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GPS and LiDAR Based Autonomous Navigation System for the Electric Vehicles Using Pixhawk

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Abstract
Nowadays Autonomous navigation is evolving rapidly in the field of robotics, electric vehicles and other sensor-based machines This paper presents the design and the implementation of the Lidar and GPS based autonomous navigation system using Pixhawk controller for an electric ground rover. This platform integrates the multiple control modes including remote control by transmitter and receiver, mobile-based control by using ESP32 with QGroundControl, and the autonomous waypoint navigation by using the Mission Planner for the auto mode driving. Here a LiDAR sensor is used for the purpose of real-time obstacle detection in order to avoid them, while the GPS ensures the accurate positioning of the path travelled by the rover and as well as the real-time position of the system. The proposed system will demonstrate the reliable navigation, flexible contr4ol mechanisms, and efficient obstacle avoidance in both the manual and autonomous modes. The results highlight the effectiveness of integrating the sensors GPS and LiDAR technologies for intelligent vehicle navigation

Keyword: Autonomous Navigation, Pixhawk, LiDAR, GPS, ESP32, Mission Planner, QGroundControl, Electric Rover.

I. INTRODUCTION

Nowadays the Autonomous navigation systems are becoming as a cornerstone of the trendy intelligent transportations, unmanned ground vehicles (UGVs) and for the robotics too. With the rapid evolution in the field of the embedded systems, sensor fusion and real-time communication [8], there is an increasing demand for the low cost and efficient navigation systems which are capable for operating in the dynamic environments and difficulty conditions where man not are able to there. In the present days the integrated platform of integrating the autopilot using not only for the electric vehicles but also there are exploring in the industrial automation and in the research and academic applications. Out of all the open sources of autopilot system platforms the Pixhawk Orange Cube has emerged as a reliable, efficient and versatile flight controller which is capable of supporting in both the aerial and as well as the ground vehicle applications. It has a precise and easy control of sensor integration and autonomous mission execution through firmware such as ArduPilot. For the ground control the sources like mission planner and the QGroundControl enhances the usability by providing real time telemetry, waypoint navigation, and the parameter tuning interfaces in the sources. Here the Global Positioning System (GPS) plays an important role in enabling the waypoint path tracking and path planning [14]. For high precision modules like Here 3 GPS provide accurate position data which is very essential for the outdoor operations especially in autonomous operations. Even though by integrating GPS alone cannot be suitable for the obstacle and non-planner or free environment so to avoid obstacle avoidance we need a sensor too. To address this limitation Light Detection and Ranging sensor is integrated to provide the real time distance measurement and the obstacle detection capability [1],[12]. So, the LiDAR sensor operate based on the laser ranging principles, which offers the more accuracy and fast response towards the obstacles without collision to them [1],[6],[7].
Nowadays the functionality of the autonomous systems was integrating more and more by incorporating the multiple modes of operation of the robotic systems for flexibility of operation. Remote control (RC) using transmitter ensures manual override capability, while the wireless communication by using the module like ESP32 which enables the robust communication between the onboard systems to the ground stations, which extends the range and the reliability over the Wi-Fi networks [2], [9], [17].
This project presents the design and the implementation of a GPS and LiDAR Based

Autonomous Navigation System for Electric Vehicles Using Pixhawk. This system integrates the multiple hardware components such as motors. Motor driver(L298N), LiDAR sensor, GPS modules and embedded controllers. The Proposed system proposes the three operational modes:

1. Manual control using an RC transmitter.
2. Mobile based controller by ESP32 Wi-Fi communication.
3. Autonomous waypoint navigation by mission planner.

The proposed system aims to achieve real time navigation, reliable obstacle avoidance and seamless switching between the control modes. By combining LiDAR based obstacle avoidance and GPS based Path planning so that the system will enhances the accurate navigation and safe operation in the real -world surroundings and environment. This work contributes for the development of the cost effective autonomous electric vehicle platforms which is suitable for the research, surveillance and smart mobility applications [3]

II. Background

The improvement in the auto-navigation systems is gaining crucial importance day by day in the last decades, because their applications are wider in intelligent transportation and repeated tasks and as well as in the army basis cause to help the soldiers in the time of wars to save the soldiers who are affected in the war zone. This auto navigated technology is also used in the robotics, surveillance and for agriculture and also in the industries for the automation. Autonomous ground vehicles (AGVs) and unmanned grounded vehicles are increasingly designed in a wide range to operate with the minimum intervention of the human for the operation of these and for doing of these tasks with less maintenance and high accuracy, safety and reliability. So, for the complex and complicated navigation tasks the integration of the embedded controllers, positioning systems and wireless communication in the dynamic environments by integration of all and as well as the environmental sensing technologies.

One of the greatest opportunities for the autonomous vehicle technology is the advancement in the use of the free off and open-source autopilot platforms. Especially the Pixhawk orange cube is widely adopted for the autonomous project and robots due to their modular architecture, better processing capability and as well as the compatibility with multiple sensors fusion and communication interfaces [3],[5],[7]. By using the ArduPilot firmware the controller can manage control of both aerial and as well as the grounded autonomous systems because this controller can include the navigation, telemetry, control over sensors and as well as the control of the motor [3]. Because of this flexibility which is offered by the Pixhawk platform which help the researchers as well as developers to utilize the different modes that can be operated in the manual, auto, assisted driving and fully autonomous navigation.

The ground control system plays an important role in the configuration and the monitoring of the autonomous systems [4], [11]. Applications which are most user friendly such as Mission Planner and the QGroundControl provides the real time monitoring and the real time visualization of the vehicle. They also help in providing the telemetry visualization of the vehicle and tuning of the parameters and also for the waypoint management particularly by the Mission Planner. These platforms mainly use the MAVLink protocol for the establishment of communication between the onboard controller to the ground station [4]. At present Mission using widely for the autonomous navigation and advanced configuration of the autonomous robots while the QGroundControl facilitates the accessibility various platforms through devices like mobiles and as well the personal computers.

The autonomous systems primarily use or depend on the Global Navigation Satellite Systems (GNSS) [3],[21]. The Here 3 GPS module provides accurate information of the rover position and also the pre-determined path it should follow and as well as the path it was moved. While the GPS-based navigation is very effective especially in the outdoor applications majorly. But it is affected by the environmental conditions like signal blockage, multipath interference, and as well as in the terrain variations [3]. So, because of that we need more additional sensing mechanisms to ensure the safe and reliable and effective operation in obstacle prone environment and as well as in the rugged surface where the ground is uneven to sense and drive safely and effectively and efficiently, we need to integrate more additional sensing devices for this purpose.

To improve the navigation safety by keeping in view of the environmental conditions, the technology of LiDAR is used to integrate for the autonomous systems. The LiDAR sensors are used to detect the obstacle by the transmitting of the laser pulses and measure the reflected signals so that the distance of the obstacle is measured in distance from the rover. By the use of this technology, we can enable accurate distance between the rover and the obstacle and terrain mapping and also the real time path correction with reference to the waypoint set in the Mission Planner. The Research is already conducted by the Zhang and Singh on the LiDAR in real time localization and the mapping applications on the LiDAR Odometry and

Mapping (LOAM) had demonstrated on real time applications [1], [18]. Because of its high precision and fast response in nature LiDAR has become popular as the one of the best and more reliable sensing technologies for the autonomous vehicles.

Nowadays wireless communication has become more use of wide range to enhance the usability and the flexibility of the robotic and autonomous systems. With the help of the ESP32 microcontroller which has the WI-FI functionality provides flexibility of operation and communication from remote place. It enhances the communication between the mobile devices to the rover. In this project, ESP32 which is configured with the DroneBridge firmware enables the MAVLink telemetry over the Wi-Fi networks [2], [17]. By the configuration of this firmware the control of the rover is enabled by the mobile and it can be monitored in the QGroundControl which eliminates automatically the telemetry modules for the shortest distance applications.

The motor actuating system is controlled by the L298N motor driver which drives the motors in which pairwise parallel connection of the motors so that the direction and speed of the motors are controlled by this driver in which it is received a control signal from the controller Pixhawk. So that the wheels are controlled its direction and speed as a whole. So, by integrating the L298N to Pixhawk gives the accurate and precise control in both manual as well as autonomous mode of operations. A 12V Battery system supplies power to the motors and electronics and sensors like LiDAR and GPS and communication devices through a regulated power distribution module [16].

The proposed system enables to combines these technologies into a single platform which is capable to operate in multiple modes. Initially the rover is configured to move with the help of radio transmitter and receiver which helps the rover to function manually which is as like as the conventional remote-controlled vehicle. Secondly, the rover about to connect via Wi-Fi which is by the help of the ESP32 and the communication by the QGroundControl communication and finally, the autonomous control of the rover via waypoint navigation and path planning which is given in the Mission Planner. So that it follows a predefined path by utilizing the information by the LiDAR for obstacle detection and avoidance and the accurate position of the rover as well as the path of the destination.

The integration of the GPS, LiDAR sensors to the Pixhawk enables the autonomous control and as well as the cost-effective and scalable solution for the electric vehicle research. So, such systems provide the potential applications for the smart transportation, military reconnaissance, environmental monitoring, industrial inspection and agricultural automation mainly in this application autonomous control is widely used and has a scope of the autonomous systems and as well as the use of the robots too [1],[3], [20].

III. PROPOSED SYSTEM

The proposed system is with the title "GPS LiDAR Based Autonomous Navigation System for the Electric Vehicles Using Pixhawk," which is designed to develop a multi-purpose and multi operational and multi-functional autonomous ground rover which is capable of operating in the manual, fully autonomous and semi-autonomous modes of operation. The system is control and integration into a single embedded platform by integrating the wireless communication to the rover, navigation of the rover, obstacle detection from the rover and motor control technologies for speed and direction of the rover efficiently and effectively. The main objective of this proposed system is to get the accurate waypoint navigation, real time navigation, real time obstacle avoidance and detection and flexible user-friendly control with less implementation cost and high operational reliability.

The proposed architecture consists of several interconnected hardware as well as software modules which includes Pixhawk Orange cube, ESP32, Here3 GPS, LiDAR sensor, transmitter and receiver unit, L298N driver, DC motors, power module and a source of 12 V battery system. The overall operation of the rover is controlled by the Pixhawk Orange cube which is running ArduPilot firmware [3] [15], [17].

Fig. 1 Block diagram of Overall Architecture

A. System Architecture:

The system proposed consists of different layers. They are

1. Communication Layer

This Layer Mainly contributes the operation with the handless wireless telemetry and user interaction through the ESP32 Wi-Fi communication and by MAVLink protocol.

2. Control layer

This Layer is responsible for the processing the commands and execute the navigation algorithms using Pixhawk Orange Cube.

3. Sensing Layer

This Layer gets the information from the sensors like positioning data from the GPS and obstacle detection from the LiDAR.

4. Actuating Layer

This Layer is also a movement control layer of the rover because this layer controls the movement of the rover through control of the motors through driver.

Here the Pixhawk acts as a central processing unit for the whole system because it receives the input data from all the devices including GPS, LiDAR, communication modules and as well as it processes the navigation algorithms and generate the signals or pulses to the motor via driver to control the wheel movement of the motors in the sense of direction and speed of the motors so that the rover speed and direction in which it should subjected is controlled by the control signals which are given by the Pixhawk to the driver.

B. Manual RC Mode:

This mode is the first operational mode for the rover to demonstrate whether the rover is perfect to follow commands or not. It consists a transmitter and receiver unit. The transmitter sends the control commands to the rover via receiver in which it is connected to the Pixhawk to follow the commands like forward, reverse and as well as left and right turn. The Pixhawk follows and interprets the commands and controls the motors accordingly through the driver module so that the rover direction and speed is controlled.

This mode primarily used for the

- Initial testing.
- Manual navigation in the bad environmental conditions.
- Safety override.
- Emergency control of the rover during autonomous navigation.

In this manual control mode, the operator can immediately can be able to take the control of the rover in case of any intervention in the navigation error or any obstacle detection failure occurs [3].

C. Mobile Based Wi-Fi Control Using ESP32:

This is the second operational mode which enables operation through wireless control of the rover through the mobile interface of QGroundControl. The ESP32 is installed with a firmware of DroneBridge to make or enables the MAVLink communication over Wi-Fi networks [2], [17].

In this mode:

- The ESP32 creates an interface of wireless communication bridge
- The telemetry data of the rover is transmitted to the mobile because of this MAVLink communication
- Commands are received and are forwarded to the Pixhawk controller and followed which is given through the QGroundControl interface

The QGroundControl can have the operations and facilitates the following:

- Monitor the status of the vehicle.
- Change the different types of driving modes and flight changes to different operating modes.
- Observes the position of the rover because of the existence of the GPS.
- Access the parameters of the telemetry.
- Control of the rover remotely.

By this approach we can eliminate the need of additional telemetry hardware and provides a low-communication solution for the short-range applications of the autonomous vehicles [4].

D. Autonomous Navigation Using Mission Planner:

We are using the capability of the Mission planner to implement the autonomous navigation. In this mode of operation, we define the waypoints in the Mission Planner and read and write the waypoints in the mission planning interface within the Pixhawk controller through the read and write of the waypoints. The GPS will continuously provide the real time position data of the rover to the Pixhawk autopilot. By considering this information the rover calculates the path error and any adjustments in the motor outputs to follow the desired route accurately with the help of the GPS and LiDAR data.

The autonomous navigation includes the following:

- Waypoint generation.
- Mission upload.
- Path correction.
- GPS coordinate tracking,
- Destination reaching.

The ArduPilot firmware allows to operation facilitate in multiple navigation modes such as AUTO, GUIDED, MANUAL, RTL (Return to Launch), and HOLD modes in which these modes will improve the operational flexibility and safety [3],[10].

E. LiDAR Based Obstacle Detection:

The detection of the obstacle is achieved by the LiDAR sensor which is mounted on the rover and so that the avoidance of the obstacle is achieved successfully. The sensor continuously scans the environment surroundings and measures if any obstacle is found for the vision of that sensor so that the distance of that obstacle from the rover is measured using the rover laser reflection principles [18].

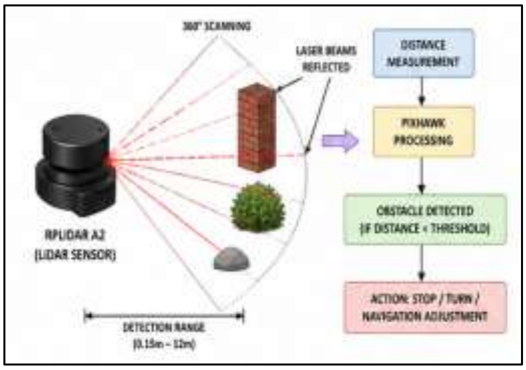


Fig. 2 LiDAR Mechanism

When the obstacle is detected for the sensor under the predefined threshold distance, the following happens simultaneously:

- Distance information will be transmitted to the Pixhawk controller.
- The navigation algorithm will modify the motion of the vehicle accordingly.
- The rover will do either stops in that position or changes the direction to avoid collision.

The integration of the LiDAR sensor in addition to the GPS will provide the navigation reliability and as well as the efficiency instead of only GPS based system. This type of system improves the effectiveness in the real time autonomous navigation and mapping applications in the any type of the environment [1], [18].

F Motor Drive and Power Management:

The propose rover uses four DC motors which are connected to the four wheels for making a movement in the rover. These motors are controlled by the L298N motor driver which achieves the bidirectional control of the rover with the help of the PWM signals which are generated by the Pixhawk controller [16], [19].

The power system consists of the following:

- A batter source of 12V.
- A power distribution module.

The power distribution module supplies stable voltage to the

- Pixhawk controller.
- ESP32.
- GPS module.
- LiDAR sensor.
- Motor drivers.

We need stable and efficient power management which is very essential for the operation of the autonomous missions.

F. Advantages of the proposed system:

The proposed system has the following advantages:

- Multiple number of operational modes.
- Low-cost implementation of the open-source hardware.
- Accurate positioning by GPS based navigation.
- Real time wireless monitoring of the system.

- Enhanced safety achieved by the LiDAR which detects the obstacle.
- Flexibility of control of the rover by the Mission Planner and QGroundControl.
- Expandable architecture for the future enhancements easily.

The combination of the autonomous navigation and obstacle detection will make the system more suitable for the research in the intelligent transportation, robotic exploration and agricultural automation and many other more applications in the modern world [1],[2].

IV.DESIGN AND IMPLEMENTATION

The design and implementation of the proposed GPS and LiDAR Based Autonomous Navigation System for Electric Vehicle Using Pixhawk involves the integration of the all the components like embedded hardware components, communication modes, navigation sensor and autonomous control algorithms. The system is developed so that it operates and supports different modes like manual remote control, wireless mobile based operation and autonomous waypoint navigation. The implementation process precisely focusses on achieving the reliable vehicle control, real time obstacle detection and accurate navigation.
The Overall development of this architecture is consisting of Pixhawk Cube Orange which acts as a central processor which it integrates with the GPS, LiDAR, ESP32, transmitter receiver unit, and a motor driver module, DC motors and power distribution module. This design makes the perfect communication between al the subsystems which are mounted on the system and ensures the safety and maintain stability of operation in all environmental and navigation circumstances.

A. Hardware Design

The Hardware design of this system is implemented by the simple integration by the modular components. The Hardware design consists of different components like chassis, four wheels, motors, motor driver(L298N), ESP32, GPS, LiDAR, Battery and Power module [2]. The specific function of each component is clearly explained below:

Component	Function
Pixhawk Orange cube	For controlling of navigation through Ardupilot
Here3 GPS	For the positioning of the rover and also for the waypoint tracking and path planning.
LiDAR	For the detection of the obstacle and measure it how far it is from the rover with reflected laser signals
ESP32	It is for the telemetry and wireless communication with the rover through the QGroundControl interface.
L298N	To control the speed and the direction of the rover by sending the signals which are commanded by the Pixhawk
DC Motors	For the vehicle movement in required direction
RC Transmitter and Receiver	For controlling the rover in the manual mode of the operation.
12V Battery	To ensure the stable power supply all the components.
Power Module	For the voltage regulation and uniform power distribution.

Hardware Components

B. Pixhawk design and Configuration:

The Pixhawk plays a crucial role in controlling and processing the data for the whole system. The ArduPilot firmware which is installed in the Pixhawk controller to support the autonomous rover-based navigation and operation effectively.
The operations performed by the Pixhawk are:

- Acquisition of the sensors data.
- Generation of the PWM signal to driver.
- Communication with the rover through MAVLink.
- Navigation control in Autonomous Mode of operation.
- GPS coordinate processing.
- Obstacle response handling.

The controller interfaces with the:

- Motor driver through PWM outputs.
- ESP32 using telemetry ports.
- LiDAR using the serial interface.
- GPS module through the UART communication.

The parameters for the firmware are configured using Mission Planners which enables tuning of the steering, throttle, navigation speed, waypoint radius and also the obstacle avoidance parameters [3], [5].

C. GPS Navigation System Implementation:

The navigation and positioning of the rover is controlled and access the information through Here3 GPS which is connected to the Pixhawk autopilot. The GPS module continuously send the information like latitude, longitude, altitude and heading information of the rover and also the motion of the rover. The waypoint navigation is achieved in mission planner by this data produced by the GPS and the waypoints are uploaded to the Pixhawk controller is through MAVLink communication.
This algorithm performs:

- Heading direction and correction of the rover.
- Distance calculation from the rover to the destination waypoint.
- Adjustment of the steering accordingly to reach the destination waypoint.
- Velocity control of the rover based on the destination and initial distance.
- Position tracking of the rover.

The rover continuously checks and compares the current position of the rover to the destination waypoint and adjusts the motor outputs to reduce the positional error and for the autonomous systems the GPS based waypoint navigation is used widely [3], [15], [21].

D. LiDAR Based Obstacle Detection Implementation:

The detection of the obstacle is achieved by the LiDAR which is mounted on the front side of the rover. The emits the laser pulses continuously and gets the reflect signals if any objects are detected within the threshold range. This information is continuously transmitted to the Pixhawk for real time monitoring of the system.
What happens when the obstacle or an object is detected within the range of the threshold predefined distance is:

- It stops the movement of the rover automatically.
- Steering correction is initiated with respect to the direction of the obstacle or object.
- Alternate path is planned and movement of the rover is attempted.

This integration and implementation of the LiDAR will improve the operational safety and reduces the collision of the objects in the predefined path in the automation. Nowadays integrating of the LiDAR in robotics and autonomous machines due to their high accuracy and rapid response time [1], [18].

E. ESP32 Wireless Communication Implementation:

Wireless communication between the rover and the mobile can be achieved by the configuration of the ESP32 with the DroneBridge firmware [2], [4], [17].
ESP32 performs the following tasks:

- Create a Wi-Fi hotspot in the name of the DroneBridge for Ardupilot.
- MAVLink telemetry transmission.
- Transmitting of the remote command and as well as the receiving of the command.
- Communication between rover and mobile is established.

By using this set up the rover is monitored and controlled by the mobile and personal commuter in the QGroundControl interface [4].
The communication architecture will provide the following:

- Real time telemetry.
- Switching modes remotely.
- Remote monitoring of the rover.
- Access of the parameters.
- Portable control capability is achieved.

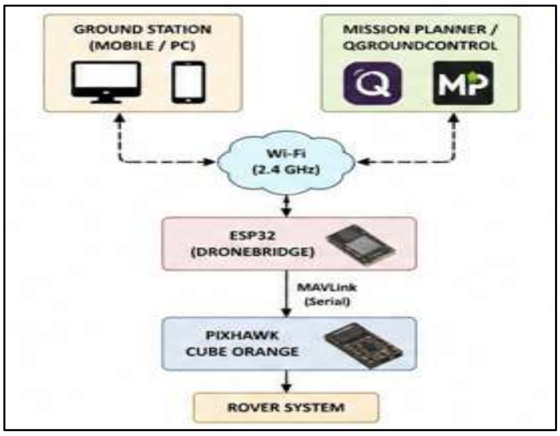


Fig. 3 Communication Architecture

F. Motor Control Implementation:

The movement of the rover in whatever direction we needed to go is achieved by the help of the DC motors which are connected to wheels which are attached to the chassis. The motors are drived and controlled by the L298N motor driver in which the control signals are commanded by the Pixhawk controller.

The motor driver performs the following;

- Forward and backward movement control.
- Left and right steering control.
- Speed variation control.

Differential steering allows the smooth tuning and accurately corrects the pat during the automation. This is implemented by varying the speed and direction of the opposite side motors of the rover [19].

G. Operational Modes Implementation:

The autonomous rover proposed is implemented in three modes:

1. Manual RC mode:

In this mode of operation, the user can directly control the rover by transmitter and receiver setup. This mode is mainly used for testing of the rover and as well as in emergency override.

2. Mobile Based Control Mode:

This mode the rover is controlled by the mobile as well as the personal computer through the QGroundControl interface in the ESP32 is installed with DroneBridge firmware to provide Wi-Fi for the connection of the rover to mobile and personal computer.

3. Autonomous Mode:

In this mode the rover is fully autonomous so that the predefined paths are given to the rover through Ardupilot and set the waypoints so that the mission will be successfully established irrespective of the obstacles because it is overcome by the LiDAR.

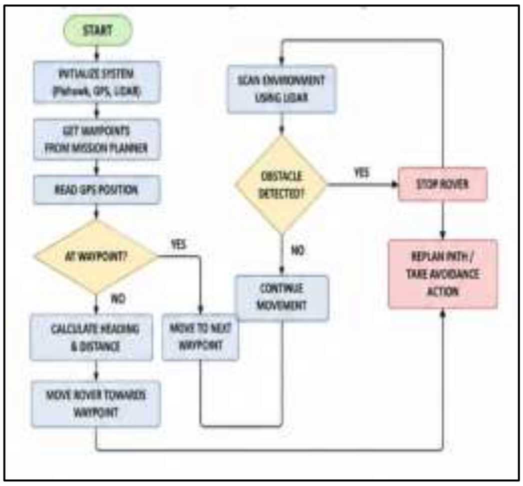


Fig. 3 Autonomous Navigation Flowchart

V.Results And Performance Evaluation

The proposed system GPS and LiDAR Based Autonomous Navigation System for Electric Vehicles Using Pixhawk was experimentally evaluated and observed under various operating conditions to analyze different operations like navigation capability, communication performance, overall operational stability and obstacle detection efficiency. The various experiments are conducted on the rover in manual control, Wi-Fi based control and autonomous control modes. The navigation data and the real time telemetry were monitored by the help of Mission Planner and QGroundControl. The system logs are used to evaluated the performance analysis which are generated by the Pixhawk Orange Cube [3], [22].

A. Experimental Setup:

The prototype of the rover was assembled by using the following:

- Pixhawk Cube Orange autopilot,
- LiDAR sensor,
- Here3 GPS module,
- ESP32 with the DroneBridge firmware,
- L298N motor driver,
- Four DC motors with four-wheel configuration,
- 12V Battery and power distribution module.

The experiments on the rover are conducted in the outdoor environment to ensure the stable GPS signal because only in outdoor the GPS is with stable signal so that the it ensures good signal reception and sufficient space for waypoint navigation testing.

B. Manual Control Performance:

In initial stage the rover to be controlled in manual mode so for that purpose we need to test it with the help of the transmitter and receiver unit. So that the rover to be tested whether it is responded or not. Here the rover is responded successfully with various directional commands such as forward movement, reverse movement, left steering, right steering, speed control and stopping actions. The manual mode of operation is smooth and stable rover operation with minimal delay between the command transmission and motor response.

So, the manual control mode was tested successfully and this will be more helpful for safety operation and initial testing and safety override during autonomous operation. We can see the results of the performance below:

Parameter	Observation
Forward Motion	Successful
Reverse Motion	Successful
Steering Response	Accurate
Control Delay	Low
Vehicle Stability	Stable

Manual Control Performance

C. Wi-Fi Communication Performance:

The configuration of ESP32 with the DroneBridge successfully established and the wireless communication between the rover and mobile device [2]. Telemetry parameters like GPS coordinates, speed, battery voltage, heading and operational mode of the rover are transmitted successfully to QGroundControl.

Here the Wi-Fi communication system enabled the following:

- Real time telemetry monitoring.
- Mode switching of the rover.
- Wireless rover control.
- Remote parameter monitoring of the rover.

Here I observed the communication performance remain stable for low and medium range of operating distances and a small are minor signal delay were observed at larger distances due to the limitations in Wi-Fi.

D. Autonomous Waypoint Navigation Results:

Autonomous waypoint navigation implemented and configure through Mission Planner by setting predefined waypoints in the path planning map. The rover is successfully followed the uploaded GPS path and reached the target waypoints using the positional feedback from the Here3 GPS by avoiding the obstacle. The Pixhawk controller continuously send the corrected signals to the rover to correct the steering and speed of the motor to minimize the positional deviation from the planned route [3], [21]. The rover maintained the stable and reliable movement in waypoint tracking and it successfully completed targeted mission navigation.

Fig. 4 Performance of Autonomous Navigation

Parameter	Result
Waypoint Tracking	Successful
GPS Accuracy	Good
Path Following	Stable
Navigation Delay	Less
Mission Completion	Successful

The above result indicates the performance of GPS based navigation system effectively which guides the rover through predefined waypoints.

E. LiDAR Obstacle Detection Performance:

The LiDAR sensor was tested to evaluate the performance of the rover with the help of LiDAR while testing the autonomous rover movement to evaluate the obstacle detection capability. The LiDAR sensor scan the surrounding environment continuously and measured the obstacle and objects which are under the predefined distance so that the data is received to the personal computer.

When the obstacle is detected under this predefined threshold distance the rover is facing the following:

- The rover was stopped automatically.
- Navigation correction was initiated and new path is developed.
- Collision was avoided successfully because of obstacle is detected by the LiDAR sensor.

The integration of the LiDAR had improved the navigation safety and operational reliability significantly [1], [18].

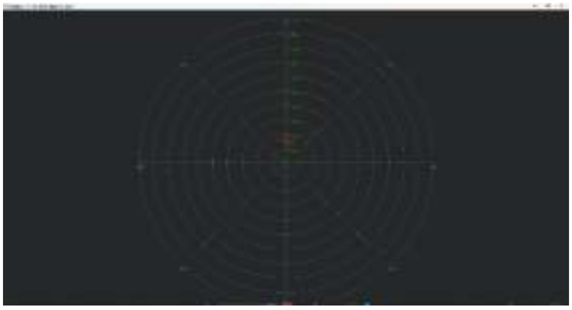


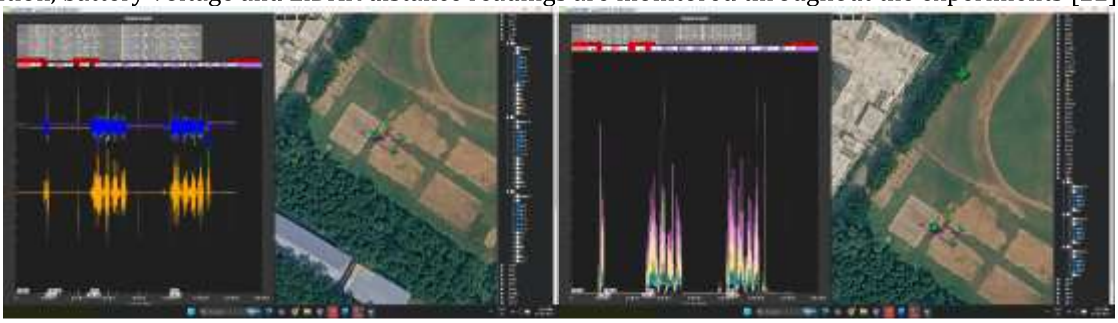
Fig. 5 Obstacle Detection Results

This shows the clear visible of an object detected by the LiDAR below the meter range.

Test Condition	Observation
Obstacle Detection	Successful
Collision Avoidance	Successful
Sensor Response time	Fast
Distance Measurement	Accurate
Rover Safety Response	Stable

F. Pixhawk Telemetry Log Analysis

With the help of the Telemetry logs recorded in the Pixhawk controller were analyzed to evaluate the behavior of the rover during the entire operation. Parameter like speed, heading, steering output, GPS position, battery voltage and LiDAR distance readings are monitored throughout the experiments [22].



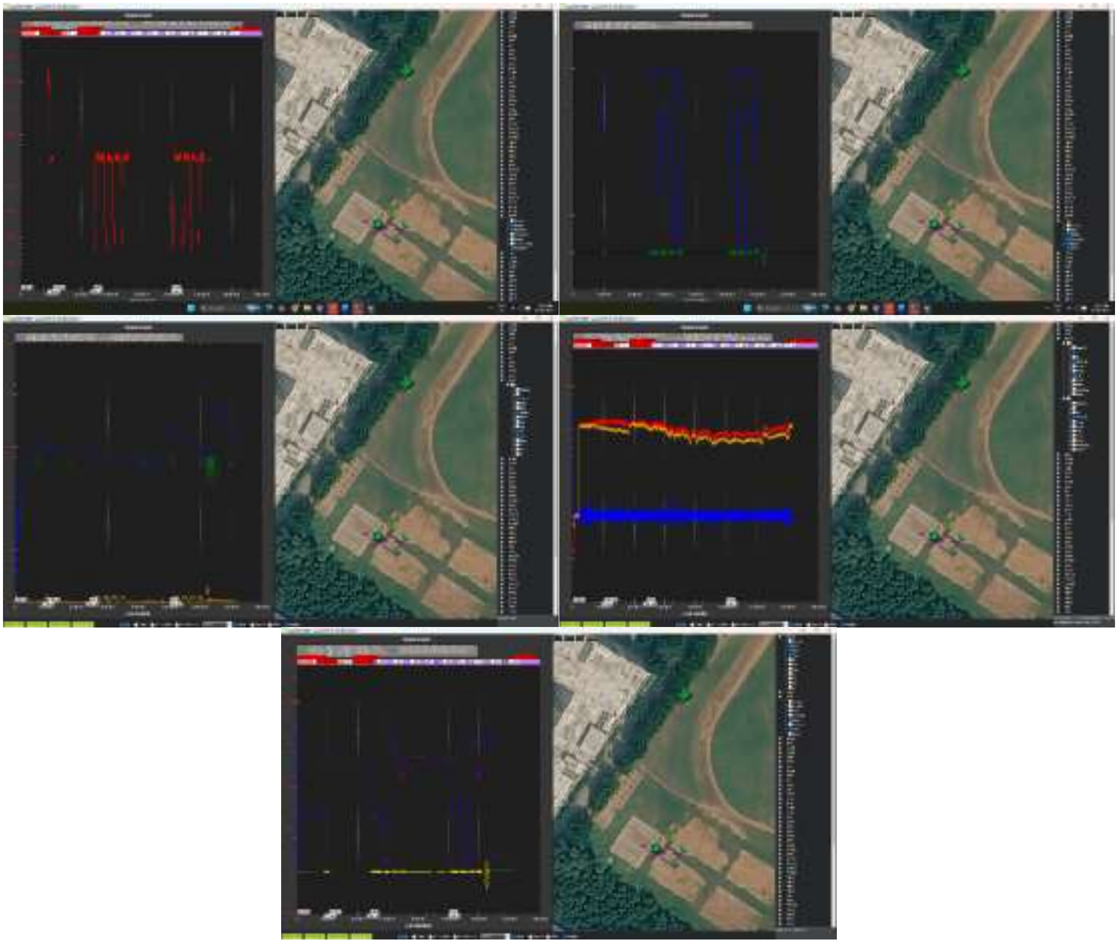


Fig. 6 Vehicle Performance

a. This shows the multiple IMU sensors data which is inside the flights controller these are for better accuracy. Here the Gyroscope data shows the rotational movement and Accelerometer data and movement. IMU sensors remains stationary when the rover stays stable, we can see visible fluctuations and vibration during the movement of the rover.
b. This shows Vibration analysis of the rover during the whole operation the graph is stable during the vehicle is stable and the maximum variations under auto and guided modes and minor vibrations shows uneven terrain and skid steering.
c. This shows the steering and turns rate during navigation. The sharp positive and negative edge gives turnings and values nearer to zero means it is showing moving in a straight path.
d. This shows the rover throttle output, speed and acceleration during the rover operation. It is stable during the straight path and small or visible acceleration during the normal rover motion and terrain.
e. This shows the GPS data here it represents the rover is stable and shows it follows the straight path and takes the right path and the paths of the waypoint and also have some minute or negligible errors.
f. This shows the barometer readings climb rate is stable because of no climb for terrain and dual barometer shows the relatively close shows the stable cruise altitude for around 10 meters.
g. This shows the AHRS and ATT data that the primary attitude yaw and the secondary AHRS track each other accurately throughout the entire travel of the rover with small or negligible variations.
The entire Log determines:

- Stable vehicle movement.
- Accurate waypoint tracking of the rover.
- Reliable telemetry communication.
- Fast and reliable sensor response

G. Overall System Performance Evaluation

The overall system successfully implemented as per the proposed system by successfully integration of the GPS navigation, LiDAR sensing, autonomous control and wireless telemetry into a single embedded system.

Parameter	Performance
GPS	Accurate
Waypoint Tracking	Successful
Wireless Communication	Stable
Obstacle Detection	Effective
Manual Control	Responsive
Telemetry Monitoring	Reliable
Autonomous Operation	Successful
System Stability	Good

Overall System Performance

The systems navigation accuracy and operational safety is improved by combined operation of the rover with GPS navigation and LiDAR sensing. The ESP32 based communication provides the systems more efficient wireless monitoring and control capabilities to ensure the stable autonomous operation by the Pixhawk controller [1],[3], [17].

Fig. 7 Experimental setup

VI. Conclusion

This entire paper presented the implementation and development of the GPS and LiDAR Based Autonomous Navigation System for Electric Vehicles Using Pixhawk. This proposed rover system successfully integrated the GPS navigation, LiDAR sensor for the obstacle avoidance and detection, wireless telemetry communication for remote operation and ESP32 with configuration of the DroneBridge and multi-mode vehicle operation and control and the ground control software such as Mission Planner and QGroundControl.

The rover operated successfully in manual mode. Wi-Fi mode and autonomous waypoint navigation mode. The experimental results demonstrated the reliable waypoint navigation and stable communication and real time telemetry effective LiDAR improved navigation accuracy and safety during the autonomous operation.

The system offers the low cost, scalable and flexible solution using open-source hardware and software making it suitable for applications such as surveillance, agriculture automation, industrial inspection and robotic research. The future enhancements may include the RTK-GPS, SLAM navigation, AI-based obstacle avoidance and computer vision techniques [7], [13]. The overall project demonstrates effectively a practical autonomous electric vehicle navigation system using GPS, LiDAR and Pixhawk technologies.

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