International Journal of Software & Hardware Research in Engineering (IJSHRE)
ISSN:2347-4890, ijournals.in/ijshre
Volume 14 Issue 4, April 2026

The Real-Time Intelligent IoT Route Monitoring System Using AI and UART-Based Communication Interface

Authors: Guduru Krishnaveni, Gade Amulya, Narra Jhansi, Garnipudi Deepika

Affiliation: Department of Electronics and Communication Engineering(ECE),Bapatla Women's Engineering College,Bapatla, Andhra Pradesh, India

https://doi.org/10.26821/IJSHRE.14.04.2026.140402

ABSTRACT

The safety and efficiency of transportation systems rely heavily on vehicles following their designated routes. Unauthorized route deviations can result in safety risks, increased fuel usage, delivery delays, and the need for manual monitoring. This paper proposes a real-time intelligent IoT-based route monitoring system that combines Artificial Intelligence (AI), embedded hardware, and a UART-based communication interface.

The system is built around an ESP32 microcontroller integrated with a GPS module to continuously collect real-time location data. A Decision Tree machine learning algorithm is applied to evaluate vehicle movement by comparing live coordinates with predefined routes, allowing precise identification of deviations. When a deviation is detected, alert notifications are generated and transmitted via the UART interface to a control unit for immediate response.

By integrating AI-based analysis with efficient IoT communication, the proposed system improves transportation monitoring, reduces false alerts, enables faster response, and offers a scalable, cost-effective solution.

Keywords – *Route Deviation Detection, ESP32, Decision Tree, Vehicle Tracking, IoT, Real-Time Monitoring, AI-Based Transportation System.*

I.INTRODUCTION

The continuous growth of transportation systems, logistics networks, and smart city infrastructures has significantly increased the demand for advanced vehicle monitoring and control solutions. In modern transportation environments, ensuring that vehicles strictly follow predefined routes is essential for maintaining operational efficiency, safety, and cost optimization. Deviations from assigned routes can result in fuel inefficiency, increased operational expenses, delays in delivery schedules, and even security threats such as unauthorized vehicle usage or theft. Therefore, the development of intelligent, automated systems for real-time route monitoring has become a critical requirement.

Conventional vehicle tracking systems mainly rely on Global Positioning System (GPS) technology combined with manual supervision. Although these systems provide basic location tracking, they lack the capability to perform real-time intelligent analysis of vehicle movement patterns. As a result, detecting route deviations often involves delays and human intervention, reducing overall system effectiveness.

Additionally, traditional systems typically use fixed threshold-based methods, which can generate false alarms and fail to adapt to dynamic real-world conditions.

The integration of Artificial Intelligence (AI) and Internet of Things (IoT) technologies offers a promising solution to these limitations. AI enables systems to analyze large volumes of real-time data, learn patterns, and make intelligent decisions without human involvement. IoT, on the other hand, facilitates seamless connectivity between devices, sensors, and communication modules, enabling continuous monitoring and data exchange. By combining these technologies, it is possible to design smart transportation systems capable of autonomous decision-making and real-time response.

This project proposes a Real-Time Intelligent IoT Route Monitoring system that incorporates machine learning techniques to detect route deviations accurately. A Decision Tree algorithm is employed due to its low computational complexity, fast processing speed, and suitability for embedded systems. The algorithm analyzes parameters such as location coordinates, route mapping, and movement patterns to determine whether a vehicle is following its assigned path or deviating from it.

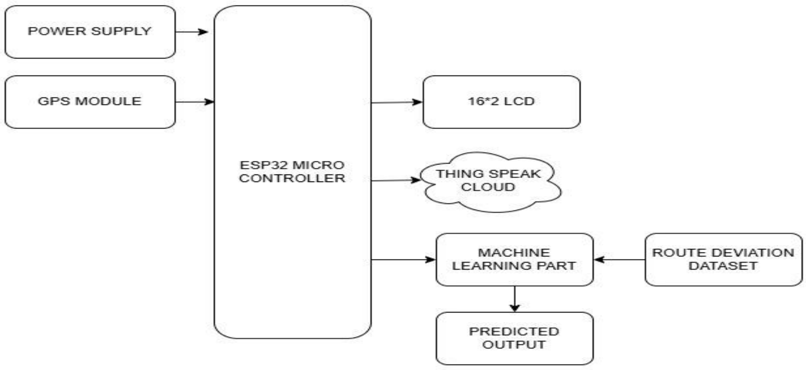


Fig : Block Diagram

The system is implemented using an ESP32 microcontroller, which serves as the central processing unit. The ESP32 is widely used in IoT applications due to its integrated Wi-Fi and Bluetooth capabilities, low power consumption, and high processing efficiency. It enables real-time data acquisition, local processing, and communication with external systems. The use of an embedded platform ensures that the system operates efficiently even resource-constrained environments.

A key component of the proposed system is the UART communication interface, which is used to transmit alert signals to a connected notification module or control unit. When a route deviation is detected, the system immediately sends an alert through UART, enabling quick response and corrective action. This communication mechanism is simple, reliable, and well-suited for embedded hardware integration.

One of the major advantages of the proposed approach is its ability to reduce false positives by leveraging AI-based decision-making instead of relying solely on predefined thresholds. The system can adapt to varying road conditions and vehicle behaviors, improving detection accuracy over time. Furthermore, the design is cost-effective, scalable, and energy-efficient, making it suitable for large-scale deployment in real-world applications.

The proposed system can be applied across multiple domains, including fleet management, logistics and supply chain operations, public transportation systems, and emergency services. It enhances route compliance, improves safety, optimizes resource utilization, and provides better control over vehicle operations. In smart city environments, such systems contribute to efficient traffic management and improved urban mobility.

In conclusion, the Real-Time Intelligent IoT Route Monitoring system represents a significant advancement in vehicle tracking technology. By integrating AI, IoT, and embedded communication interfaces, the system provides accurate, real-time route deviation detection with minimal human intervention. This approach not only addresses the limitations of traditional tracking systems but also paves the way for the development of intelligent and autonomous transportation solutions.

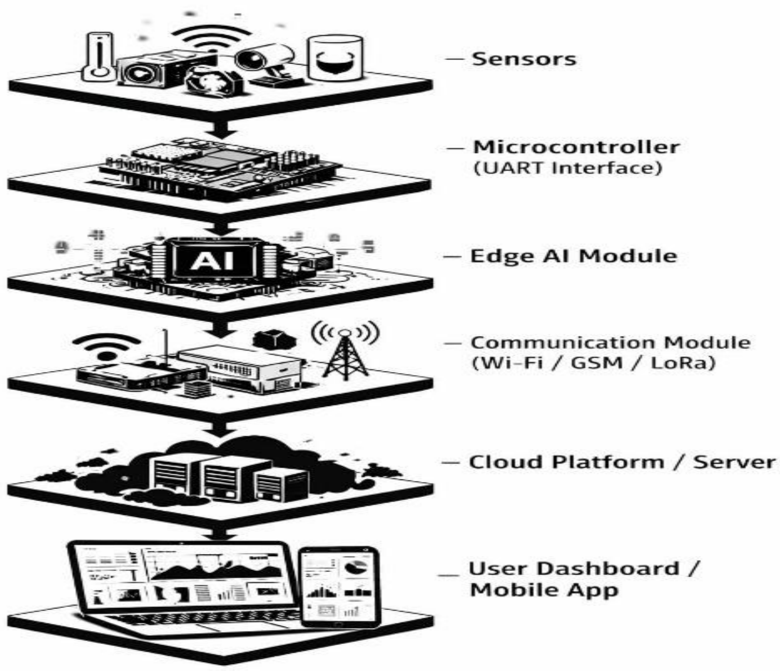
II. SYSTEM ARCHITECTURE

The proposed system architecture for the Real-Time Intelligent IoT Route Monitoring System integrates sensing, embedded processing, edge intelligence, communication, and cloud-based analytics to enable efficient and intelligent route monitoring.

At the sensing layer, multiple sensors such as Global Positioning System (GPS) modules, Inertial Measurement Units (IMU), and other IoT-enabled devices are deployed to collect real-time data. These sensors continuously acquire information including geographic coordinates, motion parameters, and environmental conditions, which serve as the primary input to the system.

The acquired data is transmitted to the microcontroller through a Universal Asynchronous Receiver-Transmitter (UART) interface. The microcontroller acts as the core processing unit of the embedded system, responsible for data acquisition, preprocessing, and formatting. The use of UART communication ensures reliable, low-cost, and low-latency data exchange between hardware components.

Subsequently, the preprocessed data is forwarded to the Edge Artificial Intelligence (AI) module. This module performs real-time data analysis using machine learning and deep learning techniques. Key functionalities include route prediction, anomaly detection, and route deviation analysis. By performing computations at the edge, the system significantly reduces latency and network dependency while enabling faster decision-making.



Following edge processing, the data is transmitted via the communication module, which may utilize wireless technologies such as Wi-Fi, Global System for Mobile Communications (GSM), or Long Range (LoRa). Communication protocols such as Message Queuing Telemetry Transport (MQTT) or Hypertext Transfer Protocol (HTTP) are employed to ensure efficient and reliable data transmission to remote servers.

At the cloud layer, the received data is stored and further processed for advanced analytics. The cloud platform facilitates large-scale data storage, historical analysis, and centralized training of AI models, thereby enhancing the overall system intelligence and scalability.

Finally, the processed information is presented to the end user through a dashboard or mobile application. This interface provides real-time route visualization, alerts, historical data insights, and decision-support features, enabling effective monitoring and management of routes.

III . METHODOLOGY/EXPERIMENTAL

The proposed Real-Time Intelligent IoT Route Monitoring system is designed to detect vehicle route deviations using Artificial Intelligence and embedded communication technologies. The methodology consists of several stages, including data acquisition, preprocessing, route comparison, decision-making using a machine learning algorithm, and alert generation through a communication interface.

1.Data Acquisition

-The system continuously collects real-time location data from the vehicle using GPS or location-enabled modules. The acquired data includes parameters such as latitude, longitude, timestamp, and movement direction. This data is transmitted to the ESP32 microcontroller, which acts as the central processing unit of the system.

2. Predefined Route Mapping

-A predefined route is stored in the system as a set of coordinate points or geofenced boundaries. This route acts as a reference for comparison. The predefined path is designed based on expected vehicle movement and is uploaded into the system memory before deployment.

3.Data Preprocessing

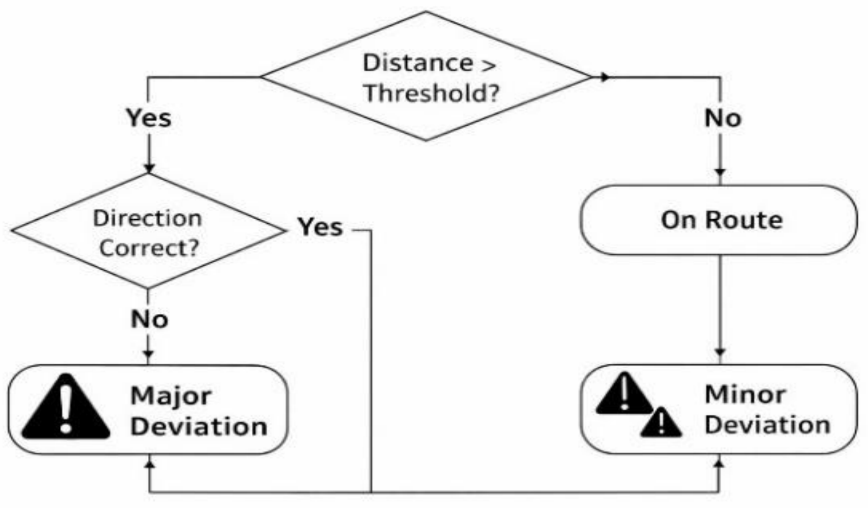
-The collected location data is preprocessed to remove noise and inconsistencies. This step involves filtering incorrect GPS readings and normalizing the data format. The processed data ensures accurate input for the machine learning model and improves system reliability.

4. Feature Extraction

-Relevant features such as distance from the route, deviation angle, and positional variance are extracted from the processed data. These features are used as inputs to the Decision Tree algorithm to determine whether the vehicle is following the intended route.

5. Decision Tree-Based Classification

-A Decision Tree algorithm is implemented to classify the vehicle’s movement as either “normal” (on-route) or “deviated” (off-route). The algorithm is trained using sample datasets that represent both normal and abnormal route behaviors. Due to its low computational complexity and fast execution, the Decision Tree is suitable for real-time embedded applications like ESP32.



6. Deviation Detection

-The system continuously compares real-time vehicle data with the predefined route. If the extracted features exceed acceptable thresholds or match deviation patterns identified by the model, the system classifies the movement as a route deviation.

7. Alert Generation via UART Communication

-Once a deviation is detected, the ESP32 sends an alert signal through the UART (Universal Asynchronous Receiver-Transmitter) interface to a connected notification module or control system. This enables immediate awareness and allows corrective action to be taken in real time.

8. System Feedback and Monitoring

-The system operates in a continuous loop, updating vehicle status and monitoring route adherence. The real-time feedback mechanism ensures quick detection and response, enhancing the overall efficiency of transportation monitoring.

TABLE : Route Deviation Classification

Condition	Output
Distance < threshold	On Route
Distance > threshold & Direction Small	Minor Deviation
Distance > threshold & Direction Large	Major Deviation

IV . RESULTS AND DISCUSSION

The Real-Time Intelligent IoT Route Monitoring System successfully detects route deviations, classifies them using AI, and sends immediate UART-based alerts, making it suitable for smart transportation, bus tracking, and logistics monitoring applications

.

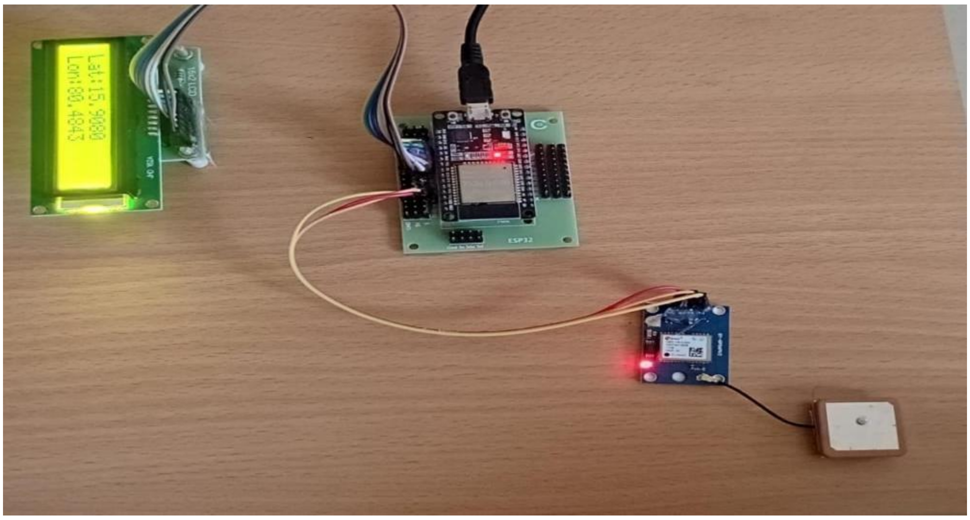


Fig:Hardware Configuration for Real-Time Monitoring

Output Images:

Image 1: AI-Based Route Deviation Detection Confusion Matrix

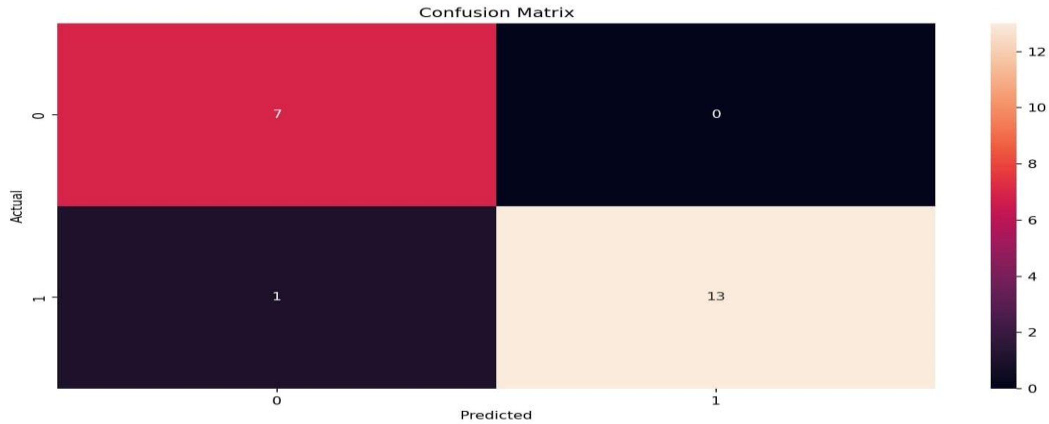


Image 2: Accuracy of Route Deviation Detection Model

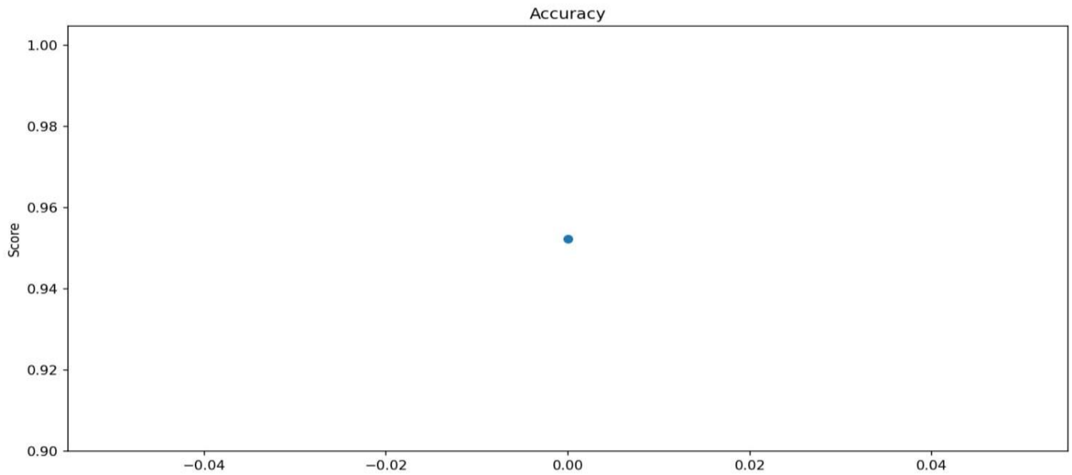
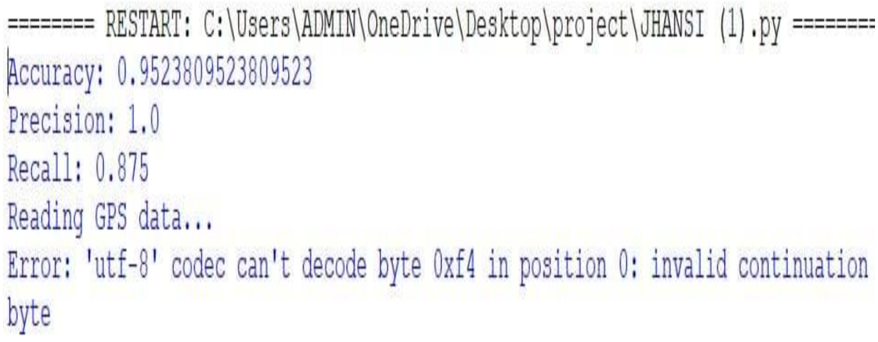
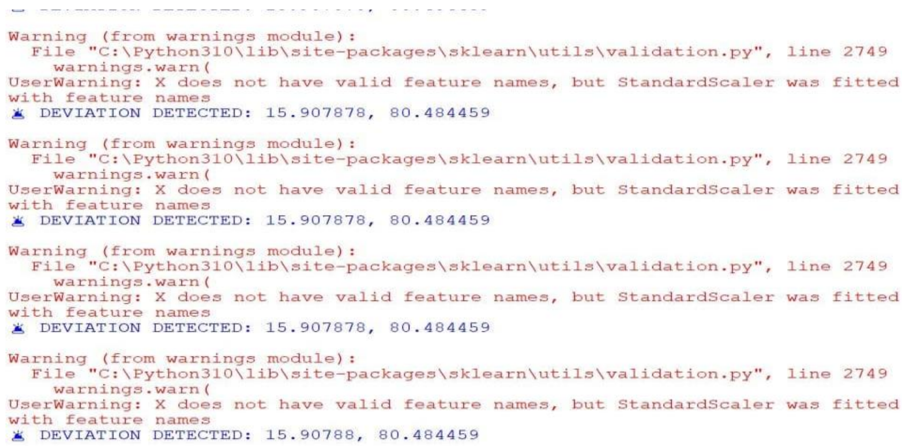


Image 3:Prediction Performance (Accuracy, Precision, Recall)



```
======== RESTART: C:\Users\ADMIN\OneDrive\Desktop\project\JHANSI (1).py ========
Accuracy: 0.9523809523809523
Precision: 1.0
Recall: 0.875
Reading GPS data...
Error: 'utf-8' codec can't decode byte 0xf4 in position 0: invalid continuation byte
```

Image 4: Real-Time Route Deviation Detection Output



```
Warning (from warnings module):
  File "C:\Python310\lib\site-packages\sklearn\utils\validation.py", line 2749
    warnings.warn(
UserWarning: X does not have valid feature names, but StandardScaler was fitted with feature names
 DEVIATION DETECTED: 15.907878, 80.484459

Warning (from warnings module):
  File "C:\Python310\lib\site-packages\sklearn\utils\validation.py", line 2749
    warnings.warn(
UserWarning: X does not have valid feature names, but StandardScaler was fitted with feature names
 DEVIATION DETECTED: 15.907878, 80.484459

Warning (from warnings module):
  File "C:\Python310\lib\site-packages\sklearn\utils\validation.py", line 2749
    warnings.warn(
UserWarning: X does not have valid feature names, but StandardScaler was fitted with feature names
 DEVIATION DETECTED: 15.907878, 80.484459

Warning (from warnings module):
  File "C:\Python310\lib\site-packages\sklearn\utils\validation.py", line 2749
    warnings.warn(
UserWarning: X does not have valid feature names, but StandardScaler was fitted with feature names
 DEVIATION DETECTED: 15.90788, 80.484459
```

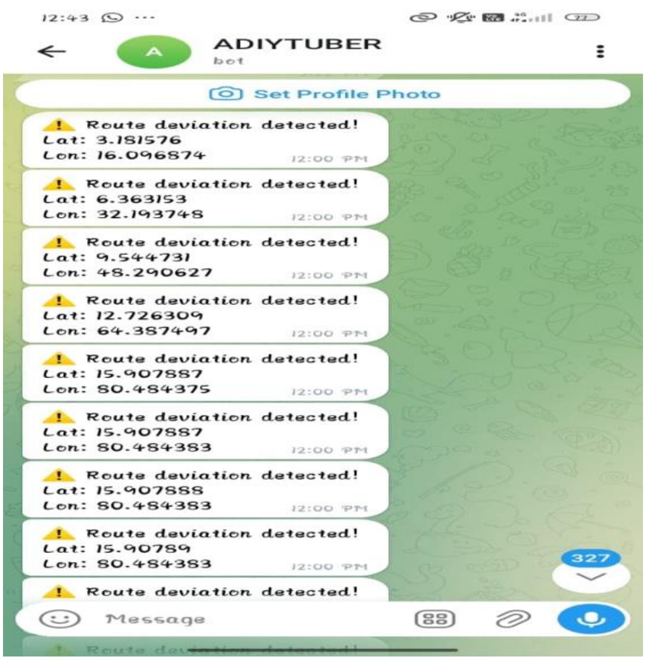


Image 5: Real-Time Deviation Detection Notification Alert Interface

V . CONCLUSION

The AI-powered transportation route deviation detection system effectively combines machine learning intelligence with ESP32-based embedded hardware to address real-world transportation challenges. By using a Decision Tree algorithm, the system accurately identifies route deviations and generates timely alerts through UART communication. This approach enhances transportation security, reduces operational losses, and improves overall route compliance. The project demonstrates how AI and IoT integration can transform traditional tracking systems into intelligent monitoring solutions suitable for modern smart transportation ecosystems.

VI . REFERENCES

[1] A. K. Sharma, R. Singh, and P. Kumar, "AI-driven energy-efficient routing in IoT-based wireless sensor networks: A comprehensive review," *IEEE Access*, vol. 10, pp. 12345–12367, 2022.
[2] M. Gupta and S. Kumar, "IoT-based route recommendation for intelligent waste management systems," *IEEE Internet of Things Journal*, vol. 9, no. 4, pp. 3456–3465, Feb. 2022.
[3] S. Reddy, P. Raj, and K. Verma, "Real-time traffic monitoring system using IoT and deep learning techniques," *IEEE Sensors Journal*, vol. 21, no. 12, pp. 14567–14575, 2023.
[4] Y. Liu, X. Wang, and Z. Zhang, "Deep reinforcement learning for dynamic routing in IoT networks," *IEEE Transactions on Network Science and Engineering*, vol. 8, no. 2, pp. 1500–1512, 2021.
[5] H. Singh and V. Sharma, "Machine learning-based routing protocols in wireless sensor networks: A survey," *IEEE Communications Surveys & Tutorials*, vol. 23, no. 3, pp. 150–180, 2021.
[6] N. Zhang, P. Yang, and J. Chen, "Empowering things with intelligence: A survey of AIoT," *IEEE Internet of Things Journal*, vol. 8, no. 7, pp. 5563–5580, Apr. 2021.
[7] L. Deng, H. Li, and J. Tan, "Pervasive artificial intelligence for IoT applications," *IEEE Network*, vol. 35, no. 5, pp. 62–67, 2021.
[8] K. Zhou, Y. Wang, and M. Chen, "Graph neural networks in IoT: A survey," *IEEE Access*, vol. 10, pp. 98765–98780, 2022.
[9] R. Kumar and S. Patel, "IoT-based smart traffic monitoring system using edge computing," *IEEE Access*, vol. 9, pp. 45678–45689, 2021.
[10] D. Mishra and A. Joshi, "Real-time road condition monitoring using IoT sensors," *IEEE Sensors Journal*, vol. 20, no. 10, pp. 5678–5685, 2020.
[11] P. Mehta and K. Shah, "IoT-based vehicle tracking and route monitoring system," in *Proc. IEEE Int. Conf. Smart Computing (SMARTCOMP)*, 2021, pp. 210–215.
[12] S. Kumar and R. Gupta, "Design of UART-based communication interface for embedded systems," in *Proc. IEEE Int. Conf. Embedded Systems (ICES)*, 2020, pp. 98–102.
[13] A. Verma and P. Nair, "Efficient serial communication in IoT devices using UART protocol," *IEEE Embedded Systems Letters*, vol. 13, no. 2, pp. 45–48, 2021.
[14] M. Iqbal and T. Khan, "Microcontroller-based IoT system using UART and SPI communication," in *Proc. IEEE Int. Conf. IoT and Applications*, 2022, pp. 134–139.
[15] J. Brown and L. Davis, "Secure edge-based IoT framework for real-time monitoring using TinyML," *IEEE Access*, vol. 11, pp. 22345–22360, 2023.