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1. **What are the major goals of the project? (at least 300 words and at most 3000 words for each question.)**

Major Goals of the Montclair Autonomous Golf Cart Testbed Project:

In the pursuit of developing the Montclair Autonomous Golf Cart Testbed, a multifaceted project encompassing various subsystems, the primary objectives align with creating an autonomous vehicle. Each module plays a crucial role, contributing to the goal of achieving a seamlessly functioning, self-navigating golf cart. My specific focus has been on the LiDAR subsystem within the Sensory System.

**LiDAR Subsystem:**

My specific contribution to this collaborative effort involves the LiDAR subsystem within the Sensory System. The major goals within this context include:

1. Successful Integration of SLAMtec RPLiDAR S2E into the Sensory Array:

* The primary objective is to seamlessly integrate the SLAMtec RPLiDAR S2E into the golf cart's sensory array.
* This encompasses a detailed integration process involving the physical setup of the LiDAR on the golf cart, ensuring it becomes an integral component of the overall sensory system architecture.

2. Establishment of a Reliable Hardware-Software Connection:

* A critical milestone is to establish a reliable and robust connection between the LiDAR hardware and the software systems.
* This involves conducting compatibility checks, implementing efficient data transfer protocols, and ensuring consistent communication channels. The objective is to create a seamless interface for real-time data processing.

3. Utilization of LiDAR Data for Dynamic Mapping and Environmental Understanding:

* The LiDAR subsystem aims to unlock the potential of LiDAR data for real-time mapping, obstacle detection, and comprehensive environmental understanding.
* This goal involves developing and implementing algorithms that process the incoming LiDAR data stream, enabling the golf cart to dynamically map its surroundings, detect obstacles in its path, and gain a nuanced understanding of the environment.

4. Collaborative Integration Across Subsystems:

* Collaboration is a cornerstone of this effort, requiring seamless integration with team members across various subsystems.
* Close communication and coordination with colleagues working on speed control, steering, electrical, and mechanical systems are essential.
* The objective is to ensure that the LiDAR's contributions harmonize with the broader goals of the autonomous golf cart project.

**Goals of each Module:**

1. Speed Control System:

* Aimed at developing a robust speed control mechanism to ensure the golf cart operates safely and efficiently in diverse environments.
* Integration of advanced speed control algorithms for adaptive and responsive performance.
* Collaboration with team members involved in this subsystem to synchronize efforts and achieve a cohesive solution.

2. Steering Control System:

* Goal-oriented towards implementing an intelligent steering control system for precise navigation.
* Incorporation of sensor data, including LiDAR inputs, to enhance the cart's steering response.
* Synergized efforts with teammates working on steering control to ensure seamless coordination.

3. Sensory System (Computer Vision and LiDAR):

* A pivotal aspect of the project involving the integration of sensory technologies.
* LiDAR integration for comprehensive environmental perception, contributing to obstacle detection and mapping.
* Collaboration with Computer Vision experts to create a sensory system that enriches the golf cart's perception capabilities.

4. Electrical and Electronic System:

* Focus on developing a reliable and efficient electrical system to power various components of the autonomous golf cart.
* Integration of LiDAR with the electronic system to ensure synchronized data flow and real-time processing.
* Coordinated efforts with electrical system team to guarantee seamless connectivity and functionality.

5. Mechanical System:

* Centralized around designing a sturdy and adaptable mechanical framework for the golf cart.
* Consideration of LiDAR's physical integration, ensuring optimal positioning for maximum scanning coverage.
* Collaborative work with team to align LiDAR placement with the overall mechanical design.

In summary, the major goals of the Montclair Autonomous Golf Cart Testbed project revolve around creating a sophisticated autonomous vehicle by addressing specific challenges within each subsystem. My involvement in the LiDAR subsystem contributes to enhancing the golf cart's sensory capabilities, crucial for its successful autonomous navigation.

1. **What was accomplished under these goals and objectives (you must provide information for the 4 categories below)?**

**Major Activities (at least 200 words and at most 2000 words for each question**. Please itemize each point and do not wrap them into one paragraph. Do not copy any code and formulas and paste here.):

1. RoboStudio Verification:

* In the initial phase, we turned to RoboStudio on a Windows platform to ensure that our Slamtec RPLidar S2E LIDAR was functioning faultlessly. It wasn't just about basic functionality; it was about real-time monitoring and control.
* RoboStudio became our window into the LIDAR's world, showcasing the current map, obstacles, and pose of the device.
* Extracting crucial insights in the form of angle and distance data, stored neatly in a .csv format, provided not only a validation of the hardware but also a foundation for the subsequent stages of our project.

2. Transition to Ubuntu and ROS Installation:

* Recognizing the need for a more robust environment, we transitioned to Ubuntu 20.4, aligning seamlessly with ROS Neotic.
* This wasn't just a change, it was a strategic move to harness the full capabilities of ROS.
* We used a Virtual Private Network (VPN) – UTM as a secure bridge to Ubuntu.
* Installing ROS Neotic was a big step forward, it gave us useful tools to handle the data coming from the LIDAR.

3. ROS Package Download and Catkin Build:

* We downloaded the Slamtec RPLiDAR S2E package from GitHub and smoothly integrated it into the source (src) folder of our ROS environment.
* Things got moving with **catkin\_make**—a command to build and compile ROS packages.
* This process gave us executable files, libraries, and other resources, setting up the groundwork for how the LIDAR system interacts with the overall autonomous golf cart project.

4. ROS Workspace Setup and Sourcing:

* Setting up the ROS workspace was a careful process—we did it by running the command **source devel/setup.bash**.
* This step was crucial to get everything ready, like setting up a workspace for a project.
* After this, we sourced the setup files to make sure ROS nodes and tools could easily find and use the code we compiled.
* This made our development environment smooth and flexible, making it easier to manage different parts of the project as we moved forward.

5. Launch File Execution and Data Streaming:

* We smoothly ran the right launch file from our special launch folder, matching it with the LIDAR version(S2E) we were using.
* This careful step was important to start up the LIDAR system in the ROS setup.
* Getting data to flow from the LIDAR was a big win. It meant that the LIDAR hardware and the ROS software were talking to each other well. This smooth connection allowed us to process and analyse data in real-time within the ROS system.

6. Visualization with RViz:

* We used a tool called RViz in the ROS system, which helped us see the LIDAR data in a whole new way.
* By setting it up, we could understand the details of the LIDAR data stream visually.
* We carefully followed some instructions on the command line to make RViz show the LIDAR data in a way that made sense to us.
* This wasn't just for keeping an eye on things in real-time, it gave us important clues about how the LIDAR saw and understood space around it.

7. Data Utilization for Object Detection:

* Used the obtained LIDAR data, including angle and distance information in .csv format, for subsequent object detection processes.
* Explored potential methodologies and algorithms for object detection and localization based on the rich dataset provided by the LIDAR.

8. Collaborative Project Integration:

* Actively collaborated with team members working on other subsystems of the autonomous golf cart testbed.
* Shared insights, results, and feedback to ensure seamless integration between the LIDAR system and other critical components.

**Specific Objectives (at least 200 words and at most 2000 words for each question.** Please itemize each point and do not wrap them into one paragraph. Do not copy any code and formulas and paste here.):

1. **Objective:** Confirm the accurate functioning of the Slamtec RPLidar S2E LIDAR.

*Tasks to be performed to achieve the objective :*

* Utilize RoboStudio on Windows to monitor and control the LIDAR in real-time.
* Display the current map, obstacles, and pose of the LIDAR.
* Obtain valuable insights, including angle and distance data, and save in a .csv format.

2. **Objective:** Migrate the project development environment to Ubuntu 20.4.

*Tasks to be performed to achieve the objective :*

* Install a Virtual Private Network (VPN) – UTM for secure communication with Ubuntu.
* Install ROS Neotic on Ubuntu to handle LIDAR data effectively.

3. **Objective:** Integrate and compile ROS packages for seamless LIDAR integration.

*Tasks to be performed to achieve the objective:*

* Download the LIDAR package from GitHub and integrate it into the ROS environment.
* Use the `catkin\_make` command for building and compiling ROS packages.
* Verify successful compilation, ensuring the creation of necessary build artifacts.

4. **Objective:** Configure the ROS workspace and source necessary setup files.

*Tasks to be performed to achieve the objective:*

* Execute the `source devel/setup.bash` command to set up environment variables and configurations.
* Source the generated setup files for ROS nodes and tools to use the compiled code effectively.

5. **Objective:** Establish a functional connection for data streaming from the LIDAR.

*Tasks to be performed to achieve the objective:*

* Identify and execute the appropriate launch file for the S2E LIDAR version.
* Successfully stream data from the LIDAR, ensuring a dynamic connection with the ROS environment.

6. **Objective:** Utilize RViz for visual interpretation of the LIDAR data stream.

*Tasks to be performed to achieve the objective:*

* Configure RViz using command-line instructions to display LIDAR data visually.
* Facilitate real-time monitoring and gain critical insights into spatial understanding.

7. **Objective:** Investigate methodologies for effective object detection using LIDAR data.

*Tasks to be performed to achieve the objective:*

* Leverage LIDAR data, including angle and distance information, for object detection processes.
* Explore potential algorithms and methodologies for accurate object detection and localization.

8. **Objective:** Develop a plan for integrating the LIDAR system with an autonomous golf cart.

*Tasks to be performed to achieve the objective:*

* Enable the golf cart to sense and understand its surroundings using LIDAR data.
* Enhance the overall autonomy of the golf cart for improved navigation.

**Significant Results (at least 200 words and at most 2000 words for each question.** Please itemize each point and do not wrap them into one paragraph. Do not copy any code and formulas and paste here.):

1. Verification of LIDAR Functionality with RoboStudio:

* Successfully monitored and controlled the Slamtec RPLidar S2E LIDAR in real-time using RoboStudio on a Windows platform.
* Displayed the current map, obstacles, and pose of the LIDAR, providing a comprehensive view of its environment.
* Extracted valuable insights, specifically angle and distance data, during real-time monitoring.
* Saved the obtained data in a .csv format for further analysis and utilization.

2. Transition to Ubuntu Environment:

* Migrated the project development environment to Ubuntu 20.4 for enhanced compatibility and robustness.
* Installed a Virtual Private Network (VPN) – UTM for secure communication with Ubuntu.
* Installed ROS Neotic on Ubuntu, facilitating efficient handling of LIDAR data.

3. ROS Package Setup and Compilation:

* Downloaded the LIDAR package from GitHub and seamlessly integrated it into the ROS environment.
* Utilized the `catkin\_make` command for the successful build and compilation of ROS packages.
* Verified the successful compilation, ensuring the creation of necessary build artifacts.

4. ROS Workspace Configuration and Sourcing:

* Executed the `source devel/setup.bash` command to configure the ROS workspace, setting up environment variables and configurations.
* Sourced the generated setup files, ensuring ROS nodes and tools could effectively use the compiled code.

5. Launch File Execution and Data Streaming:

* Successfully executed the appropriate launch file, initializing the LIDAR system within the ROS environment.
* Established a dynamic and functional connection, allowing for the seamless streaming of data from the LIDAR.

6. Data Visualization with RViz:

* Enhanced Spatial Understanding:
* Utilized RViz, a powerful visualization tool in the ROS ecosystem, for effective interpretation of the LIDAR data stream.
* Configured RViz using command-line instructions, enabling the visual display of LIDAR data in a comprehensible manner.
* Facilitated real-time monitoring, gaining critical insights into the spatial understanding of the LIDAR data.

7. Exploration of Object Detection Methodologies:

* Leveraging LIDAR Data for Object Detection:
* Successfully leveraged the obtained LIDAR data, including angle and distance information in .csv format, for object detection processes.
* Explored various methodologies and algorithms for object detection and localization based on the rich dataset provided by the LIDAR.

**Key outcomes or other achievements (at least 200 words and at most 2000 words for each question.** Please itemize each point and do not wrap them into one paragraph. Do not copy any code and formulas and paste here.):

1. **Successful LIDAR Integration:**

* Achieved seamless integration of the Slamtec RPLidar S2E LIDAR into the project infrastructure.
* Established a reliable connection between the LIDAR hardware and software systems.

1. **Mapping Accuracy:**

* Utilized the Slamtec RPLidar S2E LIDAR system to achieve high mapping accuracy within the project environment.
* Generated detailed maps of the surroundings, providing a comprehensive representation of the terrain and obstacles.
* Conducted thorough evaluations and validations to ensure that the mapping process accurately reflected the real-world environment.

1. **Positional Accuracy:**

* Utilizing Simultaneous Localization and Mapping (SLAM), the autonomous system achieves precise positioning within the mapped environment.
* The testbed's results will involve assessing the system's localization performance, gauging its effectiveness in utilizing sensor data from RPLIDAR S2/S2E in conjunction with implemented algorithms within the ROS framework.

1. **Real-time Mapping Capability:**

* Demonstrated the LIDAR system's real-time mapping capability through continuous monitoring and updating of the map.
* Achieved dynamic mapping that adapts to changes in the environment, ensuring up-to-date and accurate representations.

1. **Cross-Platform Compatibility:**

* Ensured cross-platform compatibility for the S2E RPLiDAR, allowing flexibility in deployment across different hardware and software environments.
* Considered the diverse technological landscape to enhance the adaptability and accessibility of the autonomous golf cart testbed.

1. **Comprehensive Project Documentation:**

* Maintained detailed documentation covering every stage of the project, starting from the initial verification on RoboStudio.
* Documented the transition to Ubuntu, including the installation of the VPN, ROS Neotic, and the step-by-step process of reading data from the LIDAR.

1. **Products**

**Journals:**

* Forest Roads Mapped Using LiDAR in Steep Forested Terrain

by Russell A. White,Brian C. Dietterick,Thomas Mastin andRollin Strohman

* M. S. Aslam, M. I. Aziz, K. Naveed and U. K. uz Zaman, "An RPLiDAR based SLAM equipped with IMU for Autonomous Navigation of Wheeled Mobile Robot," *2020 IEEE 23rd International Multitopic Conference (INMIC)*, Bahawalpur, Pakistan, 2020, pp. 1-5, doi: 10.1109/INMIC50486.2020.9318133.
* D. T. Son, M. T. Anh, D. D. Tu, L. Van Chuong, T. H. Cuong and H. S. Phuong, "The Practice of Mapping-based Navigation System for Indoor Robot with RPLIDAR and Raspberry Pi," 2021 International Conference on System Science and Engineering (ICSSE), Ho Chi Minh City, Vietnam, 2021, pp. 279-282, doi: 10.1109/ICSSE52999.2021.9538474.
* Autonomous Vehicle Navigation with LIDAR using Path Planning Rahul M K, Sumukh B, Praveen L Uppunda, Vinayaka Raju, C Gururaj B M S College of Engineering, Bengaluru, India

**Books:**

* LiDAR Technologies and Systems

**Book Chapters:**

* Chapter-8 LiDAR processing
* Chapter-10 LiDAR performance Metrics

**Thesis/Dissertations:**

* Albabah, N. (2021). Improving Parking Efficiency Using Lidar in Autonomous Vehicles (AV) [Doctoral dissertation, University of Akron]. OhioLINK Electronic Theses and Dissertations Center. Gaeini, Shaghayegh, "Risk-Aware Path Planning For Autonomous Vehicles" (2022).
* Gaeini, Shaghayegh, "Risk-Aware Path Planning For Autonomous Vehicles" (2022). Graduate Research Theses & Dissertations. 7052. <https://huskiecommons.lib.niu.edu/allgraduate-thesesdissertations/7052>

**Conference Papers and Presentations:**

* Lidar: a new self-driving vehicle for introducing optics to broader engineering and non-engineering audiences by Corneliu Rablau

**Other Publications:**

* Lidar for Autonomous Driving: The principles, challenges, and trends for automotive lidar and perception systems by You Li, Javier Ibanez-Guzman

**Technologies or Techniques:**

* ROS Noetic(Robot Operating System)
* SLAM

**Patents:**

Resolving Self-Driving Car Patent Conflicts: Arbitration in Waymo v. Uber and Future Autonomous Vehicle Patent Disputes" delves into a notable legal case in the autonomous vehicle industry. It centers on the dispute between Waymo and Uber concerning alleged patent infringements and trade secret misappropriation in LiDAR technology.

**Inventions:**

* High-Resolution 3D LiDAR Mapping: This invention involves the development of high-resolution LiDAR systems capable of generating detailed 3D maps of the vehicle's surroundings. These high-resolution LiDAR systems provide greater detail and accuracy in mapping, crucial for autonomous vehicles to identify and classify objects precisely, leading to safer and more efficient navigation.

**Licenses:**

* Luminar Technologies and Volvo: Volvo has partnered with Luminar Technologies, licensing their groundbreaking LiDAR technology for Volvo's next generation of cars. This collaboration aims to boost the safety and autonomy level of Volvo's vehicles, incorporating Luminar's high-resolution LiDAR systems for better object detection and road awareness.

**Websites:**

<https://vnav.mit.edu/labs/lab2/ros.html>

<https://www.slamtec.com/en/RoboStudio>

<https://wiki.ros.org/ROS/Installation/TwoLineInstall/>

<https://www.generationrobots.com/blog/en/lidar-integration-with-ros-quickstart-guide-and-projects-ideas/>

<https://bucket-download.slamtec.com/5350555d005bfd7a8685fcea6e80e9edb764adb1/SLAMTEC_rplidarkit_usermanual_S2E_v1.0_en.pdf>

<https://www.slamtec.com/en/S2/>

<https://wiki.ros.org/noetic/Installation/Ubuntu>

<https://www.slamtec.com/en/RoboStudio/VirtualTrack>

<https://www.seeedstudio.com/blog/2018/11/09/rplidar-and-ros-the-best-way-to-learn-robot-and-slam/>

<https://github.com/Slamtec/rplidar_ros>

<https://www.youtube.com/watch?v=Qrtz0a7HaQ4&ab_channel=TizianoFiorenzani>

**Other Products:**

<https://www.neuvition.com/?utm_source=googlead&utm_medium=searchcpc-all&utm_campaign=chenggongyi&utm_plan=search-again&utm_unit=vehicle&campaignid=14822719802&adgroupid=130741330680&matchtype=p&utm_keyword=lidar%20automotive&gclid=CjwKCAiApuCrBhAuEiwA8VJ6JmmCGVaQ_WOLwnMIzkvYUgdQ1FZEAmI86hvvrFeG_VMCaAqFrGwo5BoC2kwQAvD_BwE>