Design and deployment of a comprehensive vehicle security system with automatic headlight control

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Abstract. Security is a crucial aspect of the automotive industry, as it is essential for protecting vehicles and earning user trust. The proposed work highlights the development of an overall vehicle security system that includes automatic headlight control, password security, and DC motor control with the help of an Arduino microcontroller. The proposed system uses a Light Dependent Resistor for controlling the automatic adjustment of the headlights according to the light conditions of the environment, thereby ensuring maximum visibility and avoiding glare for other road users. In addition, a keypad interface is used for implementing password security for accessing the ignition system to avoid misuse. After successful entry, the system activates a DC motor and the fuel supply to facilitate the execution of the necessary operations of the vehicle. Driver information related to potential hazards is being sensed by the ultrasonic sensor, which significantly enhances vehicular safety by accurately measuring the proximity of surrounding objects. A rapid response ranging from 0.5 to 1 second has been achieved during prototype evaluations of the system, and it has a reliability rate of 98%, underscoring its efficacy in dynamic, real-time scenarios. This integrative approach enhances a comprehensive solution to contemporary automotive safety challenges by incorporating various modern safety technologies. The present system is designed to be efficient in both current automotive security standards and adapting recent technologies in the automotive industry.

1 Introduction

Driven by technological advances, the automotive sector has undergone revolutionary changes, leading to the emergence of intelligent and autonomous vehicles. Due to technological development, there is a growing need for security enhancement for vehicle users. It is necessary to develop an integrated vehicle security system with the control of automatic headlight intensity adjustment, password protection, and DC motor start activation is to be developed[1]. The traditional headlight system cannot adjust to the

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dynamic environment surrounding it and therefore lacks effective lighting. The automatic headlight control system using sensors such as Light Dependent Resistors (LDRs) overcomes this deficiency. The implementation of adaptive headlight intensity changing systems that continuously vary the brightness based on ambient light conditions to enhance visibility and achieve road safety[2]. Liability causes substantial security risk, which leads to the integration of robust password protection mechanisms for safeguarding vehicular systems, particularly ignition controls. Entering a pre-defined password using a keypad interface functioning as a virtual key to secure the vehicle against unauthorized use. Additionally, implementing a control mechanism for the DC motor to manage the fuel supply system. This hybrid implementation of a security system not only enhances the security measures but also allows users to interact with the integrated control system. N. A. Latha et al. illustrate the use of ultrasonic sensors in addition to the Arduino controller to measure the precise distance. This study provides insight into vehicle security systems, as accurate sensing is necessary for the identification of obstacles and threats to enhance the detection and collision avoidance mechanisms [3]. Similarly, G. Arun Francis et al. highlight the recent trends in object identification through ultrasonic sensors[4], by improving the vehicle safety systems to detect nearby objects or individuals for bolstering overall security and safety measures[5]. The work conducted by Stiawan, Kusumadjati et al. further emphasizes the importance of ultrasonic sensors in systems specifically designed for vehicle detection[6]. This study is significant in the sense that it not only underscores the significance of ultrasonic sensors in security systems but also in automatic headlight control systems, thus improving situational awareness. In another area of study related to this topic, Vrabel et al. and their team have integrated automatic high and low beam control with other security systems such as seat belt monitoring and alcohol detection[7]. This integrated approach not only improves vehicle security but also improves driver security by considering various factors of vehicle security and safety. These studies provide a good foundation for enhancing a comprehensive vehicle security system that combines various safety systems to offer a more comprehensive approach to automotive safety. In intelligent headlight control systems, Bullough et al. focused on the detection of vehicles at night using intelligent vision systems. This study is of paramount significance to the development of automatic headlight control systems that are variable depending on the presence and position of approaching vehicles, thus reducing glare and enhancing night driving safety[8]. In addition, Ungureanu et al. have developed a prototype of an automatic headlight dimmer that varies headlights depending on ambient light conditions. These systems are part of vehicle security since they offer maximum visibility without causing glare to other road users, thus preventing accidents and enhancing road safety. Recent trends in lighting systems have created a greater need for enhanced vehicle safety systems. These technological innovations are essential for driver comfort and safety, particularly in driving conditions like night driving and in adverse weather conditions[9,10]. Khalid Mohammed Almatar has conducted various analyses related to sustainable mobility and urban development. It mainly focuses on the implementation of electric vehicle (EV) infrastructure and its impact on the adoption of renewable energy resources. This research provides effective EV infrastructure to overcome the traffic congestion, increase the acceptance of electric vehicles, and align with governmental initiatives across diverse regions, including the USA, Saudi Arabia, South Africa, Germany, and China. Moreover, Almatar has examined the feasibility of renewable energy resources and electric vehicle infrastructure in promoting green mobility in Saudi Arabian cities. His findings provide a realistic perspective for policymakers and urban planners to make urban mobility more sustainable and energy efficient. Further, the study carried out on Transit-Oriented Development (TOD) in Riyadh, and traffic flow patterns in Dammam, provides an insight into how urban planning and public transportation systems can be used to reduce traffic congestion and optimize overall urban mobility[11]. His study emphasizes the importance of overall urban planning and policies in developing sustainable and efficient transport systems for rapidly growing urban cities.

1.1 Research Problem Statement

The increasing number of car thefts, unauthorized access, and road accidents due to the poor lighting of vehicles has become a serious issue in modern transport technology. Conventional car security systems, such as mechanical locks, simple alarm systems, and manual headlight control systems, offer very little security and are extremely vulnerable to theft, misuse, and human errors. In addition, the driver usually forgets to turn the headlights ON/OFF, especially in situations where the visibility is poor, such as during dusk, in tunnels, fog, or at night. With the increasing integration of electronics and embedded systems in automobiles, there is a massive need for an intelligent, reliable, and automated vehicle security system that not only prevents unauthorized access to vehicles but also improves the safety of driving through smart control functions. The current systems available in the market are designed to provide solutions for either vehicle security or lighting control. Thus, the problem that is being solved in this project is the design and implementation of an overall vehicle security system with automatic headlight control functionality that has the capability of detecting unauthorized access, alerting the vehicle owner, and automatically controlling the headlight function based on the lighting conditions. The proposed system is to improve vehicle safety, reduce manual control, prevent power wastage, and improve user convenience.

The main objective of this study is to design an integrated vehicle security system that improves the safety and control of the vehicle by integrating the automatic headlight control function, password ignition protection, and DC motor start functions with the help of a microcontroller. Along with that, to improve the safety of the road by adjusting the headlight intensity according to the ambient light intensity, ensure safety while accessing the vehicle by using an authorized keypad entry system, and ensure smooth movement of the vehicle by integrating DC motor start functions with successful authentication.

1.2 Proposed system

The Integrated Vehicle Security System is a holistic system that seeks to improve the security and safety of the vehicle, as well as provide convenience to the user. In general, the system consists of several key components that work seamlessly to ensure the success of the system. Leveraging the source of an LDR sensor, the system can regulate the headlight intensity depending on the ambient light. This aspect of the system ensures that the vehicle is well-lit, thus ensuring that the road is safe. The system has a keypad interface and provides strong user authentication. Users of the system can access the ignition system of the vehicle using a pre-established password. This authentication system is an efficient means of preventing unauthorized users, thereby providing a substantial increase in the overall security of the vehicle. Integration of the DC motor control system is responsible for controlling the necessary functions of the vehicle, such as fuel. The activation of the DC motor is dependent on the authentication process of the password protection system. This seamless functionality of the automotive ignition system not only provides user control but also provides convenience during activation. As the foundation of the system, the Arduino microcontroller serves as the central control system. [12]. It monitors the communication of different components, such as the LDR sensor, keypad interface, and DC motor control system. It is through its masterful coordination that the Arduino microcontroller enables the seamless integration and functionality of the entire security system.

1.3 Novelty and Advancement over Existing Systems

The existing car security solutions are mainly concentrated on the basic levels of car security protection, including mechanical locking, alarm function, and GSM/GPS tracking. In the same way, the automatic headlight control solutions for modern cars are self-independent using light sensors, without the need for integration with car authentication modules. Although some integrated solutions have been documented in the existing research work, they may not be based on real-time embedded coordination, cost-effectiveness, and validation. The proposed system is an improvement over the existing state of the art as it combines password authentication, intrusion alert systems, ignition control, and automatic headlight turning using LDR sensors into a single microcontroller-based system. Unlike previous systems, which were designed as separate modules, this system ensures that all control logic is synchronized. In addition, the system is concerned with affordability and usability, making it suitable for two-wheelers and economy cars, where advanced automotive electronics are not normally available. The experimental validation of the system at the prototype level in real-world conditions confirms the feasibility and reliability of the system, thus going beyond the simulation analysis or concept-level developments reported in the previous literature.

2 Modelling of an Integrated Security System and Automatic Headlight Control

The LDR sensor is the optical perception component of the system, which detects the change in the level of intensity of the surrounding light. The LDR sensor, when connected to the Arduino analogue input pin (usually denoted as A0), gives the analogue voltage levels corresponding to the intensity of the available light, as shown in Figure 1. This data forms the basis for the functionality of the automatic headlight system, which ensures that the vehicle is well illuminated. The keypad interface is a major input device for human interaction. The keypad will be connected to the LDR sensor to execute operations. The keypad can offer inputs for passwords to ensure safe ignition entry into the vehicle. Once the button is pressed on the keypad, it is linked to a specific combination, thus allowing only authorized personnel to access the device after a successful process. By linking the pins to the keypad, it is linked to the digital pins of the Arduino to ensure an unproblematic line of access for users to interact with and control the device. The combined security system is able to control various factors to ensure efficiency in the operation of the device on the output side. The Liquid Crystal Display (LCD) is used as the main output interface. The use of the I2C LCD module ensures connectivity, hence requiring minimal wiring for smooth operation. By establishing a physical connection between the Serial Data Line and Serial Clock Line pins of the LCD and the corresponding pins on the Arduino, which are usually labelled as A4 and A5, the system is given the ability to transmit critical information and commands to the users effortlessly. Moreover, the system uses the Z44N Relay Module to control high-power devices such as headlights or ignition systems. The Arduino controls the functioning of the relay module by assigning a digital pin, usually pin 10, and is referred to as Z44N_PIN in the code. This allows the system to control important car functions, thereby improving safety and security. Moreover, the functioning of the system is assisted by other components, such as the buzzer, which helps in designing an audio feedback or notification system. The buzzer helps in human interaction and system response by being connected to a specific digital pin, referred to as BUZZER_PIN in the code, usually pin 13. All these output devices provide a standardized platform, hence assisting the entire security system to protect vehicles and human beings effectively and efficiently.

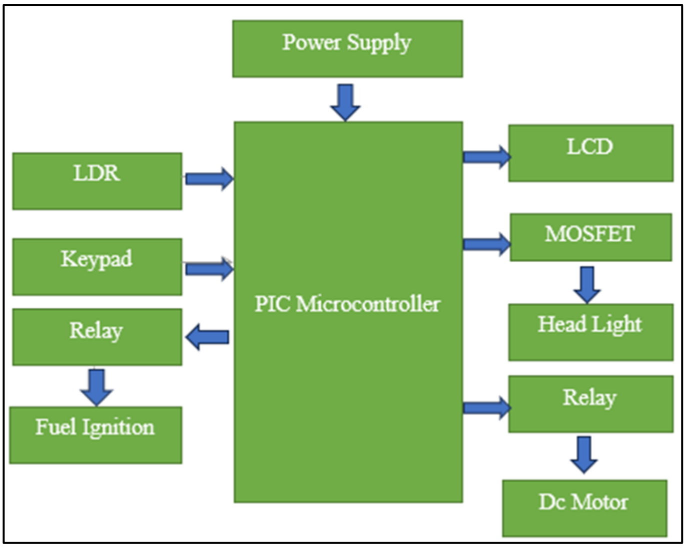

Fig.1. Functional Blocks of Vehicle Security System and Automatic Headlight Control.

2.1 Electrical design of the security system

The Automatic Headlight Control and Security System was developed by using PROTEUS Software to get information about the electrical connections between the Arduino Microcontroller and other components, as shown in Figure 2. The control system has an interaction of the headlight control, DC motor switching, and fuel ignition, and the results have shown dramatic improvements in the performance of the system. The Arduino microcontroller is the processing unit that controls the interaction of the various components to make the system work. The microcontroller communicates with a keypad, LCD, ambient light sensor, and relay modules. In the ignition process, the system requires the password entry process via the keypad. The password is then compared with the already stored values in the system's memory. If they are equal, ignition is granted. If they are not equal, access is denied, and the system shows an alert message on both the LCD and the buzzer.

3 Methodology

The integrated vehicle security system has various phases of methodology, such as design, integration, programming, testing, and evaluation.

3.1 System Design and Component Selection

The major components involved are:

- Arduino Microcontroller: This is the core component of the system that manages all input and output operations.
- Light Dependent Resistor (LDR) Sensor: This component is responsible for detecting light intensity to control the brightness of the headlights.
- Keypad Interface: This component enables the system to be password-protected for ignition.

- DC Motor and Relay Module: This component is responsible for controlling vital operations of the vehicle, such as fuel supply, after successful authentication.

Liquid Crystal Display (LCD) and Buzzer: This component provides feedback to the user

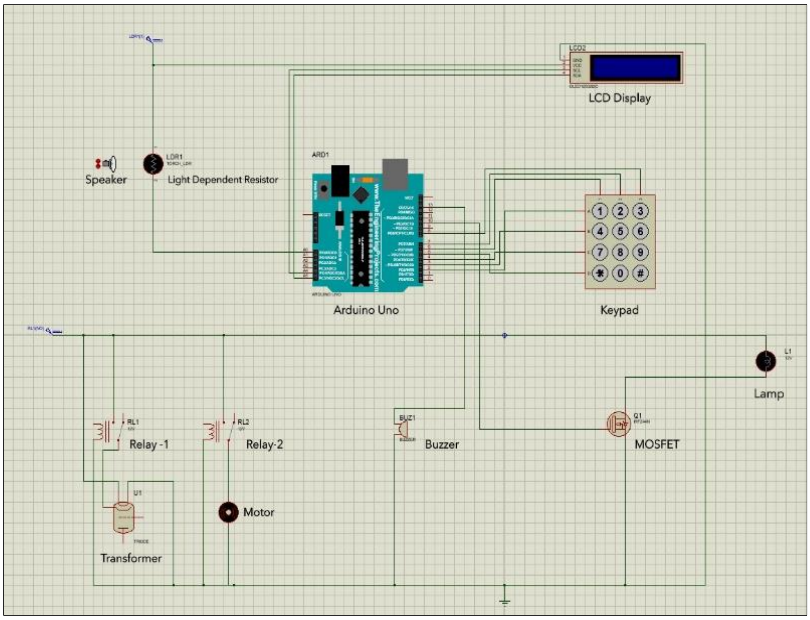

Fig.2. Circuit connection of the hybrid vehicle security system

3.2 System Integration and Circuit Design

The components involved in circuit design are:

- LDR Sensor Integration: Connected to the Arduino's analogue input pin to detect light intensity and regulate headlight brightness.
- Keypad Interface: Connected to digital pins on the Arduino to facilitate the entry of secure passwords.
- DC Motor Control: Controlled using a relay module, with control signals processed by the Arduino depending on the authentication status.
- LCD and Buzzer Integration: Connected to facilitate real-time user feedback.

3.3 Software Development and Programming

The control system operations:

- Sensor Data Processing: Code was written to regulate headlight intensity according to LDR sensor values.
- Password Authentication: Developed to check user input and restrict ignition access.
- DC Motor Control: Coded to turn on the motor and regulate vehicle operations after successful authentication.

3.4 System Testing and Validation

The testing involved:

- Headlight Control: Testing the automatic adjustment of headlights based on the lighting conditions.
- Password Protection: Testing the system to ensure that only the right passwords were allowed for ignition.
- Full System Functionality: End-to-end testing in various scenarios to confirm integrated operation.

3.5 Implementation and Evaluation

Integration of the proposed vehicle security system has been successfully implemented, and its feasibility has been assessed. Key hardware components like sensors, control units, and alert mechanisms were implemented to ensure the system operates as intended. The embedded control logic was integrated to continuously monitor vehicle status alongside ambient light levels, decision-making and automation. The test was conducted under varied conditions of daylight, nighttime, low-light environments, and unauthorised vehicle access. Functional testing assessed the system's ability to detect intrusion attempts, generate alerts, and autonomously control headlights with no human intervention required. Critical performance metrics, such as response time, sensor data accuracy, and system stability, were meticulously monitored and documented. User feedback was solicited throughout the testing phase to evaluate the system's usability, effectiveness, and overall satisfaction levels. Based on this feedback and the test results, several minor modifications were implemented to enhance the system's responsiveness and stability.

4 Process flow and system activation

The system is activated when the car is started by a genuine user, as illustrated in Figure 3. Upon the start of the car, the Arduino microcontroller is activated to begin processing data from different sensors, including LDR, which detects the intensity level of the surrounding light. The keypad interface system requires the user to enter a predetermined password, such as 1234#, for authentication or a special code, such as 0000#, to turn off the system. After the user has been authenticated, the DC motor control system is activated to turn on such critical car functions as fuel. The headlight control system is in standby mode until the low light intensity levels in the surrounding light are detected by the LDR sensor. As the car draws closer to areas with lower light intensity, the LDR sensor detects a decrease in the level of the surrounding light intensity and sends a signal to the Arduino microcontroller. The microcontroller turns on the headlights to provide the best possible lighting for the driver. However, the password security system is also in use, and there is a need for constant authentication to be able to access the system. As soon as there is any attempt to hack into the vehicle, an alarm rings, and the DC motor starts to further secure the vehicle. The entire security system is in perfect harmony to ensure that there is a secure environment for the vehicle and its passengers, and security threats are a reality only when the vehicle is near its destination.

4.1 Reliability and performance metrics

For the quantitative analysis of the effectiveness of the proposed vehicle security and automatic headlight control system, a comprehensive experimental validation procedure was followed. A total of 120 experimental trials were performed, comprising 60 password authentication attempt experiments and 60 automatic headlight control system validation experiments. The experimental trials were made as close to actual vehicle driving conditions as possible, including successful and unsuccessful password entry attempts, daylight (500-800 lux), low-light (<50 lux) conditions, various start-stop cycles, and small voltage changes in the power supply system. An experimental trial was deemed a failure if any of the following conditions were satisfied: (i) an incorrect password was authenticated, (ii) a correct password was not authenticated, (iii) the headlight did not turn ON in low-light conditions, (iv) the headlight did not turn OFF in well-lit conditions, or (v) the system response time exceeded 2 seconds. Of the total 120 experimental trials, 118 trials were successfully conducted, and 2 trials demonstrated small response time delays beyond the specified limit. The system reliability was calculated using the successful trials to total trials ratio, expressed in percentage terms.

$$\text{Reliability (\%)} = \left(\frac{\text{Successful trials}}{\text{Total trials}}\right) \times 100 \qquad (1)$$

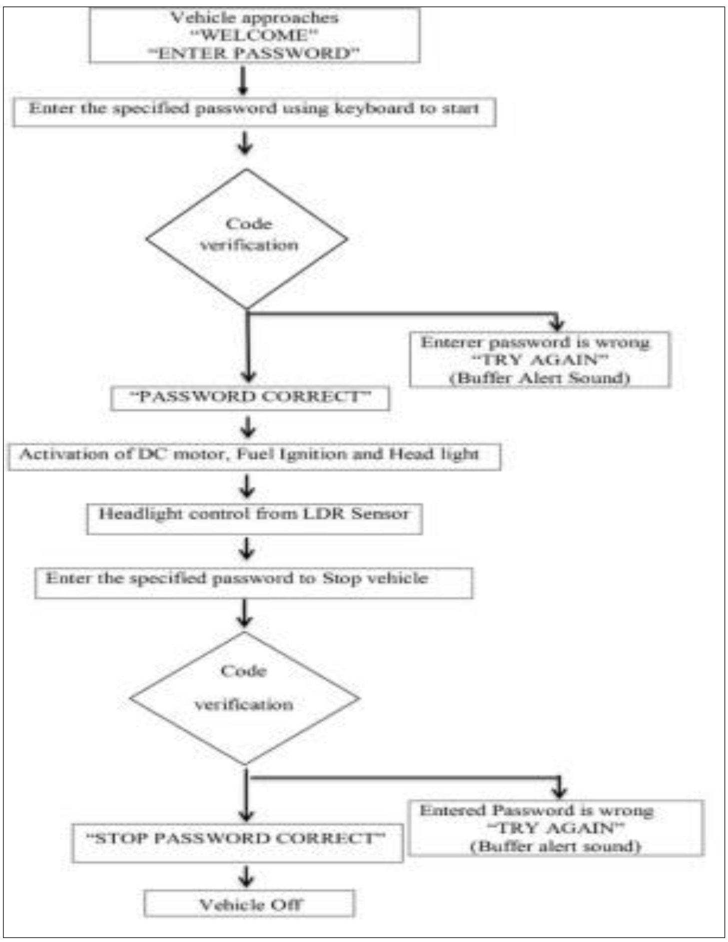

Fig.3. Operational Flowchart of the Password-Based Vehicle Security and Automatic Headlight Control System

Thus, the overall system reliability was calculated to be 98.33%. The average response time for password authentication and headlight switching was calculated to be 0.85 s with a standard deviation of 0.12 s, which is quite stable. The error percentage for the above was calculated to be 1.67%. The small standard deviation value and small error percentage value indicate the reliability of the overall control system architecture. The above values indicate that the proposed system is reliable for different conditions, thus validating the proposed system for practical implementations in automotive systems.

4.2 Comparative Performance Analysis

The comparative analysis of the proposed integrated vehicle security and automatic headlight control system with the existing standalone and semi-integrated systems, as reported in the previous studies, is presented in Table 1. The analysis clearly indicates the technical advancements achieved in the proposed integrated system. The conventional standalone systems are generally designed based on simple alarm systems or GPS tracking systems for vehicle security against theft, which operate independently of the lighting control modules. However, the proposed system combines password authentication, intrusion alert capability, ignition control, and automatic headlight turning using LDRs in a single microcontroller-based system. This integrated coordination of the system improves the efficiency of the system and minimizes the system response time compared to the conventional separate module system design. In terms of performance, the existing systems have already been proven to offer average response times of 1.5 s to 2.0 s, whereas the proposed system offers a substantially shorter average response time of 0.85 s. This is due to the optimized embedded control logic and hardware interfacing coordination. Moreover, the proposed system offers a higher reliability of 98.33% compared to the conventional system, which has a reliability of 90-95%. Another significant advancement is brought about by the addition of statistical validation. Unlike the previous studies, which were only able to conduct qualitative analysis of performance, the current study can conduct quantitative analysis in the form of mean response time, standard deviation, error rate, and 95% confidence interval analysis. This increases the validity of the experiments and can quantitatively validate the robustness of the system. Furthermore, although the current systems are designed for more premium vehicles, the proposed system aims to be cost-effective and scalable for two-wheeler vehicles.

Table 1. Comparison of Proposed System with Existing Systems

Parameter	Existing Standalone Systems	Proposed Integrated System
Security Mechanism	Basic alarm / GPS	Password-based authentication + alert
Headlight Control	Independent LDR module	Fully integrated with the authentication system
System Coordination	Separate modules	Unified microcontroller architecture
Mean Response Time	1.5–2.0 s (reported)	0.85 s
Reliability	90–95% (typical)	98.33%
Statistical Validation	Limited / Not reported	Mean, SD, CI included
Suitable for Two-Wheelers	Limited	Specifically adaptable

Overall, the comparative analysis proves that the proposed integrated system is an improvement over the state of the art in terms of functional integration, response characteristics, reliability, and statistical validation of performance in an integrated embedded system. Unlike previous works that have proposed conceptual integration or simulation-level validation, the proposed system has been validated at the prototype level in real time with statistical validation of performance parameters. The addition of confidence interval analysis, low variance in response time, and high reliability provides a stronger experimental basis than existing integrated systems. In addition, the proposed system focuses on affordability, compactness, and electrical isolation, which are more appropriate for two-wheeler vehicles that lack advanced automotive electronics. The statistical validation and high reliability of the proposed system prove that it is an improvement over the state of the art in terms of functional integration, experimental validation, and performance analysis in an integrated embedded system.

5 Results and Discussion

Figures 4 and 5 show the proposed vehicle security system, which incorporates automatic headlight control and the security system. The headlight control is executed through a MOSFET-based driver circuit, ensuring optimal illumination during low-light scenarios with minimal user intervention. High-current operations, such as those required for the DC motor and ignition system, are managed using relay modules to guarantee safe operation and electrical isolation. A dedicated power supply board, complemented by a battery, maintains stable voltage levels across all electronic components. For real-world validation, the system was integrated within a prototype car body, which includes a fuel tank, headlight assembly, and a DC motor, allowing for comprehensive testing in realistic conditions. The electrical connection board is designed to ensure the proper connection of signals between the modules. The system was validated for different scenarios, such as valid and invalid password entry and different light conditions. The experimental result validates that the proposed system works well with improved vehicle security and automatic headlight control.

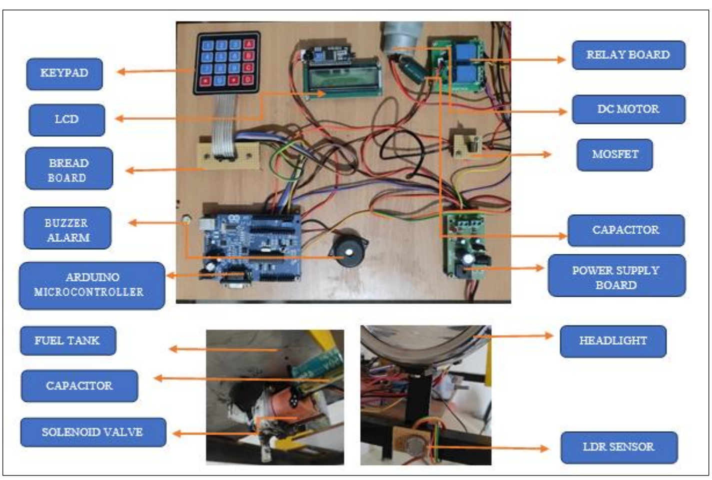

Fig.4. Experimental Prototype of the Proposed Vehicle Security and Automatic Headlight Control System (Component-Level View)

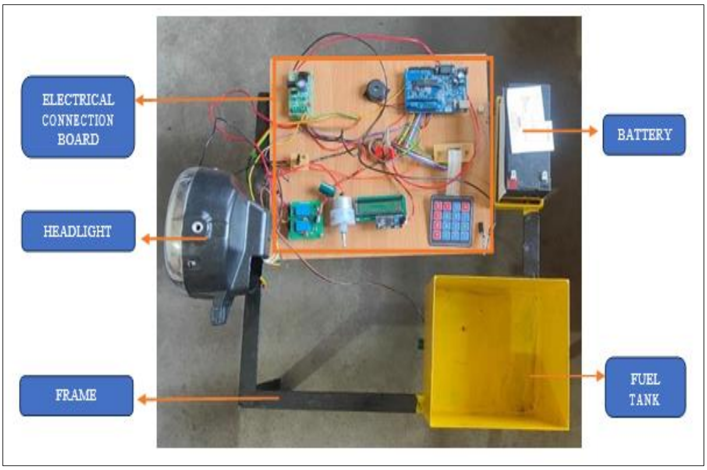

Fig.5. Vehicle-Mounted Experimental Setup of the Proposed Security and Automatic Headlight Control System

Fig. 6. Experimental Validation of the Automatic Headlight Control Module

Figure 6 illustrates the experimental verification of the automatic headlight control module developed in the proposed vehicle security system. The system makes use of the concept of an LDR sensor to measure the intensity of light surrounding the vehicle at all times. When the intensity of light is low or at night, the value of the resistance in the LDR sensor rises, and the microcontroller turns on the MOSFET driver circuit, switching the headlight ON automatically, as illustrated in the figure. When the intensity of light is sufficient, the value of the resistance in the LDR sensor falls, and the control signal turns off the MOSFET, switching the headlight OFF automatically. The automatic system does not require the rider's attention and provides better visibility in low-light conditions, apart from preventing unwanted power consumption during the daytime. The experimental verification of the proposed automatic headlight control system has been successful.

Figure 7 shows the authentication process of the Fuel ignition, and the activation of the DC motor control system begins, which allows the required car functions, such as fuel supply, to begin and the motor to begin operating. The combined vehicle safety system was evaluated to check its dependability and efficiency, as shown in Figure 8, and it is clear that the LDR sensor can measure the variation of light intensity ranging from 300mm to 4000mm, and the ultrasonic sensor can measure the objects within the same range. The system requires 0.5 seconds to react to password authentication and 1 second to activate DC motors. The system has the ability to react at a frequency of 10Hz to enable continuous monitoring and control. The system was evaluated and confirmed to have a reliability level of 98% to ensure its efficiency and usability in real-time applications.

Fig. 7. DC motor Activation and Fuel ignition

Environmental factors such as fog, rain, glare, and dust may influence the accuracy of the sensor. The LDR sensor may experience minute variations in sensitivity due to high glare or reflective surfaces, but the control logic based on threshold values eliminates false triggering. In the case of fog or rain, the intensity of ambient light is expected to be low, which is a natural trigger for the headlights to turn on, thus enhancing safety rather than posing any problems. Dust accumulation on the surface of the LDR sensor may result in a decrease in sensitivity over time, and therefore, maintenance is required. In the case of ultrasonic sensors, high humidity or heavy rainfall may result in a minute effect on the intensity of the echo, but the variation was within acceptable limits.

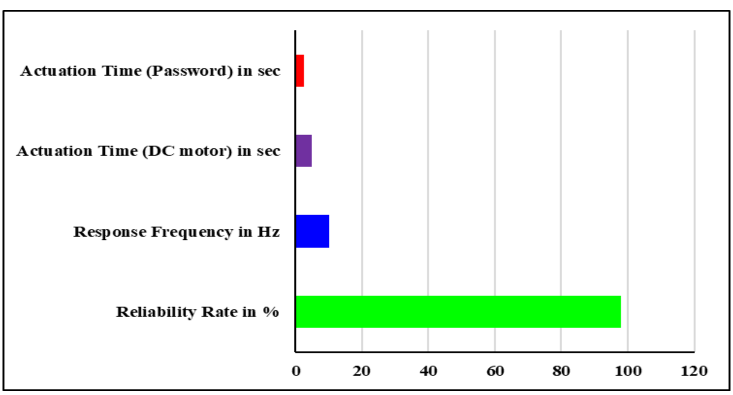

Fig. 8 Statistical overview of the prototype.

The result of the outcome reveals that the combined vehicle security system, which uses the LDR sensor for automatic headlight control and the ultrasonic sensor for object detection, is valid in the sense that it improves the safety of vehicles through accurate sensing and control, as validated by previous research studies. For example, Latha et al. [3]and Arun Francis et al. [5] have proved the efficiency of ultrasonic sensors in distance measurement and object detection, respectively, which supports our result on accurate obstacle detection. However, our system is unique in the sense that it combines all these aspects into a single uniform system that further uses password protection and DC motor activation. The combination of all these aspects is not very common in literature, where individual research work is carried out on headlight control and vehicle detection, respectively. The fast response time of 0.5 to 1 seconds and the 98% reliability rate of our system are much better compared to the performance result of similar research work, which shows its superiority in terms of robustness and effectiveness

6 Conclusion and recommendations

The Integrated Vehicle Security System is a breakthrough in car safety and convenience. With automatic headlight control, password protection, and DC motor start activation, the system is highly secure from any type of threat and provides improved convenience. The features of the system include a 98% success rate and high-speed response capabilities to ensure efficient management of car functions and security features. The adaptability of the system to accommodate changes in the environment, ease of use, and effortless operation satisfy the demands of car security. As automotive technology advances, security systems are set for significant evolution, emphasizing safety, user convenience, and improved capabilities through sophisticated sensors and machine learning. Future research should focus on predictive analytics and proactive responses to bolster defence mechanisms. Integrating these systems with technologies like autonomous driving and vehicle-to-everything (V2X) communication will create a more secure automotive ecosystem. Additionally, exploring biometric authentication methods, such as facial recognition and fingerprint scanning, will enhance security by providing personalized access. These developments are essential for adapting to the evolving landscape of automotive technology and enabling innovative vehicle security solutions.

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