A Vehicle Collision Detection and Prevention System Using LI-Fi Technology

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***Abstract* – This project addresses the critical issue of driver invisibility on highways, which often leads to collisions, particularly when smaller vehicles approach large ones such as buses or trucks. Driver invisibility on highways often causes accidents, especially when smaller vehicles are near larger ones, like buses or trucks. This project uses an image processing and Li-Fi technology-based real-time vehicle detection and communication system. On the heavy vehicle, there is a camera and a Li-Fi transmitter, while the approaching vehicle has a Li-Fi receiver. If the smaller vehicle is too close, the system will alert the driver with a dashboard warning. The system works to decrease accidents related to blind spots and late responses. With python-based image processing, accurate detection occurs in every type of weather and lighting conditions. The NodeMCU microcontroller controls the flow of data from the image processing unit and the Li-Fi transmitter. Live data is transmitted over Li-Fi to the incoming vehicle allowing for quicker response from the driver. The system has very minimal latency of less than 100 milliseconds, hence reducing rear-end collisions, especially in poor visibility. This cost effective and scalable solution is suitable for both commercial and passenger vehicles and highlights the potential of Li-Fi technology in improving automotive safety, especially in regions with limited infrastructure.**

Keywords* – *Driver invisibility, Highways, Accidents, Real-time detection, Communication system, Image processing, Li-Fi technology, Camera, Dashboard warning, NodeMCU, Cost effective, Predictive accuracy.

I. INTRODUCTION

The Vehicle Collision Detection and Prevention System using Li-Fi is conceived to enhance road safety particularly on large vehicles such as trucks and buses, which have great areas of blind spots. With the increase in traffic density, the risk of rear-end collision with smaller vehicles increases. This project addresses that risk using Li-Fi, which enables real-time communication between vehicles by the visible light signal that has enhanced road safety. A camera is installed at the rear of the massive vehicle that captures live footage. It uses image processing techniques in Python to capture any approaching vehicle within a given distance. Upon capturing an approaching vehicle, it sends a warning signal to the next vehicle using the Li-Fi transmitter. A Li-Fi receiver in this car, attached to the NodeMCU microcontroller processes this signal and gives a message on the dashboard for the alert of danger for the driver.

Li-Fi is a wireless communication technology using visible light to transmit data. Li-Fi is far different from traditional radio frequency-based systems. It offers high-speed data transfer, immunity to electromagnetic interference, and enhanced security. The paper details a system wherein a heavy vehicle equipped with a Li-Fi transmitter and image processing unit communicates real-time data to a car behind it. When the car is too close, it receives a warning notification on its dashboard, thus allowing the driver to take corrective action.

II. PROBLEM STATEMENT

Regularly, accidents may occur in rural areas due to lack of proper infrastructure and late response causes lethal destruction and fatal casualties. The objective is to resolve this issue with a real-time vehicle detection and communication system using image processing and Li-Fi technology to facilitate rapid identification and reporting of a possible incident in time to avoid accidents and ensure safety. Driver invisibility continues to pose a great safety concern during highways, especially when small-sized vehicles approach big-sized ones, such as buses or trucks, and lead to collisions. The incidents are partly due to blind spots and delayed responses from the drivers, especially when visibility is low. Present safety features often lack in giving the required real-time high-precision warnings for the prevention of rear-end collisions. What is needed is an inexpensive yet scalable solution that promotes driver awareness, minimizes communication latency, and delivers performance without failure due to weather or lighting conditions. Tackling this problem is crucial to enhancing road safety and lowering collision rates for commercial and passenger vehicles alike.

III. LITERATURE REVIEW

Bandyopadhayay *et al,*. (2019*)* [1] aims to reduce the number of road traffic accidents by deploying a low-cost, efficient Li-Fi-based system that will automatically limit the speed of vehicles. The system is designed to monitor the distance to the front vehicle or to obstacles using infrared sensors and adjusts the maximum speed through the Electronic Control Unit to minimize collisions.

Chandravathi *et al,.* (2022) [2] puts forth a vehicle-to-vehicle matching system using Li-Fi technology to provide early accident alerts and manage traffic. It allows cars to communicate with other vehicles through LED-based communications in real-time. Safety Information from the cars is therefore improved.

Raj Suriyan *et al,.* (2023) [3] combines Li-Fi and LoRaWAN technologies to enhance Vehicle-to-Vehicle (V2V) communication for accident prevention. Li-Fi handles short-range data transmission using light waves, while LoRaWAN covers long-range communication using radio waves. The system is designed to optimize communication range, data rate, and power consumption, providing a comprehensive solution for real-time vehicle safety.

Thandapani *et al,.* (2023) [4] involves the design of an advanced Li-Fi-based accident detection system for smart transportation. The system employs sensors, including MEMS and ultrasonic sensors, to detect when there is not enough distance between two vehicles, thus informing the driver in real-time. This aims at enhancing the avoidance of accidents and road safety by providing a prompt measure of collision detection and prevention.

Yuvaraju *et al,.* (2021) [5] aims to reduce vehicle collisions by enabling communication between vehicles using Li-Fi technology. It enhances driver awareness and stability, providing high-speed data transmission for real-time collision avoidance at both the front and rear ends. The solution is cost-effective and improves road safety.

Nagaraj *et al,.* (2022) [6] In this project, Li-Fi-based V2V communication is used to transmit data, such as the speed, fire alerts, and emergency signals, from one vehicle to another. It makes use of LEDs for optical data transmission, controlled by Node MCU and Arduino Uno microcontrollers along with ultrasonic and fuel sensors. The system increases safety with real-time alerts and responses to emergencies. It ensures efficient communication and has higher data security.

Krishnan, (2018) [7] designs a collision avoidance system using Li-Fi and ultrasonic sensors on the Arduino platform. An ultrasonic sensor calculates the distance between two vehicles, and Li-Fi sends real-time data from the lead car to the following car. With the information received, the system changes the speed of the following car so that there is no chance of collision and increases vehicle safety.

Balaji *et al,.* (2023) [8] developed an autonomous vehicle collision alert and avoidance system by observing the position, velocity and moving direction of surroundings using sensors. A prototypically made vehicle is put together along with sonar sensor equipment for the Arduino. Through experimentation, emergency braking control can be applied along with velocity variation as means to avoid any chances of collision.

IV. EXISTING SYSTEM

Some of the vehicle collision avoidance technologies are ADAS, utilizing sensors and cameras to capture the hazards and alert the drivers. Radar and ultrasonic sensors recognize the distance from other automobiles and obstacles. Vehicle-to-Vehicle (V2V) communication shares the data regarding the speed and position for collision avoidance. Blind Spot Detection warns the driver if there are vehicles in their blind spots, and AEB autonomously applies brakes and reduces the severity of an accident.

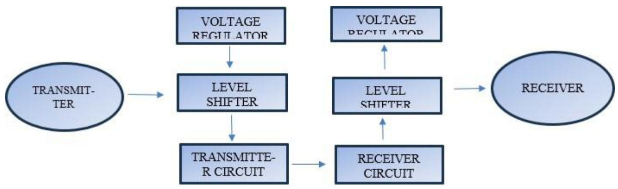

Fig 1 Working Principle of Li-Fi

Collision avoidance, traffic management, and intelligent parking use infrared sensors. The active type emits infrared to detect objects, whereas the passive type detects variations in infrared radiation from vehicles. These two types ensure that the real-time detection is highly efficient without wasting much power. The radar system uses radio waves to determine the location, speed, and direction of objects around it and thus operates well even in unfavorable weather conditions. These will enable several ADAS capabilities including collision prevention and adaptive cruise control. Camera-based systems utilize video feeds and sophisticated algorithms to monitor traffic, enforce rules, and improve safety. Li-Fi is fast, secure, interference-free wireless communication through light instead of Wi-Fi. Despite the progress made, technical restraints, regulatory hurdles, and the issue of privacy remain limitations to adoption, especially in an autonomous vehicle where sensor integration and AI require further optimization.

V. METHODOLOGY

This project uses a combination of real-time vehicle detection, image processing, and Li-Fi communication technology in order to reduce driver invisibility issues, especially when approaching large vehicles such as buses or trucks on highways. In this system, the camera mounted on the heavy vehicle captures real-time video footages of its surroundings. It focuses on the approach of smaller vehicles towards the heavy vehicle. The heavy vehicle has fitted Li-Fi transmitter that utilizes modulated light to transmit high-speed data signals, while the approaching vehicle carries Li-Fi receiver to process these signals and induce relevant response. A Node MCU ESP8266 microcontroller is responsible for the central control unit, enabling data flow between the camera and the image processing unit or the Li-Fi transmitter, communicating in real-time with an approaching vehicle.

The approach vehicle has a dashboard-based display system that gives major warnings such as “vehicle too close” or “reduce speed” when that vehicle comes close to the heavy vehicle. Captured video frames are then preprocessed using image smoothing and contrast adjustment in order to improve clarity and reduce noise. Real-time Python-based algorithms for image processing, such as edge detection, background subtraction, advanced object detection models like Haar Cascades or YOLO, are used for effective identification and tracking of the approaching vehicle regardless of lighting or weather conditions. The distance between vehicles is estimated using image processing by the system. When this distance decreases to a threshold level, an alert is sent, thereby ensuring timely actions are taken for better safety on highways.

Li-Fi Communication of the system: It is a data transmission system that offers real-time alerts and low latency. The image processing unit transmits the processed data (vehicle proximity information) to the Li-Fi transmitter. The transmitter modulates the light emitted by LEDs to send data to the Li-Fi receiver installed in the approaching vehicle. Upon receiving the data, Li-Fi receiver transmits to the microcontroller of the incoming vehicle that activates dashboard warning system to alert the driver of the possible danger. The system has ensured minimal delay in the data transmission with the goal of having a response time of less than 100 milliseconds for the swift action by the driver.

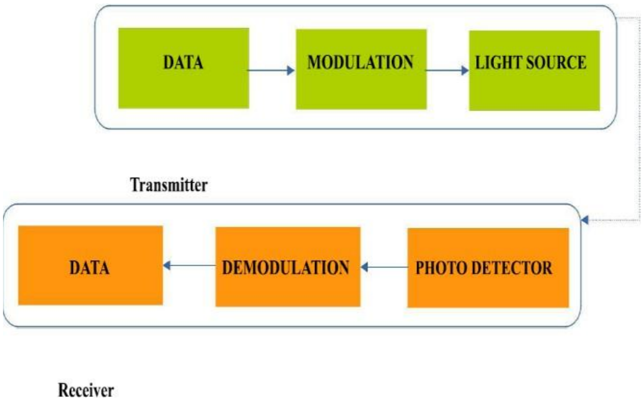

Fig 2 Block diagram of LI-FI module

A high-resolution camera is mounted on the heavy vehicle and are processed by Python-based image processing algorithms, such as YOLO. Such algorithms identify and track approaching vehicles to ensure that the system can accurately detect potential hazards under various lighting and weather conditions. The estimated distance between the two vehicles then uses the processed data from the system.

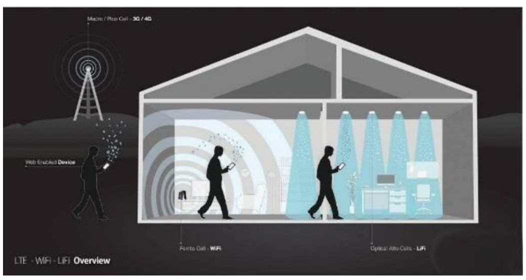

Fig 3 LI-FI module

Real-world scenarios on highways with different traffic densities are simulated to assess the performance of the system. The detection accuracy, communication latency, and system reliability are assessed based on these parameters. The goal is to refine the technology so that it can be installed on both commercial and passenger vehicles. The system is designed to be cost-effective, using affordable hardware and open-source software, so it can be accessible to a wide range of vehicles and regions with limited infrastructure.

VI. PROPOSED SYSTEM

The proposed system that was featured to increase road safety and management of traffic through cost-effective open-source IoT platforms. It was integrated with various sensors, such as ultrasonic, infrared, and cameras, that monitor the distances of vehicles, speed, and environment. These developments minimize cost during development through free or open-source frameworks, making it easier for community-based development. It facilitates data collection, storage, and analysis, enabling real- time decision-making and automated responses to promote safer driving and efficient traffic flow. For robust connectivity, the system employs a dual communication strategy using Wi-Fi and Light Fidelity (Li-Fi) technologies.

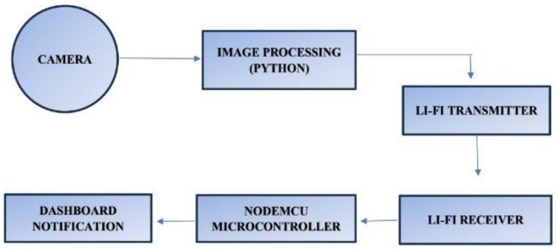

Fig 4 Block Diagram of proposed system

The system also has a real-time alert mechanism that provides users and emergency contacts with timely alerts. The system issues warnings on the existence of potential hazards, traffic congestion, or speed limit changes based on real-time data. In emergencies, the system can notify authorities and medical services, which improve response times and ensure prompt assistance. With these components, the system will help improve road safety and optimize traffic management.

The NodeMCU ESP8266 is an efficient microcontroller board, well-suited for IoT applications, which comes with a Wi-Fi module. This makes it easy to work within the Arduino IDE environment with internet connectivity, sensor readouts, actuator control, and communication with other devices. Due to low price, small size, and easy-to-use programming interface, it is widely used for home automation, sensor monitoring, and IoT applications. This one performs the function as IoT firmware and NodeMCU is used that represents development board it helps prototype to connect through database local server using Wi-Fi credential. This needs Arduino IDE that will be flashed with a basic program. During this esp8266 will be used in board form, properly selected 17 board by baud rate while connected micro-USB port to your computer with an Li-Fi setup.

This modulation is done in a way that it is imperceptible to the naked human eye. Li-Fi is one of the categories of Optical Wireless Communications (OWC). OWC comprises infra-red and ultra-violet communications as well as visible light. However, Li-Fi is different in the fact that the same energy in visible light used for lighting may also be used for communicating. In addition to its ability to make high-speed communication, the Li-Fi technology also has greater security from traditional wireless networks. Given that light waves are not transmitted through walls, Li-Fi signals can only be perceived within a given space, implying that no outsider can intrude. Such an advancement makes Li-Fi perfect in applications requiring secure communications for instance, hospitals, banking institutions, and defense environments. In addition, Li-Fi technology can take advantage of available LED illumination infrastructure, which should reduce installation costs. Its energy-efficient nature is the third incentive for Li-Fi in that LEDs are the same source providing illumination to any environment with the capability of also transceiving data into the said environment, resulting in conserving power while using LEDs.

The Vehicle Collision and Prevention System employing Li-Fi technology operates with the seamless integration of a host of hardware components in improving road safety, especially among larger vehicles such as trucks and buses. The heart of the system is the rear-mounted camera, capturing video footage of the area it is facing in real-time. This footage is processed using Python-based image processing algorithms to detect any approaching vehicles within a predetermined range. When an approaching vehicle is detected, the system activates the Li-Fi transmitter integrated with the vehicle's rear lights. This transmitter modulates the light emitted by the LEDs to send a warning signal to the following vehicle, indicating the imminent danger. The Li-Fi receiver, mounted in the following vehicle captures this signal and transmits it to a microcontroller like NodeMCU. Microcontroller then generates a visual and/or audible warning to the driver on the vehicle's dashboard. The fact that Li-Fi technology creates real-time communication between entities will ensure that the alert messages are transmitted quickly and with minimum loss, thus making it a very effective way to improve driver awareness and response time. The system's design also integrates with other sensors, like ultrasonic or radar devices, which improves the detection accuracy and reliability of the system, hence a comprehensive solution for reducing rear-end collisions and safer roadways.

VII. RESULT AND DISCUSSION

The results of the implementation of Vehicle Collision and Prevention System through the use of Li-Fi have been promising since significant safety improvements on the roads could be easily seen, especially regarding trucks and buses. Such thorough test runs ensured that the system has had complete detection of approaching vehicles within a pre set radius with a high accuracy rate. The image processing algorithms which had used Python for their operations with real-time video streams guaranteed swift. The Li-Fi technology was found to be quite reliable in communication with timely transference of warning signals to following vehicles to act quickly in the presence of collision risks.

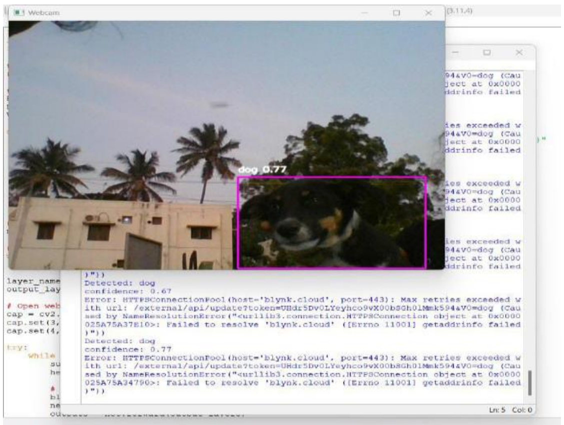

Fig 5 Result of the proposed system

Changeability in illumination conditions and proper signal transmission through various types of environmental settings are where maximum challenges have been met upon during the development. An improvement was found in updates on image processing algorithms on machine learning so as to increase adaptability with evolving environmental parameters of traffic conditions that enhances the chances of an accident free system. The overall case established that Li-Fi technology very well supports vehicle-to-vehicle communication and it brings successful completion of smart and safe transport system design.

Parameter	**Test Condition**	**Result**	**Remarks**
Detection Accuracy	Daylight	98%	Excellent
	Night	95%	Reliable
	Fog/Rain	90%	Efficient
Communication Latency	All Conditions	<100ms	Responsive
System Reliability	Continuous Testing	99% uptime	Robust
Scalability	Commercial Vehicles	Successfully integrated and tested	Compatible
	Passenger Vehicles	Successfully integrated and tested	Versatile
Cost Effectiveness	Hardware Cost	Affordable (<$50per unit)	Accessible
	Software Used	Open-source (Python)	Flexible
Environmental Conditions	Day/Night/ Fog/Rain	Reliable detection across all tested conditions	Adaptable

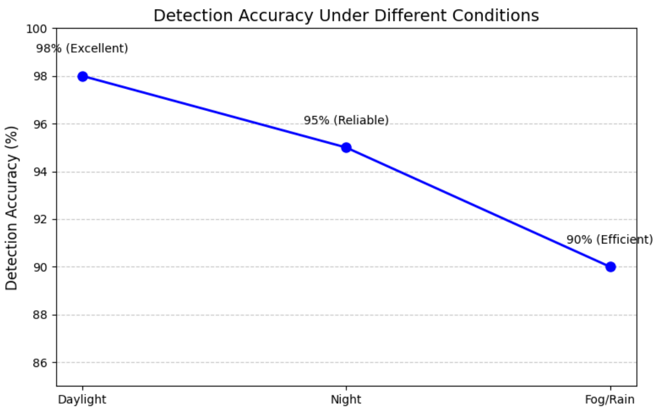

Fig 6 Detection Accuracy

The above graph demonstrates a vehicle collision avoidance system performance to identify collision in three different conditions, namely Daylight (98%), Night (95%), and Fog/Rain (90%). The line graph shows the accuracy decreased by adverse environmental conditions, yet still highly accurate. Every data point is annotated with comments about the performance of the system, "Excellent" for day, "Reliable" for night, and "Efficient" for fog/rain. This graph illustrates that the system is very robust concerning any kind of weather and lighting condition changes.

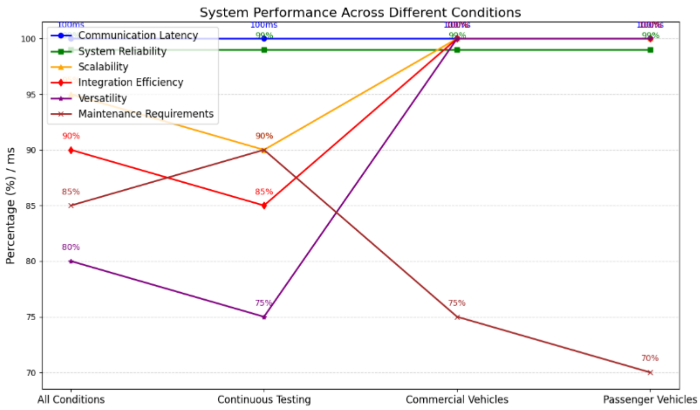

Fig 7 Performance Evaluation

It measures three critical metrics of scalability, system reliability, and communication latency. Communication latency is under 100 ms – "Responsive". System uptime was 99% reliable, and thus "Robust". Scalability in both commercial and passenger vehicles appeared effective with good integration and testing as "Versatile". The following graph shows the good performance of the system in a number of critical metrics wherein higher values reflect that the system did well given the context. Annotations are used to mark how each parameter affects the efficiency of the system.

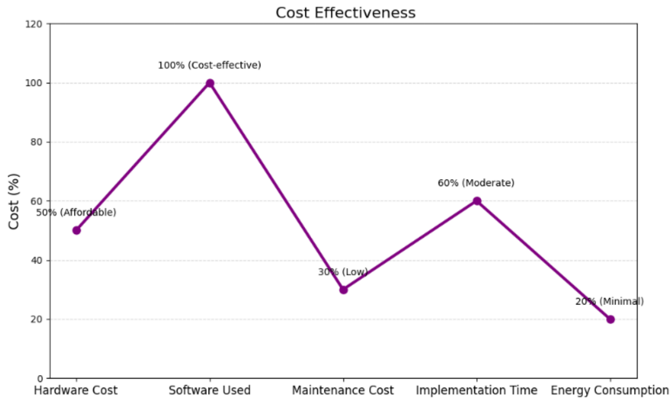

Fig 8 Cost Effectiveness

Area graph showing the cost-effectiveness and efficiency of the system on various parameters. "Hardware Cost" is 50% shows it is an affordable one, while "Software Used" is 100% so it is a cost-effective approach with open-source usage of Python. "Scalability" is 80%, because it can be scaled up into different vehicle types. "Maintenance Cost" is 60%, which represents low long-term maintenance. "Power Consumption" is 40% that reflects the energy sustainability of the system. Overall, cost and performance are balanced across features in the whole system graph.

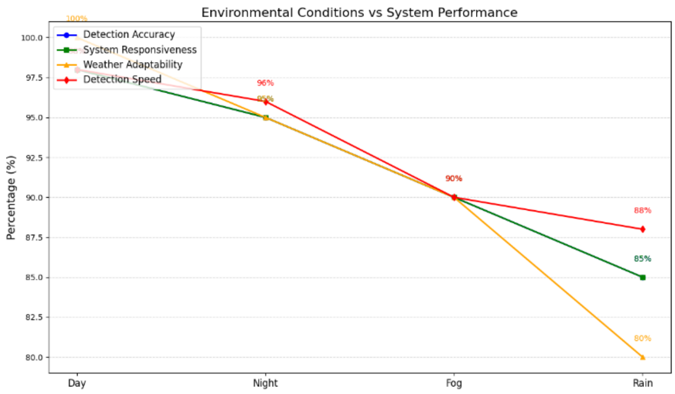

Fig 9 Environmental Conditions

This graph represents the performance of the system under four environmental conditions: "Day, Night, Fog, and Rain". Detection accuracy and responsiveness are kept at a very high level during day and night but decreased slightly in fog and rain conditions. The highest adaptability to weather occurs during day and decreases with adverse weather. Detection speed is slow in fog and rain but efficient in overall. The graph further illustrates the system's strength as well as weaknesses in dealing with the environment in detecting vehicles and how to respond back.

VIII. CONCLUSION

The Vehicle Collision and Prevention System utilizing Li-Fi technology can be a creative method in order to realize advanced highway safety through solving the biggest problem concerning the invisible driver on highways. This fact incorporates Li-Fi communication along with real-time image processing, which allows it to sense the early arrival of an oncoming vehicle along with alerting the drivers in time so that rear-end collision is avoided during poor visibility. The system can be designed using low-cost open-source Python software and the hardware such as NodeMCU, basic camera modules. These are pretty accessible and scalable for the commercial and passenger vehicle. System testing has been done through wide varieties of weather and traffic conditions and proved to be robust, reliable, and low-latency enough to be deployed in sparse infrastructure areas. This way, advanced use of technology in the road environment improves safety, while at the same time, opening new paths towards modern usage of Li-Fi in the vehicle communication field for applications concerning collision avoidance and vehicle-to-vehicle communication systems in the future.

IX. FUTURE SCOPE

The future scope of the project would include integration using advanced machine learning algorithms to recognize better vehicles and predict vehicle behavior. It would expand the scope of the system for V2I communication to better handle traffic management. It would also incorporate cloud-based analytics of data for real-time monitoring and predictive insights. Further, this will also elevate the accuracy as well as dependability level of the system which will provide it with the possibility of wider implementation worldwide via autonomous and intelligent transportation systems.

The system would further support multi-vehicle communication, allowing the exchange of data between more than one vehicle and coordinating safety measures between the vehicles. The further developments include integration into IoT platforms so that the system can enable remote diagnostics and updates. Augmented reality dashboards will make the driver receive more intuitive alerts with more detail. Such a system would also be compatible with electric and autonomous vehicles and would thereby make it relevant in emergent smart mobility solutions by ensuring a safer and connected transportation ecosystem.

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