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Study on IoT-based vehicle accident-avoidance system

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Abstract

Presents an efficient and secure platooning strategy for Industry 4.0 environments involving Automated Guided Vehicles. The strategy proposed adopts Threat and Operability (THROP) and Hazard and Operability (Hazard and Operability) to determine and eliminate hazards like system failures and cyberattacks. Adaptive risk management and real-time monitoring are guaranteed using digital twin-based simulations, with enhanced AGV coordination and collision risk reduced. The system also provides encryption and authentication to provide integrity to data. Simulation shows improved scalability, security, and efficiency, and potential use in smart cities and logistics. Large-scale deployment and AI-based predictive analytics are areas of interest for future study. This study helps advance industrial automation in Industry 4.0 through ensuring safe and reliable AGV operations.

Keywords: Convolutional Neural Networks (Cnns); Deep Learning; Computer Vision; Image Processing

1. Introduction

Various of the various IoT-based solutions to enhance safety, mobility, and efficiency in many industries are explored. A new Industrial IoT (IIoT) collision avoidance system using Bluetooth technology is proposed to improve workplace safety by providing real-time alerts to machine operators. In road safety, a multi-level Internet of Vehicles (IoV) system based on deep learning accurately predicts accidents. The research also depicts a smart railway platform based on OpenCV and YOLOv5 for real-time detection of trains and automatic access. Federated Learning (FL) is investigated to enhance IoT security with solutions like overcoming data privacy and resource shortage challenges. In addition, AI-driven IoT security solutions emphasize pre-emptive threat detection and adaptive defense. CV POp-CoRN, an intelligent city-vehicle cooperative route guidance system, utilizes urban infrastructure and vehicles to optimize traffic and urban mobility. LPWAN-based IoV solution improves communication and minimizes latency for city sensing. RiskyMove, an app that uses vehicle trajectories, identifies risky routes and provides real-time alerts to drivers. Dynamic traffic light control to ease congestion is proposed for the Social Internet of Vehicles (SIoV). Lastly, a fault-tolerant platooning strategy offers secure Automated Guided Vehicle (AGV) operation in Industry 4.0, enhancing safety and efficiency in industrial environments. The rapid advancement in the Internet of Things (IoT) has resulted in intelligent transportation systems with emphasis on road safety and accident reduction. The IoT Vehicle Accident-Avoidance System aims at reducing the threat of collision through real-time sensing, processing, and automatic alarm generation. The system utilizes sensors such as ultrasonic, infrared, and accelerometers to detect impending danger, monitor vehicle speed, and monitor driving behavior. The system provides critical information to drivers and traffic centers through IoT connectivity, enabling proactive avoidance of accidents. In addition, technologies such as GPS, GSM, and cloud computing ensure seamless data transfer and remote access for emergency personnel. Artificial intelligence integration also facilitates decision-making through the anticipation of hazardous conditions. This study examines the effectiveness of IoT- based solutions in preventing road accidents, improving vehicle safety, and offering a safer and more efficient transportation environment.

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2. Literature review

Strong research into workplace safety within the manufacturing sector has resulted in numerous collision avoidance solutions through the incorporation of Industrial IoT (IIoT) and Advanced Driver Assistance Systems (ADAS). Computer vision, Bluetooth positioning, and RFID were investigated with the Bluetooth-based solutions favored for their low cost and ease of implementation. This work presents a low-cost and scalable Bluetooth-ADAS collision avoidance solution for real-time applications. Road safety studies have evolved using deep learning algorithms like LSTM, CNN, and federated learning for real-time accident forecasting, overcoming the limitations of standard statistical models.

The Spatio-Temporal Conv-LSTM Autoencoder (STCLA) improves accident prevention by incorporating vehicle, weather, and traffic information. In rail networks, IoT has enhanced safety and efficiency by predictive maintenance and disaster avoidance. This research extends previous work by combining OpenCV and YOLOv5 for real-time train detection. Federated Learning (FL) has also been a decentralized machine learning solution for IoT security but is susceptible to adversarial attacks. To improve resilience, cryptographic techniques such as differential privacy and homomorphic encryption are investigated.IoT adoption has been accompanied by security issues, leading to research on machine learning (ML) and deep learning (DL) methods for anomaly detection. In urban mobility, intelligent city technologies enhance transportation, and the CV POp-CoRN system provides a cooperative real-time route optimization framework. The Internet of Vehicles (IoV) promotes connectivity, but solutions so far experience high-mobility challenges. This work introduces an onboard device combining LPWAN technologies for enhanced urban sensing.Machine learning-driven risk detection methods facilitate real-time forecasting of road dangers, and this study posits RiskyMove, a probabilistic Minimum Adaptive Viterbi (MAV) algorithm-based approach to accurate path safety evaluation. Artificial intelligence-powered traffic management, particularly through the Social Internet of Vehicles (SIoV), enhances traffic congestion control.

Lastly, in Industry 4.0, Automated Guided Vehicles (AGVs) are significant, and this study incorporates safety, security, and assurance frameworks for secure AGV platooning in industrial settings.IoT-based vehicle accident prevention systems discusses different technologies and approaches that help enhance road safety. Existing research has combined Industrial IoT (IIoT) with Advanced Driver Assistance Systems (ADAS) to improve workplace safety using Bluetooth-based positioning, RFID, and computer vision.Experiments involving deep learning-based accident forecasting using Long Short-Term Memory (LSTM), Convolutional Neural Networks (CNN), and Federated Learning (FL) have shown satisfactory outcomes in real-time risk assessment. The performance of conventional statistical models, however, is inadequate to address complex traffic scenarios. Spatio-Temporal Conv- LSTM Autoencoder (STCLA) has been proposed to further enhance accident prevention by studying vehicle, weather, and traffic data. Railway infrastructures have also been improved with IoT technologies, with OpenCV and YOLOv5 improving train detection and automatic level crossings. Data privacy issues in Federated Learning (FL) are still an issue, leading to the use of cryptographic techniques such as differential privacy and homomorphic encryption.

IoT security is still a major concern, with machine learning (ML) and deep learning (DL) models employed for anomaly detection and cyber threat prevention. In city mobility, intelligent city technologies like CV POp-CoRN improve traffic flow through the integration of vehicles and urban infrastructure. Internet of Vehicles (IoV) solutions based on LPWAN technologies (LoRaWAN and NB-IoT) have enhanced connectivity but are not robust in high-mobility scenarios. Furthermore, RiskyMove, an in-real-time hazard detection system, utilizes Minimum Adaptive Viterbi (MAV) algorithms for road safety analysis. Traffic congestion control has moved towards AI-based models such as the Social Internet of Vehicles (SIoV), which adjusts traffic lights dynamically. Automated Guided Vehicles (AGVs) are used in logistics in Industry 4.0, and efficient operation demands sophisticated security and platooning techniques. The survey points out the advent of IoT-based accident prevention and suggests issues like security attacks, data privacy, and real-time processing limitations.

3. Features of proposed model

Envisioned IoT-based accident detection system aims to improve road safety through the integration of an ESP32 microcontroller, ultrasonic sensor, accelerometer, buzzer, motor driver, DC motor, power supply, and the Blynk app for real-time observation and alerts. The inclusion of an accelerometer greatly enhances the system's accuracy in the detection of sudden vehicle movement such as sudden braking, sudden turns, and collisions. The accelerometer tracks variations in acceleration along multiple axes, which assists in the detection of abnormal patterns of motion common with crashes. If the system detects an abnormal tilt or bump, the system cross-references this against the ultrasonic sensor's collision detection to validate a potential crash.

After verification, the buzzer is triggered to give a sound alert, movement of the vehicle is stopped through the motor driver, and immediate alert is sent to emergency numbers through the Blynk app. This entire system provides quicker and better accident detection, decreases response time, and protects against possible harm and damage by taking quicker emergency action. The monitoring feature based on the cloud also has real-time data visualization and remote access, making the system highly efficient and easy to use.

Concept IoT-based Vehicle Crash Avoidance System combines real-time sensing, smart decision-making, and auto-response to promote road safety and avoid crashes. The system uses IoT sensors such as ultrasonic sensors, accelerometers, and GPS modules that detect a vehicle's real-time speed, how close it is to another object, a driver's trend, and road conditions. These are hooked up to a microcontroller unit such as Arduino or Raspberry Pi, which calculates the data and detects potential collisions hazards.Spatio- Temporal Conv-LSTM Autoencoder (STCLA) is employed to investigate real-time environmental and traffic information, enhancing accuracy in accident forecasting.

Machine learning algorithms and Principal Component Analysis (PCA) enhance data processing capability to enable real-time detection of hazardous driving behaviors.When danger is sensed, the system automatically alerts, adapts braking, and steers to avoidcollisions. For remote monitoring and emergency response, the system incorporates GSM and GPS modules, which allow real- time positioning and automatic alert to the emergency services and surrounding vehicles in the event of an accident. A cloud platform, like Blynk or Thingspeak, offers remote access for users and authorities to monitor road conditions and vehicle performance.The system ensures cost-effectiveness, scalability, and reliability using IoT connectivity, artificial intelligence-based risk assessment, and automation to reduce road accidents and enhance the overall safety of traffic.

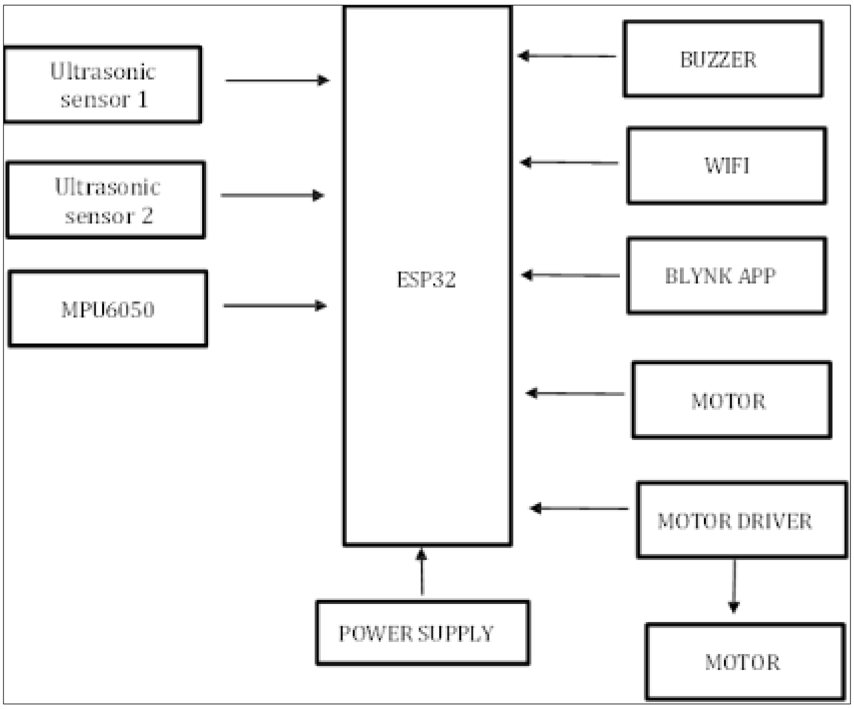

Figure 1 Diagram for Proposed System

The above figure describes an IoT-based Vehicle Accident-Avoidance System that employs several sensors and actuators and an ESP32 microcontroller for enhancing road safety. The system employs ultrasonic sensors to detect obstacles on the vehicle's path and detect distances to serve as timely warning signals. Besides, an MPU6050 sensor (accelerometer and gyroscope) tracks the motion of the vehicle, sensing sharp bumps, tilts, or crashes. ESP32 microcontroller is the brain of the system, interpreting live sensor data and performing the required action. On object detection, the system beeps a buzzer to get the driver's attention.

In case the driver fails to respond, a motor driver has an automatic brake system activated. The system leverages the WiFi connectivity by sending information related to an accident to the emergency department and stored contacts through Blynk mobile app. This facilitates real-time tracking and quick response in the event of an accident. Moreover, power supply allows continuous operation, increasing system reliability. With the combination of IoT, AI analytics, and real-time monitoring, the system offers an efficient and cost-effective means of preventing accidents, reducing delays caused by human action and increasing response time in the event of an emergency. This technology greatly improves the safety of vehicles, reducing fatalities and roadside incidents.

4. Features of existing system

Existing accident detection and monitoring systems are predominantly based on conventional approaches, including manual reporting and CCTV cameras, which tend to cause response time delays. Bystanders or drivers themselves may be required to report accidents in most instances, which can be time-consuming, particularly in less-populated or remote areas where prompt assistance may not be forthcoming. Some newer vehicles have airbag deployment sensors and emergency call systems, but these are costly and only found on high-end vehicles. Additionally, most modern systems lack real-time transmission of data and cloud monitoring, hence making it difficult to provide accurate location data and incident details to emergency responders. The lack of automated control of vehicles to stop additional damage after a collision is another serious disadvantage.

Thus, the absence of low-cost, effective, and real-time accident monitoring and detection systems creates a huge gap in road safety provisions, making late medical intervention more likely and the effects of accidents more severe.The current vehicle crash avoidance systems mainly depend on traditional safety systems, including Advanced Driver Assistance Systems (ADAS), radar collision detection, and infrared sensors. The systems utilize cameras, LiDAR, and ultrasonic sensors to sense objects and aid drivers in avoiding crashes.

Though they excel in laboratory settings, they are restricted in real-time processing, weather resistance, and expense. Most contemporary accident prevention systems utilize GPS tracking and vehicle-to-vehicle (V2V) communication to improve safety. They do not have centralized data processing and predictive analytics, which restricts their deployment in heavy traffic.

Roadside facilities like roadside sensors and cameras offer accident detection without driver notification or real-time preventive action.IoT solutions are also being designed to enhance accident prevention using AI-based analytics, cloud computing, and real- time sensor data.Nearest IoT-powered systems that are currently available use IoV (Internet of Vehicles) for traffic data sharing but typically do not support deep learning models for accurate accident prediction.

Machine learning-driven systems augment risk estimation but are hindered by poor rates of false alarms and computing capabilities. Collectively, existing systems provide rudimentary accident avoidance functionality but lack a comprehensive IoT-based solution that brings together real-time vehicle monitoring, deep learning predictive models, and adaptive safety functions, identifying the need for a high-tech IoT-based accident avoidance system.Overdependence on human action results in time lag in accident detection and response. Failure to implement automated systems to detect and respond to accidents in real-time.

Sophisticated accident detection features are usually found in high-end, costly vehicles.Most lack immediate notification to emergency services or contacts.Lack of providing proper accident location information for quicker response.No automatic safety or braking features after an accident to avoid additional damage.Inability to detect and report accidents in remote or lightly populated areas.

5. Methodology

The ad-hoc collision avoidance system to be proposed increases workplace safety by combining Advanced Driver Assistance Systems (ADAS) with Bluetooth-based location detection. It employs industrial vehicle detectors and worker-worn Bluetooth transmitters, processed through a Raspberry Pi using Kalman filtering. Haptic seatbelt feedback and LED indicators provide rapid response within prescribed safety perimeters. The low-cost solution avoids the use of costly infrastructure.For safety on roads, the Internet of Vehicles (IoV)-based Accident Prediction and Prevention System uses IoT sensors and deep learning based on a Spatio-Temporal Conv-LSTM Autoencoder (STCLA) to enhance accident prediction using Principal Component Analysis (PCA) and analysis of real-world traffic data.

Also, Federated Learning (FL) is used to enhance IoT security but with challenges such as data poisoning and adversarial attacks, which are addressed using cryptographic methods such as differential privacy and homomorphic encryption. IoT security is also enhanced with the application of machine learning (ML) and deep learning (DL) methods such as recurrent neural networks (RNN) and convolutional neural networks (CNN) for detecting intrusions.

Intelligent city mobility solutions, for example, CV POp-CoRN, incorporate vehicles and urban infrastructure to facilitate improved real-time navigation. The RiskyMove system, through Minimum Adaptive Viterbi (MAV) algorithms, foretells dangerous roads. Traffic management, aided by the Social Internet of Vehicles (SIoV), maximizes traffic flow through AI-based signal control. Finally, Industry 4.0 utilizes Automated Guided Vehicles (AGVs) with platooning techniques and digital twin-based simulations to provide secure and efficient operations.

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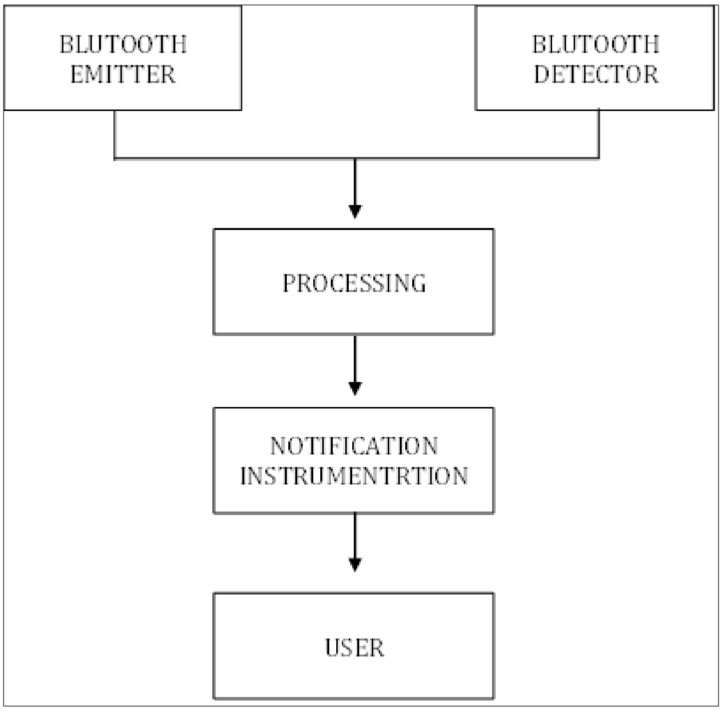

Figure 2 Ad-hoc location system architecture

The above figure depicts the Bluetooth-based communication system in an IoT-based Vehicle Accident Avoidance System. The system comprises a Bluetooth emitter and a Bluetooth detector that keep on exchanging signals to sense the surroundings of the vehicle. On detecting an obstacle or another vehicle within a critical distance, the processing unit interprets the data and activates a notification instrument to warn the driver of possible collisions. It will provide an alarm, vibration, or visual warning so that the driver is made alert in case of such conditions. The system will be most helpful when there is a lot of fog, heavy rain, or when the person is driving during nighttime. It enhances the safety of the vehicle by using integration with IoT technology for detection based on Bluetooth, and reduces human-related errors. It's a cost-effective solution for preventing accidents due to limited real- time internet connectivity in such areas but short-range communication is feasible.

6. Data flow diagram

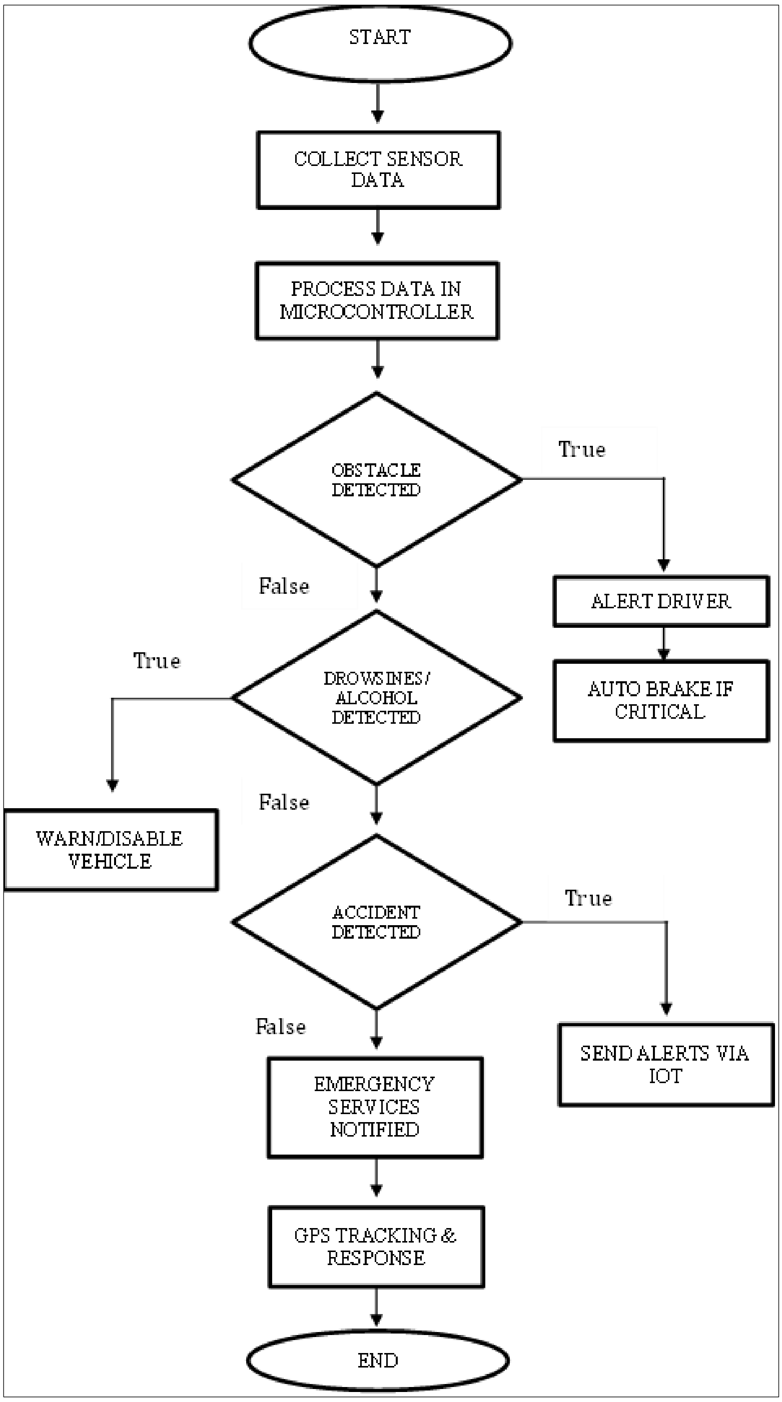

Figure 3 DataFlow Diagram

7. Result and discussion

In Industry 4.0 environments, empirical evidence is established on how effective the AGV platooning system outlined in this research is in the matter of ensuring the safe and secure transportation of commodities. Cyber-attacks, operational hazards, and communication failure were some of the relevant risks unveiled by the hazard and threat assessment through the application of the HAZOP and THROP methodology. The technology validated the effectiveness of the assurance framework by successfully alleviating and addressing these risks through digital twin simulation. The result of the simulation indicated improved coordination of AGVs, reduced risks of collision hazards, and optimally maximized mobility effectiveness. Use of real-time monitoring helped adapt operation parameter adjustments, consequently minimizing deviations in normal behavior.

Smoother communication exchange among AGVs, by facilitating improved decision-making through fog and cloud-based control. Integrity of the data in operations in AGVs was also achieved through security tools such as message authentication and encryption, which had an effective neutralizing effect towards cyberattacks. The need to incorporate security and safety features into AGV platooning is emphasized in the controversy.

Whereas conventional methods only emphasize functional safety, this research indicates the necessity of an integrated risk management approach. AGVs can effectively respond to unplanned changes in operations because of the continuous system improvement offered by real-time adaptation of assurance instances. Based on the research findings, the proposed approach can also be applied in smart cities and logistics, apart from industrial environments.

To further enhance the performance of AGVs, there should be increased focus on scaling up the proposed approach in addition to applying AI-powered predictive analytics. As such, overall, the findings authenticate to what extent the proposed method ensures safe and effective AGV platooning.

8. Future enhancement

For future prospects, the system can be further augmented by including a GPS module for precise location tracking of the accident location to facilitate quicker emergency response. A GSM module can be included for sending SMS alerts where internet connectivity is poor. Also, adding camera modules such as the ESP32-CAM can give pictorial evidence of accidents, enhancing incident documentation and evaluation. Machine learning models can also be used for sophisticated predictive analytics of collision hazard based on sensor data. Adding voice alerts, vehicle health checks, and auto-braking systems to the system's capabilities would make it even more reliable and feature-rich, and it would be an end-to-end accident avoidance and response solution.

Future development for an IoT-based car accident-avoidance system can significantly improve road driving efficiency and safety. A likely development is implementing artificial intelligence (AI) and machine learning (ML) algorithms to analyze real-time data and predict imminent collisions more effectively. Another evolution is the enhancement of 5G technology to enable quicker communication speed between vehicles (V2V) and infrastructure (V2I), reducing latency and offering immediate response to threat. Another key enhancement is the application of edge computing, whereby processing of data occurs close to the source with reduced use of cloud computing and faster decision-making. In addition, the application of advanced sensors such as LiDAR and infrared cameras will enhance improved detection of obstacles even during low visibility. Even safer can be the vehicle with more effective driver monitoring by means of biometric sensors and eye-tracking technology to identify drowsiness or distraction. Smart traffic management systems integration and GPS-based adaptive route planning based on GPS can assist vehicles in routing through safer roads and skipping accident-prone zones. Lastly, blockchain technology can be used to securely share data and avoid cyber-attacks. With all these developments, IoT-based accident prevention systems will become more efficient, smarter, and more reliable, drastically decreasing road accidents and improving transport security.

9. Conclusion

In Industry 4.0 environments, the research successfully demonstrates an effective and safe platooning system for AGVs. The research successfully identifies and prevents operation risks, communication failure, and cyber-attacks through a hybrid combination of HAZOP and THROP analysis. Digital twin simulation enables real-time feedback and dynamic risk control, ensuring high efficiency and coordination of AGVs. The security is ensured through security features such as message authentication and encryption. The findings demonstrate that the proposed method is an industrial automation technology with a scalable and flexible characteristic and an abundance of potential use in logistics and smart cities.

To further strengthen the performance of AGV, future research should focus on large-scale real-world experiments and optimizing AI-based prediction analytics. With the assurance of secure and efficient AGV movement, this work contributes to Industry 4.0. In summary, the IoT-based vehicle collision avoidance system presents a promising solution to improve road safety through the combination of real-time monitoring, data analysis, and automated response.

Through the use of sensors, GPS, cloud computing, and AI-based decision-making, this system efficiently identifies impending collisions, alerts drivers, and, in certain instances, autonomously applies corrective measures to avoid accidents. The use of such intelligent systems can reduce human mistakes to a large extent, which is one of the prime causes of road accidents. The facility for real-time alerting of emergency services also leads to a faster response, which could save lives.

Although it has its downsides like expensive installation, security threats from hacking, and connectivity problems, the advantages far outweigh the disadvantages, making it a successful solution for transportation in the future. Future technologies in IoT, artificial intelligence, and vehicle-to-everything (V2X) communication will keep developing and improving these systems, further making roads safer and the transport infrastructure smarter and more efficient.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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