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Research paper

Intelligent Development and Emulation of Vehicle Braking System Using Ultrasonic Sensor

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Abstract

Nowadays, automotive safety remains a vital concern, particularly in preventing collisions. To address the limitations of traditional braking systems, we propose a novel Smart Braking System (SBS) that controls ultrasonic sensors and an Arduino-based Micro Controller Unit (MCU). This system autonomously detects obstacles and initiates braking responses without driver intervention, offering an affordable and reliable safety solution. The ultrasonic sensor continuously measures the distance between the moving vehicle and various obstacles, including materials such as plastic, wood, paper, or cloth, and relays this data to the MCU. Based on the pre-programmed logic within the Node MCU, the system automatically adjusts the vehicle's speed or triggers emergency braking when an object falls within a critical safety range. Designed for high efficiency and reliability, the SBS dynamically responds to real-time distance measurements, reducing the risks and severity of accidents. By executing emergency braking commands precisely when needed, the system mitigates collision damage more effectively than existing automatic collision-avoidance solutions. During prototype testing, the proposed system demonstrated superior performance, revealing and addressing vulnerabilities present in other methods. Overall, the SBS provides a practical, cost-effective, and highly responsive solution to enhance vehicle safety, particularly in scenarios that require rapid obstacle detection and emergency response.

Keywords: *Smart Braking System (SBS); Arduino IDE; DC Motor; Micro Controller Unit (MCU); Electronic Control Unit (ECU); and Ultrasonic Sensor.*

1. Introduction

The braking system is a vital safety component in motor vehicles, typically activated when the driver applies pressure to the brake pedal. For effective operation, the pedal must be engaged promptly and with adequate force to achieve a controlled deceleration, thereby minimizing the risk of accidents. However, drivers often fail to recognize hazardous conditions in time, resulting in delayed braking responses that can lead to severe collisions. To overcome these limitations, the implementation of SBS is essential in vehicles, as it enhances timely response, reduces accident severity, and improves overall road safety.

1.1 Smart braking technology

The proposed system aims to develop an SBS capable of detecting both fixed and moving objects, obstacles, and pedestrians in front of a vehicle. Based on the measured distance to the obstacle, the system regulates the vehicle's speed and provides visual or auditory alerts to the driver to prevent potential collisions. If the driver fails to apply the brake within a critical threshold distance, the system automatically initiates braking through an automated control unit to bring the vehicle to a stop. The control unit is implemented using an Arduino IDE (Integrated Development Environment) with programmed logic and an ultrasonic sensor. The ultrasonic sensor continuously measures the distance between the moving vehicle and any obstacle, transmitting the data to the control unit for real-time processing.
The operation of the SBS can be divided into three phases:

1) Detection Phase: The ultrasonic sensor identifies an obstacle and transmits the information to the control unit, which then issues a warning to the driver to reduce vehicle speed.
2) Decision Phase: If the driver fails to respond within the allowable reaction time or distance threshold, the system prepares to intervene.
3) Automatic Braking Phase: The control unit activates the braking mechanism, reducing the vehicle's speed from its current level to zero, thereby preventing or minimizing the impact of a collision.

This phased approach ensures that the driver is allowed to react first, while the automated system serves as a fail-safe mechanism to enhance road safety.

2. Related Work

Numerous researchers have contributed to the development of advanced safety mechanisms within automotive systems through the integration of sensors, the formulation of control algorithms, and the implementation of intelligent braking technologies. Li (2010) proposed an automatic obstacle detection and braking system that integrates regenerative braking with modern control mechanisms. The system employs an Arduino microcontroller and a sonar sensor to execute emergency braking when required. The pre-programmed control logic adjusts the vehicle's speed, increasing or decreasing it, based on the measured distance between the vehicle and the detected obstacle. Similarly, Yuan-Lin Chen et al. (2011) developed a novel algorithm for calculating safety braking distance and Time-To-Collision (TTC) to enhance accident prevention in highway driving scenarios. Their forward collision warning system considered multiple parameters, including vehicle speed, distance to the obstacle, road slope, and surface conditions. When the vehicle approaches closer than a predefined minimum safe distance, the automated system sends a warning signal to the control unit, driver intervention, or automated braking. In Basjaruddin et al.(2016), an Advanced Driver Assistance System (ADAS) was developed using a fuzzy logic-based Active Lane Keeping Assist (ALKA) algorithm to reduce accidents caused by unintentional lane departures due to driver inattention. The algorithm considered three speed parameters: low, medium, and high. It dynamically adapts lane correction and minimizes the risk of accidents. In Hartman et al. (2017), an Anti-lock Braking System (ABS) was proposed for estimating vehicle speed through cycle period analysis. A self-adaptive algorithm has been incorporated in several research works. Researchers have contributed to the development of advanced safety mechanisms in automotive systems via sensor integration, control algorithms, and intelligent braking technologies. They compare the estimated cycle with a reference cycle, thereby ensuring accurate speed detection and providing reliable data to the Automatic Braking System for safe operation.

Chinazaekpere (2016) proposed minimizing road accidents in electric vehicles using a sensor-based multilevel redundancy approach. Their framework integrated four core functions: fault detection, system monitoring, collision control through redundancy, and a hot standby control unit, thus enhancing system reliability and safety. Additionally, an Advanced Emergency Braking System (AEBS) was designed in Thorat et al.(2016) using a sensor-based relay mechanism, which automatically alerts the driver during perilous situations and supports timely braking interventions. Ultrasonic sensors have been widely applied in obstacle detection and crash avoidance systems. In Aliyu et al. (2017), a microcontroller-based ultrasonic detection system was developed to measure distance for crash avoidance. Simulated results indicate a response time of 0.086 seconds and an error margin of 12.8% compared to the actual obstacle distance. In Kavatkar et al. (2017), an intelligent mechanical system generated ultrasonic waves to detect obstacles at a predefined distance, with the microcontroller controlling vehicle braking accordingly. Christofer et al. (2017) investigate the working principle of ultrasonic sensors in detecting obstacles composed of wood, paper, cloth, plastic, and metal. The results indicated material-dependent variations in detection performance, with a low negative correlation across the different materials. In Symum et al. (2018), an automatic accident avoidance system was designed using sonar sensors and tested with two vehicles (A and B). Three distance thresholds were established: d1 = 40 cm (automatic braking), d2 = 50 cm (vehicle slowdown), and d3 = 60 cm (driver warning). This distance-based control improved collision prevention, particularly at road junctions. Equally, the authors in Ashish et al.(2017) presented the design and fabrication of an ultrasonic-based automated braking system, where ultrasonic signals measured distance to obstacles, and the control unit automatically reduced speed without requiring manual driver input.

Extending this approach, Sanjana et al. (2018) developed a forward and backward collision avoidance system using an ATMEGA32 microcontroller. The system measured both front and rear distances, thereby protecting the vehicle from potential collisions in multiple directions. Furthermore, Abraham et al. (2018) discussed hybrid combinations of sensing technologies to enhance safety in intelligent automotive applications, highlighting the role of multi-sensor integration for accident reduction. The integration of the Internet of Things (IoT) with automotive sensing has further enhanced intelligent braking and collision-avoidance systems. Bajaj et al. (2018) presented a review on IoT applications in the smart automotive sector, emphasizing its role in vehicle-to-vehicle (V2V) communication, predictive maintenance, traffic monitoring, and safety systems. IoT enables real-time data exchange between vehicles and infrastructure, thereby supporting safer and more efficient driving. Building on this, Vinay Sai et al. (2019) proposed a novel ultrasonic obstacle detection system integrated with IoT platforms. Their system transmitted obstacle detection data via IoT networks for real-time monitoring and driver assistance. The study demonstrated how combining low-cost ultrasonic sensors with IoT connectivity can improve accident prevention, particularly in urban environments. Collectively, these studies highlight significant progress in ADAS technologies, ultrasonic sensing, automated braking, and IoT-enabled architectures. The works underline the importance of real-time detection, redundancy, adaptive algorithms, and sensor integration in creating reliable safety mechanisms for the next generation of connected and autonomous vehicles.

2.1. Ultrasonic sensor-based braking systems

Aravinth et al. (2018) recommended a prototype ultrasonic braking system that aims to prevent collisions in urban driving environments. Their work demonstrated how smart sensing could provide real-time obstacle detection, thereby assisting in safe braking operations. The study highlighted the system's potential as a low-cost solution for accident reduction in city traffic. Mohd. Sabir Khan et al. (2021) developed an electromagnetic braking system integrated with ultrasonic sensors. The system utilized a microcontroller to process distance measurements from the sensors and automatically trigger braking when critical thresholds were reached. Their approach emphasized improved reaction time, reliability, and the use of electromagnetic actuation for smoother braking compared to conventional systems. Muhammad Arsalan et al. (2021) designed an Arduino-controlled ultrasonic braking system to address driver fatigue and accident risks in congested traffic conditions. Their findings reported a stopping time of 0.6 s and a critical stopping distance of 1 m, underlining the effectiveness of ultrasonic sensors in improving safety during low-speed, high-density traffic scenarios. Together, these studies establish ultrasonic sensor-based braking systems as promising alternatives to conventional braking mechanisms. They provide evidence that such systems can significantly enhance safety, particularly in urban and congested driving environments, by offering rapid response and reliable distance estimation.

2.2. Effects of weather, humidity, and fog

The reliability of perception systems in autonomous and semi-autonomous vehicles is highly dependent on sensor performance under varying environmental conditions. Recent studies have specifically focused on the challenges posed by adverse weather and their implications for vehicle safety. Zhang et al. (2023) presented a comprehensive survey on perception and sensing in adverse weather conditions, emphasizing how fog, rain, and snow degrade the accuracy of automotive sensors. Their work underlined the importance of sensor fusion and resilience strategies, arguing that no single sensor can ensure robust perception in all environmental scenarios. Building on this, Sezgin et al. (2023) conducted an evaluation of radar, LiDAR, and camera sensors under rain and fog conditions. Their analysis demonstrated significant degradation in detection range and accuracy, particularly for LiDAR and vision-based systems. The study proposed continuous monitoring of sensor performance and adaptive safety measures as critical strategies for maintaining reliability in real-world autonomous driving applications. The MDPI Review by Vargas et al.(2021) provides a detailed analysis of ultrasonic sensor vulnerabilities under environmental influences like humidity, air composition, and fog. It revealed that ultrasonic frequencies around 60 kHz experience maximum attenuation at 60% relative humidity, posing critical limitations for ultrasonic systems in certain climates.
Further experimental evidence was provided by the MDPI Applied Physics study Jokela et al. (2019), which developed rain and fog simulators to evaluate the performance of radar, LiDAR, and cameras. The experiments confirmed that cameras and LiDAR degrade significantly under reduced visibility, whereas radar demonstrated higher resilience, providing benchmarks for sensor validation under controlled precipitation conditions. Most recently, Marek Hustava (2023) traced the evolution of automotive ultrasonic sensors from basic park assist applications to their role in autonomous driving. The article highlighted hydrophobic coatings and vibratory cleaning mechanisms. These innovations address a critical limitation identified in prior studies, the susceptibility of ultrasonic sensors to environmental interference. While sensors remain central to autonomous navigation, their performance is strongly influenced by environmental conditions. Current research highlights the importance of hybrid sensing, redundancy, and self-maintenance technologies (e.g., cleaning mechanisms or resilience-enhancing designs) to ensure reliable operation in real-world settings.

2.3. Recent academic and industry scores

Recent advances in automotive sensing have positioned ultrasonic sensors as critical components not only for low-speed applications but also for future autonomous driving systems. The author Wei (2024) provided a comprehensive review of ultrasonic sensor applications, covering their deployment in parking assistance, blind-spot detection, object recognition, and autonomous braking. The review highlighted the advantages of ultrasonic sensors, including their low cost, simplicity, and effectiveness in short-range detection, while also pointing out challenges such as environmental susceptibility and limited range compared to LiDAR or radar. In parallel, Sezgin et al. (2024) investigated the performance degradation of radar, LiDAR, and cameras in adverse weather, with a particular focus on rain and fog. Their results showed that LiDAR and camera systems suffer from substantial detection losses, while radar maintains greater robustness. Although ultrasonic sensors were not the primary focus, the study's findings indirectly reinforced the need for multi-sensor fusion, where ultrasonic sensing can play a complementary role in providing redundancy under compromised conditions. This survey deliberates that the existing system, which is either complex and costly or simple but uncertified and fragile, the proposed SBS is low-cost, simple, validated under adverse conditions, and aligned with ISO 26262, positioning it as both technically feasible and industry-ready. The following consolidated comparison Table 1 summarizes prior studies and highlights the specific gaps that the proposed Smart Braking System (SBS) addresses, providing a clear rationale for its design and contributions.

Table 1: Comparison of Prior Works and Proposed SBS

Category	Referred articles	Strengths	Limitations	The proposed (SBS) system addresses the gap
ABS & Regenerative Braking	Li [1], Chen & Lee [2], Hartman [4]	Stability, energy recovery, and precise braking distance calculations	Complex electronics, high cost, limited to premium vehicles	Uses low-cost ultrasonic sensing and lightweight control algorithms instead of expensive regenerative modules
Ultrasonic Sensor–Based Systems	Aliyu et al. [7], Yalung & Adolfo [9], Rezwan et al. [10], Annamalai et al. [16], Khan et al. [17], Arsalan & Akbar [18]	Simple, affordable, validated in prototypes	Limited range, sensitive to fog or rain, no ISO 26262 alignment	Adds emulation under adverse weather and also integrates ISO 26262 safety compliance
Intelligent / IoT-Based Approaches	Basjaruddin et al. [3], Thorat et al. [6], Sanjana et al. [12], Abraham et al. [13], Bajaj et al. [14], Vinay Sai et al. [15]	Advanced decision-making, IoT connectivity, driver monitoring	High cost, complex hardware or software, impractical for low-cost vehicles	Focuses on simplicity and affordability, avoiding unnecessary computational overhead
Sensor Reliability Under Adverse Weather	Zhang et al. [19], Sezgin et al. [20, 25], MDPI [21, 22], Hustava [23], Wei [24]	Detailed analysis of rain, fog, or humidity effects on sensors	Diagnostic only; limited real-world solutions	Emulates adverse conditions to test ultrasonic robustness in braking scenarios
Safety Standards & Compliance	Chinazaekpere & Shafik [5], Kavatkar et al. [8], Sanjana et al. [12], Abraham et al. [13]	Intelligent safety systems	No systematic compliance with ISO 26262	Explicitly designed to meet ISO 26262 functional safety requirements

3. Proposed Work

Existing research on ultrasonic braking systems demonstrates promising results in controlled environments, particularly for short-range and low-speed applications. However, these systems remain highly susceptible to environmental interference such as rain, fog, and humidity, which can significantly degrade detection accuracy. Most current designs rely solely on ultrasonic sensing without sensor fusion, limiting their reliability in diverse road conditions and at higher vehicle speeds. Furthermore, real-world validations are minimal, with most work confined to simulations or small-scale prototypes. Finally, predictive safety measures, such as integrating driver state monitoring with ultrasonic-based braking, remain largely unexplored. The objective of this research is to design, develop, and emulate a Smart Braking System (SBS) that overcomes the limitations of existing braking solutions. Unlike regenerative and intelligent braking systems, which are cost-intensive, and ultrasonic prototypes, which lack robustness and certification, the proposed SBS aims to:

- Deliver affordable and simple braking automation using ultrasonic sensing and lightweight control.

- Ensure robust operation under adverse weather conditions through emulation-based validation; and
- Achieve compliance with ISO 26262 functional safety standards, bridging the gap between academic prototypes and industry-ready automotive solutions.

This objective positions the SBS as a scalable, reliable, and safety-certified solution for enhancing vehicle safety in real-world driving environments.

The proposed efficient automobile braking system, illustrated in Figure 1, incorporates both transmitter and receiver functionalities. The system operates across three primary stages: the ultrasonic sensor, the NodeMCU, and the DC motor for actuation. Key factors influencing the system's operation, along with the performance characteristics of the ultrasonic sensor, are shown in Table 2.

Table 2: Ultrasonic Sensor Performance with Parameter Factor

Factor	Ultrasonic Sensor Performance
Speed	At higher speeds, faster data processing becomes essential, as limited as discussed below. The detection range of ultrasonic sensors significantly impacts system effectiveness.
Obstacle Type	Ultrasonic sensors perform best when detecting large, smooth, and perpendicular surfaces, but their effectiveness diminishes with angled, irregular, or smaller objects.
Temperature	In warmer air, the speed of sound increases, requiring compensation to maintain accurate distance measurements.
Humidity/Fog	Although some signal attenuation occurs, the overall impact on ultrasonic sensors is minimal compared to optical sensors such as cameras and LiDAR.
Rain	While signal propagation is largely unaffected by rain, ultrasonic sensors can be physically obstructed by water accumulation on their surface.
Contrast with LiDAR/Camera	Ultrasonic sensors demonstrate greater resilience to adverse weather conditions, but their functionality is limited to short-range detection.

3.1. Working principle of the braking system

Consider a scenario where a vehicle is traveling at a constant speed of 80 km/h, and the driver, in the worst case, has fallen asleep. In such a situation, the proposed automatic braking system functions as follows:

1) Ultrasonic Sensor: The sensor detects any object present in front of the moving vehicle and transmits the information in the form of an electrical signal, derived from reflected sound waves, to the NodeMCU controller.
2) Node Micro Controller Unit (NodeMCU): The NodeMCU shown in Figure 3 processes the received input by converting the electrical signal into a digital signal through its inbuilt Analog-to-Digital Converter (ADC). The processed data is then analyzed to determine the proximity of the obstacle.
3) Relay and DC Motor Control: A ladder logic–based relay system actuates both the alarm mechanism and the motor valve. If a potential collision is detected, the relay triggers the braking system by switching the DC motor to the valve-off condition, thereby automatically applying the brakes while simultaneously alerting the driver.

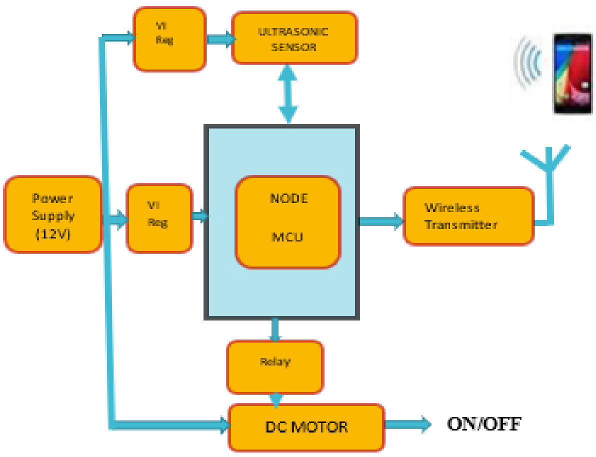

Fig. 1: Block Diagrams of an Efficient Automobile Braking System.

Finally, the system receives serial data, which is transmitted wirelessly via the antenna connected to the NodeMCU. The output of the automatic braking system in the prototype model can be monitored remotely on a mobile device or laptop through the wireless transmitter and receiver. The following hardware components are used to implement the proposed system:

1) Ultrasonic Transmitter/ Receiver
2) NodeMCU
3) DC Motor

3.1.1. Ultrasonic transmitter/receiver

Fig. 2: HC-SR04 Ultrasonic Sensor.

Figure 2 shows the ultrasonic HC-SR04 ranging model. It provides a non-contact distance measurement function from 2cm to 400cm. It contains ultrasonic transmitters, a control unit, and a receiver. There are three important steps for the working principle of an ultrasonic sensor.

1) First, reflect the input signal from the object and return the high-level output signal to an ultrasonic receiver ranging from 15 µs
2) Second, this sensor module's ability to send 940 KHz, it to automatically detect whether a backward pulse signal is present. Then, the ultrasonic detector implemented will detect the ultrasonic (us) signal.
3) Finally, if the signal is sent to the node MCU for analysis, the distance from the object to the motor vehicle is calculated.

Fig. 3: NODE MCU Chip.

3.1.2. NodeMCU

Figures 3 and 4 show the Node MCU chip and the connection of NodeMCU with the following specifications.

- Integrated TCP/IP protocol stack.
- Processor: Tensilica L106 32-bit.
- Processor speed: 80~160MHz.
- 802.11 support: b/g/n.
- Maximum concurrent TCP connections: 5.

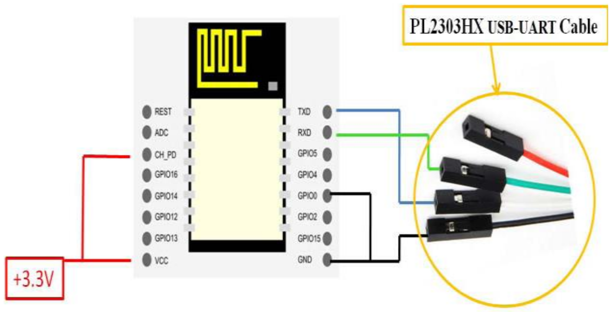

Fig. 4: PIN Assignment of Node MCU with Connection.

3.1.3. Relay and D.C motor

DC motors are widely used in robotics for their simplicity and versatility. Common types include permanent magnet iron-core and permanent magnet ironless rotor motors. In the proposed system, the NodeMCU sends control signals to a relay, which regulates the motor speed by switching the DC motor ON or OFF.

3.2. Programming logic of braking system

3.2.1. Arduino IDE

The Arduino IDE (Integrated Development Environment) is the software used to program the Arduino board. It is available as open source on the internet.

3.2.2. Bootloader

The bootloader is software preloaded onto the ATmega328 microcontroller to facilitate programming from within the Arduino IDE. It is activated when the board is powered on or reset. Upon receiving a signal from the IDE to upload a new program, the bootloader writes the program into the microcontroller's memory via serial communication.

3.2.3. Programming

The programming code in the Arduino IDE is based on the C programming language. It includes two essential functions: setup () and loop ().

The setup () function is executed once at the start of power-up or after a reset. It is used for one-time initializations.

The loop () function contains the main application code and repeats continuously until the power supply is turned off.

Both functions are mandatory, even if no specific operations are required in one of them.

3.2.4. Analog- to- digital converter

The built-in ADC present in the Arduino board has a resolution of 10 bits. Any analog voltage in the range of 0-5 volts is converted to an equivalent digital value of 0-1023. The resolution is hence obtained between readings of 5 volts / 1024 units per unit. The conversion time is about 100 microseconds (0.0001 s) to read an analog input; hence, the maximum reading rate is about 10,000 times a second.

4. Result and Performance

As a result of this paper, the intelligent vehicle braking system developed using ultrasonic sensors has been successfully implemented, with each component functioning as intended. The system is designed to detect obstacles and automatically initiate braking based on a predetermined safety distance. In this prototype model, shown in Figures 8 and 9, the ultrasonic sensor demonstrates a reliable ranging accuracy between 2 cm and 400 cm, operating effectively within this range to ensure prompt responses to nearby objects. The vehicle halts automatically when an obstacle is detected within a critical threshold of 8 cm, with braking simulated through the controlled on/off operation of the vehicle's motor.

4.1. Analyzing the proposed system performance

To evaluate system performance, tests were conducted under varying speeds. Results indicate that at higher vehicle speeds, the time available for obstacle detection and response becomes significantly shorter, necessitating faster sensor processing and actuation. Despite the limited range of ultrasonic sensors, the system reliably initiates braking within the prescribed threshold when operating at moderate speeds. However, at high speeds, the risk of delayed response increases due to the sensor's inherent range limitations. The type of obstacle also influences detection accuracy. The system performs optimally with large, smooth, and perpendicular objects that reflect ultrasonic waves effectively. In contrast, detection performance declines when encountering small, angled, or irregularly shaped obstacles, as these surfaces tend to scatter or absorb the sound waves, reducing echo strength.
Environmental conditions play a crucial role in the system's reliability. Ultrasonic sensors are relatively more resilient to adverse weather compared to optical sensors. Rain, fog, and humidity have minimal impact on sound wave propagation; however, water droplets can physically block the sensor's surface, temporarily disabling its functionality. Temperature fluctuations also affect sensor accuracy, as warmer air increases the speed of sound, leading to minor errors in distance estimation unless compensated through calibration. Despite these factors, the system demonstrates consistent performance under standard environmental conditions, making it a viable solution for short-range obstacle detection and automated braking in real-world scenarios. It has been shown in Figures 5 and 6.

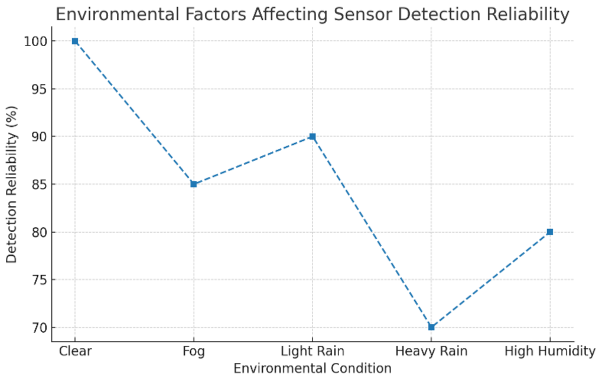

Fig. 5: Environmental Factors Affecting Sensor Detection Reliability.

The environmental conditions vs. the detection reliability graph demonstrates that adverse weather conditions, particularly heavy rain and fog, can significantly reduce the performance of ultrasonic sensors used in intelligent vehicle braking systems. While ultrasonic technology is generally more weather-resistant than optical systems (like cameras and LiDAR), certain environmental factors still impact accuracy and reliability. ultrasonic sensors detect objects by sending out high-frequency sound waves and measuring the echo. Environmental factors can interfere with this process in several ways, as shown in Table 3.

Table 3: Environmental Factors Interface with Several Ways

Condition	Detection Reliability (%)	Impact Mechanism
Clear Weather	100%	Optimal performance with no interference
Light Fog	85%	Slight sound wave scattering, minimal impact
Light Rain	90%	Minor reflection/absorption by droplets
Heavy Rain	70%	Water can block the sensor, scatter waves, or cause signal loss
High Humidity	80%	Alters sound wave propagation speed and reduces echo strength

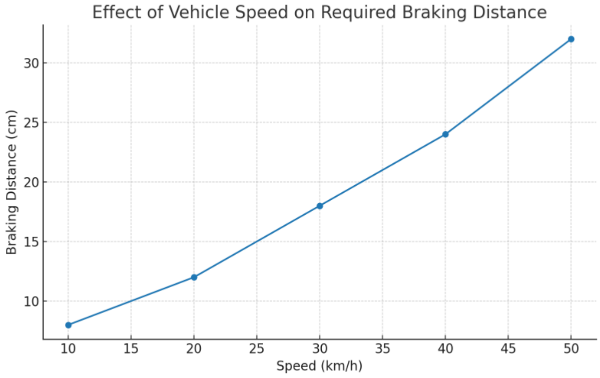

Fig. 6: Effect of Vehicle Speed on Required Braking Distance.

The speed vs braking distance graph denotes a clear upward trend, indicating that as the speed of the vehicle increases, the braking distance also increases. This relationship is critical for designing intelligent braking systems, especially those relying on ultrasonic sensors with a limited range, as shown in Table 4.

Table 4: Example from the Graph (Hypothetical Data Used)

Speed (km/h)	Braking Distance (cm)
10	8
20	12
30	18
40	24
50	32

At 10 km/h, the car can stop safely within 8 cm. At 50 km/h, it needs 32 cm to stop 4x (four times longer than at 10 km/h) more distance, which may exceed the sensor's reliable range (~400 cm depending on the prototype).

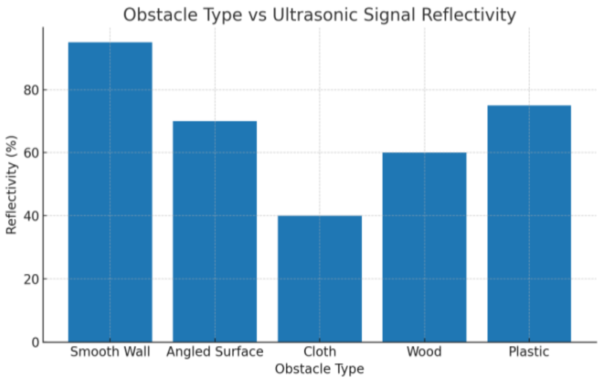

Fig. 7: Obstacle Type vs. Ultrasonic Signal Reflectivity.

The obstacle type vs signal reflectivity graph shown in Figure 7 illustrates that smooth, large, and perpendicular surfaces reflect ultrasonic waves much more effectively than small, irregular, or angled ones. Table 5 shows that the difference in reflectivity directly influences the detection accuracy and reliability of ultrasonic-based vehicle braking systems.

Table 5: Reflectivity Based on Obstacle Types (Hypothetical Values from Graph)

Obstacle Type	Reflectivity (%)	Detection Reliability
Smooth Wall (metal/glass)	95%	Very High
Angled Surface	70%	Moderate (may scatter echoes)
Cloth (soft surface)	40%	Low (absorbs sound)
Wood (textured, soft)	60%	Medium
Plastic (flat, semi-hard)	75%	High

The top view of the proposed Smart Braking System (SBS) (Figure 8) demonstrates the layout of key components, including the front-facing ultrasonic sensors, NodeMCU controller, relay module, and DC motor connections. It highlights the sensor coverage area and signal flow, aiding in optimal component placement and efficient integration. The front view (Figure 9) displays the frontal arrangement of the system, focusing on ultrasonic sensor orientation and the actuation pathway from NodeMCU to relay, and to the motor. This view helps visualize line-of-sight detection, sensor alignment, and obstacle detection efficiency, ensuring accurate braking response and proper system integration with the vehicle.

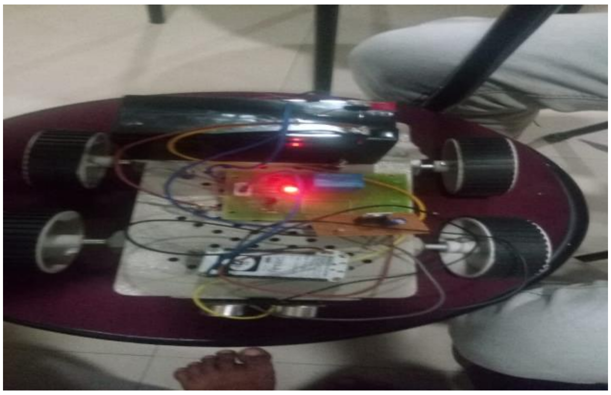

Fig. 8: Top View of Proposed System Model.

Fig. 9: Front View of Proposed System Model.

5. Conclusion and Future Scope

This proposed Smart Braking System (SBS) is designed to enhance forward collision avoidance by autonomously reducing vehicle speed when obstacles are detected, even if the driver does not apply the brakes. By utilizing ultrasonic sensors and a microcontroller, such as the ESP8266 NodeMCU, the system detects obstacles within a predefined short-range threshold (e.g., 80 cm) and initiates braking automatically. The SBS demonstrates the feasibility of a low-cost, simple, and effective automatic braking prototype, offering potential improvements in vehicle safety and driver assistance. However, several limitations remain. The reliance on ultrasonic sensors constrains detection range and performance in adverse weather conditions (fog, heavy rain, snow). The system's fixed braking threshold may not adapt optimally to varying speeds and road conditions, and its single-sensor architecture limits redundancy and fault tolerance, important considerations per ISO 26262 functional safety standards. Additionally, full integration into commercial vehicles requires further validation, sensor fusion, and regulatory compliance.

Future work will focus on overcoming these limitations by incorporating multi-sensor fusion (radar, LiDAR, cameras), developing adaptive braking thresholds for dynamic driving scenarios, and implementing redundancy and fail-safe mechanisms. Moreover, hardware-in-the-loop (HIL) testing and real-world validation will be conducted to ensure reliability under diverse environmental conditions. Ultimately, these enhancements aim to evolve the SBS from a low-cost prototype into a robust, adaptive, and safety-certified braking system, suitable for integration into advanced driver assistance systems and next-generation intelligent vehicles.

Acknowledgments

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