International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026

Design and Implementation of a Low-Power 5G-Enabled IoT Smart Vehicle System for Tracking, Collision Avoidance, and Autonomous Navigation

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Abstract - The project is the design and implementation of a low power smart vehicle system utilizing IoT (Internet of Things) and 5G communications to enable real-time tracking, monitoring, collision avoidance and semi-autonomous navigation. An Arduino based platform is used, along with various sensors, in order to create the smart vehicle system. These sensors include but are not limited to a GPS module for determining the location of the vehicle, ultrasonic sensors to detect obstacles nearby, and IR sensors for following a specific path. In addition, a convolutional neural network (CNN) is used for traffic signal recognition, which supports decision-making during semi-autonomous vehicle operation. A vehicle-to-vehicle (V2V) communication mechanism is implemented using RF modules to improve safety by sending early warning alerts between vehicles. The system also includes a fault detection feature that identifies abnormal conditions such as unexpected vehicle stoppage and sends real-time notifications to the user. The experimental evaluation showed that the system performs reliably in terms of data transmission, obstacle detection, and tracking performance. The developed system provides a practical and cost-effective solution for intelligent transportation, with improved safety and support for smart mobility applications.

Keywords— Internet of Things (IoT), 5G-Enabled Communication, Smart Vehicle System, Collision Avoidance, Vehicle Tracking, Autonomous Navigation, ESP8266, GPS, Ultrasonic Sensor, Convolutional Neural Network (CNN), Vehicle-to-Vehicle (V2V) Communication, Blynk Cloud Platform.

I. INTRODUCTION

In recent years, transportation systems have evolved with the integration of advanced technologies aimed at improving road safety and operational efficiency. However, the increasing number of vehicles has introduced several challenges, including traffic congestion, accidents, and security concerns.

Conventional vehicle systems are limited in their ability to provide real-time monitoring and adaptive responses to dynamic road conditions. This limitation highlights the need for smart vehicle solutions that combine sensing, communication, and automation to enhance overall system performance.

The Internet of Things (IoT) plays an important role in enabling connected vehicle systems by linking sensors, communication modules, and cloud platforms. Through this integration, vehicle data can be collected, processed, and accessed remotely in real time. Along with IoT, the development of high-speed communication technologies such as 5G-supported networks has improved data transmission capabilities. These networks provide faster communication and reduced delay, which are essential for applications like vehicle tracking, monitoring, and control.

In this work, a low-power smart vehicle system is developed using IoT and 5G-supported communication for tracking, monitoring, collision avoidance, and semi-autonomous operation. The system is built around an Arduino Uno microcontroller, which is connected to a GPS module for location tracking, ultrasonic sensors for detecting obstacles, and IR sensors for path detection.

Based on the detected signals, the vehicle can adjust its behavior according to traffic conditions, enabling semi-autonomous operation. In addition, a vehicle-to-vehicle (V2V) communication system is implemented using RF modules. This setup allows warning signals to be shared between vehicles, helping to improve safety and reduce the chances of collisions.

The system also includes a fault detection mechanism that monitors abnormal conditions such as unexpected vehicle stoppage and generates real-time alerts for the user. This helps improve system reliability and ensures timely awareness. By combining IoT, 5G-supported communication, and basic artificial intelligence techniques, the developed system provides a practical and efficient solution for smart transportation applications.

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II. Literature Review

In recent years, research in transportation systems has increasingly explored the use of artificial intelligence, IoT, and communication technologies to improve vehicle safety and automation.

In [1], a neural network-based autonomous mobile robot was developed using a vision-based navigation approach. The system was able to perform basic lane-following tasks, but it did not include real-time communication or multi-sensor integration, which are important for practical smart vehicle applications.

In [2], a deep reinforcement learning approach was used for autonomous driving in urban environments. The model supported decision-making under different traffic conditions, but it required high computational power and large training datasets, which limits its use in low-power embedded systems.

In [3], illumination-invariant imaging techniques were used to improve visual perception under different lighting conditions. These methods increased robustness, but they also added to system complexity and required higher processing resources.

In [4], a probabilistic robotics framework was used as a theoretical basis for autonomous navigation and decision-making. These models are effective in theory, but their practical implementation requires advanced sensors and high computational resources.

In [5], deep neural network-based methods were used for object detection and achieved high accuracy. However, these models require significant computational resources and are not well suited for low-power embedded platforms.

In [6], end-to-end learning methods were applied to self-driving systems, allowing vehicles to learn driving behavior directly from sensor data. These approaches show good performance, but they lack interpretability and require large amounts of training data.

In [7], deep reinforcement learning techniques were applied to achieve human-level control in autonomous systems. These methods show strong performance, but they require high computational resources and are not suitable for real-time embedded applications.

In [8], YOLO-based architectures were used for real-time object detection with high processing speed. These methods perform efficiently, but they rely on GPU-based computation, which limits their use in low-cost systems.

In [9], an IoT-based surveillance rover system was implemented for remote monitoring and control. The system demonstrated basic IoT functionality, but it did not include intelligent decision-making or collision avoidance features.

III. Proposed System

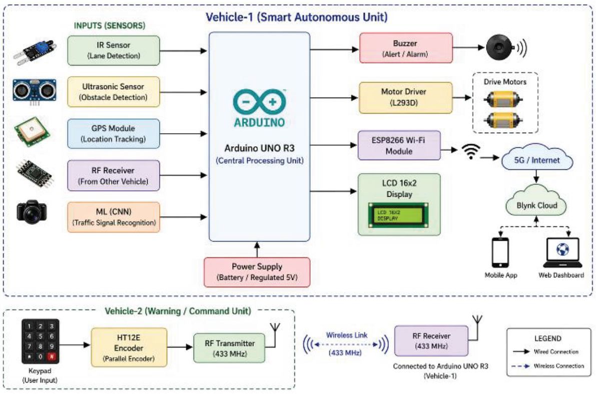

Fig. 1. Proposed Block Diagram

This work describes a low-power smart vehicle architecture that uses IoT and 5G-supported communication for tracking, monitoring, collision avoidance, and semi-autonomous operation. The system consists of two connected modules: Vehicle-1 (Smart Autonomous Vehicle Unit) and Vehicle-2 (Warning/Command Unit), as shown in Fig. 1.

Vehicle-1 functions as the main control unit and is based on the Arduino Uno R3 microcontroller. The ultrasonic sensor measures the distance between the vehicle and nearby objects, which helps in avoiding collisions in real time.

A convolutional neural network (CNN) is used for traffic signal recognition to support decision-making. The model processes visual input and identifies signals such as red, yellow, and green, allowing the vehicle to respond based on the detected signal. This improves the system's ability to perform semi-autonomous navigation.

For communication and remote monitoring, an ESP8266 Wi-Fi module is used to send real-time data to the Blynk cloud platform. The network can be supported by a 5G-enabled internet connection to achieve faster data transmission with minimal delay.

The transmitted data includes vehicle location, obstacle distance, and system status. This information can be accessed by users through smartphones or laptops using the Blynk application.

The system also includes a fault detection mechanism to identify abnormal conditions such as unexpected vehicle stoppage. When such events occur, an alert is sent to the user through the cloud platform for immediate awareness. This helps improve safety and allows timely action to be taken.

Vehicle-to-Vehicle (V2V) communication is achieved using RF 433 MHz modules. The receiver module in Vehicle-1 receives warning signals transmitted from Vehicle-2. Upon receiving such signals, the system activates a buzzer and takes necessary control actions to prevent potential collisions.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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Vehicle-2 operates as a warning and command unit. It includes an HT12E encoder, an RF transmitter module, a keypad interface, and a buzzer. The user enters commands through the keypad, which are encoded and transmitted wirelessly to Vehicle-1. This allows manual alerts and emergency signals to be sent between the vehicles when required.

The system is powered using a regulated power supply, where a 12V battery is converted to the required voltage levels (+5V and +12V) for different components. This provides stable power and supports reliable system operation.

In this work, sensing, communication, cloud connectivity, and artificial intelligence are combined into a single system to support smart vehicle applications. The developed approach offers a practical and efficient solution that can be extended for larger-scale implementations.

IV. Methodology

The methodology focuses on combining sensing, communication, and decision-making processes for smart vehicle operation. The system follows a sequence of steps, including data collection, processing, communication, and control actions. These steps enable real-time monitoring and support semi-autonomous functionality.

A. System Workflow

The system follows a step-by-step process in which sensor data is collected, processed by the microcontroller, and then sent to the cloud platform. The Arduino Uno R3 works as the main controller, receiving inputs from different sensors and controlling the vehicle based on these inputs.

The IR sensor pair detects lane markings and supports path tracking. At the same time, the ultrasonic sensor measures the distance to nearby obstacles. This distance is processed in real time to decide whether the vehicle should continue moving, slow down, or stop.

The distance measurement is computed using the time-of-flight principle:

$$Distance = \frac{Time \times Speed\ of\ Sound}{2}$$

B. Communication Mechanism

The system uses two types of communication: Vehicle-to-Vehicle (V2V) communication and IoT-based communication.

In V2V communication, RF 433 MHz modules enable direct data exchange between Vehicle-1 and Vehicle-2. Vehicle-2 sends alert signals through an HT12E encoder and RF transmitter. These signals are received by the RF receiver in Vehicle-1, allowing the system to generate collision warnings and emergency alerts.

For IoT-based communication, the ESP8266 module connects to a Wi-Fi network, which can be supported by a 5G-enabled internet connection. Sensor data such as GPS location, obstacle distance, and system status are sent to the Blynk cloud platform. This allows users to view real-time information through mobile or web applications.

C. Machine Learning Integration

A convolutional neural network (CNN) is used for traffic signal recognition to support decision-making. The model processes image data from a camera module and classifies signals such as red, yellow, and green.

The classification result is sent to the Arduino controller, which adjusts the vehicle movement accordingly. This supports semi-autonomous navigation and improves driving safety.

D. Fault Detection and Alert System

The system includes a fault detection mechanism to monitor abnormal conditions. If the vehicle stops unexpectedly due to a malfunction or other issues, an alert is sent to the Blynk platform for user notification.

A buzzer is also activated locally to indicate warnings such as obstacle detection or V2V alerts. This helps provide immediate awareness to the user.

E. Control and Actuation

The data obtained from sensors and communication modules is used to control the vehicle motion through gear motors. The Arduino microcontroller processes real-time inputs and generates control signals for actions such as forward movement, stopping, and direction changes.

The system is powered using a regulated supply, where a 12V battery is converted to the required voltage levels (+5V and +12V) for different modules. This provides stable power for reliable operation.

V. Implementation

The implementation combines hardware components, embedded programming, communication modules, and cloud-based monitoring to build the smart vehicle system. The design follows a modular approach, which supports real-time operation and allows the system to be extended for future improvements.

A. Hardware Implementation

The hardware architecture of the system is centered around the Arduino Uno R3 microcontroller, which serves as the

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026

main processing unit. Various sensors and modules are interfaced with the controller to enable data acquisition and control functionalities.

An ultrasonic sensor (HC-SR04) detects obstacles by measuring the distance between the vehicle and nearby objects. The measured data is sent to the Arduino for processing. An IR sensor pair is used for lane detection and path tracking.

A GPS module (NEO-6M) provides real-time location tracking by generating latitude and longitude data. This data is sent to the Arduino through serial communication.

The ESP8266 Wi-Fi module handles wireless communication and data transfer. It connects the system to a local Wi-Fi network and enables communication with the Blynk cloud platform. The system can also operate over a 5G-supported internet connection, which provides faster data transfer with reduced delay.

For vehicle motion control, DC gear motors are used, which are driven through a motor driver module (L293D or L298N). A buzzer is incorporated to provide audio alerts for obstacle detection, V2V warnings, and fault conditions.

Vehicle-to-Vehicle (V2V) communication uses RF 433 MHz modules. The receiver is located in Vehicle-1, while Vehicle-2 includes an RF transmitter controlled by an HT12E encoder along with a keypad interface for sending alert signals.

The entire system is powered using a 12V battery unit, which is regulated to +5V and +12V using a voltage regulator circuit to supply different components efficiently.

B. Software Implementation

The software part is developed using the Arduino IDE for embedded programming and Python-based tools for the machine learning model.

The Arduino reads sensor inputs, processes the data, and performs control actions. It also manages communication with the ESP8266 module to send real-time data to the cloud.

The ESP8266 connects to a Wi-Fi network and communicates with the Blynk cloud platform. The Blynk application displays parameters such as vehicle location, obstacle distance, and system status in real time.

C. Cloud Integration and Monitoring

The Blynk cloud platform handles real-time monitoring and control of the vehicle system. Sensor data, including GPS coordinates and obstacle distance, is sent to the cloud through the ESP8266 module.

The data can be viewed through the Blynk mobile application or web interface, allowing remote monitoring of vehicle parameters. The platform also supports alert notifications for conditions such as unexpected vehicle stoppage or obstacle detection.

D. System Testing and Validation

The system was tested under different operating conditions to evaluate its performance. Obstacle detection was checked by placing objects at different distances and comparing the sensor readings with actual measurements.

The GPS module performance was verified by comparing the obtained coordinates with real-time map data. Communication performance was examined by observing data transmission between the ESP8266 module and the Blynk platform.

The V2V communication was tested by sending alert signals from Vehicle-2 and observing the response in Vehicle-1. The buzzer and control actions were triggered correctly after receiving warning signals.

VI. Results & Discussion

The performance of the proposed 5G-enabled IoT-based smart vehicle system was evaluated under different operating conditions to validate its effectiveness in real-time tracking, collision avoidance, and communication.

A. Obstacle Detection Performance

The ultrasonic sensor was tested by placing obstacles at varying distances ranging from 10 cm to 200 cm. The measured values were compared with actual distances to evaluate accuracy.

The system demonstrated reliable detection with an average accuracy of approximately **95%** within the effective sensing range. The response time for obstacle detection was observed to be less than **100 ms**, enabling real-time collision avoidance.

B. GPS Tracking Accuracy

The GPS module was tested for real-time location tracking. The obtained latitude and longitude values were compared with actual positions using map-based verification.

The results show an average positional accuracy of around ±5 meters, which is suitable for vehicle tracking applications. The location data was transmitted to the Blynk platform with minimal delay.

C. IoT Communication Performance

The ESP8266 module was tested for real-time data transmission to the Blynk cloud platform. The system operated over a Wi-Fi network supported by a 5G-enabled internet connection.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026

The results show that communication latency remained below 1 second, allowing near real-time updates. Data transmission was reliable, with negligible packet loss under normal conditions.

D. CNN-Based Traffic Signal Detection

The CNN model for traffic signal recognition was tested using a dataset of images under different lighting conditions. The results show an accuracy of around 88–90% in classifying traffic signals such as red, yellow, and green.

A slight reduction in performance was noticed under poor lighting conditions.

E. Vehicle-to-Vehicle (V2V) Communication

The RF 433 MHz communication system was tested for alert transmission between Vehicle-2 and Vehicle-1.

The results show reliable communication within a range of about 30–50 meters. When alert signals were received, the buzzer activated and the system performed the required control actions.

F. Fault Detection and Alert System

The fault detection mechanism was tested by simulating abnormal conditions such as sudden vehicle stoppage.

The results show that alert notifications were generated on the Blynk application in real time, providing immediate user awareness. This improves overall system reliability and safety.

G. Experimental Setup and Hardware Implementation

Fig. 2 shows the experimental prototype of the smart vehicle system built on a 4-wheel robotic chassis with an Arduino-based control unit, ultrasonic sensor, and wireless communication modules. The hardware setup represents real-time obstacle detection, IoT-based monitoring, and vehicle control.

The front view presents the ultrasonic sensor positioned for obstacle detection, measuring the distance between the vehicle and nearby objects. The top view displays the control board, including the microcontroller, motor driver, and communication modules such as the ESP8266.

The side view highlights the mechanical structure of the vehicle, including DC gear motors and wheels used for motion control. The compact integration of components ensures efficient operation and low power consumption.

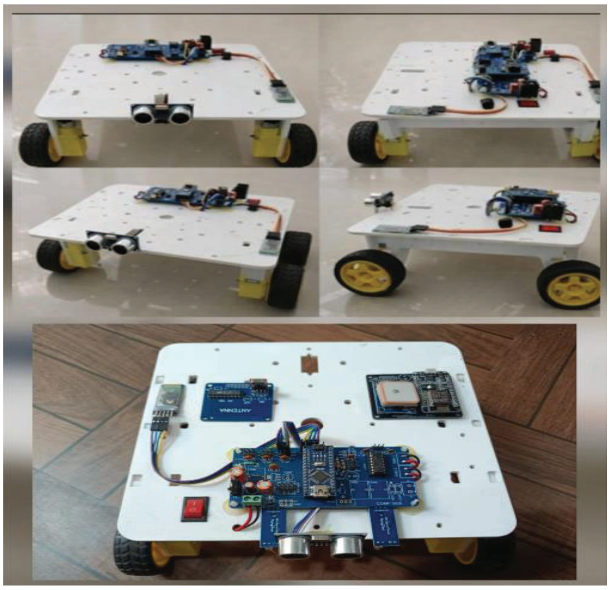

Fig. 2 Illustrates the developed smart vehicle prototype.

VII. Conclusion

This work presents the design and development of a low-power 5G-enabled IoT-based smart vehicle system for real-time tracking, monitoring, collision avoidance, and semi-autonomous navigation. The system combines Arduino-based embedded control, sensor-based data collection, cloud monitoring using the Blynk platform, and machine learning techniques for decision-making.

The results show reliable obstacle detection with high accuracy, effective real-time vehicle tracking using GPS, and low-latency communication through the ESP8266 module over a 5G-supported network. The addition of vehicle-to-vehicle (V2V) communication improves safety by enabling early warning alerts and reducing the risk of collisions.

The system includes a fault detection mechanism that generates real-time alerts during abnormal conditions, improving overall reliability. A convolutional neural network (CNN) supports traffic signal recognition and enables semi-autonomous navigation.

The system provides a practical solution for intelligent transportation, especially in smart city applications. It shows that IoT, 5G-based communication, and artificial intelligence can be combined effectively in modern vehicle systems.

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International Journal of Engineering Research & Technology (IJERT)
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