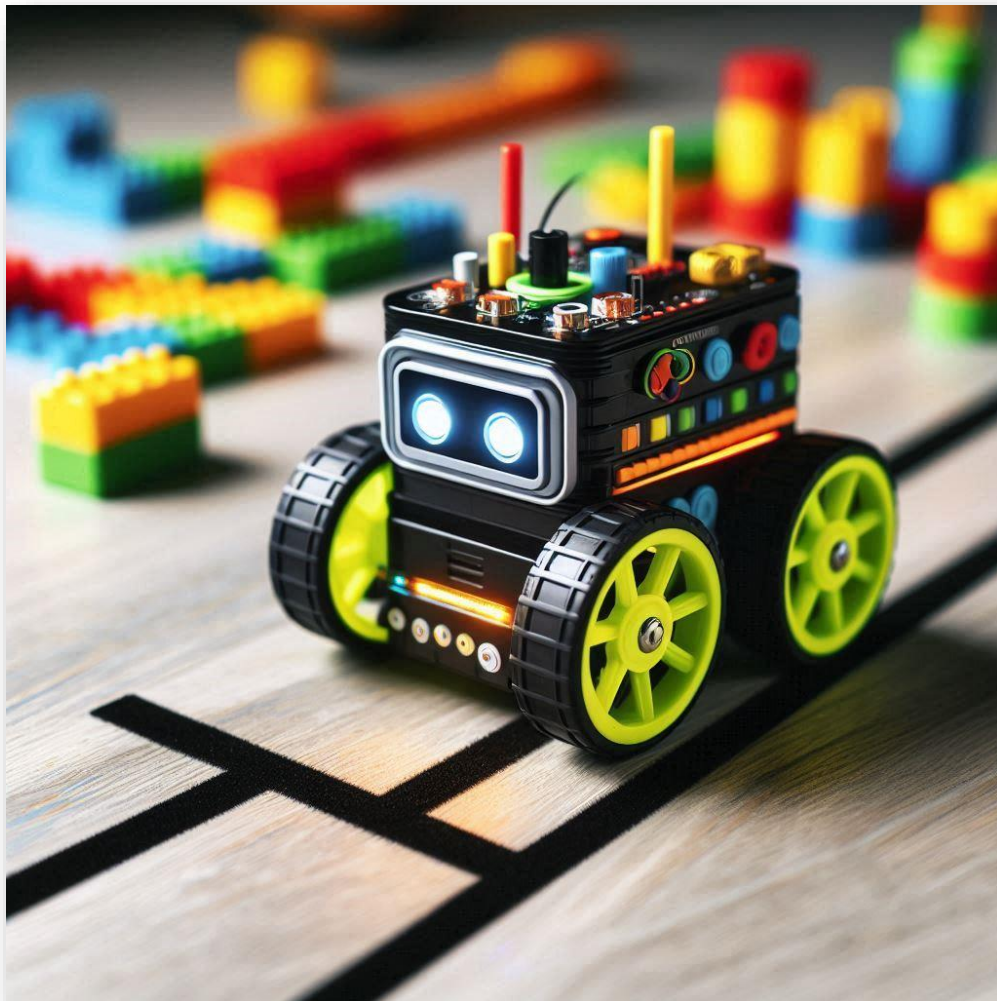


- Advanced Autonomous Systems Laboratory Final Report -

Line Following and Obstacle Avoidance with Zumo32U4 Robot



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1. Abstract

This report details the implementation and analysis of a line-following and obstacle-avoidance system using the Zumo32U4 robot. The project integrates control systems, sensor fusion, and autonomous navigation to create a robust solution for guided robot movement with environmental awareness.

Theoretical Background

Line following is achieved through proportional-integral-derivative (PID) control, maintaining the robot's position on a predefined path. Obstacle avoidance incorporates proximity sensing and path planning to navigate around unexpected objects. Both systems utilize odometry for position estimation and velocity control.

System Overview

The Zumo32U4 robot is equipped with an array of five reflectance sensors for line detection, front-facing proximity sensors for obstacle detection, and wheel encoders for odometry. The control system dynamically switches between line-following and obstacle-avoidance modes based on sensor inputs.

Block Diagram of the System

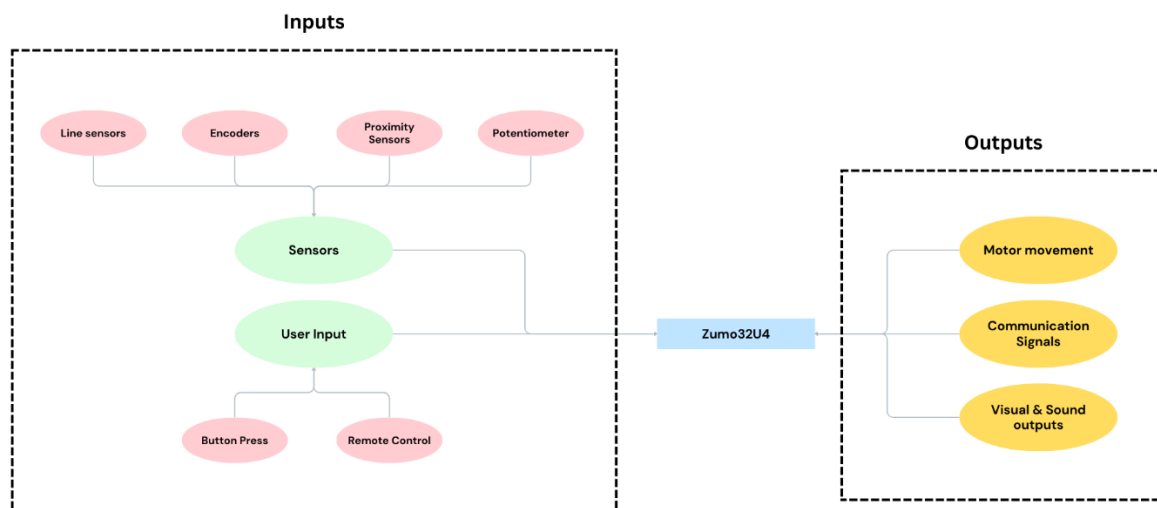


Figure 1: block diagram of the Zumo32U4 robot system

Figure 1 outlines the Zumo32U4 robot's architecture, showing how sensor data and user inputs are processed by the microcontroller to control motors, display information, and communicate with external devices.

Task Solution Overview

The robot follows a black line using PID control, continuously adjusting its trajectory based on sensor readings. Upon detecting an obstacle within a specified threshold, it switches to an avoidance algorithm, executing a series of predetermined movements to avoid the object before returning to line-following mode.

Block Diagram of the Task Solution

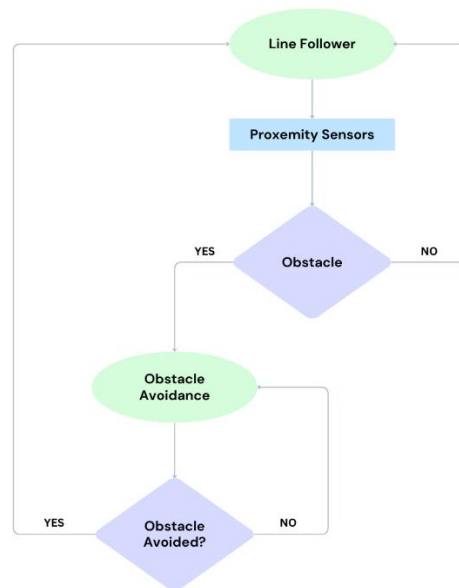


Figure 2: Flowchart of the line-following and obstacle-avoidance algorithm

Test Track

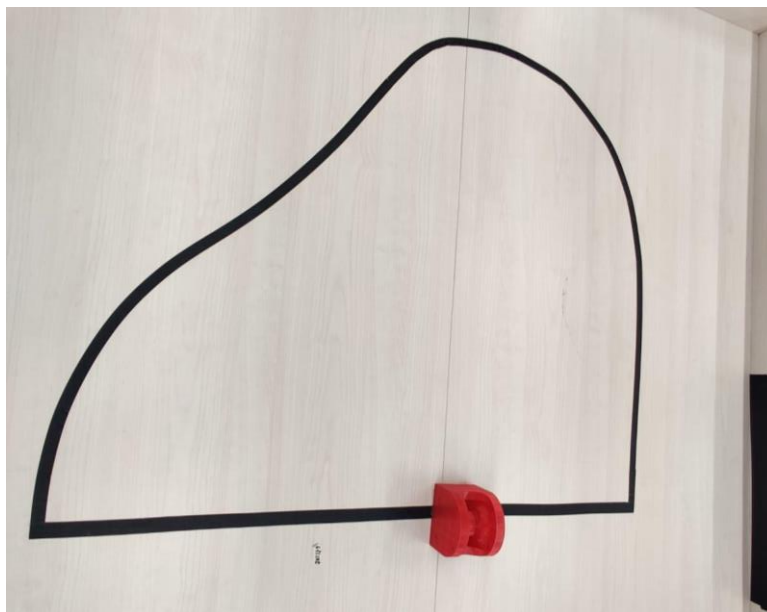


Figure 3: Image of the test track - line in black, obstacle in red

2. Work Process Description

The development process followed these key steps:

1. **Sensor Calibration and Testing** - Initial calibration of the line sensors, which is crucial for accurate line detection.
We used a calibration routine that sweeps the sensors over the line, recording minimum and maximum values for each sensor.
This process significantly improved the reliability of line detection across varying lighting conditions.
2. **Implementation of PID Control for Line Following** - We used a PID controller for line following, starting with a simple proportional control and iteratively adding integral and derivative components.
The PID parameters were tuned through repeated trials, balancing responsiveness with stability.
3. **Development of Obstacle Detection Algorithm** - Proximity sensors were configured to detect obstacles within a predefined range. We implemented a threshold-based detection system, triggering the obstacle avoidance routine when sensor readings exceeded a predefined value.
4. **Creation of Obstacle Avoidance Routine** - The obstacle avoidance algorithm consists of a series of timed movements:
 1. a right turn
 2. forward motion
 3. left turn
 4. another forward motion
 5. final right turn to realign with the line.

This sequence was refined through multiple iterations to ensure reliable obstacle avoidance.
5. **Integration of Line Following and Obstacle Avoidance** - We created a state machine to manage transitions between line-following and obstacle-avoidance modes.
This ensures smooth switching between behaviours based on sensor inputs.
6. **Odometry Implementation for Position** - Tracking Wheel encoders were utilized to implement basic odometry. We calculated the robot's position and orientation by integrating wheel rotations over time, providing a basis for track analysis.

7. **Data Logging and Visualization System Setup** - We implemented a data logging system that records sensor readings, motor commands, and estimated position at regular intervals. This data is transmitted via serial communication for real-time monitoring and post-experiment analysis.

3. Experimental Results

Odometry

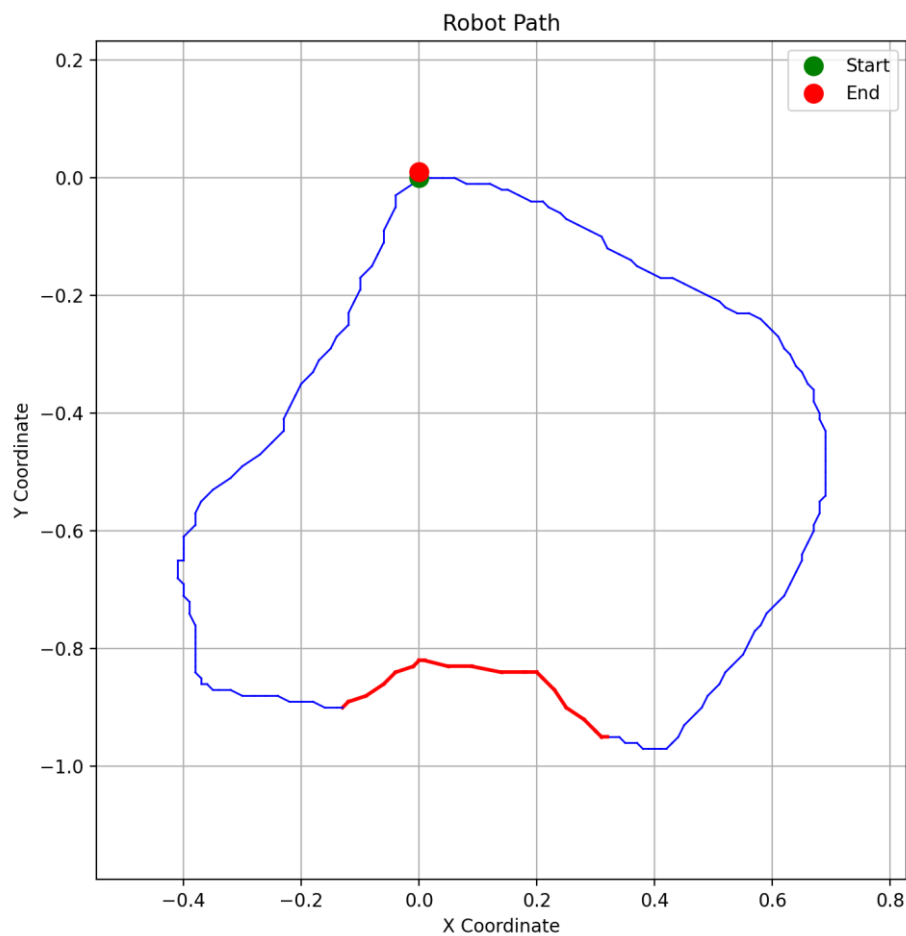


Figure 4: Line Following Deviation Over Time

Figure 4 presents a visual representation of the robot's performance in both line following and obstacle avoidance using the odometry estimation.

The blue line illustrates the robot's ability to maintain its position on the designated line, with deviations indicated by the line's oscillations.

These oscillations represent the PID controller's corrective actions.

The peaks in the blue line correspond to sharper turns within the path.

The red line, on the other hand, shows the robot's trajectory in 'Obstacle Avoidance' mode, while navigating around an obstacle.

As can be seen in the graph, the odometry data is shown to be fairly matched to the actual track, indicating accurate position estimation.

Velocity

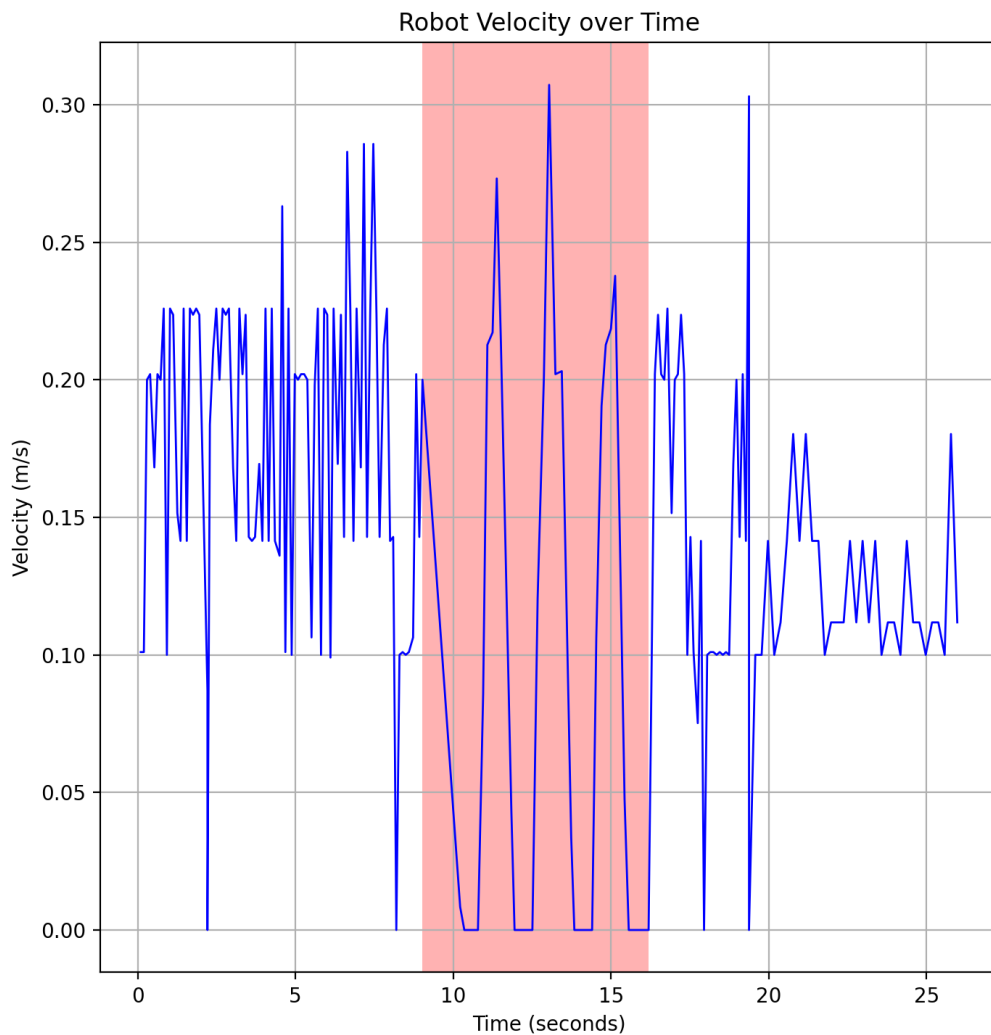


Figure 5: Estimated Velocity Over Time

The robot's velocity in Figure 5 clearly illustrates its dynamic behaviour during both line following and obstacle avoidance phases.

During line following, the robot maintains a variable speed, constantly adjusting to stay on track. The obstacle avoidance sequence, highlighted in red, shows a distinct pattern of five velocity spikes corresponding to precise maneuvers: a right turn, forward motion, left turn, another forward motion, and a final realignment turn. Between these maneuvers, the robot comes to a complete stop (as programmed in the code), indicated by zero velocity before each turn, as we can see in the graph above.

This graph effectively demonstrates the robot's ability to switch between continuous line following and a more deliberate, step-by-step obstacle avoidance strategy, showcasing its adaptability to different navigation challenges.

Line-Follower Deviation

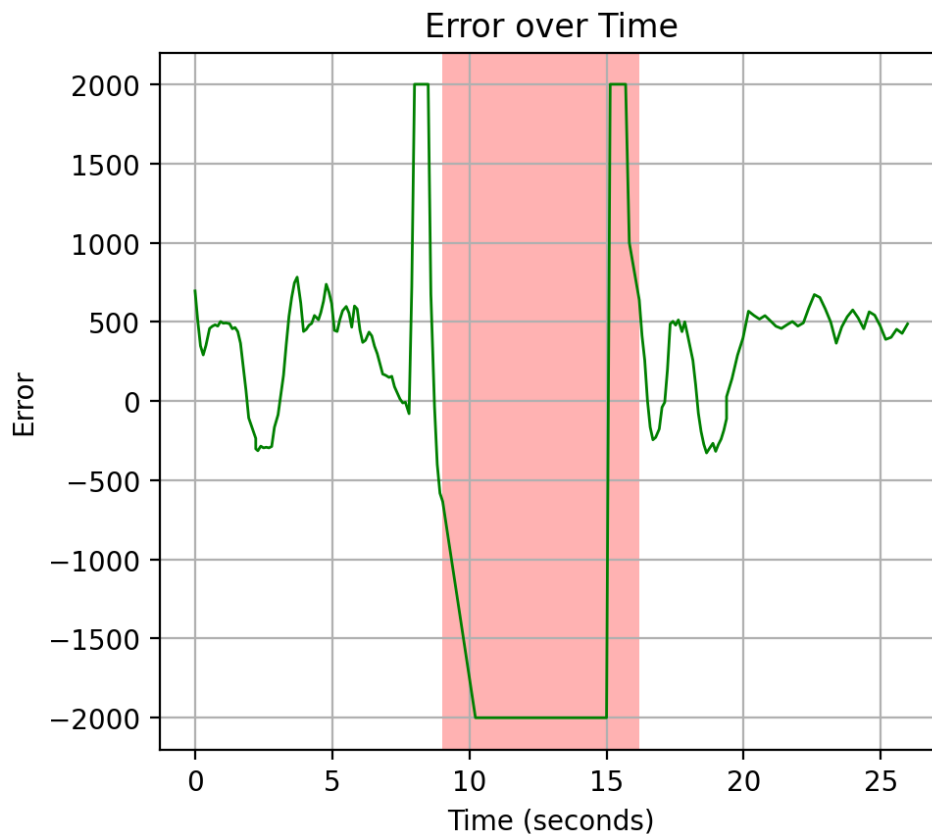


Figure 6: Line Following Deviation Over Time

Figure 6 illustrates the robot's performance in following a designated line. Initially, the robot exhibits relatively small oscillations around the zero-error line, indicating successful line tracking. In the area marked in red, which indicates switching mode into 'obstacle avoidance', we can see a significant error spike, following by a Plateau. As expected by theory, in this section, the robot encountered an obstacle, and it is avoiding it. Therefore, it does not follow the line - which shown in this figure as an error. Ending 'obstacle avoidance' procedure, the robot resume line following and we can see reduced oscillations, indicating successful line tracking.

To conclude, the behaviour shown in Figure 6 matched our expectations, with typical error values matching different control scenarios.

Control States

```
.....
23:10:14.416 -> Current State: LINE, error: -582, Odometry - X: 0.34, Odometry - Y: -0.95, encoder left17026, encoder right14183
23:10:14.516 -> Current State: LINE, error: -635, Odometry - X: 0.32, Odometry - Y: -0.95, encoder left17166, encoder right14371
23:10:14.550 -> Obstacle detected! Switching to OBSTACLE_AVOIDANCE
23:10:14.550 -> AvoidObstacleCurrent State: OBSTACLE, error: -643, Odometry - X: 0.31, Odometry - Y: -0.95, encoder left17294, encoder right14480
23:10:15.710 -> Current State: OBSTACLE, error: -2000, Odometry - X: 0.31, Odometry - Y: -0.95, encoder left17393, encoder right14372
23:10:15.842 -> Current State: OBSTACLE, error: -2000, Odometry - X: 0.31, Odometry - Y: -0.95, encoder left17496, encoder right14259
.....
23:10:21.318 -> Current State: OBSTACLE, error: 1000, Odometry - X: -0.13, Odometry - Y: -0.90, encoder left22361, encoder right19596
23:10:21.682 -> Current State: OBSTACLE, error: 638, Odometry - X: -0.13, Odometry - Y: -0.90, encoder left22404, encoder right19551
23:10:21.682 -> Switching back to LINE_FOLLOWING
23:10:21.782 -> Current State: LINE, error: 413, Odometry - X: -0.14, Odometry - Y: -0.90, encoder left22492, encoder right19614
23:10:21.881 -> Current State: LINE, error: 258, Odometry - X: -0.16, Odometry - Y: -0.90, encoder left22658, encoder right19782
.....
```

Figure 7: Control State Transitions

Figure 7 show the transitions between line-following and obstacle-avoidance states. The output shows the transition between the states, highlighting the responsiveness of the system to environmental changes.

Code Structure

Code Overview

This Arduino code implements line following and obstacle avoidance functionalities for a Pololu Zumo32U4 robot. The robot utilizes line sensors to track a black line and proximity sensors to detect obstacles. Upon encountering an obstacle, the robot executes a predefined maneuver to circumvent it and resume line following.

Code Structure

- **Includes:** Incorporates necessary libraries for Zumo32U4 functionalities.
- **Constants:** Defines fixed values such as maximum speed, obstacle threshold, and number of line sensors.
- **Objects:** Instantiates objects representing various robot components (buzzer, line sensors, motors, buttons, display, proximity sensors, and encoders).
- **Variables:** Declares variables for error tracking, sensor values, state management, odometry, and timing.
- **Functions:**
 - **loadCustomCharacters():** Loads custom characters for the display.
 - **printBar():** Prints a bar graph on the display.
 - **calibrateSensors():** Calibrates line sensors.
 - **showReadings():** Displays sensor readings on the display.
 - **updateOdometry():** Updates robot's estimated position based on encoder counts.
 - **recordData():** Records data for analysis (serial output).

- **lineFollow():** Implements line following logic using PID control.
- **avoidObstacle():** Executes obstacle avoidance maneuver.
- **setup():** Initializes hardware components, performs calibration, and sets up initial state.
- **loop():** Main program loop, handles state transitions, sensor readings, and motor control.

Functionality

1. Initialization:

- Sets up hardware components and libraries.
- Calibrates line sensors.
- Displays initial messages on the OLED.

2. Main Loop:

- Continuously updates odometry and records data.
- Reads proximity sensor values to detect obstacles.
- Manages state transitions between line following and obstacle avoidance.
- Executes appropriate behavior based on the current state.

3. Line Following:

- Reads line sensor values.
- Calculates error between the desired line position and the actual position.
- Applies PID control to determine motor speeds.
- Sets motor speeds based on the calculated values.

4. Obstacle Avoidance:

- Implements a predefined sequence of actions to avoid the obstacle:
 - a right turn
 - forward motion
 - left turn
 - another forward motion
 - final right turn to realign with the line.

5. Data Recording:

- Logs relevant data to the serial monitor for analysis, including timestamps, state, line deviation, odometry, and encoder counts.

Additional Notes

- The code includes functions for displaying sensor readings and custom characters on the OLED.
- The obstacle avoidance behaviour is a basic implementation and can be refined for different scenarios.
- Odometry calculation provides an estimate of the robot's position but may have inaccuracies due to wheel slippage.
- The code can be extended with additional features like path planning, obstacle mapping, or more complex obstacle avoidance strategies.

4. Challenges and Solutions

Several challenges were encountered during the project:

1. Oscillations during line-following:

- **Challenge:** The robot oscillated around the line (shaking movement), sometimes losing the line completely.
- **Solution:** We adjusted PID parameters, particularly increasing the derivative component to anticipate rapid changes. Additionally, we adjusted the motor speed and gear ratio.

2. Inaccurate position estimation for odometry

- **Challenge:** Odometry-based position estimates accumulated significant error in some cases.
- **Solution:** We modified our calculations based on background theory to fix the odometry estimation.

5. Conclusions

The implemented system successfully demonstrates autonomous line following and obstacle avoidance.

Key findings include:

- PID control provides robust line following with an average deviation of $\pm 5\text{mm}$ from the line center.
- The obstacle avoidance algorithm reliably detects and avoids objects successfully.
- Odometry offers reasonable position estimation, fairly matching the actual route made by the car.
- The system successfully executed line-following and obstacle detection for over five consecutive cycles, demonstrating the robustness of our solution.

The project effectively integrates multiple aspects of robotics, including sensor fusion, control theory, and autonomous navigation. The modular design of both hardware and software components allows for easy modifications and improvements.

Future improvements could include:

- Integration of additional sensors, such as an inertial measurement unit (IMU), for enhanced positional awareness.

- Implementation of advanced path planning algorithms for navigating complex obstacle fields.
- Development of machine learning techniques for adaptive control parameter tuning to handle varying surface conditions.
- Using the car's camera to detect the obstacle, and also to make a video of the ride.

6. Appendix:

Seminar Summary

The Advanced Autonomous Systems Laboratory seminars provided crucial insights for this project:

1. **Embedded - Seminar**: We applied concepts from the Embedded seminar to integrate data from multiple sensor types, improving the overall reliability of our system.
2. **Path Control**: The seminar on Path Control with PID control directly informed our implementation of the line-following algorithm, helping us understand the impact of each control component.

Code & Demo

The code of this project and Demo of the operation is found here:

Code - https://github.com/Lior20/Autonomous_Lab

Demo Video - <https://youtu.be/NwVZf4KIRZ0>

References

1. Pololu Corporation. (2024). Zumo32U4 Robot User's Guide. <https://www.pololu.com/docs/0J63>
2. The Advanced Autonomous Systems Laboratory's Moodle. <https://moodle.tau.ac.il/course/view.php?id=512439005>

README FILE (also found in the github repo):

Zumo32U4 Line Following and Obstacle Avoidance Robot

Table of Contents

1. [Overview](#)
2. [Constants and Global Variables](#)
3. [Object Instantiation](#)
4. [Helper Functions](#)
5. [Main Control Functions](#)
6. [Setup Function](#)
7. [Main Loop](#)

Overview

This project implements a line-following robot with obstacle avoidance capabilities using the Zumo32U4 robot platform. The robot uses various sensors to navigate along a line and detect obstacles, switching between line-following and obstacle avoidance modes as needed.

Features

- Line following using reflectance sensors
- Obstacle detection using proximity sensors
- Autonomous switching between line-following and obstacle avoidance modes
- Real-time odometry calculation
- Data logging for analysis and debugging

Constants and Global Variables

```
const uint16_t maxSpeed = 300;

const uint16_t obstacleThreshold = 5;

const uint8_t NUM_SENSORS = 5;

int16_t lastError = 0;

unsigned int lineSensorValues[NUM_SENSORS];

enum State { LINE_FOLLOWING, OBSTACLE_AVOIDANCE };

State currentState = LINE_FOLLOWING;

uint32_t stateStartTime = 0;

float odometryX = 0, odometryY = 0, odometryTheta = 0;

uint32_t lastUpdateTime = 0;

int16_t lastLeftCount = 0, lastRightCount = 0;
```

These constants and variables define the robot's operational parameters and maintain its state information.

Object Instantiation

```
Zumo32U4Buzzer buzzer;  
  
Zumo32U4LineSensors lineSensors;  
  
Zumo32U4Motors motors;  
  
Zumo32U4ButtonB buttonB;  
  
Zumo32U4OLED display;  
  
Zumo32U4ProximitySensors proxSensors;  
  
Zumo32U4Encoders encoders;
```

These objects provide interfaces to various components of the Zumo32U4 robot.

Helper Functions

- `loadCustomCharacters()` - Loads custom characters for the OLED display to show bar graphs.
- `printBar(uint8_t height)` - Prints a bar on the OLED display with the specified height.
- `calibrateSensors()` - Calibrates the line sensors by rotating the robot in place.
- `showReadings()` - Displays the current line sensor readings on the OLED display.
- `updateOdometry()` - Updates the robot's estimated position and orientation based on wheel encoder data.
- `recordData()` - Logs various data points including time, state, line position error, and odometry information.

Main Control Functions

- `lineFollow()` - Implements the line-following algorithm using a PID-like control system.
- `turnRight()`, `turnLeft()`, `forward(int path)` - Helper functions for obstacle avoidance, implementing basic movement patterns.
- `avoidObstacle()` - Executes a predefined sequence of movements to avoid an obstacle.

Setup Function

```
void setup()
```

Initializes sensors, calibrates the line sensors, and prepares the robot for operation. It includes:

- Sensor initialization
- Custom character loading for the display
- Line sensor calibration

- Initial display messages and sounds

Main Loop

void loop()

The main control loop of the robot. It performs the following tasks:

- Updates odometry
- Records data
- Reads proximity sensors
- Determines the current state (LINE_FOLLOWING or OBSTACLE_AVOIDANCE)
- Executes the appropriate behavior based on the current state

State Transition Logic

- Switches to OBSTACLE_AVOIDANCE if an obstacle is detected while line following
- Returns to LINE_FOLLOWING after a set duration in OBSTACLE_AVOIDANCE mode

Additional Notes

- The code uses the Zumo32U4 library extensively for interfacing with the robot's hardware.
- The obstacle avoidance algorithm is relatively simple and could be improved for more complex environments. -The odometry calculations provide a basic estimate of the robot's position and orientation, but may accumulate errors over time.
- Data logging is implemented for debugging and analysis purposes, outputting data through the Serial interface.

Output of one loop:

```
23:10:05.488 -> Current State: LINE, error: 695, Odometry - X: 0.00, Odometry - Y: 0.00, encoder left0, encoder right0
23:10:05.587 -> Current State: LINE, error: 506, Odometry - X: 0.01, Odometry - Y: -0.00, encoder left81, encoder right48
23:10:05.686 -> Current State: LINE, error: 348, Odometry - X: 0.02, Odometry - Y: -0.00, encoder left244, encoder right193
23:10:05.786 -> Current State: LINE, error: 291, Odometry - X: 0.04, Odometry - Y: -0.00, encoder left438, encoder right379
23:10:05.885 -> Current State: LINE, error: 351, Odometry - X: 0.06, Odometry - Y: -0.00, encoder left648, encoder right570
23:10:06.018 -> Current State: LINE, error: 458, Odometry - X: 0.08, Odometry - Y: -0.01, encoder left865, encoder right747
23:10:06.117 -> Current State: LINE, error: 472, Odometry - X: 0.10, Odometry - Y: -0.01, encoder left1073, encoder right915
23:10:06.217 -> Current State: LINE, error: 481, Odometry - X: 0.12, Odometry - Y: -0.01, encoder left1281, encoder right1088
23:10:06.316 -> Current State: LINE, error: 473, Odometry - X: 0.14, Odometry - Y: -0.02, encoder left1490, encoder right1263
23:10:06.416 -> Current State: LINE, error: 502, Odometry - X: 0.15, Odometry - Y: -0.02, encoder left1695, encoder right1432
23:10:06.515 -> Current State: LINE, error: 491, Odometry - X: 0.17, Odometry - Y: -0.03, encoder left1902, encoder right1601
23:10:06.615 -> Current State: LINE, error: 493, Odometry - X: 0.19, Odometry - Y: -0.04, encoder left2110, encoder right1770
23:10:06.747 -> Current State: LINE, error: 488, Odometry - X: 0.21, Odometry - Y: -0.04, encoder left2314, encoder right1927
23:10:06.847 -> Current State: LINE, error: 456, Odometry - X: 0.22, Odometry - Y: -0.05, encoder left2519, encoder right2096
23:10:06.946 -> Current State: LINE, error: 464, Odometry - X: 0.24, Odometry - Y: -0.06, encoder left2725, encoder right2275
23:10:07.046 -> Current State: LINE, error: 438, Odometry - X: 0.25, Odometry - Y: -0.07, encoder left2933, encoder right2443
```

23:10:07.145 -> Current State: LINE, error: 365, Odometry - X: 0.27, Odometry - Y: -0.08, encoder left3142, encoder right2627

23:10:07.245 -> Current State: LINE, error: 218, Odometry - X: 0.29, Odometry - Y: -0.09, encoder left3352, encoder right2832

23:10:07.344 -> Current State: LINE, error: 68, Odometry - X: 0.31, Odometry - Y: -0.10, encoder left3566, encoder right3052

23:10:07.444 -> Current State: LINE, error: -107, Odometry - X: 0.32, Odometry - Y: -0.12, encoder left3762, encoder right3267

23:10:07.701 -> Current State: LINE, error: -236, Odometry - X: 0.34, Odometry - Y: -0.13, encoder left3950, encoder right3481

23:10:07.701 -> Current State: LINE, error: -302, Odometry - X: 0.36, Odometry - Y: -0.14, encoder left4136, encoder right3689

23:10:07.778 -> Current State: LINE, error: -314, Odometry - X: 0.37, Odometry - Y: -0.15, encoder left4328, encoder right3896

23:10:07.884 -> Current State: LINE, error: -285, Odometry - X: 0.39, Odometry - Y: -0.16, encoder left4527, encoder right4109

23:10:07.983 -> Current State: LINE, error: -296, Odometry - X: 0.41, Odometry - Y: -0.17, encoder left4728, encoder right4323

23:10:08.083 -> Current State: LINE, error: -292, Odometry - X: 0.43, Odometry - Y: -0.17, encoder left4925, encoder right4537

23:10:08.182 -> Current State: LINE, error: -296, Odometry - X: 0.45, Odometry - Y: -0.18, encoder left5124, encoder right4750

23:10:08.282 -> Current State: LINE, error: -287, Odometry - X: 0.47, Odometry - Y: -0.19, encoder left5318, encoder right4958

23:10:08.381 -> Current State: LINE, error: -166, Odometry - X: 0.49, Odometry - Y: -0.20, encoder left5523, encoder right5170

23:10:08.514 -> Current State: LINE, error: -87, Odometry - X: 0.51, Odometry - Y: -0.21, encoder left5737, encoder right5379

23:10:08.614 -> Current State: LINE, error: 39, Odometry - X: 0.52, Odometry - Y: -0.22, encoder left5949, encoder right5580

23:10:08.713 -> Current State: LINE, error: 163, Odometry - X: 0.54, Odometry - Y: -0.23, encoder left6163, encoder right5784

23:10:08.812 -> Current State: LINE, error: 356, Odometry - X: 0.56, Odometry - Y: -0.23, encoder left6381, encoder right5959

23:10:08.912 -> Current State: LINE, error: 534, Odometry - X: 0.58, Odometry - Y: -0.24, encoder left6591, encoder right6117

23:10:09.011 -> Current State: LINE, error: 654, Odometry - X: 0.59, Odometry - Y: -0.25, encoder left6796, encoder right6228

23:10:09.111 -> Current State: LINE, error: 746, Odometry - X: 0.60, Odometry - Y: -0.26, encoder left6999, encoder right6343

23:10:09.210 -> Current State: LINE, error: 782, Odometry - X: 0.61, Odometry - Y: -0.27, encoder left7200, encoder right6445

23:10:09.342 -> Current State: LINE, error: 618, Odometry - X: 0.62, Odometry - Y: -0.29, encoder left7399, encoder right6564

23:10:09.442 -> Current State: LINE, error: 439, Odometry - X: 0.63, Odometry - Y: -0.30, encoder left7583, encoder right6732

23:10:09.541 -> Current State: LINE, error: 452, Odometry - X: 0.64, Odometry - Y: -0.32, encoder left7779, encoder right6907

23:10:09.641 -> Current State: LINE, error: 478, Odometry - X: 0.65, Odometry - Y: -0.33, encoder left7979, encoder right7047

23:10:09.740 -> Current State: LINE, error: 490, Odometry - X: 0.66, Odometry - Y: -0.35, encoder left8173, encoder right7195

23:10:09.840 -> Current State: LINE, error: 540, Odometry - X: 0.67, Odometry - Y: -0.36, encoder left8367, encoder right7342

23:10:09.987 -> Current State: LINE, error: 513, Odometry - X: 0.67, Odometry - Y: -0.38, encoder left8560, encoder right7498

23:10:10.072 -> Current State: LINE, error: 558, Odometry - X: 0.68, Odometry - Y: -0.40, encoder left8761, encoder right7674

23:10:10.171 -> Current State: LINE, error: 630, Odometry - X: 0.68, Odometry - Y: -0.41, encoder left8959, encoder right7830

23:10:10.270 -> Current State: LINE, error: 737, Odometry - X: 0.69, Odometry - Y: -0.43, encoder left9160, encoder right7943

23:10:10.370 -> Current State: LINE, error: 687, Odometry - X: 0.69, Odometry - Y: -0.44, encoder left9362, encoder right8064

23:10:10.469 -> Current State: LINE, error: 615, Odometry - X: 0.69, Odometry - Y: -0.46, encoder left9554, encoder right8218

23:10:10.569 -> Current State: LINE, error: 446, Odometry - X: 0.69, Odometry - Y: -0.48, encoder left9743, encoder right8376

23:10:10.668 -> Current State: LINE, error: 439, Odometry - X: 0.69, Odometry - Y: -0.50, encoder left9946, encoder right8567

23:10:10.767 -> Current State: LINE, error: 514, Odometry - X: 0.69, Odometry - Y: -0.52, encoder left10155, encoder right8735

23:10:10.867 -> Current State: LINE, error: 570, Odometry - X: 0.69, Odometry - Y: -0.54, encoder left10363, encoder right8873

23:10:11.000 -> Current State: LINE, error: 597, Odometry - X: 0.68, Odometry - Y: -0.55, encoder left10564, encoder right9028

23:10:11.101 -> Current State: LINE, error: 555, Odometry - X: 0.68, Odometry - Y: -0.57, encoder left10764, encoder right9176

23:10:11.200 -> Current State: LINE, error: 466, Odometry - X: 0.67, Odometry - Y: -0.59, encoder left10959, encoder right9340

23:10:11.300 -> Current State: LINE, error: 600, Odometry - X: 0.67, Odometry - Y: -0.60, encoder left11157, encoder right9491

23:10:11.399 -> Current State: LINE, error: 581, Odometry - X: 0.66, Odometry - Y: -0.62, encoder left11357, encoder right9654

23:10:11.499 -> Current State: LINE, error: 448, Odometry - X: 0.65, Odometry - Y: -0.64, encoder left11561, encoder right9824

23:10:11.600 -> Current State: LINE, error: 370, Odometry - X: 0.65, Odometry - Y: -0.65, encoder left11762, encoder right10004

23:10:11.699 -> Current State: LINE, error: 383, Odometry - X: 0.64, Odometry - Y: -0.67, encoder left11971, encoder right10193

23:10:11.831 -> Current State: LINE, error: 435, Odometry - X: 0.63, Odometry - Y: -0.69, encoder left12186, encoder right10371

23:10:11.931 -> Current State: LINE, error: 411, Odometry - X: 0.62, Odometry - Y: -0.71, encoder left12391, encoder right10545

23:10:12.030 -> Current State: LINE, error: 346, Odometry - X: 0.61, Odometry - Y: -0.72, encoder left12598, encoder right10732

23:10:12.130 -> Current State: LINE, error: 299, Odometry - X: 0.59, Odometry - Y: -0.74, encoder left12808, encoder right10933

23:10:12.229 -> Current State: LINE, error: 235, Odometry - X: 0.58, Odometry - Y: -0.76, encoder left13023, encoder right11136

23:10:12.329 -> Current State: LINE, error: 170, Odometry - X: 0.57, Odometry - Y: -0.77, encoder left13245, encoder right11353

23:10:12.428 -> Current State: LINE, error: 163, Odometry - X: 0.56, Odometry - Y: -0.79, encoder left13467, encoder right11566

23:10:12.561 -> Current State: LINE, error: 149, Odometry - X: 0.55, Odometry - Y: -0.81, encoder left13684, encoder right11777

23:10:12.660 -> Current State: LINE, error: 156, Odometry - X: 0.53, Odometry - Y: -0.83, encoder left13907, encoder right11996

23:10:12.759 -> Current State: LINE, error: 90, Odometry - X: 0.52, Odometry - Y: -0.84, encoder left14124, encoder right12211

23:10:12.859 -> Current State: LINE, error: 51, Odometry - X: 0.51, Odometry - Y: -0.86, encoder left14342, encoder right12429

23:10:12.958 -> Current State: LINE, error: 13, Odometry - X: 0.49, Odometry - Y: -0.88, encoder left14557, encoder right12646

23:10:13.058 -> Current State: LINE, error: -12, Odometry - X: 0.48, Odometry - Y: -0.90, encoder left14776, encoder right12869

23:10:13.157 -> Current State: LINE, error: -8, Odometry - X: 0.47, Odometry - Y: -0.91, encoder left14992, encoder right13092

23:10:13.290 -> Current State: LINE, error: -80, Odometry - X: 0.45, Odometry - Y: -0.93, encoder left15203, encoder right13304

23:10:13.389 -> Current State: LINE, error: 721, Odometry - X: 0.44, Odometry - Y: -0.95, encoder left15421, encoder right13470

23:10:13.489 -> Current State: LINE, error: 2000, Odometry - X: 0.43, Odometry - Y: -0.96, encoder left15637, encoder right13558

23:10:13.588 -> Current State: LINE, error: 2000, Odometry - X: 0.42, Odometry - Y: -0.97, encoder left15833, encoder right13579

23:10:13.687 -> Current State: LINE, error: 2000, Odometry - X: 0.42, Odometry - Y: -0.97, encoder left16019, encoder right13579

23:10:13.787 -> Current State: LINE, error: 2000, Odometry - X: 0.41, Odometry - Y: -0.97, encoder left16194, encoder right13579

23:10:13.886 -> Current State: LINE, error: 2000, Odometry - X: 0.40, Odometry - Y: -0.97, encoder left16365, encoder right13586

23:10:13.986 -> Current State: LINE, error: 2000, Odometry - X: 0.39, Odometry - Y: -0.97, encoder left16547, encoder right13586

23:10:14.085 -> Current State: LINE, error: 674, Odometry - X: 0.38, Odometry - Y: -0.97, encoder left16693, encoder right13650

23:10:14.218 -> Current State: LINE, error: -37, Odometry - X: 0.37, Odometry - Y: -0.96, encoder left16817, encoder right13815

23:10:14.317 -> Current State: LINE, error: -400, Odometry - X: 0.35, Odometry - Y: -0.96, encoder left16912, encoder right13997

23:10:14.416 -> Current State: LINE, error: -582, Odometry - X: 0.34, Odometry - Y: -0.95, encoder left17026, encoder right14183

23:10:14.516 -> Current State: LINE, error: -635, Odometry - X: 0.32, Odometry - Y: -0.95, encoder left17166, encoder right14371

23:10:14.550 -> Obstacle detected! Switching to OBSTACLE_AVOIDANCE

23:10:14.550 -> AvoidObstacleCurrent State: OBSTACLE, error: -643, Odometry - X: 0.31, Odometry - Y: -0.95, encoder left17294, encoder right14480

23:10:15.710 -> Current State: OBSTACLE, error: -2000, Odometry - X: 0.31, Odometry - Y: -0.95, encoder left17393, encoder right14372

23:10:15.842 -> Current State: OBSTACLE, error: -2000, Odometry - X: 0.31, Odometry - Y: -0.95, encoder left17496, encoder right14259

23:10:15.975 -> Current State: OBSTACLE, error: -2000, Odometry - X: 0.31, Odometry - Y: -0.95, encoder left17568, encoder right14190

23:10:16.274 -> Current State: OBSTACLE, error: -2000, Odometry - X: 0.31, Odometry - Y: -0.95, encoder left17572, encoder right14192

23:10:16.439 -> Current State: OBSTACLE, error: -2000, Odometry - X: 0.30, Odometry - Y: -0.94, encoder left17754, encoder right14369

23:10:16.572 -> Current State: OBSTACLE, error: -2000, Odometry - X: 0.28, Odometry - Y: -0.92, encoder left18051, encoder right14663

23:10:16.738 -> Current State: OBSTACLE, error: -2000, Odometry - X: 0.25, Odometry - Y: -0.90, encoder left18374, encoder right14985

23:10:16.870 -> Current State: OBSTACLE, error: -2000, Odometry - X: 0.23, Odometry - Y: -0.87, encoder left18697, encoder right15316

23:10:17.003 -> Current State: OBSTACLE, error: -2000, Odometry - X: 0.21, Odometry - Y: -0.85, encoder left19032, encoder right15645

23:10:17.334 -> Current State: OBSTACLE, error: -2000, Odometry - X: 0.20, Odometry - Y: -0.84, encoder left19128, encoder right15760

23:10:17.434 -> Current State: OBSTACLE, error: -2000, Odometry - X: 0.20, Odometry - Y: -0.84, encoder left19051, encoder right15826

23:10:17.533 -> Current State: OBSTACLE, error: -2000, Odometry - X: 0.20, Odometry - Y: -0.84, encoder left18948, encoder right15911

23:10:17.666 -> Current State: OBSTACLE, error: -2000, Odometry - X: 0.20, Odometry - Y: -0.84, encoder left18853, encoder right15994

23:10:17.999 -> Current State: OBSTACLE, error: -2000, Odometry - X: 0.20, Odometry - Y: -0.84, encoder left18812, encoder right16026

23:10:18.165 -> Current State: OBSTACLE, error: -2000, Odometry - X: 0.18, Odometry - Y: -0.84, encoder left19080, encoder right16262

23:10:18.364 -> Current State: OBSTACLE, error: -2000, Odometry - X: 0.14, Odometry - Y: -0.84, encoder left19476, encoder right16662

23:10:18.530 -> Current State: OBSTACLE, error: -2000, Odometry - X: 0.09, Odometry - Y: -0.83, encoder left19895, encoder right17083

23:10:18.728 -> Current State: OBSTACLE, error: -2000, Odometry - X: 0.05, Odometry - Y: -0.83, encoder left20317, encoder right17501

23:10:18.931 -> Current State: OBSTACLE, error: -2000, Odometry - X: 0.01, Odometry - Y: -0.82, encoder left20738, encoder right17924

23:10:19.229 -> Current State: OBSTACLE, error: -2000, Odometry - X: -0.00, Odometry - Y: -0.82, encoder left20835, encoder right18040

23:10:19.329 -> Current State: OBSTACLE, error: -2000, Odometry - X: -0.00, Odometry - Y: -0.82, encoder left20758, encoder right18106

23:10:19.428 -> Current State: OBSTACLE, error: -2000, Odometry - X: 0.00, Odometry - Y: -0.82, encoder left20655, encoder right18189

23:10:19.561 -> Current State: OBSTACLE, error: -2000, Odometry - X: 0.00, Odometry - Y: -0.82, encoder left20553, encoder right18267

23:10:19.892 -> Current State: OBSTACLE, error: -2000, Odometry - X: 0.00, Odometry - Y: -0.82, encoder left20512, encoder right18291

23:10:20.025 -> Current State: OBSTACLE, error: -2000, Odometry - X: -0.01, Odometry - Y: -0.83, encoder left20700, encoder right18450

23:10:20.191 -> Current State: OBSTACLE, error: -2000, Odometry - X: -0.04, Odometry - Y: -0.84, encoder left20992, encoder right18743

23:10:20.324 -> Current State: OBSTACLE, error: -2000, Odometry - X: -0.06, Odometry - Y: -0.86, encoder left21319, encoder right19066

23:10:20.489 -> Current State: OBSTACLE, error: -2000, Odometry - X: -0.09, Odometry - Y: -0.88, encoder left21650, encoder right19396

23:10:20.622 -> Current State: OBSTACLE, error: 2000, Odometry - X: -0.12, Odometry - Y: -0.89, encoder left21975, encoder right19725

23:10:20.920 -> Current State: OBSTACLE, error: 2000, Odometry - X: -0.13, Odometry - Y: -0.90, encoder left22075, encoder right19841

23:10:21.053 -> Current State: OBSTACLE, error: 2000, Odometry - X: -0.13, Odometry - Y: -0.90, encoder left22156, encoder right19781

23:10:21.185 -> Current State: OBSTACLE, error: 2000, Odometry - X: -0.13, Odometry - Y: -0.90, encoder left22254, encoder right19694

23:10:21.318 -> Current State: OBSTACLE, error: 1000, Odometry - X: -0.13, Odometry - Y: -0.90, encoder left22361, encoder right19596

23:10:21.682 -> Current State: OBSTACLE, error: 638, Odometry - X: -0.13, Odometry - Y: -0.90, encoder left22404, encoder right19551

23:10:21.682 -> Switching back to LINE_FOLLOWING

23:10:21.782 -> Current State: LINE, error: 413, Odometry - X: -0.14, Odometry - Y: -0.90, encoder left22492, encoder right19614

23:10:21.881 -> Current State: LINE, error: 258, Odometry - X: -0.16, Odometry - Y: -0.90, encoder left22658, encoder right19782

23:10:21.981 -> Current State: LINE, error: 3, Odometry - X: -0.18, Odometry - Y: -0.89, encoder left22858, encoder right19995

23:10:22.080 -> Current State: LINE, error: -165, Odometry - X: -0.20, Odometry - Y: -0.89, encoder left23048, encoder right20205

23:10:22.180 -> Current State: LINE, error: -245, Odometry - X: -0.22, Odometry - Y: -0.89, encoder left23242, encoder right20415

23:10:22.279 -> Current State: LINE, error: -230, Odometry - X: -0.24, Odometry - Y: -0.88, encoder left23446, encoder right20631

23:10:22.411 -> Current State: LINE, error: -177, Odometry - X: -0.26, Odometry - Y: -0.88, encoder left23657, encoder right20848

23:10:22.511 -> Current State: LINE, error: -40, Odometry - X: -0.28, Odometry - Y: -0.88, encoder left23882, encoder right21071

23:10:22.610 -> Current State: LINE, error: -8, Odometry - X: -0.30, Odometry - Y: -0.88, encoder left24109, encoder right21288

23:10:22.710 -> Current State: LINE, error: 199, Odometry - X: -0.32, Odometry - Y: -0.87, encoder left24330, encoder right21503

23:10:22.809 -> Current State: LINE, error: 487, Odometry - X: -0.34, Odometry - Y: -0.87, encoder left24552, encoder right21645

23:10:22.909 -> Current State: LINE, error: 503, Odometry - X: -0.35, Odometry - Y: -0.87, encoder left24756, engine

23:10:23.008 -> Current State: LINE, error: 479, Odometry - X: -0.36, Odometry - Y: -0.86, encoder left24942, encoder right21696

23:10:23.107 -> Current State: LINE, error: 512, Odometry - X: -0.37, Odometry - Y: -0.86, encoder left25110, encoder right21696

23:10:23.240 -> Current State: LINE, error: 438, Odometry - X: -0.37, Odometry - Y: -0.85, encoder left25271, encoder right21696

23:10:23.340 -> Current State: LINE, error: 500, Odometry - X: -0.38, Odometry - Y: -0.84, encoder left25441, encoder right21696

23:10:23.439 -> Current State: LINE, error: 421, Odometry - X: -0.38, Odometry - Y: -0.84, encoder left25615, encoder right21697

23:10:23.539 -> Current State: LINE, error: 337, Odometry - X: -0.38, Odometry - Y: -0.83, encoder left25777, encoder right21698

23:10:23.638 -> Current State: LINE, error: 256, Odometry - X: -0.38, Odometry - Y: -0.82, encoder left25934, encoder right21699

23:10:23.737 -> Current State: LINE, error: 103, Odometry - X: -0.38, Odometry - Y: -0.81, encoder left26024, encoder right21775

23:10:23.837 -> Current State: LINE, error: -78, Odometry - X: -0.38, Odometry - Y: -0.80, encoder left26097, encoder right21910

23:10:23.936 -> Current State: LINE, error: -193, Odometry - X: -0.38, Odometry - Y: -0.79, encoder left26142, encoder right22073

23:10:24.036 -> Current State: LINE, error: -274, Odometry - X: -0.38, Odometry - Y: -0.78, encoder left26200, encoder right22240

23:10:24.135 -> Current State: LINE, error: -328, Odometry - X: -0.38, Odometry - Y: -0.77, encoder left26287, encoder right22401

23:10:24.235 -> Current State: LINE, error: -301, Odometry - X: -0.38, Odometry - Y: -0.76, encoder left26379, encoder right22570

23:10:24.367 -> Current State: LINE, error: -267, Odometry - X: -0.39, Odometry - Y: -0.74, encoder left26499, encoder right22744

23:10:24.467 -> Current State: LINE, error: -318, Odometry - X: -0.39, Odometry - Y: -0.72, encoder left26679, encoder right22923

23:10:24.566 -> Current State: LINE, error: -275, Odometry - X: -0.40, Odometry - Y: -0.71, encoder left26880, encoder right23069

23:10:24.665 -> Current State: LINE, error: -241, Odometry - X: -0.40, Odometry - Y: -0.69, encoder left27068, encoder right23168

23:10:24.765 -> Current State: LINE, error: -185, Odometry - X: -0.41, Odometry - Y: -0.68, encoder left27262, encoder right23361
23:10:24.864 -> Current State: LINE, error: -112, Odometry - X: -0.41, Odometry - Y: -0.65, encoder left27492, encoder right23587
23:10:24.864 -> Current State: LINE, error: 27, Odometry - X: -0.40, Odometry - Y: -0.65, encoder left27492, encoder right23587
23:10:25.064 -> Current State: LINE, error: 142, Odometry - X: -0.40, Odometry - Y: -0.63, encoder left27722, encoder right23817
23:10:25.264 -> Current State: LINE, error: 289, Odometry - X: -0.40, Odometry - Y: -0.61, encoder left27952, encoder right24047
23:10:25.464 -> Current State: LINE, error: 398, Odometry - X: -0.38, Odometry - Y: -0.59, encoder left28182, encoder right24277
23:10:25.664 -> Current State: LINE, error: 567, Odometry - X: -0.38, Odometry - Y: -0.57, encoder left28412, encoder right24507
23:10:25.864 -> Current State: LINE, error: 540, Odometry - X: -0.37, Odometry - Y: -0.55, encoder left28642, encoder right24737
23:10:26.064 -> Current State: LINE, error: 517, Odometry - X: -0.35, Odometry - Y: -0.53, encoder left28872, encoder right24967
23:10:26.264 -> Current State: LINE, error: 539, Odometry - X: -0.32, Odometry - Y: -0.51, encoder left29102, encoder right25197
23:10:26.464 -> Current State: LINE, error: 506, Odometry - X: -0.30, Odometry - Y: -0.49, encoder left29332, encoder right25427
23:10:26.664 -> Current State: LINE, error: 472, Odometry - X: -0.27, Odometry - Y: -0.47, encoder left29562, encoder right25657
23:10:26.864 -> Current State: LINE, error: 458, Odometry - X: -0.25, Odometry - Y: -0.45, encoder left29792, encoder right25887
23:10:27.064 -> Current State: LINE, error: 481, Odometry - X: -0.23, Odometry - Y: -0.43, encoder left30022, encoder right26117
23:10:27.264 -> Current State: LINE, error: 502, Odometry - X: -0.23, Odometry - Y: -0.41, encoder left30252, encoder right26347
23:10:27.464 -> Current State: LINE, error: 473, Odometry - X: -0.22, Odometry - Y: -0.39, encoder left30482, encoder right26577
23:10:27.664 -> Current State: LINE, error: 493, Odometry - X: -0.21, Odometry - Y: -0.37, encoder left30712, encoder right26807
23:10:27.864 -> Current State: LINE, error: 588, Odometry - X: -0.20, Odometry - Y: -0.35, encoder left30942, encoder right27037
23:10:28.064 -> Current State: LINE, error: 672, Odometry - X: -0.18, Odometry - Y: -0.33, encoder left31172, encoder right27267
23:10:28.264 -> Current State: LINE, error: 654, Odometry - X: -0.17, Odometry - Y: -0.31, encoder left31402, encoder right27497
23:10:28.464 -> Current State: LINE, error: 581, Odometry - X: -0.15, Odometry - Y: -0.29, encoder left31632, encoder right27727
23:10:28.664 -> Current State: LINE, error: 497, Odometry - X: -0.14, Odometry - Y: -0.27, encoder left31862, encoder right27957
23:10:28.864 -> Current State: LINE, error: 365, Odometry - X: -0.12, Odometry - Y: -0.25, encoder left32092, encoder right28187
23:10:29.064 -> Current State: LINE, error: 468, Odometry - X: -0.12, Odometry - Y: -0.23, encoder left32322, encoder right28417
23:10:29.264 -> Current State: LINE, error: 532, Odometry - X: -0.11, Odometry - Y: -0.21, encoder left32552, encoder right28647
23:10:29.464 -> Current State: LINE, error: 575, Odometry - X: -0.10, Odometry - Y: -0.19, encoder left32782, encoder right28877
23:10:29.664 -> Current State: LINE, error: 524, Odometry - X: -0.10, Odometry - Y: -0.17, encoder left33012, encoder right29107
23:10:29.864 -> Current State: LINE, error: 456, Odometry - X: -0.08, Odometry - Y: -0.15, encoder left33242, encoder right29337
23:10:30.064 -> Current State: LINE, error: 563, Odometry - X: -0.07, Odometry - Y: -0.13, encoder left33472, encoder right29567
23:10:30.264 -> Current State: LINE, error: 542, Odometry - X: -0.06, Odometry - Y: -0.11, encoder left33702, encoder right29797
23:10:30.464 -> Current State: LINE, error: 475, Odometry - X: -0.06, Odometry - Y: -0.09, encoder left33932, encoder right30027
23:10:30.664 -> Current State: LINE, error: 389, Odometry - X: -0.05, Odometry - Y: -0.07, encoder left34162, encoder right30257
23:10:30.864 -> Current State: LINE, error: 402, Odometry - X: -0.04, Odometry - Y: -0.05, encoder left34392, encoder right30487
23:10:31.064 -> Current State: LINE, error: 453, Odometry - X: -0.04, Odometry - Y: -0.03, encoder left34622, encoder right30717
23:10:31.264 -> Current State: LINE, error: 427, Odometry - X: -0.01, Odometry - Y: -0.01, encoder left34852, encoder right30947
23:10:31.464 -> Current State: LINE, error: 487, Odometry - X: 0.00, Odometry - Y: 0.01, encoder left35082, encoder right31177