Smart Navigation and Pickup (S.N.A.P.)

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***Abstract* — This paper presents the design and implementation of the Smart Navigation and Pickup (S.N.A.P) project, a home automation solution capable of autonomously navigating a home environment and retrieving small pet toys. The robot utilizes both LiDAR and ultrasonic sensor technologies for obstacle detection and pathfinding, while a camera equipped with image recognition allows the robot to identify a toy for collection. The system's arms, powered by servo motors, perform the toy-grabbing task and place them into an onboard storage basket. The design prioritizes user-friendliness with minimal input required. This project aims to address the gap in existing home automation devices by enabling the collection of larger objects that traditional solutions cannot handle.**

***Index Terms* — Autonomous navigation, image recognition, LiDAR, object pickup, robotics.**

I. INTRODUCTION

The idea for Project S.N.A.P was first conceived as an answer to a problem many pet owners are familiar with; toys being left scattered across the floor of their home after a play session. In the current market, there is a distinct lack of products designed to autonomously collect and organize items such as pet toys. S.N.A.P not only provided a fun and challenging idea for a Senior Design project but also presents solutions to problems that members of the group have firsthand experience with.

Throughout the contents of this paper, we will provide an overview of the hardware and software components that were used to make the project a reality. This includes the various components used in accomplishing autonomous navigation with obstacle avoidance, image recognition to identify the toy balls we are specifically targeting for collection, and a close look at the PCB design and power requirements needed.

Major goals of the project include ensuring the robot can operate safely in a home environment by avoiding collisions entirely, quickly and efficiently collecting a toy, and ease of use from the user perspective which will only require the user to simply turn on a power switch to have the robot begin searching for and collecting toys. By bringing all these qualities together we hope to create something that can be used by anyone regardless of their knowledge and experience with technology.

II. SYSTEM COMPONENTS/HARDWARE

For full operation of the product, there are many main components for its operations. The components are hardware parts selected for all basic operations of the system.

A. Microcontroller

The microcontroller is responsible for controlling all other components through software, it controls the voltage to activate or deactivate other components. The chip chosen was the ESP32-S3-WROOM-1 due to its decent amount of RAM, clock speed, usability, and cost.

B. Microcomputer and Camera

The microcomputer will be responsible for running the camera and the computer vision model. The microcomputer chosen was the Raspberry Pi Zero 2W due to its low cost, physical size, decent clock speed, and decent amount of RAM. The camera will be responsible for taking the live image and sending that information for the computer vision model for object identification. The camera chosen was the ArduCam 5MP OV5657 due to its high resolution and decent framerate.

C. Chassis and Mobility

The LewanSoul Mecanum Wheel Chassis was chosen to be a blank slate upon which we could build onto, specifically chosen for its omnidirectional movement capabilities. This type of navigation will be helpful in any tight spaces, improving the robot's ability to retrieve the object efficiently. The Chassis houses all major hardware components including the arm and scoops, and the basket, and all major electrical components, including the power supply, motor drivers, and microcontroller.

D. Arm and Scoop Mechanism

To retrieve the pet toys efficiently and consistently, a custom-designed arm and scoop mechanism was designed and 3D printed for optimal fit and weight efficiency. The arm is actuated by servo motors, allowing for controlled movement of the arms and precise pickup. The scoop utilizes a bucket-style design split down the middle, for the arms to surround the pet toy to avoid dropping it. This ensures that spherical objects can be securely collected and lifted into the onboard storage basket system.

E. Sensors for Object Detection and Navigation

To enable autonomous navigation and pickup, S.N.A.P. integrates multiple sensors each with a specific task designed to aid in autonomous operation throughout the entire collection process.

The MakerFocus OMENT LiDAR is used for detecting any objects that the object might run into before it reaches the pet toy.

An HC SR04 ultrasonic sensor was placed at the front of the robot to detect the pet toy specifically and activate the collection sequence of the arms and scoop.

The ArduCam 5MP Camera is used for object recognition, allowing the system to differentiate between pet toys that should be collected and other regular household items.

F. Battery

We chose the Talentcell 12V lithium-ion battery as our main power source for our autonomous pet-toy collecting robot because of its ability to balance energy density, reliability, and efficiency. Lithium-ion batteries are an ideal choice for our mobile application because they offer a high energy to weight ratio, meaning they can provide substantial power without adding excessive weight. This is crucial because reducing the weight increases mobility and prolongs operating time. Li-ion batteries are viable and long-lasting alternative to other battery chemistries, such as lead-acid or NiMH, as they offer greater efficiency, longer cycle life, and lower self-discharge rates.

H. PCB Design

A key component of our system's operation is the PCB design, which guarantees effective power distribution, sensor integration, and motor control for our autonomous pet toy collecting robot. Our design consists of four separate PCBs: the main control board, motor driver, and two voltage regulator boards. This modular approach enhances maintainability, troubleshooting, and scalability, as each board can be tested and replaced individually if needed.

III. HARDWARE DETAIL

Each of the major subsystems between the hardware components and overall hardware integration will be explained to show the critical role they play in ensuring smooth and efficient operation of the robot.

A. Hardware Block Diagram

To understand a general idea of how these parts will interact, this block diagram highlights each component's roll within this system.

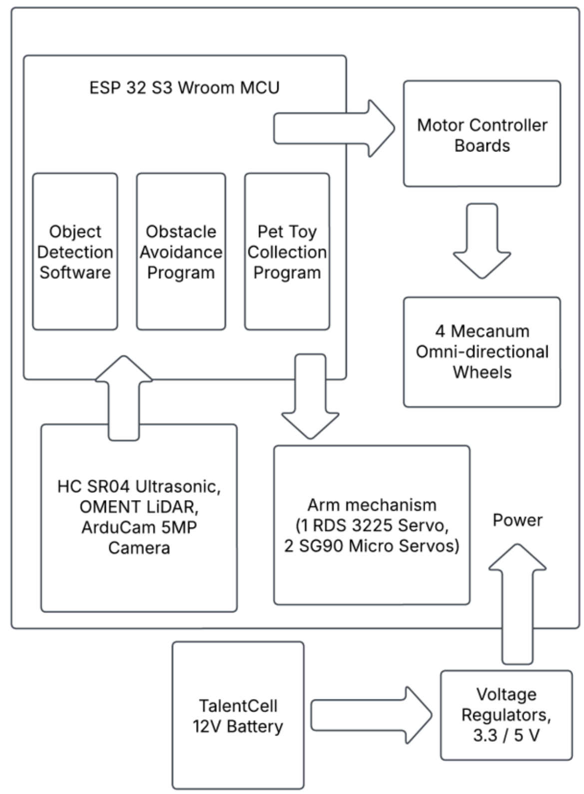


Fig. 1. Low-level hardware block diagram

B. Structural Integration and Component Placement

The structural design of our robot plays a critical role in ensuring the stability, durability, and efficient component placement. Since the robot comprises of multiple subsystems including the chassis, the arm and scoop mechanism, sensors, battery, and electronics, our approach to structural integration focuses on custom 3D printed mounts to connect these pieces together with efficient space utilization and modular assembly to ease any kind of maintenance and adjustments that would need to be made during testing.

The LewanSoul Mecanum Wheel Chassis serves as a base for our robot supporting the weight of all the components. The structural design prioritizes balanced weight distribution to prevent tipping during movement or any instability in operation. The PCB is mounted centrally in between the two plates of the chassis to shorten wire lengths and reduce signal interference or power loss. The 12V Talentcell battery is placed in the middle of the top plate in its own mounted compartment to provide counterbalance for the front mounted scoop. The arm and scoop mechanism is mounted on a 3D printed bracket connected at 6 different points to reduce any flexing during operation. The LiDAR sensor and camera are mounted at the front for the best viewing angle and unobstructed field of view, each have their own dedicated mount.

To achieve a precise and secure fit for all the components, 3D printed mounts were designed and fabricated to attach the components in their proper placement to either the top or bottom plate of the chassis. Components that are subjected to mechanical stress were fabricated with reinforced infill patterns to withstand repeated motion. Components such as the arms and scoop that may cause instability being placed out in front of the robot, were optimized for structural integrity while reducing unnecessary bulk. Modularity was also a large focus for the 3D designs. The mounting system for the sensors and pcb's were made removable to allow for easy component swapping and debugging without requiring a complete disassembly of the chassis.

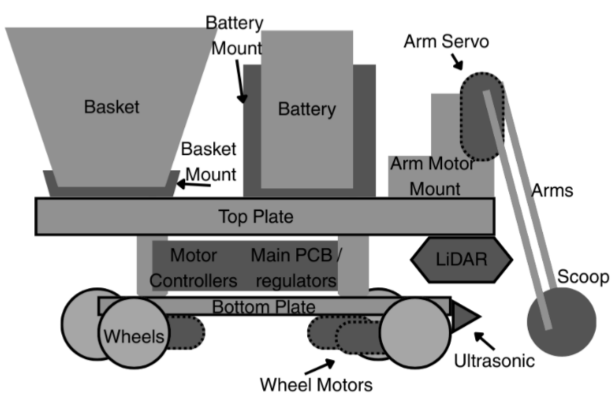


Fig. 2. Diagram showing major component placement.

C. Object Detection and Sensor Systems

The robot's object detection and sensor recognition system are what allow it to identify, locate, and retrieve objects while navigating its surroundings. This system relies on a combination of LiDAR, a camera, and ultrasonic sensors, working together to provide real time environmental awareness and precise object localization.

The MakerFocus OMENT single-point LiDAR is used for distance measurement and basic spatial awareness so that the robot can autonomously avoid obstacles that may stand in the way of the pet toy to be retrieved. This LiDAR sensor scans the distance in front of the robot by using a laser beam pulse and measuring the time it takes for the reflection to return. This system will ensure that if any object appears in front of the robot as it is travelling, the data that the LiDAR sensor sends to the MCU will ensure that the robot is able to avoid that obstacle and continue its navigation.

The camera module will be used for object recognition to start the process of collection. This camera uses a 640*480 resolution which is enough to accurately detect the pet toy, while staying low enough to keep power draw low. The image is processed using computer vision techniques such as edge detection and analyzes shape and contour of the object to increase accuracy. The processed image data is then sent to the MCU along with all the other sensor data to control decision making throughout the collection process. The interaction between these sensors, their data, and the MCU, is what makes this system work. Detection of the object from afar, the avoidance of any obstacles during the pathing towards the object, and the detection that the robot is in its correct spot, make up all the parts of the collection process that we need to perform accurately and efficiently.

D. Mobility and Motor Control System

Giving the robot mobility will be accomplished with four TT DC motors, with each of the four wheels having its own dedicated motor. These motors will be controlled with a custom motor driver board that utilizes two L293NE drivers ICs. The motor driver board will be connected to the main board through both a 12V and 5V input connection. Additionally, each motor will require three GPIO pin connections from the main board. One pin will use PWM to control the speed of the motor, and the other two will be used to determine the direction the motor spins; with one being set to high and one to low to determine direction.

Implementing the desired mobility will be done by assigning each type of movement its own dedicated function within the software. Certain types of movements require specific wheels to turn and variable speeds. The performance of the movement functions depends heavily on the type of material the robot is traversing. For example, hardwood floors and carpets require separate adjustments in the motor behavior to achieve the same results across both surface types. For the sake of the demo, testing will be exclusively focused on movement performance on carpet.

E. Arm and Scoop Mechanism and Motors

To accurately describe the process that the arms undergo during the collection process, each individual piece must be described that make up the arm system. First is the main servo motor mount which basically holds the entirety of the arm system. This main servo motor mount holds the main servo motor, and the rest of the arms are connected to this piece so that it has the capability of rotating vertically for collection and deposit of the pet toy. Connected to the main servo motor is the arm connector. This piece connects the two separate arms, to either side of the main vertical motor so that both sides are always aligned in their movement. On either ends of this arm connector are the micro servo motors which are responsible for arm rotation and therefore opening and closing of the arms. The combination of these micro servos and main servo makes up the 2 degrees of freedom necessary for our arm's full movement capabilities. Connected to each of these micro servos are the left and right arms and scoops which extend further to just above the ground and the scoops are what encapsulate the object for pickup.

Once an object is in the correct position and ready for pickup. The main servo motor moves the arms from their default, upright, and open position, down to just above the ground around the pet toy. Now that the arms are lowered, the micro servos can rotate the arms to enclose the object inside the scoops. Once the scoops securely hold the pet toy, the main servo motor can move the arm vertically back up to its default upright position above the basket. Finally, the micro servos rotate to separate the arms, therefore opening the scoops, therefore dropping the pet toy into the basket. The combination of motors and 3D-printed designs come together to ensure that if the pet toy is picked up, there is no point of error in which it could be released without making it into the basket.

E. Power Distribution

One of the key advantages of our chosen Talentcell battery is its integrated protection circuitry. It helps against short circuits, overcharging, and over discharging. Our power supply's longevity and safety are guaranteed by this integrated battery management system, which lowers the possibility of electronic damage. Additionally, its 12V output is well suited to our system, as it directly powers our motor driver and serves as the input for our voltage regulator PCBs, which step down the voltage from 5V to 3.3V. This allows for an efficient power distribution plan without excessive energy loss due to voltage conversion.

Another crucial factor in our battery selection was its capacity and discharge rate. The Talentcell battery provides sufficient capacity to power our robot continuously for about 30 minutes, allowing the battery to meet our design specifications. Its ability to deliver consistent voltage under load ensures constant and stable performance for all subsystems, including our motor control, microcontroller, and sensors. Lithium-ion batteries also have a comparatively quick recharge time, which reduces downtime between usage and is also advantageous for extended testing and deployment.

Overall, the Talentcell 12V lithium-ion battery is a great fit for our system due to its lightweight design, high energy density, integrated safety features, and suitability for our power needs. It guarantees that our microcontroller and sensor receive steady and regulated voltage levels while supplying the power required for effective motor performance. By selecting this battery, we enhance the reliability and performance of our robot, ensuring it can navigate its surroundings and complete its tasks without frequent recharging or power interruptions.

F. PCB

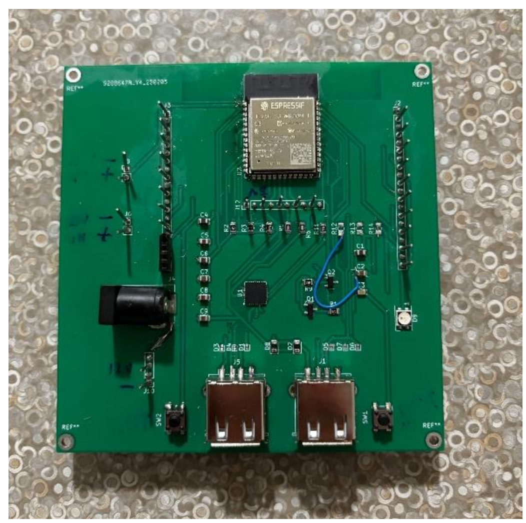


Fig. 3. Main board PCB

The main PCB houses the ESP32-S3-WROOM microcontroller, which processes sensor data and carries out motor control commands. This board integrates the USB-to-UART connection, which enables debugging and firmware changes. We also included GPIO headers for our servos, LiDAR, and ultrasonic sensors. To ensure stable power, we included voltage regulators to provide 5V and 3.3V to various peripherals.

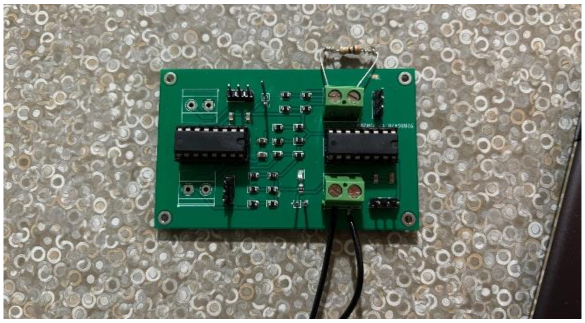


Fig. 4. Motor driver PCB

Our four DC motors, which allow the robot to move, are controlled by our motor driver PCB. Since each L293NE motor driver IC can handle two motors, we are using two of them. The L293NE allows for bidirectional control using an H-bridge configuration, allowing the robot to move forward, backward, and turn. The logic control operates at 5V, but the motor supply voltage (VVC2) is set to 12V, matching the output of our battery. We also incorporated flyback diodes to protect the circuit from voltage spikes.

Fig. 5. Regulator PCB

Our voltage regulator PCBs ensure steady power for various components by stepping down the 12V battery supply to 5V and 3.3V. As stated earlier, instead of integrating the regulators directly onto our main board, we opted for separate breakout boards, making replacements easier in case of failure. The regulator we chose to use is the LMR5140. They operate at 500 kHz switching frequency, providing efficient power conversion with minimal heat dissipation. We also have filtering capacitors to cut down on noise and an LED indicator to verify power delivery to each board.

There was a number of difficulties during the design phase, such as USB-to-UART wiring errors, interference with TVS diodes, and initial grounding issues that affected our signal integrity. These problems were systematically addressed through redesigns and manual modifications.

Overall, our PCB design places a high value on efficiency, versatility, and modularity, ensuring seamless integration between power management, and sensor communication.

IV. SOFTWARE DETAIL

The software is divided in two parts, the computer vision model, which is responsible for identifying an object and the embedded software, which is responsible for controlling all the components in the system. The computer vision model will be running in the Raspberry Pi, and the rest of the software will be running in the ESP32-S3-WROOM.

A. Embedded Software

The Embedded software, in which will be running in the ESP32-S3-WROOM, is written in C++ using the Arduino IDE. The software has a header file containing all basic functions from the project, and a main file in which those functions are called within the logic. The functions are made for controlling the motors, the servos, the sensors, and the LED. The main file will hold the logic for separating the pick-up and search modes.

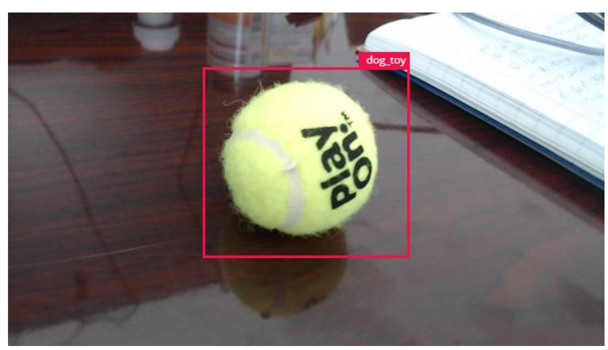


Fig. 6. Labeled image for training

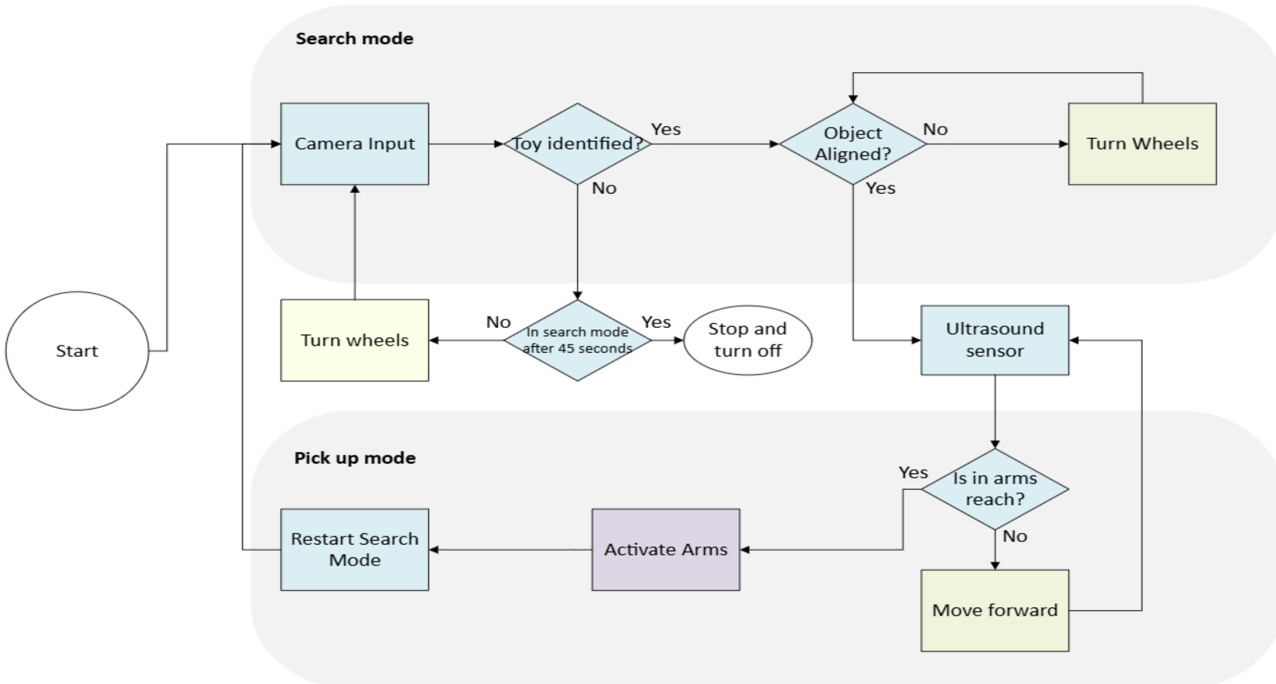


Fig. 7. Software Design Flowchart

B. Computer Vision Software

The computer vision software is divided into two parts, the model and the script. The model is where the images were trained and where the new images captured by the camera will be sent for identification. The model was trained using a tool called Edge Impulse. For sending the images from the camera to the model, a script is required for it, in which is written in Python. The script is responsible for taking the image, sending the image to the model, get the coordinate returned for the object's location, and send those coordinates through UART serial communication to the microcontroller.

The training process for the computer vision model consists of three steps, acquire data, defining label, and train model. Acquiring data consisted of gathering pictures manually from some objects acquired for testing and gathering datasets online from different sources. Defining the label is separating the objects by different labels, so the computer vision model can differentiate the objects by color, size, and different characteristics. The training step is basically letting Edge Impulse train the model by using some images with the labels and some without it. The one with the labels are called training set, which creates the model and the images without the labels are called testing set, in which will test the trained model so it can identify accuracy and prediction rate. The last step usually takes some time as the machines will run the training algorithm and depending in how large the dataset and input cores. In addition, it requires some tuning to improve accuracy.

C. Overall Software Design

The project's software runs in two different models, the search mode, in which it will be looking for an object. During this mode, the body is rotating until an object is found. If not, object is found in 45 seconds, the motors stop for power saving and the LED turn to red specifying no object found. On the other hand, if an object is found, the coordinate is sent to the microcontroller for adjusting the angle of the body with object. Whenever it is adjusted, it starts to move forward, with the assistance of the ultrasonic sensor for checking the distance from the body to the object. If the object distance is between 9 and 17 centimeters, the motors will stop, and the pick-up mode will commence.

The pick-up mode is responsible for picking up an object and placing it in the basket. It first activates the arm servo, in which lowers the arm to the ground level. After that, the scoops move to the close position, and the arm servo raises, and the object rolls into the basket. Then, the scoops open again for the next pick-up operation. If the object is still being identified, it tries picking the object up again.

V. COLLECTION PROCESS

For the sake of user friendliness, the collection process is being designed to begin once the power switch on the battery is turned on. At the beginning of the process, the robot will pause briefly for five seconds before beginning. Throughout the entire process the robot will be using both the LiDAR and ultrasonic sensors to check that the path forward is clear. Assuming the path is clear, the robot will move forward while the camera searches for a toy ball.

If an obstacle blocks the robot's path, the motors will stop, and the robot will begin turning in place until the path forward is deemed to be clear by the sensors. With the path clear, the robot will continue. If a toy ball is not spotted by the camera within 45 seconds of powering on (or the last successful toy recovery), the robot will enter a standby state where it waits to be powered off. This state will be indicated by a yellow LED located on the main PCB and it's purpose is to avoid needlessly wasting battery with prolonged searches for toys.

Once a ball is spotted, the location of the ball will be associated with X and Y coordinates from the camera's perspective. At this stage, the goal will be to use the X coordinate to get the ball into the center of the camera's view, meaning the ball is directly in front of the robot. The X values being read will be used to tell the motors how to behave to center the ball. Once the ball is centered, the robot will move forward towards the ball while the ultrasonic looks for the appropriate distance from the ball to be in range for collection. Once in range, the robot will stop, and the servo motors will be used to collect and deposit the ball into the basket.

VI. TESTING

A. Software Testing

The first software test was made with all components separated, making sure that each of the components' software worked as expected. Then, testing the software in all of them together. For example, for the pick-up operation, the arm servo was testing first with focus in tuning it perfectly and testing values, after that the micro servos for the scoops were tested. After both satisfied the design proposed they were tested together, and then the ultrasonic sensor was added, and so on.

The computer vision model was tested in two different ways, the first time was right after it was trained using Edge Impulse's online testing tool, in which allowed to use a computer camera to test the model live. After that testing was completed, the next step was to test the model running directly on the Raspberry Pi, in which consisted in downloading the model and writing the Python script for identifying an object. Both tests were successful, with extra testing required whenever the model or the script was changed.

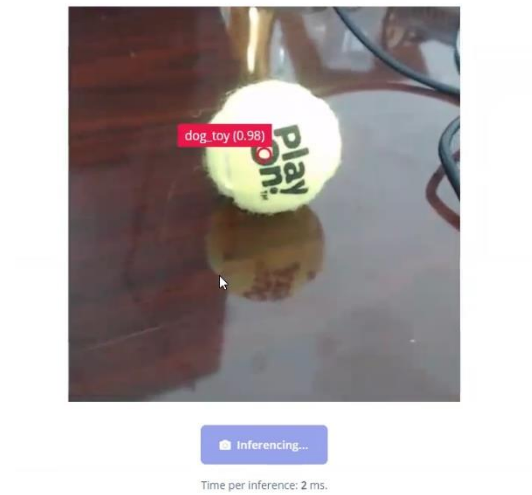


Fig. 8. Testing the model in Edge Impulse's website

B. Main PCB and Regulator Testing

Testing of the main PCB, as well as the 5V and 3.3V regulator boards was done by connecting each voltage input source with the correct amount of voltage and measuring and comparing the actual voltage outputs with the expected outputs. Additionally, testing proper connection of components was done by verifying the ESP32 on the main board was being recognized by a computer when connected via the USB port, as well as verifying GPIO pins could be set high and low through software using the Arduino IDE.

The main board was also subjected to tests that accurately represent the conditions in which the robot will operate. This included connecting all the peripherals that will be used on the robot such as motors and sensor to verify the PCB performs as expected under heavy load.

To ensure the motor driver board was functioning correctly, we conducted a series of tests to verify voltage levels, logic control, and current handling. To check if we had proper power distribution, we first took out the IC and checked the voltage across each pin in the socket. We verified this by reinserting the IC and measured the outputs to see if the motors would respond correctly to the expected logic states. The logic was systematically switched from high to low, testing different input combinations to observe whether the motor outputs stopped, rotated in one direction, or reversed accordingly. In order to make sure the board could manage the load without failing or overheating, we lastly attached the actual motors and watched how they responded while also monitoring the stall current.

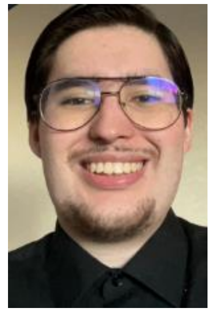
CONCLUSION

Implementing the tools and technologies mentioned throughout this paper, Project S.N.A.P aims to autonomously collect pet toys using a combination of sensors and computer vision for navigation and object recognition. Challenges such as sensor calibration, power efficiency, and mechanical optimizations for accurate navigation were addressed through iterative refinements. S.N.A.P demonstrates a practical and scalable solution for autonomous pet toy collection that can potentially be expanded to include other applications and contribute to advancements in home automation and robotics.

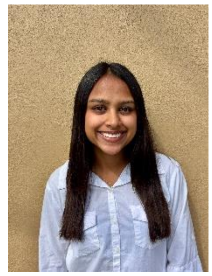
THE ENGINEERS

Walker Phillips is a 23 year old student at the University of Central Florida and will receive his Bachelor's of Science in May of 2025. He has attended the University for 5 years and plans to move to Tampa after his graduation to pursue a career in hardware design.

Corey Swafford is originally from Oxford, Ohio but has lived in Orlando Florida since 2014. He started attending the University of Central Florida in 2021 and will receive his Bachelor's of Science in May of 2025 for Computer Engineering. Since October of 2023 he has been part of the CWEP program with Lockheed Martin and looks forward to joining the company full-time shortly after graduation.



Rodrigo Costa is a 23 year old Computer Engineering student at the University of Central Florida. He hopes to pursue a PhD in Computer Engineering to follow a career in the academic field since he has been working as a teaching assistant since 2023.



Ria Patel is an electrical engineer studying at the University of Central Florida. She intends to pursue a master's degree specialized in RF and microwave engineering. Ria has plans to join Lockheed Martin with a full-time position after graduation.

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