Design and Prototype of an Autonomous Shopping Cart

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Background

Since the invention of the first shopping cart in 1937, there have only been modest updates to the device design driven by innovation in materials and manufacturing processes. With modern advances in sensing and mechatronics, the shopping cart is prime for a redesign that leverages these technologies.

Project Goals

This project's goal was to build a functional prototype of a motorized cart with storage volume and the capacity to avoid and navigate around obstacles. This system will serve as a platform to develop, prototype, and test features towards a fully-fleshed autonomous shopping cart.

Fully implemented, an autonomous shopping cart will consist of the following features:
- Offers storage volume comparable to standard shopping carts
- Motion plans around obstacles
- Follows shopper around store
- Automatically scans items placed into the cart
- Provides a payment terminal for shopping

Mechanical Design
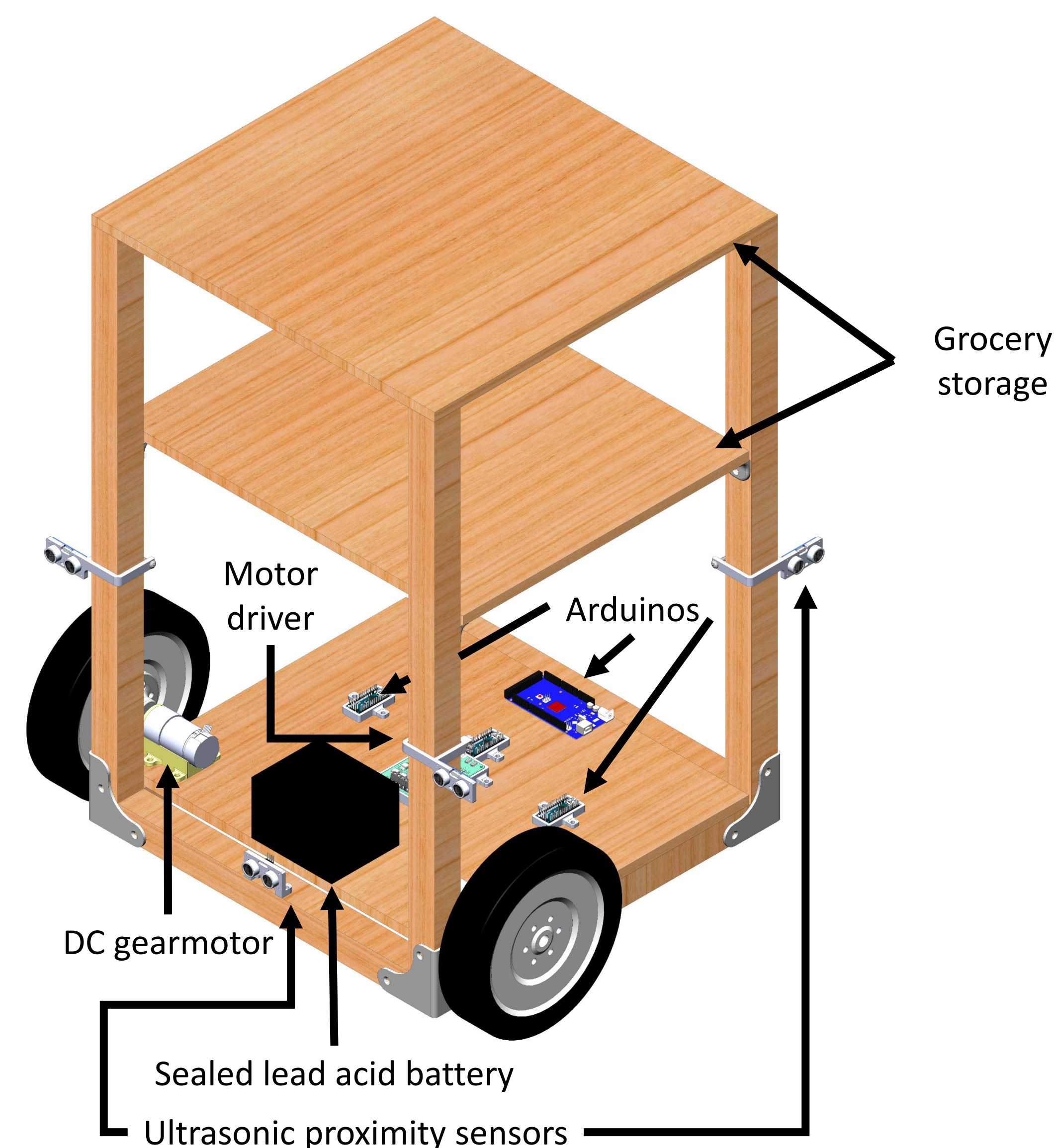
The wheel base was modeled on a differential drive robot with one driven caster and two driving wheels. The controllers, power storage, and drive units are all stored on the bottom platform to maximize usable grocery storage volume. This functional prototype has a wooden construction and uses 3D-printed brackets, fixtures, and mounting adapters.
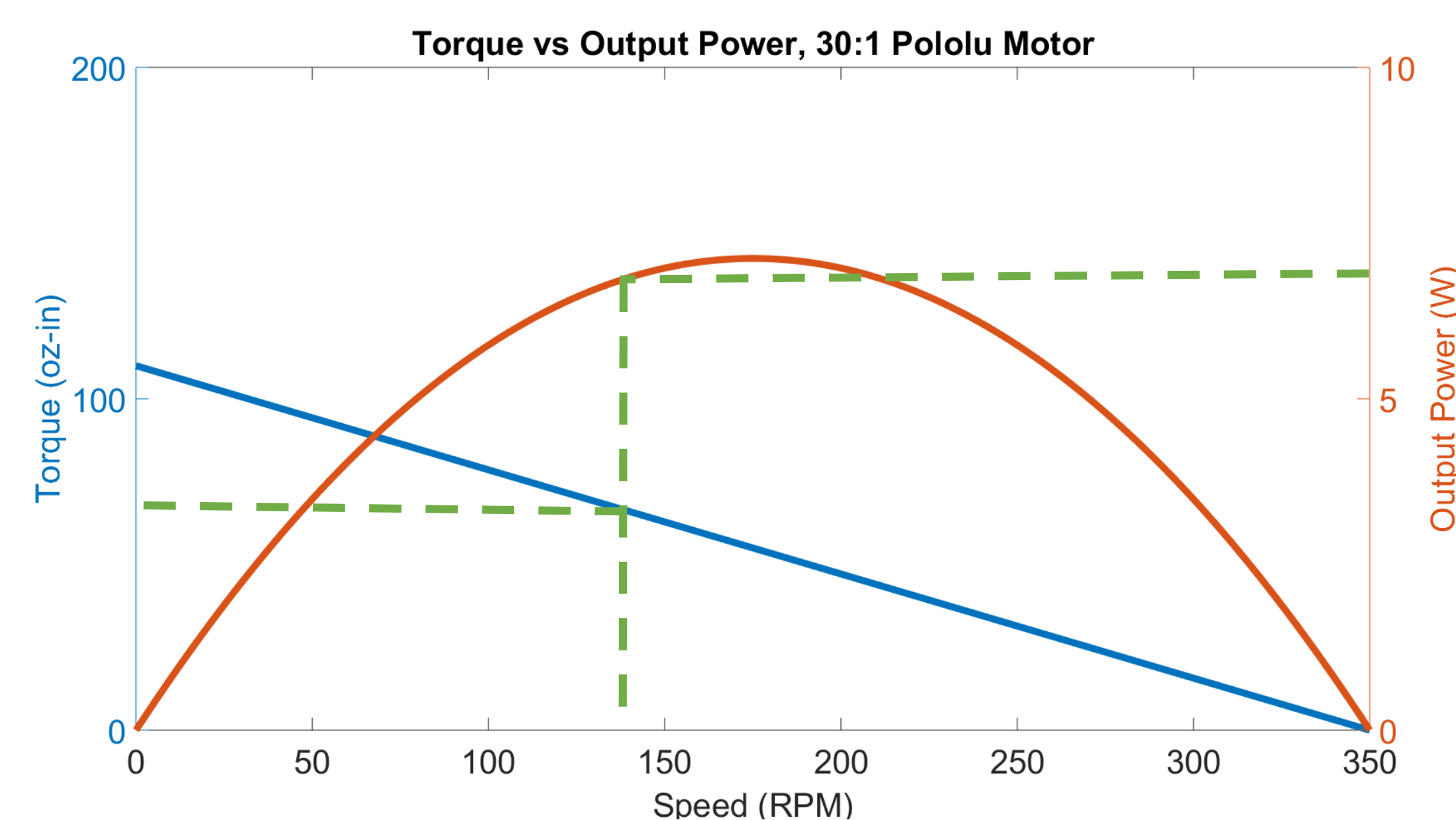
Based on torque-speed analysis, the DC gearmotor was appropriately sized to handle torque loads based on a 25 lb cart load, human walking speed (5 ft/s), 1 ft/s^2 acceleration, a 0.25° incline, and 70% efficiency.

Control System Architecture
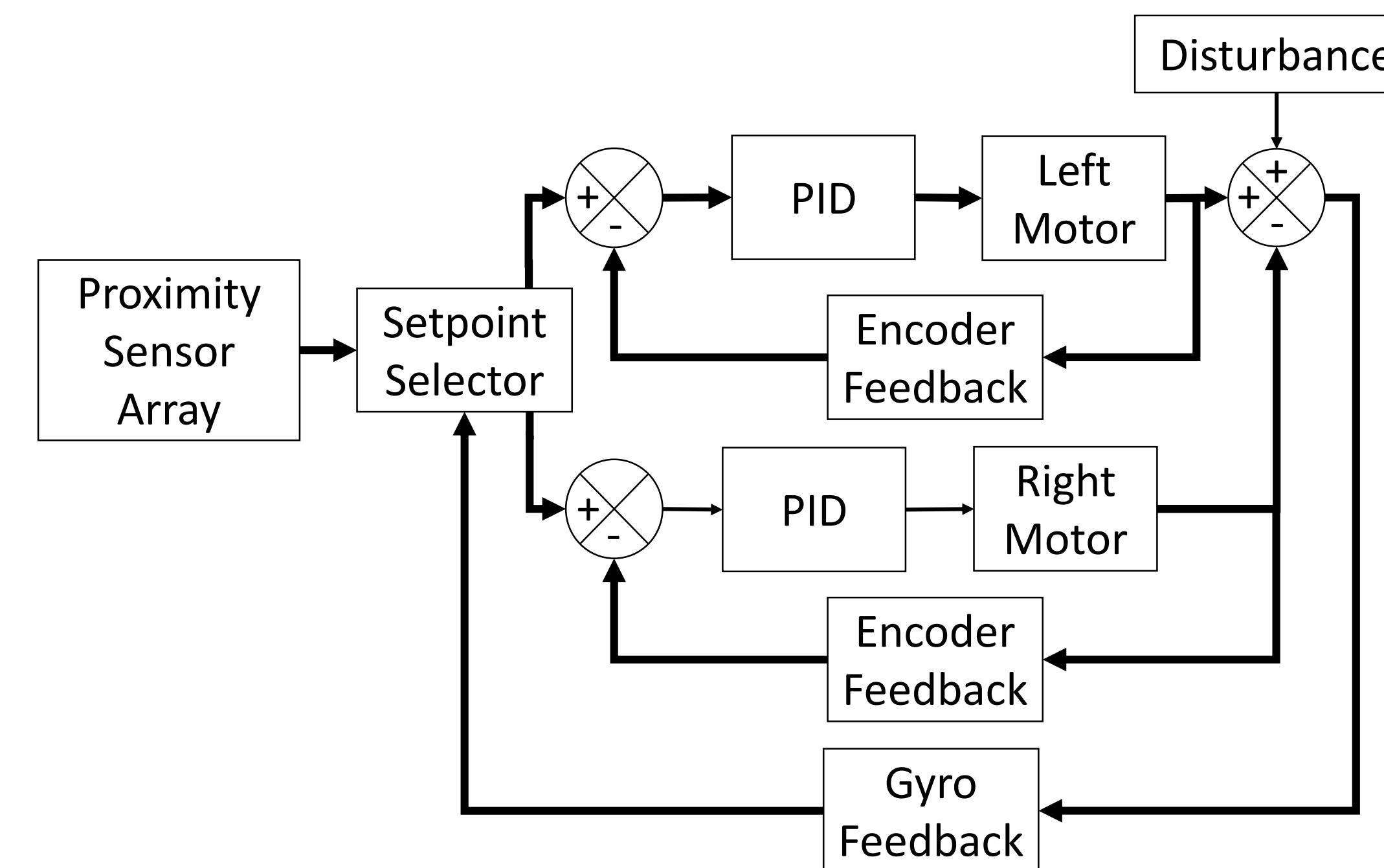
Closed-loop speed control is achieved with encoder feedback of each motor. However, motor speed differential is insufficient to determine heading of the system in slip conditions. Therefore, a gyro provides closed-loop heading control.

[TO DO: PID TUNING IMAGES]

To tune the motor PID controllers, the Ziegler-Nichols tuning method was applied. This method is procedure to experimentally estimate optimal PID parameters (K_P, K_I, and K_D) to maximize response time, eliminate steady-state error, and maintain system stability.

Distributed Computing over I^{2}C Network
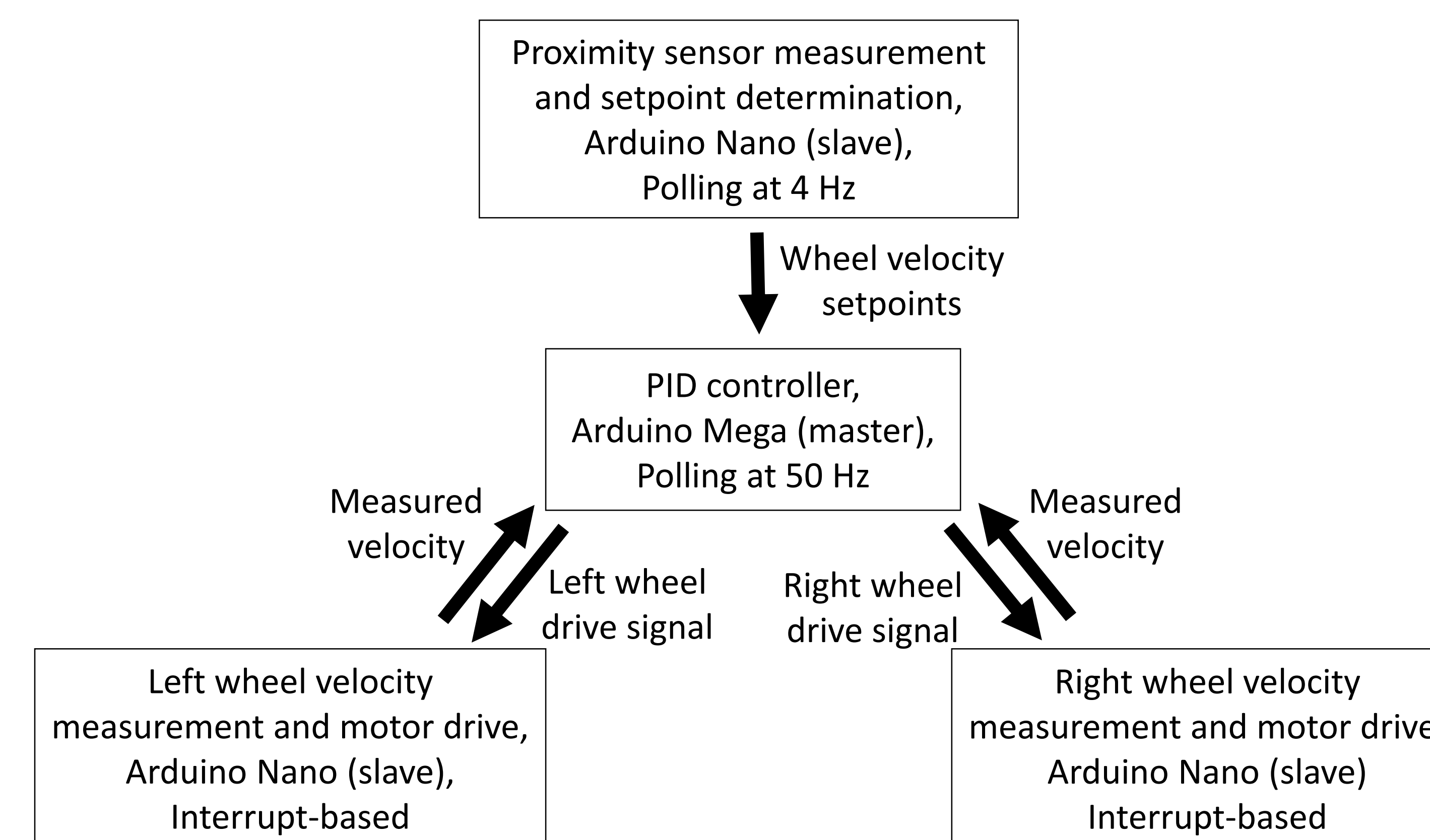
At a normal walking speed, each encoder clicks at a 3500 Hz frequency. Further, each proximity sensor requires a minimum 50 ms delay as its operation is limited by the speed of sound. If these tasks were handled serially by a single controller, the PID loop rate would be extremely limited by the high controller transport delay. To improve dynamic system stability and response time with changing setpoints, computational tasks were distributed over 4 Arduino microcontrollers and communicated over I^{2}C protocol. By managing tasks in parallel to minimize transport delay, the system achieved a 50 Hz PID loop rate.

Obstacle Avoidance Logic
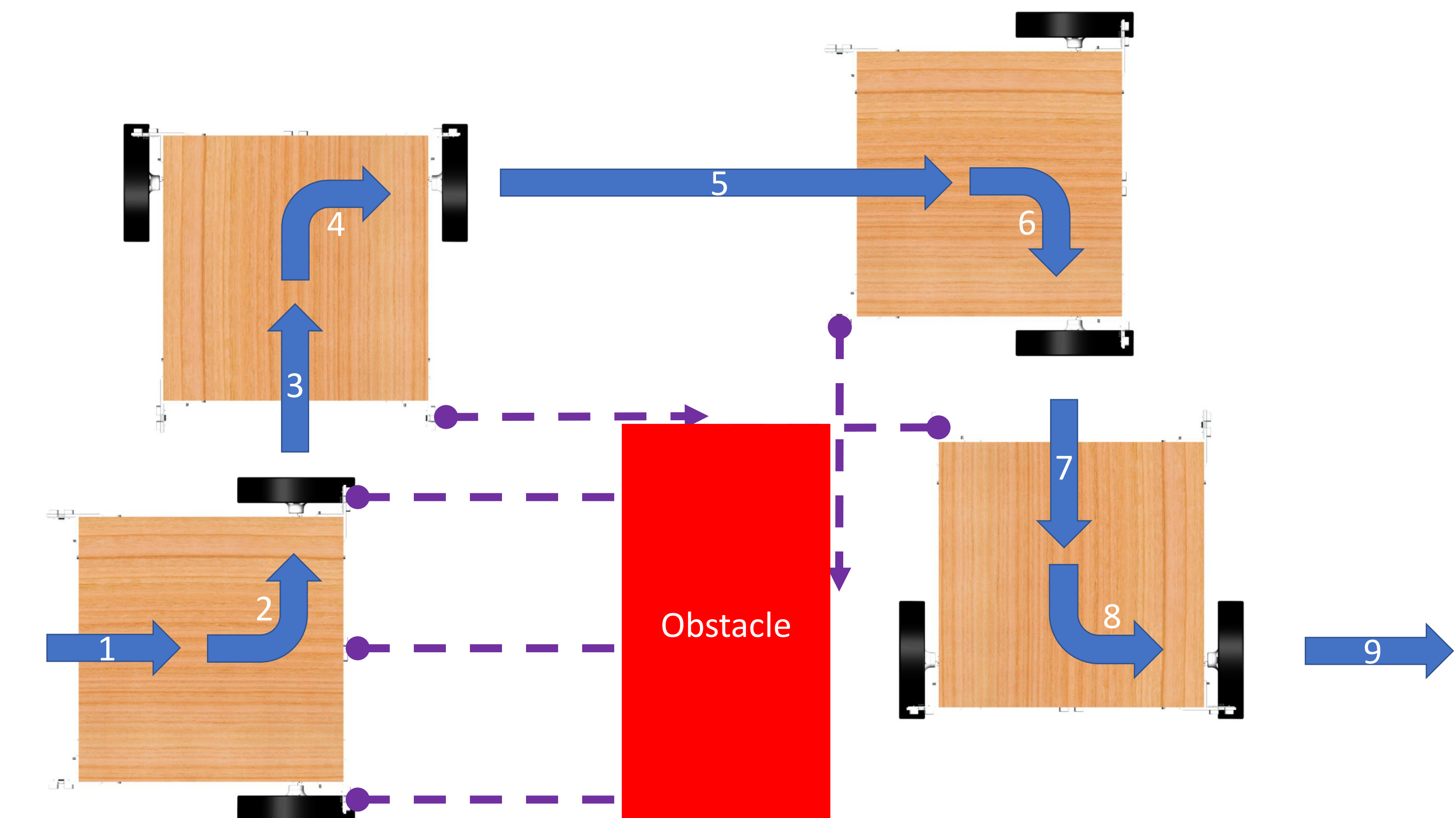
1. Cart approaches obstacle and forward proximity sensors detect obstacle.
2. Cart performs a 90° turn using gyro feedback.
3. Cart moves forward until rear right proximity sensor crosses obstacle.
4. Cart performs a -90° turn using gyro feedback.
5. Cart moves forward until rear right proximity sensor crosses obstacle.
6. Cart performs -90° turn using gyro feedback.
7. Cart moves forward until rear right proximity sensor detects obstacle.
8. Cart performs a 90° turn using gyro feedback.
9. Cart moves forward along initial path.

Conclusions and Future Work

The semester's project goals have been achieved as the functional prototype performs obstacle avoidance, carries groceries, and offers sufficient onboard processing power to enable testing and implementation of new features.

Improvements to make to the existing system:
- Add a bearing block on the motor shaft to reduce bending and shear loads.
- Mount ultrasonic sensors on a continuous servomotor to provide 360° proximity detection, eliminating the existing "blind-zones".
- Develop smoother path-planning around obstacles rather than solely 90° turns.

New features to incorporate:
- Indoor localization sensing. Several off-the-shelf options exist including PixyCam, Bluetooth transmitters/receivers, and Wi-Fi.
- RFID sensors and onboard payment terminals.
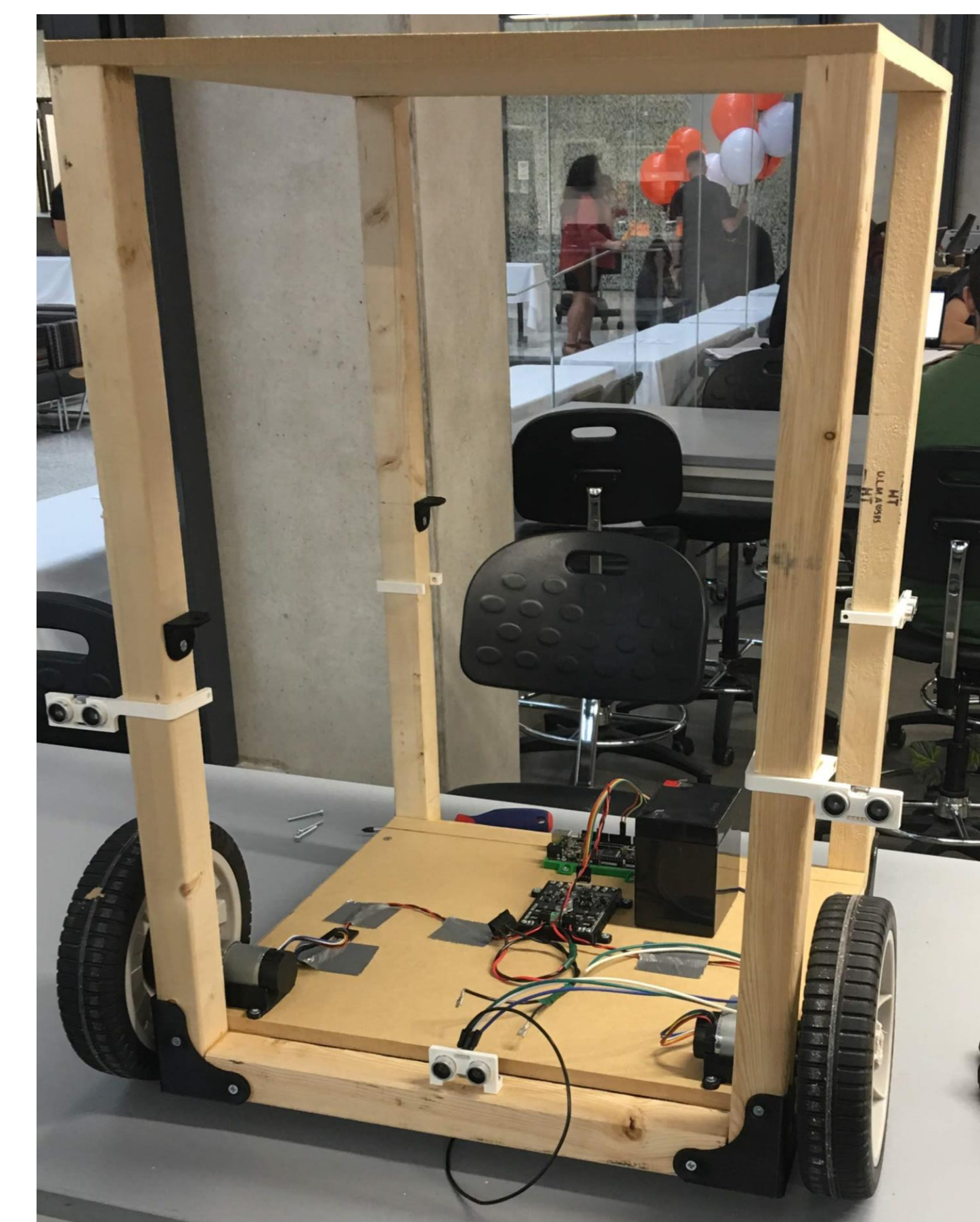
Acknowledgements

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Further Information

CAD, source code, BOM, documentation: https://github.com/skurwa/smart-cart
To learn more about Sid: https://skurwa.github.io

References

Zafari, F., Gkelias, A., & Leung, K. K. (2018). *A Survey of Indoor Localization Systems Technologies* (Rep. No. 1709.01015). https://arxiv.org/pdf/1709.01015.pdf