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INC01

AUTONOMOUS GOLF CART SYSTEM FOR NAVIGATION

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INTRODUCTION

This project presents an autonomous navigation system for an electric golf cart, focusing on robust localization and reliable path tracking in outdoor environments. It utilizes LiDAR-based 3D mapping with scan registration, combined with Xsens odometry fusion to improve robustness in feature-sparse or dynamic conditions, while operating under a standard map–odom–base_link framework for consistent state estimation. For control, a Pure Pursuit algorithm with adaptive velocity ensures stable tracking along predefined waypoints, and an AI assistant with voice and Natural Language Understanding enhances user interaction. The system is implemented in ROS2 and validated on a campus route with both straight and curved segments.

OBJECTIVES

- To design an autonomous golf cart system using LiDAR for real-time environmental perception.
- To implement vehicle control and communication using the ROS 2 framework.
- To develop accurate Localization and 3D Mapping (SLAM) for efficient path planning.
- To create an AI Assistant for voice interaction and a Real-time Dashboard for system monitoring.
- To enhance the navigation system for fully autonomous driving within the King Mongkut's University of Technology Thonburi football field.

METHODOLOGY

OVERVIEW

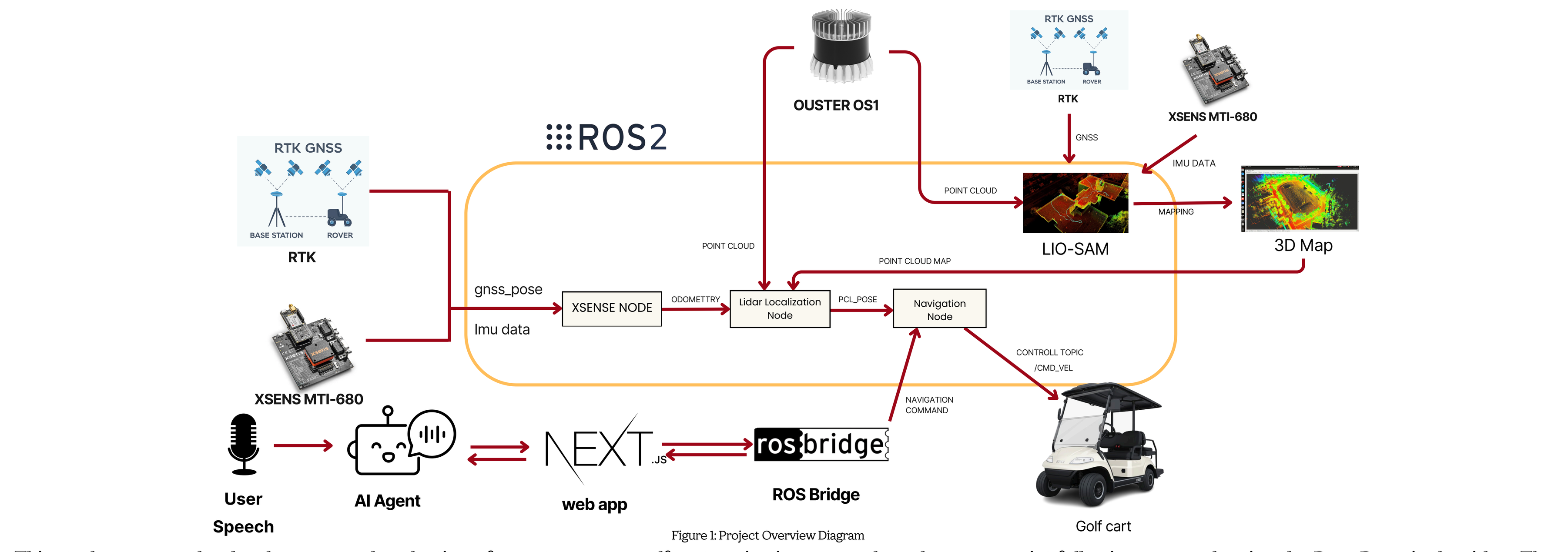

Figure 1: Project Overview Diagram

This study presents the development and evaluation of an autonomous golf cart navigation system based on a waypoint-following approach using the Pure Pursuit algorithm. The system integrates data from multiple sensors, including LiDAR, IMU, and GNSS, to estimate the vehicle's pose within a global reference frame. A predefined path is generated and published as a sequence of waypoints, which are then processed by the controller to compute steering and velocity commands in real time. The Pure Pursuit method determines the steering angle by selecting a lookahead point on the path and calculating the curvature required to reach it, while additional corrections based on cross-track error (CTE) are applied to improve tracking accuracy. The system also incorporates adaptive mechanisms such as dynamic lookahead adjustment, speed modulation based on path curvature, and filtering techniques to reduce noise and improve stability. Experimental validation is conducted by logging vehicle pose, speed, steering angle, and CTE data, which are later analyzed and visualized through trajectory plots and time-series graphs to evaluate tracking performance and system robustness.

3D MAPPING AND LOCALIZATION

- **3D Mapping**

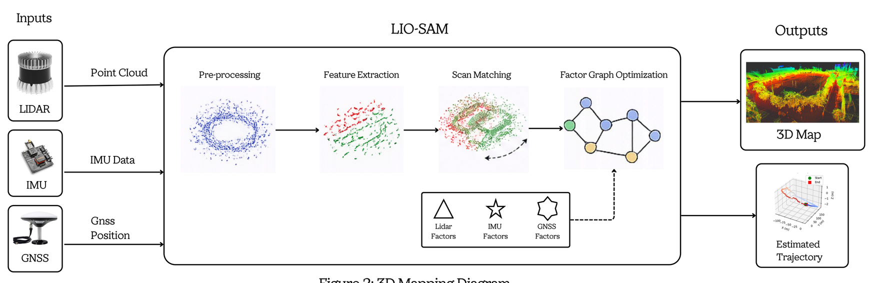

Figure 2: 3D Mapping Diagram

This system performs 3D mapping using LIO-SAM by integrating LiDAR, IMU, and GNSS measurements within a factor graph optimization framework to generate a consistent map aligned with real-world coordinates. LiDAR provides point cloud data for feature extraction and scan matching to estimate relative motion, while the IMU supports motion estimation and corrects distortion in the LiDAR scans through deskewing. GPS, particularly RTK GNSS, is incorporated as an absolute position constraint to anchor the map to a global reference frame and reduce long-term drift. By combining these sensor inputs, LIO-SAM produces an accurate and globally consistent 3D map, where both the vehicle's trajectory and the surrounding environment are optimized simultaneously.

- **Localization**

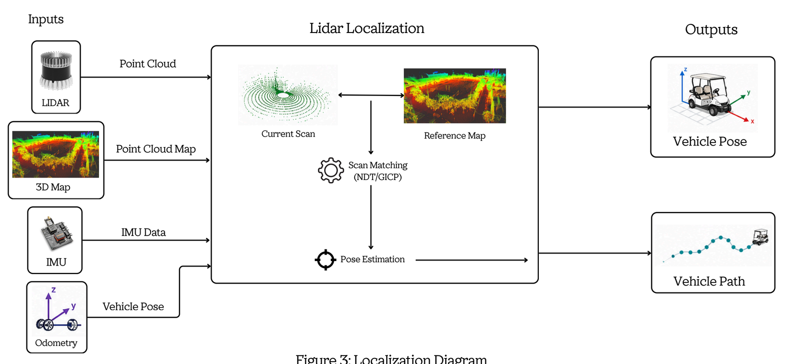

Figure 3: Localization Diagram

In a localization system, LiDAR data and a prebuilt map are used as the main references. The current point cloud is matched with the map using scan matching methods such as NDT, while odom provides an initial estimate to improve speed and stability. IMU data enhances orientation accuracy, and initialpose is used to set the starting position when needed. The system outputs pcl_pose, representing the vehicle's position in the map frame, and path, showing its trajectory. Overall, it integrates LiDAR, map, and odometry data to estimate the vehicle's position accurately and continuously.

AI ASSISTANT AND DASHBOARD

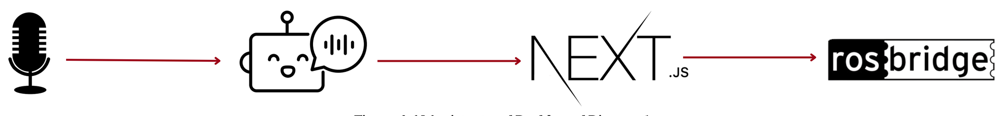

Figure 4: AI Assistant and Dashboard Diagram 1

The system transforms voice commands into real-time navigation data by utilizing AI to identify destinations. This information is processed through the backend to fetch precise coordinates from OpenStreetMap, which are then visualized on the web frontend. Simultaneously, the AI provides an interactive response to confirm and guide the user through the navigation process.

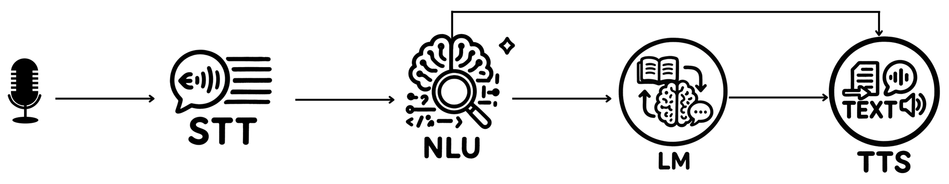

Figure 5: AI Assistant and Dashboard Diagram 2

The core AI architecture begins with a Speech-to-Text engine that converts vocal input into processed text. This data is then analyzed by a Natural Language Understanding (NLU) module to classify the user's intent. When a navigation intent is detected, the system performs entity extraction to identify the destination and triggers the backend location search. To ensure system reliability, a Fallback Mechanism is integrated; if the NLU encounters ambiguous queries, the system routes the input to a Large Language Model (LLM) to interpret context and provide an intelligent response, ensuring a seamless and intuitive navigation experience."

NAVIGATION AND CONTROL SYSTEM

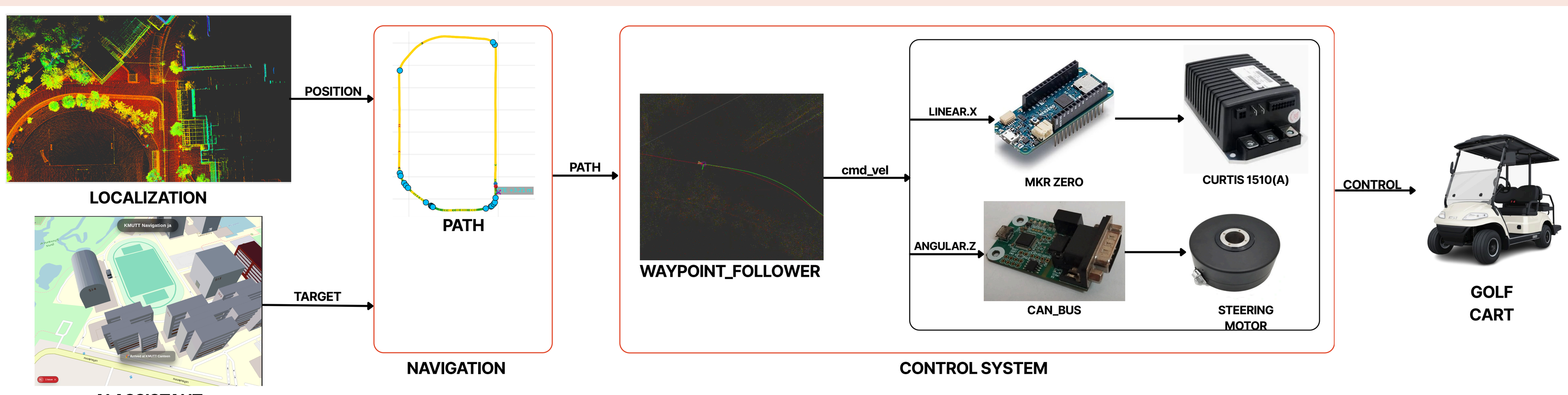

Figure 6: navigation And control system Diagram

The methodology of this system begins with the localization process to estimate the vehicle's current position within the map frame. The obtained pose data is then recorded into a CSV file and later converted into a reference path for navigation, where path smoothing techniques are applied to reduce noise and ensure continuity. This path is used by the waypoint follower, which computes control commands based on the Pure Pursuit algorithm combined with Cross-Track Error (CTE) correction to improve tracking accuracy. The resulting control commands are published as /cmd_vel, where the linear velocity (linear.x) controls the vehicle speed and the angular velocity (angular.z) controls steering through a CAN bus interface connected to the steering motor. Finally, experimental data including path tracking, speed, steering, and CTE are analyzed to evaluate the system's performance in terms of accuracy, stability, and overall effectiveness in autonomous navigation.

RESULTS

3D MAPPING

Figure 7: Satellite Image of the Environment

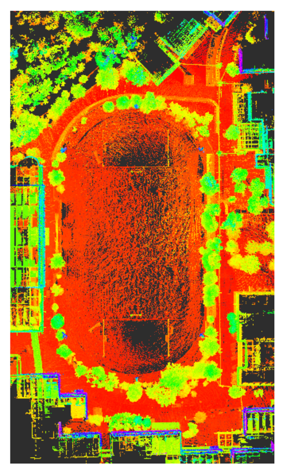

Figure 8: LiDAR-Based 3D Map Representation

Figure 9: Real-World Environment

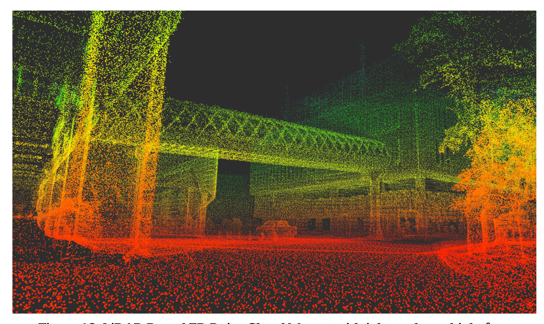

Figure 10: LiDAR-Based 3D Point Cloud Map at midnight under vehicle-free conditions.

In this experiment, sensors including LiDAR, IMU, and GNSS were mounted on an autonomous electric golf cart and tested in an open area around the football field at King Mongkut's University of Technology Thonburi (KMUTT). The test route consisted of diverse environments, including areas with clear building structures and areas containing various objects within the surroundings. The experimental results show that when the vehicle was driven at speeds higher than 1.5 m/s during map data collection, the resulting map tended to exhibit inaccuracies, as the algorithm was unable to process sensor data fast enough to keep up with changes in the environment and vehicle motion. In contrast, operating at speeds below 1.5 m/s allowed the system to generate maps more effectively. Furthermore, methods relying solely on odometry or LiDAR odometry tend to accumulate drift over time, especially during long-duration operation. In contrast, the proposed system, which utilizes LiDAR-based mapping and localization (LIO-SAM) together with GNSS data and loop closure, is able to significantly reduce accumulated drift. GNSS provides a global reference for position correction, while loop closure refines the estimated pose when the vehicle revisits previously mapped areas, resulting in improved trajectory consistency and overall accuracy.

LOCALIZATION

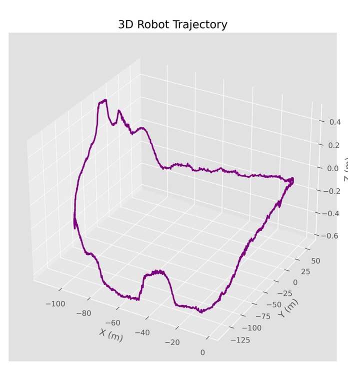

Figure 8: 3D trajectory of the robot.

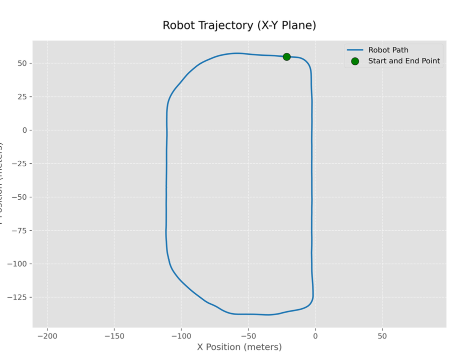

Figure 8: Robot Trajectory in the X–Y Plane

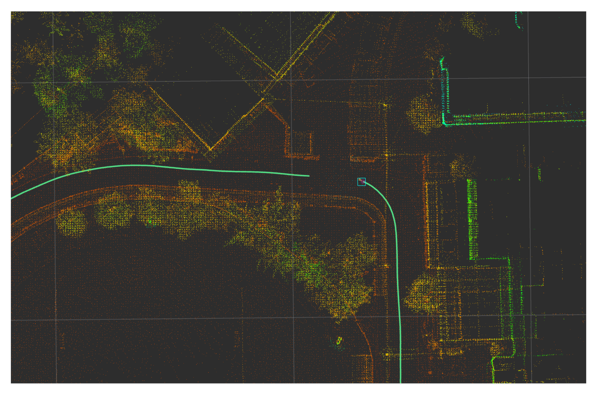

Figure 8: Localization with Path-Following Robot Trajectory

In the localization experiment, the robot was tested by driving around the KMUTT football field. As shown in the figure, the estimated trajectory generally forms a closed-loop path, indicating that the system can maintain positional consistency over time. However, slight noise and fluctuations can be observed in certain segments of the trajectory. These variations are mainly caused by sensor uncertainty, as well as differences between the real-world environment and the referenced 3D map, resulting in minor deviations during motion.

AI ASSISTANT AND DASHBOARD

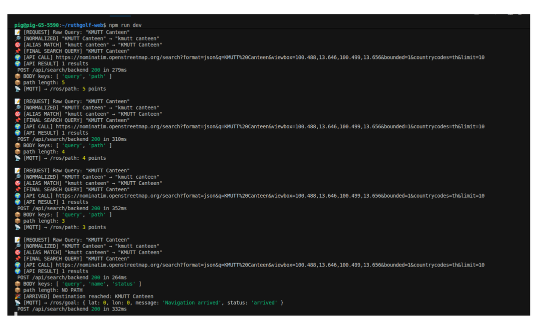

Figure 14: Backend System and API Processing Interface

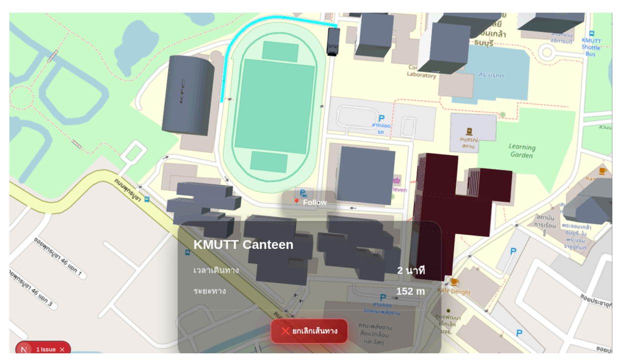

Figure 15: Real-Time Navigation and Map Visualization

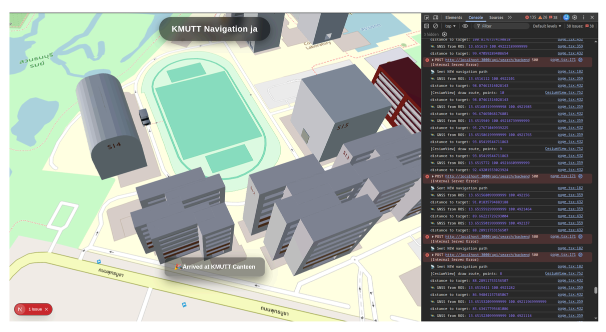

Figure 16: Real-Time GNSS Localization and Dashboard Monitoring

The system features continuous real-time vehicle tracking via integrated GPS sensors, operational in both standby and navigation modes. Users can seamlessly initiate navigation through voice commands or touchscreen interaction, triggering an instant coordinate search and route generation. The interface provides high-precision synchronization between the vehicle's dynamic position and the navigation path, ensuring accurate second-by-second updates.

NAVIGATION AND CONTROL SYSTEM

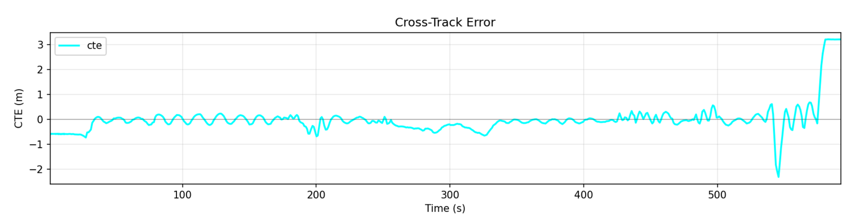

Figure 17: Cross-Track Error (CTE) over Time

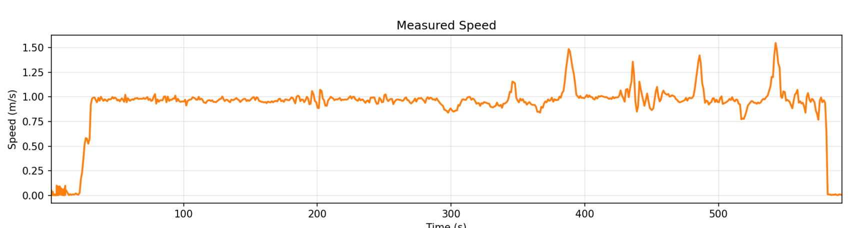

Figure 18: Vehicle Speed over Time

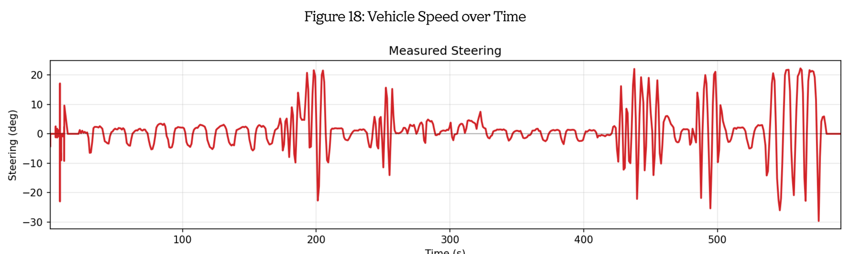

Figure 19: Steering Angle over Time

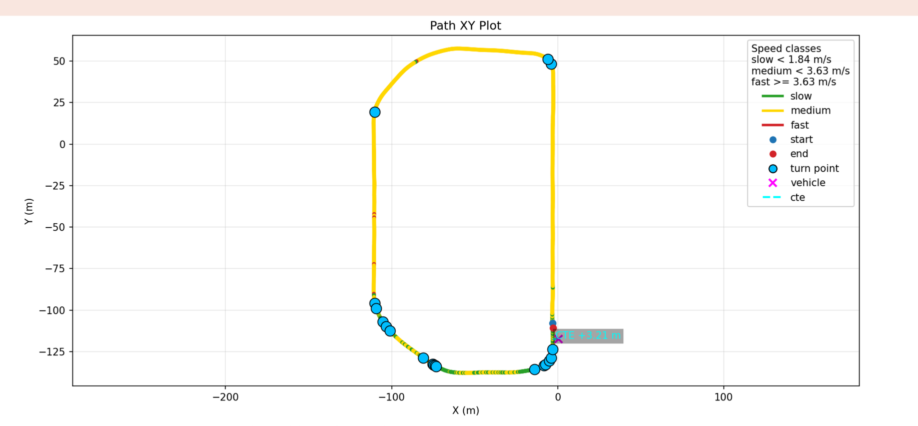

Figure 20: Vehicle Trajectory and Path Tracking Performance (XY Plane)

The figures illustrate the vehicle trajectory in the XY plane along with the corresponding speed, steering angle, and Cross-Track Error (CTE) over time. The results show that the vehicle can accurately follow the predefined path, particularly along straight segments, with minor deviations in curved areas. The speed remains relatively stable throughout the experiment, indicating consistent motion control. The steering response varies according to path curvature, with larger adjustments observed during turning maneuvers. The CTE remains small for most of the operation, demonstrating good tracking accuracy. Although significant fluctuations in steering and a sharp increase in CTE are observed near the end, this behavior occurs after the vehicle reaches the goal and stops following the path. Overall, the system demonstrates stable control and effective path-following performance during active navigation.

CONCLUSION

This project successfully demonstrates the development of an autonomous golf cart navigation system by integrating robotics, sensor fusion, and AI technologies into a unified platform. The use of LIO-SAM with loop closure enables the system to generate accurate and globally consistent 3D maps while significantly reducing localization drift. The integration of LiDAR, IMU, and RTK-GNSS enhances robustness in diverse outdoor environments and ensures reliable real-time pose estimation. The waypoint-following approach based on the Pure Pursuit algorithm provides stable and effective path tracking performance, with low cross-track error during most of the navigation process. Additionally, the AI Assistant and real-time dashboard improve user interaction by enabling intuitive voice-based navigation and seamless system monitoring through web technologies. However, the system performance is affected by factors such as vehicle speed, sensor noise, and environmental variations, which may introduce minor trajectory deviations. Future work should focus on improving speed adaptability, implementing advanced safety mechanisms such as emergency braking, and enhancing multi-goal navigation capabilities to support more complex real-world scenarios. Overall, the proposed system demonstrates strong potential for practical autonomous vehicle applications in controlled outdoor environments.

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