Item Retrieval Robotic Assistant

ECE 445 Design Document - Fall 2024

Ziyi Han, Chen Peng, Haotian Wang

Professor:Cunjiang Yu
TA:Zutai Chen

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1. Introduction

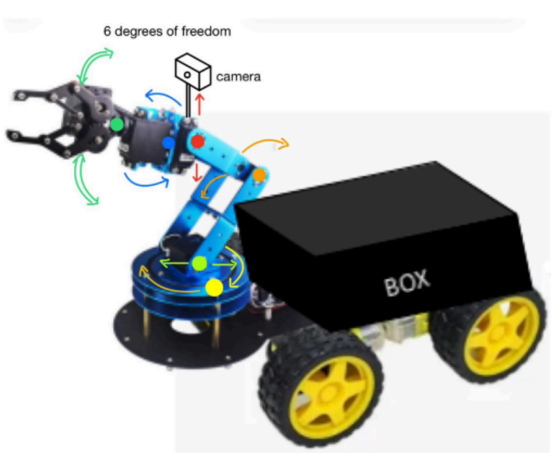
1.1 Problem

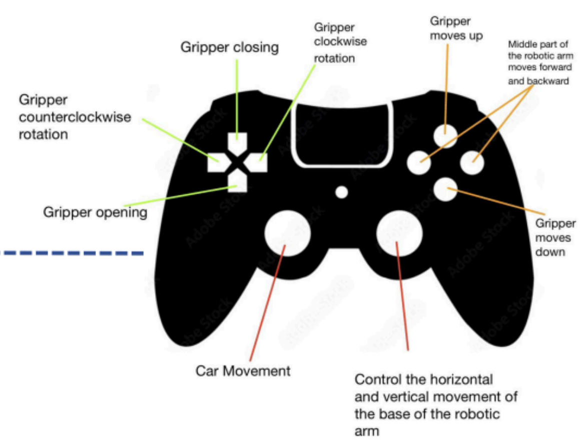
When someone with a leg injury or mobility issues needs to retrieve items from another room at home, it can be quite inconvenient. Without assistance from others, they often need to rely on crutches or wheelchairs to reach the location of the item and pick it up, then return. While this may seem like a simple task, for those with limited mobility it can be very exhausting and inconvenient. Therefore, having a device that can help these individuals retrieve and deliver items they need would make their lives much easier.

1.2 Solution

Our project is a remote-controlled car equipped with a robotic arm, designed to enable people to retrieve objects without the need to move. Users can operate the movement of the car and the robotic arm using joysticks on the controller. The remote controller features a screen that displays the camera feed from the robotic arm, allowing users to see the car's surroundings and select items they want to pick up. After the robotic arm picks up an item, it will flip backwards and put the item into the box on the car. In addition, for items stored at heights, users can utilize the telescopic function of the robotic arm to reach the item. Moreover, by rotating the gripper of the robotic arm, users can open cabinets and drawers to retrieve items inside.

1.3 Visual Aid





Robotic Arm and Car **Remote Controller on Phone**

1.4 High-level requirements list

1.4.1 Item Handling

The robotic arm must be able to successfully pick up items such as bottles, books, or small tools, weighing up to 200 grams(g) in 85% of trials. The robotic arm is equipped with a gripper capable of exerting a force of up to 4 Newtons(to hold 200g item) to accommodate items of varying fragility and weight, ensuring no slipping and damage during the grasp.

1.4.2 Stability

When the gripper holds an item, the robotic arm must maintain stability and place the item into the box on the car. To achieve this, the gripper’s torque must be at least 0.2 Newton-meters to hold an item weighing up to 200g without twisting. The entire process of picking up and placing an item should succeed in 80% of the experiments, ensuring that the gripper can securely hold the item with sufficient force and torque without twisting, slipping, or causing damage, and that the robotic arm can maintain stability when transferring the item from the gripper to the box. After determining the shape, orientation, and approximate weight of the objects, the user can easily use the controller to handle the item appropriately with the gripper.

1.4.3 Telescopic Function and Rotation Access

The telescopic function of the robotic arm must extend to at least 80 cm (including the combined height of the car and robotic arm) when the robotic arm is perpendicular to the ground, allowing it to retrieve items successfully placed on a table with a height of at least 30 cm. The items may be positioned up to 20 cm from the table's edge, with a success rate of at least 70%. Additionally, the gripper has 3 degrees of freedom: it can move up and down, rotate vertically, and open and close.

To open drawers, the gripper must rotate vertically to be perpendicular to the drawer handle to grasp it effectively, while the car provides enough traction and stability to pull the drawer open, with a success rate of at least 70%. Once the drawer is open, the gripper must move downwards to use its open and close function to grab an item stored in the drawer, then move upwards to pick up the item, also with a success rate of at least 70%.

1.4.4 Camera Integration & Delay

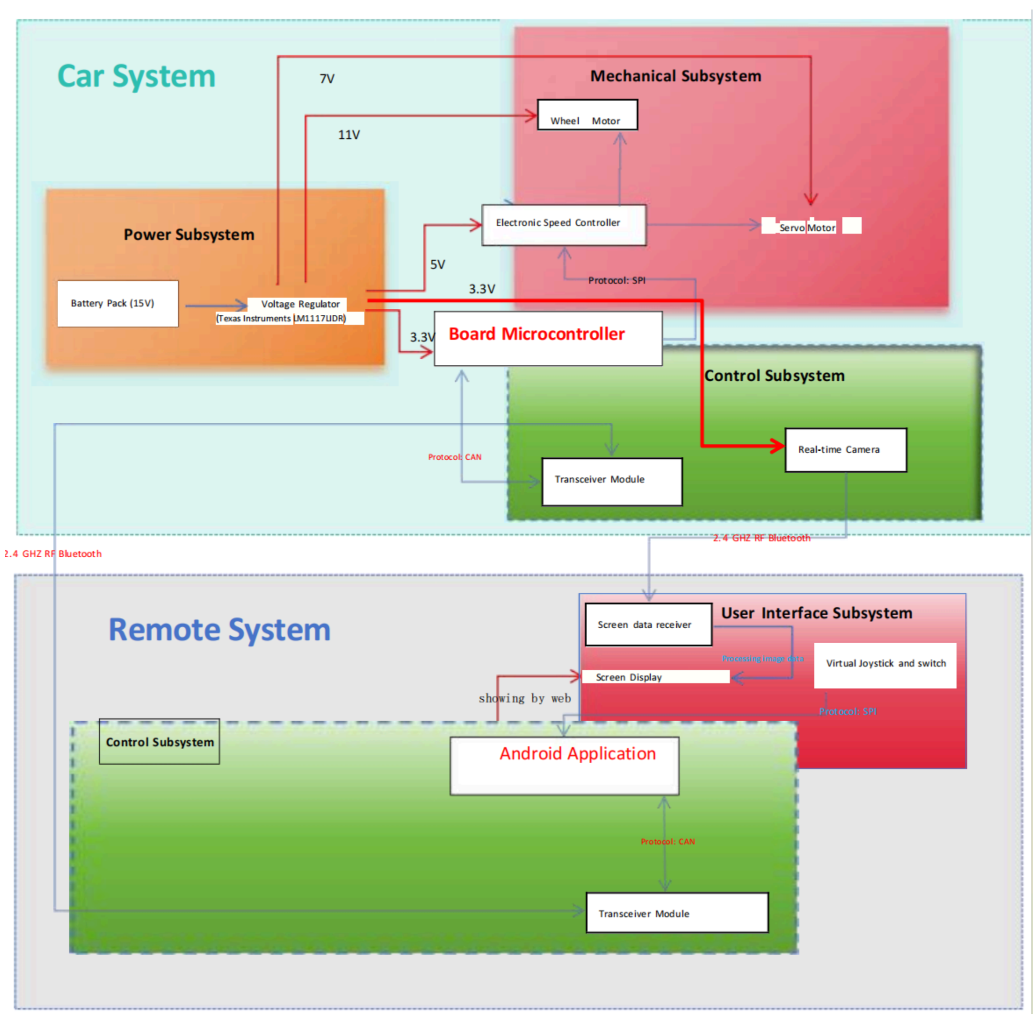
The robotic arm will rely on a camera system to identify and track items for picking, which should have a delay tolerance of up to 300 milliseconds between the visual input and the robotic arm's movement initiation. Despite this delay, we should also consider the dynamic adjustments to the arm's trajectory, ensuring accurate picking without misalignment. The robotic arm must be able to adjust for the delay in real-time to ensure smooth operation during object picking and placing tasks.

2. Design

2.1 Block Diagram

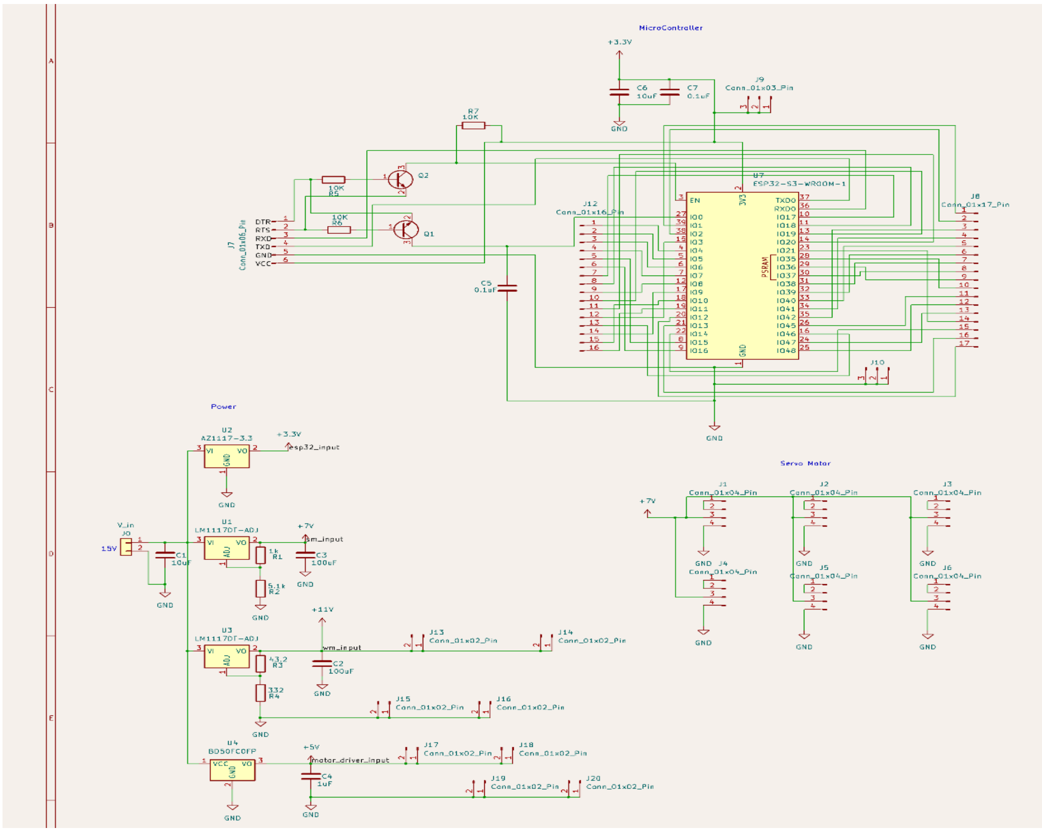
Red line is power supply

Blue line are protocol and wireless transmission



Block diagram

2.2 Subsystem Overview



Complete Subsystem Schematic

There are two systems in the block diagram: Car System and Remote System, and each system is composed of three subsystems. So we will design one PCB for the Car System and one Android Application for Remote System. The PCB of the Car system will be installed on the car with a robotic arm, and the android application of the Remote System will be achieved by using android studio. The Car System is used to provide power for the PCB which is installed on the car with a robotic arm , wheel motors of the car, servo motors of the robotic arm, and real-time camera and also the Car System controls all three subsystems to finish tasks according to instructions by the Microcontoller and Transceiver module. The Remote System is the system of the controller, which provides power for the screen which will display the image of the real-time camera, and the Remote System controls all three subsystems to transmit the instructions of switch and joystick designed on the android application to the Car System by the transceiver module (Bluetooth).

The Power subsystem in the Car System provides power for both mechanical subsystem and electronic subsystem. The Car MCU (Microcontroller) in the Mechanical Subsystem could give instructions to wheel motors and servo motors of the robotic arm. What's more, the voltage regulator will change the battery voltage into the ideal voltage for the PCB of the Car system, wheel motors, servo motors and real-time camera. And, the transceiver module in the Car System can transmit signals to and receive signals from the Remote controller, and these signals will be the input signal into the Car MCU to decide how wheel motors and servo motors should run. Also, the real time camera will transmit the image data to the screen by bluetooth.

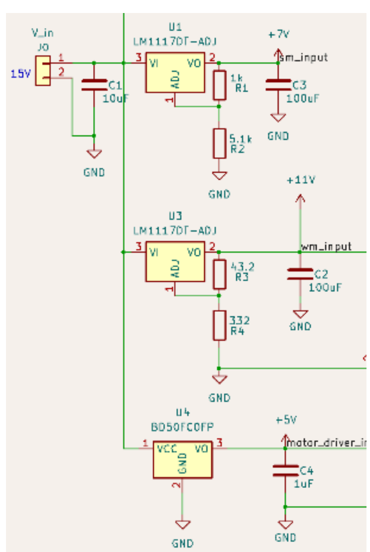
In the Remote System, the Power subsystem offers power to support User Interface Subsystem and Control Subsystem, and the voltage regulator will change the battery voltage into the ideal voltage for the screen which will display the image of the real-time camera. By the User Interface Subsystem, Item Retrieval Robotics Assistant could interface with the user; for example, the user could watch the screen to view the environment around the car by real-time camera installed on the car, and the user can use a joystick and switch designed on the android application to control the Item Retrieval Robotics Assistant by two transceiver modules in the Car system and Remote system. And two transceiver modules in the Car system and Remote system transmit and receive signals with each other by bluetooth. Finally, the Control Subsystem in Remote System works for transmitting and receiving signals, and all of these will be finished by android studio. So the user could open the designed application and touch buttons on the screen of the smartphone to control the Item Retrieval Robotics Assistant remotely.

2.3 Subsystem Requirements

2.3.1 Car System

In the Car System, there are three subsystems: Power subsystem, Mechanical Power subsystem and Control subsystem.

2.3.2 Car Power Subsystem

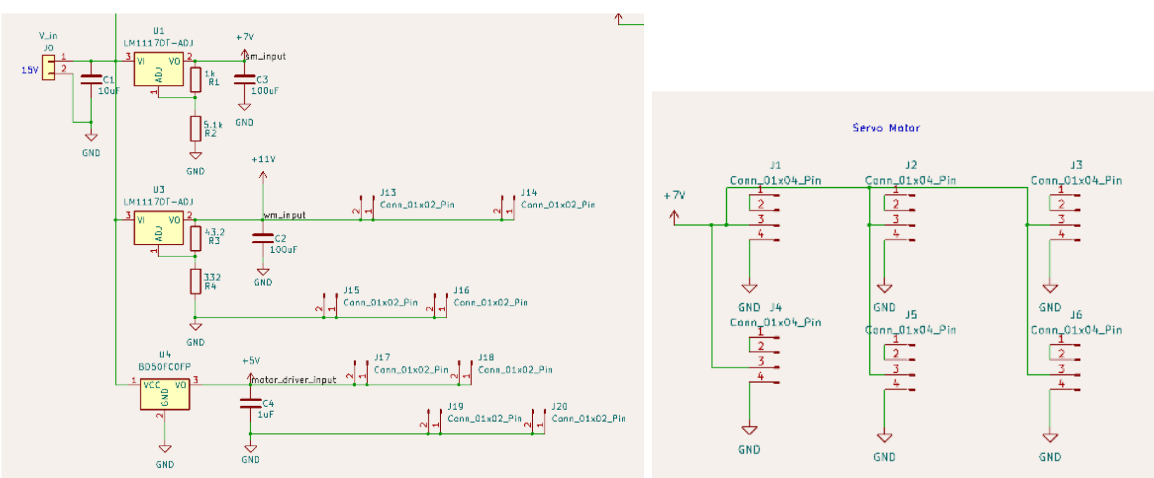


Car Power Subsystem Schematic

In the Car Power subsystem, the battery pack could provide 500 mA direct current (DC) with 15 V. The voltage regulator which uses Texas Instruments LM1117 Adjustable Voltage Regulator regulates the current, generating 7 V DC to power servo motors which allow the robotic arm to rotate its joints, 11 V DC to power wheel motors which allow the car to move forward and backward, 3.3 V DC to power the PCB and 3.3 V DC to power the real-time camera.

Requirements	**Verification**
the battery pack could provide 500 mA direct current (DC) with 15 V, and the voltage fluctuation is less than 0.5V	Using facility on ECEB 2070 to test the voltage of the battery and checking whether the voltage is around 15 V and the voltage fluctuation is less than 0.5V
LM1117 Adjustable Voltage Regulator regulates 15 V from the battery to 7 V and 11 V, and resulting voltage fluctuation is less than 0.3 V	Using breadboard to stimulate how LM1117 Adjustable Voltage Regulator works on PCB, and using facility on ECEB 2070 to test the result voltage and check whether LM1117 Adjustable Voltage Regulator could successfully regulate 15 V from the battery to 7 V and 11 V, and resulting voltage fluctuation is less than 0.3 V

2.3.3 Car Mechanical subsystem

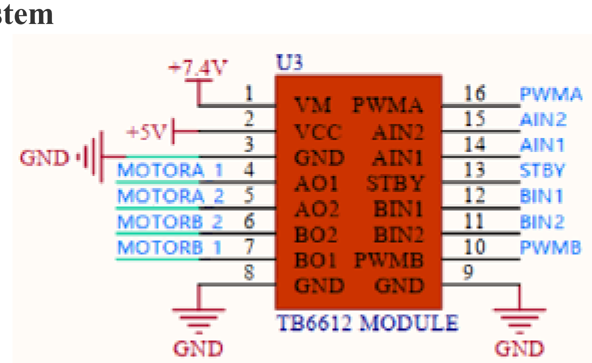


Car Mechanical Subsystem Schematic

In the Car Mechanical subsystem, wheel motors would drive the car to move, and we will use H-bridge to allow the wheel motor to rotate bidirectionally so that the car could move forward or move backward. What's more, the car could turn left or turn right by controlling the Revolutions per minute (RPM) of each wheel motor. The wheel motor that we use has a speed of 100 RPM. Servo motors will allow the robotic arm to rotate its joints, and we will use servo motors, which have enough torque to pick up and place items weighing up to 200g into one box. So servo motors with a large torque achieves the first high-level requirement. Also, servo motors are able to maintain stability without twisting when the gripper holds on an item due to its large toque, so the stability requirement in high-level requirements will be achieved. What's more, servo motors will provide more static force when the robotic arm extends to 0.8 meters, and the torque of servo motors will achieve the Telescopic Function requirement in the high-level requirement.

Requirements	**Verification**
wheel motor that we use has a speed of 100 RPM	Power supply the wheel motor with ideal voltage, and check whether wheel motors could drive the motion of the car and the robotic arm
servo motors have enough torque to pick up and place items weighing up to 200g into one box	Power supply the servo motor with ideal voltage, and check whether servo motor has enough torque to pick up 200g object and keep stable when it picks up 200g object
servo motors will provide more static force when the robotic arm extends to 0.8 meters	Assembling all mechanical parts of the robotic arm, and powering all servos motors to check whether it could keep stable when it extends to 0.8 meters

2.3.4 Car Control subsystem



DC Motor Driver Board Schematic

Moreover, the Electronic Speed controller could give instructional signals to control whether wheel motors and servo motors rotate or not and how wheel motors and servo motors rotate. The Electronic Speed controller interfaces with the Car Microcontroller (MCU), and the Board Microcontroller inputs signals into the Electronic Speed controller to make it interface with wheel motors and servo motors. In the Car Control subsystem, the transceiver module transmits signals to and receives signals from the transceiver module in Remote System by the bluetooth with 2.4GHZ, and ESP 32 will provide bluetooth connectivity. Then, when the transceiver module receives signals of instructions from the remote controller, the transceiver will interface with the Car MCU to make the Car MCU input correct instructions which are consistent with the user's operations to other modules by the communication protocol Controller Area Network (CAN).

Finally, the battery pack should provide 500 mA direct current (DC) with 15 V, and the voltage fluctuation that the battery provides should be smaller than 1 V. Also, the voltage regulator needs to provide voltages stably even with different loads. The protocol: bluetooth with 2.4GHZ, SPI and CAN need to be stable and set correctly; otherwise, some subsystems in the Car System would fail to function.

Requirements	**Verification**
MCU has enough GPIOs to output correct signals to wheel motors and servo motors	Testing the MCU on the breadboard and programming it with simple code to test whether these GPIOs work correctly
The transceiver module transmits signals to and receives signals from the transceiver module in Remote System by the Bluetooth with 2.4GHZ	Programming the MCU to make it support transmitting and receiving the Bluetooth, and then using facility to check whether it could receive the Bluetooth signal from the MCU

2.3.5 Remote System

In the Remote System, there are three subsystems: User Interface Subsystem and Control subsystem.

2.3.6 Remote User Interface Subsystem

In the User Interface Subsystem, the joystick and switch are designed on the android application as peripherals so that any operations on the joystick and switch by the user could be received by the designed android application. Then the android application interfaces with the Car MCU by transceiver modules (Bluetooth), and the Car MCU input correct instructional signals to other modules like wheels motors and servo motors so that the movement of the car and the rotation of the robotic arm could be consistent with the user's operation on the joystick and switch. And the user could control each joint of the robotic arm to rotate and successfully open cabinets or drawers by the joystick and switch on the android application.

What's more, the Real-time camera will send image data into the screen data receiver by the bluetooth with 2.4GHZ, and the screen data receiver could receive and process image data, and display it on the screen, so the user could view the environment around the car. Also, we would use image techniques like compressing and so on to have a delay tolerance of up to 300 milliseconds between the visual input and the robotic arm's movement initiation, which achieve the camera delay requirement in high-level requirements.

Requirements	**Verification**
Android application interfaces with the Car MCU by transceiver modules (Bluetooth) correctly	Finishing the android application on android studio and testing whether the android application could output correct Bluetooth signal by doing some operations on the joystick and switch are designed on the android application
user could control each joint of the robotic arm to rotate and successfully open cabinets or drawers by the joystick and switch on the android application	Testing whether each servo motors work well to make sure each joint of the robotic arm could rotate, and checking whether robotic arm is flexible enough to open cabinets or drawers

2.3.7 Remote Control Subsystem

In the Remote Control subsystem, when the user do some operations on the joystick and switch are designed on the android application, the transceiver module receives the signal of instructions from the android application, then the transceiver module transmits the signal of instructions to the transceiver module of the Car System by the bluetooth with 2.4GH. Then the Car MCU (ESP 32) will receive the signal and input the instructional signal to other modules of the Car System. Then the Car System will execute correct instructions and finish tasks successfully.

Finally, the battery pack should provide 200 mA direct current (DC) with 5 V, and the voltage fluctuation that the battery provides should be smaller than 0.5 V. Also, the voltage regulator needs to provide voltages stably even with different loads. And the camera delay should not be larger than 300 milliseconds. The protocol: bluetooth with 2.4GHZ, SPI and CAN need to be stable and set correctly; otherwise, some subsystems in the Car System would fail to function.

Requirement	**Verification**
The transceiver module transmits the signal of instructions to the transceiver module of the Car System by the Bluetooth with 2.4GH	Using android studio to finish the android application, and then using another smartphone which could receive Bluetooth signal to test whether the smartphone could receive the Bluetooth signal from the smartphone installed the android application when the smartphone installed the android application has opened the android application and is outputting signals by Bluetooth

2.4 Tolerance Analysis

2.4.1 Camera connection

One aspect of our design that poses a risk to successful completion of the project is the image data transmitting from the real-time camera to screen data receiver. When the car with a robotic arm is driven far away from the computer, some image data may be lost during the process transmission from the real-time camera to screen data receiver through bluetooth 2.4GHZ protocol, which causes the problem of unclear or discontinuous pictures appearing on the screen of the computer.

Suppose we use the computer to display a video with 640*480 resolution with 25 Frame Rate Per second(fps)
We can use this formula to calculate the video bitrate:
Video Bitrate Per Second (bps) = Target pixel count/resolution × Frame rate × 1/2/4 (depending on how dynamic your video is) × 0.07
Video Bitrate = 640 * 480 * 25 fps * 2 * 0.07 = 1.0752 Mbps

Usually, the maximum bluetooth 2.4 GHz data rate is around 3 Mbps to guarantee stable communication.
Our data rate result is for video with 640x480 resolution is 1.0752 Mbps which is within the bluetooth 2.4 GHz data rate
Therefore, this should not cause any problems.

2.4.2 Motor Performance

Another aspect of our design that poses a risk to the successful completion of the project is that the voltage assigned to the motor by the voltage regulator might fluctuate, impacting the motor's performance.

According to the LM1117 Adjustable Voltage Regulator DataSheet, the output voltage(V) regulation is 0.5%. In our block diagram, the voltage regulator assigned 7V to the servo motor and 11V to the wheel motor. Based on the description of servo motor and wheel motor, the driving voltage of servo motor is at least 4.8volts, with a range between 4.8V-8.0V, and the driving voltage of wheel motor is at least 9V.
The voltage of servo motor = 7V $\pm$ 0.5% = 6.965V ~ 7.035V
The voltage of wheel motor = 11V$\pm$0.5% = 10.945V ~ 11.055V
The the voltage of servo motor 6.965V ~ 7.035V is within the range 4.8V-8.0V,
And the voltage of wheel motor is greater than 9V
Therefore, even if the voltage allocated by the voltage regulator fluctuates, these are still within the effective voltage range of the motor, so there won't be any problems.

2.4.3 Servo Motor Torque

Another aspect of our design that poses a risk to the successful completion of the project is the servo motor might not be able to provide enough torque for the gripper to pick up an item weighing 200g. Without enough torque, the servo motor may miss steps or stall causing the gripper to fail in lifting the item and leading to the project failure.

According to the information of servo motor, it can provides a torque up to 0.2 Newton*Meter(NM).
To find the actual torque we need to use to pick up an item with 1kg weight, we can use this formula T = F * (r * sin(a)) where
T is torque
F is Force
r is the the radius of the applied force
a is the angle of the force applied
In our case, force is based on our item that F = m*g = 0.2kg * 9.81m/s^2 = 1.962N

Assume the length of our gripper is 10 cm = 0.1m then r = 0.1 m
Also, since we need to pick the item up so the force is perpendicular to the ground then the value of a = 90 degrees
Finally, put them together T = 1.962N * (0.1m * sin(90)) = 0.1962 Nm
Therefore, the final torque required to pick up an item weighing 0.2kg is 0.1962 Nm, which is less than the 0.2 Nm torque provided by the servo motor. This means that the servo motor can provide enough torque to pick up the item without failure.

2.5 Cost Analysis

Component	Quantity	Unit price	Total price
Car system component	1		
Robotic arm	1	$225.99	$225.99
Four wheel car	1	$51.99	$51.99
Voltage regulator	1	$21.89	$21.89
Real-Time Camera	1	$37.99	$37.99
USB to TTL serial adapter	1	$12.49	$12.49
Camera connector board 24 pin	1	$8.49	$8.49
Adafruit tb6612 dc motor driver breakout board	2	$25	$50
Total Price			$408.84

2.6 Schedule

Week	**Task**
7	Design PCB layouts for Car and Remote systems. Order necessary components.

8	Develop power subsystems for both Car and Remote systems.
9	Implement motor control subsystems and test mechanical movements.
10	Integrate servo motor with robotic arm and test item retrieval function.
11	Integrate camera system with the car and remote display.
12	Test full system functionality (Car System and Remote System integration).
13	Implement motor control subsystems and test mechanical movements.
14	Fall Break
15	Final Demo

3. Ethics and Safety

According to IEEE Code of Ethics and ACM Code of Ethics, our project addresses several key ethical principles:

1. **<u>Privacy Protection</u>**

   The device's use of a camera for navigation could violate user privacy. To comply with the ethical principle of IEEE code 1 that protects the privacy of others, the camera feed is directly connected to the screen on the controller which is exclusively used by the user. Since the video feed is not transmitted eternally and the camera doesn't have a video recording function, this can only be viewed by the user which minimizes the risk of unauthorized access or misuse of the camera system.

2. **<u>Public Safety</u>**

   We commit to ensuring that our project "Item Retrieval Robotic Assistant" prioritizes the safety and health of its users. This aligns with the ethical principle of IEEE code 1 that holds paramount the safety, health, and welfare of the public. The robotic arm is controlled directly by the user and will be equipped with force-limiting features to prevent excessive force when handling items. This could reduce the risk of injury to items, furniture and humans.

3. **Respect for Others**

   In the development process, we will ensure that all team members and contributors are treated fairly and respectfully. This aligns with the ethical principle of treating all persons fairly and with respect. Our project ensures that the design is inclusive and accessible to all users, particularly those with disabilities.

4. **Improving Understanding of Emerging Technologies**

   Our project contributes to improving society's understanding of how emerging technologies can enhance the quality of life for individuals with mobility issues. This aligns with the ethical principle of IEEE code 2 which is enhancing individuals' and society's understanding of the potential and societal impacts of both conventional and emerging technologies, including intelligent systems.

5. **Support for Colleagues and Upholding Ethics**

   During the development of our project, we commit to supporting all team members in adhering to the ethical standards, aligning with the principle of IEEE code 10 that assisting colleagues in adhering to this code of ethics, work to ensure its enforcement, and refrain from retaliating against those who report violations.. We will create an open and respectful environment where ethical issues can be resolved without the fear of retaliation.

6. **Honesty and Trustworthy**

   Regarding ACM code 1.3 that a computing professional should be open and fully disclose all relevant system capabilities, limitations, and potential issues to the appropriate stakeholders. Our project team will provide clear documentation on how the device functions, including potential risks or limitations. In addition, users will be fully informed about the device's operational boundaries, ensuring they can make the right decisions when using the system

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