Advanced Mechatronics

Integrated Term Project

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Abstract

The project's goal is to create an autonomous robot that cleans trash in cities that is tailored to its needs. This mobile robot, which combines Arduino and Raspberry Pi, makes use of an Ultrasonic sensor that was moved from the Propeller platform. With the help of the Raspberry Pi, the robot can be wirelessly controlled by an operator. Its capacity to automatically identify and categorize waste utilizing an ultrasonic sensor system and a camera system is a crucial feature, since it allows a robotic arm to be autonomously activated for garbage collection. Efficient navigation and trash handling in intricate urban environments are made possible by the smooth data flow and control that serial connectivity between Arduino and Raspberry Pi provides.

1. Introduction

In the pursuit of innovative urban waste management solutions, our project introduces a semi-autonomous litter-cleaning robot. This robot integrates a Raspberry Pi and Arduino, utilizing their computational and control capabilities to navigate and interact within urban environments effectively. Central to its operation, the PiCamera module captures images of objects within range of the robotic arm, which is processed using the MobileNetV3 model to identify and classify objects as trash. Coupled with this advanced image recognition is the use of an ultrasonic sensor mounted on the Arduino, enabling the robot to detect objects within a range of 20 cm and trigger image capture. This sensor data is communicated to the Raspberry Pi via a robust serial connection, allowing for sophisticated decision-making processes.

2. Objectives

Our primary objectives as set forth by our project proposal were:

- Integrate the Arduino and Raspberry Pi onto our mobile robot platform.
- Implement full wireless control and communication of the robot.
- Autonomously detect trash and trigger the deployment of the robot arm for trash pickup using the ultrasonic sensor.

3. Methodology

3.1 Main Features

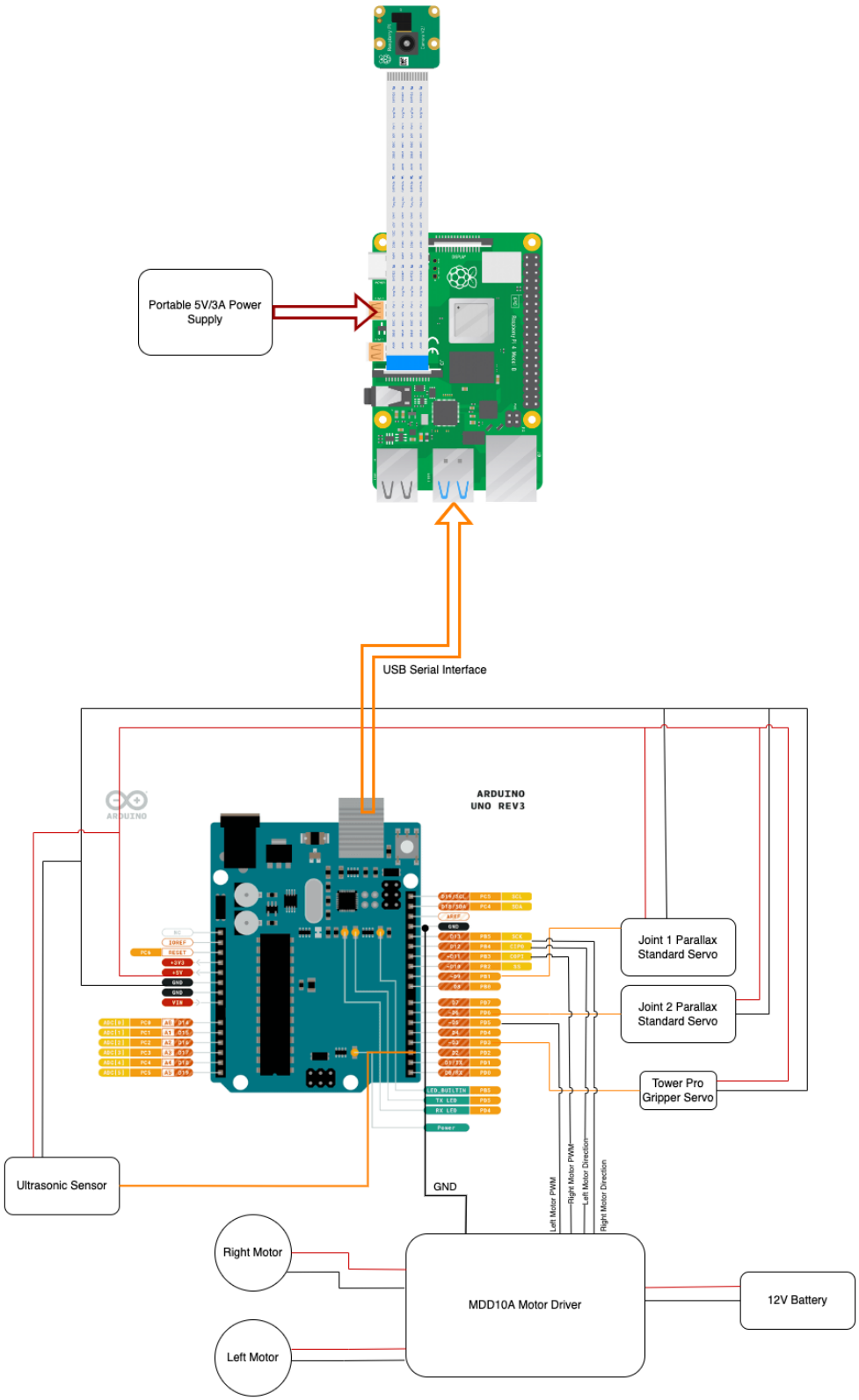
Wireless Operation: Enable users to wirelessly command the robot via the Raspberry Pi for enhanced maneuverability and control.

Efficient Communication: Establish robust serial communication between Raspberry Pi and Arduino to transmit object detection notifications and classifications.

Sensor Optimization: Utilize ultrasonic sensors to detect objects within a 20 cm range regardless of orientation.

Object Recognition: Utilize the MobileNet model to reliably identify objects

3.2 Circuit Diagram



3.3 Object Detection and Recognition

The robot is programmed to specifically recognize items commonly categorized as litter, such as paper cups. Once an object is identified as trash by the PiCam, i.e. the paper cup, and is within a 20 cm range detected by an ultrasonic sensor, the system triggers the robotic arm to collect the item and deposit it into an onboard bin. Conversely, objects not recognized as trash are moved aside, allowing the robot to effectively manage waste by segregating and disposing of litter appropriately in urban environments. This integration of machine learning and robotics technology streamlines waste management processes, enhancing the robot's utility and efficiency.
The MobileNetV2 model for real-time object detection was utilized via a Raspberry Pi equipped with a PiCamera. This advanced neural network is adept at identifying various objects within visual frames, allowing our autonomous litter-cleaning robot to detect and classify items effectively. By processing images captured when triggered by the ultrasonic sensor, the system can identify specific waste items such as paper cups.

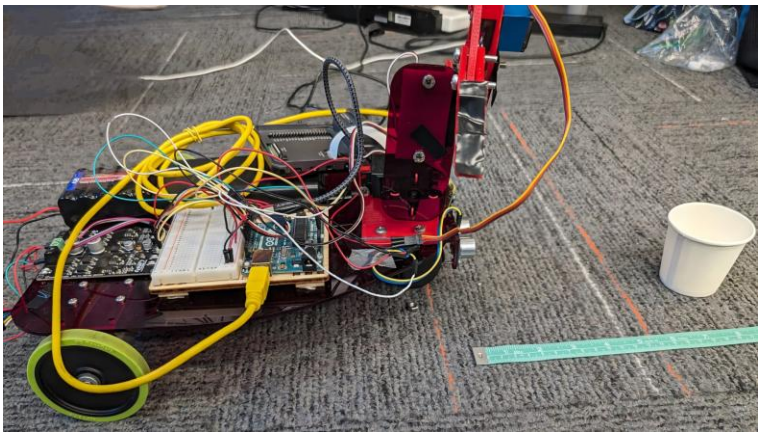
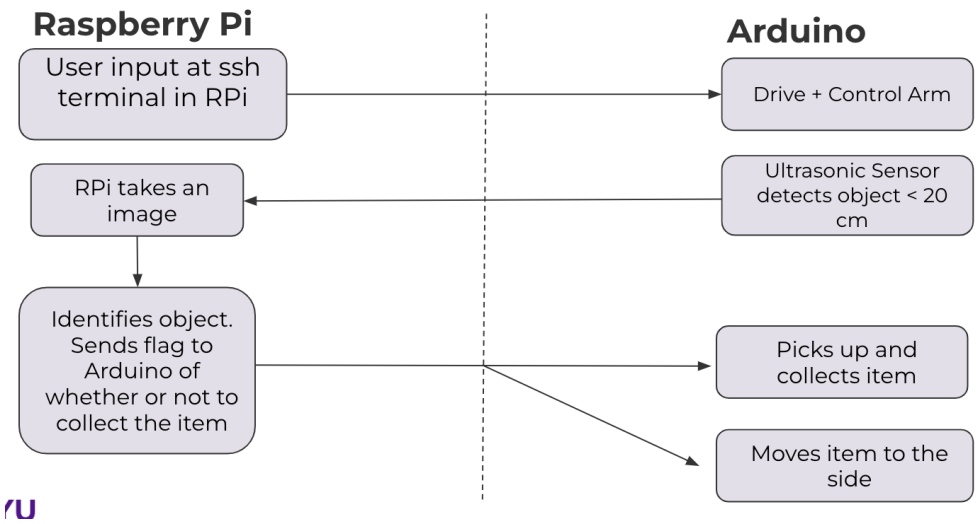


Fig: Paper cup detection

The software at a high level performs the following tasks. The RPi receives keyboard input through ssh via WiFi connection and forwards them directly to the Arduino. This allows the users to drive the robot and control each joint of the robotic arm and command it into some pre-saved positions such as “stowed” or “deployed”.

The trash detection operates in a functional loop between the Arduino and Rpi. The Arduino first detects an object within range. In this case, we’ve defined that range to be 20 cm. It then stops reading any user input for driving or robotic arm control and sends a request to the RPi to capture an image and identify the object that was detected. The RPi will process the image and run it through the MobileNet model to identify the type of object that was detected. If the item is suitable for collection and classified as “trash”, a flag is sent to the Arduino to perform a series of actions to pick up the object and place it in the on-board bin. If the item is not classified as “trash”, a flag is sent to the Arduino to move the object to the side.



3.4 RPi Pseudocode

1. Virtual Environment Setup

Check if the virtual environment (venv) package is installed:

- If not installed, install the venv package using system pip

#Create a new virtual environment:

- Define the directory where the virtual environment should be stored

- Execute the command to create the virtual environment in the specified directory with the system site packages flag enabled

Activate the virtual environment

- source <env name>/bin/activate

#Install project dependencies:

#Run the project code:

- Execute the Litterbot.py Python script or application that runs the project

#Deactivate the virtual environment when done:

- Run the deactivate command to exit the virtual environment

#Shutdown the Raspberry Pi

- Proper shutdown protects peripheries from possible voltage spikes

// End of pseudocode

2. Litterbot.py

```
# import necessary libraries
#import object_detection (pseudocode in next section)

#Open a Serial connection to Arduino by device ID with 115200 baud rate

#Read received message from Arduino and decode into ascii character

while (1)
        Read stdin keyboard input
        Echo user input to terminal and send to Arduino encoded as an ascii character

        If data is received over Serial interface from Arduino (data only sent when ultrasonic sensor
        reads less than 20cm):
                Call object_detection to capture image, identify object, and set trash identification
                flag.
                Deploy arm and close gripper.
                Read the flag
                If flag == 1 trash can be collected:
                        Stow arm straight back, and open gripper
                Else:
                        Move arm to the side, and open gripper
                Sleep 5 seconds
                Flush serial buffer
```

3. Object Detection

#Import necessary libraries
- torchvision for models and transforms
- torch for tensor operations
- PIL for image handling

Load the MobileNetV3 model with pre-trained weights

#Define image transformations
- Resize image to 256 pixels on the shortest side
- Crop to get a 224x224 square

- Convert the image to a tensor
- Normalize the tensor using predefined mean and std values

#Open and preprocess the image
- Open the image file 'capture_0000.jpg'
- Rotate the image by 270 degrees
- Apply the defined transformations

#Prepare the image for model input
- Add an additional dimension to simulate a batch of one image

#Set the model to evaluation mode

#Perform inference
- Pass the preprocessed image through the model

#Load class labels from a file 'trash_classes.txt'

#Interpret the output
- Determine the class with the highest score
- Calculate the percentage confidence
- Assign to trash or not trash category

#Output flag

3.5 Arduino Pseudocode

```
# Import the libraries
# Initialize the servo and set motor pins
#  Set ultrasonic sensor digital pin
# Function definitions
drive_forward()
drive_backward()
turn_left()
turn_right()
arm_stow()
arm_stow_right()
arm_deploy()
```

arm_up()
arm_down()
arm_left()
arm_right()
gripper_open()
gripper_close()
# setup()
Setup serial baud rate
Assign digital pins to the servos and set pin modes
loop()
check if serial input from keyboard is available and assign keys that will call the functions
Set the wheel motor pins to low
If object is detected < 20 cm
    Seral.println(1) to the RPi to raise flag for image capture and identification

4. Results and Discussion

The project succeeded in fulfilling the objectives of wireless driving and arm control of the robot, establishing a serial interface between the Arduino and RPi to pass characters back and forth, and integrating an ultrasonic sensor to autonomously trigger trash pickup.
The integration of wireless control allows users to command the robot remotely via Raspberry Pi, generating effective communication between the Raspberry Pi and Arduino via a serial interface.

In identifying a paper cup as “trash” or various other objects as “not trash”, the MobileNet model falls short. The current accuracy stands at about 60%. This suggests a need for further training or enhancement of the MobileNet model to improve reliability.
It could be that when the ultrasonic sensor detects an object within range, the alignment of the camera does not center the object in the image. It could also be that the lightweight nature of the model running on the RPi is not as effective as an offline model being run on a laptop computer. Some potential fixes could be to run the model offline on an offboard computer and transmitting the results back to the RPi, or isolating the object from the background in the image so that the model is not reading or processing irrelevant data.

The robot’s ultrasonic sensor effectively detects objects within a 20 cm range, but it does so irrespective of the angle between the robot and the object. Therefore, the objects are not always in an ideal position for the arm to pickup, which results in objects not being picked up or sometimes knocked over. Either camera based pose estimation or additional sensors

can be used for better positioning of the robot. Combined with additional tuning of the 20 cm range parameter could improve the functionality of trash pickup into the onboard bin.

5. Conclusion

This project successfully demonstrates the design and implementation of an autonomous litter-cleaning robot, integrating advanced technologies like Raspberry Pi, Arduino, and MobileNet for object detection. The shortcomings of the existing approach highlight the need for increased mechanical precision and object detection accuracy. Future generations of the robot should see the addition of technologies like inverse kinematics and image-based pose estimation, which should improve its operating efficiency. All things considered, this robot is a major advancement in urban environmental management since it successfully combines robotics and artificial intelligence to solve problems that arise in the actual world.

6. References

[1]Howard, A. et al. (2019) Searching for MobileNetV3, arXiv.org. https://doi.org/10.48550/arXiv.1905.02244.
[2]Raspberry Pi Forums at: https://forums.raspberrypi.com/.