Automated Sorting Bot

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Date: Dec. 12, 2021

TABLE OF CONTENTS

1. Introduction

a. Statement of Purpose

The purpose of this project is to design and develop **SortBot**, a versatile and efficient robotic system specifically engineered to autonomously sort and transport a wide range of objects based on user-defined criteria. SortBot will be equipped with a robust chassis supported by a set of wheels, ensuring smooth mobility across various surfaces. At the front of the robot, an adjustable wall mechanism will be incorporated, allowing it to securely trap, manipulate, and push objects toward their designated destinations.

A key feature of SortBot will be its integration of advanced visual recognition technology, enabling it to accurately identify objects and categorize them accordingly. Once an object has been identified, SortBot will intelligently follow a predetermined path corresponding to the object's classification, ensuring precise and efficient sorting operations. This capability will allow SortBot to handle multiple object types simultaneously, each directed to its appropriate location with minimal human intervention.

By automating the sorting process, SortBot aims to streamline workflows in environments that require the constant handling and organization of materials, such as warehouses, factories, or distribution centers. With a focus on user convenience, SortBot will be designed to offer an intuitive and seamless experience, minimizing the need for complex instructions or setup. The result will be an efficient and reliable system that optimizes both time and resources while enhancing the overall ease of use.

In summary, SortBot represents a significant step toward automating routine sorting tasks, combining the power of robotics with intelligent recognition systems to deliver a flexible and user-friendly solution for various operational contexts.

b. Features and Benefits

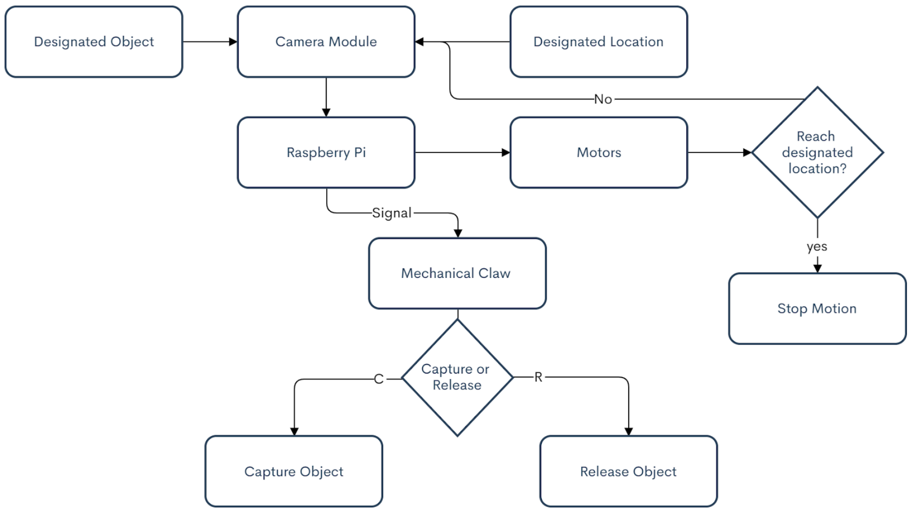
Our project is designed to significantly reduce the time and effort required by users to perform the often repetitive and labor-intensive task of sorting and organizing. By automating this process, we aim to eliminate the need for manual intervention, allowing users to focus on more important tasks. One of the key advantages of this robotic system is its fully autonomous operation, meaning users won’t have to monitor or supervise the sorting activities once the bot is activated. This hands-off approach ensures both convenience and efficiency, streamlining workflows in environments that require frequent organization.

The robot's mobility system, which utilizes a sturdy chassis rather than traditional wheels, enables it to navigate a wide variety of surfaces and obstacles with ease. Whether it's operating in a cluttered warehouse, uneven terrain, or confined spaces, the robot is designed to adapt to different environments, continuing its sorting tasks uninterrupted. This versatility ensures that the robot can be deployed in diverse conditions without compromising its functionality.

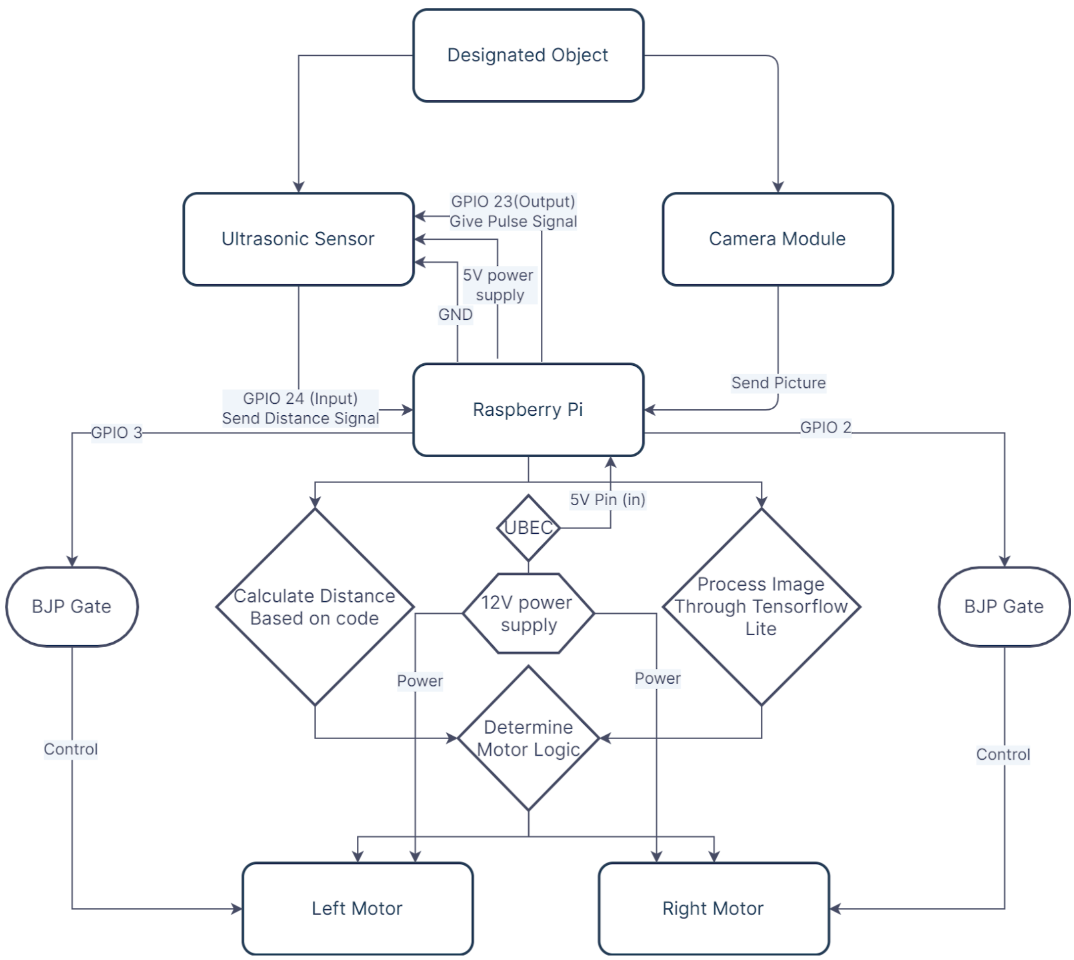
Moreover, the robot’s power source is deliberately designed to be both simple and cost-effective. It runs solely on AA batteries, making it extremely user-friendly and accessible. Users can easily replace the batteries when needed, avoiding the complexities and costs associated with more advanced power systems. This design choice not only keeps operational costs low but also ensures the robot remains practical and easy to maintain for a wide range of users.

2. Design

Original Design



Revised Design



a. System Overview

As we progressed with the project, we realized that it was critical for the robot not only to identify the objects but also to accurately determine their distance. This additional requirement was essential for ensuring precise and safe interaction between the robot and its environment. To address this, we incorporated an ultrasonic sensor into our design. This sensor allows the robot to measure the distance to nearby objects and automatically halt when it approaches too closely, thereby initiating the capturing procedure in a controlled manner. The inclusion of this feature significantly enhances the robot's ability to perform its sorting tasks with greater accuracy and reliability.

Additionally, when faced with the challenge of controlling the motor, we encountered another hurdle. Since we did not purchase a dedicated motor controller for the Raspberry Pi, we had to devise an alternative solution. We opted to build a custom motor control system using two Bipolar Junction Transistor (BJT) circuits that we constructed ourselves. Initially, our intention was to design a more advanced H-Bridge circuit to allow for full motor control, including both forward and reverse movement. However, due to material limitations, we were unable to achieve this, as each H-Bridge requires four BJTs, and we did not have enough components. As a result, the motor in our current design can only move in the forward direction.

Despite these constraints, our adjustments represent a creative and resourceful approach to overcoming challenges, and they have allowed us to keep the project moving forward while identifying areas for future improvement.

b. Design Details

In our final design, we power the raspberry pi through two 4AA battery packs connected in series and a UBEC with the input of 5 to 23 volts and an output of 5 volts. Through connecting the positive output pin of UBEC to the 5V pin of the raspberry pi and the negative output pin of UBEC to the ground pin of the raspberry pi, we were able to produce a self-made portable raspberry pi power supply. This design is fully functional as the raspberry pi did not draw huge current and the point of operation for the raspberry model was 5 volts.

As the ultrasonic sensor also operates on 5 volts, we connected the other 5 volts pin of raspberry pi to the Vcc of the ultrasonic sensor and GND to GND for powering the device. We also utilize codes and send voltage signals to the Trigger pin of the ultrasonic sensor through pin GPIO 23 to initiate distance detection. After that, we use a voltage divider to step down the output of the Echo pin of the ultrasonic sensor from 5V to 3.3V and connect pin GPIO 24 to receive the signal. After recording the start time and the end time for the pulse sent to the raspberry pi through the Echo pin of the ultrasonic sensor, we were able to compute the distance between the object and the sorting bot.

Finally, by using Google Vision to train our own AI model and exporting the file as a tensorflow lite file plus a txt file (for label), we were able to integrate the functionality of object identification into our sorting bot. We also utilized codes to determine the movement patterns for the motor based on the object identified.

3. Results

In the course of the project, we successfully achieved our primary objective of enabling the sorting bot to identify objects and control its motor system based on the characteristics of the detected object. This was a crucial milestone, as it laid the foundation for the bot's autonomous sorting functionality. We spent considerable time fine-tuning the object recognition algorithm to ensure it could consistently and accurately identify the specific types of objects we programmed it to detect. By leveraging visual recognition technology, the sorting bot could differentiate between objects of various shapes, sizes, and colors, and then adjust its movement accordingly. This dynamic object detection and motor control system was key to the robot's ability to perform its task without direct human intervention.

As we progressed, we identified an opportunity to further enhance the bot's capabilities by integrating an ultrasonic sensor. This sensor enabled the sorting bot to accurately measure distances, allowing it to autonomously approach objects while avoiding collisions. The ultrasonic sensor played a critical role in improving the precision of the robot's movement, particularly when positioning itself in front of objects for collection. By using this sensor, the robot could detect the proximity of an object and stop at the optimal distance before initiating the capturing process. This addition significantly improved the robot's interaction with its environment, making its operations smoother and more efficient. It also reduced the risk of damage to the objects being sorted or to the robot itself, as the sensor prevented accidental collisions.

However, despite these advancements, we faced an unexpected challenge during the final stages of testing. In one of our trial runs, the Raspberry Pi—an essential component responsible for managing the bot's operations—was damaged. This incident occurred due to unforeseen circumstances during the testing process, and unfortunately, the damage was severe enough that it could not be repaired within the limited timeframe available to us. As a result, this setback prevented us from fully demonstrating and recording the complete functionality of the sorting bot in action, which was a disappointment after the significant progress we had made.

Although we were unable to capture the bot's full range of capabilities on video, this experience provided valuable insights into the importance of careful hardware management and redundancy planning in robotics projects. The damage to the Raspberry Pi also highlighted potential areas for improving the durability and robustness of our system for future iterations. Despite the challenges, the project as a whole was a success in terms of achieving the primary technical goals, and the lessons learned will inform future improvements and refinements.

4. Problems and Challenges

One significant challenge we encountered during the project was integrating reliable object detection with the Raspberry Pi, which was crucial to the bot's ability to identify and categorize objects accurately. Initially, we implemented a method that relied on detecting the RGB (Red, Green, Blue) values from images captured by the Raspberry Pi's camera module. While this approach seemed promising at first, it quickly became apparent that it was highly sensitive to variations in lighting and background colors, which introduced significant noise into the system. The method often struggled in environments where the background contained colors similar to the objects being detected, leading to inaccurate or inconsistent results. This variability undermined the effectiveness of the sorting bot, as it could not reliably distinguish between objects, especially in dynamic or uncontrolled settings.

To overcome this issue, we decided to pivot toward a more robust solution by leveraging Google Vision AI, a cloud-based artificial intelligence platform that specializes in image recognition. This shift allowed us to train a custom AI model tailored specifically to the objects we wanted the sorting bot to recognize. We began by collecting a large dataset of images featuring the objects we needed to sort, taken from different angles and in various lighting conditions, to ensure comprehensive training. By uploading this customized training data, we were able to fine-tune the AI model to recognize these specific objects with a high degree of accuracy.

The switch to Google Vision AI proved to be highly effective. The custom AI model dramatically reduced the noise and inaccuracies that had plagued our initial approach. The AI was able to successfully identify the labeled objects approximately 95 percent of the time, a significant improvement over our previous method that relied solely on RGB detection. This change not only enhanced the bot's object recognition capabilities but also made the system more adaptable to different environments, as the AI could now handle more complex visual inputs without being as affected by background noise or lighting variability. This marked a pivotal moment in the project, allowing us to progress with more confidence in the bot's core functionality.

Another major challenge we faced was configuring a portable power supply for the Raspberry Pi, which is essential for the bot's mobility and independence from stationary power sources. Due to budget constraints, we were unable to purchase the recommended battery pack specifically designed for the Raspberry Pi. Without this power solution, we risked compromising the robot's autonomous functionality, as it would require a tethered power source, limiting its movement and practical use.

To address this issue, we devised a cost-effective alternative by designing our own portable power system. We combined two 4-AA battery packs in series to generate a total output of 12 volts, which would provide sufficient power for the bot's needs. However, the Raspberry Pi model we were using operates at 5 volts, so we needed to step down the voltage from the 12-volt battery pack to the appropriate level. To accomplish this, we incorporated a UBEC (Universal Battery Elimination Circuit), a voltage regulator commonly used in remote-controlled devices, which allowed us to reduce the voltage to the necessary 5 volts. This approach successfully powered the Raspberry Pi and enabled us to continue testing and developing the sorting bot without the need for the official battery pack.

5. Future Plans

Looking ahead, there are several key enhancements and improvements we plan to implement in the next phases of development to elevate the functionality and efficiency of our sorting bot.

First and foremost, we aim to resolve the issue with our damaged Raspberry Pi, which hindered our ability to fully showcase the bot's automated capabilities. Once the hardware is restored, we will complete the remaining testing phases and properly document the sorting bot in action, including its ability to autonomously approach, identify, and capture objects. We anticipate that resolving the Raspberry Pi issue will allow us to refine our code and integrate more advanced object recognition features, enhancing the bot's performance in diverse and complex environments.

A major enhancement we plan to add in the future is a **3D-printed claw mechanism**. This will significantly expand the bot's capabilities by allowing it to physically grasp and manipulate objects, rather than relying solely on its current pushing and trapping method. With a functional claw, the robot would be able to pick up and sort objects of varying sizes, shapes, and materials, thereby increasing its versatility. The claw will be designed to interface seamlessly with the existing chassis and sensor systems, allowing for smooth and precise control. Additionally, we plan to integrate more advanced motion control algorithms to ensure the claw operates efficiently in various conditions and environments.

Another future development involves improving the **power management system** of the sorting bot. While our current power solution using AA battery packs and a UBEC is functional, it is not the most efficient or long-term solution. We intend to explore more sustainable and high-capacity power sources, such as rechargeable lithium-ion batteries, which would offer longer operational time and more consistent energy output. Integrating a rechargeable battery system would also reduce the need for frequent manual intervention to change batteries, further enhancing the bot's autonomous capabilities. To support this, we also plan to explore options for implementing **smart charging systems** that could allow the bot to recharge autonomously, possibly using a docking station, further minimizing user involvement in its operation.

In addition, we aim to improve the bot's **navigation system** by incorporating more sophisticated sensor technologies. Currently, the robot relies on ultrasonic sensors for distance measurement and obstacle detection. In future iterations, we plan to integrate technologies such as LiDAR (Light Detection and Ranging) or depth cameras. These sensors would provide a more detailed understanding of the bot's surroundings, allowing for more precise and efficient navigation, especially in cluttered or dynamic environments. By incorporating LiDAR, the sorting bot could develop a map of its environment in real-time, enabling it to make better decisions regarding object sorting paths and avoid obstacles more effectively.

We are also considering **enhancing the AI-driven object recognition system** by integrating a wider range of training data to improve the accuracy and versatility of the bot's identification capabilities. Our current implementation using Google Vision AI has shown promising results, but expanding the dataset and exploring other machine learning models could further improve the bot's ability to identify a greater variety of objects in diverse lighting and environmental conditions. Additionally, we aim to make the system more adaptive, allowing users to update or customize the object recognition model based on their specific needs, giving the sorting bot greater flexibility in different applications.

Lastly, another area of future development includes refining the **user interface and interaction** with the sorting bot. Currently, the robot operates autonomously with minimal user input. However, we aim to create a more interactive experience by developing a mobile app or web-based interface that allows users to monitor the bot's performance in real-time, adjust sorting criteria on the fly, and receive notifications about the robot's status (such as when an object has been successfully sorted or when maintenance, like battery replacement, is required). This interface could also include options for manual control if needed, giving the user greater flexibility and control over the sorting process.

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