ECE 445 Project Proposal

Follow-Me Cart: App Controlled smart assistant

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Introduction

1. Problem

In supermarkets and malls, shoppers often face inconvenience when pushing heavily loaded carts while simultaneously browsing items, handling phones, or managing children. This situation not only reduces comfort but also efficiency, leading to a poorer shopping experience.

With the growing trend of smart retail and service robots, there is a demand for semi-automatic shopping carts that can reduce physical strain and allow customers to shop more comfortably and efficiently. Prior works such as autonomous luggage and robotic carts have demonstrated feasibility, further justifying the importance of developing such a system.

There is a need for a semi-automatic shopping cart system that follows customers and allows them to control it through a user-friendly mobile application. Such a system would increase convenience, reduce physical strain, and improve the shopping experience for a wide range of customers.

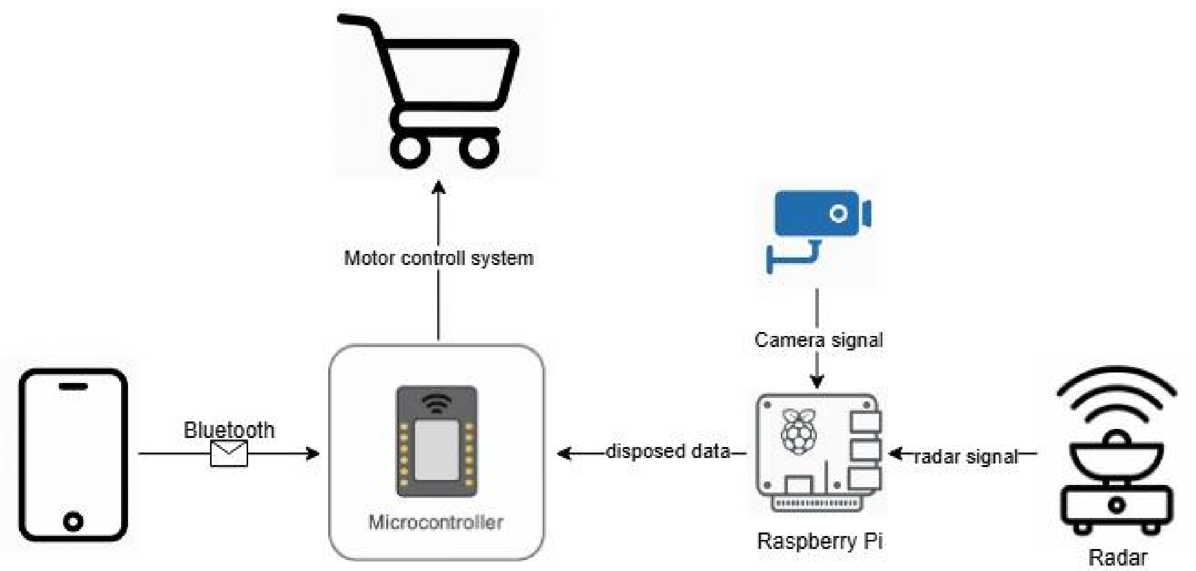
2. Solution

To address this challenge, we propose a Follow-Me Cart system controlled via a mobile application. The architecture integrates a Raspberry Pi for high-level processing, such as sensor fusion, user tracking, and communication with the app, with an ESP32 microcontroller responsible for low-latency motor control and ultrasonic safety features. This hybrid design balances computational intelligence with real-time reliability.

The Pi processes data from an mmWave radar and camera to track the user, while the ESP32 enforces safety and ensures low-latency motor response. This architecture will balance high-level intelligence with reliable real-time control.

Instead of being completely automatic, the cart connects to a smartphone app through Wi-Fi or Bluetooth. Customers can enable follow-me mode, control the car's speed, adjust the following distance and stop or start the cart as needed. The user carries a Bluetooth transmitter (or an infrared remote), while the shopping cart prototype is equipped with a receiver and simple motor control. The cart is able to maintain a following distance of 1–2 meters in an open experimental area, and it can stop or bypass when encountering obstacles. The navigation system can be based on a fixed map, since supermarket layouts are generally static. Instead of dynamic pathfinding, the cart only needs basic obstacle avoidance when encountering people or objects. As long as the paths remain open, the cart can reach its destination. In cases where a path is completely blocked, the cart may stop, which is acceptable since it is outside the system's responsibility. To remain affordable and safe, we will construct the system at a scaled-down size (roughly 50–70% of a real shopping cart), with a payload capacity of 5–10 kg instead of 30–40 kg.

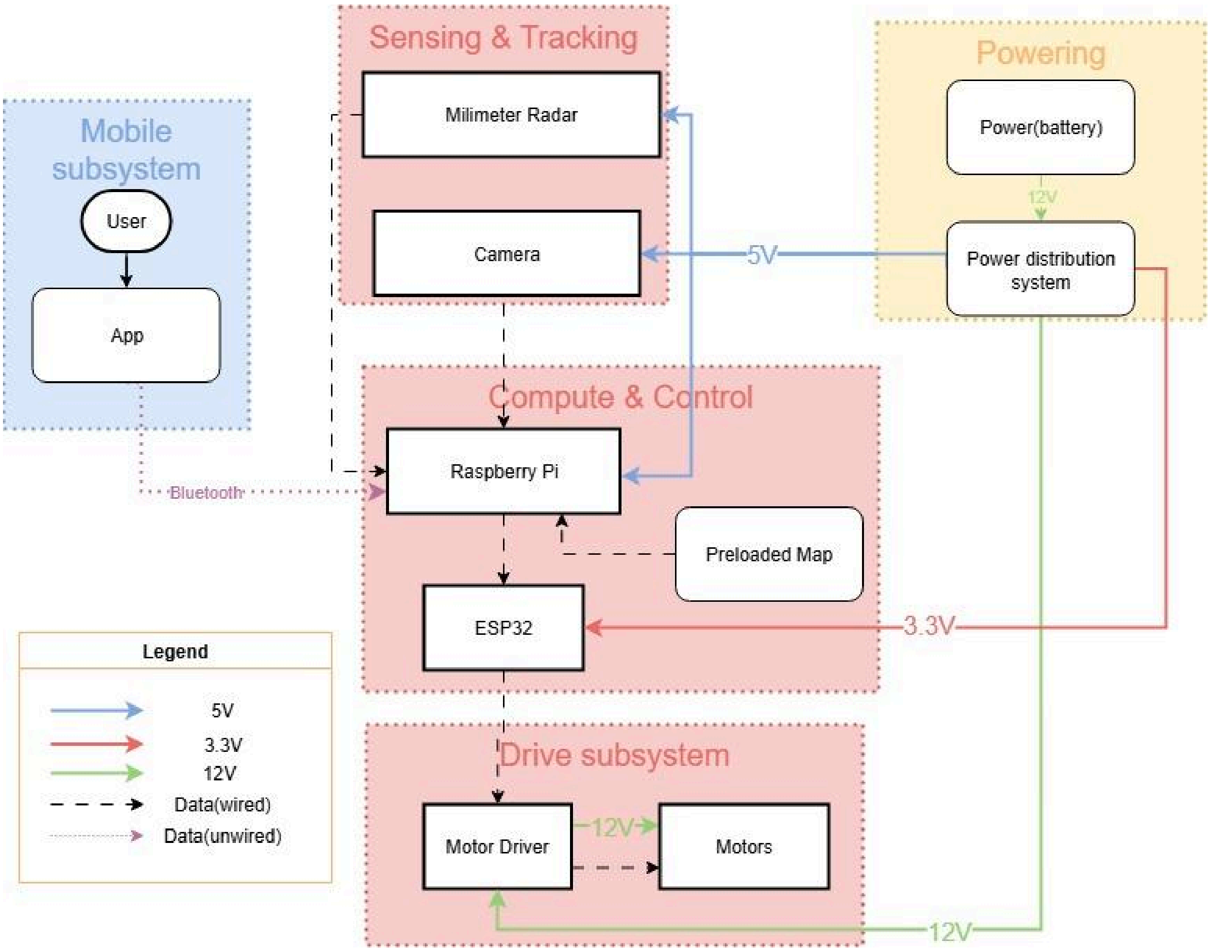
3. Visual aid



4. High-level Requirements List
    a. Maneuvers: We aim for the cart to achieve a 90% success rate in avoiding collisions with other objects in environments similar to grocery stores. The abovementioned objects include but are not limited to people, shelves, tools, and other shopping utilities.
    b. Uptime: According to a recent market survey by Drive Research, about 74% of U.S. consumers report that their full grocery shopping trip takes under 44 minutes. [Drive Research] While this includes all activities (entering store, browsing, checkout, etc.), it provides an empirical basis for requiring our cart to operate continuously for 40-60 minutes to cover the majority of typical shopping sessions.
    c. Accuracy: The cart is designed to maintain a following distance of 1–2 meters from the designated customer within a pre-mapped supermarket-like environment. This range ensures that the cart remains close enough to be convenient, while avoiding excessive proximity that could inconvenience the user or risk collisions.

Design

1. Block Diagram:



2. Subsystem Overview:
   a. Subsystem 1: Sensing and Tracking subsystem
      This subsystem consists of sensors and a camera. In this project, we will use several mm-wave radars working together with a camera. In this mode, the camera will handle most of the data collection, while mmWave sensors will be activated as needed in situations like turning or approaching other objects to better assist with maneuvering the cart.
   b. Subsystem 2: Compute and Control subsystem
      This system will receive data from all other systems, analyze them using Raspberry Pi if needed, then forward the abovementioned processed information to ESP32, while the latter component drives motors on the cart.
   c. Subsystem 3: Mobile App
      The mobile application allows users to check on the connection status of their assigned cart. The application will also be used during the Bluetooth pairing process.
   d. Subsystem 4: Drive Subsystem

This system consists of the chassis, wheels, and motors of our cart, it is powered by the on-board battery and will follow instructions given by the ESP32 chip.

e. Power system
The power system consists of a central battery and a power distribution unit. It provides 12 V to the motor driver, 5 V to the sensing and tracking modules as well as the Raspberry Pi, and 3.3 V to the ESP32 microcontroller.

3. Subsystem Requirements:

a. Subsystem 1: Sensing and Tracking subsystem
   - Be able to correctly identify foreign objects with a minimum distance of 7 m and transmit the information to the control and navigation systems.

b. Subsystem 2: Control and Navigation subsystem
   - Be able to process data received from sensing and tracking subsystems and make decisions to maneuver and avoid collisions. Decisions include but are not limited to turning and yielding.
   - Be able to recognize humans from objects by computer vision and realize the following function.
   - Be able to connect with the user's phone application via Bluetooth
   - Be able to drive the motors within the drive subsystem

c. Subsystem 3: Mobile App
   - Be able to have an interface to allow users to connect to their assigned cart.
   - Be able to allow the user to see connection status of their assigned cart

d. Subsystem 4: Drive Subsystem
   - Be able to maneuver per instructions given by the control and navigation system.

e. Subsystem 5: Power System
   - Be able to supply the whole system continuously with 3.3V, 5V, and 12V power.
   - Be able to sustain for at least 40 minutes to an hour.

4. Tolerance Analysis:

With a maximum speed of 1.1 m/s, assuming a conservative control delay of 0.5 s and a deceleration of 0.5 m/s², the total stopping distance is approximately 1.8 m. Given that the radar provides a 10 m detection range, even if the system only makes decisions when an obstacle is detected at 7 m, the cart can still stop safely before reaching the obstacle under worst-case conditions.

$$d_{total} = v * t_{reaction} + \frac{v^2}{(2\times a)} = 1.1 \times 0.5 + \frac{1.1^2}{2\times 0.5} \approx 1.76\, m$$

Another important point concerns the durability of the power system. According to official specifications, the Raspberry Pi 4 may consume up to 3 A at 5 V (≈15 W) under peak load (*Raspberry Pi Foundation*). In addition, other peripherals contribute to the total consumption: the ESP32 microcontroller draws approximately 0.5 A at 3.3

V (Espressif Systems), the Logitech USB camera requires about 0.25 A at 5 V (Logitech), and the TI mmWave radar sensor consumes around 0.36 A at 5 V (Texas Instruments). Summing these values, the peak demand of the compute and sensing subsystems is roughly 17.5 W, which establishes the baseline requirement for the power distribution system.

For the drive system, four MG513 motors were selected as propulsion units. Assuming each motor draws 0.6 A at 12 V under typical load, the estimated power consumption is calculated as:

$$P = 0.6\, A \times 12\, V \times 4 = 28.8\, W$$

Thus, the total estimated peak power requirements are

$$P_{total} = P_{compute\ and\ sensing} + P_{drive} = 17.5\, W + 28.8\, W = 46.3\, W$$

Since we are using a 2550 mAh battery, the duration will be at least

$$T = 2.55\, Ah \times 12\, V \div 46.3W = 30.6\, Wh \div 46.3W \approx 0.66h \approx 40min$$

Hence, the proposed cart system is guaranteed to maintain operation for no less than 40 minutes under peak power demand. Given that the motors in real-world usage are not always operating at maximum output, the effective endurance is likely to be significantly higher.

Ethics and Safety

As our project advances, we stay steadfast in our commitment to comply with the ethical and safety standards set out by the Association for Computing Machinery (ACM) and the Institute of Electrical and Electronics Engineers (IEEE). We commit to maintaining these standards in the creation of this autonomous shopping cart system, ensuring that all our decisions and actions embody the utmost professionalism and integrity.

In accordance with the IEEE Code of Ethics, Clause 1, we pledge to prioritize the safety, health, and welfare of the public and to endeavor to adhere to ethical design and operating standards. Safety will be paramount during the design process, and ethical considerations will be incorporated at each phase. We shall furnish explicit guidelines to users, including parents and guardians, concerning the appropriate utilization and constraints of the robotic cart to facilitate educated and responsible decision-making.

Adherence to all pertinent rules and regulations governing this technology will remain a primary focus. Additionally, in accordance with Clause 3 of the IEEE Code of Ethics, we commit “to aid colleagues and co-workers in their professional growth and to endorse their adherence to this code of ethics.” We will cultivate a culture of ethical awareness and mutual accountability, promoting open communication that allows team members to express issues and seek help without reservation.

References

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