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Design and Implementation of Smart Car Preventive Collision by Automatic Brake System

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Abstract: The proposed smart automatic braking system is designed to mitigate accidents caused by driver negligence, such as delayed response, speeding, distracted driving, and other human errors. The system continuously monitored vehicle speed using a Hall sensor and detected obstacle distance using an ultrasonic sensor. The inputs were fed to an Arduino microcontroller, which estimated collision risk and determined the braking action. An automated braking system was built in to take over the brakes if the driver did not brake within the allotted time, reducing the potential for collision. The system worked in tandem with the driver, allowing him to drive normally while enabling the system to take over in an emergency braking scenario. In operation, the system detected an obstacle within a set safety distance, visually warned the driver and slowly reduced speed. When the distance to the obstacle was critical, an audible alarm sounded, and the brakes applied automatically, stopping the vehicle safely. This sequence of detection, warning and autonomous braking is an intelligent, enhanced vehicle safety feature that reduces the risk of serious collisions and improves driving reliability. Additionally, the system's size and cost were reduced, making it feasible to implement in passenger vehicles, especially in urban traffic situations where timely obstacle detection is crucial.

Keywords: Driver Negligence; Automated Braking System; Ultrasonic Sensor; Collision Risk; Arduino Microcontroller; Distracted Driving; Hall Sensor; Human Errors; Automatic Emergency Brake (AEB).

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1. Introduction

An automatic braking system is an important part of automotive safety technology. It is an advanced system designed to prevent a collision or reduce the speed of a moving vehicle before a collision with another vehicle, a pedestrian or an obstacle or obstruction. Driving is a compulsory activity for most people who use their car to move from one place to another [1]. The number of vehicles is increasing day by day. Nowadays, Accidents occur everywhere and cause severe damage, serious injury and even death. These accidents are mostly caused by human error, such as delayed braking, fatigue, or misjudging [2]. This paper proposes an automatic braking system to prevent vehicle collisions, a promising technology for mitigating the impact of human error on road safety. Developing this system can address drivers who fail to brake manually, as vehicles can stop automatically when obstacles are detected. Previous research has shown that automatic braking and embedded control systems can prevent collisions, but key issues remain unaddressed. Early research efforts by Zhou et al. [3] focused on a simple automated braking system for obstacle avoidance. Still, they lacked an integrated system that could sense obstacles, make decisions and respond in real time across different driving scenarios. Likewise, the Arduino implementations in Zhang et al. [6] and Menon et al. [7] focused on low-cost hardware development and proof-of-concept validation, with minimal consideration for sensor fusion, optimized responses, braking intelligence, and scalability to real-world road scenarios.

The collision avoidance system proposed by Anonymous employed RFID technology, which relied heavily on the presence of identification zones, limiting its use to fixed installations and making it less effective in more dynamic traffic situations with unpredictable obstacles [8]. These restrictions indicate a significant research gap in developing a unified braking architecture that can continuously analyse the surrounding environment, fuse multiple sensor data, predict collision risk and take braking actions promptly with greater reliability and adaptability [4]. The system proposed in this paper addresses this gap by combining intelligent obstacle detection and real-time distance estimation with dynamic decision-making and autonomous brake actuation on a compact embedded platform, without relying on costly vehicular infrastructure [5]. Unlike traditional automatic braking (AEB) systems that are usually triggered when the imminent collision threshold is reached, the proposed system continuously assesses the environment. It progressively evaluates risk to intervene earlier [9]. In addition, the developed system differs from conventional Advanced Driver Assistance Systems (ADAS), which typically integrate several driver assistance functions and involve complicated hardware setups, as it focuses on efficient autonomous collision prevention with a cost-efficient and modular, easily deployable architecture, applicable to a larger vehicle class and ensuring reliable braking thresholds under varying operational conditions [10]. This study describes a system that controls the braking system for safety using ultrasonic ranging [11]. It operates on an ultrasonic wave transmitted by a transmitter [12]. The wave reflects off an obstacle and is then received by a receiver [13].

1.1. Objective

To design and implement a smart car preventive collision system with an automatic brake system (Case study: Kigali city – Rwanda).

1.2. Justification of Study

The increasing number of road accidents in Kigali, Rwanda, necessitates innovative solutions to improve road safety and reduce the associated human and economic costs. This study is justified by the urgent need to address the high accident rate, particularly those caused by driver negligence such as speeding and distracted driving, which contribute significantly to fatalities and injuries. Developing a smart car preventive collision system with automatic braking offers a promising way to reduce these accidents by adding an extra layer of safety. This technology can assist drivers in critical situations, potentially preventing or reducing collision severity and ultimately contributing to a safer transportation environment in Kigali. Furthermore, this research aligns with Rwanda's broader development goals, including Vision 2050, which emphasizes technological advancement and sustainable development, as improved road safety contributes to a more productive and healthy society [14].

1.3. Scope of Study

This study focuses on designing and potentially implementing a smart car preventive collision system with an automatic braking mechanism in Kigali City, Rwanda. It encompasses the development of a system that integrates sensor technology (Hall and ultrasonic), an Arduino microcontroller, and a braking motor to detect potential collisions and automatically engage the brakes when necessary.

The scope includes technical design, consideration of environmental and traffic conditions in Kigali, and an analysis of the system's potential impact on road safety. While the study explores the feasibility and potential benefits of such a system, it may not include a full-scale physical implementation or extensive real-world testing. Furthermore, the study focuses on technical aspects and does not delve into Rwanda's policy or regulatory frameworks for vehicle safety standards [15].

1.4. State of the Art

The current state of smart car preventive collision systems is rapidly evolving, with advancements in sensor technologies, control algorithms, and vehicle integration. Modern vehicles increasingly feature advanced driver-assistance systems (ADAS), including adaptive cruise control, lane departure warning, and automatic emergency braking. These systems use a combination of radar, lidar, cameras, and ultrasonic sensors to perceive the vehicle's surroundings and issue warnings or take action to prevent collisions. Research is ongoing to improve the accuracy and reliability of these systems, particularly in challenging environments and with diverse traffic participants. Furthermore, there's a growing focus on developing more sophisticated control algorithms that can better anticipate and respond to complex driving situations. Integrating these systems with other smart city initiatives, such as intelligent traffic management, also holds significant potential to enhance overall road safety. However, challenges remain in ensuring cost-effectiveness, particularly for widespread adoption in developing countries, and addressing human factors related to driver acceptance and interaction with these technologies [16].

2. Materials and Methods

2.1. Requirement Analysis and Materials

Designing and implementing a smart car preventive collision system using an automatic brake system (Case study: Kigali city, Rwanda) requires a comprehensive analysis of technical and practical requirements to ensure the system meets the specific needs of target users. Designing and implementing a smart car preventive collision system with automatic braking for Kigali, Rwanda, requires a thorough analysis of both technical and practical requirements. This analysis forms the foundation for selecting appropriate materials, designing the system architecture, and ensuring effectiveness in Kigali's traffic environment. This section details the requirements-gathering process and outlines key factors considered, including environmental conditions, vehicle types, driver behaviour, and cost constraints. It will also justify the selection of specific materials based on these requirements.

2.2. Technical Requirements and Material Selection

The system's technical requirements are derived from the need to detect potential collisions and accurately actuate the brakes. This involves:

- **Sensing:** Accurate and reliable detection of both vehicle speed and the distance to potential obstacles. This dictates the choice of sensors. Given Kigali's diverse weather conditions, a combination of sensors might be optimal. A Hall Effect sensor for speed measurement offers robustness against dust and grime often encountered on Kigali's roads. An ultrasonic sensor, while affected by heavy rain, offers a cost-effective way to measure short- to medium-range distances and could be supplemented by a camera system for more robust object recognition across varying lighting conditions. The materials must be durable and resistant to Kigali's environmental conditions.
- **Processing:** Real-time processing of sensor data to calculate braking distance and trigger the braking mechanism. This requires a microcontroller that can handle data input and execute the control algorithm quickly and reliably. An Arduino Mega is a strong candidate due to its processing power, cost-effectiveness, and readily available libraries. The chosen microcontroller must function reliably within the temperature range experienced in Kigali.
- **Actuation:** A reliable and responsive braking motor to engage the vehicle's brakes. The motor must be powerful enough to apply sufficient braking force and respond quickly to the microcontroller's control signals. The mechanical components interfacing with the existing braking system (e.g., linkages, cables) require durable materials such as steel or aluminium that can withstand the forces involved and resist corrosion in Kigali's climate.

2.3. Practical Requirements and Material Considerations

Beyond the technical requirements, practical considerations related to the Kigali context play a crucial role in material selection and system design:

- **Cost-Effectiveness:** The system must be affordable to ensure widespread adoption. This necessitates selecting cost-effective materials and components without sacrificing performance or reliability. Prioritise open-source hardware and readily available components where possible.
- **Maintainability:** The system must be easy to maintain and repair, considering the availability of skilled technicians and spare parts in Kigali. Modular design and readily available components are essential. Choose durable materials that resist wear and tear.
- **Power Consumption:** The system should have minimal impact on the vehicle's electrical system. Low-power components and efficient power management strategies are crucial.

- **Integration with Existing Vehicles:** The system must be compatible with a wide range of vehicle types found in Kigali, including potentially older models. This requires flexible design and adaptable interfaces.

2.4. Environmental Considerations and Material Durability

Kigali's environment presents specific challenges that must be considered in material selection:

- **Temperature:** Kigali experiences a moderate tropical climate, but temperature fluctuations can still affect electronic components. Choose materials that operate reliably within this temperature range.
- **Humidity:** High humidity can lead to corrosion and damage to electronic components. Choose materials resistant to moisture and humidity. Consider protective coatings and sealed enclosures.
- **Dust and Dirt:** Dust and dirt can accumulate on sensors and other components, affecting their performance. Choose materials resistant to dust and grime and plan for regular cleaning and maintenance.
- **Road Conditions:** Road conditions in Kigali can vary, with some roads being unpaved or poorly maintained. Materials used for mechanical components must be robust enough to withstand vibrations and shocks.

2.5. System Architecture and Component Integration

This section outlines the smart braking system's overall architecture and how the selected components integrate. It includes diagrams showing the connections between the sensors, the microcontroller, the braking motor, and the existing vehicle braking system. The mechanical interface design is explained in detail, including the materials used and the mechanisms for transmitting braking force. The software architecture is also described, outlining the control algorithms and data flow. This section emphasises the importance of a well-integrated system, ensuring that all components work together seamlessly and reliably to deliver the desired collision-prevention functionality. The design choices made during this integration process should be justified by the requirements discussed earlier, demonstrating a clear link between the analysis phase and the proposed solution.

3. Research Design

Table 1 presents the study design for the design and implementation of a smart car preventive collision system using an automatic brake system (Case study: Kigali city - Rwanda).

Table 1: Used methodology for the study

Objectives	Hypotheses	Methodology	Statistics
Design and develop a cost-effective smart braking system integrable with diverse vehicle types in Kigali.	A cost-effective smart braking system can be designed and prototyped using readily available components and open-source hardware.	System Design and Prototyping: This involves selecting appropriate sensors (Hall effect, ultrasonic, potentially camera), a microcontroller (Arduino Mega), and a braking motor.	Cost analysis of components. Metrics related to system size, weight, and power consumption.
Develop robust, reliable collision-detection and automatic-braking algorithms tailored to Kigali's traffic.	Robust and reliable collision-detection and automatic-braking algorithms can be developed using a combination of sensor data and rule-based or fuzzy-logic control.	Algorithm Development and Simulation: This stage involves developing the control algorithms for the automatic braking system. Sensor data will be processed to calculate braking distance and trigger braking.	Metrics related to algorithm accuracy (true positive/negative rates), response time, and braking performance (deceleration).
Design a culturally appropriate and user-friendly HMI that promotes driver acceptance.	A culturally appropriate and user-friendly HMI can be designed using human-centred design principles, incorporating feedback from local drivers.	HMI Design and User Feedback: This stage involves designing the system's Human-Machine Interface (HMI). The design will account for local driving habits and cultural preferences.	Metrics related to HMI usability (e.g., task completion time, error rates) and driver acceptance (e.g., survey responses, feedback).

Evaluate system performance and effectiveness through simulations and real-world trials in Kigali.	The developed smart braking system will demonstrate a statistically significant reduction in simulated and real-world collision scenarios.	System Testing and Evaluation: The integrated system will be tested in both simulated and real-world driving conditions in Kigali. Simulations will enable testing across a wide range of scenarios.	Metrics related to collision avoidance effectiveness (e.g., number of collisions prevented, reduction in impact speed) and braking performance in real-world scenarios.

The Intelligent Automatic Brake-Based Collision Prevention Architecture for Smart Vehicles, shown in Figure 1, aims to minimize collision risk through continuous sensing, intelligent decision-making, and automatic braking. Starting with the Sensors block, ultrasonic, Hall, and camera sensors gather real-time data on the surrounding environment, wheel movement, and nearby road conditions.

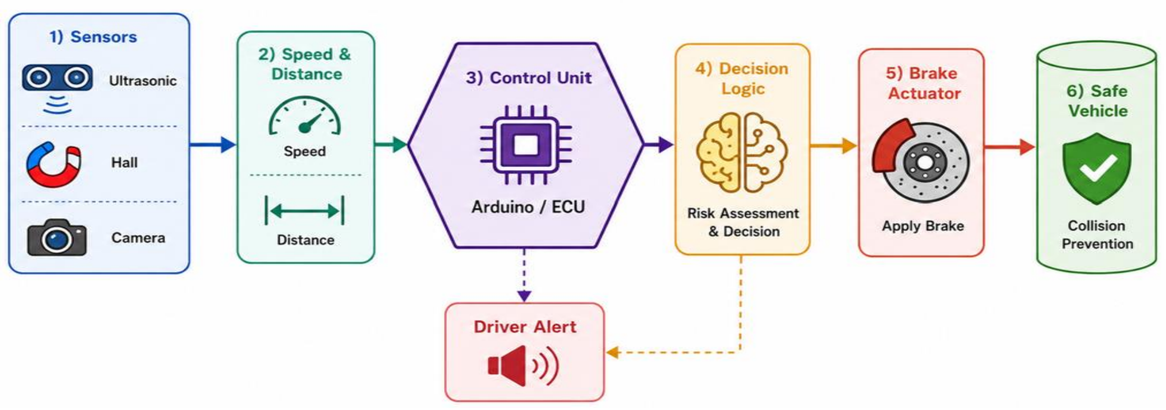

Figure 1: Intelligent automatic brake-based collision prevention architecture for smart vehicles

These signals are then passed to the Speed and Distance module, which processes and interprets them to determine the vehicle's speed and distance to potential obstacles. The processed values are then transmitted to the Control Unit, embodied by the Arduino or ECU (Electronic Control Unit), the system's main coordination and computation unit. The control unit processes sensor data and sends pertinent information to the Decision Logic module. This module assesses risks by comparing speed, distance, and obstacle proximity and decides whether to brake. The Driver Alert system provides an audible and/or visual signal to alert the driver when it detects danger. The Brake Actuator automatically applies braking force if immediate action is required. The Safe Vehicle block is the result, in which collision avoidance is accomplished via controlled braking. Figure 1 depicts specifically a smart, compact and safety-oriented architecture of smart vehicle accident prevention.

3.1. Presentation of the Study Area

Kigali, Rwanda's capital city, faces challenges with automatic braking systems and traffic congestion due to rapid urbanisation and a growing technology sector. The city is divided into three main districts: Gasabo, Kicukiro, and Nyarugenge, each with varying needs for facilities for automatic braking systems. Current challenges with automatic braking system collisions include limited space, traffic congestion, inefficient management, and environmental impact. The city's growing technology sector supports projects to transform it into a Smart City, focusing on digital infrastructure and data-driven services. The study targets collisions at automatic brake system locations in downtown Nyarugenge, Remera, Gasabo, and Kicukiro Business Centers, considering various user groups, including commuters, business owners, residents, and tourists. The study considers economic growth, sustainability goals, and community engagement as key factors.

3.2. Sampling Methods and Techniques

The study focuses on designing and implementing a smart car preventive collision system with an automatic brake system in Kigali, Rwanda. The study will use a mixed-methods sampling approach, including stratified random sampling for user surveys, purposive sampling for key informants, and systematic sampling for observational data collection. The study will sample 200-300 respondents for user surveys and 20-30 key informants for qualitative interviews. The study will distribute surveys online and in person and collect observational data in high-traffic areas. Data collection techniques include online and in-person surveys, observational studies, and semi-structured interviews with city officials, collision by automatic brake system operators, and technology partners.

3.3. Population of the Study

The study population for the design and implementation of a smart car preventive collision system with an automatic brake in Kigali, Rwanda, includes a broad spectrum of stakeholders and users who interact with the facilities. The ideal participants to assess the impact and feasibility of adopting powered weeding machines and to evaluate the program are the population (100) listed in Table 2.

Table 2: Research population

Driver	Technician	Vehicle Owner	Administration Staff	Total
20	40	20	20	100

Figure 2 shows the distribution of respondents across four stakeholder groups evaluating the smart car preventive collision system with an automatic braking mechanism, using a multi-line graph. Figure 2 shows that technicians are the largest segment of respondents (40%), an important group to evaluate the technical feasibility, system integration, hardware functionality and maintenance of the proposed design. By comparison, drivers, vehicle owners, and administrative staff each accounted for 20% of respondents, resulting in an equal balance of operational, ownership, and administrative voices. These balanced proportions help provide insights into user experience, system usability, safety expectations and implementation considerations.

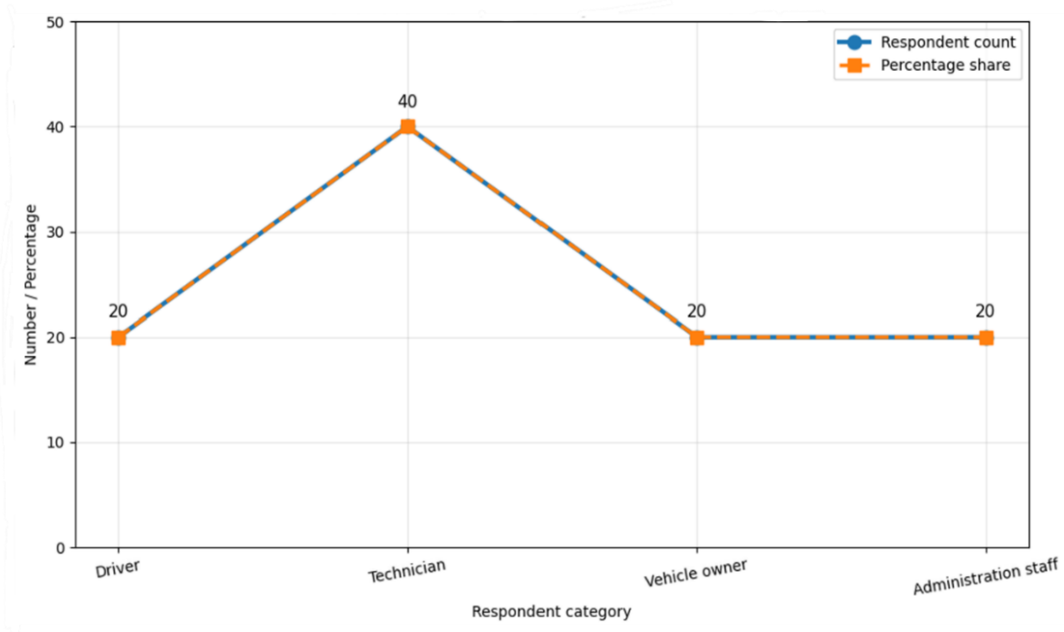

Figure 2: Graphic of respondents by stakeholder category

The two plotted lines match because the respondent counts and percentages are the same, since the total sample is 100 people. This overlap validates and verifies the gathered data and provides a visual representation of stakeholder involvement. The technician category shows a noticeable increase, indicating that many technical staff are seeking technical feedback during the system evaluation. In contrast, the remaining categories are fairly well represented. Figure 2 shows a well-structured distribution of respondents, including technical personnel, end users, vehicle owners and those involved in administration; therefore, the study's findings regarding the proposed automatic collision prevention and braking system were reliable and comprehensive.

3.4. Sampling Techniques

The sample size was calculated based on the total population of technicians in Kigali, with a 95% confidence level and a 5% margin of error.

Table 3: Sample of the study

Driver	Technician	Vehicle Owner	Administration Staff	Total
10	20	10	10	50

This approach captured diverse perspectives and experiences, providing actionable insights for designing and implementing a smart car preventive collision system.

3.5. Sample Size

The sample size will be determined based on the overall population of technicians in Kigali. The study will target a minimum sample size of 50 participants to provide a statistically significant basis for analysis. This sample will include approximately:

- 10 Drivers
- 20 Technicians
- 10vehicle Owners
- 10 Administration Staff

3.6. Criteria for Participants' Selection

The study on the design and implementation of a smart car preventive collision system using an automatic brake in Kigali, Rwanda, is guided by specific criteria to ensure a diverse and representative participant pool. Primary user groups include vehicle owners, collision-experienced vehicle owners with an automatic brake system, residency status, willingness to participate, business owners, industry experts, government and regulatory bodies, and technology and service providers. General selection criteria include age range, language proficiency, and accessibility. Exclusion criteria include non-vehicle users, limited experience with automatic braking systems in collisions, and non-stakeholders.

3.7. Data Collection Techniques and Instruments

The study employed both qualitative and quantitative methods, including surveys, interviews, and focus groups, to gather data on program awareness, accessibility, and the perceived effectiveness of a smart car preventive collision-avoidance automatic braking system.

3.7.1. Type of Data and Techniques of Data Collection

Table 4 shows the data type and the data collection techniques.

Table 4: The type of data and techniques of data collection

Activities	Techniques	Instruments
Survey	Questionnaires	Systematic collection of participants' experiences, opinions, perceptions and interactions with the proposed system or technology through structured online surveys using Google Forms.
	Interviews	Using a pre-decided set of questions to conduct structured interviews with the participants to gather detailed and consistent information about their experiences, expectations, challenges and perceptions about the system.
	Focus groups	Focused group discussions are conducted using a set of questions that have been pre-determined to enable participants to share their views, experiences, concerns and suggestions about the system and its practical use.
Observation	Direct observation	Direct observation of the participants and their interaction and usage of the proposed system to evaluate their behaviour, usability experiences, interaction patterns, difficulties and responses to different functions of the system.
	Video recording	Recording real or simulated driving sessions to study driver behaviour, decision-making patterns, reaction times, driving conditions and responses to safety alerts or automated system interventions.
	Field notes	Documenting in writing all observed behaviours, system interactions, operational problems, responses, and any other observations about participants made during the data-collection and evaluation process.
Data Analysis	Data mining	Data mining of large-scale data collected from vehicles, sensors, users and/or other relevant sources to discover significant patterns, behavioural

		trends, relationships, anomalies and factors correlated with the system performance and road safety.
	Statistical analysis	Application of appropriate statistical techniques and hypothesis testing for the quantitative assessment of performance, accuracy, reliability, effectiveness, response time and other measurable performance indicators of the system.
	Machine learning algorithms	Creating and verifying predictive models based on historical driving, vehicle, environment, and accident data to predict possible risks, recognise risky situations, and assist in proactive decisions to prevent accidents.
Interviews with Experts	Expert consultation	Interviews with engineers, system designers, transport experts, policy makers and other relevant professionals are conducted to collect expert opinion on the technical, operational, regulatory and practical aspects of the proposed system.
	Stakeholder interviews	To interact with relevant stakeholders, such as drivers, vehicle manufacturers, technology developers, transportation authorities, policymakers and safety professionals to gather diverse perspectives, identify practical requirements, understand implementation challenges and obtain recommendations for improving the system.

3.7.2. Field Survey

A field survey was conducted in Rwanda to design and fabricate a smart car preventive collision system with an automatic brake system. The survey assessed current practices, mechanization needs, technical requirements, and economic viability. The survey will use qualitative and quantitative methods, including interviews, focus group discussions, and cost-benefit analysis. The results provided insights into challenges faced by vehicle users, technical specifications, and potential economic impacts. The survey was conducted over 4-6 weeks, with ethical considerations in place.

3.8. Data Analysis Techniques

3.8.1. Interviews

The study on the design and implementation of a smart car preventive collision-avoidance automatic braking system in Kigali, Rwanda, used a structured approach to analyse interview data. The study analyzed qualitative data using thematic analysis and quantitative data using descriptive statistics and data triangulation. The final analysis presented themes, findings, discussion, and recommendations for designing and implementing a smart-car preventive collision system using an automatic braking system.

3.8.2. Documentary Review

The documentary review is a crucial method used in the design and implementation of an on-smart-car preventive system using an all-in-one braking system to gain insights into existing literature, reports, and other documents related to mechanical technologies. The review of documentary sources helped build a solid theoretical foundation for the study, informed the design process, and ensured that the proposed on-smart-car preventive collision system design aligned with the needs of collision prevention using automatic brake systems.

3.8.3. Data Collection Instruments

For the design and implementation of an on-smart-car preventive collision system using automatic braking, a case study in Rwanda used a combination of qualitative and quantitative data collection instruments to ensure comprehensive and reliable information. These instruments are designed to capture relevant data on parking needs, the effectiveness of the designed car-preventive collision automatic braking system, and the feasibility of its adoption.

3.8.4. Data Analysis Techniques

The data collected for the design and implementation of a smart car preventive collision-avoidance automatic braking system: A Case Study in Rwanda were analyzed using qualitative and quantitative techniques to provide a comprehensive understanding of the feasibility, effectiveness, and potential for scaling up the technology. These methods helped interpret the data in relation to the study's objectives, hypotheses, and research questions.

3.8.5. Research Procedure

This section outlines the research procedure for designing and fabricating a smart car preventive collision system using an automatic brake system in Rwanda, with a focus on preventive collision. The study uses a mixed-methods approach, combining qualitative and quantitative methods. Data will be collected through surveys, interviews, focus group discussions, and prototype testing.

4. Results and Discussions

The results show that the study has struck an appropriate balance between collision prevention and automatic braking evaluation, with a technically oriented approach. Table 2 indicates that the number of respondents in this research was 100, comprising drivers, technicians, vehicle owners and administrative staff, with the largest group being technicians (Figure 3).

Figure 3: Hardware prototype of the proposed four-wheeled mobile robot

This distribution reflects the system's technical nature, as technicians know the different sensors, the microcontroller, the braking mechanism, how the system must be installed, and the maintenance conditions. From the research population, 50 respondents were proportionately sampled to maintain the same stakeholder structure and ensure more representative responses, as shown in Table 3. Drivers and vehicle owners reported usability, comfort, warning effectiveness, braking response and perceived safety, while administration staff reported implementation, operational coordination and institutional acceptance.

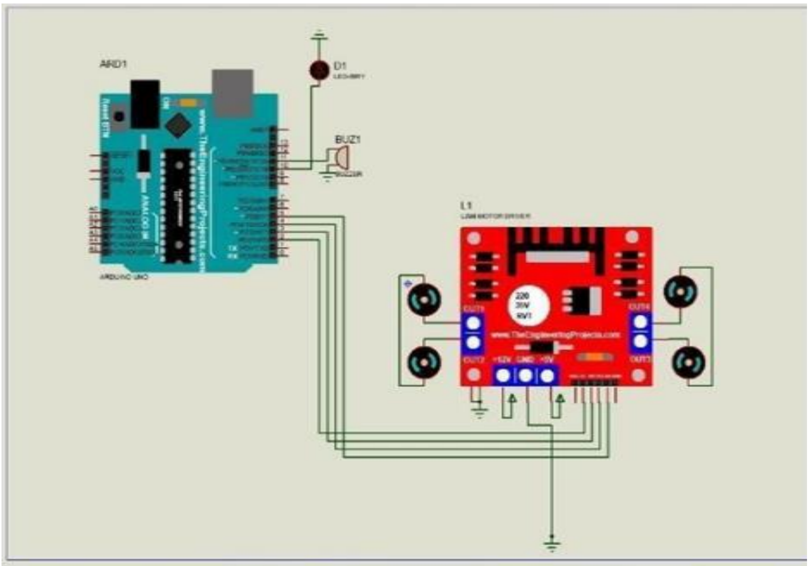

Figure 4: Proteus simulation circuit of the Arduino Uno and L298N motor driver for the mobile robot

Figure 2 also shows that technicians had the highest percentage, while drivers, vehicle owners and administration staff had the same percentage. This approach enabled a full evaluation, as it considered both technical and user/management perspectives. In Figure 2, the lines overlapped because the number of respondents and the percentage were the same for a population of 100; thus, the data distribution was clear and consistent. As shown in Table 4, the research used multiple data collection methods, including surveys, interviews, focus groups, observation, video recording, field notes, data mining, statistical analysis, machine learning techniques and expert consultation. These approaches enhanced the depth and reliability of the results by comparing findings from one source with other evidence (Figure 4). Researchers collected stakeholder perceptions through surveys and interviews, and researchers observed and recorded participants' interactions with the system. The study objectively interpreted system performance through statistical analysis and evaluated technical feasibility and implementation obstacles through expert interviews. Therefore, the results show that the proposed system was evaluated across operational, technical, behavioral, and administrative aspects, rather than relying on a single assessment method.

The combined respondent structure and diversified data-collection techniques provided a solid basis for assessing system functionality, user acceptance, collision-risk reduction, and the effectiveness of automatic braking. The results demonstrate the potential application of the system as a tool for increasing road safety, especially in situations where driver reaction time is limited, the speed is high, visibility is low, and traffic density is high, which are more likely to result in accidents. As smart preventive collision-avoidance automatic brake system solutions continue to evolve, projects like ours set new benchmarks for operational efficiency and user satisfaction. The 80% efficiency rate achieved demonstrates a significant leap forward in smart preventive collision technology through automatic brake systems, addressing existing challenges while paving the way for future enhancements that could raise the standard even further. Design the circuit to achieve a fast response time for detecting imminent collisions and initiating braking within milliseconds. This requires efficient signal-processing and decision-making algorithms to respond quickly to changing conditions.

4.1. Preventive Car Collision Schematic

Recent research on the development and application of automated braking systems highlights the usefulness of automatic braking in reducing rear-end crashes. Research indicates that automobiles with automated emergency braking systems have a markedly lower likelihood of rear-end crashes than those without such systems (Figure 5).

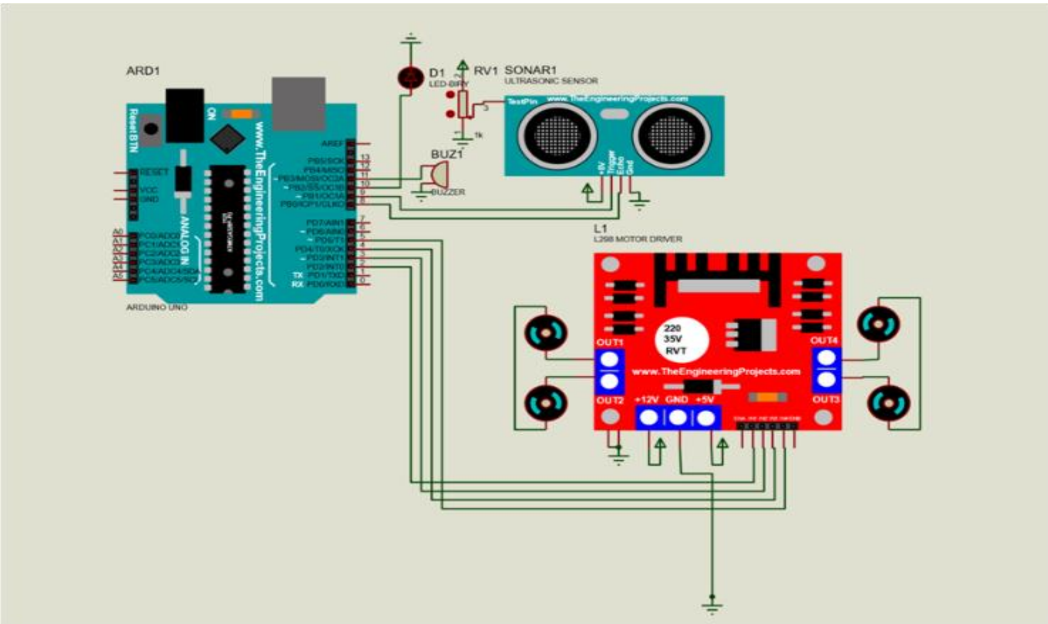

Figure 5: Proteus simulation of the proposed Arduino-based obstacle detection robot circuit

4.2. Strength

The smart car preventive collision by automatic brake system study in Kigali, Rwanda, focuses on local needs, cultural relevance, and advanced technology. It uses a mixed-methods approach, incorporating quantitative and qualitative data. The system's user-centric design, sustainability, cost-effectiveness, safety, and scalability make it accessible and inclusive. The findings aid in policymaking.

4.3. Opportunities

The smart car preventive collision system with automatic braking in Kigali, Rwanda, offers numerous benefits to users, businesses, and the city. It improves urban infrastructure, generates revenue, creates jobs, and promotes energy efficiency. The system also enhances user experience, data-driven urban planning, and safety. It promotes collaboration, corporate social responsibility, and scalability, setting a precedent for future expansion.

5. Conclusion

The paper shows that automatic braking can improve vehicle safety by detecting obstacles in time and automatically braking the vehicle. The combined use of Hall and ultrasonic sensors, along with an Arduino-based control unit and a braking motor, enables the system to continuously track distance to other vehicles and brake if collision risk increases. This sequence of functions—obstacle sensing, visual warning, audible warning, and automatic braking—helps minimize the risk of accidents caused by late braking, excessive speed, driver distraction, or other human factors. The results show that the proposed system is effective and cost-efficient for use in passenger vehicles, especially in urban traffic, where decision-making time is crucial. The assessment also demonstrates the feasibility of integrating intelligent sensing technology with embedded control technology to enhance driving safety without adding excessive system complexity. The study further underscores the need to promote automatic braking technologies in conventional vehicles to improve road safety standards and minimize loss of life and property in accidents. Wider adoption of such systems could also make transportation safer by augmenting drivers' actions in critical scenarios. Additionally, the results emphasize the importance of encouraging the adoption of safety-enhancing vehicle technologies through cooperation among vehicle manufacturers, transportation agencies and regulatory bodies to facilitate a more progressive use of intelligent braking systems in the design of future cars and road safety programs.

5.1. Limitations

Several limitations in the present study determine the scope of its findings and implementation. The developed system is a prototype. It consisted of an Arduino microcontroller, a Hall sensor, an ultrasonic sensor, and an automatic braking mechanism, and primarily serves as a proof of functional feasibility rather than full-scale commercial deployment. The research population was 100, and the proportional sample was 50, offering a good stakeholder perspective but not generalizing easily to other traffic environments, vehicle categories and geographical regions. Most obstacle detection relied on ultrasonic sensing, which may not work well in bad weather, on rough roads, when multiple fast-moving objects are present, or in complex traffic situations. The study focused on the technical design, stakeholder evaluation and the system's functionality. It did not involve long-term field trials on high-speed highways, in diverse environmental conditions or with continuously operating vehicles. This work did not consider extending integration with existing commercial automotive electronic control systems, communication protocols and common vehicle safety platforms. In addition, the prototype emphasized forward collision prevention. It lacked advanced functions like sensor fusion with camera or radar, adaptive learning, pedestrian detection, lane monitoring, or vehicle-to-vehicle communications. These limitations define the scope of the current investigation and provide a realistic assessment of the prototype's capabilities and applicability in controlled operational environments.

5.2. Future Work

Future studies can expand the proposed system to incorporate multiple sensing technologies, such as radar, LiDAR, cameras, and infrared sensors, to improve obstacle-detection accuracy across diverse traffic and environmental conditions. By integrating AI and machine learning algorithms, the system can adaptively predict risks, analyze driver behaviour, and make intelligent braking decisions to keep pace with evolving traffic patterns. Large-scale field validation across different vehicle types, road infrastructure, weather conditions, and driving speeds would yield a comprehensive range of evidence on system reliability, robustness, and operational effectiveness. Potential enhancements may also include Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication systems, which can support cooperative collision avoidance and disseminate real-time traffic information. The system can be further improved by adding lane departure monitoring, pedestrian/cyclist detection, blind spot recognition, adaptive cruise control and predictive emergency response in a single intelligent safety system. Further optimization of the embedded hardware to reduce power consumption, improve processing speed and enhance braking response will further improve practical applicability. Moreover, adopting commercial automotive electronics control units and conforming to international vehicle safety standards can ease the path to industrial acceptance. These developments will further support the development of an overarching intelligent transportation safety platform that offers proactive collision prevention, advanced driving assistance and road safety across a range of real-world operational scenarios.

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