Report No	2
Team	UADE Racing Team
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1 Introduction

This report summarizes the work completed during the second development sprint (December 2025 – January 2026). The main milestone was linking camera input to a control output (camera → perception → steering), enabling lane keeping. We implemented an OpenCV-based perception-and-control pipeline that ingests camera frames, extracts lane geometry, estimates the lane center with lookahead, and outputs stable steering commands, with speed adaptation based on curve demand.

2 Planned activities

Activities planned at the beginning of the reporting period:

- Integrate the camera pipeline for real-time acquisition and processing (low-latency stream, messaging, decoding).
- Implement robust lane detection (HSV color segmentation + morphology) suitable for variable lighting.
- Add bird's-eye view (perspective transform) to improve geometric modeling and curve handling.
- Implement lane tracking and polynomial fitting (sliding windows + temporal smoothing).
- Design and implement steering control (PID-inspired) with adaptive smoothing and steering limits.
- Link speed to steering demand for improved curve stability.
- Validate full chain: camera input → steering output and demonstrate in an evidence video.
- Maintain hardware expansion plan for next autonomy stages (Jetson Orin Nano, LiDAR, ToF, battery).

3 Status of planned activities

Progress and outcomes for each planned activity:

Camera pipeline integration

- Status: Completed.
- Implementation / results: Dedicated acquisition thread captures 512×270 frames; frames are base64-encoded and sent via internal messaging; processing thread decodes and reconstructs images with OpenCV.
- Difficulties / notes: Architecture decouples acquisition from processing to keep stable real-time throughput.

Lane detection (HSV + morphology)

- Status: Completed.
- Implementation / results: Brightness/contrast normalization; HSV conversion; separate masks for white and yellow lanes; masks merged; dilation + closing/opening + Gaussian blur to improve continuity.
- Difficulties / notes: Handled yellow hue wrap-around and improved dashed-line stability via morphology.

Bird's-eye view transform

- Status: Completed.
- Implementation / results: Defined trapezoidal ROI and warped to a rectangle using perspective transform; lanes become more parallel to support better curve estimation.
- Difficulties / notes: ROI tuning is sensitive; values were iterated to balance near/far visibility.

Sliding window tracking + polynomial fit

- Status: Completed.
- Implementation / results: Histogram initialization; 12 sliding windows with recentering; search-around-poly when available; 2nd order polynomial fit; averaging over last 8 fits to reduce jitter.
- Difficulties / notes: Temporal smoothing reduces noise but can lag in sudden changes; parameters will be tuned.

Lane center with lookahead

- Status: Completed.
- Implementation / results: Lookahead evaluation at ~60% of image height; center computed from left/right polynomials to anticipate curves earlier.
- Difficulties / notes: Requires reliable detection of both lanes; fallback strategy needed when one lane is missing.

Steering control + smoothing + limits

- Status: Completed (tuning ongoing).
- Implementation / results: PID-inspired control with proportional sensitivity and derivative term; adaptive smoothing based on curve intensity; steering clamped to ±25°; bird's-eye center mapped back to original space for error in camera coordinates.
- Difficulties / notes: Controller gain tuning continues to improve smoothness at higher speeds.

Speed control linked to steering

- Status: Completed.
- Implementation / results: Speed reduced for sharp curves or large steering; intermediate speed for moderate steering; max speed for straights.
- Difficulties / notes: Thresholds will be tuned after more track testing.

End-to-end validation and evidence

- Status: Completed.

- Implementation / results: Steering and speed commands formatted for actuator protocol (scaled ×10 strings) closing the chain from perception to actuation; video shows overlays and computed commands.
- Difficulties / notes: Additional tests needed for challenging lighting and worn markings.

Hardware expansion planning

- Status: Ongoing.
- Implementation / results: Jetson Orin Nano as main compute; 360° LiDAR for obstacles/mapping; ToF sensors for redundancy; LiPo 2S/3S with XT90.
- Difficulties / notes: Integration will start once lane keeping is stable on hardware and ROS pipeline is consolidated.

4 General status of the project

The project is on track with BFMC milestones. The vehicle start-up pipeline remains verified, and we have implemented the full camera-based lane-following stack (robust lane detection, bird's-eye view geometry, lookahead center estimation, and a PID-inspired steering controller with speed adaptation). Lane keeping is functional and currently in the tuning phase to improve stability under diverse lighting conditions and at higher speeds. ROS and simulator environments are installed, with integration/validation ongoing for consistent testing. Next autonomy steps target obstacle-aware behavior and stronger fault handling.

5 Upcoming activities

Planned activities for the next reporting period:

- Improve lane detection robustness for challenging lighting and worn lane markings.
- Add sanity checks and fallback strategies when one lane line is missing.
- Tune controller gains for smoother tracking at higher speeds.
- Integrate obstacle detection (first in simulation, then on hardware).
- Begin integration planning and mounting for LiDAR and ToF sensors on the physical vehicle.