Portable Plotter Robot

Project Proposal

Team 34: Matthew Paul (mjpaul3), Shinan Calzoni (calzoni2), Sagnik Chakraborty (sagnik3)

TA: Dongming Liu

Fall 2024

1. Introduction:

1.1 The Problem:

During the design process of any system, it is often necessary to create a visual aid that provides more detail and intuition regarding a particular idea. If one is not particularly artistically adept, this can prove to be a challenge. Although it is possible to utilize applications and electronic tools such as smart pencils or photo editing software, this is often impractical in certain collaborative settings where the working surface takes up a large amount of area (posters, large diagrams, etc.). Furthermore, current solutions for plotters that include fixed railings lack flexibility when it comes to the maximum size they can support.

1.2 The Solution:

What if there was a solution that met the criteria of its predecessors and exceeded it with the ability to draw over virtually any canvas? This is the mission of our project; our group aims to design a device that can support the illustration of basic shapes across any canvas size with reasonable accuracy. The basic design is as follows: we plan to develop a vehicle with three omni wheels to allow for omnilateral movement along a 2-D plane, equipping it with a camera and flexible border detection system. A web application will serve as the interface for users to choose from a selection of shapes to draw and specify their dimensions and position.

1.3 Visual Aid:

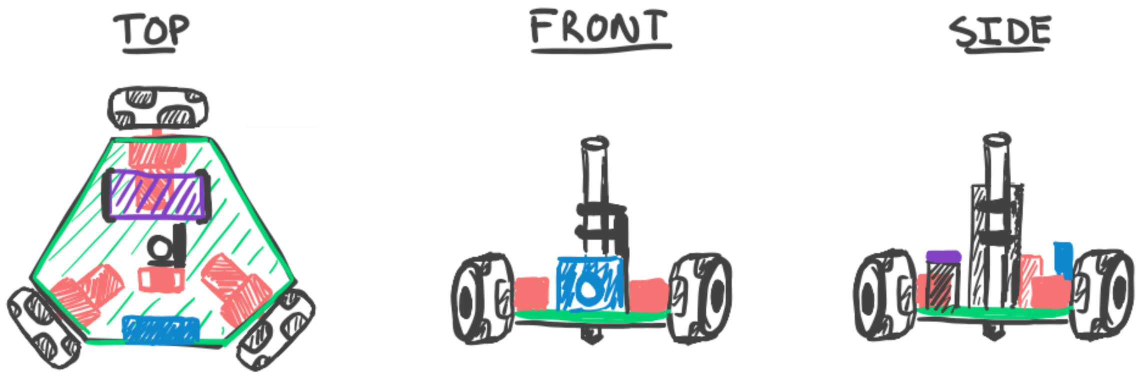

Figure 1: Device Appearance

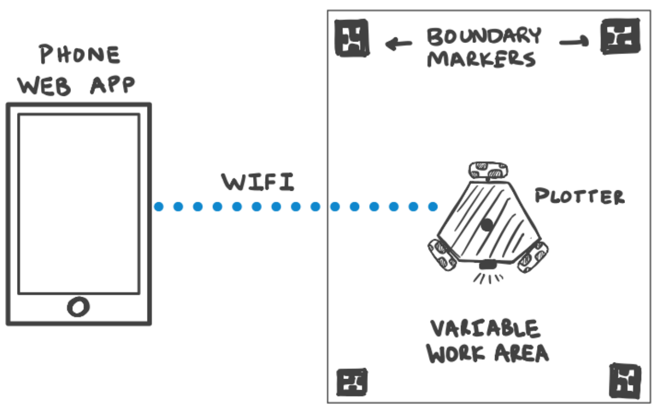

Figure 2: Solution in Context

1.4 High-Level Requirements:

- The device can communicate with the web application maximum latency constrained to *one second* or less.
- The device footprint stays within the boundary dictated by corner markers and draws near the borders with a margin of *five centimeters.*

- Illustrations are accurate within a margin of error of *three centimeters* and the toolhead has the ability to actuate off and on to the canvas.

2. Design

2.1 Block Diagram:

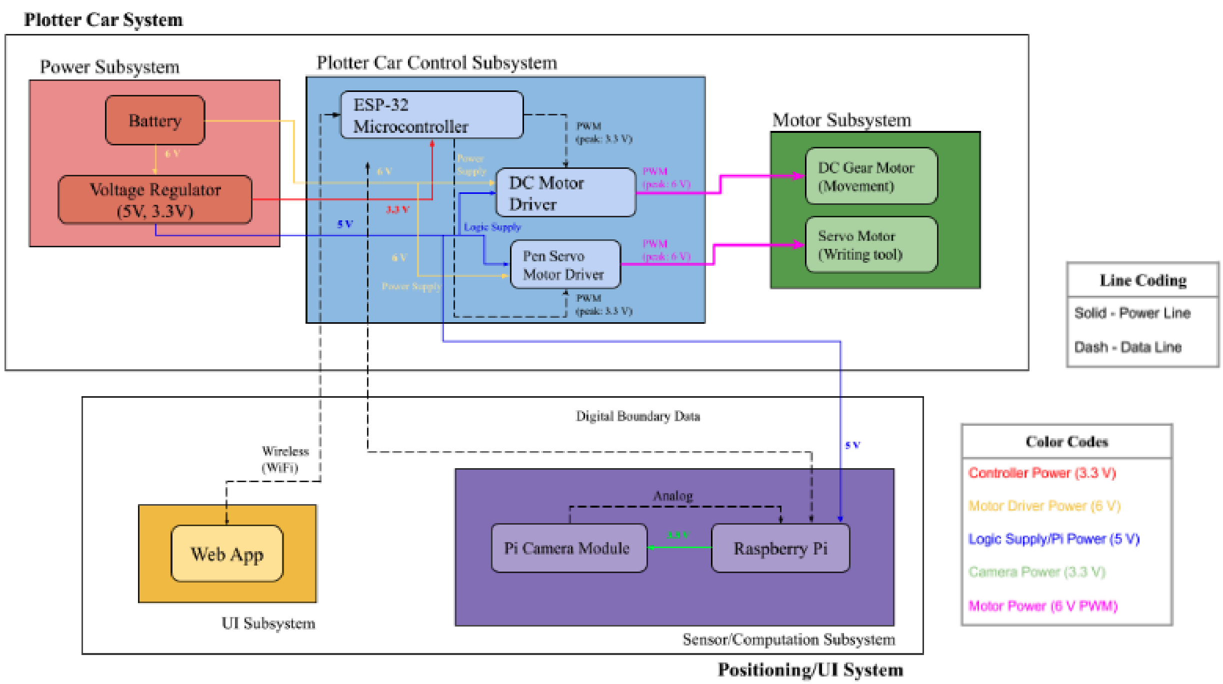

Figure 3: Full System Block Diagram

2.2 Subsystem Overview:

2.2.1 Power: This subsystem manages the power from a Lithium-Ion Rechargeable Battery with sufficient energy to power each of our components. This output will then be stepped down to 5V for the ESP32 and Raspberry Pi. The 6V can directly be used with the motor controllers to power the three 6V DC brushless motors for the wheels and a smaller stepper motor used for actuating the tool head.

2.2.2 Robot Control System: All of the robot's movement is managed by this control system; namely the three wheels and tool head actuator. An ESP32 is our microcontroller of choice due to its built-in Wi-Fi module, letting us connect to our web application without any extra hardware. This microcontroller also interfaces with a Raspberry Pi additional UI on the robot. Additionally, a motor controller will be directly on the PCB to regulate each of the four motors and control their movement and power draw.

2.2.3 Sensors and Computation:

2.2.4 UI: The main user interface is the web app which handles sending the robots commands for where to move or what shapes to draw. It communicates wirelessly to the ESP32 to relay the necessary information to perform those actions. Additionally, there will be an LCD display and LEDs on the robot itself to display information about position and/or debugging without needing the web app.

2.3 Subsystem Requirements:

2.3.1 Power:

1. Provide a stable output of 5V +/- 0.1V at least 400mA to the needed subsystems.
2. Provide a stable output of 6V +/- 0.1V at least 1.4A for the motors.

2.3.2 Robot Control System:

1. ESP32 can connect to the web app with at most 1 second of latency.
2. ESP32 must provides an accurate PWM signal to motor controls such that the target location is within three centimeters of the actual position.
3. The stepper motor must be able to actuate quickly such that there is no less than a .5 s delay between when the signal is sent and when the tool head is touching the writing surface

2.3.3 Sensors and Computation:

1. The camera module can accurately calculate the robot's current position within five centimeters.
2. The robot must be able to calibrate the camera's positioning and calculate the size of the boundary.
3. Raspberry Pi must be able to communicate with the ESP32 via data line to relay the results of the positioning calculation.

2.3.4 UI:

1. The web app must have an interface that allows users to select both what shape they want to draw and its dimensions.
2. The web app must be secure with a login registered to the device and only allow one user to control the robot at a time.
3. The LCD display needs to show the current position of the robot; data will be received directly from the ESP32 such that it is always the most updated location data.

2.4 Tolerance Analysis:

First calculate movement speed of the portable plotter car:

Omni wheel diameter: d = 38 mm
Zero load motor rotations per minute: RPM = 200 rotations/minute

$$C = \pi d$$

$$C = \pi * 38\, mm * \frac{1m}{1000mm} = 0.11938\, m$$

$$speed = RPM * C$$

$$speed = 200\, rotations/min * \frac{1\, min}{60\, s} * 0.11938\, m/rotation = 0.49794\, m/s$$

The calculation above indicates that the speed of our car with no load is just under 0.5 m/s, which is approximately the top speed of a Roomba vacuum, for comparison.

Now to analyze the torque and force of our portable plotter, first define variables:

τ_w: Wheel torque (Nm)
r_w: Wheel radius (m)

μ_w: Wheel-floor static coefficient of friction
m: total mass
F_N: normal force
F_g: gravitational force
F_{FW}: Wheel-floor static friction force
g: acceleration due to gravity constant
Three DC gear motors are arranged in a triangular orientation, and the total force generated by the wheels can be summarized with the following:

$$F_{net} = F_1 + F_2 + F_3 \quad (1)$$

Furthermore, net torque can be derived as such:

$$\tau_{net} = \tau_1 + \tau_2 + \tau_3 = rF_{net} = r_w(F_1 + F_2 + F_3) \quad (2)$$

In order for the car to not slip and continue rolling, the following inequality must be satisfied:

$$|F_{net}| \leq \mu_w mg \quad (3)$$

Substituting net torque (2) into the above inequality (3):

$$|\tau_{net}| \leq \mu_w mgr_w \quad (4)$$

Given a radial static coefficient of friction of approximately 1 and a transverse static coefficient of friction of approximately 0.25, it is evident that transverse movement is the limiting factor when it comes to slip prevention. Furthermore, with our wheel radius of 17 mm and an estimated total mass of approximately 1-2 kg, in theory, the net torque exerted by the motors should not exceed 0.04165 Nm in the transverse direction in order to prevent slipping.

3. Ethics and Safety

Our project involves the development of a mobile drawing device equipped with a camera and web connectivity, designed to operate over various canvas sizes. While innovative, this technology raises several ethical and safety considerations that we must address to ensure responsible development and use.

Safety considerations:

- **Physical Safety**: The module will be mobile, and will operate in environments close to people. The robot will be designed to run with tabletop canvases in mind. This means that we will have protections in place to prevent the robot from misjudging the environment and rolling off the table. In accordance with the IEEE Code of Ethics, Canon 1, which emphasizes the imperative to "hold paramount the safety, health, and welfare of the public," we will integrate obstacle detection sensors and implement controlled speed limits to prevent accidents.
- **Electrical Safety**: The toolhead's actuation mechanism could pose risks as well. To uphold safety standards, we will design all mechanical and electrical systems to meet relevant industry regulations, ensuring they include fail-safes like emergency stop functions and overload protection, aligning with IEEE's commitment to public safety.
- **Honesty and Transparency**: We are committed to being upfront about the device's capabilities and limits. Whenever we must make a direct change to say the torque of the motors or potential force in the moving parts (e.g. the toolhead), we will be upfront about those changes, and the steps we took to make them safe. According to IEEE Canon 3, engineers must "be honest and realistic in stating claims or estimates." We will provide accurate information to users and stakeholders in order to establish reasonable expectations.

- **Accessibility and Inclusivity**: Ethical practice requires consideration of diverse user needs. As per ACM Principle 1.4, which encourages "being fair and taking action not to discriminate," we aim to make the device accessible to users with disabilities by incorporating features like audible alerts when the robot is too close to the edge and interfaces compatible with assistive technologies. We aspire to have as much control over the robot as needed.

Adherence to Professional Ethical Standards:

In developing this project, we are guided by the ethical principles outlined by both the IEEE and ACM:

Commitment to Public Welfare: Upholding the IEEE Code of Ethics, Canon 1, we prioritize the safety, health, and welfare of the public in all aspects of our project. Furthermore, in alignment with ACM Principle 1.6, we respect user privacy and are dedicated to implementing measures that protect personal data. As the plotter may rely on web applications for control and updates, it is vital to respect user privacy and protect sensitive data. We will adhere to best practices in data protection, ensuring that all communications between the plotter and the web app are secure and encrypted. In line with **ACM Principle 1.6**, which advocates for respect for privacy, we will safeguard any personal data collected during the use of the web app, ensuring transparency about data usage. The project must also consider the environmental impact of its materials and energy use. We will design the system to minimize power consumption, such as using the right voltage ranges for operation, continuous testing of our components, using recyclable materials where possible, and ensuring that the lithium-ion batteries meet sustainability standards. This commitment reflects the broader responsibility engineers have to the environment and society, as outlined in **IEEE Code of Ethics, Canon 5**, which calls for engineers to improve "the understanding of technology, its appropriate application, and potential consequences."

4 Citations

IEEE - IEEE Code of Ethics. Accessed October 4, 2024. https://www.ieee.org/about/corporate/governance/p7-8.html.

"The Code Affirms an Obligation of Computing Professionals to Use Their Skills for the Benefit of Society." Code of Ethics. Accessed October 3, 2024. https://www.acm.org/code-of-ethics.