A Microcontroller-Based Car Parking Warning System for Improved Parking Safety Using Ultrasonic Sensor

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ABSTRACT

The increasing number of vehicles on the road has led to a higher risk of accidents, especially during reverse parking and in congested traffic conditions. Many minor collisions occur due to limited rear visibility and the driver's inability to accurately judge distance. As a response to this problem, this project research focuses on the development of a low-cost and reliable reverse parking assistance system using an Ultrasonic Sensor and an Arduino Uno R3. The background of this study is rooted in the need for an affordable alternative to commercial parking sensors that can still provide accurate and real-time obstacle detection.

The main objective of this research is to detect obstacles located at the rear of a vehicle and provide timely warnings to help avoid collisions while parking or moving slowly in traffic. Specifically, the system aims to measure the distance between the vehicle and nearby obstacles and alert the driver through visual and audio indicators based on the detected distance.

The methodology of the study involves integrating an ultrasonic sensor with an Arduino Uno R3 microcontroller. The ultrasonic sensor continuously measures the distance of objects behind the vehicle by emitting and receiving sound waves. Based on the measured distance, the Arduino processes the data and activates a buzzer and LEDs. The LEDs light up sequentially in green, yellow, and red to indicate safe, caution, and danger zones, respectively, while the buzzer provides an audible warning as obstacles get closer.

The key results of the project show that the system is capable of accurately detecting obstacles in real-time and effectively providing distance-based alerts. In conclusion, the proposed system demonstrates a practical and efficient solution for reverse parking assistance, with potential for further improvement and application in advanced vehicle safety systems.

Keywords: Microcontroller; Ultrasonic Sensor; Distance; Parking system; LED indicator

INTRODUCTION

Sensors have a fundamental role in smart buildings since they gather data that is used to control appliances and building systems. It is relevant to virtually all aspects of life, including safety, security, surveillance, monitoring, and awareness in general, and widely used in various fields, including industrial automation, environmental monitoring, healthcare, and smart technologies [1]. As technology becomes more automated, the demand for accurate, dependable, and cost-effective sensor-based systems has grown rapidly. Sensors are frequently referred to as the "eyes and ears" of modern technology because they allow machines and systems to gain insight into their environment and make intelligent decisions based on real-time data [2]. Sensors have become essential in the automotive industry for enhancing safety and decreasing human error, especially during low-speed movements like parking, where limited sight and driver error commonly result in minor crashes and property damage [3]. To solve these issues, parking assistance systems using ultrasonic sensors have been developed to give drivers real-time distance information and warning messages [6].

During the implementation of microcontroller-based car parking warning system, researchers are often faced with challenges such as unstable wiring connections, constraints due to a limited budget, insufficient tools and

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equipment, and limited technical knowledge and experience of the researchers. Furthermore, integrating sensors with microcontrollers requires a clear understanding of electronic components, programming logic, and system calibration to ensure accurate and stable performance [8]. Addressing these challenges is important in developing reliable systems that can be applied in real-world situations.

This study focuses on designing and developing a microcontroller-based car parking warning system using an ultrasonic sensor, which measures the distance from the ground of selected points of a motor vehicle where it employs ultrasonic sensing technology in conjunction with a microcontroller to detect the distance between the sensor and the target object [7]. A car parking warning system that sends a sound pulse and measures how long it takes to return, allowing the Arduino to calculate the distance. This value is smoothed using averaging to avoid flickering. The project is designed to demonstrate the accurate data acquisition while maintaining the simplicity and cost-effectiveness.

The significance of this is its practical applications in automation and safety monitoring and also its educational value for computer engineering researchers. By creating and testing this project, the researchers are better able to comprehend the basic ideas of electronics and programming. The study contributes the basic principle of ultrasonic sensors, interfacing of microcontrollers, and data processing, which leads to a better understanding of sensor-based systems and their real-world applications. The ultrasonic sensor has a practical application because of its distance measurement and object detection without any physical contact. It is mostly used for vehicle parking assistance, in robotics for obstacle avoidance, and for automated industrial processes.

REVIEW OF RELEVANT THEORY, STUDIES, AND LITERATURE

Theoretical Framework

The theoretical framework explains the basic principles behind the microcontroller-based car parking warning system. The system uses an Arduino uno to calculate the distance, a microcontroller data that activates warning and ultrasonic sensor to send a sound pulse to measures how long it takes to return, LEDs and buzzer to provide the visual and buzzer for sound alerts. This process helps to improve the parking safety by providing an accurate distance warning during the parking.

Figure 1: Input-Process-Output (IPO) Model

Framework Summary

This Input-Process-Output (IPO) demonstrate how the car parking warning system works, from sensors input to actionable warning. As the car begin to turn on it will do first a self-test where all the LEDs and buzzer turn on for a moment then the ultrasonic sensor begin to detect the obstacle in its area then send the data to the microcontroller Arduino. When the Arduino receives the distance data it will start the calculation of the distance to determine the zone, this is where the LEDs and buzzer provide the feedback to the driver. Green lights for the safe zone, Yellow for caution and Red for danger zone and as for the buzzer slow beeps meaning a caution and fast beeps for danger zone. This ensures a real-time obstacle detection and improved parking safety.

Related Literature

Automotive Parking Assistance Systems using Ultrasonic Sensors (Barone & Lombardo, 2015)

This study examined the integration of ultrasonic sensors in automotive safety, focusing on the precision of signal processing. The researchers emphasized the importance of mathematical algorithms to filter out environmental noise and improve the reliability of distance readings. While technically advanced, the study focused primarily on high-end automotive applications rather than accessible, low-cost prototyping for aftermarket vehicle upgrades.

Ultrasonic Based Easy Parking System Based on Microcontroller (Mohapatra et al., 2020)

The authors developed a prototype aimed at assisting drivers during parking maneuvers using a microcontroller-based architecture. The research demonstrated that ultrasonic sensors provide a cost-effective solution for proximity detection. However, the system primarily relied on basic audio alerts, missing a multitiered visual warning system that could help drivers better gauge specific distance ranges intuitively.

Car Parking Distance Controller Using Ultrasonic Sensors Based On Arduino Uno (Susilo et al., 2021)

This research focused on the accuracy of distance measurement using the HC-SR04 sensor and the Arduino Uno. The study provided a framework for a distance controller that presents numerical data to the driver. While precise, the study noted that providing only numerical data may increase driver cognitive load; there is a identified need for a simplified, color-coded warning system to facilitate faster decision-making.

Microcontroller-Based Car Parking Warning System (Labrador et al., 2024)

The current study proposes an integrated safety system that combines an ultrasonic sensor with a three-tier warning mechanism (Green, Yellow, and Red LEDs) and a synchronized buzzer. Developed and validated through Tinkercad simulation, this research focuses on creating an intuitive user interface that allows for immediate reaction to obstacles. It addresses the gap between complex industrial systems and basic prototypes by providing a tiered safety-zone framework.

Table 1. Comparison Matrix of Related Studies and Current Research

STUDY	SENSOR USED	PLATFORM/TECHNOLOGY	KEY FEATURE(s)	GAP ADDRESSED BY THIS STUDY
Barone & Lombardo. (2020)	Ultrasonic	Automotive Signal Processing	Advanced signal filtering and reliability logic.	High technical complexity and cost; not designed for low-cost DIY or aftermarket application.
Mohapatra et al. (2020)	Ultrasonic	Microcontroller/Arduino	Simple audio alerts for proximity detection.	Lacks a tiered visual indicator system to help drivers judge varying levels of danger.
Susilo et al. (2021)	Ultrasonic (HC-SR04)	Arduino Uno	Numerical distance display and controller.	Relies on reading numerical data; lacks an intuitive color-coded response for rapid reaction.
Current Study (Labrador et al.)	Ultrasonic (HC-SR04)	Tinker cad/Arduino Uno R3	Three-tier LED indicators (Green, Yellow, and Red) and synchronous buzzer alerts.	Addresses the need for an intuitive, visual safety framework that simplifies distance judging for the driver.

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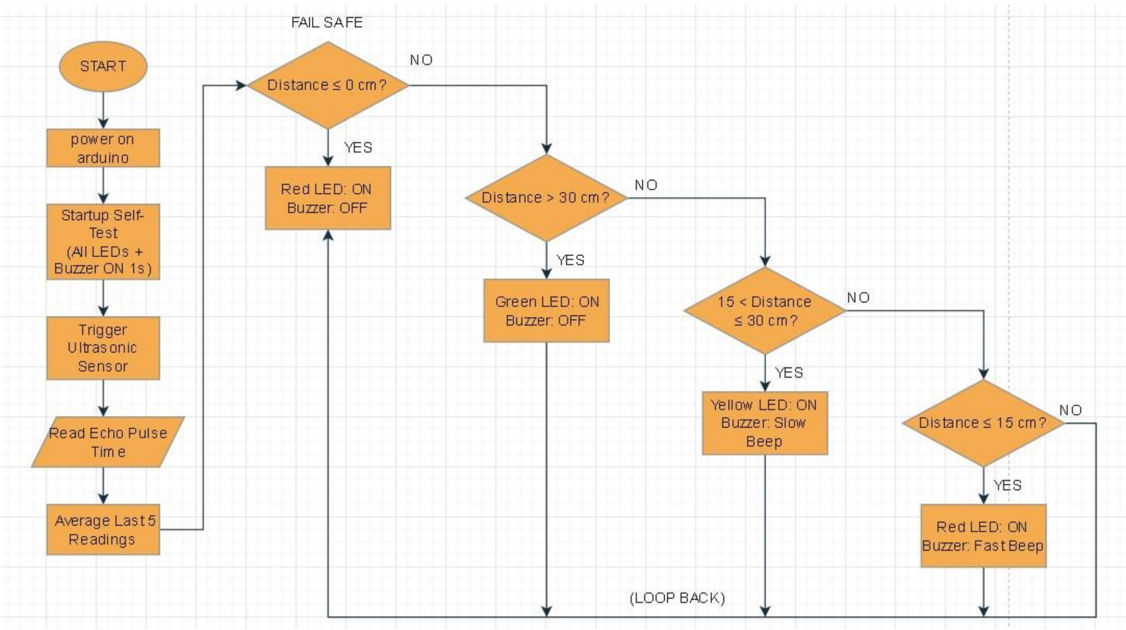
METHODOLOGY

The methodology of this project follows a systematic and step-by-step approach to ensure the proper design, development, and testing of the reverse parking assistance system.

Step 1: Project Planning and Conceptualization

The initial phase of the project involves conducting brainstorming sessions to clearly define the project concept, objectives, and expected output. During this stage, the required materials and components such as the Arduino Uno R3, ultrasonic sensor, LEDs, buzzer, resistors, breadboard, and wiring are identified. A preliminary project layout is also designed to determine the placement of components, and an estimated budget is calculated to ensure that the project remains cost-effective and feasible.

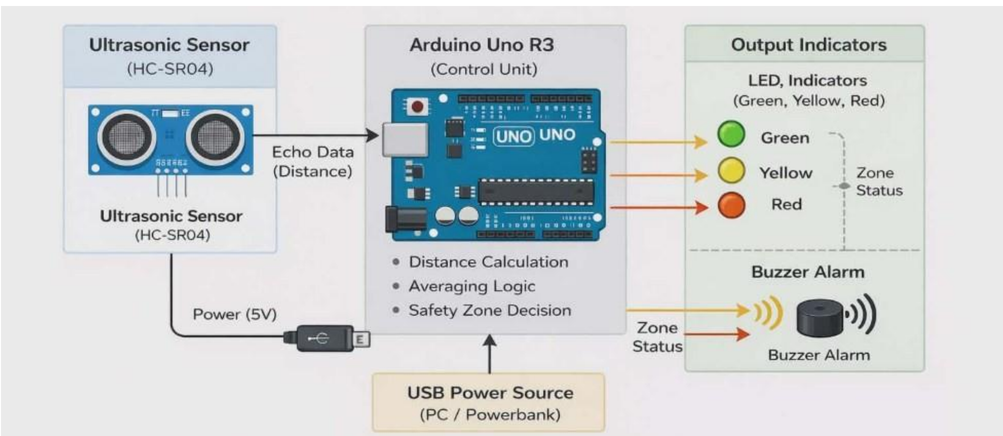
Figure 1. Flow Chart



This flowchart shows how the parking sensor system works from start to finish. When the Arduino is turned on, it first performs a self-test by turning on all LEDs and the buzzer to check if the components are working. After that, the ultrasonic sensor sends a signal to measure the distance of an object, and the system averages the last few readings to make the result more stable.

The system then decides what warning to show based on the distance. If the object is far, the green LED turns on to show it is safe. If the object gets closer, the yellow LED lights up and the buzzer beeps slowly as a warning. When the object is very close, the red LED turns on and the buzzer beeps faster to signal danger. The process repeats continuously to keep monitoring obstacles while parking.

Figure 2. Block Diagram



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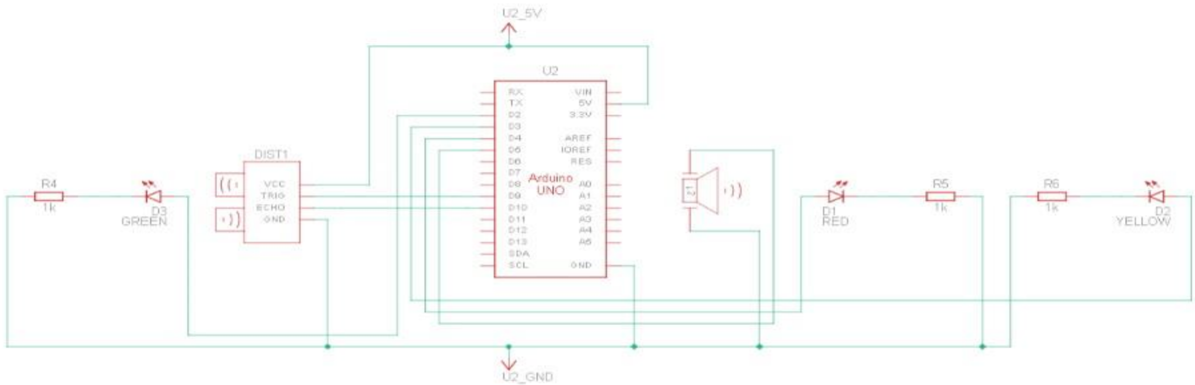
The block diagram shows how the car parking safety system works using an ultrasonic sensor and an Arduino Uno. The ultrasonic sensor detects the distance of objects behind the vehicle and sends this distance data to the Arduino Uno. The Arduino acts as the control unit where it calculates the distance, smooths the readings, and decides which safety zone the object is in.

Based on the processed distance, the Arduino activates the output indicators. The green LED turns on when the object is far, the yellow LED lights up as a warning when the object is closer, and the red LED turns on when the object is very near. At the same time, the buzzer produces sound alerts depending on how close the obstacle is. The entire system is powered by a USB power source such as a power bank or computer, allowing the system to work continuously while the vehicle is in use.

Figure 3. Schematic Diagram



It shows the complete schematic wiring of the ultrasonic sensor–based parking system, showing how each component is connected to the Arduino Uno to detect obstacles and give warnings. The trigger and echo pins of the ultrasonic sensor are connected to the Arduino to measure the distance of objects behind the vehicle. The green, yellow, and red LEDs are connected to different digital pins to show safe, caution, and danger distances. A buzzer is also connected to the Arduino to give a sound warning when an object is very close. All components use the same power and ground connections from the Arduino. This schematic shows how the Arduino, sensor, LEDs, and buzzer work together to help avoid accidents while parking.

Step 2: Circuit Simulation and Programming

Before actual hardware assembly, the circuit wiring and Arduino program are simulated using Tinkercad. This step allows the researchers to verify the correctness of the circuit connections and test the logic of the Arduino code. Possible errors in wiring and programming are identified and corrected at this stage, reducing the risk of damage to components during physical implementation.

```
  total -= readings[index];
  readings[index] = rawDistance;
  total += readings[index];
  index = (index + 1) % 5;

  distance = total / 5;

  Serial.print("Distance: ");
  Serial.println(distance);

  if (distance <= 0) {
    digitalWrite(greenLED, LOW);
    digitalWrite(yellowLED, LOW);
    digitalWrite(redLED, HIGH);
    digitalWrite(buzzer, LOW);
    return;
  }

  if (distance > 30) {
    digitalWrite(greenLED, HIGH);
    digitalWrite(yellowLED, LOW);
    digitalWrite(redLED, LOW);
    digitalWrite(buzzer, LOW);
  }
```

```
  else if (distance > 15 && distance <= 30) {
    digitalWrite(greenLED, LOW);
    digitalWrite(yellowLED, HIGH);
    digitalWrite(redLED, LOW);

    int beepDelay = map(distance, 15, 30, 100, 400);
    digitalWrite(buzzer, HIGH);
    delay(beepDelay);
    digitalWrite(buzzer, LOW);
    delay(beepDelay);
  }
  else {
    digitalWrite(greenLED, LOW);
    digitalWrite(yellowLED, LOW);
    digitalWrite(redLED, HIGH);

    int beepDelay = map(distance, 1, 15, 50, 150);
    digitalWrite(buzzer, HIGH);
    delay(beepDelay);
    digitalWrite(buzzer, LOW);
    delay(beepDelay);
  }
}
```

This code is used to run an ultrasonic sensor parking system using an Arduino. The ultrasonic sensor measures the distance of an object by sending and receiving sound waves. The Arduino then calculates the distance and shows the result using LEDs and a buzzer.

When the system starts, all LEDs and the buzzer turn on for a short time to check if they are working. During operation, the distance readings are averaged to make the output more stable. If the object is far, the green LED turns on to show it is safe. When the object gets closer, the yellow LED lights up and the buzzer beeps slowly as a warning. If the object is very close, the red LED turns on and the buzzer beeps faster to show danger.

Overall, the code helps detect obstacles and gives simple warnings to avoid accidents during reverse parking.

Step 3: Structural Redesign of the Car Model

The car structure is then modified to accommodate the additional electronic components. Openings and slots are carefully created to properly mount the ultrasonic sensor, LEDs, and wiring without affecting the overall stability and appearance of the model.

Step 4: Hardware Assembly

All electronic components are assembled inside the car model. The Arduino Uno, breadboard, resistors, LEDs, buzzer, and connecting wires are securely installed based on the finalized circuit design to ensure proper electrical connections and system reliability.

Step 5: Power Supply Integration

A portable power bank is used as the main power source of the system. This provides a stable and sufficient power supply to the Arduino and all connected components, allowing the system to operate independently.

Step 6: System Testing and Evaluation

Finally, the system is powered on and tested under different conditions. The ultrasonic sensor's distance detection, LED indicators, and buzzer alerts are observed to ensure that the system functions accurately and as intended. Any necessary adjustments are made to optimize performance.

RESULTS & DISCUSSION

The development and simulation of the Microcontroller-Based Car Parking Warning System yielded significant empirical data confirming its efficacy as a real-time safety tool for obstacle detection. By utilizing a developmental research design, the system was verified in a simulated environment to ensure that the integration of hardware and software met all predefined safety objectives. The following subsections detail the functional requirements, the comprehensive empirical test results, and an in-depth analytical discussion of the system's operational behavior

Requirements

The system's operational reliability is centered on the interaction between high-precision sensors and a microcontroller programmed with a specific safety logic. The table 2 defines how the primary inputs are translated into tiered visual and auditory outputs based on distance parameters, which ensures an intuitive and responsive interface for the driver.

Table 2. Variables and Conditions of the Car Parking Warning System

Variable/Component	Type	Function	Control from Arduino	According to Logic
Ultrasonic Sensor	Sensor	Measures distance between vehicle and obstacle	Trigger and Echo pins	Continuously provides distance data

Green LED	Output Indicator	Indicates safe distance	ON when distance > 30 cm	Safe parking condition
Yellow LED	Output Indicator	Indicates caution	ON when 15 cm < distance ≤ 30 cm	Warning zone
Red LED	Output Indicator	Indicates danger	ON when distance ≤ 15 cm	Immediate stop warning
Buzzer	Output Alarm	Audible warning signal	Beep rate based on distance	Beep rate based on distance
Arduino Uno R3	Controller	Processes sensor data and controls outputs	Executes loop logic	Real-time monitoring
9V Battery	Power Source	Supplies power to the system	External supply	Independent system operation
220Ω Resistor	Protection	Limits LED current	Series connection	Prevents LED damage

The system was subjected to ten distinct test cases to verify the reliability of the thresholds and the stability of the output signals. These tests confirm that the Arduino-based logic accurately interpreted the sensor data across all safety zones.

Table 3. Variables and Conditions of the Car Parking Warning System

Test #	Input Condition	Observed Output	Expected Output	Pass/Fail	Remarks/Behavior
1	No object detected (distance > 100 cm)	Green LED ON, buzzer OFF	System in safe mode	Pass	Correct safe-zone detection
2	Object at 50 cm	Green LED ON, buzzer OFF	Safe distance indication	Pass	System remains stable
3	Object at 30 cm	Yellow LED ON, slow buzzer beep	Caution mode activation	Pass	Accurate threshold response
4	Object at 25 cm	Yellow LED ON, moderate buzzer beep	Increased warning	Pass	Distance-based alert works
5	Object at 20 cm	Yellow LED ON, faster buzzer beep	Strong caution alert	Pass	Warning intensity increases
6	Object at 15 cm	Red LED ON, fast buzzer beep	Danger mode activation	Pass	Critical distance enforced

7	Object at 10 cm	Red LED ON, very fast buzzer beep	Immediate stop warning	Pass	Maximum alert triggered
8	Object approaching rapidly	LEDs and buzzer update instantly	Real-time response	Pass	Loop logic verified
9	Sensor reading fluctuates (noise simulation)	Stable LED behavior	No false triggering	Pass	Distance averaging effective
10	Sensor error or invalid reading	Red LED ON, buzzer OFF	Fail-safe mode	Pass	System enters safe state

The results of the study indicate that the car parking warning system is a reliable and accurate alternative to the commercial sensors, providing a real-time obstacle detection with high precision. Based on the data in Table 3, the system demonstrated a 100% success rate in activating the correct visual and audio indicators at the specified distance. The integration of the ultrasonic sensor with the Arduino Uno R3 allowed for seamless data processing, where the trigger and echo pins provided instantaneous distance readings that the micro-controller then translated into the tiered warnings, or in this case, the LEDs.

A significant technical achievement observed was the system's stability during "noise simulation" (Test Case 9). By implementing a distance-averaging algorithm in the code, the researchers were able to smoothed out signal fluctuations, which in return prevents the flickering of LEDs, a common issue that is always present in basic proximity circuits. Furthermore, the inclusion of a fail-safe mode (Test Case 10) ensures that the system enters a safe state if an invalid reading occurs, preventing erroneous signals from misleading the driver. This automated tiered response significantly reduces the cognitive load on the driver, allowing for faster reactions without the need for monitoring numerical displays during stressful parking maneuvers.

CONCLUSION & RECOMMENDATIONS

The Microcontroller-Based Car Parking Warning System successfully fulfilled its primary objective of providing an accurate, low-cost solution for enhancing vehicle safety. By integrating an Arduino Uno R3 and HC-SR04 ultrasonic sensor, the study demonstrated that a tiered alert system that utilized color-coded LEDs and variable-frequency audio, which can effectively guide drivers and prevent minor collisions on vehicleheavy environment. Simulation results validated the system's ability to maintain total accuracy across safe, caution, and danger environments/scenario.

During the developmental phase, the study addressed several technical challenges, such as loose connections and signal instability. These were resolved by transitioning to a more stable circuit layout and refining the software logic to include data filtering and distance averaging. These solutions ensured the prototype's operational integrity and reliability throughout the testing phase. On the other hand, for the future development and expansion of this research, it is recommended to:

1. **Integrate an LCD Display:** To provide drivers with exact numerical distance data along with the color indicators for better and enhanced precision.

2. **Implement Multiple Sensors:** To cover a wider field of view, thereby reducing blind spots at the vehicle's rear corners, which in some cases is susceptible to contact with the environment.

3. **Transition to Physical Prototyping:** Move from simulation to physical vehicle installation to test the system against real-world environmental factors, such as varying weather, road conditions, and vehicle type.

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