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Sustainable Wildlife Interaction through AI-Enhanced Bird Feeding System

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Abstract

This thesis project centers around the development and implementation of an innovative bird feeding system that utilizes artificial intelligence to foster a sustainable interaction between birds and their environment.

The project involves designing and constructing a specialized bird feeder equipped with AI-based technology that incentivizes birds to exchange collected trash for food.

Keywords

AI, CNN, Object Detection, Machine Learning, Bird Feeding System, Sustainable Interaction, Innovative Feeder, Trash Exchange, Recycling, AI-Based Bird Feeder

FOREWORD

I would like to begin this thesis by expressing my gratitude to the individuals who played a significant role in the completion of this project. Their guidance, support and contributions were invaluable throughout this journey.

I extend my sincere thanks to teachers: Toni Aaltonen, Petteri Pulkinen and Pauli Valo. Their expertise and mentorship were instrumental in influencing the path of this thesis.

I am also deeply appreciative of my friends who not only took an active role in this project but also provided unwavering support during its course. Ilja Salmi, Milja Lindholm, Miikka Satama and Ville Bärlund, your collaboration and camaraderie made this endeavour both enjoyable and enriching.

I must express my gratitude to my grandparents, who generously provided the necessary space and environment for conducting essential testing and research. They also didn't hesitate to motivate me to finish my studies.

This thesis would not have been possible without the collective efforts and encouragement of these individuals. Their contributions have left an indelible mark on this work.

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LIST OF SYMBOLS AND TERMS

GUI	Graphical User Interface
R-CNN	Regional Convolutional Neural Network
SSD	Single Shot Detector
YOLO	You Only Look Once
CNN	Convolutional Neural Network
TACO	Trash Annotations in Context

1 INTRODUCTION

This project draws its inspiration from the remarkable intelligence, inquisitiveness, and sometimes, the mischievous behavior exhibited by birds (Smoll Ansley, 2023). It is not rare to see these birds rummaging through trash bins, searching for a potential treat (García-Arroyo, et al., 2023). Such behavior, while intriguing, often results in unintended consequences, leaving a trail of litter and disarray in their wake.

In the age of readily available information, the internet has become a repository of innovative projects and solutions. Among the plethora of projects encountered online, there emerged a recurring theme - initiatives designed to counteract the tendency of birds to scatter trash from bins. These initiatives aimed to redirect avian curiosity and intelligence towards a more constructive purpose.

Motivated by this idea, I embarked on this project in collaboration with my engineer companion, Ilja Salmi, who dedicated substantial effort to the design and 3D printing of components for the project.

The central concept is to shift the dynamic from birds removing trash from bins to encouraging them to utilize their innate curiosity and intellect to collect litter from the surrounding environment. In doing so, we sought to reward their efforts with a nutritious alternative to the occasional fast-food scraps and chocolates they might find within bins. Furthermore, we recognized the potential for this project to serve as a valuable resource for avian populations during the challenging winter months.

Our project scope is specifically focused on implementing object detection through the integration of 3D printed components. These components are operated by the Arduino UNO and Jetson Nano.

Throughout the course of this thesis, you will gain insights into the comprehensive work undertaken, encompassing the utilization of AI object detection techniques and the application of 3D printing technology. By delving into the intricacies of this project, you will witness how innovation and environmental stewardship converge to address a unique challenge, ultimately fostering a healthier coexistence between humans and the avian inhabitants of our shared environment.

2 CORVID INTELLIGENCE AND BEHAVIOUR

Birds, the feathered denizens of our natural world, have long captivated the imagination of researchers, naturalists and enthusiasts alike (Kevin J. McGowan, 2005). Their aerial acrobatics and diverse behaviors have spurred scientific inquiry for centuries (Droege, et al., 2016). Among the avian wonders that have garnered special attention, corvid birds, including ravens, crows, magpies and jays, stand out as exemplars of intelligence, adaptability and intriguing social dynamics (Nathan J. Emery, et al., 2005).

The study of bird behavior has evolved from rudimentary observations to encompass a multidisciplinary approach, integrating fields such as ornithology, ethology, ecology and cognitive science. Understanding avian behavior offers unique insights into the ecological roles of birds, their evolutionary adaptations and their interactions with both their natural habitats and the anthropogenic environments they increasingly inhabit (Benmazouz Isma, et al., 2021).

This chapter embarks on a journey through the fascinating realm of bird behavior, with a particular focus on the exceptional attributes of corvids. As we delve into the intricacies of their behavior, cognition and social structures, we aim to shed light on the remarkable abilities that have earned these birds a place of distinction in the avian kingdom (Zorina Zoya & Obozova Tatyana, 2012).

The Chapter 2 will delve into specific aspects of corvid behavior and their problem-solving prowess and tool use to their complex social relationships and foraging strategies. Additionally, this thesis will explore the broader implications of corvid behavior, particularly as it pertains to their interactions with human-modified landscapes and their potential role in addressing environmental challenges.

In an era marked by environmental concerns and a growing appreciation for the intricacies of the natural world, the study of bird behavior takes on renewed significance. Through this exploration, the aim is to not only deepen the understanding of these remarkable avian creatures but also contribute to a broader dialogue about the coexistence of humans and wildlife in an ever-changing world.

2.1 Overview of Corvid Species

Corvids belong to the family Corvidae, encompassing highly intelligent and adaptable avian species (Clayton Nicola & Emery Nathan, 2005). Known for their problem-solving skills, these birds display a remarkable level of intelligence, engaging in tool use and complex social behaviours (Thomas Bugnyar, 2023). Crows, ravens, magpies, jays and rooks are among the most well-known members of this avian family.

One of the defining features of corvids is their exceptional intelligence (Danielle Sulikowski, 2019). They exhibit the capacity for problem-solving, intricate communication through a range of vocalizations and gestures and remarkable memory (Emery Nathan & Clayton Nicola, 2006). These birds can remember the locations where they have hidden food, recognize individual humans and learn from their experiences and observations (Davidson Gabrielle & Clayton Nicola & Thornton Alex, 2015).

Corvids are highly adaptable creatures, thriving in diverse environments ranging from urban areas to forests and open fields (Abou Zeid Farah, et al., 2023). They have a reputation for being opportunistic feeders, consuming a varied diet of insects, small mammals, seeds, fruits, carrion and human food scraps (Gjermund Gomo, 2017).

These birds display complex social structures, often living in family groups with hierarchical systems (Nicola S Clayton & Nathan J Emery, 2007).

Playfulness is also observed in corvids, engaging in playful behaviours in both juvenile and adult stages, from aerial acrobatics to object manipulation (llicent S Ficken, 1977).

Known for their glossy black plumage, strong beaks (Jen A Bright, 2016) and sharp talons, corvids vary in size and appearance. Some species, like the magpie, bear distinctive black-and-white markings. Their cultural significance spans various myths, folklore and literature, associating these birds with intelligence, mystery and sometimes as symbols of both good and bad omens (Daniel Allen, 2014).

The notable corvid species encompass the hooded crow (Corvus cornix), magpie (Pica pica), jackdaw (Coloeus monedula) and the rook (Corvus frugilegus).

Figure 1. The notable corvid species (Svetoslav Spasov, 2023; Pierre-Selim, 2012; Adrian Pingstone, 2019; Bird Aware Solent, 2023)

2.2 The Intelligence of Corvids

Research has provided substantial evidence supporting the remarkable cognitive abilities of large-brained birds, with corvids and parrots serving as notable examples (Emery & Clayton, 2005).

These avian species, neither primates or mammals, have demonstrated capabilities once believed to be unique to humans. Such abilities include recalling specific past events, described as episodic-like memory (Clayton & Dickinson, 2001), as well as engaging in future planning (Raby et al., 2007), adopting the visual perspective of their peers (Dally et al., 2006), participating in cooperative problem-solving (Seed et al., 2008) and creating innovative tools for addressing challenges (Weir et al., 2002).

The revelation of these cognitive feats has expanded our understanding of animal intelligence, prompting further exploration into the nature and implications of such capabilities in corvids.

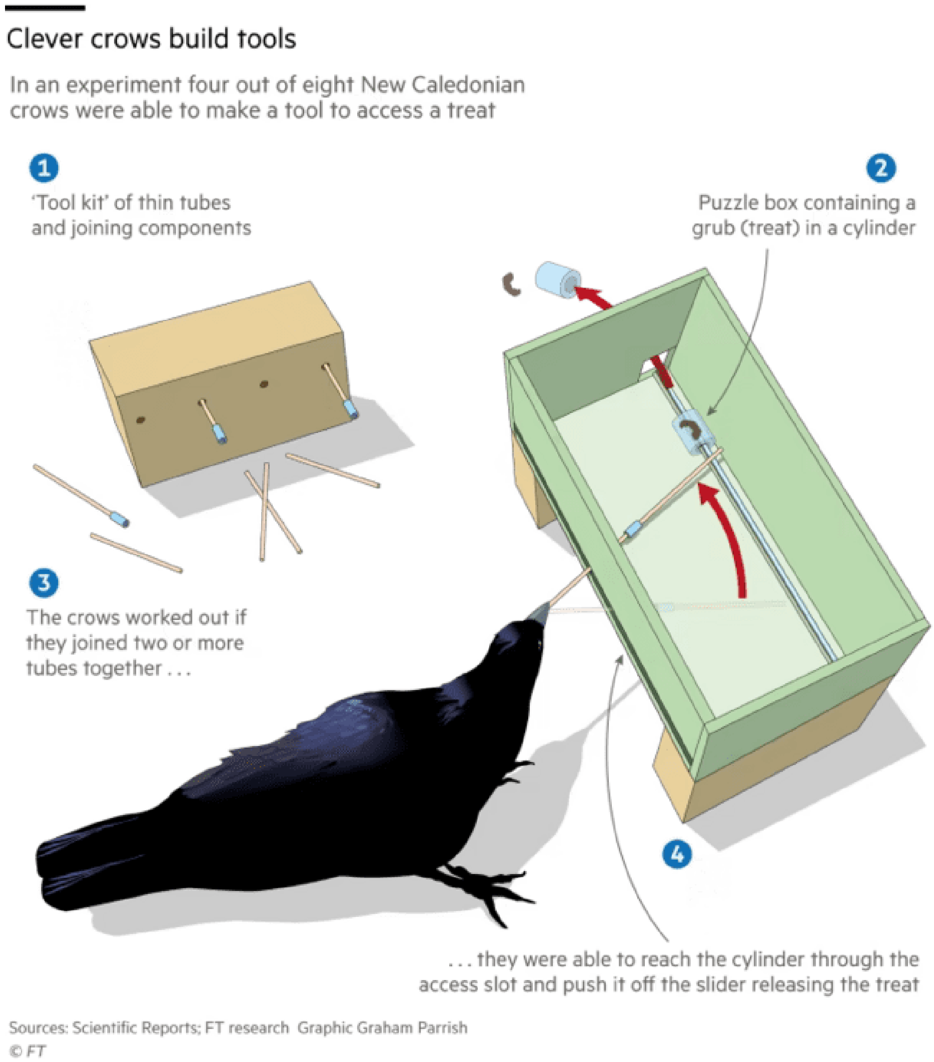

Figure 2. Crows make complex tools (Guardian News, 2018)

Despite their remarkable intelligence, corvids' cleverness sometimes leads to mischievous behavior, especially when it comes to trash cans (Kurosawa et al., 2003). Their problem-solving abilities and adaptability allow them to figure out ways to access trash bins, making a big mess in the process. These resourceful birds, with their keen observational skills and capacity for learning, may see trash cans as a potential source of food, leading them to engage in hooligan-like activities by overturning bins and scattering their contents. While their intelligence is a testament to their adaptability and survival skills, it also showcases the more mischievous side of their behavior in urban environments (Preininger et al., 2019).

Figure 3. Raven outsmarts a trash can (Sarah Gibbens, 2017)

3 ECOLOGICAL PROBLEM

3.1 The Problem of Cigarette Butts

The issue of trash, particularly cigarette butts, in the environment poses a significant environmental concern (Kurmus et al., 2020). Improper disposal of waste, including plastic items and cigarette butts, contributes to pollution, adversely affecting ecosystems and wildlife (Kadir et al., 2015).

In an innovative approach, there is potential to leverage the intelligence of certain bird species, such as corvids, to contribute to waste management efforts (Günther-Hanssen, 2022). Training these intelligent birds to recognize and collect specific types of litter, especially cigarette butts, could offer a unique solution. By encouraging a symbiotic relationship between humans and birds, we could tap into their problem-solving abilities to help keep public spaces cleaner.

Cigarette butts, known for containing harmful chemicals, pose risks to the environment as they leach into the soil and water (Slaughter et al., 2011). Moreover, the non-biodegradable nature of the filters exacerbates the problem (Shah et al., 2023). Training corvids, with their remarkable intelligence, to collect and deposit such waste in designated bins could be a creative and environmentally friendly approach.

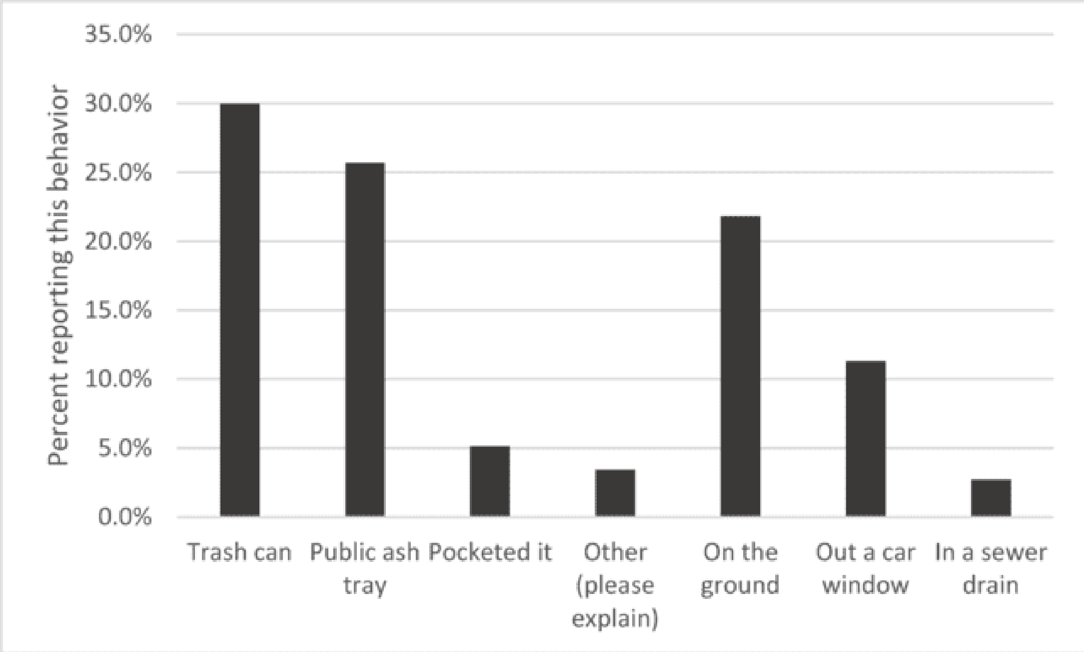

Figure 4. Outdoor Cigarette Butt Disposal (Webler & Jakubowski, 2022)

3.2 Birds as Environmental Volunteers

In recent initiatives, certain bird species, notably magpies and crows, have been observed participating in recycling projects (Independent, 2022). Their natural intelligence and adaptability make them potential allies in addressing environmental challenges (Domonoske, 2018). In specific instances, these birds have been spotted collecting litter, including cigarette butts, and depositing them in designated recycling bins (Gregory, 2019).

Magpies, known for their curious and resourceful nature, have demonstrated a propensity for recognizing and collecting small items, making them effective contributors to cleaning efforts (Forsberg, 2020). Similarly, crows, renowned for their problem-solving abilities, can be trained to identify and retrieve specific types of waste, showcasing the potential for a harmonious partnership between humans and birds in waste management (NBC News, 2022).

Observations of these bird species actively participating in recycling projects highlight the opportunity to engage them as environmental volunteers. Leveraging their natural behaviors could offer a novel and sustainable approach to addressing the persistent issue of litter in the environment.

4 PROJECT INSPIRATIONS

The development and implementation of the current project have been significantly influenced and inspired by the successes and innovations observed in existing recycling initiatives, with a particular focus on avian contributions to recycling efforts.

By closely examining and drawing insights from these diverse projects, the current endeavor aspires to build upon their achievements and integrate the unique aspect of avian recycling.

This section offers a comprehensive overview of the key features and accomplishments of select recycling projects, highlighting the noteworthy role of avian contributors in actively participating and contributing to recycling efforts. These projects not only serve as inspiration for the design and objectives of the present undertaking but also underscore the potential of birds as active participants in sustainable waste management practices.

4.1 Overview of Avian-Inclusive Recycling Projects

4.1.1 Cap-Nut Trade with Inductance Measurement

In this project magpies actively participate in recycling by exchanging bottle caps for nuts. The system operates with a specialized 3D-printed metal detector, based on Arduino code and utilizing inductance measurements. When magpies deposit bottle caps into the designated area, the metal detector detects and "accepts" them, triggering a reward mechanism that dispenses nuts for the birds.

To facilitate the monitoring of these experiments, a user-friendly GUI has been developed for the Raspberry Pi. This, coupled with Anydesk, enables remote observation, while a wide-angle Picam attached to the Raspberry provides a real-time visual of the experiments.

This setup proves invaluable for conducting fully autonomous experiments, allowing for the initial setup, independent operation throughout the day and subsequent result analysis.

The innovative project not only highlights the intelligence of magpies but also showcases the integration of technology to facilitate autonomous and efficient experimentation.

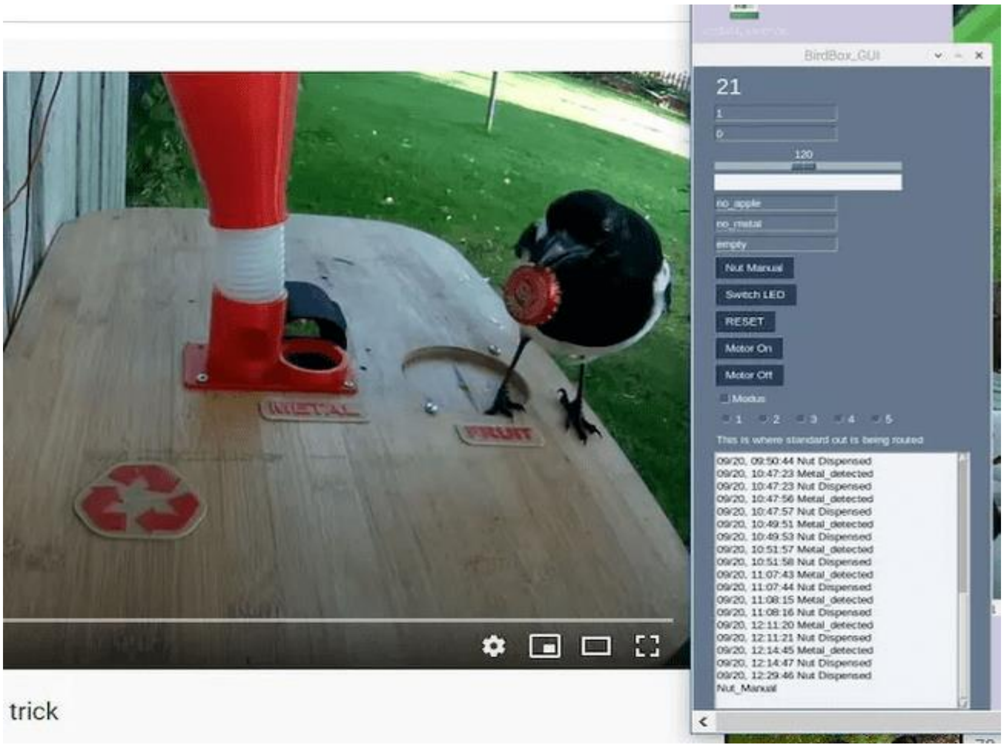

Figure 5. Trading Bottle Caps for Nuts with Inductance Measurements (Hans Forsberg, 2020)

4.1.2 Magpie Recycling Project with Image Classifier

In this project, a basic classifier was developed to discern between litter and non-litter items within images. The classifier primarily focuses on analyzing color patterns in images, computing the average representation for both litter and non-litter images.

Notably, magpies have demonstrated a consistent pattern during interactions with the machine. Through 5000 interactions, it was observed that magpies consistently brought objects categorized as trash by the classifier. Intriguingly, the classifier never identified non-trash items, such as sticks or leaves, during these interactions.

Figure 6. Magpie collecting litter (Magpie Recycling Project, 2021)

4.1.3 Autonomous Crow Training CrowBox

The CrowBox represents a groundbreaking project that seamlessly merges hardware components with sophisticated software logic to autonomously train corvids, specifically crows. This innovative system has successfully trained captive crows to deposit discovered coins in exchange for peanuts, showcasing the potential for human-bird interaction through cutting-edge technology.

The core of CrowBox's functionality lies in its dedicated coin detection sensor. An interrupt-driven mechanism ensures precise coin counting by preventing multiple counts caused by contact bounce.

The system dynamically tracks bird presence on the perch, allowing for responsive engagement and the execution of specific training protocols based on the crows' behavior. This adaptability accommodates various bird responses and behaviors.

CrowBox employs diverse training protocols executed in different phases, fostering a connection between dropped coins and peanut rewards. Safety features and error handling mechanisms are integrated to ensure the well-being of the birds and system reliability.

Figure 7. Stage two of autonomous bird training (CrowBox, 2018)

5 PROJECT DESCRIPTION

5.1 Project Configuration

In the initial phase of the project, extensive research and analysis of other relevant initiatives were conducted. Drawing conclusions from these examinations, the groundwork for the project was laid, emphasizing the need for a well-thought-out setup.

Understanding the importance of real-time monitoring, a live-streaming system and camera were strategically installed. This decision stemmed from the recognition that a dynamic, recorded stream was essential for comprehensively tracking and understanding the corvid interactions throughout the experiment.

To attract and guide the birds, a deliberate effort was made to create an inviting space. Food was strategically placed on the wooden board, acting as both an incentive for the birds and a focal point for the experiment. This meticulous arrangement was crucial to encourage the desired behavior and ensure the success of the subsequent stages of the project.

5.1.1 Construction of Wooden Board

Special thanks to Milja Lindholm for her contributions to building this wooden board.

5.1.1.1 The Base

The foundation of the project rested on the construction of a specialized wooden board, designed to serve as the central platform for monitoring the entire process. Wood that could withstand varying weather conditions, especially exposure to moisture, was carefully chosen by Milja for this project.

After our discussion about the construction of the wooden board, several chosen wooden boards were measured and cut by Milja to precise specifications. Following the cutting process, Milja thoroughly sanded each board to ensure a smooth and consistent surface.
This construction aimed to provide a stable and durable platform for the project, facilitating consistent and reliable observations throughout the experimental phases.

Figure 8. Measuring the wooden boards

5.1.1.2 Aluminum Supports

Using a magnet tester, we identified suitable aluminum sheets for the project. To secure the wooden boards Milja skillfully cut the sheets on the sheet metal cutting machine (Figure 9). Immediately after the cutting process, we approximately measured the position of the metal parts on the wooden boards (Figure 10) in order to be able to connect them properly to achieve a secure fit and sturdy support for the wooden platform. Finally, we worked together to assemble the metal sheets onto the wooden board, by making holes in the aluminum parts and affixing metal components to the wooden boards, securely fastening them in place.

Figure 9. Crafting aluminum supports

Figure 10. Approximated metal parts arrangement

In Figure 9, a strategically drawn hole can be observed, purposefully designed to later serve as the point where birds could dispense trash. This planned feature was integrated into the structure to encourage natural interactions, providing a designated area for the birds to participate actively in the recycling process. The combination of wood and metal elements in the construction aimed to create a resilient and functional platform that would withstand environmental conditions while facilitating the core objectives of the project.

Figure 11. Screenshot of the working stream

5.2 Design and Functionality of The Nut Dispenser

Following extensive prototyping and testing collaboration, a specialized nut dispenser was skillfully crafted by Ilja Salmi for this project, utilizing 3D-printed components. The chosen design operates seamlessly, driven by a stepper motor controlled by Arduino UNO. Powered by a portable power bank, the Arduino UNO is equipped with a programmed code that facilitates the precise dispensing of nuts. In the initial project phase, the dispenser functions with a timer, as detailed in Appendix 1.

Figure 12. Attached nut dispenser

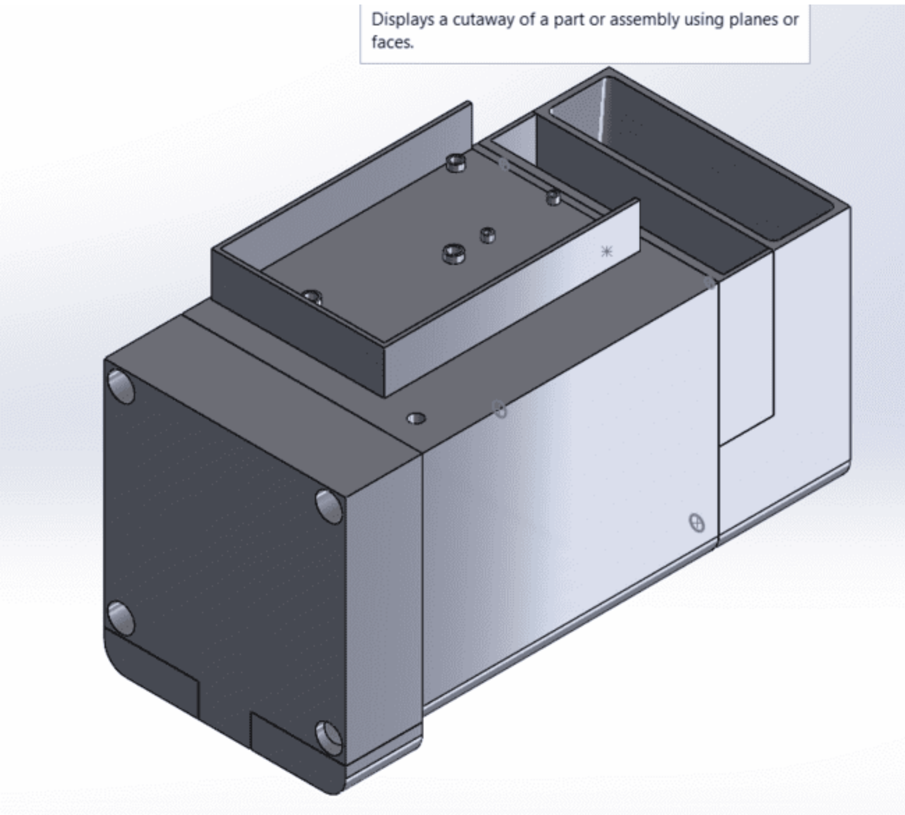

Figure 13. 3D model of nut dispenser

5.2.1 The Main Box

The primary component of the nut dispenser is the main box (Figure 14), serving as the central hub to which various parts are connected.

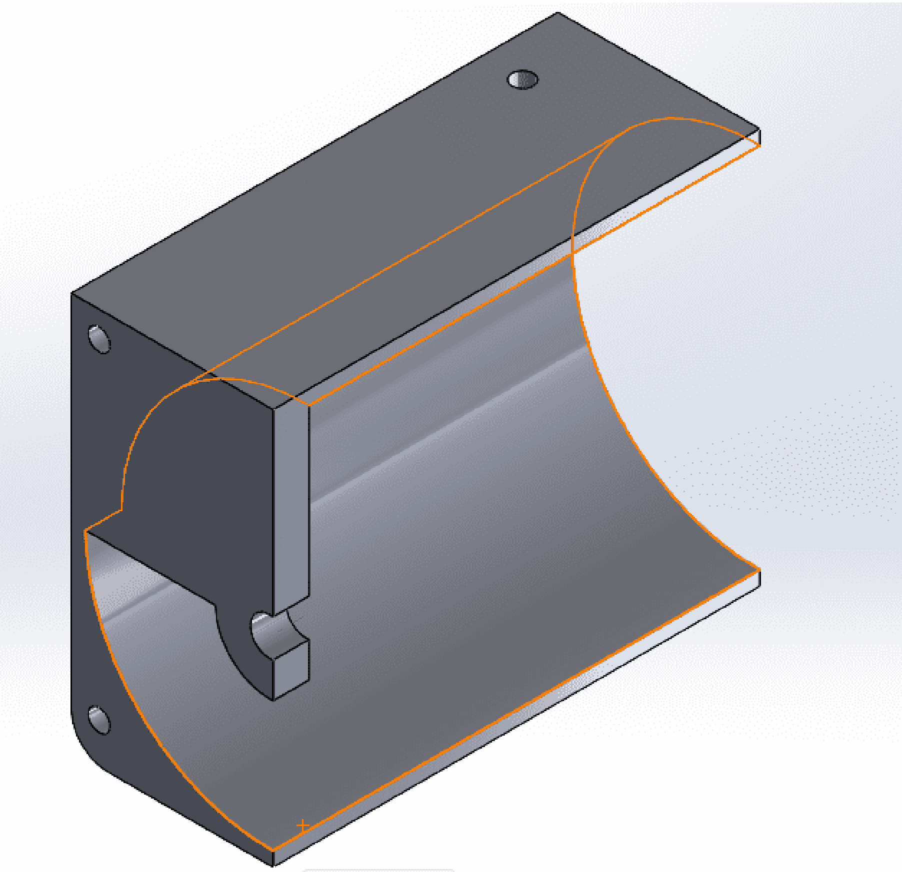

Figure 14. Main box: sliced view

Within this design, a spiral mechanism is integrated, situated inside the main box. The spiral plays a crucial role as it rotates the nuts along its path, guiding them to the designated dispensing point. This engineered arrangement ensures a controlled and efficient nut dispensing process, contributing to the overall functionality and success of the recycling project.

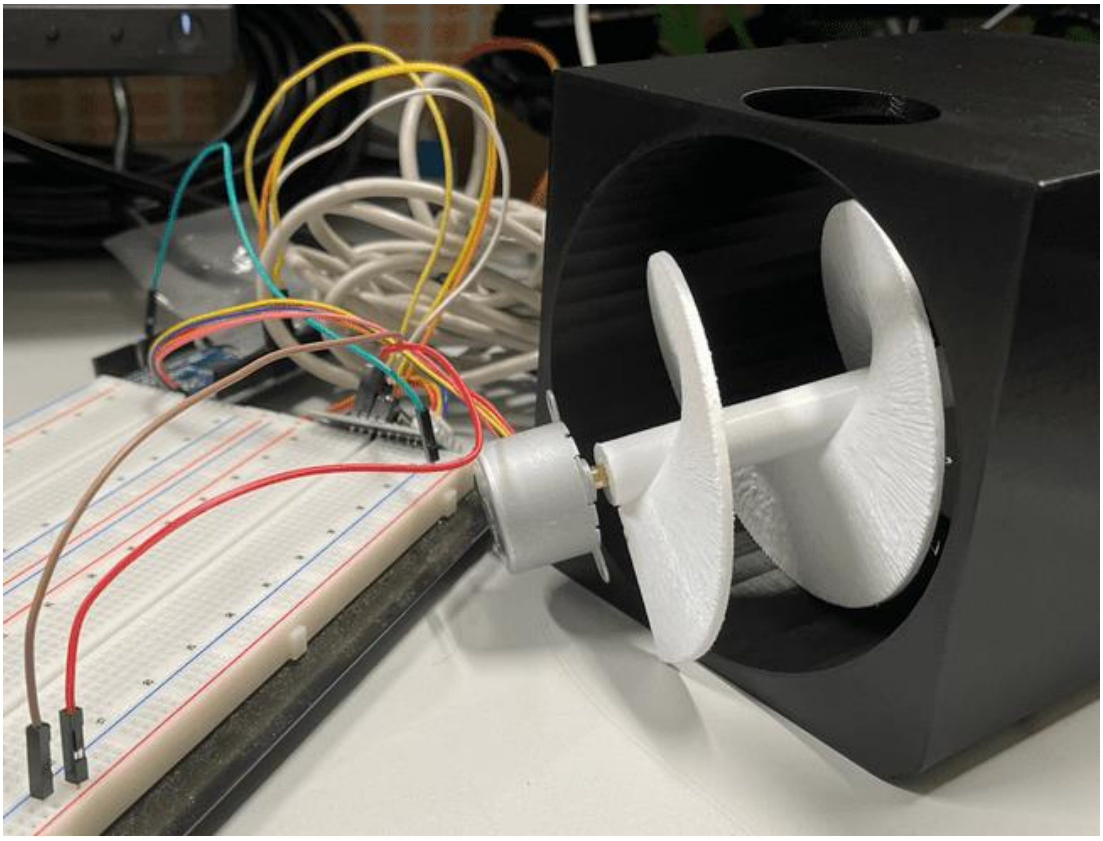

Figure 15. Stepper-motor connected to the spiral

5.2.2 Front Cover

The front cover of the main box boasts a built-in food trough, creating a temporary storage space for the seamless dispensing of bird food. This design guarantees a constant supply of nuts, neatly delivered into the small tray (Figure 17), which is attached to the front cover, as illustrated in Figure 13.

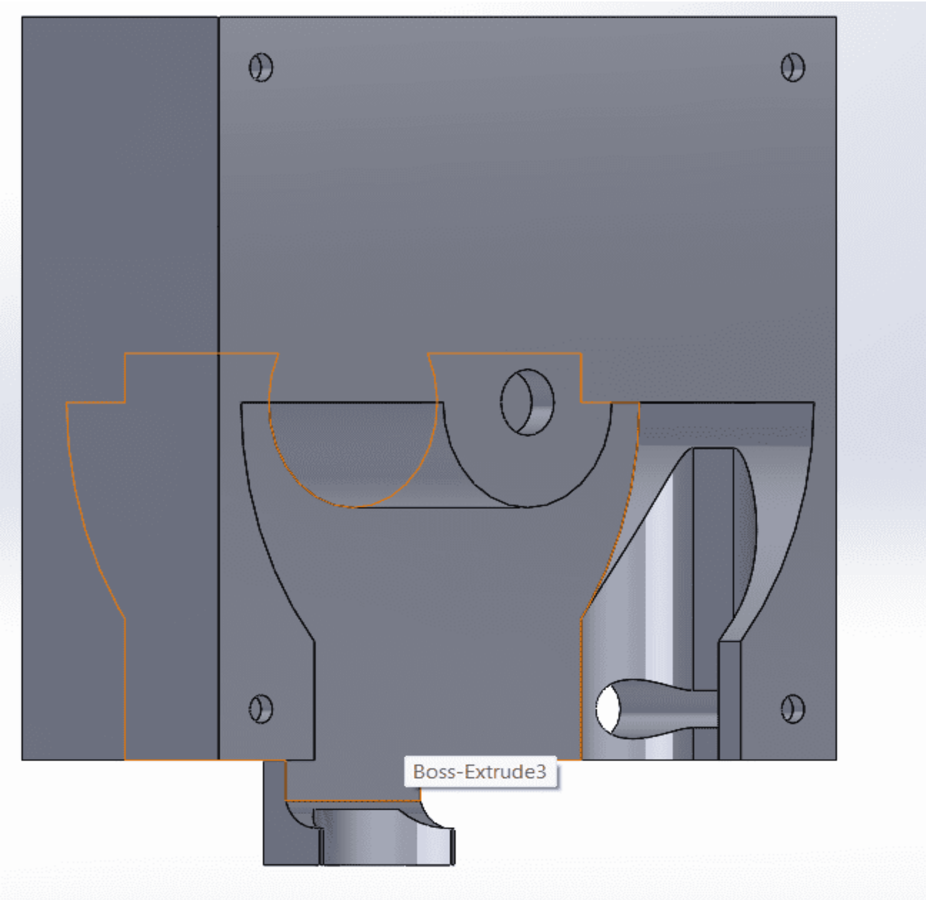

Figure 16. Front cover of the main box

5.2.3 Small Tray

The small food tray, connected to the front cover, serves as a central collection point for all dispensed nuts. This strategic design ensures that the gathered nuts is seamlessly channeled through a connected white long tube (Figure 12), facilitating the descent of nuts onto the wooden board below.

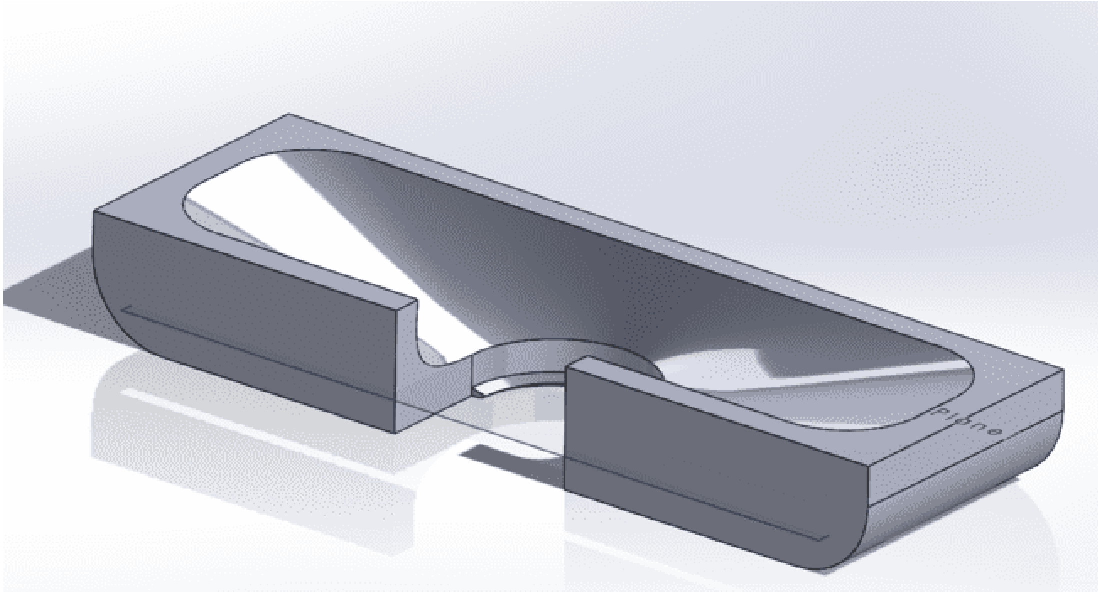

Figure 17. Small temporary food tray

5.2.4 Food Storage

The food storage functions as a manual hub where all bird food is placed and initially stored. This strategic design allows for efficient control and placement of the bird's nourishment before further processing and dispensing.

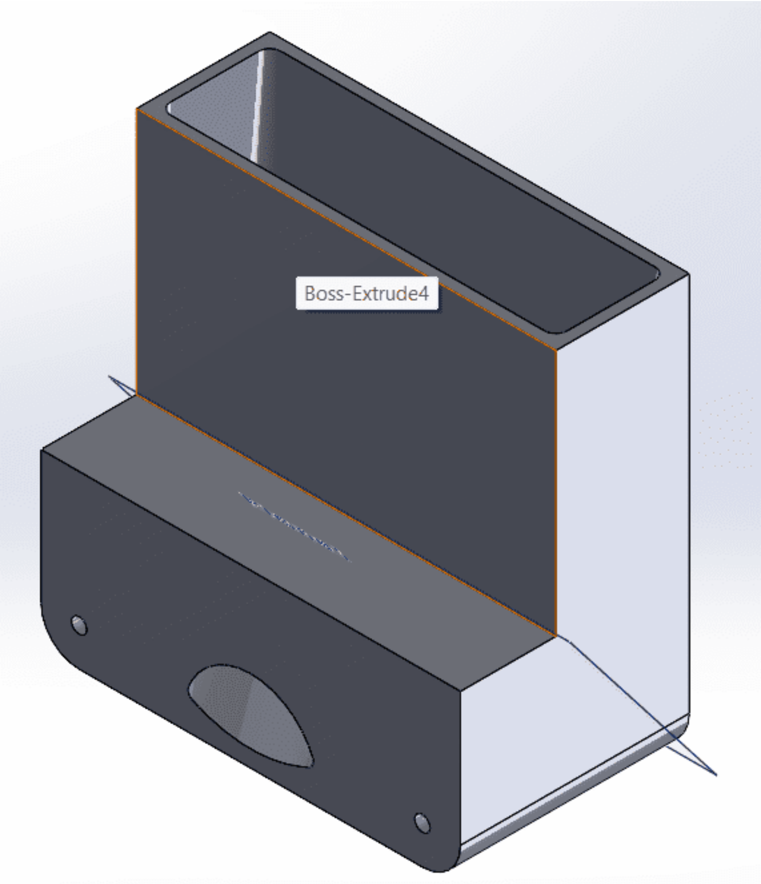

Figure 18. Food storage

5.2.5 Back Cover: Motor Holder

The motor holder, positioned atop the food holder and attached to the back of the main box, serves as a crucial component. Featuring a strategically placed hole, it facilitates secure attachment of the motor using screws. This design ensures stability and efficiency in the overall functioning of the nut dispenser mechanism.

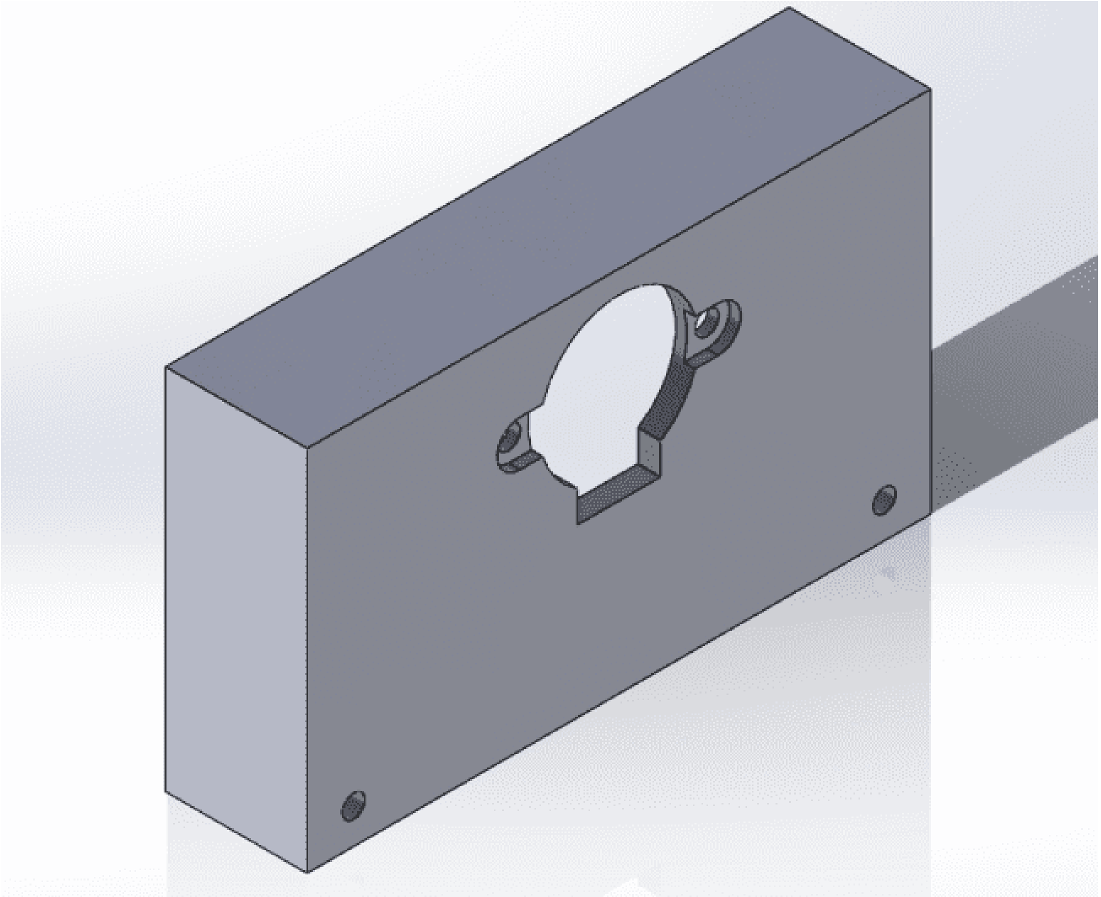

Figure 19. Back cover of the main box

5.3 Implementation of a Trash Detection System

A pivotal aspect of this project revolves around the implementation of an object detection system for detecting trash. This system utilizes a camera connected to Jetson Nano, capturing images that undergo detection by a model running on this compact computer. Upon detection of trash, Jetson Nano, powered by a portable power bank, signals the Arduino UNO to dispense nuts accordingly. This integration of technology ensures an automated response to the presence of trash, contributing to the overall success of the recycling project.

5.3.1 Object Detection

Object detection stands as a crucial facet of computer vision, intimately tied to image processing, focusing on identifying instances of semantic objects within digital images and videos (Shanahan James, 2020). The landscape of object detection has undergone a transformative shift with the emergence of deep neural networks, commanding a pivotal role in the evolution of computer vision (Barbara Latosinska, 2020). Notable models have been devised, including R-CNN and its variant, Faster R-CNN, SSD and the renowned YOLO models alongside their diverse iterations.

Typically, object detection models fall into two primary architectural categories: single-stage detectors exemplified by YOLO and SSD and dual-stage detectors typified by R-CNN (Sirisha U., Praveen S.P., Srinivasu P.N. et al, 2023). The fundamental distinction lies in their approach. In the two-stage object detection models, the initial step involves determining the region of interest, followed by the subsequent detection process applied solely to this identified region (Du Lixuan & Zhang Rongyu & Wang Xiaotian, 2020). Consequently, two-stage models generally exhibit superior accuracy compared to their single-stage counterparts (Lu Xin & Li Quanquan & Li Buyu & Yan Junjie, 2020). However, this enhanced accuracy comes at the cost of heightened computational requirements and reduced processing speed (Soviany Petru & Ionescu Radu Tudor, 2018).

The schematic representation below delineates the two types of object detection models. Figure 20 portrays the streamlined process of one-stage detection and illustrates the intricacies of a two-stage detection model. This dichotomy in architectural design reflects the trade-off between computational efficiency and detection accuracy within the realm of object detection.

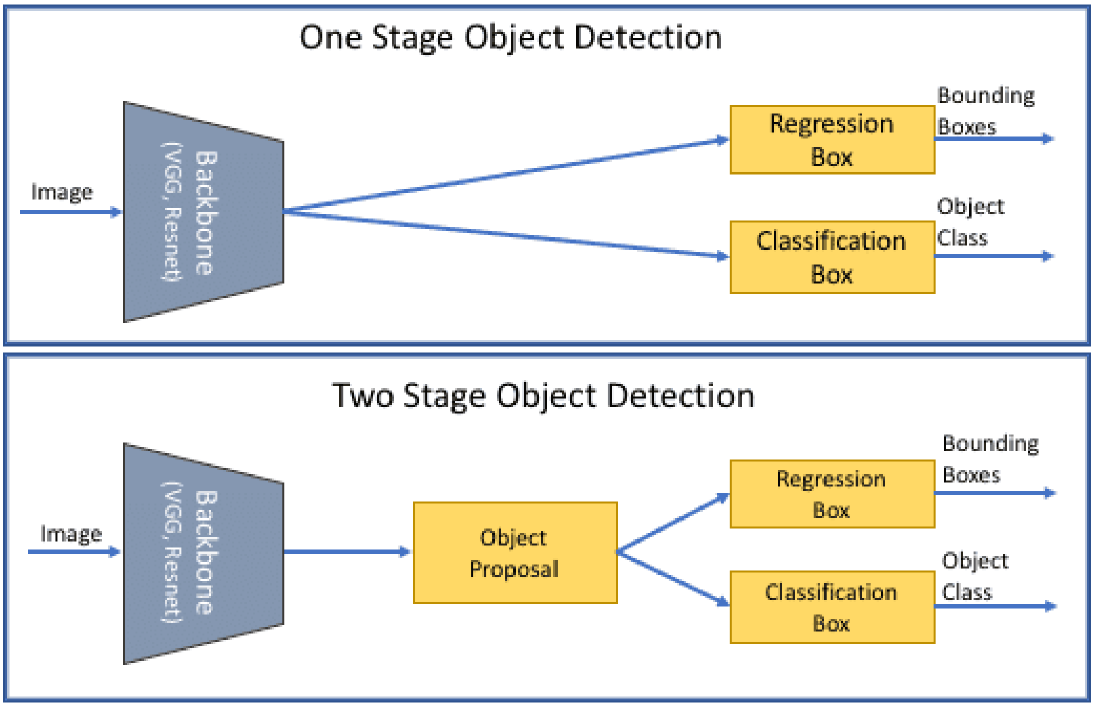

Figure 20. One stage vs two stage object detection models (Oriol Corcoll Andreu, 2021)

5.3.2 SSD MobileNet V2

SSD MobileNet V2 belongs to the family of single-shot object detection frameworks. Unlike traditional two-stage detectors that involve region proposal networks, SSD directly predicts bounding boxes and class scores in a single forward pass (Neha Vishwakarma, 2023). This streamlined approach contributes to its efficiency in terms of speed (Bi Hanqing & Wen Vincent & Xu Zhenyu, 2023).

MobileNet is a CNN architecture specifically designed for mobile and edge devices with limited computational resources (Sandler Mark, et al., 2018). "V2" refers to the second version of MobileNet, which improved upon the original architecture by enhancing performance and efficiency.

MobileNetV2's efficiency and balance between model size, speed and accuracy make it well-suited for deployment on edge devices like the Jetson Nano (Galliot, 2020). The Jetson Nano is a small, low-cost computer designed for AI and robotics applications, and its limited computational resources make it ideal for models like MobileNetV2.

5.3.3 What is CNN?

CNN stands for Convolutional Neural Network, which is a type of artificial neural network designed for processing structured grid data, such as images (Rikiya Yamashita, et al.,2018). CNNs are widely used in computer vision tasks, including image and video recognition, image classification and object detection (Gao Mingjie & Fessler Jeff & Chan Heang-Ping, 2023).

CNNs are composed of layers that have different functions, including convolutional layers, pooling layers and fully connected layers (Qattous Hazem, et al., 2023). Convolutional layers apply filters to the input data to create feature maps, pooling layers reduce the spatial dimensions of the feature maps and fully connected layers make decisions based on the features extracted by the previous layers (Phung & Rhee, 2019).

The architecture of CNNs allows them to automatically and adaptively learn spatial hierarchies of features from the input data (Handle, 2023). This makes them well-suited for tasks that involve spatial relationships, such as image recognition and computer vision applications.

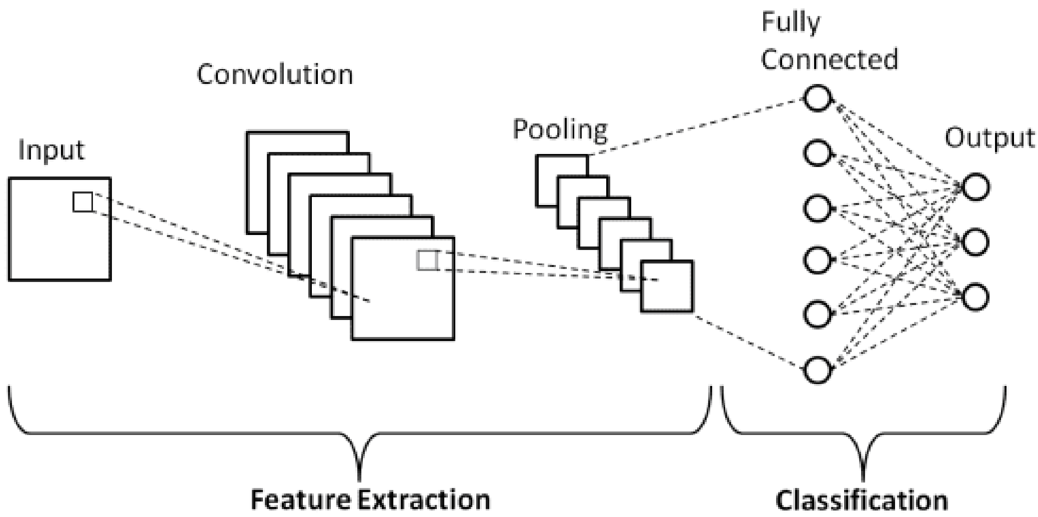

Figure 21. Schematic diagram of a CNN architecture (Phung & Rhee, 2019)

5.3.4 Dataset

For this project, the TACO (Trash Annotations in Context) (Proença & Simões, 2020) open image dataset of waste in the wild was utilized. This dataset comprises photographs of litter captured in various environments, ranging from tropical beaches to urban streets in London. Each image within the dataset is labeled and segmented based on a hierarchical taxonomy. As of the latest update, the dataset contains 1500 images with 4784 annotations and it encompasses 60 classes (categories of trash). TACO dataset serves as a valuable resource for training and evaluating object detection algorithms, contributing to the implementation of the trash detection system in the project.

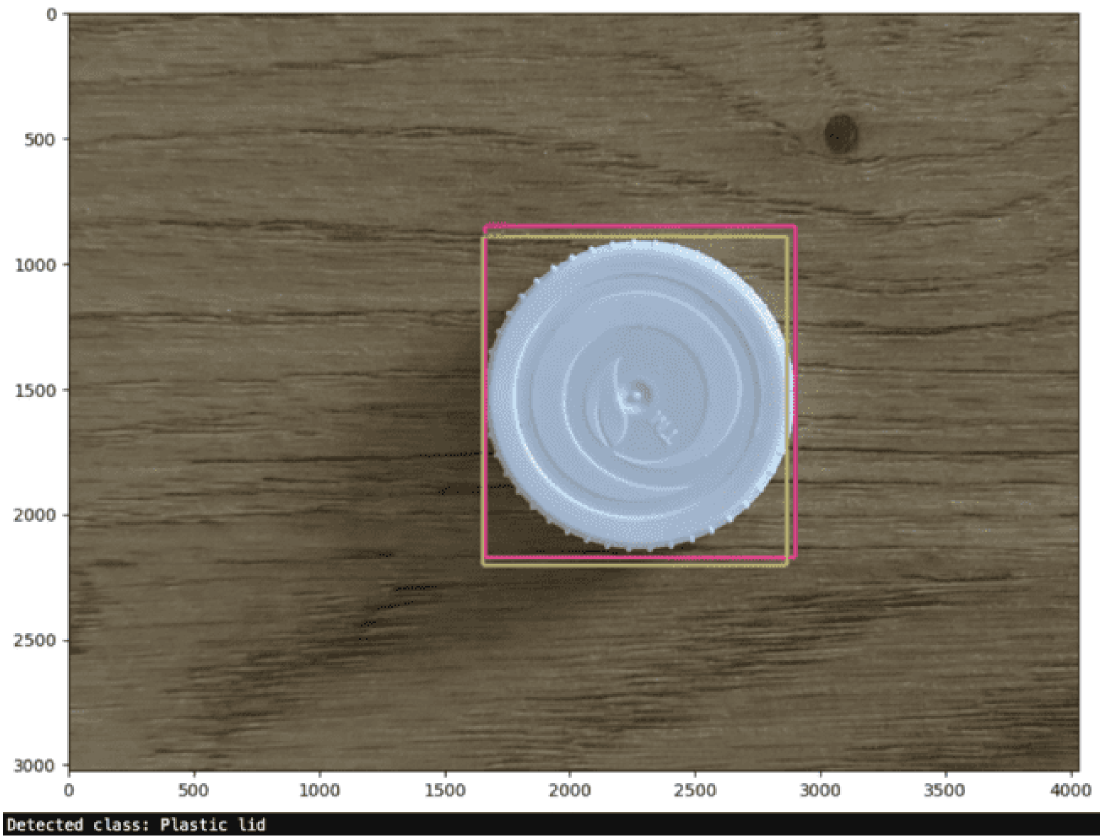

Figure 22. Detected trash with TACO dataset

5.4 Stages of Avian Recycling Training

To achieve the goal of this project, the process of training birds involves several key steps. These steps collectively aim to educate and encourage birds to associate the designated hole with both a source of food and a place to deposit trash, fostering the desired behavior of recycling. Regular observation and adjustments in response to bird behavior contribute to the effectiveness of the training process.

5.4.1 Familiarization with the Feeding Area

Introduce the birds to the designated area with a special setup where you can place food and treats. Ensure that the setup is spacious enough to accommodate larger birds, such as crows and magpies, and positioned at a height that prevents wild animals from reaching it.

5.4.2 Introduction to the Dispensing Machine

Familiarize the birds with the dispensing machine, which provides nuts on a timer (approximately every 30 minutes). This step helps them acclimate to the sounds of the machine and become comfortable with the new setup.

5.4.3 Tactical Trash Placement

Place trash strategically around the designated hole, emphasizing it as a destination for disposing of trash. Create an association for birds that accidentally drop trash into the hole; they will receive a nut as a reward.

5.4.4 Observation and Behavioral Monitoring

Monitor the behavior of the birds closely during the training process.
Alter any aspects of the setup that may influence the birds' interactions or understanding of the recycling process.

6 RESULTS

The project, while ambitious in its scope, encountered challenges that affected the full implementation within the designated timeframe.

A series of tests were undertaken to enhance the nut dispenser's design and functionality. In the process, we deliberated on the choice of treats for birds considering options like pumpkin and sunflower seeds, oat grains and peanuts. After conducting numerous tests, we concluded that peanuts were the most suitable choice due to issues with other treats getting stuck in the spiral during their transit to the small food tray (Figure 17). Following the tests, we encountered challenges with nuts becoming lodged in both the food storage and small tray sections, prompting numerous adjustments to the nut dispenser box. Discussions led to decisions on modifications and Ilja tweaked the design of the parts to address issues. However, the process proved time-consuming as it involved extensive changes and thorough testing.

An optimal model has been found which was trained for 100,000 steps. This model has demonstrated satisfactory performance, at this stage of the project, in identifying trash. However, it is essential to acknowledge that while testing the model struggled to assign the proper class as illustrated in Figures 23-25 and requires further training to accurately specify object classes. Despite this limitation, the model has fulfilled its primary role in the project by effectively detecting and flagging items as trash. This highlights the need for additional training iterations to enhance the model's classification accuracy.

Figure 23. Plastic tube misclassification

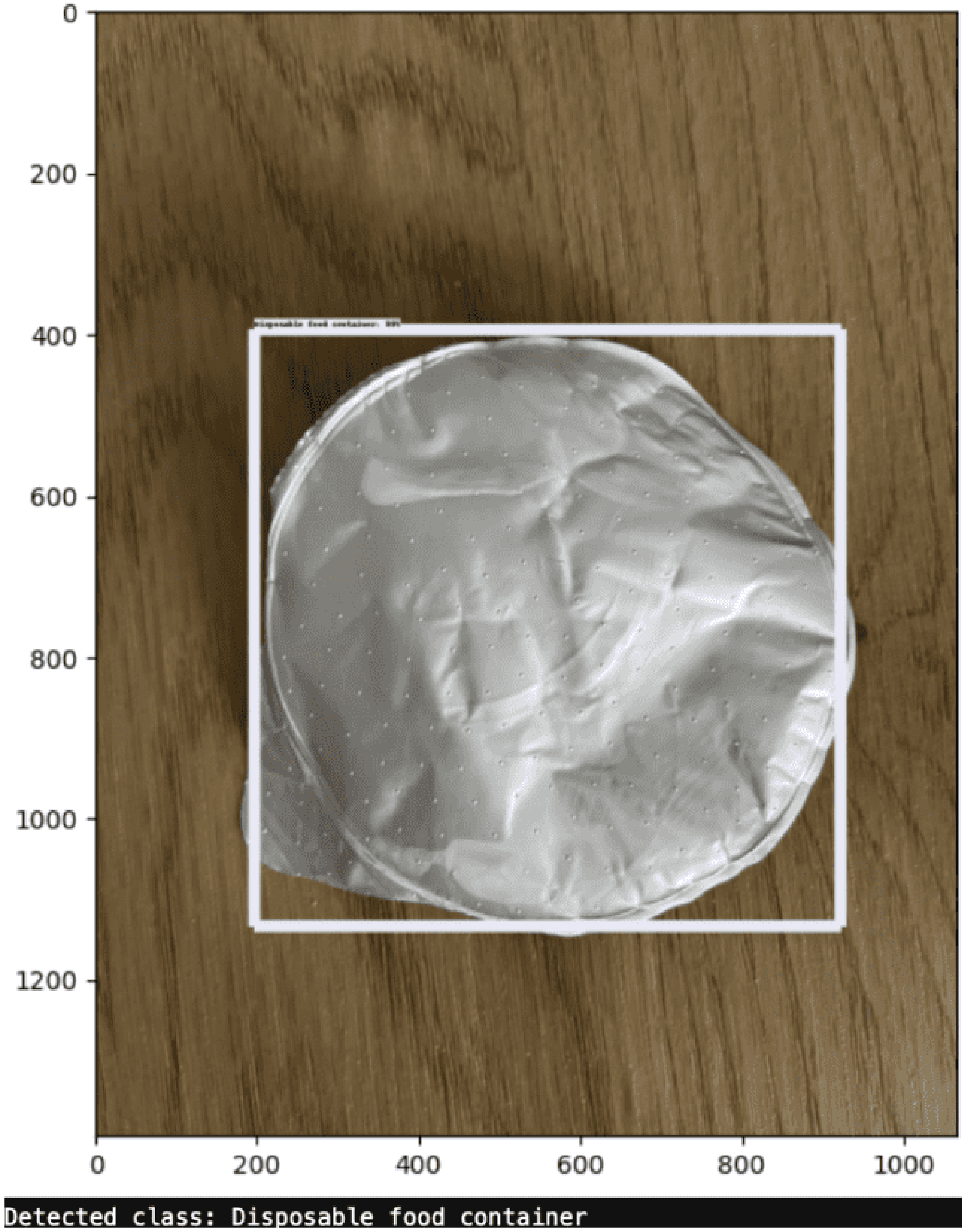

Figure 24. Folio lid misclassification

Figure 25. Plastic package misclassification

7 FUTURE WORK

To further advance this project, a promising avenue would involve exploring the possibility of utilizing the current object parts to develop an ergonomic design for the product, tailored to various stages of bird training. This design should prioritize compactness and ease of assembly, ensuring placement in locations inaccessible to people while allowing convenient access for refilling with treats for the birds.

Currently, the model encounters challenges in correctly assigning the proper class for the trash object. Future work should prioritize additional training to enhance the model's capability to accurately categorize various objects, ensuring more precise outcomes.

Additionally, conducting research based on the collected data could yield valuable insights. Analyzing factors such as the types of trash brought by birds most frequently, identifying bird species participating in the recycling efforts and observing changes in bird behavior, such as a potential reduction in instances of birds scavenging through traditional trash bins, could inform conclusions and guide future iterations of the project. This comprehensive approach will contribute to the ongoing refinement and effectiveness of the bird training initiative.

8 CONCLUSION

Looking ahead, the potential development of an ergonomic design for the product, coupled with ongoing improvements to the model and continuous research based on collected data, offers exciting possibilities. This includes gaining insights into the types of trash frequently brought, understanding the volunteer participation of various bird species and assessing the impact on bird behavior.

As we navigate the intersection of technological innovation and environmental stewardship, this project represents a step toward creating harmonious interactions between wildlife and waste management. By continuing to refine and expand upon these initiatives, we can contribute to sustainable practices while fostering a unique and mutually beneficial relationship with our avian counterparts.

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APPENDIX 1

```
#include <AccelStepper.h>

#define IN1  8
#define IN2  9
#define IN3  10
#define IN4  11

AccelStepper stepper(AccelStepper::FULL4WIRE, IN1, IN3, IN2, IN4);

const unsigned long MOTOR_RUN_INTERVAL = 900000;  // 15 minutes
const int STEPS_TO_MOVE = 2000;
const int MAX_SPEED = 4000;
const int ACCELERATION = 100;

void setup() {
  Serial.begin(115200);

  // Motor settings
  stepper.setMaxSpeed(MAX_SPEED);
  stepper.setAcceleration(ACCELERATION);
}

void loop() {
  static unsigned long lastMotorRunTime = 0;
  unsigned long currentTime = millis();

  if (currentTime - lastMotorRunTime >= MOTOR_RUN_INTERVAL) {
    lastMotorRunTime = currentTime;

    // Move the motor
    stepper.move(STEPS_TO_MOVE);
    stepper.runToPosition();
  }

  stepper.run();
}
```