Ready-to-Serve Trash Bin
Project Proposal

Team #19

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1 Introduction

1.1 Problem

Throwing away trash is a simple task that many people take for granted. However, those with little to no mobility as a result of a disability, hospitalization, natural aging, or other health conditions struggle to carry out this necessary task. According to the CDC, 12.1 percent of U.S. adults have a mobility disability with serious difficulty walking or climbing stairs [1]. As a result, these people either require an assistant to dispose of their trash for them, which may not always be feasible, or they are forced to hold their trash and let it accumulate by their side. Letting trash accumulate is a sanitary concern that could escalate into further problems. A trash bin could be placed next to the person, but this solution has various problems. An open trash bin would allow the odor of the trash to spread throughout the room, and a bin with a lid could pose difficulty for users whose conditions make them unable to open the lid directly with their hands or use their foot to press the pedal.

1.2 Solution

In order to eliminate the problems with existing trash bins for people with limited mobility, we propose a trash bin that would be ready to take a user's trash once they perform a particular hand gesture to call it. A camera will be part of the motion and object detection system. This system to detect hand gestures would be placed somewhere in the room where it would be able to monitor whether the user needs the trash bin to pick up their trash. The trash bin would be attached to a set of wheels to allow it to move. The lid of the bin would also be controlled to open and close. Once the camera detects that the user wishes to dispose of trash, the camera system would wirelessly communicate with the bin to prompt the bin to move toward the user. Upon arriving at the user, the lid would open, ready to collect the user's trash. Once the user has disposed of trash into the bin, the lid would close, and the bin would return to its resting position. This solution simplifies the process of throwing trash by only requiring the users to call it and drop their trash into the bin.

1.3 Visual Aid

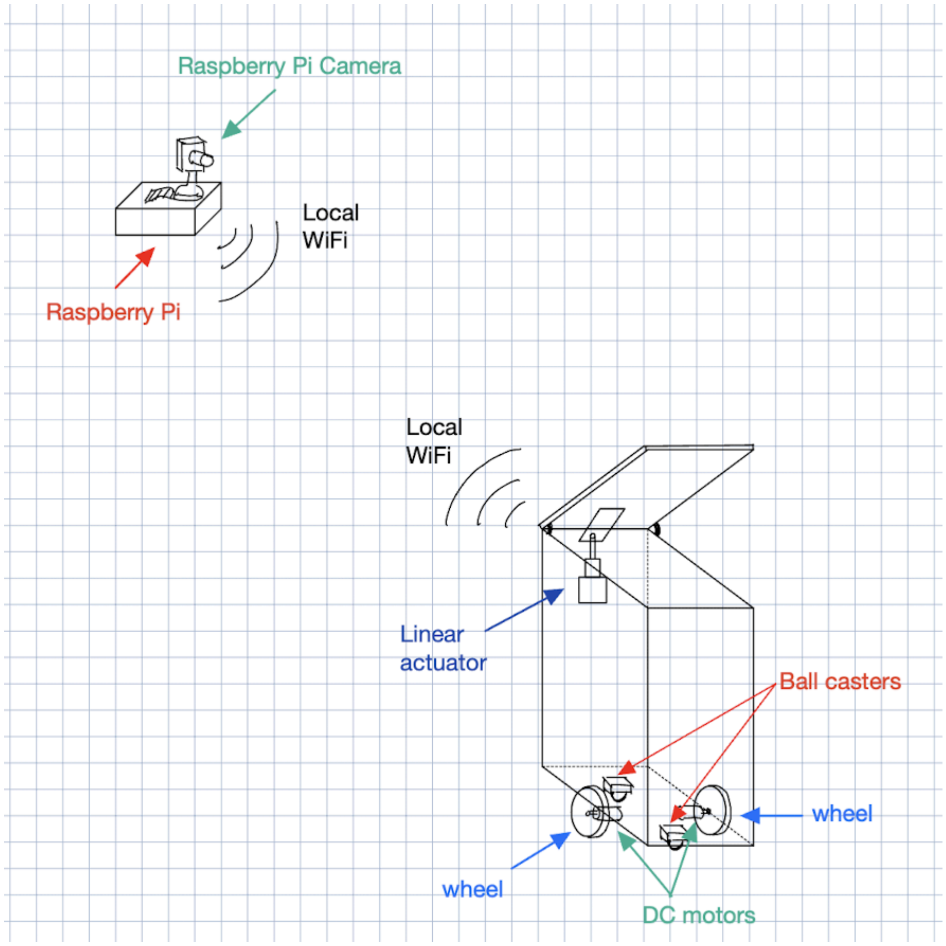

Figure 1: High Level Overview of the Ready-to-Serve Trash Bin

1.4 High-Level Requirements

- The camera system must be able to recognize a person's gesture for calling the trash bin. The camera will only recognize one single gesture, which will be similar to the one when someone is hailing a taxi.
- The trash bin must be able to travel close to the user and return back to its resting position. The distance the bin stops is 25 cm +- 5 cm, a side to side distance.
- The lid of the trash bin must open when collecting trash from the user and remain closed at all other times, including traveling to and from the user. The bin should react in 2 seconds before it begins to travel. And the speed of the bin should be in the range of 1-1.5 m/s. Once the bin reaches the destination, the lid should open in less than 1 second. The lid will remain open for 30 seconds before gradually closing in 1 second and then travel back to the bin station at the same speed as it comes.

2 Design

2.1 Block Diagram

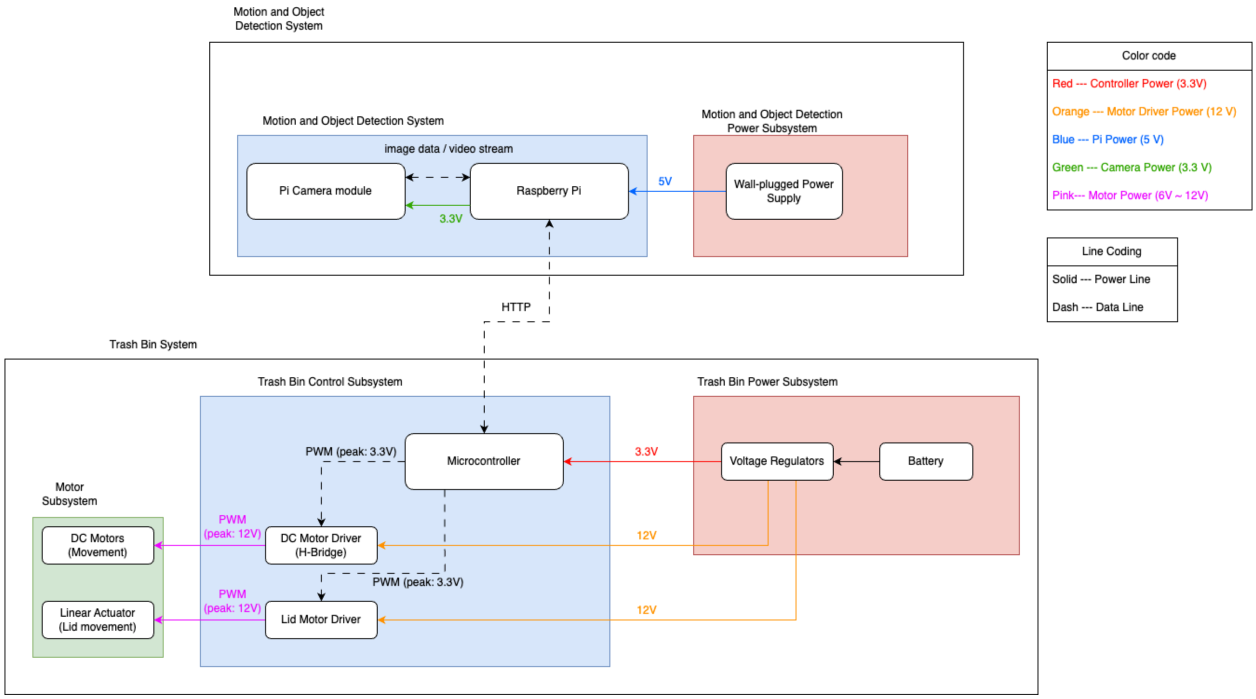

Figure 2: Block Diagram

2.2 Motion and Object Detection System Overview and Requirements

2.2.1 Control System

Overview

The Raspberry Pi uses a camera module (Smraza Raspberry Pi 4 Camera Module) to capture and analyze the environment using computer vision. Once the Raspberry Pi recognizes a specific hand gesture, it sends commands with HTTP requests to the trash bin control system via WiFi. Before sending the next command, it waits until the trash bin responds (an HTTP response). Then the camera will either lead the bin to the new task destination or send it back to the resting place.

Requirements

The Raspberry Pi needs to continuously power the Raspberry Pi camera module with a voltage of 3.3V ± 0.2V. The RTT (Round Trip Time) of the communication should be around 200ms to 500ms.

2.2.2 Power System

Overview

A power adapter (iRasptek Raspberry Pi 4 Power Adapter) will power the Raspberry Pi 4B and the Raspberry Pi camera module. The Raspberry Pi 4B will receive power from its USB-C port and supply power to the camera module through its onboard camera module port.

Requirements

The power adapter should continuously provide at least 5V and 15W to the Raspberry Pi

2.3 Trash Bin System Overview and Requirements

2.3.1 Control System

Overview

The control system is powered by the power subsystem of the trash bin system. The control system consists of a MCU and multiple motor drivers. The MCU receives commands from the Motion and Object Detection System using the built-in WiFi module and processes them. Based on the commands, it then signals the motor drivers to control the voltages on the motors and manipulate the motion of the trash bin.

Requirements

The MCU of the control system is ESP32-S3-WROOM-1-N16R8. This MCU needs to ensure a persistent WiFi connection and receive most of the requests (commands) coming from Motion and Object Detection System. The RTT (Round Trip Time) of the communication should be around 200ms to 500ms. The MCU needs to distinguish different commands, set the correct duty cycles of the PWM signals, and output the PWM signals to the motor drivers. The motor drivers are responsible for amplifying the incoming PWM signals, ensuring that the motors can move with the desired speed.

2.3.2 Power System

Overview

The power system here needs to provide the right amount of power to the control systems and the motor system. It consists of a battery and a voltage regulator.

Requirements

The power system needs to provide a voltage with a range from 6V to 12V to the DC motor and a voltage with a range from 6V to 12V to the linear actuator. The voltage regulators of the power subsystem should supply a voltage of 3.3V ± 0.2V and a current of 550 mA ± 0.50 mA to the MCU.

2.3.3 Motor System

Overview

The motor system controls the movement of the trash bin. It is powered by the power subsystem and controlled by the control subsystem. The two DC-geared motors help the trash bin move around in the space (forward, backward, left turn, right turn). The linear actuator controls the opening and closing motion of the trash bin lid.

Requirements

The DC-geared motors can smoothly accelerate to the configured max speed. The linear actuator needs to open/close the lid gently. The DC-geared motors should work at a voltage from 6V to 12V. The motors needs to provide a torque of at least 0.8 kg*cm and at least 150 RPM. The linear actuator should work at a voltage from 6V to 12V. It needs to provide at least 20N to move the lid of the trash bin.

2.4 Tolerance Analysis

The diameter of the wheel is about 6 inches (0.1524 m). When the motor is not loaded, the RPM of the motor is at least 150.

$$C = \pi d = 0.1524 * \pi = 0.47878\, m$$

$$Speed\ per\ second = RPM * C = 150 * 0.47878 / 60 = 1.19634\, m/s$$

With no load, the speed of the DC motor is 1.19634 m/s. It is close to the lower end of the average walking speed.

Since we are using a voltage regulator to step down the battery voltage to a fixed voltage for the microcontroller, we have to verify that we will not draw too much power and risk overheating the component. The microcontroller needs about 0.5 A of current delivered from its power source, and it takes in a voltage of 3.3 V. Our battery voltage is 12 V to meet the needs of the motors. From these requirements, we can calculate the power that the regulator would have to dissipate:

$$P_D = i_{out}(v_{in} - v_{out}) \tag{1}$$

Using (1) with the parameters the regulator would have, we find that it would consume 4.35 W of power, which is a large amount for a small component. Knowing how much power the regulator would dissipate, we calculate the junction temperature to see how it would compare to the maximum junction temperature on the datasheet. For this analysis, we use [2] as a representative for typical voltage regulators we would consider.

$$T_j = P_D\Theta_{ja} + T_a \tag{2}$$

The junction-to-ambient thermal resistance is about 100 ℃/W. We use an ambient temperature of 38℃, which could happen if the circuit heats up. Therefore, the junction temperature, according to (2), will be 473℃, which is higher than the maximum temperature of the linear regulator. Therefore, we would need a buck converter to step down the voltage before applying it to the voltage regulator.

3 Ethics and Safety

To ensure a successful project, it is important that we follow the IEEE Code of Ethics. Our project has some safety and privacy concerns that we must address as per Section I.1 of the Code [3]. Since our product is targeted towards those with limited mobility, we need to take care that our product accommodates for their safety as well.

The power subsystems for both the Trash Bin System and the Motion and Object Detection Systems have different safety concerns that must be addressed. The trash bin would be powered by batteries, which could overheat, cause a fire, or create a shock. To minimize the chance of batteries overheating, we will ensure that the power needs of our motors, drivers, microcontroller, do not exceed what the batteries can provide. The Raspberry Pi and the camera would be using a plug to receive power from a 120VAC outlet. Since electric shocks will be severe with this voltage, we need to warn the user of the dangers.

When the trash bin is moving, it could potentially collide with people and obstacles. Since the trash bin is only moving at walking speeds, which is about 1.2 m/s, and the trash bin will not be too heavy, the impact of a collision would be minor. Additionally, people would have ample time to react with the trash bin traveling at a low speed. When planning the path to destination, the bin will prefer to walk along the middle of the corridor, as people with immobility tend to walk against the wall, such path planning can reduce the possibility that the bin collides with them. Another concern related to movement is objects getting caught in the wheels and gear motors, which would damage both the drive system and object caught. While there is not much we can do on our end, we would have to warn the user of moving parts and rely on the user to keep the trash bin's path clear.

Since the product is designed to collect trash, various kinds of solid and liquid materials will enter our product, which could potentially create sparks and other hazards if they come in contact with the electronics. To mitigate this risk, the electronics would be housed underneath the trash bin where they will be separated from the trash inside the bin. During normal operation, the user should not be able to easily access the circuit. And it is the duty of the users to check regularly the situation of the battery to ensure the whole system is in good condition.

Since the lid of the bin is automatically controlled, the lid may jam people's fingers when they are throwing trash. To avoid this issue, we will extend the time of the lid remaining open to cooperate with the fact that people with limited mobility may need more time to finish throwing all their trash. Moreover, the lid will close gradually which will give people enough time to react and reduce the impact if a jam occurs. And in the worst case, since the bin is made with light-weight materials, a jam will not be severe.

A privacy concern must be addressed since we are using a camera in this project. The camera is only used to capture users' hand gestures and will have no local or online storage for these photos, which means all the information the camera has is for one-time use. The camera will not need to capture photos to improve the machine learning output, as the model will be trained with a huge data size which significantly outnumbered the number of pictures the camera captures in daily use, making the new learning progress have little effect. The camera will also not transmit photographic data to other devices. The only data that the camera system sends out is whether a gesture to call the trash can was made.

4 Citations

[1] “Disability Impacts All of Us.” Centers for Disease Control and Prevention. https://www.cdc.gov/ncbddd/disabilityandhealth/infographic-disability-impacts-all.html. (accessed February 6, 2024).

[2] Diodes Incorporated, “Low Dropout Linear Regulator” AZ1117C datasheet, September 2022.

[3] “IEEE Code of Ethics.” IEEE. https://www.ieee.org/about/corporate/governance/p7-8.html. (accessed February 7, 2024).