ECE 445

Project Proposal

Spring 2025

Table Cleaning Robot: Autonomous Elevated Surface Cleaner

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1. Introduction

1.1 Problem

In homes, workplaces, and restaurants, cleaning tables is a repetitive and time-consuming chore that must be completed on a regular basis. Spills, food particles, and dust can quickly build up, requiring frequent cleaning. While floor-cleaning robots have made floor cleaning easier, there aren't many automated options for cleaning tables. Without a table-cleaning robot, people must physically clean surfaces, which takes time and effort. In places like cafes and restaurants, where tables need to be cleaned frequently, an automated solution could reduce labor costs and improve efficiency.

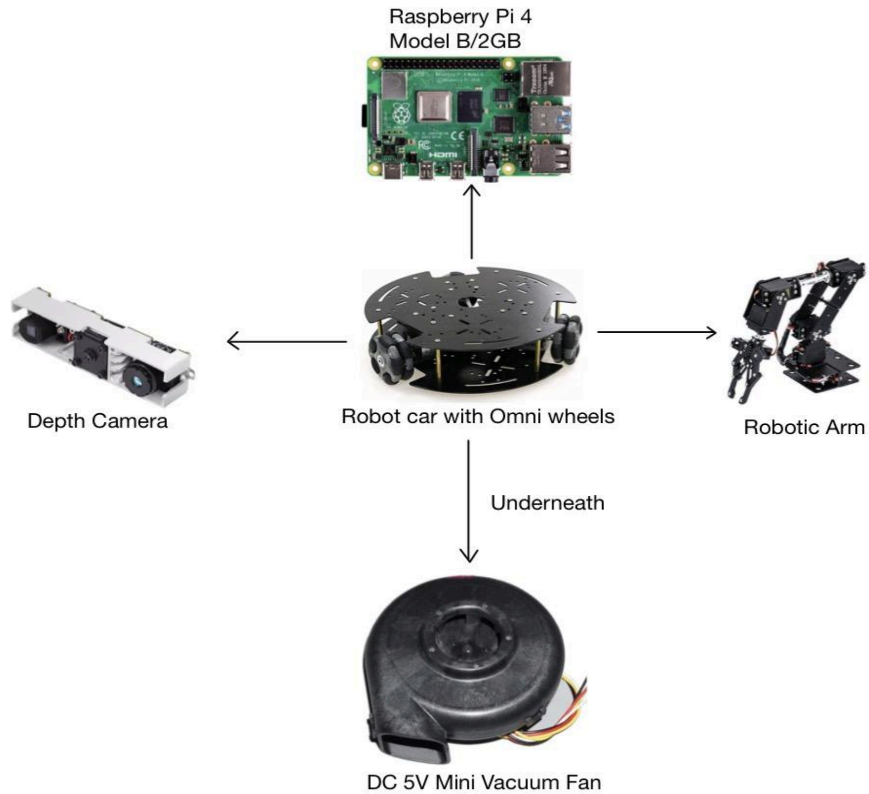
Unlike floor-cleaning robots, designing a table-cleaning robot has its own set of difficulties. The robot must be able to move around objects like plates and cups, identify table edges to avoid falling and clean efficiently without pushing stuff off the surface. Current cleaning robots focus on flat and large floor areas, but a table-cleaning robot needs more accurate control and obstacle interaction.

1.2 Solution

Our solution is a small, self-operating table-cleaning robot that can effectively clean flat surfaces while avoiding falls and obstacles. This robot is designed for elevated surfaces, ensuring safe and reliable operation. The robot will navigate around objects like plates and cups, detect edges to prevent falls, move around objects like plates and cups, and use a small vacuum system or rotating brushes to collect dust and crumbs.

To achieve these functions, the robot will include several key components. Depth-detecting cameras will recognize the table’s borders, ensuring the robot stops or turns before reaching an edge. It will also help the robot navigate around objects without knocking them over. Debris will be collected by a vacuum and placed in a collection bin for cleaning. Additionally, the robot may clean beneath objects without tipping them over. The table-cleaning robot will provide a dependable and automated solution for maintaining clean tabletops by combining these elements.

1.3 Visual Aid



1.4 High-level Requirement List:

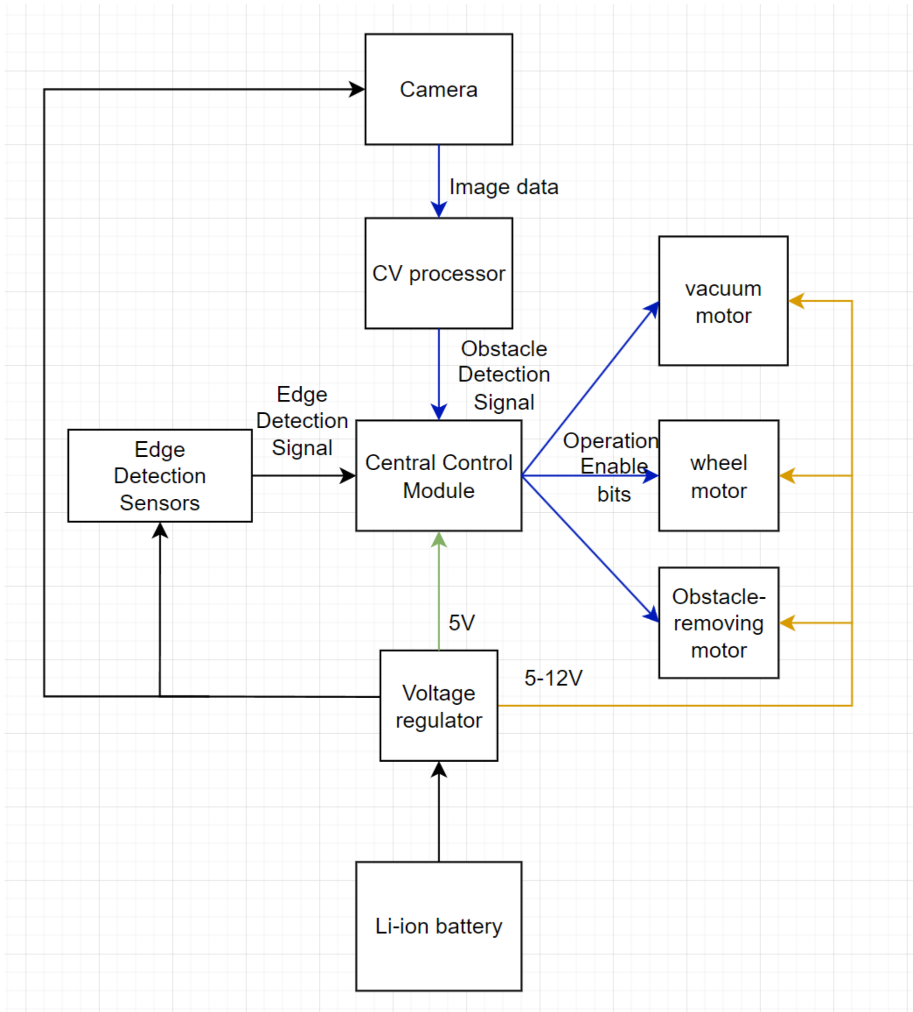
- Edge Detection and Fall Prevention: The robot must detect table edges and respond by stopping or changing direction within 2 cm of the edge to prevent falling.

- Debris Collection Efficiency: The cleaning system must remove at least 90% of dust, crumbs, and small debris from a 60 cm x 60 cm table surface in a single cleaning cycle and store the collected debris in a removable bin that holds dirt from at least three full cleaning cycles.

- Obstacle Avoidance and Object Interaction: The robot must detect and navigate around objects as small as 5 cm in diameter and as large as 20 cm in diameter with at least 95% success while lifting or repositioning objects weighing up to 500 grams without knocking them over.

2. Design

2.1 Block Diagram



2.2 Subsystem Overview

There are three subsystems in our design. The edge detection and fall prevention subsystem is a critical component that ensures the robot does not fall off the table by detecting edges in real time. It uses a depth camera to detect the edge and control the movement of the robot car by stopping or changing its direction. This subsystem is crucial for safety, as failure to detect edges accurately would cause the robot to fall. It directly interacts with the motion control, ensuring that the movements of the robot car are adjusted based on its distance to the edges.

The debris collection subsystem is responsible for cleaning the table by vacuuming dust and crumbs into a collection bin. It consists of a mini vacuum motor and a collection bin. When the robot is moving, the vacuum will stay on.

The motion control subsystem will control its movement to ensure proper table coverage. It also interacts with object detection, changing its cleaning path or pausing when obstacles are detected.

The obstacle detection and interaction subsystem allows the robot to avoid obstacles such as cups, plates, and utensils, by using depth camera sensors to detect the objects in real-time. A robotic arm will be used to lift or move lightweight objects(up to 500g) in order to clean surfaces under it. It is controlled based on the signal from the obstacle detection system. Once the cleaning process is complete, the arm returns the object to its original position.

2.3 Subsystem Requirements

2.3.1 Central Control Module

The Central Control subsystem is the “brain” of the robot, featuring: a Raspberry Pi, which runs the main control software, the motor control logic, which might include the L298N driver for drive wheels (and possibly the cleaning brush motor), and the decision-making processes for edge avoidance, obstacle navigation, and cleaning patterns.

There are five interfaces with other blocks:

Edge Detection Subsystem
Input: Receives IR sensor signals indicating proximity to the table edge.
Action: If the distance threshold is exceeded (meaning an edge is detected), the Pi halts or reverses the motors.

Debris Collection Subsystem
Output: Pi sends PWM signals to control brush/vacuum motor speed via the L298N (or a dedicated channel).
Input: (Optional) Receives bin-full sensor signals or brush jam signals, if implemented.

Obstacle Detection Subsystem
Input: Receives distance or camera-based data indicating object presence.
Action: The Pi adjusts the cleaning path (e.g., navigates around, attempts to push or skip area).

User Interface (Optional)

A screen, LEDs, or buzzer can indicate battery status or request bin emptying.
Wi-Fi or Bluetooth for remote monitoring/control if needed.

Power Subsystem
The Pi requires a stable 5 V ± 0.1 V supply at up to 2–3 A (depending on the model). The L298N requires an appropriate motor voltage (5–12 V range typically) plus separate logic power.

2.3.2 Edge Detection

This subsystem uses infrared (IR) proximity sensors to detect the table's edge and prevent the robot from falling off. Each IR sensor is mounted near the perimeter of the robot chassis at a slight downward angle to sense the sudden increase in distance when the table surface ends.

Each IR detection sensor needs to reliably detect the table edge at 2-10 cm from the chassis, which has a 10% uncertainty tolerance under various indoor light environments. The frequency of sensors needs to be at least 5Hz so that the central control module has enough time to respond once the obstacle or edge is detected.

2.3.3 Debris Collection

This subsystem physically cleans the table. It includes a rotating brush and a vacuum in order to suck and collect tiny debris and trash on the table into a 150ml bin. Raspberry Pi sends PWM or ON/OFF signals through an L298N motor driver to control brush and vacuum motors. The motors need 5-12V power to operate functionally before the bin becomes full.

2.3.4 Obstacle Detection

This module identifies objects on the table by sending and processing images captured by a camera through a computer vision algorithm to signals sent to the central control module. It's utilized to prevent collisions and determines how to navigate around or interact with objects to clean underneath or near them. The camera typically draws up to 250mA at 5V. To reliably capture object position, distance measurements must be accurate to ±2 cm in typical table settings, updating at a frequency of 5Hz.

2.4 Tolerance Analysis

2.4.1 Brief description of potential risk

The IR edge sensors might not detect the table edge soon enough—or accurately enough—for the robot to stop before falling. Variations in sensor accuracy, ambient lighting, reflectivity of the table surface, or slight mechanical delays could cause late detection, risking the robot driving off the edge.

2.4.2 Mathematical calculations

We assume:

-The robot runs Edge Detection checks at a certain sampling frequency (In this case 5Hz)

-The IR sensor can detect a drop-off at nominal d_s = 5 cm from the edge with a typical uncertainty of measurement e = ±1cm.

-The robot moves at v = 15 cm/s (0.15 m/s)

-Reaction time t_r = 0.2s (at 5Hz)

-Deceleration rate a = 0.5 m/s^2

Under such assumptions, the numerical calculation is below:

The distance during reaction time:

$$d_r = v * t_r = 0.15m/s * 0.2s = 0.03m$$

The braking distance:

$$d_b = v^2/2a = (0.15)^2/(2 * 0.5) = 0.0225m$$

The distance needed to stop:

$$d_{stop} = d_r + d_b = 0.03 + 0.0225 = 0.0525m$$

Distance of effectiveness:

$$d_{effective} = d_s - e = 0.05 - 0.01 = 0.04m$$

Since 0.0525m > 0.04m, in the worst case, the robot might not be able to stop after detecting the edge of the table, and it might fall. To resolve this problem, a higher frequency of IR detection or a lower speed of movement is needed.

3. Ethics and Safety

The design, development, and deployment of the Table Cleaning Robot must adhere to ethical principles to ensure safety, reliability, and responsible engineering practices. This section assesses ethical issues and safety concerns, drawing guidance from the IEEE Code of Ethics.

Ethical considerations

1. Public Safety and Welfare
   According to IEEE code #1: "Hold paramount the safety, health, and welfare of the public", public safety and welfare must be ensured. The Table Cleaning Robot must operate safely without causing harm to users, pets, or property. It must be designed to prevent falls and avoid pushing objects off the table so that no one will get hurt during the cleaning process. Therefore, rigorous testing for edge detection, fall prevention, and obstacle detection is required.
2. Honesty and Transparency in Design
   According to IEEE code #5: "Be honest and realistic in stating claims or estimates based on available data", honesty and transparency in design are required. The capabilities of the robot should be accurately presented. If the robots have limitations, the limitations must be clearly disclosed.
3. Privacy Protection
   According to IEEE code #4: "Avoid unlawful conduct in professional activities", we as designers should notice the importance of privacy protection. When we use visual sensors, we must ensure that data is encrypted, avoid storing unnecessary information, and comply with privacy regulations.
4. Fairness and Non-Discrimination
   The project must not create biased or discriminatory outcomes. We will conduct bias testing and ensure inclusivity in design and deployment.

Safety Considerations

1. Mechanical and Electrical Hazards
   The robot has moving parts that could cause injury if mishandled. Electrical components, particularly lithium-ion batteries, pose risks of overheating or short-circuiting. Implementation of protective casing around moving parts can mitigate the hazards.
2. Fall Prevention and Object Handling Risks
   The robot must reliably detect table edges to avoid falling and prevent damage to itself and surrounding objects. If the robot attempts to move objects, it could accidentally push items off the table. Therefore, high-precision edge detection systems and object detection systems should

be strictly tested. Also, implementing redundant safety measures will mitigate risks of failure in mission-critical applications.

3. Safe Charging and Energy Efficiency
   The charging station must be designed to prevent overheating and electrical fires. Therefore, auto-shutoff is recommended.

Regulatory Compliance

1. Battery Safety

   If the robot uses a lithium-ion battery, it must meet UN/DOT 38.3 certification to ensure safe transport and usage.

2. Campus and Lab Safety Policies

   If deployed in university environments, the robot must follow campus safety protocols, especially concerning fire hazards, electrical devices, and laboratory usage.

Mitigation Strategies

To avoid ethical and safety breaches, the following strategies will be implemented:

1. **Regular Ethical Audits**: Conduct periodic reviews of the project's compliance with ethical guidelines.
2. **Risk Assessments**: Identify and mitigate potential hazards through systematic risk management frameworks.
3. **Stakeholder Involvement**: Engage with users, regulatory bodies, and ethicists to ensure accountability.
4. **Transparency and Documentation**: Maintain clear records of decisions, safety tests, and compliance measures to facilitate oversight.

By integrating these ethical principles, safety measures, and regulatory standards, the Table Cleaning Robot will be safe, reliable, and responsibly engineered. Compliance with the IEEE Code of Ethics ensures that the product prioritizes public welfare, environmental responsibility, honesty, and fairness