2025 6th International Conference on Mobile Computing and Sustainable Informatics (ICMCSI) | 979-8-3315-2266-7/25/$31.00 ©2025 IEEE | DOI: 10.1109/ICMCSI64620.2025.10883122

Design and Development of IoT Smart Driving Protocol for Unmanned Ground Vehicles

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***Abstract*— UGVs have enormous potential in industries such as defense, agriculture, and autonomous transportation. Efficiency and effectiveness can be achieved by UGVs through the sophistication of their control systems, mainly with regard to navigation and decision-making. In this study, a new IoT-based smart direction control system is proposed for UGVs. The system presented herein integrates state-of-the-art sensor fusion techniques against the backdrop of a robust and adaptive communication framework for enhanced navigation accuracy and reduced latency, with the overall goal of improving system efficiency. Equipped with GPS, IMU, and LiDAR sensors, our system provides accurate environmental perception and real-time adaptability to various terrains. The heart of this device is a high-performance, military-grade microcontroller, which ensures the reliability and handling of numerous data streams simultaneously with minimal latency. On the software side, modular design makes use of edge computing and machine learning algorithms to facilitate adaptive control and real-time decision-making. The performance was verified by rigorous testing in simulated environments and real-world field trials. The results show an improvement in the navigation accuracy and system responsiveness compared to previous solutions. A comparative deep analysis shows the superiority of our approach to hardware design, software integration, and prototype testing.**

***Keywords*—Intrusion Detection Systems, Genetic Algorithm, Reinforcement Learning, Feature Selection, Network Security**

I. Introduction

The segment of autonomous vehicles has been growing rapidly in the last few years, aided by the integration of technologies into the Internet of Things. UGVs are basically pioneering this evolution into applications as diverse as military operations, agricultural automation, and autonomous transport systems [1]. Their performance depends highly on how sophisticated and reliable the control systems are in handling complicated tasks such as navigating, avoiding obstacles, and making decisions in real time. Fig 1 shows the IoT-based smart driving protocol for UGVs.

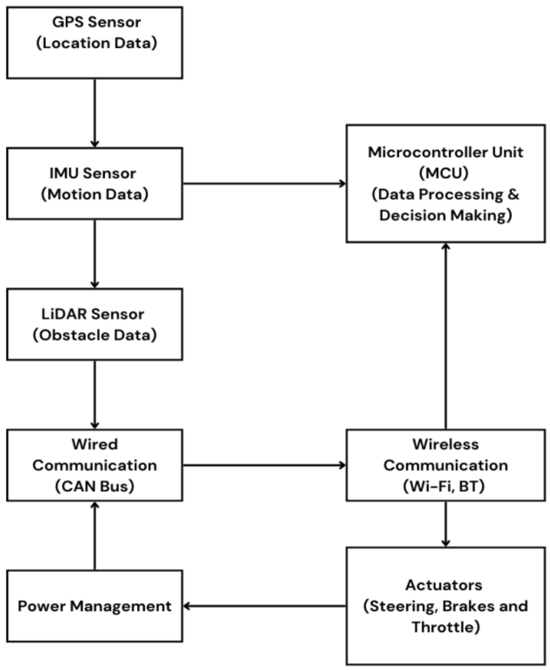

Fig 1: IoT-Based Smart Driving Protocol for UGVs

The advent of the IoT has provided new opportunities for the development and perfection of UGV control systems. By embracing IoT technologies, these types of systems would enable further and more flexible responses to environmental situations by processing real-time data from different categories of sensors. The integration of IoT allows for perfect communication between the different parts of the system, allowing UGVs to work efficiently in dynamic and challenging environments [2]. This paper presents the development of an advanced IoT-based smart direction control system for UGVs. Our system focuses on solving some of the following critical challenges related to the navigation and control of UGVs, which ensures location tracking with high accuracy and control of movement in various terrains [3] and deals with the reduction in time required for processing data and making a decision to enhance real-time responsiveness [4]. It improves the overall operational performance by integrating hardware and software components in a significantly optimized manner. These goals integrate GPS, IMU, and LiDAR sensors to provide full 360-degree situational awareness and precise control.

A military-grade microcontroller ensures reliable performance and efficient handling of several independent data streams [5]. Sensor data processing, decision-making, and actuator control are all segregated into independent modules: edge computing and machine learning guarantee adaptability and real-time decisions [6]. It is regarded as the greatest advancement in UGV technology owing to its sophisticated navigation and real-time responsiveness. In this paper, we present the design, implementation, and testing of an IoT-based smart direction control system and an in-depth performance analysis in relation to other existing systems. Outlining the approach to major challenges and leveraging the advancements in IoT, this work contributes to the development of more efficient and capable self-driven vehicles.

II. System Specifications

The system specifications outline the various components and capabilities of the IoT-based smart direction control system for unmanned ground vehicles. They are designed for high performance, reliability, and adaptability across various operational scenarios. Table I presents the data for the sensor-integration GPS.

TABLE I: SENSOR INTEGRATION GPS DATA

Data	Description
Type	High-precision GPS receiver with RTK capability
Accuracy	Up to 1-2 cm under optimum conditions
Function	Provides precise geolocation and navigation IMU

The 9-axis IMU combining the accelerometer, gyroscope, and magnetometer has an acceleration of ± 16 g, angular velocity of ±2000°/s, and magnetic field of ±4800µT. It detects velocity changes and orientation, which aids in maintaining stability and movement accuracy. It contains a 360-degree LiDAR scanner with multi-return capability, up to a 100-meter range, with a vertical FoV of 30° and a horizontal FoV of 360 °. Functionality includes high-resolution distance measurements and three-dimensional (3D) environment mapping for obstacle detection and navigation. The Microcontroller Unit Type includes a military-grade ARM Cortex-M7 microcontroller that assists in processing real-time data, running control algorithms, and aging communication between sensors and actuators. Fig 2 presents the integration of the GPS, IMU, and LiDAR Sensors with the Microcontroller on UGV.

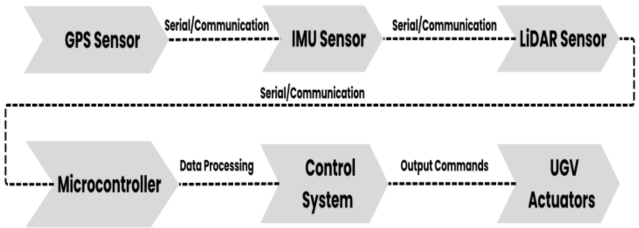

Fig 2: Integration of GPS, IMU, and LiDAR Sensors with Microcontroller on an Unmanned Ground Vehicle (UGV)

III. Hardware Architecture Design

The hardware architecture of an IoT-based smart direction control system for UGVs was designed to provide reliable, efficient, and scalable operations for diverse applications. It integrates several key components that contribute to the overall functionality and performance of a system.

A. Microcontroller Unit (MCU)

The MCU is selected based on its robustness, real-time processing capability, and potential to deal with various streams of data. In this case, a military-grade microcontroller unit was used to guarantee reliability under harsh conditions and high computational performance. The main function of the control layer is the management of sensor data and control algorithms and the coordination of actuator signals. It also gets information from and sends information to other components of the system.

B. Sensor Modules

This is useful for giving precise geographic coordinates, which are useful for navigation. The benefit is that it is equipped with a GPS module to output high-resolution position data that guarantees its proper functioning in a difficult environment. It is an IMU module for acceleration, angular velocity, and tilt of the device or anything it is attached to. Specifically, the IMU is useful for keeping one's bearings on uneven ground, which the rover often sets foot upon.

C. Communication Modules

The system incorporates wireless modules, such as Wi-Fi, Bluetooth, or some other type of proprietary radio frequency, to transfer the commands and status updates between a UGV and the external control systems. In applications where high data integrity with low latency is required, wired communication interfaces, such as the CAN bus, are used to ensure reliable data exchange among internal components.

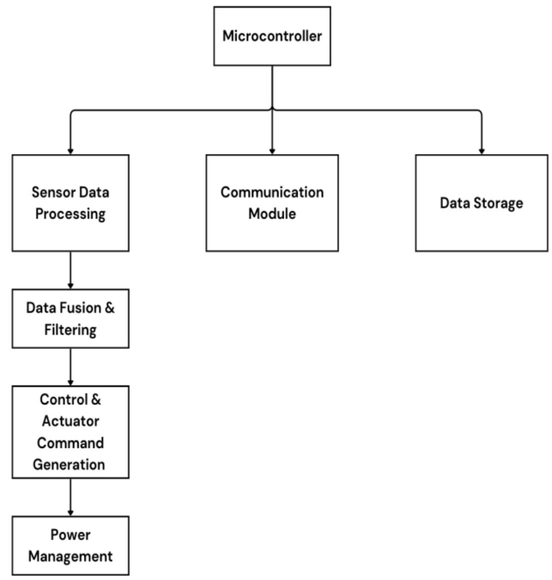

Fig 3: Microcontroller Architecture for Managing Sensor Data and Actuator Commands

D. Sensor Data Processing Unit

This unit integrates and processes the data from GPS, IMU, and LiDAR sensors. The data fusion unit merges sensor inputs to provide a coherent and accurate view of the environment in which the UGV is operating. It is equipped with sufficient processing power to support various complex algorithms running in real time, ensuring real-time response to changes in the environment [7]. Fig 3 presents the microcontroller architecture for managing sensor data and actuator commands.

E. Actuator Control

It controls the motion and functions of the UGV with respect to the processed data and decision-making algorithms. These include steering, throttle, and braking systems. It interfaces with the MCU to execute commands and adjust the vehicle's trajectory and speed accordingly in real-time.

F. Power Management

This involves a strong power supply in the system that carries all of the components onboard, such as sensors, MCU, and communication modules, including backup power solutions, to ensure no break in operation. Energy Its design considerations entail ensuring low power consumption to ensure maximum operation time and less time spent recharging or replacing batteries.

IV. SOFTWARE DESIGN AND INTEGRATION

This IoT-based smart direction control system software design would ensure modularity, real-time processing, and flexibility. The software architecture shall be designed to work in complete coherence with the hardware parts and harness the capabilities of IoT for functionality enhancement.

A. Software Architecture

The software is divided into modules, each responsible for a certain set of functions. Such modularity ensures easy updating, maintenance, and scalability. This module is responsible for data acquisition, filtering, and preprocessing from the GPS, IMU, and LiDAR sensors. This module transforms the raw sensor data into meaningful information. This has employed path planning, obstacle avoidance, and navigation control algorithms. This module utilizes the information provided by the Sensor Data Processing Module to make real-time decisions related to vehicle movement. The Actuator Control Module transforms decisions into actuator commands [8]. This module ensures that, based on the processed information, the movements of the UGV are controlled with precision. Fig 4 presents the software architecture flow for UGV control.

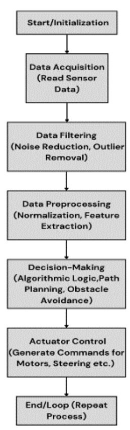

Fig 4: Software Architecture Flowchart for UGV Control.

B. Edge Computing

The critical computations are processed locally on the MCU to minimize latency and ensure timely decision-making. This approach reduces dependencies on cloud-based processing and improves system responsiveness. It handles efficient data storage and retrieval, thereby ensuring that critical data is available to the critical modules for decision-making without any delays [9].

C. Integrating Machine Learning

The embedded machine learning models improve decision-making. The algorithms are trained with operational data to adapt to changing environmental conditions and optimize navigation strategies. The system allows periodic updating of machine learning models whenever new data are available so that it remains effective under varying conditions.

D. Communication Framework

This is used for communication between the UGV and external control systems, such as remote monitoring and command interfaces. It is expected to support reliable and secure data transfer with significantly low latency and offer robustness to the exchanged data.

E. Integration and Testing

Every single software module and part of the hardware must be fine-tuned, and the integration test has to be performed because it has to sail through in actual real-world environments. The performance of the software is ascertained through formal testing, which is sometimes conducted in a simulated environment and, at other times, in a field setting. That performance and reliability guarantees will be achieved to make its implementation appealing to potential investors.

V. PROTOTYPE TESTING AND VALIDATION

The performance and functionality of the IoT-based smart direction control system will be tested under various conditions. The purpose is to ensure that this system works to its desired specifications and reliably in real-life scenarios.

A. Test Cases Simulated Environments

An environment imitates reality and different operations scenarios, including virtual obstacles, landforms, and dynamic conditions. Metrics, including navigation accuracy, obstacle avoidance, and system responsiveness, are evaluated.

Prototype testing in real-life conditions and evaluation of its performance in different environments include deployment of the UGV outdoors in urban streets, rural areas, and rugged terrain.

B. Performance Evaluation Navigation Accuracy

The deviation between the planned path and the actual path traveled by the UGV Results. Latency Measurement involves a time delay between data acquisition, processing, and actuator response. The latency should allow for real-time operation and responsive control [10].

The system shall be tested for its capability to detect and avoid obstacles in different scenarios. Obstacle detection accuracy and reliability and avoidance maneuver effectiveness quantification system. It checks for performance under challenging situations, such as high interference, extreme temperatures, and variable lighting conditions.

C. Validation and Optimization Validation

Performance is measured by comparing prototypes against predefined criteria and benchmarks. The system meets all design specifications and performs effectively in real-world scenarios [12].

Based on test results and feedback, point out the areas for improvement. The result is system adjustments and refinement for better performance, reliability, and user experience. Elongate field trials and simulated tests for feedback in further development and refinement.

VI. INSIGHTS

The "Autonomous Vehicles Enabled by the Integration of IoT, Edge Intelligence, 5G, and Blockchain" by Biswas and Wang [11] discusses the contributions of various technologies to the development of autonomous vehicles (AVs). It highlights how the integration of IoT, edge computing, AI, and blockchain has been explored in existing literature to address challenges in AVs, such as safety, security, and latency. The paper also reviews advancements in vehicle-to-everything (V2X) communication facilitated by 5G and 6G networks, emphasizing their role in enabling real-time, reliable vehicular interactions.

Smith in [12] builds on existing smart irrigation systems, which primarily automated irrigation using basic sensors and microcontrollers. This paper distinguishes itself by implementing a more advanced system that integrates AT89c51 and ESP8266 microcontrollers for IoT connectivity, enabling remote monitoring and dual-mode operation. The use of a backup microcontroller for enhanced reliability marks a significant improvement over previous systems, making it more adaptable and user-friendly.

The paper “A Survey on Sensor Technologies for Unmanned Ground Vehicles” by Qi Liu, Shihua Yuan, and Zirui Li [13] provides a comprehensive overview of sensor technologies utilized in Unmanned Ground Vehicles (UGVs). It focuses on the awareness of sensors in operation of UGV and review different types of sensors, their advantages and their uses. It describes the fusion of the sensors and trends of the sensors’ advancements needed for improved UGV performance and dependability.

Some of the related work focus on the provision and uses of sensors in the autonomous systems. Studying the self-driving car systems and robotics, it has been underlined the relevance of using redundant sensory systems, including LiDAR, cameras, and radar. These studies also discuss issues as the accuracy, reliability and real time processing of sensors, which is the topic of this paper as well.

The article “A Comprehensive Survey of Unmanned Ground Vehicle Terrain Travers ability for Unstructured Environments and Sensor Technology Insights” by Semih Beycimen, Dmitry Ignatyev, and Argyrios Zolotas provides an in-depth review of terrain travers ability analysis for unmanned ground vehicles (UGVs) [14]. They divide terrain evaluation into terrain categorization, terrain characterization, and cost-based navigability, with more subcategories such as appearance-based, geometry-based, and a mix of the two. The study focuses on ML, DL, and RL for enhanced analysis and the importance of the synergy of exteroceptive and proprioceptive sensors. This is more than just a review of more recent studies; it also brings forward useful propositions over the vehicle platforms and the kind of sensors typically employed in travers ability analysis, making it a really useful frame of reference for this kind of work.

VII. COMPARATIVE ANALYSIS

The authors perform a comparative study of key technologies that define the advancement of autonomous vehicles (AVs) [15]. IoT makes connections, IoV/IoAV makes decisions on the edge, 5G/6G optimizes data transport, and blockchain protects data. The paper also underlines the fact that every technology has certain aspects, and although they have distinctive features, every single one of them tackles problems like latency, AI explainability, or security. Future research directions are identified to address these issues and accelerate AV development.

Traditional irrigation systems primarily focused on manual or basic automated controls, which often led to inefficiencies such as water wastage and inconsistent irrigation.

VIII. CONCLUSION

This paper’s proposed system integrates the AT89c51 microcontroller and ESP8266 for IoT connectivity, allowing for remote monitoring and dual operation modes (automatic and manual). The inclusion of a backup microcontroller further enhances system reliability, addressing limitations seen in previous systems and making it more adaptable and user-friendly. This innovation is found to have gone a notch higher than previous irrigation systems that were constructed without IoT incorporation, which makes it inoperable from a remote environment, thus making this irrigation system more efficient and sustainable for current farming.

The study also explores the adoption and improvement of sensors on UGVs with a side-by-side feature analysis of various sensors accompanied by the key advantages and limitations of each kind for use on UGVs. On the other hand, multi-disciplinary pieces, including "Autonomous Vehicles Enabled by the Integration of IoT, Edge Intelligence, 5G, and Blockchain," explicate other technologies required for AVs.

VIII. CONCLUSION

The application of IoT, edge computing, 5G/6G, and blockchain in supporting the autonomous vehicle, as discussed in "Autonomous Vehicles Enabled by the Integration of IoT, Edge Intelligence, 5G, and Blockchain," means that further sophisticated improvements are being introduced to the self-driving vehicle to meet the critical factors including safety and latency. This is supported by advancements in IoT kind of systems in precision agriculture, which are much more efficient and precise than traditional practices. The research reaffirms that advanced machine learning integration and sensor systems are vital components of UGV enhancement for better adaptability in challenging terrains. Our research contributes to the knowledge of the ways through which AI-based innovations can improve the performance and robustness of self-sufficient or semi-sufficient systems in numerous applications.

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