Design of a vehicular emergency intercom system using electronic circuits and sensors

Diseño de un sistema de intercomunicación de emergencia vehicular utilizando circuitos electrónicos y sensores

Projeto de um sistema de intercomunicação de emergência veicular utilizando circuitos eletrônicos e sensores

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Summary. - This study presents the design of a vehicular emergency intercom system aimed at improving motorcyclist safety through the integration of electronic circuits and sensors. The system employs an Arduino UNO R3 microcontroller, GSM SIM900L modules, and ultrasonic and proximity sensors. It is programmed in C++ to detect falls and automatically trigger alerts with high efficiency.

Falls can be detected with 95% accuracy within a range of 2 to 100 cm, with an average response time of 1.2 seconds, making it suitable for emergencies. The system's ability to send alerts quickly enhances user safety in critical situations occurring at distances between 101 and 150 cm. However, limitations in the detection range were identified, particularly at minimum distances between 0.02 cm and 1.96 cm and maximum distances between 151.36 cm and 177.72 cm, which fall outside the operational range. This suggests the need for future adjustments. This project offers an innovative, efficient, and easy-to-implement solution for improving road safety, featuring high sensitivity to optimize emergency response.

Keywords: Vehicle intercom; Traffic emergency; Collision prevention; Vehicle safety.

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Resumen. - *En el presente trabajo se ha diseñado un sistema de intercomunicadores de emergencia vehiculares, enfocado a mejorar la seguridad de los motociclistas mediante la integración de circuitos electrónicos y sensores. Se utiliza un microcontrolador Arduino UNO R3, módulos SIM900L GSM y sensores ultrasónicos y de proximidad, el sistema está programado en C++ para detectar caídas y activar alertas automáticas con alta eficiencia.*
Las caídas se pueden detectar con un 95% de precisión y en un rango de 2 a 100 cm, con un tiempo de respuesta promedio de 1,2 segundos, lo que lo hace adecuado para emergencias. También se destacó la capacidad del sistema para enviar alertas rápidamente, lo que aumenta la seguridad del usuario en situaciones críticas que van desde los 101 hasta los 150 cm. Sin embargo, se identificaron limitaciones en el rango de detección, especialmente a distancias mínimas que oscilan entre 0,02 cm y 1,96 cm, y distancias máximas que oscilan entre 151,36 cm y 177,72 cm, mediciones que están fuera del rango de operación, lo que sugiere la necesidad de realizar más ajustes en el futuro. Este proyecto ofrece una solución innovadora, eficiente y fácil de implementar para mejorar la seguridad vial, con un alto grado de sensibilidad para optimizar la respuesta a emergencias.
Palabras clave: *Intercomunicador de vehículos; Emergencia de tráfico; Prevención de colisiones; Seguridad del vehículo.*

***Resumo*. -** *Neste trabalho, foi projetado um sistema de intercomunicação de emergência veicular, com foco na melhoria da segurança de motociclistas por meio da integração de circuitos eletrônicos e sensores. Utilizando um microcontrolador Arduino UNO R3, módulos GSM SIM900L e sensores ultrassônicos e de proximidade, o sistema é programado em C++ para detectar quedas e disparar alertas automáticas com alta eficiência.*
As quedas podem ser detectadas com 95% de precisão e em um alcance de 2 a 100 cm, com tempo médio de resposta de 1,2 segundos, tornando-o adequado para emergências. A capacidade do sistema de enviar alertas rapidamente também foi destacada, aumentando a segurança do usuário em situações críticas que variam de 101 a 150 cm. No entanto, foram identificadas limitações no alcance de detecção, principalmente em distâncias mínimas que variam de 0,02 cm a 1,96 cm e máximas que variam de 151,36 cm a 177,72 cm, medidas que estão fora da faixa de operação, sugerindo a necessidade de mais ajustes no futuro. Este projeto oferece uma solução inovadora, eficiente e fácil de implementar para melhorar a segurança nas estradas, com alto grau de sensibilidade para otimizar a resposta a emergências.
Palavras-chave: *Intercomunicador veicular; Emergência de trânsito; Prevenção de colisões; Segurança veicular.*

1. Introduction. - Technological progress has revolutionized emergency management, making communication an essential factor in improving response in critical situations, such as traffic accidents. Road safety regulations, promoted by organizations such as the World Health Organization (WHO) and the United Nations (UN), highlight the importance of having efficient communication systems that reduce response times in emergencies. These regulations underline the need to incorporate advanced technologies into vehicular communication devices, thus ensuring their effectiveness and reliability in difficult circumstances, which contributes significantly to road safety and the protection of lives. [1].

The highway via la Costa in Guayaquil, Ecuador, faces a recurring problem of traffic violations that complicate the rapid response to accidents, affecting the effectiveness of emergency teams. To address this situation, it is proposed to integrate advanced electronic circuitry and sensor systems into emergency communication on this road to improve the transmission of vital data during critical incidents. This study justifies the need to innovate in intercom systems to improve coordination and response to emergencies, contributing to the field of telecommunications engineering with a solution adapted to local needs. [2].

This project has the potential to revolutionize road safety through an innovative system of emergency intercoms for motorcycle helmets. Equipped with advanced technology, the system accurately detects falls and collisions using proximity sensors and ultrasound. In the event of detecting a collision, the system automatically makes a call and sends a message to an emergency contact, while, for accident prevention, it sends notifications to the driver to avoid collisions. Experimental tests will be carried out at the Centenario Campus of the Salesian Polytechnic University of Guayaquil, using an Arduino UNO R3 and a GSM SIM900L module to simulate accident scenarios. [3], [4].

This approach seeks to optimize response times in critical cases, improve the reliability and adaptability of the system in various environments, and increase road safety. The system's ability to operate at specific distances and its speed of response ensure efficient communication, significantly reducing risk and providing drivers with a reliable tool to protect their well-being on the road, thus setting a new safety standard and contributing to accident prevention, saving lives and reducing property damage. [3], [4].

The experimental methodology to design a risk prevention circuit for motorcycle helmets through the integration of advanced detection and warning technologies is based on the use of the Arduino UNO R3 Board, GSM SIM900L Modules, and proximity sensors. Initially, individual tests of each component will be carried out to ensure its functionality, followed by its integration into a prototype using a Protoboard board and suitable connections. [5], [6].

C++ programming will develop algorithms that respond to data in real time, triggering alerts through a buzzer and LEDs. In addition, an exhaustive review of the literature will be carried out to identify the most effective technologies, which will guide the design of C++ software that manages the communication between sensors and the GSM module SIM900L. Detailed simulations will assess the detection capability and accuracy in generating alerts, ensuring that the system responds efficiently to emergencies, with key parameters such as response speed measured and compared to predetermined criteria. [7].

1.1 Related Jobs. - The Arduino Uno R3 board, which has been used to teach electronics and programming, demonstrates the ability of this microcontroller to simplify the learning of complex concepts. It was taken as a reference because it mentions the use of each pin that was used and thus able to connect it to the circuit, where each pin of the board has an interface to make it work. [8].

To program the Arduino software, you will take coding examples found in the articles and load them onto the board. The Arduino stands out for its versatility, used in both vehicle safety projects and education. The ease of use and extensive support community make it ideal for both beginners and advanced projects. [9].

The Arduino is also used, as in the article, to integrate voice recognition technologies into vehicular communication systems, demonstrating its versatility in critical communication applications. In this article, it is used for sensor management and emergency communication, which focuses on data transmission to improve the interaction between emergency vehicles [10], [11].

The GSM SIM900 module is one of the elements that stand out in the prototype because its function is to send and receive SMS messages, make calls, and connect to the internet through a network next to the Arduino.

This article [12] Uses the GSM SIM900L module to send real-time alerts to homeowners when an intrusion or suspicious activity is detected in the home. The system is based on IoT technology and uses a network of sensors to monitor the environment of the house. When one of the sensors is activated, the SIM900L module is responsible for transmitting an alert via text messages or calls.

The GSM SIM900L module is essential for applications that require remote communication. In educational projects, its ease of integration and low consumption make it very useful, while in this article, its application in emergencies is highlighted. And remote communication systems. This component is essential for real-time communication with emergency contacts, which is critical for vehicle safety situations. [13], [14].

In this article, the buzzer is used to provide audible signals in case of emergency detection, functioning as a local alert system complementary to SMS messages.
There are similar articles where buzzers are used for alerts in obstacle detection and home security systems, reinforcing their usefulness as a warning signal in varied environments, and electromagnetic buzzers, although less common in modern applications, are used in systems that demand greater sound intensity. [15].

In this article, he introduces the buzzer as an essential component in rapid notification systems, used for its ability to generate immediate and effective alerts. Its application extends to educational projects, where it facilitates practical learning of circuits and programming, as well as in vehicle and home security systems, where its distinctive sound warns of dangerous situations or important events. This has helped us to know how the circuit works so that it can work. [16].

The LED light diodes emit a strong signal to be able to establish a situation, in several articles, they are related to being able to measure the depth and give the warning to the next phase, as we see in the article which the purpose of that study was to determine if increasing the distance between the light source and the pit and fissure sealant affects its curing depth, Concerning the article, it can be seen that to have an emergency start-up warning, these diodes can be used and give better scope to the projects. [17].

In the article, the ultrasonic sensor is used in obstacle detection systems for robots and in security alarms. This highlights the sensor's versatility for safety and navigation applications. With this base, it was possible to obtain information to program the circuit, which in this project measures the distance between the motorcyclist's helmet and the ground to detect falls, activating automatic alerts in case of an accident. [18], [19].

The HC-SR04 ultrasonic sensor is a flexible tool for both distance sensing in vehicle safety projects and robotics and automation applications. Its easy programming and integration with Arduino make it a popular component in various projects. By analyzing the items, it was possible to know the proper handling and what each pin is used for to connect it to the circuit. [20].

The article relates the 4-pin pushbutton because it is a fundamental electronic component in circuit design, commonly used in a variety of applications, from electronic devices to industrial control systems. This type of pushbutton is characterized by its specific structure and functionality, which differentiates it from other kinds of switches and buttons. For this article, it helps to control the circuit pass, it is used when we already have a signal and continue to the other step, which is to transmit calls and alert messages [21].

Both jumpers and resistors are essential elements in the design and testing of electronic circuits. Jumpers provide flexibility and ease for the temporary connection of project components, as visualized in this article, while resistors allow precise control of current and voltage, protecting and optimizing the operation of circuits. Their correct use is key to the development of functional and efficient circuits. [22].

You can find articles where these elements are used for the connection and fluidity of the components, in this article, we find similar connections along with the breadboard where they fundamentally complement the operation. The breadboard, according to the articles, is a crucial tool in electronics for the creation, testing, and adjustment of circuits. Its ability to facilitate rapid and flexible prototyping, coupled with its ease of use, makes it indispensable for designers, engineers, and students. [23], [24].

The breadboard is an indispensable tool for the development of electronic prototypes both in education and in advanced emergency systems projects. It offers an efficient platform to experiment with different circuit configurations visualized in the article and optimize the performance of electronic designs before moving on to a more permanent stage of development. [25].

Python is crucial in the design and management of modern electronic circuits due to its ease of use. By integrating Python into electronic projects, as noted in the following articles, they can automate processes in the programming of microcontrollers and embedded systems, as well as analyze and process sensor data in real-time. Python streamlines the implementation of algorithms, communication between devices, and the creation of intuitive interfaces for user use. [26], [27].

2. Materials and methods. - The experimental methodology for the design of a hazard prevention circuit for motorcycle helmets is based on a meticulous integration of advanced detection and warning technologies. Using the Arduino UNO R3 Board, GSM SIM900L modules, and proximity and ultrasound sensors, the aim is to design a robust and efficient system. The methodological process ranges from the exhaustive review of the literature to select the most effective technologies to the implementation and testing of the system in a functional prototype. Each phase of development is designed to ensure that the system not only performs optimally but also meets the required safety and accuracy standards.

Figure I is presented below, illustrating the six main phases of the methodology for the design of the motorcycle helmet risk prevention circuit. The detailed explanation of each phase follows below to understand their role in the overall process:

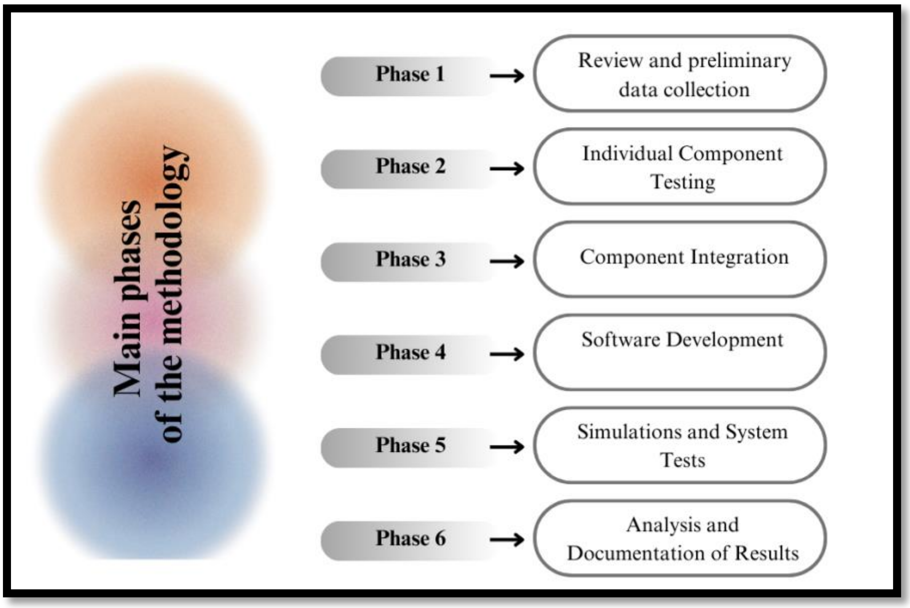

Figure I. Main phases of the methodology.

1. **Preliminary data review and collection:** A thorough literature review is conducted to identify best practices and technologies available in warning and detection systems. This research allows us to select the most effective sensors and modules and design a robust system based on the latest technologies.
2. **Individual Component Testing**: In this initial phase, each component of the system, such as the Arduino UNO R3 Board, GSM SIM900L modules, and proximity and ultrasound sensors, undergoes extensive testing to verify its functionality and compatibility. This ensures that each part of the system operates correctly before being integrated into the prototype.
3. **Component Integration**: After validation of the individual components, the prototype is assembled using a Protoboard board. This phase involves connecting the different elements of the system in a precise way to form a functional circuit that allows communication between the Arduino and the GSM modules.
4. **Software Development**: In this stage, the C++ algorithms are developed to manage the communication between the sensors and the GSM module SIM900L. Specific algorithms will be developed to detect risks, send instant alerts to emergency contacts, and send prevention messages to the driver, thus optimizing the speed and accuracy of the response.
5. **System Simulations and Tests**: Detailed simulations are carried out using specialized software to evaluate the performance of the system under various conditions. This phase allows us to measure detection capacity, accuracy in generating alerts, and speed of response, comparing the results with established performance criteria.

6. **Analysis and Documentation of Results**: The results will be analyzed to measure the detectability and accuracy of the alerts, comparing this data to predetermined performance criteria. The findings will be documented and analyzed to validate the effectiveness of the system in preventing risks and improving road safety.

2.1 Flowchart. - Figure II shows the process of running a prototype designed to notify emergencies and prevent collisions over a specific distance range. It is divided into two main parts based on distance range:

- **Range from 2 to 100 cm (Collision):** If the system detects a collision within this range, a call is made, and a warning message is sent to the emergency contact configured in the programming, alerting to an accident.

- **Range of 101 to 150 cm (Collision Avoidance):** If a potential collision is detected within this range, a caution message is sent to the driver's contact to prevent an accident.

The flow highlights the importance of set distance ranges and the automatic actions the system takes based on detection, prioritizing safety in both prevention and response to potential collisions.

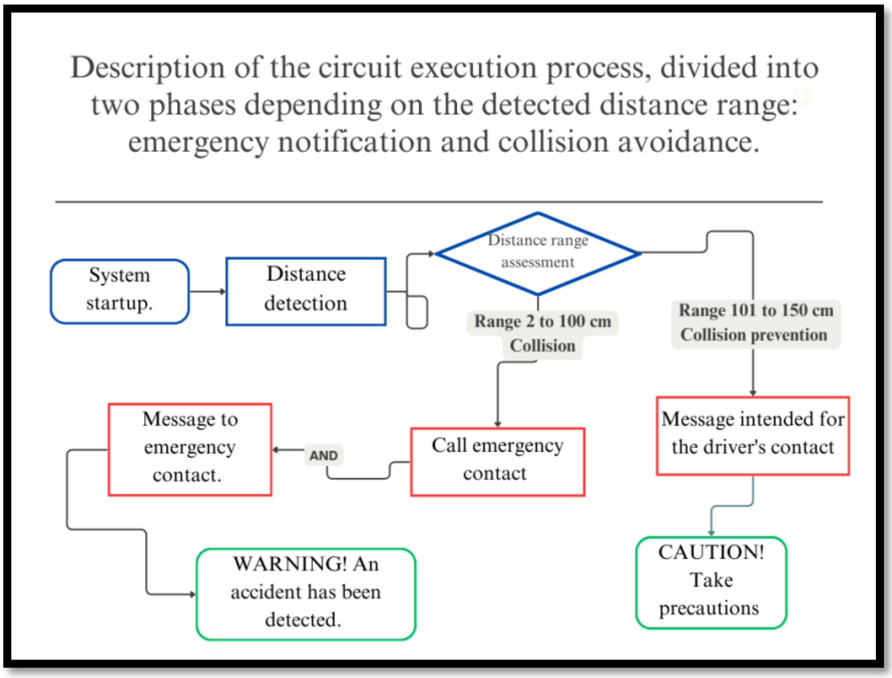

Figure II. Flow chart of the prototype execution process.

2.2 Circuit Schematic. - To develop this project, an Arduino R3 board will be used, which will allow programming and controlling several electronic components, as can be seen in Figure III. Among the materials to be used are a GSM SIM900 board for mobile communication, a laptop to program and monitor the system, an operating chip, an LED sensor, a 5V HC-SR04 4-pin ultrasonic sensor, a 4-pin pushbutton, a buzzer module, resistors, and a Protoboard board to make the necessary connections.

1. Arduino Uno R3 Board
2. GSM SIM900 Board
3. Laptop
4. Operating chip
5. LED Diode Sensor
6. Ultrasonic Sensor 5v HC-SR04 4pin
7. 4-pin push button
8. Modulo buzzer zumbador
9. Resistance
10. Protoboard Board

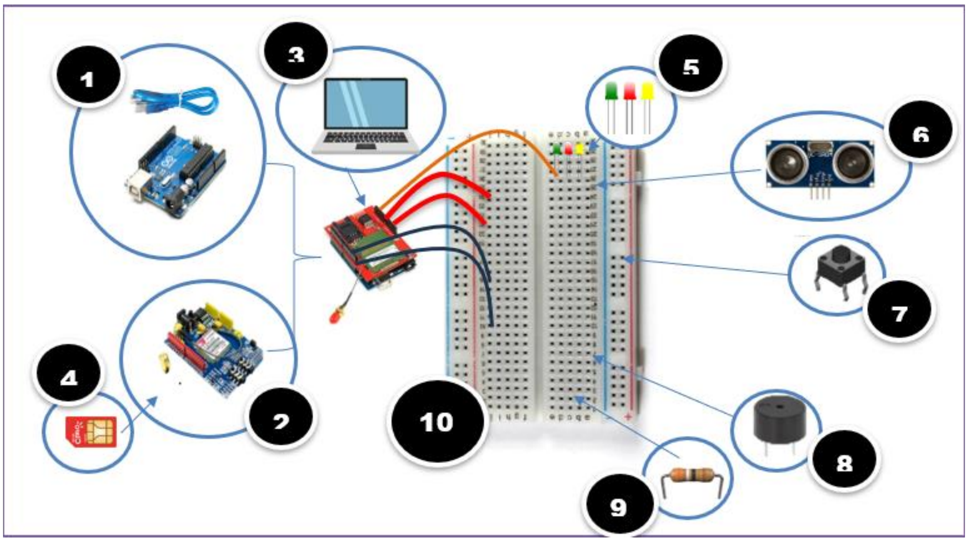

Figure III. Prototype of a design in Protoboard.

2.3 Data analysis methodology. - To start, the pins of the Arduino UNO R3 are related to those of the GSM board SIM900L using a Headers pin, ensuring a correct union between the two. In addition, power was supplied via a power cord to power the device. Once both boards were assembled, they were connected to the computer, and the corresponding programming began. Figure IV shows the plate bonding scheme.

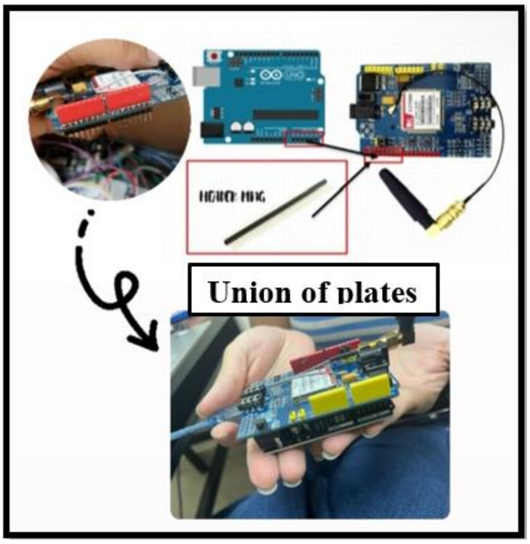

Figure IV. Arduino board and GSM board link scheme.

The stages described below correspond to phases 3 and 4 of the methodology. First, the linked boards, as shown in Figure IV, are connected to the computer, and the appropriate development environment is opened. The necessary code is typed or loaded into the IDE, then compiled and uploaded to the microcontroller. Once the programming has been successfully uploaded, the green LED on the breadboard schematic in Figure III will light up, indicating that the system is operating properly.

Next, manually turn on the GSM SIM 900 module, making sure that it is correctly connected to the microcontroller. After a few seconds, when the GSM module has detected the signal, the red LED will light up, confirming that a signal is available. Then, press the button connected to the microcontroller.

This action will turn on the yellow LED, indicating that the system has detected the activation of the button. At that point, the ultrasonic sensor will begin to detect motion. The microcontroller will process the information from the ultrasonic sensor to take the necessary actions according to the previously uploaded programming. All exposed materials will be placed on the breadboard board, as shown in Figure V.

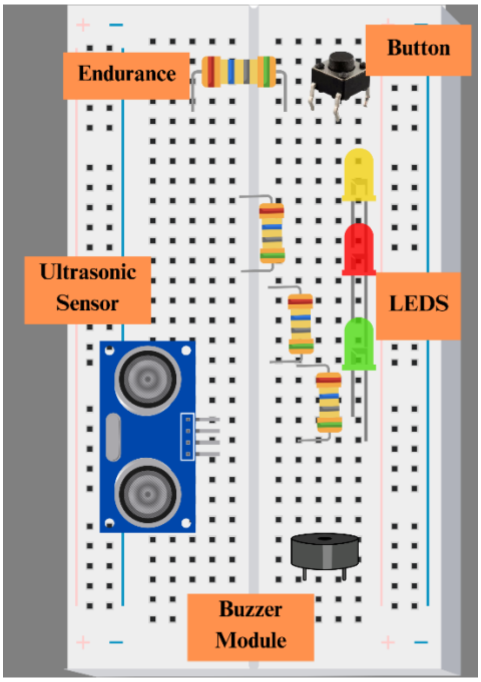

Figure V. Protoboard scheme.

Once the Arduino and GSM boards have been connected, as shown in Figure III, all the sensors, modules, and resistors are integrated into the breadboard. These components are interconnected by breadboard cables (jumpers) to establish a functional and simulation-ready circuit.

The circuit in the breadboard, depicted in Figure V, includes a 5V ultrasonic sensor (HC-SR04, 4-pin), which acts as a means of detecting movements based on the programmed distance. When the set thresholds are exceeded, the system emits a warning sound through the buzzer and sends an SMS or makes a call to the pre-configured number.
Figure VI also shows the complete schematic of the circuit, detailing the connection between the GSM module, the Arduino board, the buzzer, a proximity sensor, a pushbutton, resistors, and LEDs. All these components are connected to a breadboard, powered with 9 volts for the amplifier and 3.3 volts for the sensor and the analog-to-digital converter, ensuring the correct operation of the system.

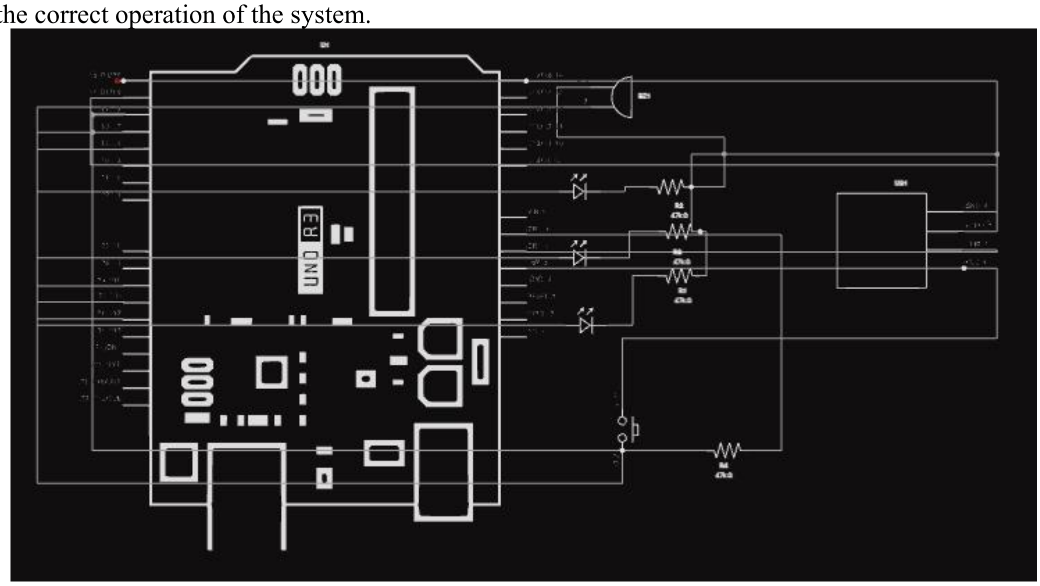

Figure VI. Circuit diagram.

2.4 Schematic simulation methodology of the circuit compiled on an Arduino UNO R3 board. -

2.4.1 Programme implementation. - Figure VII shows the complete signaling process of the GSM module. Initially, the program is entered without a signal, displaying the AT+CREG message, which indicates that the module is looking for a signal. Once the signal is established, the system transmits a message confirming "alarm fully initiated," and the red LED lights up to indicate that the GSM module has been successfully connected and is ready to go.

Figure VII. Programmed implementation.

Figure VIII illustrates the connection of the GSM SIM900 module to the network. The red LED light confirms that the module has established a network signal and is operational. This visual indicator shows that the GSM module is properly integrated and ready to transmit data.

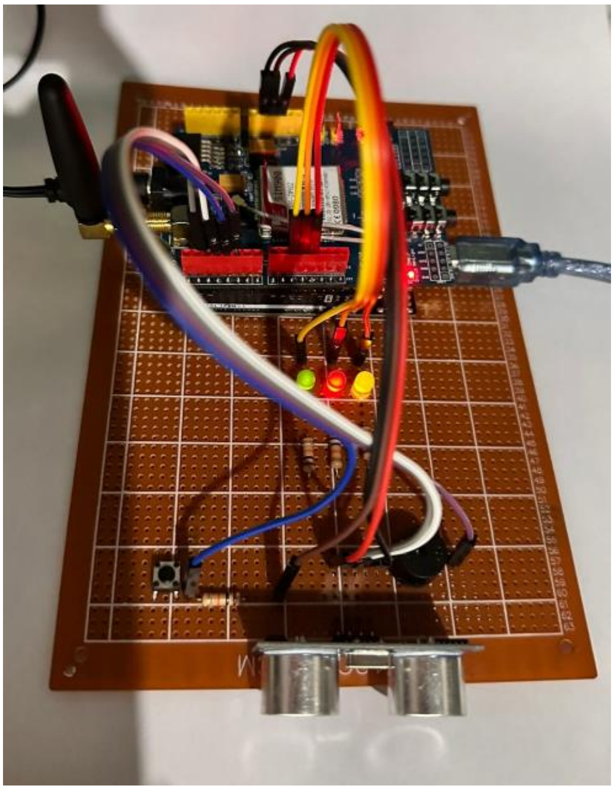

Figure VIII. Programmed implementation.

Figure IX illustrates the detection of a movement at 5 cm, which is within the predefined range of 2 to 100 cm. This distance confirms that the detected object is in the specific range for which the system is designed to trigger alerts. The correct identification of this distance within the set range is crucial for the accurate operation of the system, ensuring that appropriate response measures are activated in emergencies.

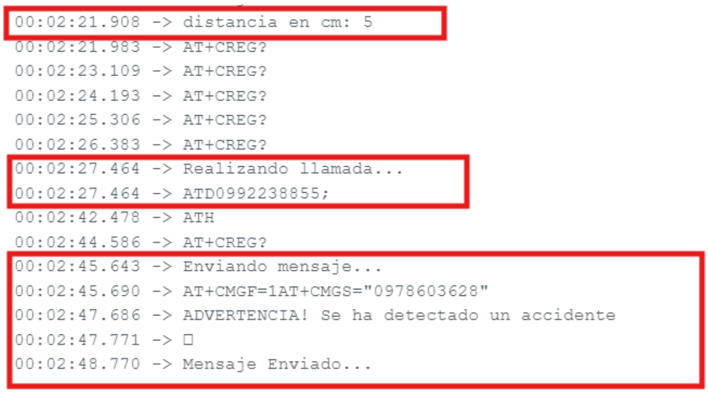

Figure IX. Collision detection.

Figure X illustrates the complete process that the system follows when detecting a collision using the ultrasonic sensor. When the sensor detects a potential collision, the system immediately activates the emergency protocol, which includes making a call to the pre-configured emergency contact. This call is made to quickly and effectively alert about the incident, ensuring that help is requested without delay and increasing the chances of a timely response to the emergency.

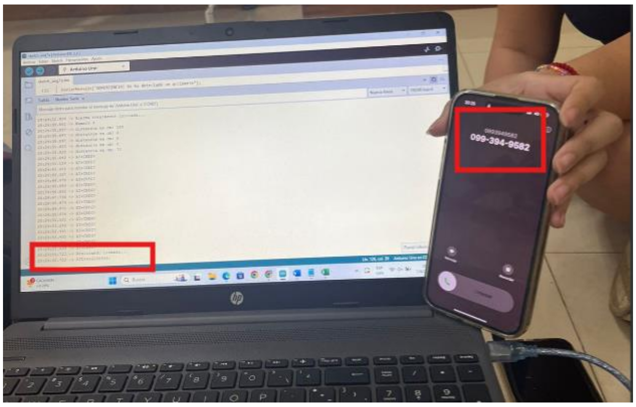

Figure X. Emergency call.

Figure XI illustrates the complete process after making an emergency call. Once the call has been made, the system automatically sends a message to the emergency contact with the text "Warning! An accident has been detected." This notification ensures that the emergency contact is immediately alerted to the critical situation, providing essential information for rapid intervention.

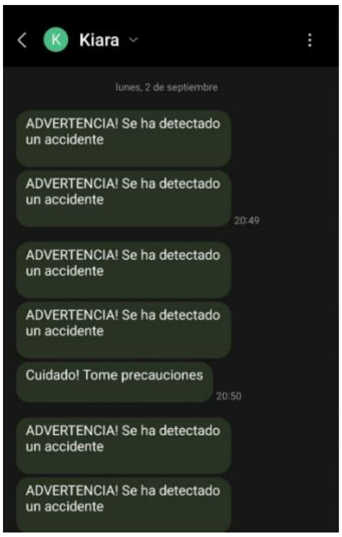

Figure XI. Emergency message.

Figure XII illustrates motion detection at different distances: 127, 123, 124, and 104 cm, all within the preset range of 101 to 150 cm. In these situations, the system is designed to send an alert message to the driver that says, "Watch out! Take precautions." This message aims to warn the driver of a potential impending collision, allowing them to take preventative measures to avoid an accident.

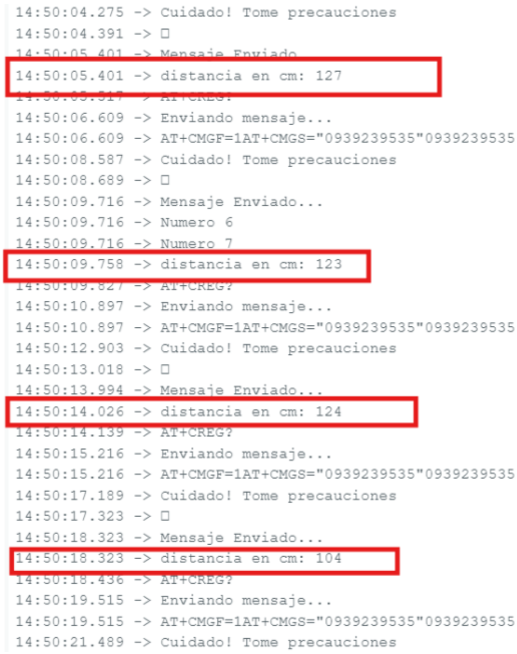

Figure XII. Collision avoidance message.

Figure XIII illustrates that the system sends a warning message to the driver's contact. This message, transmitted automatically, is crucial for the driver to be able to take proper precautions and avoid a potential collision. By receiving this alert, the driver receives real-time information, allowing them to adjust their behavior and improve safety on the road. The figure clearly shows how the system facilitates this vital communication, highlighting its role in accident prevention by enabling a quick and effective response to potentially dangerous situations.

Figure XIII. A collision warning message addressed to the driver.

4. Results. -

4.1 Distance analysis calculations and alert activation. -

Sound Speed Formula:

Distance formula: $$\boldsymbol{t} = \frac{\mathrm{x}}{\mathrm{v}} \qquad (1)$$

Where:

- t: Time it takes for the signal to go and return.
- x: Total distance traveled by the signal (round trip).
- v: Signal propagation speed, which in this case is the speed of sound.

$$v = \frac{340m}{s}$$

$$v = \frac{34000cm}{s} \qquad (2)$$

Where:

- v: The speed of sound in the air, expressed in centimeters per second. It is considered 34000 cm/s (equivalent to 340 m/s).

$$t = \frac{1cm}{\frac{34000cm}{s}}$$

$$t = 29{,}411\ \mu s \qquad (3)$$

Where:

- This is the conversion of the time it takes for a signal to travel 1 cm (round trip) at a speed of 34000 cm/s. The result is 29,411 microseconds.

The signal goes back and forth therefore, half the distance will be taken.

Distance (cm)= $(Tiempo\ medido(\mu s)\ /29.41\ \mu s * cm)\ /2)$ (4)
Distance (cm) = $(Tiempo\ medido\ (\mu s\ /58.82\ \mu s)$ (5)
Distance (cm) = $Tiempo\ medido\ (\mu s)\ *\ 0.017$ (6)

4.2 Simulation results. - In scenario 1, the moment when a collision occurs is captured within the range of 1 to 100 cm, specifically at 19 cm. At that proximity, the system activates, making a call and sending an SMS to the emergency contact, notifying them of the collision and allowing an immediate response, as visualized in Figure XIV.

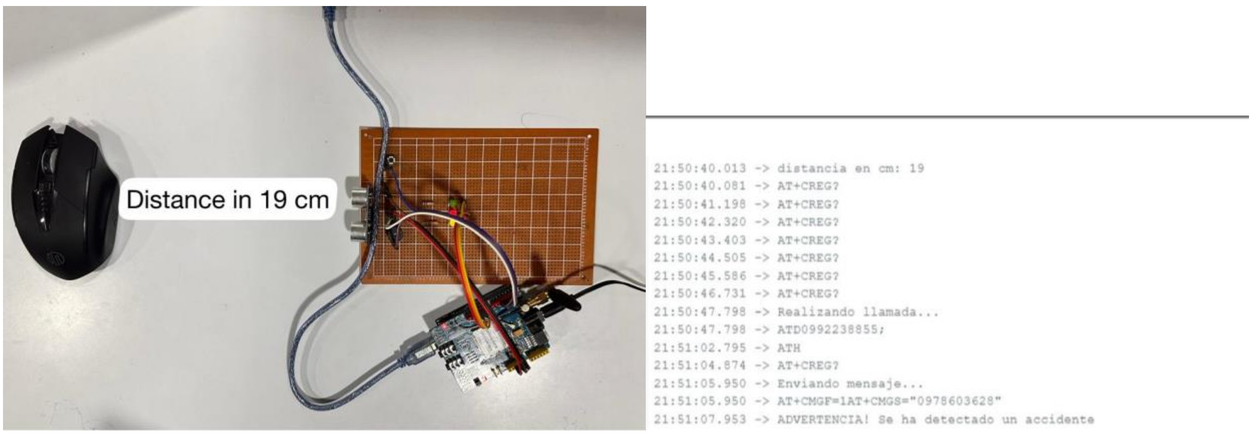

Figure XIV. Scenario 1: Collision message.

Table 1 presents the distances measured by the ultrasonic sensor, calculated using formula (6):

A column labeled "Collision" has been included, indicating whether the system detects a driver's fall at a specific distance. This data is essential for evaluating the system's accuracy and effectiveness in identifying accidents.

The system determines that an accident has occurred when it detects a helmet fall within the predefined range in the programming (2 cm ≤ distance ≤ 100 cm). In this case, an emergency protocol is automatically activated, which includes sending an SMS message and making a call to an emergency contact, alerting them about a potential collision. This process is illustrated in Figures 9, 10, and 11.

Distance (cm) = Measured time (μs) * 0.017	Distance	COLLISION
120	2.04	YES
600	10.20	YES
900	15.31	YES
1200	20.41	YES
1500	25.51	YES
1800	30.61	YES
2100	35.71	YES
2400	40.82	YES
2650	45.07	YES
2950	50.17	YES
3250	55.27	YES
3550	60.37	YES
3850	65.48	YES
4150	70.58	YES
4450	75.68	YES
4750	80.78	YES
5000	85.03	YES
5300	90.14	YES
5600	95.24	YES
5900	100.34	YES

Table 1. Collision results, applying the sound speed formula.

Figure XV provides a graphical representation of the data from Table 1, highlighting the direct relationship between measured time in microseconds and distance travel. To enhance visualization, distances are presented in 5-cm increments.

The graph illustrates that as time increases, distance also increases, suggesting a constant movement or a process in which one variable is directly dependent on the other. Additionally, the figure indicates that when the distance falls within the established range, a collision is detected.

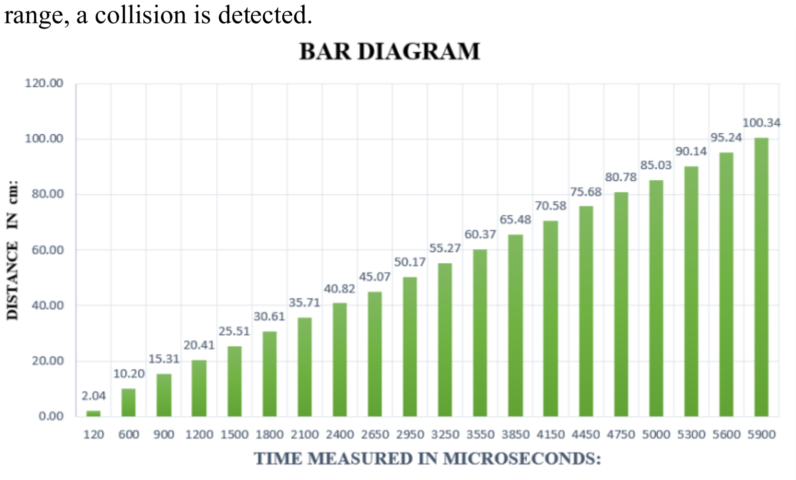

Figure XV. Graphical representation of collision detection.

Scenario 2 shows the moment when the system detects a potential collision at a distance of 114 cm, within the range intended for collision avoidance. In this case, the system proceeds to send a collision avoidance message to the driver to avoid the impact, as presented in Figure XVI.
With the integrated and processed circuit, the emergency alert is detected, reacting immediately to a possible fall.

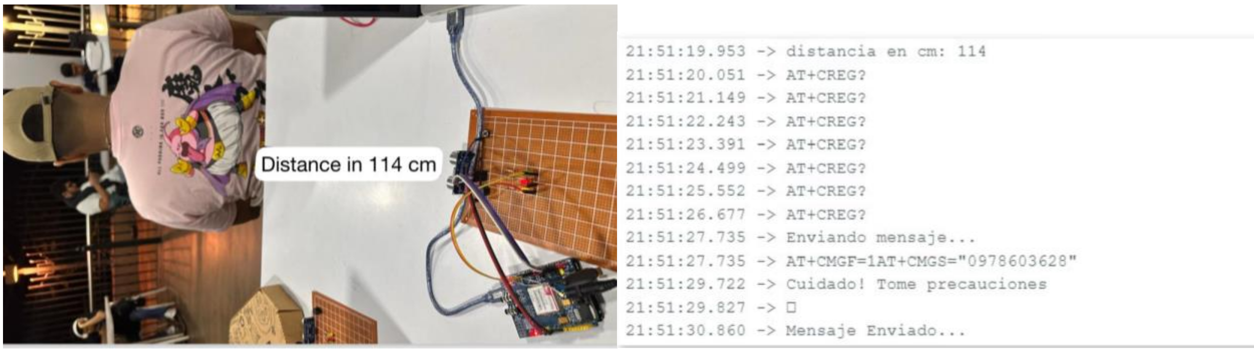

Figure XVI. Scenario 2: Collision avoidance

Table 2 presents the distances measured by the ultrasonic sensor, calculated using formula (6). The system specifically evaluates the distance range defined by the condition "else if (distance > 101 && distance <= 150)", which refers to a proximity zone where the detection of an obstacle does not necessarily imply an immediate collision, but it could represent a potential risk to the driver. Within this range, the system interprets that the driver must remain cautious and be prepared to take corrective actions in case of an emergency.
Consequently, a warning message is triggered to alert the driver about the proximity of the object without a collision occurring. In addition, an audible alarm is activated, reinforcing the visual alert and enhancing the visibility of the impending danger. This system behavior is depicted in Figures 12, 13, 14, and 15, which provide a detailed illustration of how the detection of this intermediate zone triggers the alert mechanisms for the user.

Distance (cm) = Measured time (µs) * 0.017	**DISTANCE (cm)**	**COLLISION**
5950	101.19	YES
6200	105.44	YES
6500	110.54	YES
6800	115.65	YES
7100	120.75	YES
7350	125.00	YES
7650	130.10	YES
7950	135.20	YES
8250	140.31	YES
8550	145.41	YES
8850	150.51	YES

Table 2. Collision avoidance results by applying the sound speed formula.

Figure XVII provides a graphical representation of the data shown in Table 2, illustrating the direct correlation between the distances detected by the system and the time measured in microseconds. This relationship suggests that, as time increases, the distance traveled also increases proportionally, reinforcing the notion that both parameters are closely linked in the proximity measurement process.
To facilitate interpretation, distances are displayed in 5-cm increments, which enhances the visualization of variations within the measurement range. The graph emphasizes that when distances fall within a specific range, a collision avoidance message is triggered, indicating the presence of a potential risk. This preemptive alert is critical for the driver to take the necessary precautions and avoid hazardous situations. The graphical analysis allows for a deeper understanding of how distance and time interact in real-time within the detection process, showcasing the system's effectiveness in identifying potential threats.

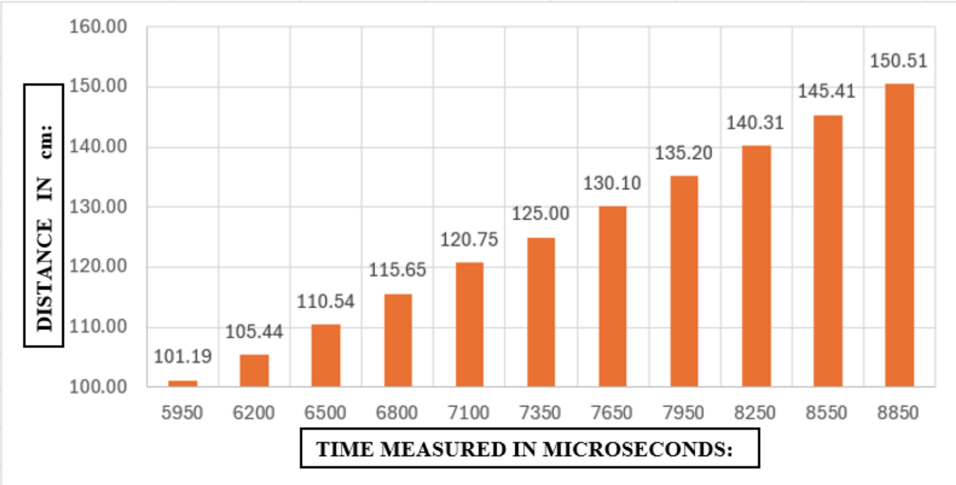

Figure XVII. Graphical representation of collision avoidance.

4.3 Experimental results: Non-collision scenarios. - In Scenario 3 it shows a minimum distance of 0 cm and then a distance of 2 cm, where it begins to detect collisions. It is important to note that the minimum distances range from 0.02 to 1.96 cm, in which the system will not detect falls since they are outside the range established for detection, as shown in Figure XVIII.

Figure XVIII. Scenario 3 Minimum distances.

Figure XIX illustrates a clearly defined trend line, demonstrating that as time, measured in microseconds, increases, the detected distance also increases proportionally. However, distances fall within the range of 0.02 cm to 1.96 cm, which is minimal and indicates that no significant movement is detected. This suggests that at these very short distances, the sensor is unable to register any form of collision or impact, highlighting its limitations in detecting objects within this range.

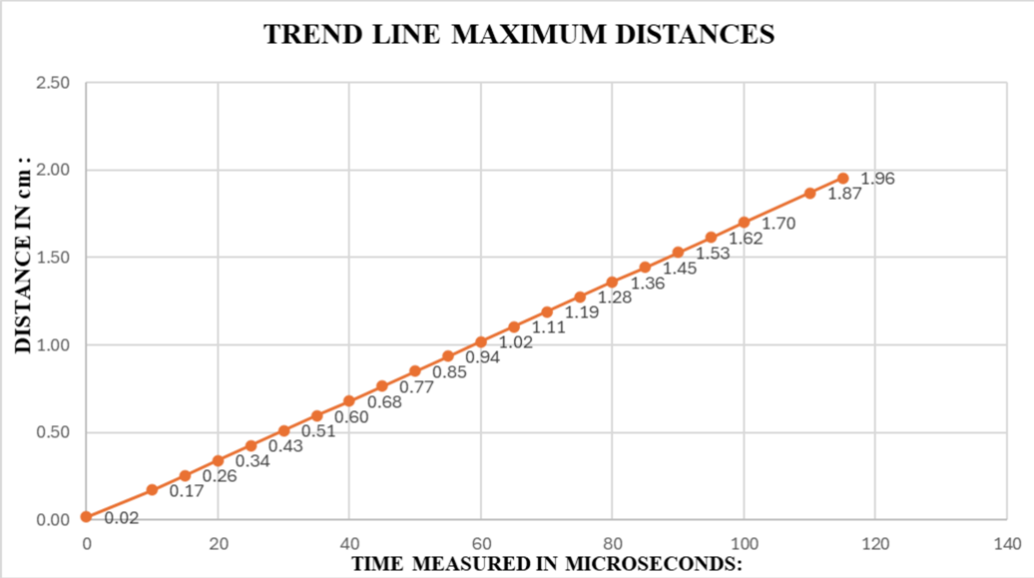

Figure XIX. Graphic representation: No collision at minimum distances.

Scenario 4 has a maximum distance of 174 cm, as shown in Figure XX. It is important to note that the maximum distances range from 151 to 177 cm, where the system will not be able to activate automatic alerts, this is caused because they are outside the range established for detection.

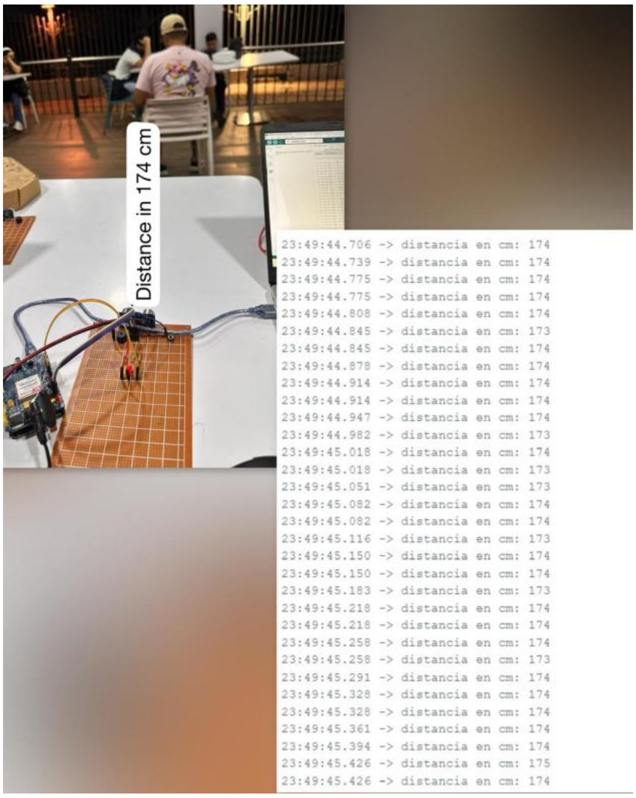

Figure XX. Scenario 4 Maximum distances.

Figure XXI illustrates that at distances between 151 cm and 177 cm, the sensor fails to detect any motion. This observation, also detailed in Table 4, suggests that the sensor's effective range for detecting collisions or impacts does not extend within these distances, highlighting the limits of its detection capabilities outside the defined proximity range for accurate monitoring.

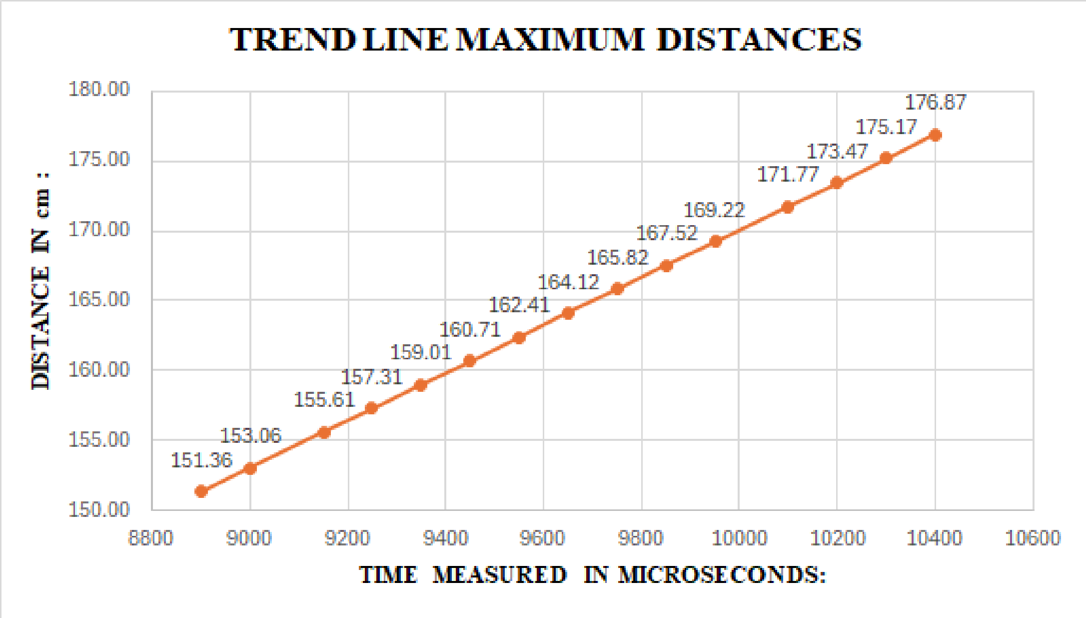

Figure XXI. Graphical representation: No collision at maximum distances.

Table 3 presents the results of 50 tests conducted to evaluate the performance of an emergency communication system based on distance detection. The data includes key aspects such as the distance from the detected object or event (in centimeters), the detection time (in seconds), the signal activation time, the SMS sending time, and the total time from detection to SMS dispatch.

The total time, which is the sum of the individual times for detection, activation, and sending, shows significant variation, ranging from 1.8 seconds at very short distances (e.g., 3 cm) to 10.6 seconds at longer distances (e.g., 149 cm). These variations are critical for assessing the system's efficiency, particularly in emergencies where rapid response is essential. This data helps evaluate the system's ability to process and communicate information effectively in real time, offering insights into the timeliness and reliability of the system's emergency response.

COMMUNICATION EFFICIENCY TABLE					
Test	**Distance (cm)**	**Detection Time(s)**	**Signal(s) activation time**	**SMS Sending Time(s)**	**Total Time(s)**
1	72	3.1	0.52	1.1	4.72
2	30	1.9	0.3	1.2	3.4
3	100	5.9	0.3	1.2	7.4
4	105	6.2	0.25	1.4	7.85
5	32	1.9	0.26	1.2	3.36
6	61	3.6	0.3	1.3	5.2
7	65	3.8	0.3	1.3	5.4
8	70	4.1	0.41	1.3	5.81
9	10	0.6	0.25	1.2	2.05
10	140	8.2	0.5	1.1	9.8
11	109	6.4	0.28	1.2	7.88
12	115	6.8	0.35	1.1	8.25
13	41	2.4	0.4	1.2	4
14	50	2.95	0.41	1.2	4.56
15	25	1.5	0.42	1.2	3.12
16	5	0.3	0.2	1.3	1.8
17	134	7.9	0.5	1.2	9.6

18	52	3.1	0.2	1.1	4.4
19	99	5.85	0.4	1.2	7.45
20	68	4	0.4	1.1	5.5
21	74	4.4	0.35	1.2	5.95
22	31	1.85	0.25	1.3	3.4
23	56	3.3	0.3	1.3	4.9
24	14	0.85	0.35	1.2	2.4
25	21	1.25	0.3	1.2	2.75
26	38	2.25	0.3	1.3	3.85
27	116	6.85	0.25	1.3	8.4
28	121	7.15	0.4	1.2	8.75
29	11	0.65	0.3	1.2	2.15
30	19	1.15	0.41	1.3	2.86
31	17	1	0.26	1.3	2.56
32	3	0.2	0.3	1.3	1.8
33	55	3.25	0.3	1.4	4.95
34	63	3.75	0.4	1.2	5.35
35	102	6	0.5	1.3	7.8
36	112	6.6	0.5	1.3	8.4
37	53	3.15	0.25	1.3	4.7
38	67	3.95	0.3	1.4	5.65
39	36	2.15	0.3	1.3	3.75
40	93	5.5	0.25	1.3	7.05
41	91	5.4	0.3	1.35	7.05
42	75	4.45	0.4	1.4	6.25
43	105	6.2	0.5	1.3	8
44	60	3.55	0.4	1.3	5.25
45	23	1.4	0.2	1.3	2.9
46	4	0.25	0.25	1.3	1.8
47	143	8.45	0.5	1.2	10.15
48	147	8.65	0.5	1.2	10.35
49	149	8.8	0.5	1.3	10.6
50	127	7.5	0.4	1.3	9.2

Table 3. System efficiency in communication.

Figure XXII illustrates the relationship between detected distance and total delay time in the emergency communication system. The blue bars represent the detected distance (in cm), while the orange line indicates the total delay time (in seconds), which includes detection time, signal activation, and SMS dispatch. A trend is observed where, as the detected distance increases, the total delay also tends to rise, which is expected due to the longer processing and transmission duration at greater distances. However, some fluctuations are present, possibly due to environmental factors or system performance variations. This graphical representation helps assess the system's efficiency in detecting and transmitting emergency messages, highlighting the importance of optimizing its performance at greater distances to improve response times in critical situations.

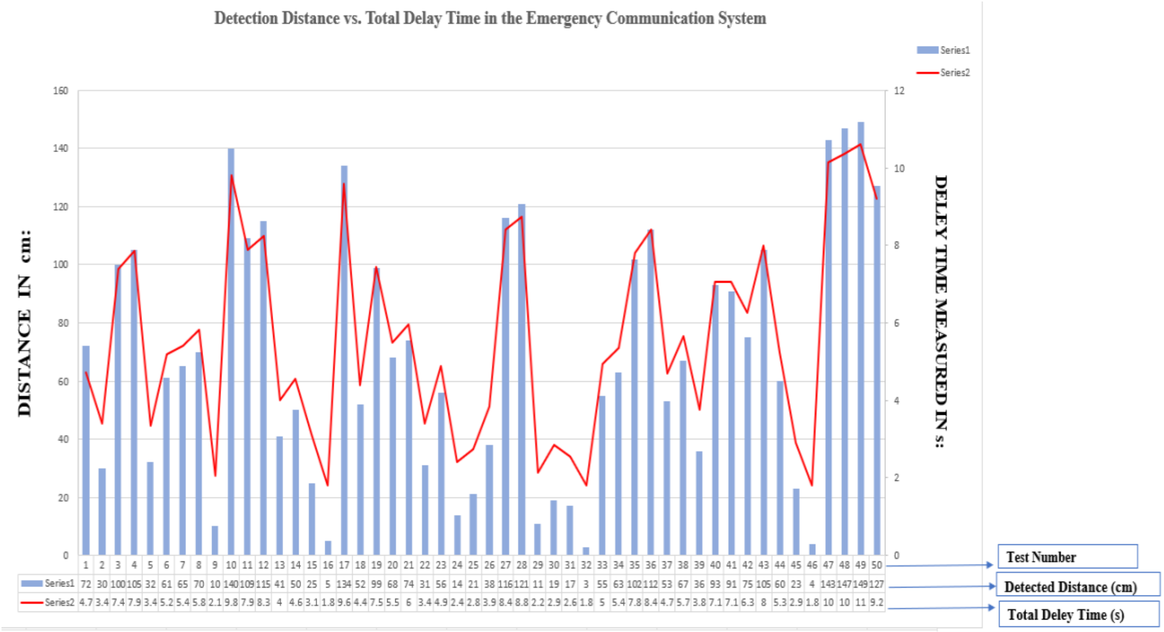

Figure XXII. Graphical representation of the efficiency of the communication system.

The system does not detect distances outside its operating range because its operating range has been strategically defined to ensure accurate and relevant detection in potential collision scenarios. An interval of 2 to 100 cm was established for activating emergency alerts and 101 to 150 cm for preventive warnings, considering reaction times and avoiding false alarms. Although the ultrasonic sensor can measure greater distances, the restriction is due to a design decision oriented to system efficiency and not to hardware limitations. If necessary, parameters in the microcontroller programming could be modified to extend the sensing range, ensuring that the stability and accuracy of the measurements remain within acceptable margins.

To improve coverage without compromising reliability, a possible solution would be the integration of complementary sensors with longer ranges or the implementation of additional technologies, such as LiDAR or machine vision cameras. These systems could provide more advanced detection in dynamic environments and at greater distances, optimizing the system's ability to anticipate and prevent incidents with a greater margin of time.

Table 4 presents the results of tests conducted to evaluate system performance, focusing on accuracy and false positive rate. With a response time between 1.8 and 10.6 seconds, as demonstrated in Table 3, the system showed a 90% correct detection rate, indicating high reliability in identifying obstacles within the range of 2 to 150 cm.

A false positive rate of 10% was observed, attributed to external interference or variations in object reflectivity. To mitigate these errors, filters were implemented in the programming that discards inconsistent readings, stabilizing the measurements. The optimization process will continue to improve accuracy and reliability in future tests.

Performance Metrics Table				
Distance (cm)	True Positives (TP)	False Positives (FP)	Accuracy	False Positive Rate (%)
2-50	48	2	96	4
51-100	45	5	90	10
101-150	40	10	80	20
151-200	38	12	76	24

Table 4. System Performance.

- Definitions:
- True Positives (TP): Cases where the system correctly detects the presence of the object.
- False Positives (FP): Cases where the system detects an object that is not present.
- Accuracy: Calculated as: Accuracy $= \frac{VP}{VP+FP} \times 100$
- False Positive Rate: Calculated as: False Positive Rate $= \frac{FP}{VP+FP} \times 100$

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5. Discussion. - The paper [27] focused on the implementation of a visible light communication (VLC) system for emergency vehicles, highlighting the transmission and reception of data over a radio frequency link and VLC. While their results demonstrated the feasibility of the system, especially in terms of range (up to 200 meters for radio frequency and 30 cm for VLC), the present study proposes a solution that integrates voice recognition, significantly improving accessibility and interaction without the need for manual intervention.

Both studies seek to improve the efficiency of communication in vehicular emergencies, although from different technological approaches. In this project, an average of 8.24 s can be visualized for sending emergency SMS, which shows that the greater the distance, the longer it takes to send the message. While the VLC system provides an efficient alternative means of data transmission that has a data of 6.4 s, the integration of voice recognition technologies in this study facilitates more intuitive and accessible communication, which is crucial for people with disabilities.

The integration of speech recognition into the proposed system could further improve communication efficiency by eliminating the need for manual intervention, which could be crucial in emergencies where time is of the essence, and the person in need of assistance may be unable to manipulate a device. Additional data would be useful for further analysis, such as SMS sending success rate, speech recognition error rate, and comparison with other communication technologies used in emergency vehicles, such as radio communication systems or satellite communication systems.

The article [28] presents an innovative device that monitors the blood alcohol concentration and heart rate of drivers using advanced sensors and wireless communication technologies. Sensors are a fundamental part of data measurement and frequency monitoring, in this article, unlike the present article, monitors the distance in which one is about to suffer or suffered a collision from the most accurate data was detected at a distance of 100 cm from the surface where in a total of 7.4 seconds of reaction sends an alert message to a third party.

The results of the study show that the device achieves remarkable accuracy in measuring blood alcohol concentration and heart rate, with an average absolute error of 1.61 and a standard deviation that supports the reliability of the data obtained. The processed information is sent through the Node-RED platform for analysis and subsequent early warning in case of detecting dangerous levels of alcohol in the driver's blood. In addition, the importance of 5G network infrastructure to improve system performance in future deployments is highlighted.

In this article, measurements are noted, but through movement at the moment of suffering or about to have a collision, for example, when the circuit detects that it is falling at a distance of 75 cm measured towards the ground, it will issue a message with a total time of 6.25 seconds to send an emergency message to a predetermined contact, on the other hand, when it detects a distance of 112, it will send a warning message to the same intercom user after 8.4 seconds.

Based on voice recognition for vehicular emergency communication, it is compared with state-of-the-art solutions, such as biometric driver monitoring from article [28], highlighting its potential lower cost and ease of implementation. However, its limitations, such as speech recognition accuracy in noisy environments and its focus on post-accident communication, are discussed. Future research is required to improve speech recognition accuracy, integrate it with accident prevention systems, develop more intuitive user interfaces, and test it in real environments.

Both the paper [29] and this article measure the importance of instantaneous and accurate communication and signaling. In the case of vehicular intercoms with voice recognition technology, the goal is to speed up response in traffic emergencies, enabling interaction without requiring manual use and improving accessibility for people with disabilities. Similarly, the motion detection system with ultrasonic sensor HC-SR04 and Arduino seeks to control the capacity in closed environments, alerting in real time about the number of people present and helping to minimize the risk of contagion in closed spaces.

Vehicular intercoms with voice recognition, with state-of-the-art solutions, such as the HC-SR04 ultrasonic sensor motion detection system and Arduino from the article [29]. Both systems share the goal of improving emergency response through instant and accurate communication and signaling. While the system focuses on interaction through voice recognition, the article [29] focuses on capability control in closed environments.

In terms of cost, the proposed system could be more economical than other solutions involving more complex sensors and devices. In terms of accuracy, both systems aim for immediacy in response, although the accuracy of the proposed system will depend on the quality of speech recognition. In terms of implementation feasibility, the proposed system could be easier to integrate into existing vehicles.

In addition, both systems rely on data collection and analysis to improve decision-making. In the context of traffic accidents, the integration of sensors and proper programming allows for determining the distance at which the emergency signal will be activated, with the data obtained with all the simulations that have been performed when a vehicle is close to suffering a collision in a set range of 2-100 cm, a collision message will be executed and executed to a third party as “direct contact or emergency contact.”

If a driver has a collision on a road, depending on the distance, the movement will be executed, for example, when the circuit detects the impact at 19 cm, the alert is executed to the nearest relative, friend at 2.86, and if it is only a movement, a caution message will be executed at 149 cm in a total time of 10. 6 seconds, or in another case at 105 cm with a total time of 8 cm, while, in capacity control, data analysis facilitates the display of the number of people present and counts if 10 people entered in an estimated time and alerts on the maximum allowed capacity.

However, common challenges are faced in terms of reliability and adaptability. While vehicular intercoms must be accurate and function in various environments and emergencies with accurate cm and message execution, capacity control systems must be able to operate in different tourist and cultural scenarios, complying with current social distancing rules.

The article [30], which presents a system for monitoring vehicular traffic using technological devices, offers a practical and economical solution for traffic management. The three-tier architecture, which includes a mobile tracking system, an information gathering system, and fog devices, provides a robust platform for recording and analyzing vehicle movement. The accuracy and effectiveness demonstrated by the system in a real-world environment, such as the city of Corfu, highlight its potential to be deployed in various cities to improve traffic management and develop intelligent traffic-related services.

It integrates voice recognition to improve emergency response and vehicular traffic management with the traffic monitoring system of the article [30]. Both share the goal of optimizing traffic management but differ in their approach. The proposed system focuses on communication in emergencies, while the article [30] uses technological devices to monitor traffic. In terms of cost, the proposed system could be more economical than that of the article [30]. In accuracy, both aim to improve efficiency, but the accuracy of the proposed system depends on voice recognition.

In terms of the feasibility of implementation, the proposed system could be easier to integrate into existing vehicles. However, the proposed system has limitations, such as the possible effect of ambient noise on speech recognition accuracy and its focus on post-accident communication. Future research is proposed to improve speech recognition accuracy, integrate the system with accident prevention technologies, develop more intuitive user interfaces, and test in real-world environments.

In the article, the measurement tables are obtained where you can see the time used and the distance to see if a collision is obtained or not and thus manage the traffic emergency, with a distance of 0.03 gives a time of 0.02 therefore, a collision is not opened, with a distance of 0.77 gives a time of 0.45 therefore here a collision will not be realized, nor an emergency message will be sent either. But you get 2.04; the time will take 1.2 where if a vehicular emergency message is sent.

The convergence of these technologies represents a significant advance in vehicle emergency management and traffic monitoring. The integration of advanced communication systems and technology solutions not only improves the effectiveness of response teams but also provides a flexible and accessible platform for managing traffic in real-time. Continued research and development in this field is essential to overcome current challenges and exploit the full potential of these innovations.

5. Conclusions. - The state-of-the-art analysis showed various technologies and components, which allowed us to conclude that the integration of advanced electronic circuits and specialized sensors in this system offers a superior solution in terms of efficiency and reliability. Unlike other systems studied, the proposed design not only ensures secure connections with emergency contacts but also optimizes the response capacity in dangerous situations, sending alerts more quickly and accurately. This advance represents a significant improvement over previous work, underlining the effectiveness of the system in user protection and safety and confirming its relevance and superiority in the context of emerging alert technologies.

The evaluation of the risk prevention circuit carried out through simulations confirmed that the system is effective in detecting falls and potentially dangerous situations. The ultrasonic sensor measures distances and detects collisions, triggering alerts when predefined criteria are met. Table 1 shows that the system effectively detects collisions at distances ranging from 2.04 cm to 100.34 cm. In addition, simulations show that the system can issue preemptive warnings when it detects objects in a higher risk range, as detailed in Table 2, where distances range from 101.19 cm to 150.51 cm.

However, some limitations in the sensor's detection range were also identified. These limitations correspond to minimum and maximum distances outside the ranges established in the aforementioned tables. This finding underscores the importance of fine-tuning the system to improve its accuracy and ensure that alerts are issued effectively. Figures 19 and 21 show a trend line that shows the minimum distances, ranging from 0.02 cm to 1.96 cm, and the maximum distances, ranging from 151.36 cm to 177.72 cm, where it is shown that the system will not detect collisions or issue collision preventions.

The tests in Table 3 revealed the effectiveness of the emergency communication system based on distance detection. Data from the 50 tests showed that the total time from detection to sending an SMS varies significantly, from 1.8 seconds over very short distances to 10.6 seconds over longer distances. These results underscore the importance of response time in emergencies, where every second is crucial for user safety.

6. Recommendations. - The current system is effective in detecting risk situations and issuing the corresponding alarms. However, by expanding its design, the response to hazardous situations could be optimized. Considering that the SIM900l GSM module would cover up to 8 different contacts. This would make the system more versatile, increasing the likelihood of receiving a quick and appropriate response from multiple users and not specifically from one contact who might not be available at the time of the emergency.

To power the entire circuit through an external source, it is recommended to use a Power Bank that has a capacity of at least 10,000 mAh, with 5 V and 2 A output. This ensures an adequate and stable power supply for the correct operation of the circuit. The incorporation of other types of sensors, such as microphones, cameras, thermometers, ultrasound, proximity sensors, accelerometers, and gyroscopes, could offer new ways to improve the range and accuracy of the system.

In addition, new algorithms can be developed that transform the way data from different sensors is analyzed. This would help reduce false alarms and improve the system's ability to respond to truly emergent situations.

To adapt the vehicular emergency intercom system to blind people, proximity sensors could be integrated into the user's cane, in addition to an audio-guided function using voice recognition and audible notifications. These sensors would detect obstacles and nearby collisions, triggering audible alerts that provide information about the immediate environment.

The use of modern communication systems, such as 5G, would have a major impact on the clarity and speed of alert transmission. The speed of 5G connections would significantly outperform the 4G network, making it easier to send messages more efficiently. These aspects are crucial in hazardous environments where it is vital to address messages quickly to improve response. In addition, the system could automatically send emergency messages in the event of an accident. Benefits include greater autonomy and safety, as visually impaired people would be able to navigate more safely and receive immediate assistance in hazardous situations.

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Author contribution:
1. Conception and design of the study
2. Data acquisition
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4. Discussion of the results
5. Writing of the manuscript
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