Developing an add-on autonomous control for a commercially available zero-turn lawn mower

Matthew Charlton

Mentored by Darren Brown and Dr. David Brown

Introduction

Current autonomous lawn mowers are more comparable to outdoor Roombas than traditional mowers. The purpose of this project was to develop an autonomous navigation control system that could be added onto a commercially available zero-turn lawn mower. The specific mower used in this project was the Troy-Bilt Mustang 50 XP. A previous study by Hottinger et al. (2018) showed how frequent and deadly lawn mower injuries can be, so safety was very important during this project.

To get the mower moving autonomously, it first needs to know where it is. The mower's ability to track its position is known as odometry. This was accomplished using sensor fusion, the process of combining data from multiple sensors to get more reliable or comprehensive information than you could get with a single sensor (Laurell et al., 2022). The sensors used in this project were an MPU9250 Inertial Measurement Unit (IMU) to track the heading (where the mower is facing relative to North), and a BN880 Global Navigation Satellite System (GNSS) unit to track position and distance traveled.

Methods and Materials

This project was divided into phases, with multiple stretch goals if the main phases were completed faster than expected. Each phase had corresponding test data to evaluate performance along the way. Phase 1 focused on initial setup and sensor evaluation. Sensors were run using an Arduino Uno. The primary challenge from this phase was tackling the IMU's magnetometer calibration. The calibration was handled using the Magneto v1.2 software from Sailboat Instruments until phase 3 where the ellipsoid fitting algorithm used was recreated in a Python script. The algorithm involved recording magnetometer data over many orientations to correct for sensor bias and magnetic noise. This allows the IMU to measure Earth's magnetic field and determine heading. For phase 2, which involved designing the initial yaw controller, the sensors and Arduino were attached to a wheeled robot (Figure 1).

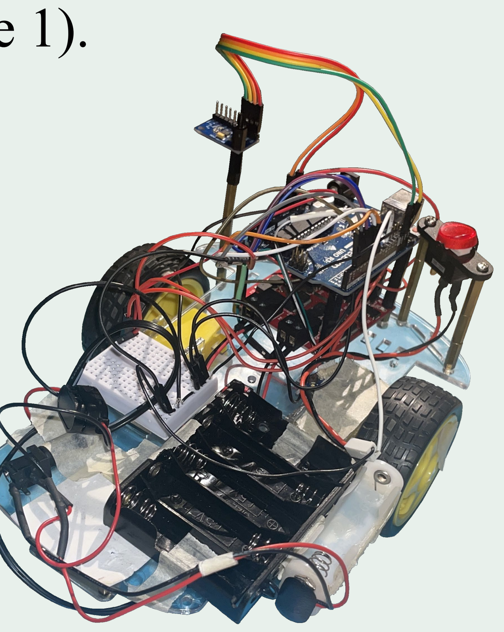


Figure 1 (right): Picture of an Arduino robot programmed using the Arduino IDE that was used as a small-scale mower for testing. It is equipped with the IMU and GNSS sensors, Arduino Uno, AA battery holders, motors, and a motor controller. It was used during phase 2, where the sensors were tested under fully autonomous operation. The goal of the created yaw controller was to drive a straight line utilizing the IMU. It was used again during phase 3 to test the mowing patterns created in simulation before being applied to the mower.

Methods and Materials (continued)

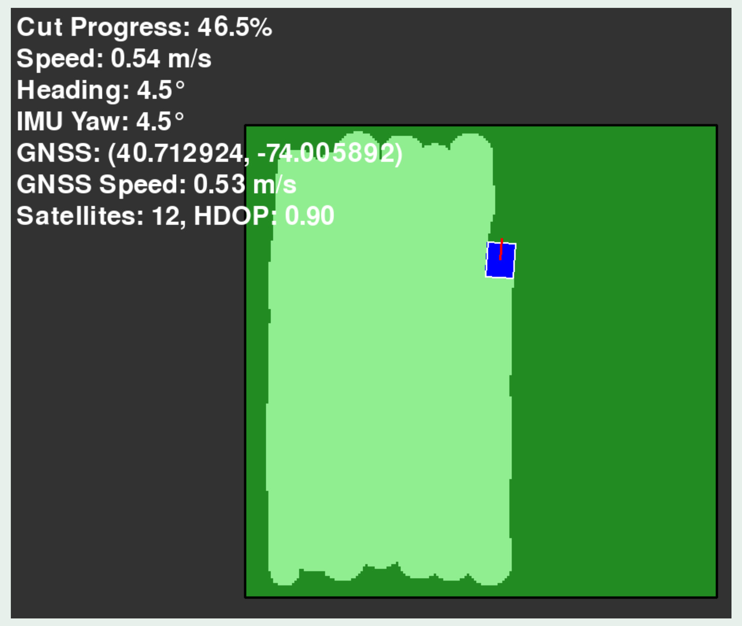
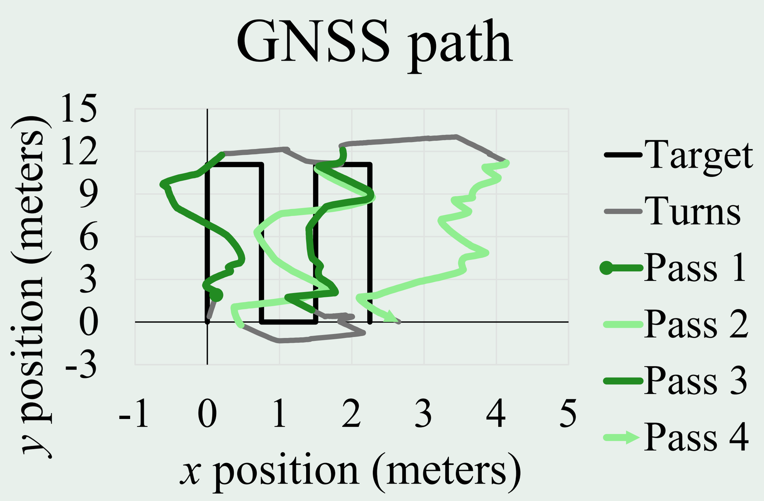


Figure 2 (left): Output during the simulation of a 20 m × 20 m yard created during phase 3. It was originally planned to be made in ROS but was made in Python instead. The simulation was used to rapidly test mowing patterns to maximize coverage without hitting any edges. The pattern consisted of down and back passes, followed by an edge cleanup phase. Yards are built from the GNSS coordinates of three corners.

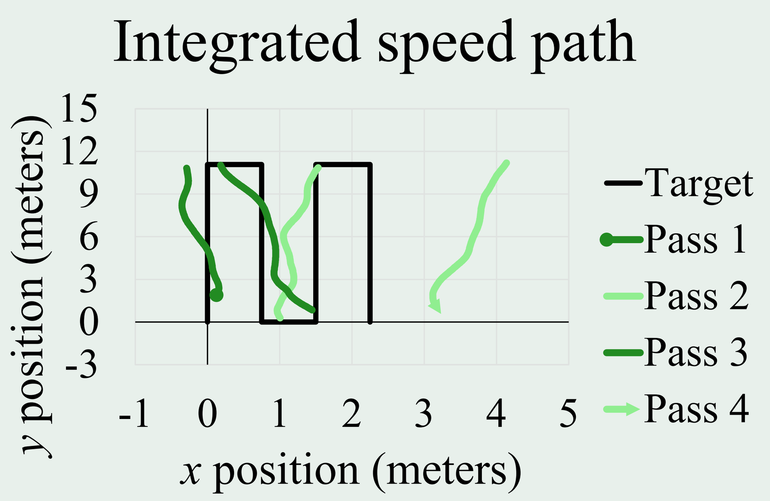
Figure 3 (right): Picture of the mower used in phase 3 with the mowing deck removed. The seat was replaced with a wood board to mount the electronics. Linear actuators were attached to the steering bars for autonomous control. Sensor data was collected by the Arduino and sent to the Python mowing pattern script. Commands were then sent back to Arduino as inputs for a cascaded PID loop that controlled the linear actuators. During runs, latitude, longitude, speed, and heading values were recorded for data analysis. Only the main coverage passes were tested.

Phase 3 included developing a simulation (Figure 2), along with implementing the yaw controller and pattern onto the mower (Figure 3). Phase 4 would have involved adding obstacle detection and avoidance to the system, but this phase was not reached.

Results



Graph 1 (above): The recorded latitude and longitude data was converted into positions on the yard. Mean lateral error (in meters) from eight passes over two runs was collected to get the final lateral error values ($M = 0.46$, $SD = 0.70$).



Graph 2 (above): The recorded speed was integrated along the heading to get yard positions. Mean lateral error (in meters) from eight passes over two runs was collected to get the final lateral error values ($M = 0.29$, $SD = 0.88$).

Results (continued)

Graph 3 (above): Two runs with four passes each were analyzed. Each pass's target heading was found and used to get the heading error over the run. The summarized data from left to right is ($M = −1.55$, $SD = 4.3$), ($M = −2.63$, $SD = 6.7$), ($M = −9.21$, $SD = 4.6$), ($M = −0.07$, $SD = 5.6$), ($M = −1.58$, $SD = 4.3$), ($M = −1.21$, $SD = 5.0$), ($M = −8.17$, $SD = 6.1$), and ($M = −5.03$, $SD = 5.4$).

Conclusion

The project's purpose was met, as a full add-on control system was created. Each required subsystem was created and tested to work separately, and they were all implemented together on the mower, but they could still be improved. This research determined that the GNSS sensor is not accurate enough to serve as the positioning sensor. Previous research demonstrated similar problems with an optical flow sensor. The GNSS data recorded shows very jagged paths, despite the IMU data and videos of the runs showing that the mower maintained fairly straight lines. This project can be improved in further research with the use of improved odometry approaches such as increasing the robustness of magnetometer calibration, using an RTK-GPS, or implementing an Extended or Unscented Kalman Filter like the one used by Meng et al. (2017) for improved sensor fusion.

References

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