EGR 4830 – Senior Project

F1TENTH Senior Design Project - Executive Summary

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1. How long did it take to complete this executive summary? 4 Hours
2. Did you attend or watch the lesson provided by Mr. Paul Hottinger regarding Information Literacy (check the correct box)? ☐YES ☒ NO

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Objective of the Project

The CPP F1TENTH Senior Design Project designed and implemented a 1:10-scale autonomous race car for robotics and autonomous systems research. The primary goal was to create an affordable, scalable autonomous vehicle capable of navigating complex environments with minimal human intervention, addressing the growing demand for low-cost solutions in the autonomous vehicle industry.

Literature Review

The F1TENTH platform builds upon prior autonomous systems research, such as the DARPA Grand Challenge, emphasizing scalability and accessibility. While existing platforms like TurtleBot offer valuable educational tools, they often lack the performance, scalability, and competitive edge necessary for advancing the state-of-the-art in autonomous vehicle technology. F1TENTH addresses these limitations by providing a competitive platform that encourages the development of high-performance, real-world applicable autonomous systems.

Research conducted within the F1TENTH framework significantly contributes to the advancement of autonomous systems, with potential applications extending beyond the realm of miniature race cars. The project’s innovations included leveraging ROS2 for modular communication and implementing advanced algorithms like Follow Gap and SLAM (Simultaneous Localization and Mapping). Recent improvements, such as graph-based pose estimation and particle filtering, enhance real-time decision-making in dynamic environments. Comparatively, the project offers a cost-effective alternative with robust algorithmic adaptability for autonomous navigation challenges.

Autonomous vehicles improve safety by reducing human error, the main cause of traffic accidents. For example, Waymo's autonomous vehicles recorded zero bodily injury claims per million miles driven, compared to 1.11 claims for human drivers [6]. This contrast highlights the potential of autonomous systems to significantly enhance road safety. Human errors, such as distracted driving, fatigue, and impaired judgment, contribute to most traffic incidents. Autonomous vehicles mitigate these risks by maintaining constant vigilance, processing vast amounts of data from sensors, and making precise decisions in real-time. Extensive testing and real-world applications underscore these safety benefits, showing how autonomous technology can reduce accidents and save lives. NHTSA notes that higher automation levels could prevent crashes caused by distractions, impaired driving, and other human factors [7].

Environmentally, autonomous vehicles can reduce fuel consumption and emissions. Advanced systems improve traffic flow and reduce idling, potentially cutting greenhouse gas emissions by 6–9% over a vehicle’s lifetime [6]. NHTSA emphasizes the environmental benefits of pairing autonomous technologies with electric vehicles, reducing pollutants and optimizing land use through shared fleets [7].

Autonomous systems also promote mobility for underserved populations, including the elderly and people with disabilities. By eliminating the barriers of manual driving, these systems can increase access to transportation for millions, as highlighted by studies from NHTSA [7]. Additionally, although the transition may disrupt transportation jobs, new opportunities in software development and fleet management are expected to emerge, potentially offsetting economic losses [6].

Cybersecurity and liability remain challenges. Companies are developing encryption protocols and robust Vehicle-to-Everything (V2X) communication systems to secure data exchanges, as Gartner's 2024 analysis reveals [8]. Clear guidelines defining system accountability will foster public trust in autonomous technologies [7].

Results and Discussion

We used components, such as the Nvidia Jetson Orin Nano, Hokuyo UST-10LX LiDAR, and Intel RealSense D345i camera, integrated through ROS2 Foxy and later ROS2 Humble. These frameworks enabled communication, data processing, and component coordination. By implementing the SLAM Toolbox in ROS2, the team achieved accurate localization and map generation in simulated environments. Optimizations such as loop closure detection and parameter tuning significantly enhanced SLAM performance.

The Follow Gap algorithm, initially limited in navigating tight corners and avoiding obstacle collisions, underwent refinements to address these challenges. The team introduced a penalty system for high-angle points and explored alternative strategies. These adjustments improved the algorithm's ability to select safer paths and reduced collision rates in simulation. Further enhancements, such as transitioning to the Disparity Extender or Pure Pursuit algorithms, could address remaining limitations related to vehicle width in tight spaces.

Together, our advancements in SLAM and Follow Gap algorithms bring the vehicle closer to real-world applications while identifying areas for future refinement.

The following table summarizes the voltage and current specifications of critical components:

Component	**Voltage Requirement (V)**	**Current Requirement (mA)**
Hokuyo UST-10LX LiDAR	12	150 (450 at startup)
Nvidia Jetson Orin Nano	5	1400 (2000 in 10W mode)
Intel RealSense D345i	5	700

Conclusion and Recommendations

The CPP F1TENTH project advanced autonomous vehicle systems development within the F1TENTH competition's constraints. Key accomplishments include enhanced algorithmic performance, improved hardware-software integration, and successful migration to ROS2 Humble Hawksbill. Despite unresolved challenges in obstacle navigation and mapping, the project provides a strong foundation for future iterations.

Recommendations:

- Further refine the Follow Gap algorithm or implement alternative strategies like Pure Pursuit, or the Disparity Extender Algorithm to address its limitations in complex environments.
- Enhance SLAM parameters for better localization in complex environments.
- Conduct physical testing to validate simulation results and identify additional areas for improvement.

Work Cited

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