AutoServe

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1. Introduction

1.1 Problem

In hotels and other service industries, guests or residents often request small amenities such as snacks, toiletries, chargers and more. Fulfilling these requests typically requires manual labor, such as a staff member traveling long distances across hallways and between floors which is time-consuming, inefficient, and tedious. According to industry reports from organizations such the Hoover Institution at Stanford and media outlets like ETFTrends, the adoption of service robotics has been increasing worldwide to address issues such as labor shortages and improve efficiency or service quality. According to the International Federation of Robotics, "With 102,900 units (+14%) sold in 2024, more than every other professional service robot was built for the application class transportation and logistics," highlighting the rapid growth of demand for mobile robots designed for supplementing service objectives.

However, while some automated delivery robots exist, current commercial solutions are extremely expensive and often impractical for smaller deployments or retrofitting existing buildings. There is a need for an affordable yet flexible indoor delivery system capable of autonomously transporting small items within multi floor buildings while operating within existing building infrastructure constraints. An affordable autonomous service robot can also have several societal implications such as reducing worker fatigue, tackling workforce staffing shortages, and minimizing response times for operational efficiency.

1.2 Solution

Our proposed solution is building an autonomous indoor delivery service robot capable of transporting items between locations in a multi-floor building such as a hotel. The robot will navigate hallways autonomously via communicated predetermined paths, and deliver items from a central base location such as the hotel lobby desk or snack bar to a specified room destination. The robot's movement will be entirely autonomous and be monitored wirelessly by staff. Elevator actuation is assumed to be externally triggered by the building staff as is most common in real service situations, while the robot will autonomously handle entering, riding, and exiting the elevator at the correct floor with sensor detection. This design choice reflects realistic constraints of existing building logistics while allowing the project to focus on autonomous navigation, system integration, and practicality. An ESP32-based controller located on the robotic navigation unit will handle sensor integration and communication with the base server, while heavy processing work for computation such as a SLAM algorithm will be offloaded to a Raspberry Pi. We would also incorporate graphed routes that are optimized for avoiding obstacles, with an IR based proximity sensor to avoid obstacles and an accelerometer to track xyz position in a known map. Two brushless motors with encoders will be used to move the robot while accurately assessing its position. This system would reduce staff workload, improve response time for guests, and demonstrate how embedded robotic platforms can be useful to automate common but repetitive manual logistics tasks.

1.3 Visual Aid

Figure 1: Example conceptual diagram showing high-level interaction between robot system and destination, with communication outlined by basic arrows.

1.3 High Level Requirements

- **Delivery:** Robot should be connected to computer via wifi sending back information about current task and taking commands to start deliveries (Robot should be capable of carrying at least 20 lb of payload weight).
- **Maneuverability:** Robot is able to detect and maneuver around simple obstacles within 10 centimeters (person blocking straight path).
- **Reliability**: The Robot should be able to use position sensing to accurately arrive at a location and return within 10 minutes and have a battery life that can last the duration of delivery.

2 Design

2.1 Block Design

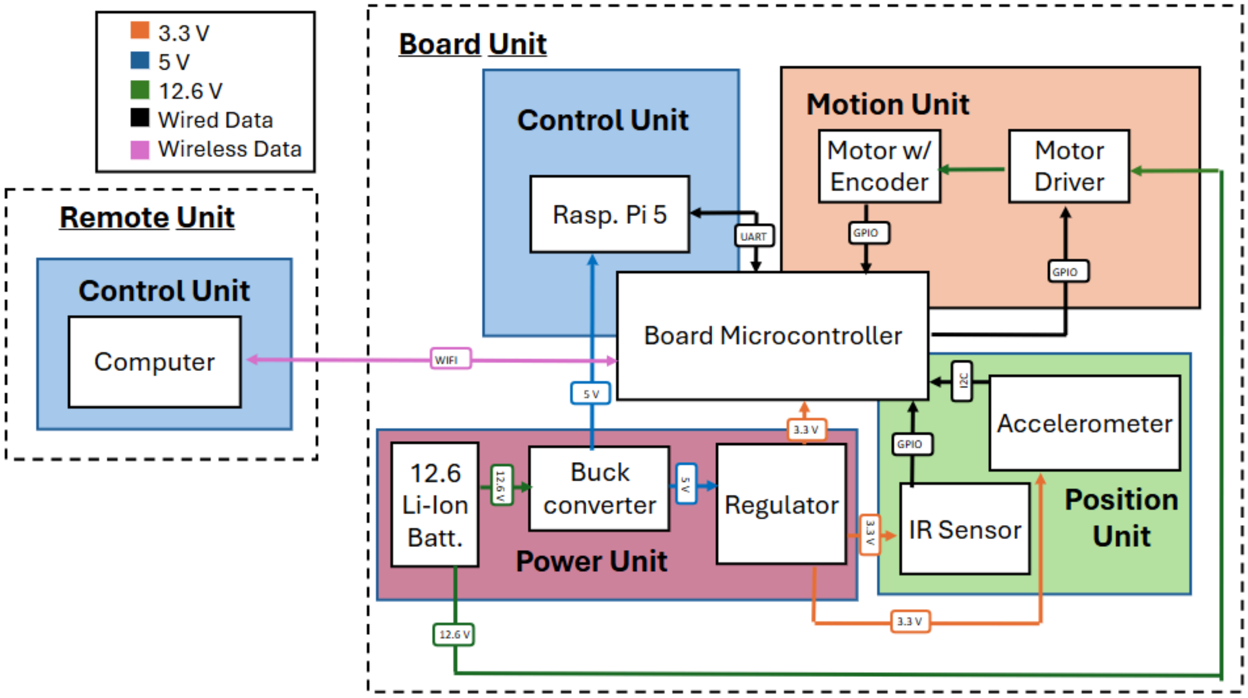

Figure 2: Block Design depicting our overall system integration.

2.2 Subsystem Overview

- **Control:** The control subsystem will use a ESP32 microcontroller (ESP32-WROOM-32E-N4) which will be wired into the control part of the Motion and Position subsystems. The ESP32 will connect to the computer via its built-in wifi module. On the computer a hardcoded map will be stored and an algorithm will be run to figure out the path from the starting point to the end. This controller has 26 GPIOs (18 of which can do analog to digital conversion) and 16 KB of memory. To do collision avoidance and path recalculation, the microcontroller will be connected via UART to a raspberry pi that will have the processing power required to run the depth first search algorithm on a locally generated graph of the building map (SLAM algorithm) which will be stored on the pi.
- **Motion:** The motion subsystem will use two 12 volt motors (VXB.com) with encoders for motion feedback. The motors will be driven with two controller ICs (LMD18245) connected to our microcontroller. This IC needs 12-55 volts supply and will need to have 6 connections to the microcontroller one for direction, brake and 4 for inputs for chopping the signal which would control the step size. This subsystem will be driven with the digital inputs by the microcontroller.

The feedback values from the encoders will need to each have 4 connections to the microcontroller to give position data to the control subsystem.

- **Position:** The position subsystem is used to communicate the cartesian map coordinates of the robot and if there is anything blocking its next step forward to the control subsystem. To get the relative motion of the robot an accelerometer (LIS2DH12TR) will be used to assist the microcontroller in approximating motion by acceleration data with the motor encoders and map data. It will be connected to the control subsystem via I2C and will read out the differential motion in all axes. To detect obstacles IR sensor circuits will be created to find the distance of the nearest obstacle at the front, left, right and back of the robot.
- **Power:** The power subsystem will consist of a buck converter and a voltage regulator to provide stable current to the motion, position and control subsystems. A 3.3V linear voltage regulator (LM3940IT) will be used to create stable current for low voltage subsystems (control & position). For the raspberry pi a 5V 3A buck converter will be created using the TL494CN. Lastly the motion subsystem will be connected directly to power to maximize current delivery.

2.3 Subsystem Requirements

- **Control**:
    - **Delivery:** Microcontroller connects to Wifi and is capable of sending/receiving packets from a computer.
    - **Manuverability:** Microcontroller connects via UART to a Raspberry Pi sending local map data so that it can run the SLAM algorithm to recalculate robot path.
    - **Manuverability/Reliability:** Connects to the position subsystem (I2C with accelerometer, direct ADC connection with custom built IR sensor circuits) to get position and obstacle data.
    - **Reliability:** Connects to the motion subsystem directly via GPIO to send command signals to precisely move the robot.
- **Motion**
    - **Manuverability:** Connects with the Control subsystem directly enabling it to control x and y-axis motion.
    - **Reliability:** Encoder feedback will directly feed back to the control subsystem enabling the microcontroller to poll the frequency and offset to get direction and speed.
- **Position**
    - **Manuverability:** Proximity IR sensor circuit will directly be wired to the control subsystem via GPIO to enable sensing of obstacles within a fixed distance of the robot.
    - **Reliability:** Accelerometer will be connected to control subsystem via I2C giving data that can be used to integrate and get a rough estimate of the motion.
- **Power**
    - **Delivery:** Power subsystem is able to deliver 3.3 Volts at around 100 mA to the position and control subsystem.

- **Delivery:** Power subsystem is able to deliver 12 Volts at around 1 A to the motion subsystem.
- **Delivery:** Power subsystem is able to deliver 5 Volts at 3 A to power the raspberry pi.
- **Reliability:** Batteries must be able to supply at least 1100 mAh and be rechargeable.

2.4 Tolerance Analysis

2.4.1 IR Sensor

The IR sensor system is based on detecting reflected light from an object. The color and material of the object can influence the amount of reflection resulting in different depth capabilities for the sensor. Figure 3 shows experimental data done on an IR sensor pulsing out a 37.5 kHz signal. It can be seen that to account for this tolerance we will only be able to detect obstacles ~5cm away from the robot and should calibrate our sensors accordingly.

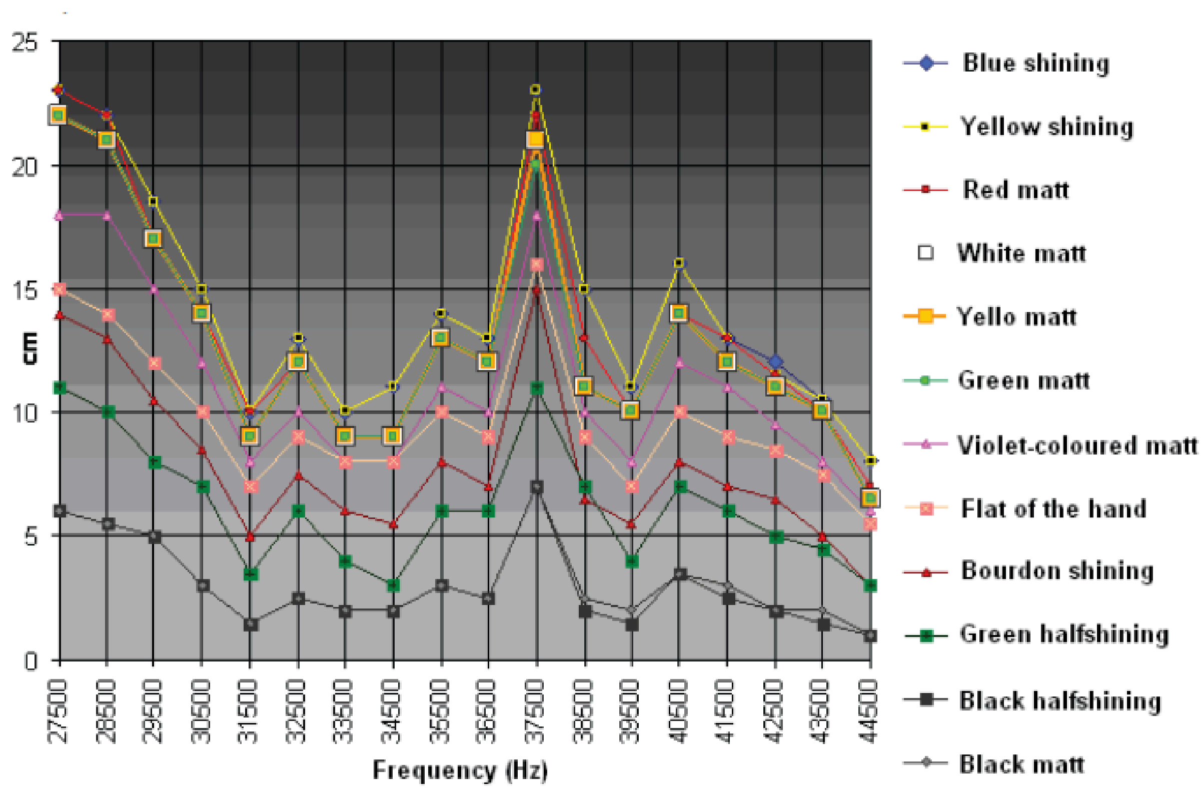

Figure 3: Experimental data on IR sensor detection capabilities based on the frequency [1].

2.4.2 Motor Torque

To move the robot the motors will need to exert enough force to overcome the friction force allowing it to drive. The motor speed is 600 RPM which will be connected to two 6 inch diameter wheels. Using equation 1 we can calculate our maximum velocity under no load is 15.70 ft/s. This speed is incredibly fast so we will need to step it down using a gear box ratio (with help of the machine shop).

$$v = \frac{RPM}{60} * \pi * D = 15.70 \frac{ft}{s} \quad (1)$$

We want the robot to move at walking speed for the safety of our surroundings and to give sensors enough time to build a map of the surroundings (~4 ft/s). Equation 2 shows the relation for slowing down the RPM using the gear ratio (N) and Equation 3 shows the increase in torque (Eta is the efficiency of the gear box system which is a mechanical value ~ 90-98% efficient).

$$RPM' = RPM/N \quad (2)$$
$$\tau' = \tau N \eta \quad (3)$$

Using Equations 2 and 1 to achieve a speed of 4ft/s we need a gear ratio N = 3.925. The motors initial rated torque is .25 kg/cm. Plugging this into Equation 3 gives us an expected maximum torque force from both wheels at around 0.98125 kg/cm (65.94 lb/ft). This is sufficiently high which means using these motors is operable.

2.4.3 Voltage Control

Different subsystems will need to run on different voltages, motion(atleast 12V), control/sensors(3.3V), raspberry pi (5V). The buck converter will be used to convert the 12 Volts signal into 5 Volts. Figure 4 shows simulation output of a 12 Volt input buck converter circuit successfully creating 5 volts output current at 3.5 Amps [2].

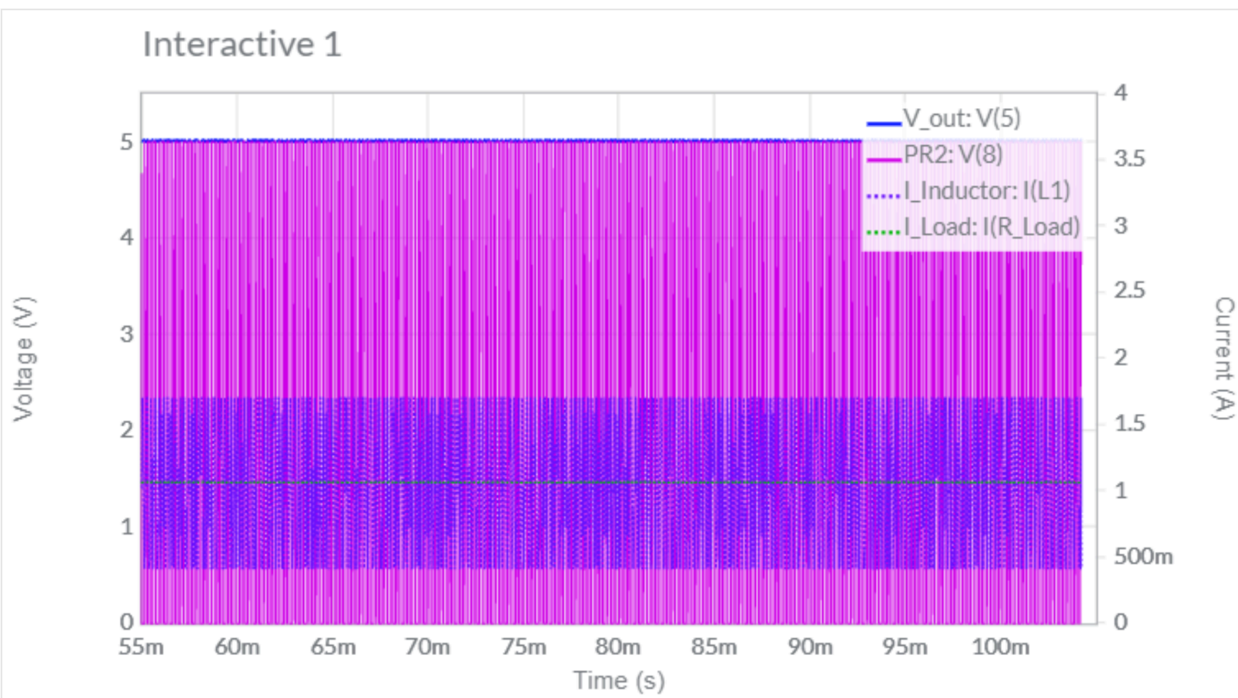

Figure 4: Simulation of Buck converter 12V to 5V [2].

The output from the Buck converter will also be fed into a 3.3 Volt power regulator. From the data sheets the output voltage has an expected error of 3% which is well within the margins of the ESP32 microcontroller and accelerometers safety limits. Figure 5 shows experimental data for Voltage in versus Voltage out for low voltage values [3].

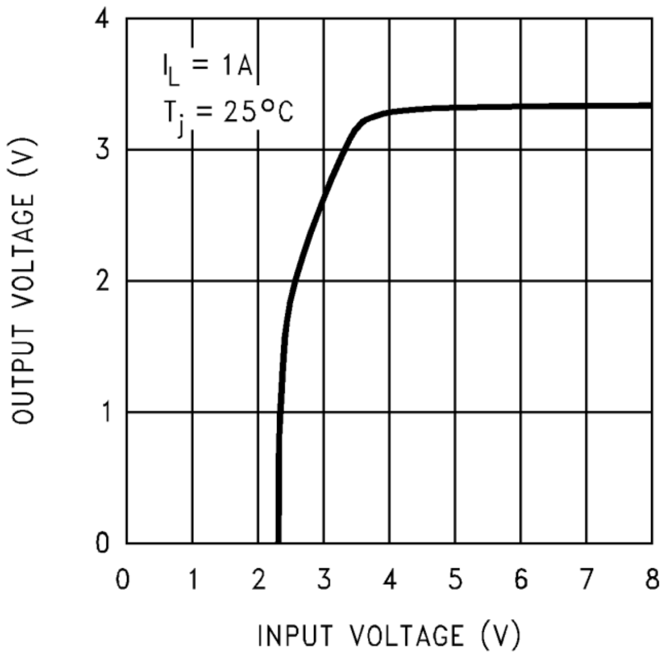

Figure 5: Experimental data of Voltage output for Voltage regulator [3]

3. Conclusion

3.1 Accomplishments

This project should accomplish several goals revolving around its physical capabilities, and provide an affordable solution to autonomous room service style robots that can make deliveries autonomously across a building. Our project aims to develop an indoor-operated service robot capable of navigating building hallways, delivering items to specific designated rooms, and interfacing with obstacles and elevators to enable sufficient operation. Our proposed system above will integrate our own custom-designed PCBs, which connect our various sensors to be used for processing path planning algorithms and proximity sensing for safe navigation in dynamic indoor environments. By incorporating localization techniques and mapping pre-determined paths alongside our sensors and odometry, the robot will be able to follow routes that lead to room destinations while responding to unexpected obstacles such as pedestrians or furniture. Successful completion of this project will accomplish a demonstration of a fully integrated robotics system with functioning hardware, sensing, controls, and autonomous decision-making suitable for applications such as hotel room service, hospital delivery assistance, or campus logistics.

3.2 Uncertainties

Some of the uncertainties regarding our project during the proposal and design process so far include reliable connection throughout the elevator, consistent obstacle detection or rerouting, and other design choices that may not be the best option going forward during implementation phases. Reliable elevator interaction presents a key challenge, including detecting elevator arrival, ensuring safe entry and exit, and coordinating room or floor selection. Additionally, integrating SLAM and path finding algorithms with limited microcontroller processing resources requires careful optimization to balance real-time operation while considering computational constraints that may limit or bottleneck our systems features. Some of our more ambitious goals relating to these algorithms or extensive features may be limited due to our available time and resources throughout a single semester, and design deadlines that conflict with our individual workloads may pose challenges in the future during the building process.

3.3 Ethical considerations

As responsible engineers, we recognize that ethical considerations associated with developing autonomous robotic systems that interact with people in public spaces are important to address and keep in mind when making design decisions for our project. Safety is a primary concern that is addressed through features such as obstacle detection, where we will implement emergency stop mechanisms and fail-safe behaviors to minimize risk of injury or property damage, adhering to the second code in the IEEE Code of Ethics. This also coincides with the University of Illinois policies with university facility use, as we plan to demo our completed and functioning project in the ECE building on campus and utilize various university resources in order to achieve this.

Privacy considerations are also an important consideration in ethics, also highlighted in the IEEE Code of Ethics. Any sensing data used for navigation will avoid unnecessary collection or storage of personally identifiable data. If any vision or environmental related sensing is employed, it will be limited to navigation purposes only and not used for surveillance of any sorts.

Potential misuse must also be considered to avoid any possible ethical breaches by users. Autonomous delivery robots could be repurposed in ways that create safety hazards or privacy risks. To mitigate this, the system will include clearly defined documentation clarifying intended use for service needs, incorporate speed limits, and limited authentication for who has permission to access controls.

Societally, autonomous service robots may also have potential economic impacts, including increased efficiency in hospitality settings, but also possible workforce displacement which can be negatively perceived in terms of ethics. Our project focuses on augmenting and aiding human service roles rather than replacing them completely, especially since many facets of proper operation still require human oversight or control, demonstrating how technology can assist people with repetitive logistical tasks.

3.4 Future work

In the future, we can implement improvements beyond the scope of our senior design project. Some upgrades we have in mind include more advanced localization techniques and enhanced human to robot interaction such as voice interfaces or mobile app integration. There is always room to improve on or expand mapping algorithms as well as efficient rerouting calculations. As this product will support logistical tasks involving humans, interactions can be later improved by developing more intuitive user interfaces for control, or software/mobile app connections that allow remote access to our robot. We would also love to implement additional sensor functions and machine learning methods which we believe could improve navigation reliability in crowded or unfamiliar environments. On top of those features, some general performance enhancements include further expanding battery efficiency, payload/weight capacity, and long-term reliability testing which would all be necessary in the case of any plans for potential commercial deployment. Ultimately, further developments and advancements could enable broader applications in more environments including hotels, hospitals, office buildings, and campus facilities.

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