. As shown in Figure 5.2.3.1, the laser will reflect off of 12 mirrors into a photodetector when aligned.

The maximum distance of space without a laser is shown as 2.699cm, less than 3cm.

This design also minimizes the chances that a cigarette or some other trash falls without breaking the plane. The goal is to misread falling objects only 5% of the time. Other mechanical designs will be discussed as to ensure the trash does fall through the laser light. This could be created in the form of a bumper causing long objects to spin forcing a greater surface area, or an edge designed to feed trash into the center of the chamber.
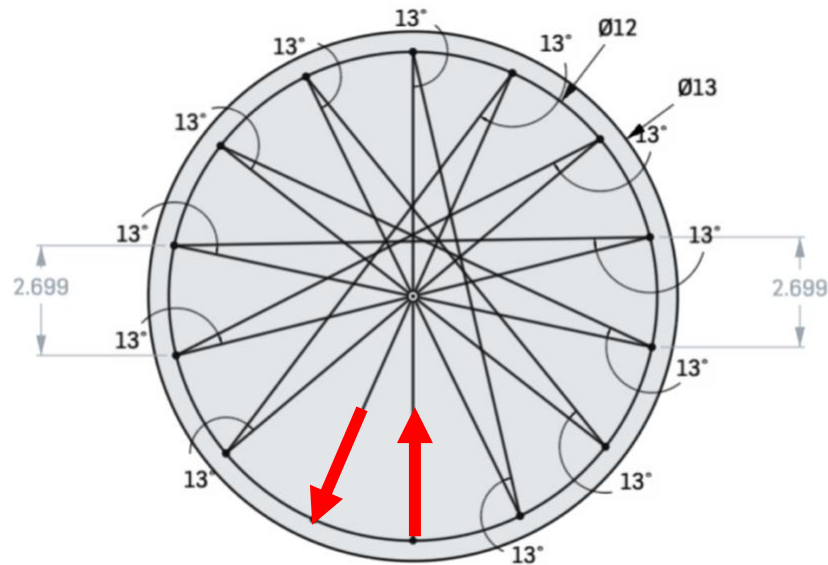
Figure 5.2.3.1. Laser Grid Design 1

A secondary design option for the laser grid, shown in Figure 5.2.3.2, would require multiple laser diodes and photodiodes. This method would form an actual grid-like structure with no mirrors used to maximize the surface area coverage. This specific design mitigates the potential error of misaligning the laser so that it would never reach the intended photodiode. However, the grid created, creates gaps of up to 4cm wide. This characteristic increases the chances of an object falling undetected by the motion sensor. To further assist in solving this problem, more laser diodes and photodiodes would be required by increasing the surface area covered by the laser grid. Cost of this system would thus go up rapidly, and the complexity of the communication between the optical system and the MCU of the BIRDS would also increase.
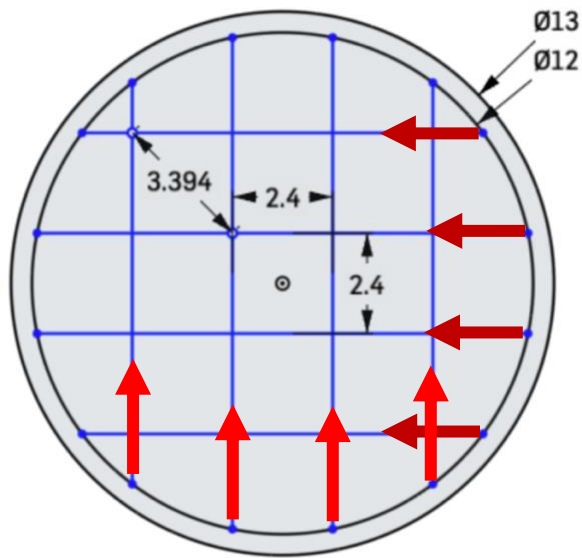
Figure 5.2.3.2. Laser Grid Design 2

The third and final design option for the laser motion sensor is including two laser diodes and two photodiodes, each with their own system of mirrors. This method is a simplification of both the first and second technique discussed. There are less reflections to minimize aligning errors, fewer diodes in use to decrease cost and complexity, and the surface area covered is greater to reduce detection errors.
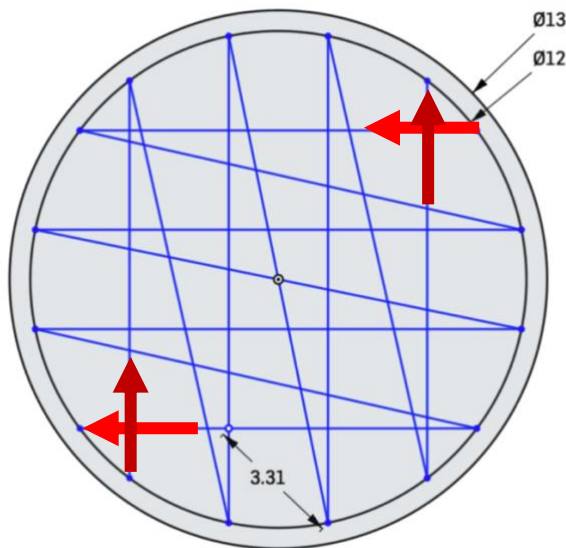

Figure 5.2.3.3. Laser Grid Design 3

5.2.4 Trash Sorter

The trash analysis chamber will have some type of holding area, most likely a cylindrical wall, and a floor pad that can rotate around an axis parallel to the ground plane. This configuration allows the trash analysis chamber to simply apply a rotational force to a beam connected to the floor plate that will tip the entire floor to either of two sides, one towards the trash storage and another towards the trash discard chute.

Because the trash analysis chamber will depend on the size and dimensions of the final housing, we have not attempted to alter the previous design yet. The most noticeable changes we will make is to change the actuator to a 9-gram servo motor. This will only require a change in mounting to fit the servo physical dimensions.

Figure 5.2.4.1. Previous Attempt's Trash Analysis Chamber

The only design objective that was not explicitly designed for was the water draining system of the trash analysis chamber, most importantly, preventing water from entering the trash storage. We could implement a software policy of slightly tilting the floor plate towards the discard plate when in sleep mode. That way, if water or any object does fall through the trash intake terminal, it will automatically fall of the discard chute and not the trash storage.

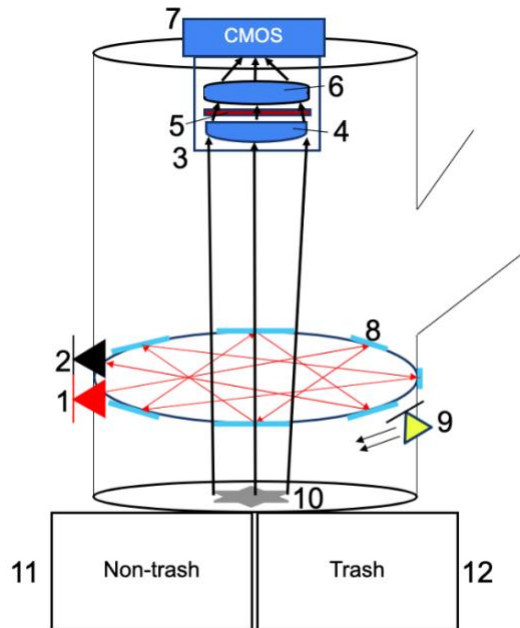### 5.2.5 Integrated Analysis Chamber Design

Figure 5.2.5.1. Integrated Trash Analysis Chamber Design
(with components: 1 = laser diode, 2 = photodiode, 3 = lens mount, 4 =
collimating lens, 5 = IR filter, 6 = focusing lens, 7 = CMOS sensor, 8 = mirror, 9 =
LED, 10 = object, 11 = non-trash container, 12 = trash container)

5.3 Bird Imaging System

This section will discuss the calculations and optical design for the bird imaging system. The imaging system will be comprised of a CMOS sensor at the image plane, two lenses for effective image demagnification from the bird onto the sensor, an infrared filter, housing for the lenses and filter attached to body for the sensor, and the bird as the object at its respective plane, restricted to the position of the landing pad where the bird will be forced to land.

This section goes into detail on the optical design for the lens system of the bird imaging system, including the measurements from our design's constraints and planning. The discussion of optical design includes factors like considering effective focal length and field of view for the system, as well as mentioning the potential to consider how the aperture size of the lens system will affect the depth of field. A discussion about where the camera will be placed and how it will be mounted is included in this section on the imaging system design as well. This part of our system is crucial because it creates the images that our software will be reading and processing, so it needs to be done effectively for results to come easily.

5.3.1 Lens System

To both alert the system of a bird that has been identified and give our image recognition software an image of the bird with sharp enough focus for identification, a proper lens system will be required to effectively focus light into the camera's sensor. Given the measurements and specifications that our housing setup would create, we set off to determine the most efficient way to give our software a detailed enough image for processing. Our decision to build a camera for imaging stemmed mostly from our desire to tune the specifications closest to those which we desire for our setup's optical design. The distance from the camera, which will be directly attached to the housing, to the point of best focus of a bird on the landing pad, which will be a specified distance from the main housing, and the desired field of view that would fully image the bird will ultimately be the determining factors for the specifications of the bird camera's lens system.

In the initial research for the optical design of the bird camera's lens system, we modeled the camera design after that which is typical of high-resolution cameras. Specifically, the lens system we planned to design resembled the typical multiple lens system in modern, high-quality cameras. Our goal was to utilize the quality of such a system while adjusting according to the specifications of our system, but we quickly realized the complexity of this approach, and we also realized there wasn't a need for such an approach. The complexity of designing a multiple lens system lies in the precision with which the optical components of such a system need to be placed and aligned to give the best and sharpest images. We concluded that a two-lens system would be sufficient, given that the lenses provide the desired magnification for our system. Given that we also don't need extremely high-quality images to perform image recognition with a certain percentage match that represents a certain confidence level, a double lens system is sufficient for our camera's optical design. Therefore, the only features of our system will be the object or subject to be imaged (the bird), a CMOS sensor, and a lens placed at optimal position in relation to the bird and the sensor.

Bird and Sensor Measurements

Before considering the components that would be needed for the external imaging system for a bird interacting with the system, many factors needed to be considered. One significant factor is the desired dimensions of the system, including the key measurements in lens system calculations. These key measurements include object distance, image distance, object size (horizontal and vertical), and image size (horizontal and vertical), and they determine the desired focal length and position of the lens' effective position.

Object distance (d_o) refers to the distance between the object (a bird in this case) and the front principal plane (FPP) of the lens system, and it would be roughly the distance from the front area of the bird landing pad to the front of the lens system. It is important to note that it is rare for the object distance to be measured from the physical front of the lens itself, as the front pupil, or front principal plane, of most

lenses differs from the front of the actual lens. On the other side of the lens, image distance (d_i) refers to the distance between the back principal plane (BPP) of the lens system and the image, which would be roughly the distance from the back of the lens system to the sensor area on the CMOS, but this is only an approximation. The same note that was made about the object distance not typically being measured from the physical lens system applies here for the image distance. Going back to the front of the system, object size refers to the dimensions of the object being imaged by the system, which would be the horizontal and vertical size of the bird being imaged. To capture a full image of the bird, with room for an offset in the setup in the case of the bird not landing directly in the center of the system's field of view (FOV), our object size will be slightly bigger than the size of the bird. And lastly, at the end point of the system, image size refers to the size of the image being focused onto the CMOS sensor, which refers to the dimensions of the image created at the image distance. The dimensions of the image created at the image plane for our sensor happen to be very small given the desired demagnification effect for our system.

It is important to note that the typical sensor size of a CMOS will mostly determine our image size, as we will be filling the sensor mostly with the image of the bird to give the best possible resolution. Specifications for the desired detail of images captured of birds, specifically the minimum detail size needed for a certain percent match, are included in sections on image processing. A diagram showing the key lens system measurements that were just outlined, along with more geometric optics, is shown in Figure 5.3.1.1.

Focal Length and Field of View

As explained previously, before optical components were to be purchased for the bird camera system, an understanding of the specifications of our overall setup was needed. Specifically, the object distance, image distance, object size, and image size were all measurements that needed to be considered. The figure below shows the relationships between those measurements in the object and image dimensions.

First, we must consider the object dimensions. The working distance (WD) is the distance from the object plane to the front surface of the lens system, and it's the distance at which our system gives the best focus for the bird that will be imaged. The field of view (FOV) shown is the same as the object height (h_o), and when measured in both the horizontal and vertical directions, it represents the width and height, respectively, of the best focused area of the object. The FOV is directly influenced by the angular FOV (AFOV), or the total acceptance angle of light from this best focused area for the lens [42]. Ensuring the AFOV of our system is wide enough to capture the full image of a bird on the landing pad is a crucial aspect of our project.

Next, we must consider the image dimensions. The back focal length (BFL) is approximately equivalent to the effective focal length of the combination of lenses.

It's measured from the back of the lens system to the image plane. On the other hand, the image distance is the distance from the BPP to the sensor. When the object's distance is much larger than the image's distance, the incoming light rays are nearly perpendicular to the optical axis of the lens system, which is characteristic of a system where the object's distance is considered infinite. In this scenario, the outgoing light rays behind the lens are focused to the focal point of the lens, giving the sharpest image at the focal length of the lens. Our lens system will act in a similar fashion, but with finite distances used in the calculation for the focal length of the lens. Lastly, the height of the image (h_i) is equivalent to what was referred to as the image size, and when this image size is measured in both the vertical and horizontal dimensions, it gives the dimensions of the image that will be cast onto the CMOS sensor. The image size will be roughly equal to the sensor size to give the highest resolution, or minimum detail size for each pixel on the camera sensor. This desired minimum detail size will be discussed later, as it is impacted by the matching required by our image recognition. The sensor size will be made sure to be slightly more than the desired image size so that the full image can be captured, specifically so variations in object size will be accounted for.
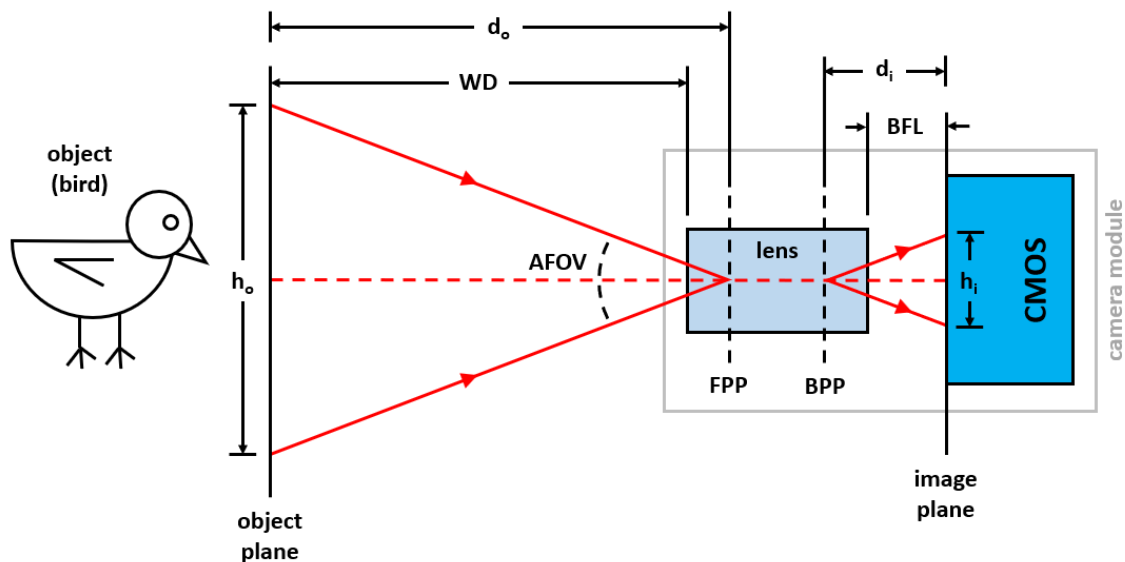

Figure 5.3.1.1. General Bird Imaging System (reproduction permission requested from Edmund Optics)

Now that all measurements have been considered, the next step in developing a design for our lens system is considering the relationships between these measurements. The magnification relationships of optics define the total magnification for our double lens system as the proportion of the image size to the object size. This would be calculated by dividing the width or height of the image by the width or height, respectively, of the object. The lens magnification is also approximately equal to the back focal length divided by the working distance.

Setting those proportions equal to each other and solving for the focal length allows us to have a formula for the desired focal length of our lens system as a function of the sensor size, working distance and field of view. Therefore, the impact of the field of view, given the sensor size and distance at which the camera will be working from, on the focal length of the lens system that we should create is clearly shown.

Pictured below, in Figure 5.3.1.2, is a ray trace for the proposed two-lens system, not drawn to scale, but as a visual for the design of the lens system to be used for imaging birds. The figure shows two images, the top one with ray traces from the top and bottom of the object, which is centered on the optical axis of the lenses, and the bottom one with a more detailed look at the ray trace from the height of the object off the optical axis, as usually represented by a simple imaging system and the measurements for the system. As outlined in the trash lens system design section, the relationships between these measurements and the desired demagnification of this system, which is a little bit higher, affect the desired focal lengths of the lenses and the separation between components that will need to be used.

The desired demagnification for the bird imaging system is found by dividing the image size, which is no bigger than the size of the CMOS sensor it will be cast onto in the image plane, by the object size, which will need to be no less than the size of the biggest bird we plan will interact with our system. With a CMOS sensor size just over 3mm, we have set desired our image size to be about 3 mm, and with the typical size of larger crows being around 40 cm, we have set our preliminary desired object size to be around 50 cm, or 500 mm. The demagnification for this setup comes out to 0.006, so as long as our double lens system has a magnification number of equal to or less than that, the imaging system should perform as expected.
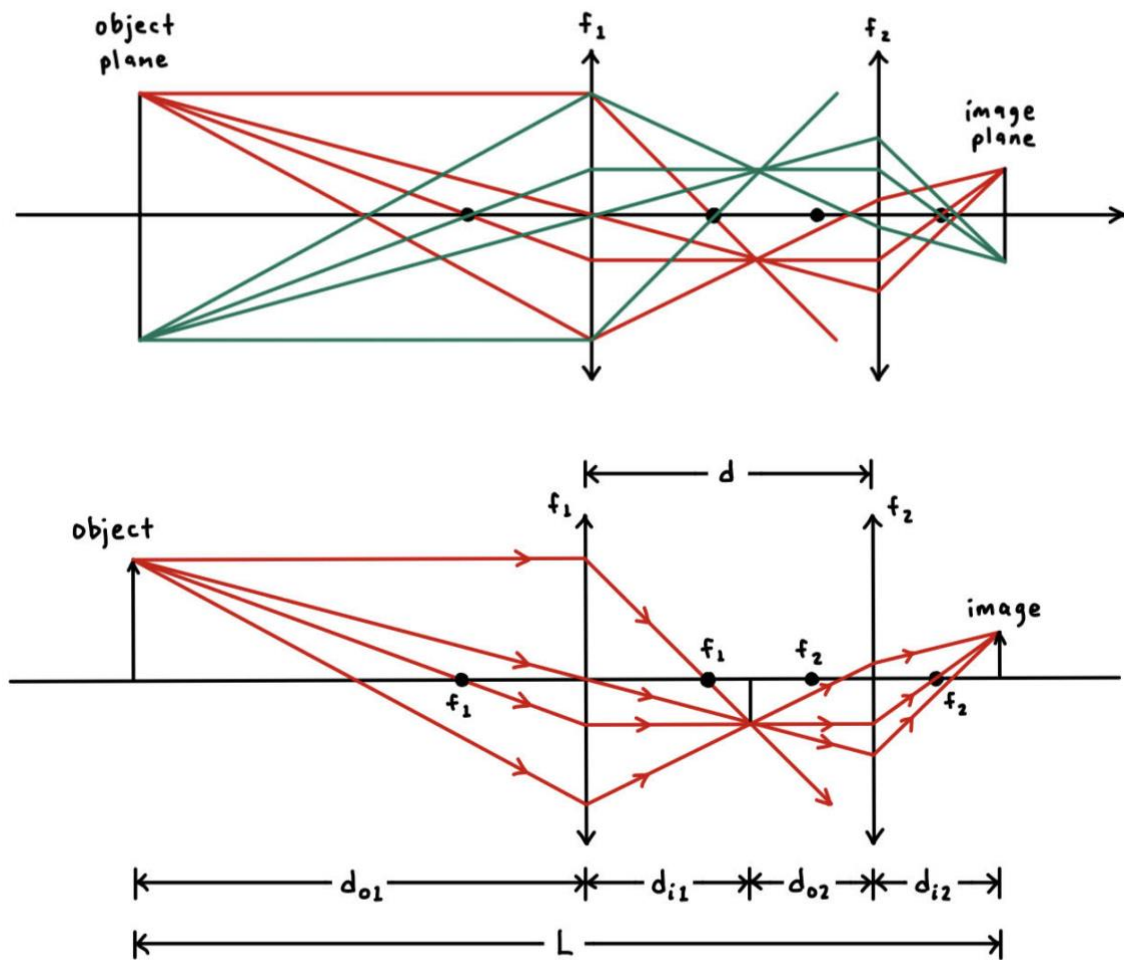
Figure 5.3.1.2. Lens System Ray Trace Diagrams

While referring to the diagrams above, calculations for both the best focal lengths and lens separation to use for the lens system were carried out. These measurements and calculations closely reflect the process taken in designing the trash lens system. The problem at hand was to create a double lens system that could provide our desired magnification that was just outlined, and do it given the limitations in size and focal length of the lenses available. A calculation test of two different sets of focal lengths, with each lens being the same focal length, was run for a lens separation of roughly 2 cm and an initial object distance, from the object to the first lens in the system, of about 20 cm, and then about 30 cm. These distances are roughly characteristic of the way are system will be designed. These measurements aren't final, but these calculations provide a system of approach given the measurements we ultimately decide on defining our overall and integrated system with.

The first focal length tested by calculation was 5 mm, with both lenses at this specification. After calculating the object distance, image distance, and magnification for each lens in the system, for a lens separation of 2 cm, the

resulting total magnification was about 0.01267, which was too high given the magnification we desire for the relationship between the bird and sensor dimensions. Changes in the focal length and lens separation needed to be tested. By changing both of the focal lengths of the lenses to 4 mm, while keeping the lens separation at 2 cm, the total magnification lowered to 0.0068, which is very close to the desired magnification number. Similarly, by increasing the lens separation to 3 cm, while keeping the focal length of each lens at 5 mm, the total magnification came out to be 0.0065, also very close to 0.006. Finally, by combining these two effects, with a system of 4 mm focal length lenses and a 3 cm separation, the total magnification significantly decreased below our goal to 0.0037, giving plenty of room for imaging to perform well. These measurements aren't final, but they are foundational for further design and testing of our system. This proof of concept, given the lenses focus a sufficient amount of light from the bird, serves as our design.

Aperture Size and Depth of Field

Another important feature of our lens system to consider is the aperture size of our lens design, which affects the depth of field of our imaging. Since the optical design of our lens system does not feature the mechanics required for an auto-focusing lens, the ideal position of focus for the bird will be fixed. This means that variation in the position of the bird with respect to the plane of best focus, which can't completely be controlled, will need to be considered. This problem poses a challenge for the design of the physical hardware of the BIRDS as well, since the landing pad will need to be designed in a way that minimizes the variation in the position of the bird and forces the bird to land closest to the point of best focus. Discussion of hardware design that takes these factors into account is included later on in the report. When researching lens design, we found that the answer to minimizing this problem of focusing without an auto-focusing mechanism lies in the aperture size of the lens.

As shown in Figure 5.3.1.3, a smaller aperture, which corresponds to a higher f number (f/#), yields a longer depth of field in the object domain. In short, the depth of field is measured between the intersections of the cone of light representing the resolution of the system (in red lines) and the ray trace for the object location of the best focus (in dotted black lines) [43]. Since the resolution and contrast of the image are negatively affected as the object is blurred when moved to be in front of or behind the best focus, the depth of field of a system must be defined along with our system's desired resolution and contrast. Therefore, the minimum resolution or detail size needed by our software to recognize a bird with a certain confidence will be what determines our margin for error within the depth of field. Choosing an aperture size with a depth of field that gives this margin for error will be key. It is also important to note that, as can be seen in the figure below, the depth of field behind the point of best focus is much longer than that in front of the same point. To take this into account, a design that exaggerates the plane of focus to be at a point that leaves more of the bird at or behind the point of best focus of the system

will be better than a design that has the bird closer to the lens system and within the narrower front of the depth of field.
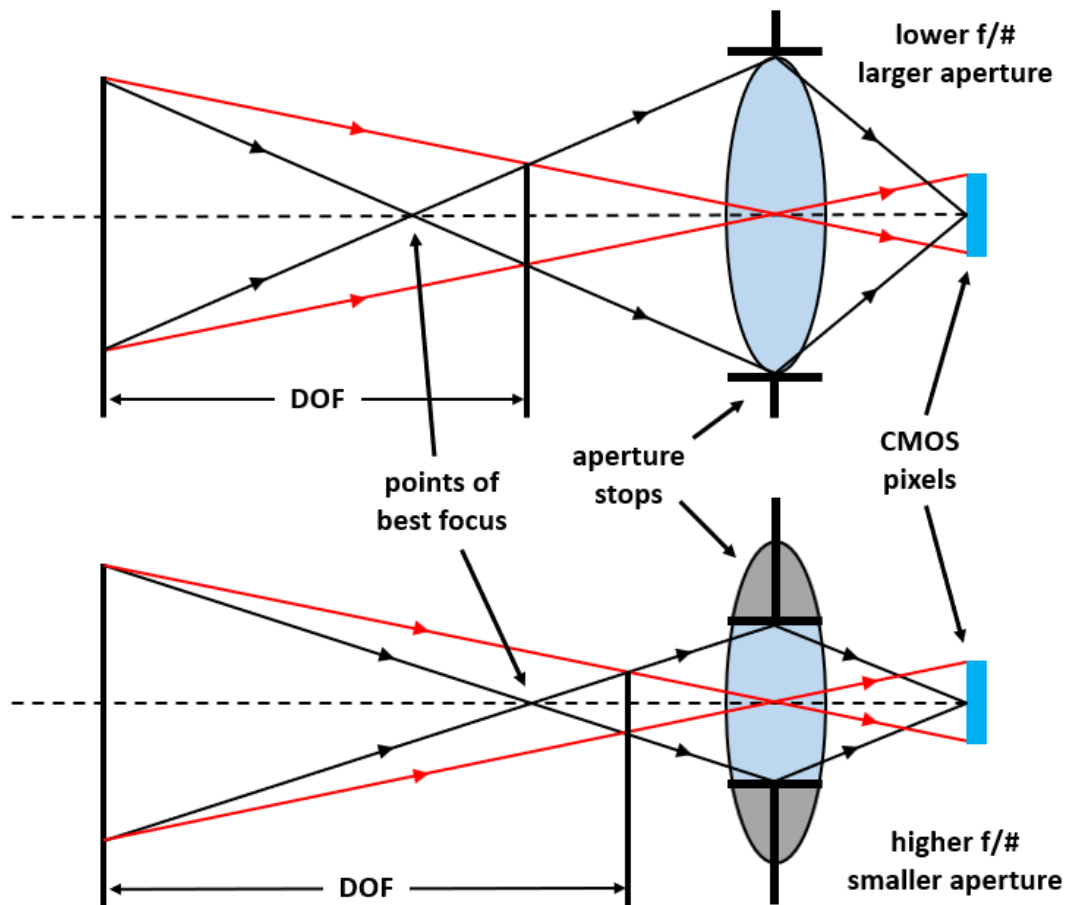

Figure 5.2.1.3. Geometric Depth of Field Diagram. Reproduction permission requested from Edmund Optics.

It's also worth noting that the lens' focal length itself also has a notable effect on the depth of field of the lens system. The longer the focal length of the lens, the smaller the depth of field. The shorter the focal length, the larger the depth of field. With a desire for a larger depth of field, we will use a lens with a small focal length, most likely around 4 or 5 mm or smaller, preferably.

5.3.2 Bird Camera Placement

Another important design feature to consider when setting up the optics and imaging system for imaging birds is the placement of the camera on the feeder. The imaging system will need to be in a position that gives the best angle and field of view for identifying birds as they land on the feeder.

As shown in Figure 5.1.4.1 earlier in the report, the bird camera will be mounted to the exterior of the bird feeder housing, at the front, facing and centered with the landing pad. The design of the mounting and positioning of the bird camera will need to work hand-in-hand with the design of the landing pad, as the position and height the bird lands at with respect to the camera will directly impact that images that are taken by our system. The camera will need to be at a height on the front of the feeder that gives the most consistent output across multiple types of birds, with acceptable results for both the tallest and shortest birds. The field of view of the camera's lens system will come into play here, as it will need to encompass the bird, however large it may be. With the landing pad and lens system descriptions already outlined, the bird camera will need to be placed at a high vantage point, preferably higher than lower, with the goal of having a good angle of view of the birds that interact. Testing and prototyping will need to take place for us to truly get a good look at how the camera will be placed best. Testing and prototyping will also most likely pose other problems that need to be solved considering this part of the design.
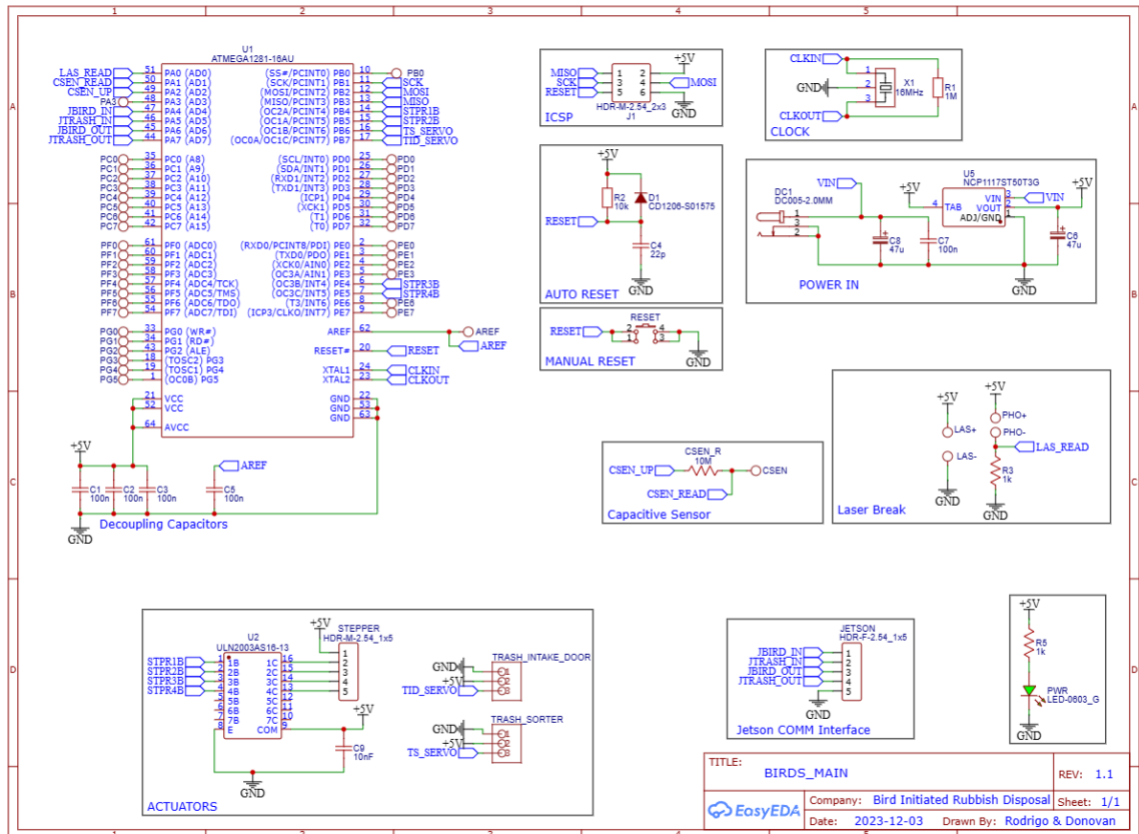
5.4 PCB Schematic Design

Because of the intentional planning of a smooth transition from the demo prototype, powered by an Arduino MEGA2560, to a custom PCB powered by the same family of microprocessor as the Arduino MEGA2560, the design of the PCB schematic was somewhat straight forward.

While some design choices are liable to change in SD2, the schematics for the sensors and motors are mostly confirmed.

For now, the current design of the PCB will utilize the ATmega1281 microprocessor. We observed how other boards, such as the Arduino MEGA2560 was connected for the ICSP, clock, auto reset, and power in circuits and adapted them for our custom board.

The only meaningful design choice was to add a through hole for every left-over pin of the MCU just in case we ever needed it for debugging. The rest was just implementing the simple set up for the peripheral devices such as the sensors and actuators.

Figure 5.4.1. PCB Schematic

6. Software Design

In approaching software design there are many different methods to choose from that change how to go about solving a problem. These can change the entire paradigm of how our software design is tackled by our team. We will be discussing some different pros and cons of different design methodologies and how they will affect our team. This will be our chosen approach to stick with while we progress further into our design.

Agile

Agile is a development method that is used to minimize risk when adding any new functionality. [44]In an Agile method teams develop software in iterations, which is just a small part of the project. These are almost like individual sections that will come together at a later stage. Each iteration is individually done then evaluated then to proceed to a further part of the project or to fix the current working iteration. This form of iteration software development is a big pro of Agile, as it allows teams to fix defects and properly align the expected outcomes early on in the development process. The downside to Agile is that these iterations happen very

regularly and quickly. This means that there needs to be real time communication when developing anything. This can sometimes to be challenging as in order to finish an iteration the entire feature needs to be working as expected. This can range from taking a couple hours to maybe even weeks. This method is very good for rapid development, but it does make this a bit more labor intensive. There are some derivations of the Agile method that use the overall ideology, but with some twists. Some of these derivatives include Crystal Method, Dynamic Systems Development Model (DSDM), and Scrum. These are still mainly Agile methods but mostly for splitting chunks of projects into teams. Since we already are working with a small team, and an even smaller team working on software, these methods are not super useful among us.

Waterfall

The Waterfall method is a traditional software development approach. This method involves completely finishing a phase to 100 percent before moving on to the next. When this phase is done it can no longer be modified. This is a very rigid and linear approach but the simplest, as it splits things into phases to follow. [44] This makes it very beneficial to a newer team in software development as we have a very clear path to follow. The biggest pro to this methodology is that it has very clear deadlines that everyone can know and follow. This not only makes the managerial role easier by setting the deadlines, but also makes everyone else's role easier that needs to follow a specific deadline. It is much easier to make sure that a product is completely ready for that specific deadline. The downside to this method is a very big pitfall of not being able to go back and correct or change any phase. This can be very detrimental during the integration part of our software development. During each phase individually it is great to work with one thing and make sure that it works perfectly, however during integration nothing ever works as expected. When things start to get added together, things never interact with each other as first expected.

Spiral

The Spiral methodology functions by continuously goes through a circular process throughout the lifespan of the project. The spiral being consistently traveled through includes Planning, Risk Analysis, Engineering, and ending with Evaluation. After this process is gone through once it starts back at the beginning of planning and travels through a new iteration of the spiral. [45] Due to risk analysis happening very regularly, it is easy to handle something new with every single iteration through the spiral. This model improves communication since there is regular reviews throughout the spiral, as well as improving quality since there is multiple iterations through the spiral over and over. The downside of the spiral method is that it is very complex. This makes it harder to follow by the entire team since there is not as clear guidelines to what is going on. This model is good for large projects, which does not really suit our needs properly.

DevOps

DevOps is a method of developing and updating the system in a loop as time goes on. [44] The pros focus on marketing and lowering failure of new releases. There are little to no drawbacks to DevOps in terms of post software development. This method is mostly focused on keeping an existing system updated and working rather than developing a new system. This means that it is not as great a methodology for our team at this time as we are not planning on consistently updating the software, as there is not any connection to the internet to the devices.

Software Development Method Choice

After carefully considering all of our different choices of software development, we have determined that for what we are dealing with the waterfall method makes the most sense. We are working with independent systems that will be easy to make work individually in stages. When a stage is done there will likely not be much way for it to break in the future when integrating different software with it. This method is also among the simplest of the different methodologies, making it easy to pick up for those of us who aren't super familiar with software development and its processes.

6.1 Embedded Software IDE

A software IDE (Integrated Development Environment) is a crucial piece of software development. It is a special piece of software that aids in developing other programs through the use of tools such as debuggers, auto generation of code, and many more. Some of these IDE's include, but are not limited to, Code Composer Studio, Visual Studio, Visual Studio Code, and tons and tons more with special features that have some quality-of-life upgrades to them.

Because of our selection of the ATMega1280, we need to make sure that we have an IDE that can compile our program down to the right instructions that this microprocessor can understand. One such IDE that does this is the Arduino IDE. This is an open-source software that allows for the programming of all sorts of Arduino support microprocessors. This is a very high-level programming language meaning that it has a lot of abstraction making it very easy to interface the processor. The Arduino IDE also allows access to a debugger on top of all of its other quality features that allows for rapid development.

6.2 Image Recognition

In order to do any sort of classification on images, there needs to be something that can actually detect what is in the images. Images just like any other data on computers, is just a series of bits that are 0's or 1's. In order to pull data out of these images we need a sophisticated kind of software known as artificial intelligence. In image classification this is generally known as a neural network.

There are many different kinds of neural networks out there and different frameworks that interface these networks. In the upcoming section we will discuss how we chose our network framework as well as how we trained it to find data that we needed it to find.

Image Recognition Framework Choice

In image recognition there are many different frameworks to choose from. A few of these that we considered all have python libraries that make it really easy to access with our chose Jetson Nano. Some of the libraries we considered are OpenCV, Scikit-Image, SciPy, Pillow, NumPy. In the end many of these libraries do the same thing just using different syntax, so we ended up choosing the one that is very high in popularity, OpenCV. OpenCV is an open-source computer vision library that was developed by Intel in 2000. Due to its popularity, this library comes with many different examples of how to use it and very large amounts of documentation. [46]

Along with the computer vision we also need a neural network to be able to pass the images through to correctly identify them. In picking our neural network framework to use we ended up going with TensorFlow. TensorFlow is another very widely used neural network framework developed by Google that has many different tutorials and examples to work through. These examples were pivotal in making the network to classify birds and trash in reasonable amounts of time.

We plan on using a supervised learning approach to machine learning. Supervised learning is where the correct label is known during training. This is used to correctly identify whether the model has predicted accurately or not accurately during the training phase of the model. The labels must be given by the dataset or labeled by us during the cleaning phase of training where all the data must have the correct values. The weights get adjusted appropriately based on these labels that is given. This is different from semi-supervised and unsupervised training where the model has unlabeled data, and it learns to find patterns in the data to classify. Since we already have labeled data there isn't much reason to work through unsupervised learning of any sort in our case.

Training Platform

Any use of a neural network means that there needs to be training of the network. Training a neural network takes a lot of computational power, as well as a lot of data. Training a network on image detection using the Jetson Nano isn't exactly feasible if we want our project to be done on time. In order to train the network, we need to train the model using external resources and compile the model down to just have its weights on the final product. We used Google Collaboratory to train the TensorFlow model using cloud-based resources. This allowed us to edit code and retrain the network from anywhere that had internet access. This hastened the development of making the image classification models. In Google Collaboratory they give free access to a GPU that can train neural networks. After everything is

done in Google Collaboratory, it is as simple as downloading the python script and the compiled model onto the Jetson Nano and running the script. [47]

Training Data

In order to train a neural network to classify things properly, there needs to be data for the network to learn on. The data we used for image classification was first found from a dataset on Kaggle. Kaggle is one of the world's largest data science communities with many different datasets and tools to help machine learning applications. Kaggle is free and open source allowing us to grab data very easily from the database. The dataset we chose was an image classification for classifying 525 different bird species. This dataset came with just over 80000 images to train and validate the model with. [48] The main goal of this image classifier is not to classify what kind of bird lands in front of our camera, instead it is to just identify if it is a bird or not. A binary classifier such as this will become very skewed if all we give it to train on are images of birds. It would just classify bird 100 percent of the time rather than actually learning anything. So, to add some variance into our data we used another Kaggle dataset that was meant for classification of animals. This was another dataset made with the intention of classifying different kinds of animals. [49]

The trash dataset was a bit harder to find something would be helpful with what we are trying to see. Our main goal is to make the model be able to be a binary classifier that can classify cigarettes versus non-cigarettes. As a team we couldn't find any dataset that had what we were looking for, so we made our own dataset. This dataset consisted of images that we took of cigarettes in a trash chamber and filled it with images of sticks and other things birds may bring. This then gets further filled in the programming stage with data augmentation.

We wrote a small script that could clean our data so that instead of classifying the kinds of birds and kinds of animals we just had 2 folders. One of these folders was populated with birds, the other folder being populated with non-birds. This was now the data being used train with on the neural network image classification.

Training Neural Network

In training the network originally, we attempted to make our own model from scratch. This proved to be a very challenging endeavor with results consistently not able to match anything in pictures. While doing research on how to improve our training to be able to properly classify images, we discovered transfer learning. Transfer learning is a technique that reuses a pre-trained model on a new problem. We used a model from TensorFlow Hub that could classify over 800 different species of birds using the MobileNet V2 architecture. [50] Since we want a model that can classify if we are looking at a bird or not this is perfect for retraining our system. In order to use this in our model we perform feature extraction and use our training data to squash down the 800 types of birds it can classify to be able to classify bird or not bird. This was very successful having a testing accuracy of over

95 percent before compiling down to TensorFlow Lite, which is just a more mobile friendly version of TensorFlow.

For the model that can recognize trash, this was a little bit harder to find a pretrained model on. So, the goal for this one is to use a generic model that is using one of the MobileNet neural network architectures. This will help in making the network as this is a generic computer vision model that is good at recognizing features in photos.

Compiling Model

After training our model, it gets compiled to run independently so that it doesn't have to be trained every single time it gets used. This is due to the large amounts of resources needed in training. This gets compiled down to TensorFlow Lite which is a lightweight version of TensorFlow making it take less resources in total to use. As any tradeoff less resources also mean less accuracy. After transferring to the Lite model, we still achieved a testing accuracy of 90 percent on the bird classification.

6.3 Prototype Board Software

To limit our power usage, we are using an embedded system with low power modes that can turn on and off peripherals as needed. As discussed above this will be using the ATmega 1281 to control this system with its low power processing. This will be interfaced through software and hardware interrupts to be able to properly handle any changes in systems. This system will have separate stages to travel through in order to progress through the system.

Stage 0

In the first stage we have named stage 0 as this is the super low power state that has all of the main peripherals in their low power or off states. All that is happening here is the system is waiting for the capacitance to change in the capacitive sensor. This is done by taking the new current reading of how long the resistor is taking to charge and comparing it to the previous reading of how long it took to charge and taking the difference between them. If this difference is high enough, then we proceed to the next stage.

Stage 1

Stage 1 is when the capacitive sensor has been triggered and now, we are looking to see what is in front of our system. To do this we send a digital signal to the Jetson Nano using the GPIO pins from the ATmega to trigger what camera needs to be used. The Jetson Nano then through its processor and image recognition software detects if what is in front of the system is bird. The ATmega then goes into a low power state waiting to see if there was a bird in front of it with a timeout of not having a bird and going back to stage 0. If a bird is in front of the system,

then the Jetson Nano sends a digital signal back to the ATmega saying there is a bird and then it gets processed to go to stage 2.

Stage 2

In stage 2 the Jetson goes back to its waiting state with no cameras currently active. In this stage the ATmega is waiting for a break in our laser grid that we have connected to a photodiode as previously discussed. This is a pin on the ATmega that is going to use reverse logic so that when the photodiode is active current is traveling through it meaning that the pin is reading high. If at any point the light going into the diode is broken or lowered enough, the current no longer flows meaning the pin is grounded going to digital low. This waits for a specified time so that the system will timeout and doesn't sit idling forever. If a digital low gets triggered on the microcontroller, we send a digital signal back to the Jetson Nano to trigger the camera, then we go to stage 3.

Stage 3

The ATmega is now back in its low power state waiting for the Jetson to send a signal back to it. In this stage the Jetson turned on its trash analysis camera and is using its image recognition software to detect if a cigarette has been dropped or something else. From here we send a digital signal back to the ATmega with a digital high being cigarette whereas a digital low is anything else. After a specified time or a digital high we move on to the next stage.

Stage 4

Stage 4 is the final stage where we read the digital signal from the Jetson Nano on the ATmega and determine which way to rotate the actuators. If a digital high was received, then we properly received a cigarette, so we rotate the platform to drop it into trash. After dropping into the trash, we then rotate the spiral food container so that the bird gets its reward. It then goes back to the beginning to its low power mode in stage 0. If a digital low was received then we rotate the platform to drop it back onto the ground, as it will most likely be a stick. This will then go back to stage 0 just without giving any food.

7. Prototype Fabrication

In this section we will describe and explain the Odyssey we went through in order to construct our first proof of concept demo prototype.

While originally exaggerated, the development of the demo prototype was actually very smooth and straight forward, except for a small scare when translating the bird recognition software from a computer software to the Jetson Nano.

7.1 Laser-Break sensor grid

Building the demo prototype required the setup of the laser motion sensor system. This setup included aligning the laser off of five mirrors and into the photodiode and plugging in the two diodes. In order to aligning the laser properly, all of the components were raised to the same height, 15cm. The mirrors were then roughly aligned to create a star-like shape for the path of light. Once the laser diode was turned on, each mirror, one by one, was aligned so that the incoming laser light hit in the middle of the mirror and the outgoing laser light hit the middle of the next mirror. This was done five times until the light was directed into the photodiode. After a sufficient voltage was read from the photodiode, the alignment process was complete.

Through this prototype fabrication of the laser motion sensor, we learned that the system must be robust in the sense that vibrations or bumps of the system must not change the alignment of the laser. If the alignment it changed, we must design a system with greater room for error of the laser alignment. This may lead to a solution involving beam expansion or a different light source. Regardless, this fabrication was a success and taught the team many things.

7.2 PCB Layout

We believe that the specific configuration and physical characteristics of our custom printed circuit board have no immediate design objectives. The only possible design considerations is to allow for through hole soldering of wires to connect the physically remote components such as motors and sensors. Other than that, we have no design preference. However, as an advanced goal, it would be cool if we were able to add a custom decal on our PCB when it is fabricated.
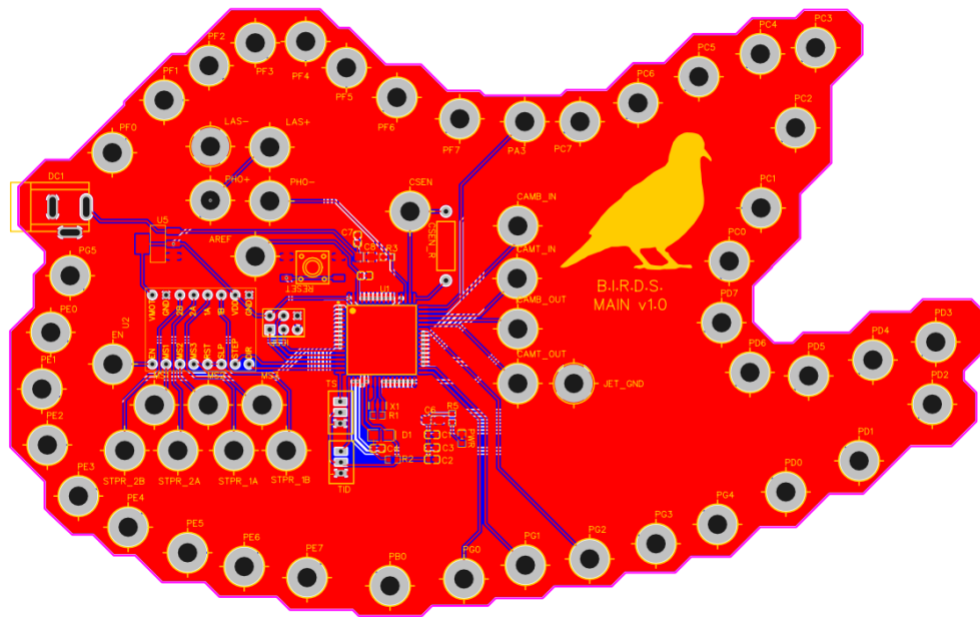
Figure 7.3.1. Proposed Main PCB Layout

We achieved the advanced goal of adding a bird decal to the board. Interestingly, we figured out that we could turn the board itself into a bird shaped board. It does nothing for operation but it looks more unique and fun. Although, connecting and routing all the components was annoying.

However, we will hold off on ordering this board just yet. Until we can get an absolute confirmation of the final schematic on the demo prototype.

8. Prototype Testing

After completing our research of the core components and parts implemented into the BIRDS, we acquired them and tested them to ensure they would function properly. Below is a description of how we tested the components and what it means for our project.

Communication

In our original design we had planned on using UART to transmit and receive data from the Jetson and ATmega. After spending countless iterations of trying to debug why we could send data but not receive we found this issue online. This is when we found out that the Jetson GPIO pins do not run at the same voltage as the Arduino GPIO pins. This was causing UART to only work in one direction making it very difficult to test. Since we are only sending binary data of "Success" or "Fail" we figured that digital pins, since we have so many leftovers anyway, should be plenty sufficient to communicate. Now that we are using digital logic to transmit

and receive everything is now working as expected and we can send and receive start and stop bits as needed.

8.1 Optical Component Testing

In this section, we will elaborate on the testing done with the optical components that were selected and received.

<u>**CMOS Sensor**</u>

When researching applicable products for our bird and trash lens system designs, we decided to purchase and analyze some typical CMOS sensors with an attached lens system to get an idea of how we could replicate and fine-tune such a setup for our project. We anticipated that having a working camera, working with it hands-on, and seeing results would serve as a beneficial observation stage for our own optical system design for the bird lens system, and the trash lens system to follow. Cameras compatible with the Jetson Nano were researched, and we took note of the various AFOVs and resolutions of the cameras. CMOS sensor modules with standard lens module encasements were found to be a promising product option for our camera designs, since choosing and integrating our desired lens and aperture size would work well with an empty slot for screwing in a desired lens module. This approach fits in perfectly with the design research we did for our bird and trash camera systems.

The most important part of acquiring and testing a CMOS sensor was making sure it would interface properly with the Jetson Nano. As stated earlier in our research, a USB 3.0 interface is to be used between the imaging sensor and image recognition hardware. During the research process we purchased two CMOS sensors that were not a USB 3.0 interface: one with a MIPI and one with only metal junctions that would require soldering. This was done to ensure the selection of a USB interface was indeed the best option. This would also give us access to two separate lens systems to assist in the lens design process. Both of the aforementioned CMOS sensors were found to be incompatible with the Jetson Nano. We then purchased a CMOS sensor with a USB 3.0 interface that complemented the Jetson Nano producing the images shown in the next two sections.

<u>**Bird Lens System**</u>

The bird lens system was tested by focusing the image through the lens system and onto the CMOS sensor. The existing optical system was set up at first for us to get a feel for how our design should take place. Our demos in Senior Design I were set up to model the trash lens system, with the camera pointing downward to simulate the trash chamber design, but the system is similar and was shown to be bale to image imges of birds on our phones effectively, with a sufficient percent match by our software recognition, which will be discussed below. The measurements and design for the bird camera have not fully been hashed out, so

that has limited the amount of testing and design that can take place, and we can't easily image real birds as of now given that they are pretty hard to collaborate or plan anything with.

Trash Lens System

Additionally, the trash lens system was implemented onto the selected CMOS imaging sensor for testing. This enabled us to view the images focused onto and captured by the sensor and run these images through the image recognition software. For this specific lens system, only a narrow field of view is required with the calculated effective focal length of 4mm. The images taken by this system are seen below.

Laser Diode

The laser diode was obtained and tested to guarantee the specifications given by the vendor: an output power of 2.5mW, a spot size of 6mm at 5m away from the source, and a divergence angle of 1.2mRad. Before using the laser for any tests, the output power was measured to check the harm that could potentially be caused to humans or animals. This power was found to be at a safe power of about 2.2mW, but caution was still used for further testing. By pointing the laser onto a nearby wall, the spot size and divergence angle specifications were found to have been met. Also, the ability of the laser diode to be aimed at and collimated into the photodiode was tested and verified.

Photodiode

After acquiring the photodiode, it was put into a simple circuit to measure the voltage gain once the laser light was introduced to it. These values were used in the software to help build the laser motion sensor. An LED was also added to the circuit to display light when the photodiode was receiving sufficient laser light to achieve the voltage gain. The rise time specification of the photodiode was tested by introducing an object into the plane of the laser and viewing the emission of the LED. If the LED would remain on, the laser light was read by the photodiode. If the LED would turn off, the laser light was not being seen by the photodiode.

8.2 Image Recognition Testing

After having a model trained on image recognition for birds on a supported framework, we thought that this would be an easy transfer over. Export the model and then load it just like loading any other model. This testing of importing and exporting was tested on a computer, and it seemed like it would be a very simple task. When we started testing with the Jetson it turns out that this was way wrong. While the Jetson does support many popular frameworks, the version of TensorFlow that it uses is an older version. Updating the version of TensorFlow was impossible and it just didn't have the right libraries to support the version we wrote the model on. This is when we discovered that the Jetson has a lot of tools

already built into its software that is given with one simple download. From here moving forward was much easier.

Software

Now that we had access to this Jetpack library moving forward became much easier. There came a pre-trained model for object detection out of the box that could be used to test. Luckily this object detection model already had a bird class that it was able to classify. Setting this up became very easy as it was as simple as one call to load the model and another to read from the camera. This was originally tested on just a standard USB webcam with the intention of moving over to other cameras later.

For training on the cigarettes this became a little trickier. The original plan of using TensorFlow wouldn't work as previously explained. Training on the Jetson is a possibility, but training on low power computing devices like that can often take way too long to make it worthwhile. After doing some more research we have found a tool online that can actually train our data using their resources. This a site called Edge Impulse. [51] This tool can train all of our data through a cloud service, and it gives a model that is already supported by the Jetson Nano which is perfect for what we need. This means that the next steps will be to get a dataset full of cigarettes and individually label each image. This step will take some time, but it isn't too hard of a step to take.

Hardware

During the process of testing the image recognition, a sufficient hardware setup was necessary to acquire the best image possible for the jetson nano to receive. The biggest lesson learned was the fact that the software needed an image to be upright and not sideways, at an angle, or even upside down. There was a specific angle the image had to be at with respect to the CMOS sensor to enable to software to run accurate testing. This can be solved by either a hardware fix involving the correct mounting of the CMOS sensor, or a software fix to accurately flip the picture every time.

8.3 Plans for Senior Design

While being at a great place to leave SD1 off, we still have some significant amount of work left to do. We have the capacitor sensor able to detect changes in parasitic capacitance. We have the laser-break sensor detecting object intrusions. And most importantly, we have a bird recognition software running on the Jetson Nano. The biggest challenge will be housing it all in one place.

The following are some of the biggest objectives we will work on in Senior Design 2:

- Finalize a design and build a housing to fit all the components.

- Calculate and find a suitable battery to power the system.
- Build and mount the bird and trash analysis cameras.
- Most importantly, either train or upload a trash detection system for the trash analysis chamber.
- What looks to be the more challenging part, figuring out how to mount the laser break sensor in an effective way to maximize the scan area.
- Finalizing and ordering the PCB to arrive by the start of the SD2.

It will be a challenging and interesting process, but we believe that senior design will be the fun part of this entire project.

9. Administrative Content

This section includes some business talk about the administrative resources that were used for our team to conduct report writing and project research and design efficiently. This section also includes information on the project budget and project milestones that were created by the team to dictate our design process.

9.1 Organizational Software Used

In order to maintain a seamless flow of communication and ensure that all team members remained well-informed about any modifications, we strategically leveraged an array of diverse organizational tools. These instrumental tools served as the linchpin of our collective success, enabling us to harmoniously pursue our shared objectives while working autonomously.

Discord

Discord was the most important tool we used to keep communication with everyone on the team. Discord has many different features that really made it stand out as our main form of communication. Members of our group were already very familiar with discord and all of its amazing features that it has to offer. Discord started as a platform mostly for gamers to voice chat and over the years turned into the Discord we know today.

The main feature that made Discord so appealing to our team is the use of making servers with different channels. Servers are a way of having everyone in one group to be able to see all forms of information being posted. Inside of these servers we have different text channels that form independent information from each other. That means that different topics can be isolated to that channel. For example, there could be a channel that is for a section on only printed circuit boards or a channel that is meant for software development. This helps keep information neatly organized and easy to find whenever necessary. This allowed for us to develop our project without the stress of looking through mass messages that other group communication might run into. Inside of these channels there is even more organization tools allowing for pinning of posts. When a post gets pinned, it can

then be accessed from an external button rather than having to even scroll through a channel. This is a great way to have import information and deadlines posted that can always be checked right away. Just as every channel is independent of each other, so are the pins from the channels.

As an added bonus these text channels can be used to post media of any kind. We had a dedicated channel to tutorials any time we found a useful link that had a video describing something similar to what we were needing to do. Along with links to different YouTube tutorials or links to products found on the internet, we could also post pictures and videos. This feature became very useful in testing our bird classifier. Since we can't always be together, we could test images taken from the camera we are planning to use for our project and pass that into the model to classify the bird. In addition to media being posted discord also allows for code to be posted. This means that whenever one of us is working on code from another device that is not cloud based, we would be able to send it to each other very easily and quickly. This helped for rapid debugging and development of software.

Draw.io

Our team used Draw.io to create our hardware schematics that show how work was divided amongst the students. Draw.io is a free, open-source diagramming tool primarily used for creating various types of diagrams and visual representations. It is a web-based application that allowed us to create the visuals necessary to explain how our project will run. The overall optical systems and electromechanical components were placed in ways to explain how certain functions of the BIRDS will be initiated and what other functions they will trigger.

ChatGPT

During the writing of this report, we decided to experiment with how the writing process could be enhanced through the use of generative artificial intelligence. In this paper we utilized the popular generative AI, ChatGPT to write a short description of how electronic components worked to skip the tedious writing. Whenever ChatGPT was quoted, a footnote was added to inform that a section of the writing was generated by ChatGPT.

GitHub

While working on the website for all of our information for senior design, we found that we were having a lot of times where we would change code or accidentally break something when trying out a new feature. That is when we remembered the very popular version control platform GitHub. GitHub is a version control platform that allows for users to store entire folder directories on a cloud-based storage. From there anyone with access to the GitHub repository can push, pull, and clone the folder onto their local machine. This allowed for development between different users as well as different machines. On top of being able to develop from different places it has the ability to rollback code to previous states, hence the name version

control. It does this by taking advantage of having branches in code. A branch is almost like a new section of code that is generally made to create a new feature of some kind or edit a previously existing feature. If for whatever reason something breaks in already working code, then the branch can be dropped and rolled back to a previous working version. If the new feature does work, then that new bit of code can be merged into the main branch making it the newest version of working code. This helps in developing and will continue to help on our journey as we create software for both machine learning and for microcontroller programming.

9.2 Budget

The following table shows our estimation of the budget for our project, including the prices for each part or component that will be purchased.

Table 9.2.1. Budget

Item	Price	Quantity
Microcontroller	$13	1
Nvidia Jetson Nano	$150	1
Servo Motor	$10	2
Stepper Motor	$13	1
Battery	$23	1
Solar	$50	1
Custom PCB	$20-$30	1
Housing Material	$20	1
LED Light Source	$15	10
Collimating Lens	$23.50	2
Focusing Lens	$20	2
CMOS	$33	2
Laser Diode	$13.18	1
Photodiode	$0.32	20
Mirror	$0.18	50
Total	**$664.58**	**96**

9.3 Milestones

The tables below roughly outline the milestones for both our Senior Design I (Fall 2023) and Senior Design II (Spring 2024) semesters. Started dates and end dates are given to show the progression of the phases of the project, along with descriptions provided for further information about each milestone.

Table 9.3.1. Milestones for Senior Design 1

Milestone	Start Date	End Date	Milestone Description
Form Group	8/22/23	8/22/23	Begin the process of forming a group and begin to set up proper communication methods.
Brainstorm Ideas	8/22/23	8/28/23	Brainstorm ideas that will meet the scope of engineering projects for senior design.
Project Selection	8/28/23	9/1/23	Selecting one of the projects from the list of prospective projects from brainstorming.
Divide & Conquer	9/1/23	9/15/23	The official presentation of our project idea and a small list of requirements, parts, and general ideas of our plans.
Website	9/1/23	12/5/23	Setup up the website that will have all of our supporting documentation, as well as some extra introductions and descriptions.
Divide & Conquer Meeting	9/20/23	9/20/23	Meeting with committee and senior design professors to discuss our proposal.
Divide & Conquer Revision	9/20/23	9/25/23	Make revisions to our proposal and any other details that will be transferred to the bigger paper later.
60 Page Draft	9/20/23	11/3/23	The draft of what will come to the final paper. This will include some of the needed topics from the final paper requirements.
100 Page Report	9/20/23	11/23/23	This will be the final meeting to go over any formatting issues before the final submission of the report.

Final Paper	9/20/23	12/5/23	This will be the final project report and will have all of the design specs, philosophies, and research that we did as a group.
Prototype	11/1/23	12/5/23	This will be a working prototype of our design that will showcase what our design can do.

Table 9.3.2. Milestones for Senior Design 2

Milestone	Start Date	End Date	Milestone Description
Order Parts	1/8/24	1/15/24	This will be the time to finalize all the parts we need and make sure everything is ordered and on the way.
Build Subsystems	1/15/24	2/15/24	This will be time to get all the subsystems working independently of each other.
Integration	2/15/24	3/15/24	Bring all the subsystems together to work out what does and doesn't work together.
Testing	3/15/24	4/15/24	After getting all the subsystems together this time will be meant for testing everything together and seeing how it works in practice.
Presentation Prep	4/15/24	4/24/24	Get all the necessary materials ready for the presentation of our materials.
Final Presentation	4/24/24	4/30/24	This will be the final presentation for Senior Design 2 marking a finished working product.

10. 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 avian creatures and humans. The historical context provided earlier highlights the potential for positive

outcomes when humans cooperate with other species, and the BIRDS project builds upon this legacy.

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. The collective analysis of these products has enabled the BIRDS team to learn from both successes and shortcomings. This has formed a well-rounded design strategy that incorporates the best elements while addressing specific challenges identified in existing solutions. As the BIRDS project moves forward, this thorough understanding of the market landscape will contribute to the creation of a novel and effective system for training birds to pick up trash, aligning with the project's unique goals and objectives.

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.

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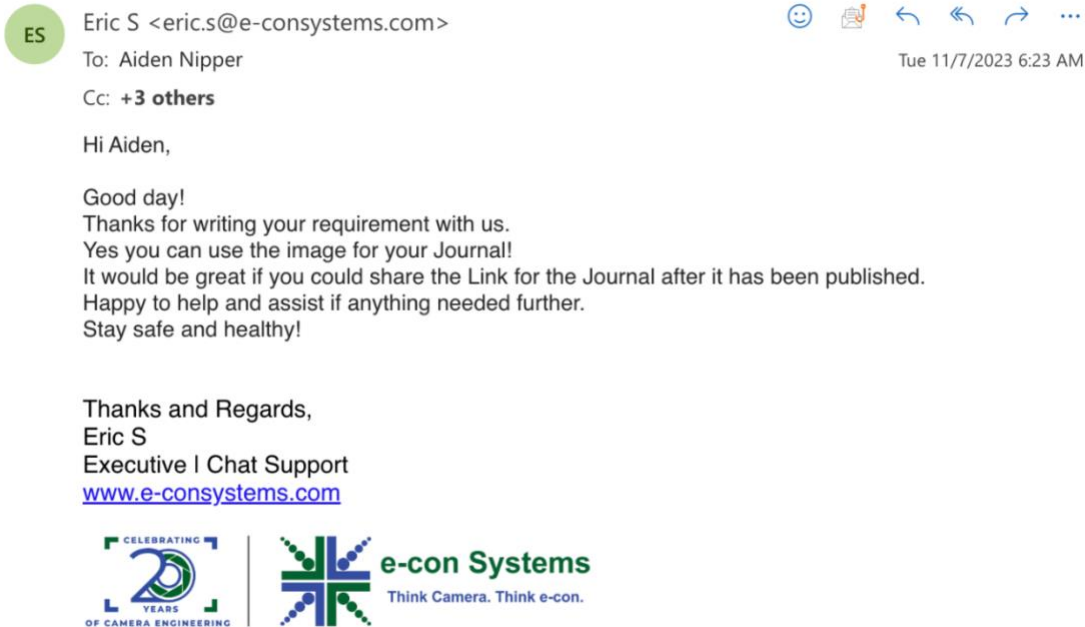
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Appendix B - Copyright Permissions

Refers to Figure 3.4.4 Interfacing Comparison Chart

Eric S <eric.s@e-consystems.com>

To: Aiden Nipper

Cc: **+3 others**

Tue 11/7/2023 6:23 AM

Hi Aiden,

Good day!
Thanks for writing your requirement with us.
Yes you can use the image for your Journal!
It would be great if you could share the Link for the Journal after it has been published.
Happy to help and assist if anything needed further.
Stay safe and healthy!

Thanks and Regards,
Eric S
Executive | Chat Support
www.e-consystems.com

Refers to Figure 3.4.5.4. Image Circle and Sensor Size

Your Name or Account Name *

Aiden Nipper

Your Email *

ai880754@ucf.edu

We will send follow-up via this email.

Your Phone Number *

3865897331

The link to the web page with issues

If there is one, please copy and paste it here.

How can we help you? *

Would you be willing to assist us in obtaining permission for reproduction of your images. We are hoping to obtain permission for the following images: https://docs.arducam.com/Optics-and-Lenses/Introduction/ entitled Figure 3 Image Circle.

Please let me know if this is possible and how we can move forward.

Respectfully,
Aiden Nipper

Refers to Figure 3.4.5.1. Comparative Schematic of CMOS and CCD Data Acquisition

To	nicolas.postec@univ-lemans.fr ✕	Bcc
Cc		

Copyright Usage Request for Educational Purposes   Draft saved at 2:20 PM

Greetings,

I am a student at the University of Central Florida, and I am part of a team of engineering students tasked with building a Senior Design project. We are building a bird house with image processing capabilities, and we would like to use some of your images in our documentation. Our research will be published on a UCF website when it is completed (https://www.ece.ucf.edu/seniordesign/).

Would you be willing to assist us in obtaining permission for reproduction of your images. We are hoping to obtain permission for the following images: "Figure 33:CMOS principle" under section "CMOS sensors" on your website http://www.optique-ingenieur.org/en/courses/OPI_ang_M05_C06/co/Contenu_20.html

Please let me know if this is possible and how we can move forward.

Respectfully,
Aiden Nipper

Refers to Figure 5.2.1.1. Two Lens System Schematic Diagram

ContactLivePhysics

Home 🏠   Contact 📖

Contact Our Team

Name	Aiden Nipper
Email	ai880754@ucf.edu
Message	Greetings,

I am a student at the University of Central Florida, and I am part of a team of engineering students tasked with building a Senior Design project. We are building a bird house with image processing capabilities, and we would like to use some of your images in our documentation. Our research will be published on a UCF website when it is completed (https://www.ece.ucf.edu/seniordesign/).

Would you be willing to assist us in obtaining permission for reproduction of your images. We are hoping to obtain permission for the following images: The two lens system schematic diagram on your webpage "Two lens system – Image distance and magnification" (https://www.livephysics.com/problems-and-answers/optics/lens-system-image-distance-magnification/)

Please let me know if this is possible and how we can move forward.

Respectfully,

Aiden Nipper

Submit

Refers to Figure 5.3.1.1 and Figure 5.3.1.3

Requesting Permission for Reproducing Images

Will DiSalvo <wddisalvo@gmail.com>
to sales

Dec 2, 2023, 5:51 PM (2 days ago)

Greetings,

I am a student at the University of Central Florida, and I am part of a team of engineering students tasked with building a Senior Design project. We are building a birdhouse with image processing capabilities, and we would like to use some of your images in our documentation on lens system design. Our research will be published on a UCF website when it is completed (https://www.ece.ucf.edu/seniordesign/).

Would you be willing to assist us in obtaining permission for reproduction of your images? We are hoping to obtain permission for reproducing the following images from your website:
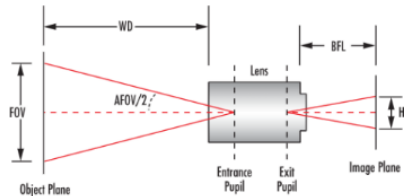

Figure 2: *Relationship between FOV, sensor size, and WD for a given AFOV.*

Webpage: https://www.edmundoptics.com/knowledge-center/application-notes/imaging/understanding-focal-length-and-field-of-view/#:~:text=The%20first%20and%20often%20easiest%20option%20is%20to,lens%20with%20one%20of%20a%20different%20focal%20length
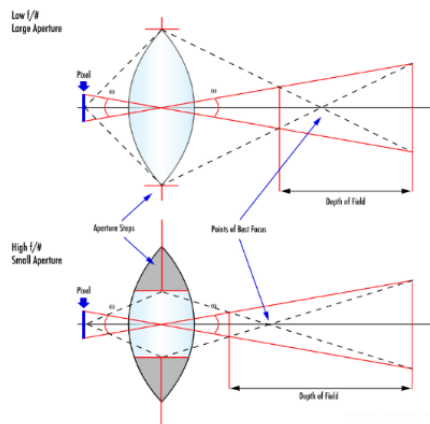

Figure 3: *Geometric representation of DOF for high and low f/# lenses.*

Webpage: https://www.edmundoptics.com/knowledge-center/application-notes/imaging/depth-of-field-and-depth-of-focus/

These images above will be reproduced in the following ways, shown as the images that will be included in our report, each with a reference noting they were adapted from the images above.
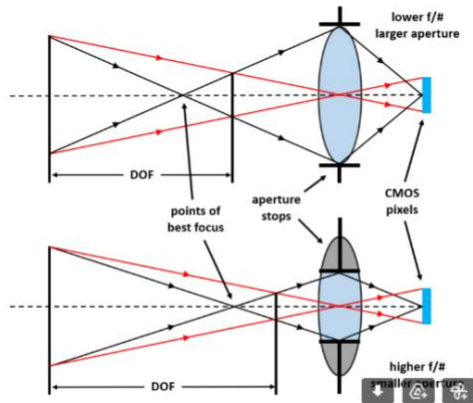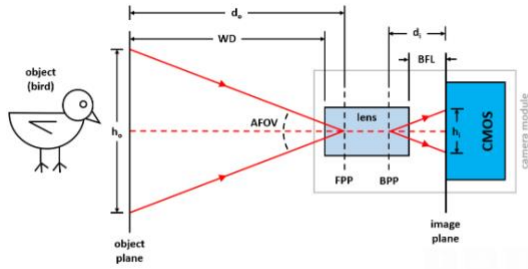
Appendix C - ChatGPT

[GPT - COMPONENT RESEARCH]

A continuous conversation with ChatGPT 3.5:

Prompt 1:
"i am writing a IEEE project report and i need to add a section on researching possible technologies to use for actuators. how does a DC motor work"

Answer 1:
"A DC (direct current) motor is a common type of electric motor that converts electrical energy into mechanical motion. It operates based on the principles of electromagnetic induction and the Lorentz force, which are fundamental concepts in electromagnetism. Here's a simplified explanation of how a DC motor works:

1. **Basic Components:**

  - **Armature:** The central rotating component of the motor, typically a coil of wire.

  - **Stator:** The stationary part of the motor, which houses magnets or field windings.

- **Commutator:** A split ring attached to the armature that reverses the direction of the current flow through the coil.

2. **Magnetic Field:**

   Inside the motor, there are two magnetic fields:

   - **Stator Magnetic Field:** This is typically generated by permanent magnets or field windings (coils of wire carrying a constant current). It creates a fixed magnetic field within the motor.

   - **Armature Magnetic Field:** The armature (coil of wire) also produces a magnetic field when an electric current flows through it.

3. **Lorentz Force:**

   When a current flows through the coil in the armature, it generates a magnetic field. This magnetic field interacts with the fixed stator magnetic field, resulting in the Lorentz force. The Lorentz force causes the coil to experience a torque (rotational force).

4. **Rotation:**

   As the coil experiences the torque, it starts to rotate. The commutator, a split ring, is crucial in this process. It periodically reverses the direction of the current flowing through the coil as it rotates. This reversal of current changes the direction of the magnetic field in the coil, which keeps the motor spinning in the same direction.

5. **Continuous Rotation:**

   By maintaining the constant flow of current and reversing it at the right moments with the help of the commutator, the DC motor can achieve continuous rotation. The speed and direction of rotation can be controlled by adjusting the voltage and polarity of the applied current.

It's important to note that there are various types of DC motors, including brushed and brushless DC motors, which differ in terms of the commutation method and efficiency. The principles described above apply primarily to brushed DC motors. Brushless DC motors use electronic controllers and sensors to achieve commutation without physical brushes and commutators, offering improved efficiency and reliability.

When researching possible technologies for actuators in your IEEE project report, you can consider both brushed and brushless DC motors, as well as other types of actuators such as stepper motors, servo motors, pneumatic actuators, and more, depending on your specific application requirements. Each type of actuator has its advantages and disadvantages, and the choice will depend on factors like precision, speed, torque, and control requirements for your project."

Prompt 2:

X

"could you rephase it in a few paragraphs"

Answer 2:

"Certainly, here's a more concise explanation of how a DC motor works:

A DC (direct current) motor is an electric motor that converts electrical energy into mechanical motion. It operates on the principles of electromagnetic induction and the Lorentz force. The motor consists of an armature (a coil of wire), a stationary stator (containing magnets or field windings), and a commutator (a split ring attached to the armature).

When an electric current flows through the coil in the armature, it generates a magnetic field. This magnetic field interacts with the fixed stator magnetic field, resulting in the Lorentz force, which creates a torque, causing the armature to rotate. The commutator is responsible for reversing the direction of the current flow in the coil, ensuring continuous rotation of the motor.

There are various types of DC motors, including brushed and brushless varieties, which differ in commutation methods and efficiency. Brushed DC motors use physical brushes and a commutator, while brushless DC motors employ electronic control and sensors for commutation, offering improved efficiency and reliability. When researching technologies for actuators in your project, consider the specific requirements of your application, as various types of actuators, including different motor types and non-electric actuators like pneumatics, may be suitable based on your needs."

Prompt 3:

"explain how does a stepper motor works"

Answer 3:

"A stepper motor is an electromechanical device that converts electrical pulses into precise and incremental rotational motion. Unlike traditional DC motors or servo motors, which rotate continuously, stepper motors move in discrete steps, making them well-suited for applications that require accuracy and control. Here's how a stepper motor works:

1. **Basic Components:**

   - **Stator:** The stationary part of the motor, typically made up of multiple coils or windings.

   - **Rotor:** The rotating part of the motor, usually consisting of a toothed gear or shaft.

   - **Magnetic Poles:** The stator poles are magnetized to create a magnetic field.

2. **Phases and Windings:**

A stepper motor can have multiple phases, typically two or four. Each phase consists of a coil or winding, and they are electrically energized in a specific sequence to produce rotation.

3. **Magnetic Attraction:**

The rotor of the stepper motor has teeth or magnetic regions, which align with the magnetic poles of the stator. When a particular phase is energized, the magnetic field produced by that phase attracts the rotor's teeth or magnetic regions.

4. **Step Sequence:**

Stepper motors operate in discrete steps. To make the motor move, you energize the coils in a specific sequence. The most common sequences are "full step" and "half step." In a full step, each phase is energized one at a time, and in a half step, two phases can be energized simultaneously at varying levels to achieve smaller steps.

5. **Direction Control:**

By changing the order in which the phases are energized and the duration of each phase, you can control the direction and speed of rotation. Reversing the sequence or changing the timing reverses the motor's rotation.

6. **Precise Control:**

Stepper motors provide precise control over the rotation angle and can move in very small increments, making them suitable for applications such as 3D printers, CNC machines, and robotics.

7. **Open-Loop Operation:**

Stepper motors are typically used in an open-loop system, meaning there is no feedback mechanism to verify the motor's position. However, this can lead to issues like missed steps if the load becomes too great or if the motor is overdriven.

8. **Driver Electronics:**

To control a stepper motor, you need a stepper motor driver or controller, which generates the necessary sequence of electrical pulses to energize the motor's coils in the correct order and timing.

Stepper motors are popular for applications where precision and position control are essential, as they offer a straightforward and predictable way to achieve discrete and controlled rotational motion. Their simplicity and reliability make them well-suited for a wide range of industrial and hobbyist applications."

Prompt 4:
"rephrase it in a few paragraphs"

Answer 4:

"A stepper motor is an electromechanical device that translates electrical pulses into precise and incremental rotational movement. Unlike conventional motors that rotate continuously, stepper motors operate in distinct steps, making them ideal for applications requiring fine control and accuracy. Here's a breakdown of how a stepper motor functions:

A stepper motor consists of two key components: the stator and the rotor. The stator comprises coils or windings, while the rotor is equipped with teeth or magnetic areas that interact with the stator's magnetic poles.

Stepper motors are categorized by the number of phases they possess, typically two or four. Each phase involves a coil that can be electrically energized in a particular sequence to induce rotation.

To initiate movement, a specific phase is energized, and the magnetic field generated by that phase draws the rotor's teeth or magnetic regions towards it. These motors operate in discrete steps, with common sequences being "full step" and "half step." In full-step mode, each phase is energized sequentially, while in half-step mode, two phases can be energized simultaneously at varying levels to achieve smaller steps.

Stepper motors provide meticulous control over the angle of rotation, enabling precise positioning. By adjusting the order and duration of phase energization, you can manage the motor's direction and speed. Reversing the sequence or altering the timing reverses the motor's rotation.

Stepper motors do not require feedback mechanisms for position verification, operating in an open-loop system. However, this simplicity can lead to issues such as missed steps if the motor faces excessive loads or overdriving. To control a stepper motor effectively, a dedicated stepper motor driver or controller is necessary. This device generates the required sequence of electrical pulses to energize the motor's coils correctly in terms of order and timing.

Stepper motors find extensive use in applications where precision and precise position control are crucial, offering a reliable and predictable means of achieving controlled rotational motion in discreet increments. Their straightforward operation and reliability make them highly suitable for a broad array of industrial and hobbyist applications."

Prompt 5:

"explain how servo motors work"

Answer 5:

"A servo motor is a rotary actuator that allows for precise control of angular position, speed, and acceleration. It is widely used in applications that require accurate and controlled motion, such as robotics, industrial automation, and aerospace systems. Here's how a servo motor works:

1. **Basic Components:**

- **Motor**: The core of the servo motor is a regular DC motor or a brushless DC motor.

- **Position Feedback Device**: This is typically a potentiometer or an encoder that provides feedback on the motor's current position.

- **Control Circuitry**: A control system, often called a servo drive or amplifier, interprets the desired position and compares it to the actual position feedback.

- **Gears**: Some servo motors have gears to increase torque and reduce the speed of the output shaft.

2. **Feedback System:**

The key to a servo motor's precision is its closed-loop control system. The position feedback device continuously monitors the motor's shaft position and reports it to the control circuitry. This feedback mechanism ensures that the motor knows its current position at all times.

3. **Setpoint and Error Calculation:**

You specify a target or setpoint position for the servo motor. The control circuit calculates the error, which is the difference between the desired position and the current position.

4. **Control Signal:**

The control circuit computes the control signal based on the error and sends it to the motor. This control signal typically takes the form of a pulse-width-modulated (PWM) signal. The control signal adjusts the voltage or current supplied to the motor.

5. **Motor Movement:**

The motor responds to the control signal and starts moving. It will continue to move until the feedback system reports that the desired position has been reached.

6. **Continuous Adjustment:**

The servo motor continuously adjusts its position by comparing the feedback with the desired position. It responds rapidly to any deviations, making it suitable for applications that require precise and real-time control.

7. **Speed and Acceleration Control:**

Servo motors not only control position but also speed and acceleration. By modulating the control signal, you can achieve smooth and controlled motion profiles.

8. **Torque Output:**

Servo motors provide a high level of torque even at low speeds, making them ideal for applications that require both accuracy and strength.

9. **Applications:**

Servo motors are commonly used in robotics, CNC machinery, conveyor systems, camera gimbals, and many other applications where precise and adjustable motion control is necessary.

In summary, a servo motor is an electromechanical device that uses a closed-loop control system to maintain and adjust its position. The position feedback mechanism continuously monitors the motor's actual position and ensures it closely matches the desired position, allowing for precise and dynamic control of motion."

Prompt 6:
"rephrase it in a few paragraphs"

Answer 6:
"A servo motor is a precision-based rotary actuator known for its ability to provide accurate control over angular position, speed, and acceleration. It is a fundamental component in applications demanding meticulous and controlled motion, like robotics, industrial automation, and aerospace systems. The operation of a servo motor can be explained as follows:

At its core, a servo motor consists of several essential elements, including the motor itself, a position feedback device (commonly a potentiometer or encoder), control circuitry (referred to as a servo drive or amplifier), and in some cases, gears to modify torque and speed on the output shaft.

The servo motor's precision arises from its closed-loop control system. This system employs the position feedback device to continually monitor the motor's current shaft position. This real-time feedback ensures that the motor is always aware of its exact position.

To guide the servo motor's movement, a target position, also known as the setpoint, is specified. The control circuit calculates the error, which represents the variance between the desired position and the motor's actual position.

A control signal, often in the form of a pulse-width-modulated (PWM) signal, is computed by the control circuit based on the error calculation. This signal regulates the voltage or current supplied to the motor, influencing its movement.

The motor responds to the control signal and initiates motion, adjusting itself until the feedback system confirms alignment with the desired position.

The servo motor continually fine-tunes its position by assessing the feedback against the target position, enabling it to respond quickly to any deviations. This adaptability makes servo motors well-suited for applications demanding precise and real-time control.

In addition to position control, servo motors also manage speed and acceleration. By modulating the control signal, they deliver smooth and controlled motion profiles. Furthermore, servo motors offer substantial torque output, even at low speeds, catering to applications that require both accuracy and strength.

Servo motors find wide application in diverse fields, including robotics, CNC (computer numerical control) machinery, conveyor systems, camera gimbals, and various scenarios where precise, adjustable, and dynamic motion control is essential."

Prompt 7:

"how do lithium-ion batteries work"

Answer 7:

"Lithium-ion (Li-ion) batteries are rechargeable energy storage devices commonly found in numerous portable electronics, electric vehicles, and more. They function based on the movement of lithium ions between two electrodes within the battery. Here's a simplified explanation of how lithium-ion batteries work:

1. **Basic Components:**

   A typical lithium-ion battery consists of three main components:

   - **Positive Electrode (Cathode):** Made of a lithium-based compound, usually lithium cobalt oxide ($LiCoO_2$), lithium iron phosphate ($LiFePO_4$), or other materials.

   - **Negative Electrode (Anode):** Typically made of carbon (graphite) that can intercalate (absorb) lithium ions.

   - **Electrolyte:** A lithium salt dissolved in a solvent, which allows for the movement of lithium ions between the cathode and anode.

2. **Charging Process (Li-ion Intake):**

   When you charge a Li-ion battery, an external voltage source (like a charger) applies a voltage across the battery terminals. This voltage causes lithium ions to move from the positive cathode to the negative anode through the electrolyte. The lithium ions are stored in the anode's carbon structure.

3. **Discharging Process (Li-ion Release):**

   When you use the battery to power a device, the stored lithium ions in the anode begin to move back towards the cathode through the electrolyte. This movement of lithium ions creates an electric current, which powers the device.

4. **Ion Movement:**

During both charging and discharging, lithium ions move back and forth between the anode and cathode. This ion movement is accompanied by the flow of electrons in the external circuit, producing electric energy.

5. **Chemical Reactions:**

The movement of lithium ions is facilitated by chemical reactions that occur at the electrode surfaces. These reactions involve the exchange of electrons between the cathode and anode materials. These chemical processes are reversible, allowing the battery to be charged and discharged repeatedly.

6. **Safety Mechanisms:**

Lithium-ion batteries are equipped with safety features to prevent overcharging and overheating, which can lead to safety hazards. These features include protection circuits and thermal management systems.

7. **Voltage and Capacity:**

The voltage and capacity of a Li-ion battery are determined by the specific materials used in the cathode and anode. Different materials yield various voltage ranges (typically around 3.6 to 3.7 volts for most Li-ion batteries) and energy storage capacities.

8. **Cycle Life:**

Li-ion batteries have a limited number of charge and discharge cycles before their capacity degrades. The cycle life varies depending on the battery's design and usage conditions.

Lithium-ion batteries have become ubiquitous due to their high energy density, rechargeability, and relatively low self-discharge rate. However, they do require proper care to prolong their lifespan and ensure safe operation, such as avoiding extreme temperatures and not overcharging or discharging them excessively. Advances in Li-ion battery technology continue to improve their performance, energy density, and safety, making them a key component in modern electronics and electric vehicles."

Prompt 8:
"rephrase it in a few paragraphs"

Answer 8:
"Lithium-ion (Li-ion) batteries are rechargeable power sources found in a wide range of portable devices, including smartphones, laptops, and electric vehicles. The fundamental operation of these batteries relies on the movement of lithium ions between two critical components within the battery structure. Here's a simplified breakdown of how lithium-ion batteries work:

A typical Li-ion battery comprises three key elements: a positive electrode (cathode) made of a lithium-based compound, a negative electrode (anode) usually composed of

carbon (graphite), and an electrolyte solution containing a lithium salt in a solvent. The interplay of these components is central to the battery's functioning.

During the charging process, an external voltage source, like a charger, applies a voltage across the battery's terminals. This voltage drives lithium ions from the cathode to the anode, where they become embedded within the carbon structure of the anode, effectively storing electrical energy.

In contrast, during discharge, when the battery powers a device, the stored lithium ions begin their journey back to the cathode through the electrolyte. This movement of lithium ions generates an electric current, which is harnessed to operate the device. The movement of ions is closely associated with the flow of electrons in the external circuit, resulting in the production of electrical energy.

The transfer of lithium ions between the cathode and anode is facilitated by chemical reactions at the electrode surfaces. These reactions involve the exchange of electrons, and they are entirely reversible, enabling the battery to be charged and discharged repeatedly. Lithium-ion batteries also incorporate safety mechanisms, including protection circuits and thermal management systems, to safeguard against overcharging and overheating, mitigating potential safety risks. The specific voltage and capacity of a Li-ion battery are determined by the particular materials employed in the cathode and anode. Variations in these materials lead to different voltage ranges and energy storage capacities. However, it's essential to note that Li-ion batteries have a finite number of charge and discharge cycles before their capacity diminishes, which varies depending on factors like battery design and usage conditions.

In conclusion, the widespread adoption of lithium-ion batteries is attributed to their high energy density, reusability, and relatively slow self-discharge rate. Nonetheless, ensuring their longevity and safe operation necessitates responsible handling, including avoiding extreme temperature conditions and refraining from excessive overcharging or discharging. Ongoing advancements in Li-ion battery technology continue to enhance their performance, energy storage capacity, and safety features, making them a vital component in the modern world of electronics and electric vehicles."

Prompt 9:
"how do lithium-ion batteries work"

Answer 9:
"Lithium-polymer (LiPo) batteries are a type of rechargeable battery commonly used in various electronic devices, including remote-controlled vehicles, drones, and radio-controlled gadgets. They work on principles similar to lithium-ion batteries but use a different electrolyte and packaging. Here's how lithium-polymer batteries work:

1. **Composition:**

   LiPo batteries consist of multiple layers of a flexible, porous polymer separator impregnated with an electrolyte, along with positive and negative electrodes. The positive

electrode typically contains lithium cobalt oxide (LiCoO2), while the negative electrode often includes graphite.

2. **Electrolyte:**

   Unlike the liquid electrolyte found in traditional lithium-ion batteries, LiPo batteries use a solid or gel-like electrolyte. This polymer-based electrolyte is less prone to leakage and allows for flexible packaging.

3. **Ionic Movement:**

   During the charging and discharging process, lithium ions move between the positive and negative electrodes through the solid or gel-like electrolyte. This ionic movement is what stores and releases electrical energy.

4. **Charging (Lithium-ion Intake):**

   When you charge a LiPo battery, an external power source applies a voltage across the battery terminals. This voltage drives lithium ions from the positive electrode (cathode) to the negative electrode (anode) through the polymer electrolyte. The energy is stored in the form of chemical potential.

5. **Discharging (Lithium-ion Release):**

   When the battery is used to power a device, the lithium ions migrate back from the anode to the cathode through the solid or gel-like electrolyte. As they return, they release the stored energy, generating an electric current that powers the device.

6. **Safety Considerations:**

   LiPo batteries are known for their light and flat pouch-like design, which makes them suitable for various applications. However, they can be sensitive to overcharging, over-discharging, and physical damage. Overcharging or puncturing the pouch can lead to thermal runaway and, in extreme cases, fires or explosions. Therefore, proper handling and care are crucial.

7. **Voltage and Capacity:**

   LiPo batteries come in various voltages and capacities, depending on their size and the specific application they are designed for.

8. **Advantages:**

   LiPo batteries offer several advantages, including high energy density, lightweight and flat form factor, and the ability to be molded into various shapes. These characteristics make them particularly suitable for applications requiring compact and custom-fit energy sources.

In summary, lithium-polymer batteries function similarly to lithium-ion batteries in terms of the movement of lithium ions between the positive and negative electrodes during charging and discharging. However, they use a solid or gel-like polymer electrolyte, which allows for more flexible packaging and provides advantages such as light weight and the ability to fit various form factors. Proper handling and charging are essential to ensure their safety and longevity."

Prompt 10:
"rephrase it in a few paragraphs"

Answer 10:
"Lithium-polymer (LiPo) batteries, like their lithium-ion counterparts, are rechargeable power sources found in numerous electronic devices, particularly in applications where a flat and lightweight design is essential. The operational principles of LiPo batteries share commonalities with lithium-ion batteries, yet they exhibit distinctive characteristics. Here's an overview of how LiPo batteries function:

LiPo batteries are constructed with multiple layers of a flexible, porous polymer separator embedded with an electrolyte. These layers encompass positive and negative electrodes, with the positive electrode often containing lithium cobalt oxide ($LiCoO_2$) and the negative electrode frequently including graphite.

What sets LiPo batteries apart is their utilization of a solid or gel-like electrolyte as opposed to the liquid electrolyte found in conventional lithium-ion batteries. This polymer-based electrolyte not only enhances safety by reducing the risk of leakage but also allows for a pliable packaging approach.

The operation of LiPo batteries revolves around the movement of lithium ions within the solid or gel-like electrolyte. During charging, an external power source applies voltage across the battery's terminals. This voltage initiates the migration of lithium ions from the positive electrode (cathode) to the negative electrode (anode) via the polymer electrolyte. The energy is stored in the form of chemical potential.

Subsequently, when the battery is employed to power a device, the lithium ions undertake a return journey from the anode to the cathode via the solid or gel-like electrolyte. In this process, the stored energy is liberated, generating an electric current that powers the device.

It is essential to exercise care when handling LiPo batteries due to their sensitivity to factors like overcharging, over-discharging, and physical damage. Mishandling can result in thermal runaway and, in severe instances, pose risks of fire or explosion. Thus, proper precautions and charging practices are imperative. LiPo batteries come in various configurations, varying in voltage and capacity, to suit different applications. Their attributes, such as high energy density and adaptable, flat form factor, make them an ideal choice for compact and customized energy solutions in a variety of scenarios."

Prompt 11:
"how do NiMH batteries work"

Answer 11:

"Nickel-Metal Hydride (NiMH) batteries are rechargeable energy storage devices commonly used in various consumer electronics, such as cordless phones, digital cameras, and power tools. They function based on the movement of charged ions within the battery. Here's how NiMH batteries work:

1. **Basic Components:**

   A typical NiMH battery consists of three primary components:

   - **Positive Electrode (Cathode):** Made of a nickel oxyhydroxide compound ($NiOOH$).

   - **Negative Electrode (Anode):** Composed of a hydrogen-absorbing alloy, often a mixture of metals like rare earth metals and nickel.

   - **Electrolyte:** A potassium hydroxide (KOH) solution that enables the flow of ions between the anode and cathode.

2. **Charging Process (Nickel Oxide Formation):**

   When you charge a NiMH battery, an external voltage source, such as a charger, applies a voltage across the battery terminals. This voltage causes nickel ions (Ni^{2+}) to oxidize from the cathode, forming nickel oxide ($NiOOH$). Simultaneously, hydrogen ions (H^+) are released at the anode.

3. **Discharging Process (Hydrogen Absorption):**

   When the battery is used to power a device, the reverse process occurs. Hydrogen ions (H^+) at the anode react with the metal hydride alloy to release electrons, creating an electric current. Nickel oxide at the cathode accepts electrons and releases nickel ions (Ni^{2+}).

4. **Ion Movement:**

   During both charging and discharging, charged ions (nickel ions and hydrogen ions) move back and forth between the anode and cathode through the electrolyte. This ion movement is what stores and releases electrical energy.

5. **Chemical Reactions:**

   The chemical reactions that take place at the anode and cathode are reversible, allowing the battery to be charged and discharged multiple times. The transition between nickel oxide and metal hydride alloys is at the core of these reversible reactions.

6. **Voltage and Capacity:**

NiMH batteries typically provide 1.2 volts per cell, which is lower than the 1.5 volts of alkaline batteries. However, they have higher capacity and are rechargeable, making them suitable for devices that require longer-lasting power.

7. **Self-Discharge:**

One drawback of NiMH batteries is their relatively higher self-discharge rate compared to some other rechargeable batteries, which means they can lose stored energy over time, even when not in use.

NiMH batteries are known for their rechargeability, making them a cost-effective and environmentally friendly choice for many applications. However, they require proper care, including occasional full discharge and recharge cycles to maintain their performance and longevity. Advances in NiMH battery technology continue to improve their capacity and reduce self-discharge rates."

Prompt 12:
"rephrase it into a few paragraphs"

Answer 12:
"Nickel-Metal Hydride (NiMH) batteries are rechargeable power sources widely utilized in various consumer electronics like cordless phones, digital cameras, and handheld tools. These batteries operate by enabling the movement of electrically charged ions within their structure. Here's a simplified account of how NiMH batteries work:

A standard NiMH battery consists of three primary constituents: a positive electrode known as the cathode, which is made from a compound containing nickel oxyhydroxide (NiOOH); a negative electrode, referred to as the anode, composed of a hydrogen-absorbing alloy, often featuring a blend of metals including rare earth metals and nickel; and an electrolyte, typically a potassium hydroxide (KOH) solution that facilitates the flow of ions between the anode and cathode.

During the charging process, when you connect a NiMH battery to an external voltage source, like a charger, a voltage is applied across the battery terminals. This voltage prompts the oxidation of nickel ions (Ni^{2+}) from the cathode, resulting in the formation of nickel oxide (NiOOH). Concurrently, hydrogen ions (H^+) are liberated at the anode.

When the battery is deployed to power a device, the inverse of the charging process unfolds. Hydrogen ions (H^+) at the anode engage with the metal hydride alloy, leading to the release of electrons, thus generating an electric current. Meanwhile, nickel oxide at the cathode accepts electrons and releases nickel ions (Ni^{2+}).

Throughout both charging and discharging phases, charged ions, encompassing nickel ions and hydrogen ions, journey back and forth between the anode and cathode via the electrolyte. This reciprocal ion movement is the basis for storing and discharging electrical energy.

The beauty of NiMH batteries lies in their ability to recharge and discharge multiple times owing to the reversibility of chemical reactions occurring at the anode and cathode. NiMH batteries typically provide 1.2 volts per cell, which is slightly lower than the 1.5 volts of alkaline batteries, yet they compensate for this with higher capacity and the reusability factor. It's worth noting that NiMH batteries experience somewhat higher self-discharge rates compared to some other rechargeable batteries, which implies they may gradually lose stored energy over time, even when not in active use. Regular full discharge and recharge cycles help maintain their performance and longevity. Advances in NiMH battery technology are progressively enhancing their capacity and reducing self-discharge rates, contributing to their continued popularity."

Prompt 13 & 14:
"how do lead-acid batteries work" & "rephrase it in a few paragraphs"

Answer 14:
"Lead-acid batteries, known for their durability and long history of use, are prominent as rechargeable energy storage devices in various applications, including vehicles and uninterruptible power supplies. The core of a lead-acid battery's operation hinges on electrochemical reactions taking place between lead dioxide (PbO_2) and sponge lead (Pb) immersed in a sulfuric acid (H_2SO_4) electrolyte. Here's a simplified elucidation of how lead-acid batteries function:

A standard lead-acid battery is composed of crucial components, including the positive plate (made of lead dioxide), the negative plate (consisting of sponge lead), a separator to prevent short-circuits between these plates, and the electrolyte, a dilute sulfuric acid solution that enables ion flow between the plates.

During discharge, when the battery is employed to power a device, the lead dioxide at the positive plate (anode) reacts with the sulfuric acid (H_2SO_4) in the electrolyte, leading to the formation of lead sulfate ($PbSO_4$) at the positive plate. Simultaneously, electrons are released at the anode, setting in motion an electric current that provides power to the connected device.

Conversely, when the battery is being charged, a reverse chemical process unfolds. Lead sulfate at the positive plate undergoes conversion back into lead dioxide, while sulfuric acid is regenerated in the electrolyte. During this operation, electrons are consumed, effectively reversing the direction of the electric current. Electrons flow from the negative plate (cathode) to the positive plate via an external circuit, constituting the electrical energy.

In both the charging and discharging phases, sulfate ions (SO_4^{2-}) traverse between the plates through the electrolyte, ensuring a balanced electrochemical environment. Lead-acid batteries typically deliver around 2 volts per cell, and they are employed in numerous applications by connecting multiple cells in series to achieve the desired voltage. Although these batteries possess commendable qualities like cost-effectiveness and high current output, they necessitate regular maintenance, particularly for flooded (wet-cell) types to

monitor water levels. Additionally, due to the emission of hydrogen gas during charging, they should be used in well-ventilated spaces to mitigate potential flammability concerns."

Prompt 15:
"in a few paragraphs describe how solar cells work for an IEEE paper at a high level"

Answer 15:
"Solar cells operate on the principle of converting sunlight into electricity through the photovoltaic effect. At a high level, solar cells consist of semiconductor materials, commonly silicon, designed to absorb photons from sunlight. When photons strike the semiconductor material, they transfer their energy to electrons, causing them to become mobile and generate an electric current.

The semiconductor material in a solar cell is intentionally doped with specific impurities to create a p-n junction. This junction is a crucial element that facilitates the separation and movement of charge carriers. The energized electrons move through the semiconductor material, creating a flow of electricity. Metal contacts placed on the cell's surface then capture this electric current, allowing it to be harnessed for practical use.

Essentially, solar cells transform sunlight into electrical power through a direct conversion process. This clean and renewable energy source has gained prominence in addressing global energy challenges, contributing significantly to the pursuit of sustainable and environmentally friendly power generation. Advances in solar cell technology continue to drive efficiency improvements and cost reductions, making solar energy an increasingly viable and widespread solution for meeting the world's growing energy demands."

Prompt 16:
"in a few paragraphs explain how Bluetooth works at a high level"

Answer 15:
"At a high level, Bluetooth is a wireless communication technology designed for short-range data exchange between electronic devices. The Bluetooth protocol operates in the 2.4 GHz ISM (Industrial, Scientific, and Medical) frequency band and uses a frequency-hopping spread spectrum to reduce interference from other devices in the same frequency range.

Bluetooth devices communicate through a master-slave architecture. In a network, one device serves as the master, while the others act as slaves. The communication involves the exchange of packets of data between devices, and the devices take turns transmitting and receiving information.

When two Bluetooth devices want to communicate, they initiate a process known as "pairing." During pairing, the devices establish a secure connection and exchange encryption keys, ensuring the confidentiality and integrity of the data being transmitted. Pairing may involve entering a PIN or using more modern methods, such as Near Field Communication (NFC) or Bluetooth Low Energy (BLE) pairing without a PIN.

Once paired, devices can establish a connection and exchange data. Bluetooth supports various profiles that define the types of applications and services it can provide, such as the Hands-Free Profile (HFP) for hands-free calling or the Advanced Audio Distribution Profile (A2DP) for streaming audio.

Bluetooth operates in different modes, including the traditional Bluetooth Classic and the more energy-efficient Bluetooth Low Energy (BLE). Bluetooth Classic is suitable for applications requiring higher data transfer rates, while BLE is optimized for low power consumption, making it ideal for devices with limited energy resources.

Overall, Bluetooth technology simplifies the wireless communication between devices, enabling seamless connectivity for a wide range of applications, from audio streaming and file sharing to smart home devices and wearable technology. The versatility and widespread adoption of Bluetooth have made it a standard for short-range wireless communication in the modern world."

[GPT – Power Circuits]

Prompt 1:
"i am writing a IEEE project report and i am currently on the topic of the power supply. can you explain how buck converters work"

Answer 1:
"Certainly! A buck converter, also known as a step-down converter, is a type of DC-DC power converter that takes a higher input voltage and reduces it to a lower output voltage with increased current. Buck converters are widely used in various electronic devices and power supplies to efficiently provide the required voltage levels.

Here's how a buck converter works:

1. **Input Voltage**: The buck converter starts with an input voltage (Vin) that is higher than the desired output voltage (Vout). The input voltage can be from a power source such as a battery or an external power supply.

2. **Switching Element**: The key component of a buck converter is a switching element, typically a semiconductor switch (often a MOSFET). The switch is used to control the flow of current through the circuit. When the switch is closed, current flows through the circuit; when it's open, no current flows.

3. **Inductor (L)**: Connected in series with the load, the inductor stores energy when the switch is closed and releases it when the switch is open. This helps smooth out the voltage and current.

4. **Diode (D)**: A diode is connected in parallel with the inductor. It allows current to flow in one direction and blocks it in the reverse direction. The diode is necessary to provide a path for the inductor's energy when the switch is open.

5. **Output Capacitor (C)**: The output capacitor is connected in parallel with the load. It helps stabilize and filter the output voltage, reducing ripple and noise.

Here's how the operation of a buck converter proceeds:

1. When the switch is closed (turned on), current flows from the input voltage source through the inductor and into the load. At this time, the inductor stores energy in its magnetic field, and the diode is reverse-biased and blocks current flow through it.

2. When the switch is opened (turned off), the inductor releases the stored energy. The inductor's energy is transferred to the output capacitor and the load. During this phase, the diode becomes forward-biased and provides a path for the inductor's energy to flow to the load.

3. The switching between these two states happens at a high frequency, controlled by a pulse-width modulation (PWM) signal. By adjusting the duty cycle (the ratio of time the switch is on to the total switching period), the output voltage can be controlled. Increasing the duty cycle leads to a higher output voltage, while decreasing it results in a lower output voltage.

The key advantages of a buck converter are its high efficiency, small size, and ability to provide a stable and regulated output voltage even when the input voltage varies. However, it's important to consider factors like component selection, switching frequency, and output current requirements when designing a buck converter for a specific application."

Prompt 2:
"can you rephrase it in a few paragraphs"

Answer 2:

"Certainly! A buck converter, also known as a step-down converter, is a type of DC-DC power converter widely used to efficiently reduce a higher input voltage to a lower output voltage. It operates as follows:

The buck converter consists of several key components: an input voltage (Vin), a semiconductor switch (usually a MOSFET), an inductor (L), a diode (D), and an output capacitor (C). When the switch is closed, current flows from the input source through the inductor into the load, storing energy in the inductor. During this phase, the diode blocks the current. When the switch is opened, the inductor releases its stored energy, transferring it to the output capacitor and load, with the diode allowing this energy flow.

This switching process occurs rapidly at a controlled frequency, thanks to pulse-width modulation (PWM). By adjusting the duty cycle (the time the switch is on relative to the total switching period), the output voltage can be precisely regulated. Buck converters are prized for their high efficiency, compact size, and the ability to provide a stable output voltage despite input voltage variations. When designing a buck converter, it's crucial to consider factors such as component selection, switching frequency, and output current requirements to match specific application needs."

Prompt 3 & 4:
"Can you explain boost converters too?" & "rephrase it in a few paragraphs"

Answer 4:
"A boost converter, also referred to as a step-up converter, is a type of DC-DC power conversion device with the primary function of raising a lower input voltage to a higher desired output voltage. Its operation can be broken down as follows:

The essential components of a boost converter include an input voltage (Vin), a semiconductor switch (usually a MOSFET) responsible for controlling current flow, an inductor (L), a diode (D), and an output capacitor (C). When the switch is closed, current flows from the input source through the inductor, and this phase results in the storage of energy in the inductor. Simultaneously, the diode blocks current flow in the reverse direction.

When the switch is opened, the stored energy in the inductor is released. What distinguishes the boost converter is the way in which this energy is transferred to the output. Rather than simply passing it along, the boost converter adds this energy to the input voltage, consequently increasing the output voltage.

The operation of a boost converter is managed through pulse-width modulation (PWM), where the duty cycle of the switch is adjusted to control the output voltage level. A longer switch-on time leads to a higher output voltage, while a shorter switch-on time results in a lower output voltage. Boost converters are often used in scenarios where the input voltage is lower than the required output voltage or subject to variation. This is particularly valuable in applications like battery-powered devices, where the voltage must be elevated to efficiently power other electronic components. Boost converters excel in their ability to efficiently raise the output voltage while delivering a consistent and stable power supply for a range of electronic devices."

Prompt 5:
"write a few paragraphs about how low dropout regulators work"

Answer 5:
"Low Dropout Regulators (LDOs) are essential electronic components used to ensure a stable and precise output voltage, even when the input voltage is only slightly higher than the desired output voltage. They play a crucial role in various electronic devices, providing a reliable power supply for sensitive components like microcontrollers, sensors, and RF circuits. Here's a closer look at how LDOs work.

At the core of an LDO is the pass transistor, typically a MOSFET, which serves as a valve controlling the flow of current from the input voltage to the output. The key challenge for LDOs is to maintain a stable output voltage when the input voltage drops, and this is where their low dropout feature comes into play.

LDOs employ a feedback mechanism to continuously monitor and adjust the output voltage. They have an internal voltage reference, often implemented as a bandgap voltage reference, that establishes the desired output voltage level. An error amplifier continuously compares the actual output voltage with the reference voltage. When any deviation is detected, the error amplifier generates an error signal.

This error signal guides the pass transistor's operation. If the output voltage falls below the desired level, the pass transistor opens up, allowing more current to flow and thus increasing the output voltage. Conversely, when the output voltage exceeds the desired level, the pass transistor reduces current flow to lower the output voltage. This continuous feedback loop ensures that the output voltage remains regulated, even when the input voltage is close to the output voltage.

To further stabilize the output voltage and reduce voltage fluctuations, LDOs are often equipped with an output capacitor. This capacitor helps mitigate transient voltage changes and provides additional filtering to ensure a clean and steady power supply.

One of the notable advantages of LDOs is their simplicity, low noise characteristics, and fast response to load changes. However, they are less efficient than switching regulators, as any excess energy is dissipated as heat in the pass transistor. Nonetheless, LDOs are widely used in applications where precision and low dropout performance are critical, making them a valuable tool in the world of electronics."

Prompt 6:
"write a few paragraphs about how solar cells work"

Answer 6:
"Solar cells, often referred to as photovoltaic (PV) cells, are the core components of solar panels and are responsible for converting sunlight into electricity. Their operation is grounded in a fascinating phenomenon known as the photovoltaic effect. Here's how solar cells work:

Solar cells are typically made from semiconductor materials, with crystalline silicon being the most common choice. When sunlight, which consists of tiny packets of energy called photons, strikes the surface of a solar cell, some of these photons are absorbed by the semiconductor material. This energy absorption excites electrons in the semiconductor, causing them to jump from a lower energy state to a higher one.

The semiconductor material in solar cells is specially designed with a p-n junction. The p-side is doped with materials that create an excess of positive "holes," while the n-side is doped to have an excess of electrons. This difference in doping creates an electric field at the junction. When the excited electrons and "holes" are generated, the electric field in the cell separates them. Electrons are pushed toward the n-side, while holes are pushed

toward the p-side. This separation of charges results in the generation of an electric current.

Metal contacts on the surface of the solar cell collect the liberated electrons and facilitate their transfer to an external circuit. The flow of electrons in the external circuit creates electric current, which can be harnessed to power various electrical devices, charge batteries, or be fed into the grid for broader use.

Solar cell efficiency is a crucial factor, and it represents the proportion of incoming sunlight that can be converted into electricity. The efficiency of commercially available solar cells typically ranges from 15% to 22%, although advanced designs have achieved even higher efficiencies. Solar cells have become a key component of renewable energy systems, contributing to the global shift toward clean and sustainable energy sources. They are used in diverse applications, from residential and commercial solar installations to powering spacecraft in space exploration missions."