PDE3823 – Project Proposal - Formal Form

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Program of study	BEng Mechatronics and Robotics Engineering
Topic area	Autonomous Systems / Robotics Perception and SLAM

What are you going to do? (Problem Definition & Project Rationale)

What is the core problem or question your project addresses?

Autonomous racing vehicles require robust perception and localization systems to navigate dynamic track environments marked by traffic cones. The core challenge is developing an integrated system that can detect cone positions from sensor data and simultaneously localize the vehicle within the track - a fundamental requirement for autonomous navigation that must work reliably in real-time simulation environments before real-world deployment.

Why is this important in the context of your field?

Autonomous vehicle systems rely on accurate environmental perception and self-localization (SLAM - Simultaneous Localization and Mapping) to make safe navigation decisions. This project addresses a critical gap in developing and validating these systems in simulation before expensive real-world testing, which is essential for Formula Student AI competitions and the broader autonomous vehicle industry.

Include any relevant background, literature, or real-world context to justify the need for the project.

Formula Student AI competitions require autonomous vehicles to navigate unknown tracks defined by colored traffic cones. Current development relies heavily on physical testing, which is expensive, time-consuming, and limits iteration speed. Industry-standard simulation tools like IPG CarMaker provide realistic testing environments, but require sophisticated perception and SLAM pipelines to process simulated sensor data and build track maps autonomously.

What are you trying to achieve? (Aims, Objectives, Scope, and Feasibility)

State your main aim, followed by clear, measurable objectives.

Main Aim:

To develop and validate an integrated perception and SLAM system for autonomous racing vehicles in simulation.

Objectives:

1. Implement a multi-node ROS2 perception pipeline that detects traffic cones from camera and depth sensor data with measurable accuracy
2. Integrate a SLAM system that localizes the vehicle and builds a map of cone positions in real-time
3. Validate the system performance in IPG CarMaker simulation environment using ground truth comparison

4. Document the integration challenges, design decisions, and testing methodology

Briefly define the scope of the project, what will and will not be included.

Scope:

Included:

• Camera-based cone detection using YOLO models
• 3D localization of detected cones using depth information
• SLAM integration for vehicle localization and map building
• Testing and validation in IPG CarMaker simulation

Not included:

• Path planning or vehicle control systems
• LiDAR sensor fusion (optional stretch goal if time permits)
• Autonomous exploration algorithms (optional stretch goal)
• Physical hardware implementation or real-world testing

Comment on feasibility (e.g. time constraints, access to equipment, skills).

Feasibility:

The project is feasible within the timeline with access to university GPU resources sufficient for model training and software development. The modular ROS2 architecture allows independent development and testing of individual components.

Highlight any risks and how you plan to manage them.

Risks and Mitigation:

• IPG CarMaker license availability: Some system components can be developed without the license using demo/placeholder data, which will be swapped for actual simulation data once available

• IPG CarMaker learning curve: This is new software that requires time to learn, which will be managed through early familiarization and parallel development of ROS2 components

• SLAM integration complexity: Managed through modular development, incremental testing, and use of established SLAM libraries

How are you going to do it? (Technical Plan and Resource Needs)

Outline your approach, e.g. design process, experimentation, testing methods, simulation, etc.

Technical Approach:

The project will follow an iterative development approach:

1. Design Phase:

Develop a modular ROS2 perception pipeline that processes camera and depth sensor data to detect and localize traffic cones in 3D space

2. Integration Phase:

Integrate perception outputs with a SLAM system to enable simultaneous vehicle localization and map building

3. Testing and Validation:

Use IPG CarMaker simulation environment to test the system with various track configurations, comparing system outputs against simulation ground truth to measure accuracy

Mention the resources you expect to need: software, hardware, lab access, specialist input.

Resources Needed:

• Software: ROS2, IPG CarMaker simulation software, deep learning frameworks, SLAM libraries

• Hardware: University GPU computing resources for development and testing

• Specialist Input: Supervisor guidance on SLAM algorithms and ROS2 integration best practices

Flag any potential ethical issues or requirements for approval.

Ethical Considerations:

No ethical approval required as all development and testing is conducted in simulation with no human subjects or real-world data collection.

What will you produce? (Expected Deliverables and Impact)

List the intended deliverables, such as prototypes, design documentation, test results, models, etc.

Expected Deliverables:

1. Software System: ROS2-based perception and SLAM pipeline for processing simulated sensor data

2. Trained Detection Models: YOLO models trained for cone detection with documented performance metrics

3. Test Results: Performance analysis and metrics from simulation testing, documenting what worked and challenges encountered

4. Technical Documentation: Comprehensive report covering system design, implementation attempts, integration process, and lessons learned

5. Demonstration: Documentation of system behavior in IPG CarMaker simulation, including visualizations of perception outputs and SLAM performance

Explain the expected impact, how the outputs relate to your project goals and their potential use in industry, research, or society.

Expected Impact:

This project explores the development of autonomous vehicle perception systems using simulation as a testing platform. The modular ROS2 architecture provides a framework that could be extended for autonomous racing applications. The work demonstrates the viability of simulation-based development approaches for reducing reliance on physical testing in early development stages.

The methodology and findings may inform future Formula Student AI development efforts and contribute to understanding the practical challenges of integrating perception with SLAM systems in racing contexts.

You may also include 3–5 key references or sources you've already consulted.

Key References:

[1] J. Fayyad, M. A. Jaradat, D. Gruyer, and H. Najjaran, "Deep Learning Sensor Fusion for Autonomous Vehicle Perception and Localization: A Review," Sensors, vol. 20, no. 15, p. 4220, 2020, doi: 10.3390/s20154220.

[2] P. Ping et al., "A comprehensive survey on multi-sensor information processing and fusion for BEV perception in autonomous vehicles," Information Fusion, vol. 126, Art. no. 103653, 2026, doi: 10.1016/j.inffus.2025.103653.

[3] S. Macenski and I. Jambrecic, "SLAM Toolbox: SLAM for the dynamic world," Journal of Open Source Software, vol. 6, no. 61, p. 2783, 2021.

[4] H. Matsuki, R. Murai, P. H. J. Kelly, and A. J. Davison, "Gaussian Splatting SLAM," in Proc. IEEE/CVF Conf. Comput. Vis. Pattern Recognit. (CVPR), 2024.

[5] N. Keetha, J. Karhade, K. M. Jatavallabhula, G. Yang, S. Scherer, D. Ramanan, and J. Luiten, "SplaTAM: Splat, Track & Map 3D Gaussians for Dense RGB-D SLAM," in Proc. IEEE/CVF Conf. Comput. Vis. Pattern Recognit. (CVPR), 2024.

[6] I. Ivanov and C. Markgraf, "Lane Detection using Graph Search and Geometric Constraints for Formula Student Driverless," arXiv preprint arXiv:2405.16369, 2024.

Signed (digitally) ……Oluwatunmise…… Date…23rd January 2026……