Cost-effective IoT-based automated vehicle headlight control system: design and implementation

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ABSTRACT

The current world would be difficult without vehicles, which offer vital advantages for social connectivity, mobility, and technical advancement. Though motor vehicles provide benefits to passenger transportation, they also present certain challenges in their use. A major issue is nighttime traffic accidents caused by headlamps from automobiles traveling in reverse directions, that's why there is a high probability of accidents due to the glare on the driver's eyes. The phrase "Troxler effect" refers to an unexpected glare that a motorist recognizes. In this paper, we will provide an optimal solution to this challenge/Troxler effect. The primary objective of this paper is to design an internet of things (IoT)-based smart headlight control model. Our system introduced a cost-effective vehicle’s headlights controlled by light detection. According to this paper, a vehicle’s headlights are automatically rotated down when the sensor detects lights from the opposite direction of the vehicle headlights. We tried to reduce the road accident rate with our proposed system. This type of technology will prove useful in the motor vehicle sector and offer an innovative approach that ensures driver safety as well as increasing economic development.

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1. INTRODUCTION

One of the most significant facets of our lives is travel. There is nothing that can be done except travel and drive carefully. As it is darker at nighttime than during daylight, traveling at night can be more challenging. All throughout the world, accidents happen frequently, and many of them happen at night. This abrupt brightness coming from the approaching car is responsible [1]. On the other hand, our lives are now easier due to the infrastructure built and technology’s rapid progress. Technology has also made traffic dangers more common, and because of insufficient emergency facilities, road accidents frequently result in significant loss of life and property.

However, road transportation is essential for maintaining accessibility, promoting economic growth, and offering a versatile and effective way to move people and products. Addressing negative issues like the rise in traffic accidents has become more difficult as a result of the massive increase in motorization and the growth of the road network. Nevertheless, the ongoing shift toward sustainable and environmentally friendly transportation solutions is an important consideration for addressing the challenges associated with vehicle usage. According to road accident data, most accidents happen at night. The data on car accidents reveals a higher rate of incidents during nighttime compared to daytime, as indicated in reference [2]. After nightfall, 42% of all car accidents happen, of which 58% result in deaths and 67% in pedestrian fatalities [3]. Therefore, nighttime visibility is a critical factor in safe driving. The most important aspect of safe driving at night is having a clear vision of the road ahead. But because drivers are worried about blinding other people, they don't use highlights very often. For this reason, cost-effective automated headlight control with sensor technology is needed. By sensing the light levels in approaching cars, an automated headlight method dynamically shifts from high beam to low beam, which reduces the glare effect [4].

When driving at night, many drivers choose to utilize their high-beam headlights, which enhance visibility by enabling them to see a wider area ahead of them. These high beams can cause eye strain for the driver of the car approaching from the opposite direction, in addition to improving sight and making the road ahead more visible. However, the major problem for the driver is that the strain on the driver's eyes may result in a brief glare effect that impairs vision and increases the risk of collisions. The headlights on the other side of the car are using high beams, which create glare. Located at the front of a car, headlamps are essential for lighting up roadblocks at night. Nevertheless, the Troxler effect and glare from incoming cars might reduce a driver's sight [5], [6]. To overcome this issue, our proposed system optimizes headlamp regulation so that it lessens the glare effect on drivers when approaching traffic.

The ability of our proposed system to reduce the glare effect that drivers experience as they approach traffic is its main contribution. Our innovative headlamps are activated by detecting the light from the headlights of oncoming vehicles. The system automatically rotates both headlights downward when two cars detect each other's lights, greatly reducing the strain from high beams. This automated process aims to eliminate the need for manual adjustment of headlights by drivers, enhancing safety and convenience. Additionally, our system is designed to be cost-effective by utilizing low-cost equipment such as light dependent resistor (LDR) sensors and Arduino UNO, making it accessible and practical for widespread implementation.

In this paper, we explore the impact of automated vehicle headlight control systems on IoT-based, cost-effective solutions. We start by providing background information on headlight control, highlighting the need for further investigation in this area. The primary goal is to have the headlights automatically change from upward to downward as an oncoming vehicle approaches, and vice versa when a car passes by. The paper is organized as follows: in section 2, we review the relevant literature on headlight control systems. Section 3 outlines our research methodology, including hardware, system flowchart, and prototype. In section 4, we present our findings and discuss their implications. Finally, in section 5, we conclude with a summary of key findings.

2. RELATED WORK

There is a lot of research to be done on automatic headlight control for vehicles at night. Such a study is helpful when the headlight angle is adjusted upward and downward and the headlight light is detected by the LDR sensor. Numerous researchers have given presentations on the topic. This section provides an overview of the most recent techniques that researchers have suggested, along with related systems. As far as we are aware, not many headlight control systems are being developed at this time. These are some of them.

On the other hand, Sevekar and Dhonde [7] explore night-time vehicle detection for intelligent headlight control, addressing image-based challenges and implementation hurdles. It advocates for cost-effective solutions in low-budget vehicles and discusses two approaches: cameras for image processing and light intensity sensors for estimating presence. The study also addresses headlight glare reduction by using an LDR sensor. Zheng *et al.* [8] suggest an intelligent car headlight control system using a single-chip microcomputer and sensors for distance, velocity, and light assessment. This system optimally adjusts light for enhanced safety in adverse conditions. The main goal of this [9] research is to provide an effective image processing method that can be evaluated in a simulated environment to guarantee enough light intensity for ego-vehicle drivers and minimize intensity for opposing drivers. Luo *et al.* [10] introduce an adaptive high-beam control system that uses group light emitting diode (LED) particles to reduce nighttime glare in assisted driving systems. It divides lighting zones, identifies headlights and tail lights, and offers potential for further research. Yang *et al.* [11] introduce an intelligent vehicle headlight switching system using a support vector machine (SVM) to reduce traffic accidents and driver distraction, demonstrating high practicality and accuracy.

Similarly, in [12] uses Arduino and random forest (RF) sensors to synchronize lamp movement with steering wheel movement, providing a low-cost solution to automobiles with inadequate lighting. This approach adds features like automatic windshield wipers and dimmers, as well as increased visibility and improved car comfort. Saha *et al.* [13] uses NodeMCU microcontrollers to detect light and distance, automatically adjusting car headlights to reduce Troxler's effect, and has been tested in computer simulations to prevent accidents. Similarly, Al-Subhi *et al.* [14] paper goal is to create an intelligent Arduino-based car lighting management system that will automatically adjust beam intensity levels at night by employing an ultrasonic sensor and a light-dependent resistor to detect the availability of vehicles from the opposite direction.

Automatic headlamp dimming systems have been the subject of several studies in an effort to lower the number of car accidents brought on by improper beam utilization in inclement weather. By removing human error from beam switching, recent developments [15] use sensors and microcontrollers to operate headlights based on real-time environmental data, improving driving safety. To create a sophisticated lamp system with automated beam intensity adjustment, weather-based activation, and nighttime lighting, this [16] work makes use of Arduino and sensors. Automatic image analysis for adaptive lighting in various situations, such as rain and limited visibility, improves driving safety.

Sairam *et al.* [17] investigate the use of sensors, IoT [18], and microcontrollers to improve vehicle light systems. Automating beam modifications depending on traffic and environmental circumstances solves problems like glare, lever wear, and human control. Circuit designs are simulated with Proteus 8.0, and real-time data monitoring and analysis are made possible with Thing Speak. Sinha *et al.* [19] examines the use of artificial intelegence (AI) and IoT [20] in transportation applications, such as headlight automation, object identification for self-parking, and global positioning system (GPS) for traffic monitoring. It is recommended that future studies utilize Arduino and long range (LoRa) sensors. Dubey *et al.* [21] does away with human control by reducing glare from high beam headlights during night driving using an LED matrix, object detecting module, and live video feed. A vehicle headlamp system that reduces glare improves visibility during snowstorms and increases lane and marker contrast was proposed by Muralikrishnan [22] to improve road safety. However, their method requires sophisticated software and hardware. A computerized headlight dimmer that automatically switches from high to low beams to reduce glare was created by Poornima *et al.* [23].

A smart lighting system was presented by Masood *et al.* [24]. It incorporates capabilities to identify drunk drivers and modifies street light intensity based on vehicle movement and ambient light. While the goals and intricacies of each system vary, they are all intended to increase safety and visibility. Masud *et al.* [25] analyze IoT-based automated headlamp dimmer systems, contrasting technology such as sensors and AI for beam modulation, addressing operational issues, and emphasizing enhancements in safety and reductions in accidents. Rahman *et al.* [26] suggested an IoT-enabled system that adapts to traffic demand, automates control, identifies problems, minimizes expenses, maintains enough lighting for drivers, and enhances the overall driving experience. In addition, this [27] study introduces an economical IoT smart parking system using machine vision, attaining 96.40% accuracy and improving urban mobility via real-time monitoring and user notifications.

Moreover, Dahou *et al.* [28] created an intelligent headlamp adjustment system that use machine vision and binocular cameras to assess road conditions and surrounding cars, therefore improving driving safety via adaptive illumination, while Aramice *et al.* [29] devised a headlight beam control system with a fuzzy control algorithm, demonstrating advantageous dynamic properties. Similarly, this [30] study examines intelligent headlight beam management techniques, focusing on sensor-based and machine learning methods, and addresses prospective developments. Nkrumah *et al.* [31] research presents an economical, sensor-driven Arduino system for automated illumination regulation, enhancing safety and accessibility during nighttime driving. Furthermore, LI [32] examines AI-controlled matrix headlights, emphasizing their benefits. Experimental findings indicate a 16% decrease in energy consumption, a 34% enhancement in regulation rate, and a 12% advancement in lighting relative to conventional headlights. Dahou *et al.* [33] suggested adaptive front-lighting system employs pulse width modulation (PWM) technology in conjunction with an field-programmable gate array (FPGA) to improve vehicle safety and minimize energy usage, dynamically altering according to steering angle, speed, and weather conditions.

3. PROPOSED METHOD

The proposed methodology's block diagram, illustrated in Figure 1, outlines the composition of our research. This system comprises several key components: a power supply (battery), a motor driver, an Arduino UNO, an LDR sensor, and a servo motor. Each component's function and role within the system are elaborated upon in section 3.1., hardware configuration. Section 3.2. provides a detailed explanation of the system's flow chart, describing the sequence and logic of operations. Finally, section 3.3. discusses the prototype and experimental setup, detailing the practical implementation and testing of the system. Figure 1 explains the developing system that provides the solution for temporary blindness, where we used an 11.11 V battery to provide a power supply for the whole system, and a phototransistor/LDR sensor is used to sense the headlight intensity of the coming vehicle. By using Arduino UNO, we can control the motor; collect sensor data, and much more. When LDR senses high-intensity light from a coming vehicle, we create dynamic headlight systems using servo motors to adjust the direction and angle of headlights for optimal illumination without blinding others.

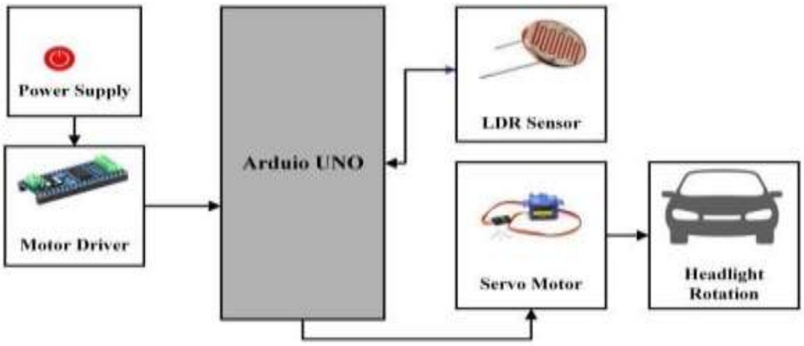

Figure 1. Flow chart of IoT-based vehicle headlight control system

The implementation of our proposed system involves several key hardware components that are essential for its functionality. An 11.11 V battery serves as the power source for the motor driver, Arduino UNO, and other system components first and foremost. This battery ensures uninterrupted power delivery for the smooth operation of the system. Additionally, a motor driver is utilized to regulate the movement of the vehicle's wheels, offering precise control over their motion. This component is crucial for ensuring the vehicle's manoeuvrability and responsiveness to the automated headlight control system. Central to the operation of our system is the Arduino UNO microcontroller board, renowned for its versatility and user-friendly interface. The Arduino UNO facilitates various tasks, including motor control, sensor data collection, and overall system management. With its ample input/output (I/O) pins and compact design, the Arduino UNO serves as the brain of our automated vehicle headlight control system, orchestrating its various functions seamlessly. Adding a LDR sensor improves the system's features by letting the headlights turn on automatically based on the amount of light in the area. This sensor detects changes in light intensity, triggering the headlights to turn on or off accordingly, thereby enhancing both safety and convenience for the vehicle's occupants. Lastly, the servo motor plays a pivotal role in our system by enabling precise adjustments to the headlights' direction and angle. This dynamic functionality ensures optimal illumination without causing glare or discomfort to other road users, further enhancing the overall effectiveness of our IoT-based [30] automated vehicle headlight control system.

3.1. Hardware

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3.2. System flowchart

In Algorithm 1, we have shows the pseudocode for initializing the proposed system. Here, we have an 11.11 V battery that we employed for the current source purpose based on the system flowchart. However, the car battery can be used to draw power instantly. The headlight switching is managed by the Arduino code. When two cars are travelling in opposite directions at night, their headlights are more likely to cause an accident. So, we used two cases to overcome this problem. The first case is when the LDR sensor is used to detect the presence of other car lights. So, by detecting the light of the headlight through the LDR sensor, the angle of the headlight will change. If the detected car is in a specific angular range, adjust the headlight angle downward to direct the light beam away from the other car's mirrors and windshield. Continuously update the headlight angles as the relative positions of the cars change, ensuring optimal visibility without causing glare. Arduino UNO is used as a microcontroller. SG90 micro-servo motor is used for changing the angle of light. Another case is when the cars cross each other, and then the headlights of each car automatically rotate up if the LDR sensor does not detect any light from the headlights.

Algorithm 1. Pseudocode for proposed headline control

```
Global Variables
    battery voltage = 11.11;
    motor driver initialized = False;
    arduino initialized = False;
    switch state = False;
    ldr sensor value = 0;
    SERVO MOTOR PIN = 9;
    SWITCH PIN = 8;
    LDR SENSOR PIN = A0;
 Function initialize system ()
    motor driver initialized = True;
    arduino initialized = True;
    pinMode (SERVO MOTOR PIN, OUTPUT);
    pinMode (SWITCH PIN, INPUT);
    pinMode (LDR SENSOR PIN, INPUT);
 Function read switch ()
    switch state = digitalRead (SWITCH PIN);
    return switch state;
 Function read ldr sensor ():
    ldr sensor value = analogRead(LDR SENSOR PIN);
    return ldr sensor value;
 Function move servo motor(position)
 if position ==”up” then
    digitalWrite (SERVO MOTOR PIN, HIGH);
 else if position ==”down” then
    digitalWrite (SERVO MOTOR PIN, LOW);
 end if
```

3.3. Prototype

When the parts are assembled by the block diagram and a power source is provided, the machine begins to operate and shows the headlight's present condition. It is an extremely basic device that requires little setup work and is cost-effective. Figure 2 presents the prototype model.

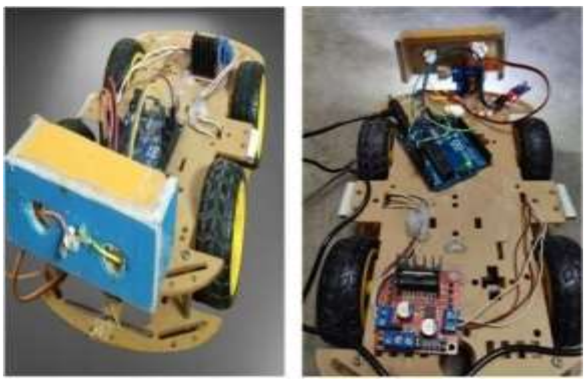

Figure 2. Proposed system prototype

4. RESULT AND DISCUSSION

In this section, the results of the research are explained and, at the same time given a comprehensive discussion. Nighttime vehicle headlight control is still an open area for research since a cost-friendly solution

to this problem can only incorporate such a system into low-budget automotive. Nevertheless, the implementation of such a system is still a challenging task for many automotive manufacturers. A new automatic headlamp control system has been developed using a LDR sensor. This device switches the headlight to a low beam when it detects an oncoming vehicle. By preventing temporary blindness from high beam headlights, this solution lowers the likelihood of nighttime accidents and makes nighttime travel safer for people. The result of our proposed system is shown in Figure 3. By using such a smart headlight control system, the driver can safely drive at night. As a result, it will reduce the number of accidents concurrently. Additionally, this equipment is simple to maintain. So, we can confidently say that this system is cost-effective as it has a low cost and a low piece of equipment. There were three cases to show our experiment result; these are mentioned below and explained in case (A, B, and C).
Case A - cars were at high beams: cars are coming toward one another with high beams in this situation, as illustrated in Figure 3(a). The LDR detector is then used to identify the high beam.
Case B - cars were at low beams: in this mode, the sensor detects light from the headlight and instantly changes to a rotated-down headlight. This is demonstrated in Figure 3(b).
Case C - both cars switch to a high beam after passing: as shown in Figure 3(c), the vehicle automatically shifts from low to high beam when it returns to the track where no oncoming high beam cars are present.

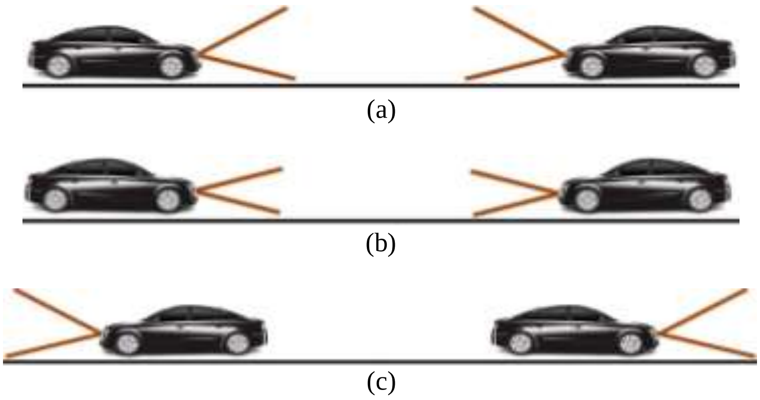

Figure 3. Vehicle headlight automated controlling: (a) both vehicles at high beam, (b) both the vehicles in low beam, and (c) after passing both vehicles becomes high beam

In our study, we looked at how well our new system works compared to the old way of controlling headlights. We found that our system is really good at letting drivers see well while using less electricity. We expected that most of the drivers could see better when driving at night with our new system. The research question and answer of the framework are described in tabular form in Table 1.

Table 1. Research question and answer or our proposed system

SL.	Research question	Answer
RQ1	How does the IoT-based automatic headlight control system enhance road safety by reducing headlamp glare-related accidents?	The system automatically adjusts headlights to minimize glare, reducing the risk of glare related accidents.
RQ2	In what ways does the automated headlight control system improve driver comfort by eliminating the need for manual headlight adjustments?	It automates headlight adjustments, allowing drivers to focus on driving without the distraction of manual adjustments.
RQ3	What are the key considerations and required minor adjustments for integrating the proposed IoT-based headlight control system into existing vehicles?	The system can be integrated into existing vehicles with only minor modifications. Key considerations include compatibility with current vehicle electronics. This makes the integration process simple and cost-effective.

The cost breakdown of the proposed model is detailed in Table 2. The bill of materials for this vehicle outlines the individual expenses of all necessary components. At the core of the system is an Arduino UNO microcontroller board, priced at 1000 Bangladeshi Taka (BDT), accompanied by a 200 BDT connection cable. A 1650 BDT LiPo battery powers the vehicle. Four 6V DC-geared motors, essential for movement, cost 400 BDT each, totaling 1600 BDT. The chassis costs 600 BDT, and four wheels priced at

360 BDT each add up to 1440 BDT. A motor driver for controlling the motors is included for 200 BDT. Sensors play a vital role, with an 80 BDT LDR sensor module likely used for light detection. Additionally, a servo motor for precise movements costs 150 BDT, and a basic LED light is included for 25 BDT. The list is completed with 40 BDT for wiring and 500 BDT for unspecified connectivity components. Summing these costs, the total expense to build one vehicle is 5205 BDT. Consequently, constructing 20 vehicles would cost 104,100 BDT (20 vehicles * 5205 BDT/vehicle).

The significance of our proposed innovations to the motor vehicle industry lies in its ability to improve driver safety by reducing glare and lowering the likelihood of accidents, particularly during nighttime. By mitigating the "Troxler effect" the technology enhances visibility and driving comfort. Due to its cost-effective design, this technology can be extensively used, improving vehicle safety without substantially raising production expenses. Thus, this phenomenon contributes to economic growth by diminishing expenses associated with accidents, decreasing insurance premiums, and fostering customer trust in safer and more intelligent automobiles, thereby stimulating demand and fostering innovation within the automotive sector.

Table 2. Cost estimation for one set of hardware

S.N.	Instruments name	Quantity	Price (BD)
1	Arduino UNO	1	1,000
2	Cable for Arduino UNO	1	200
3	Lipo battery 1500 mAh 11.1 3 S	1	1,650
4	6 V DC geared motor 180RPM dual shaft	4	400
5	Wheel	4	360
6	Car chassis body	1	600
7	Motor driver	1	200
8	LDR sensor module	1	80
9	Servo motor micro SG90 180 degree rotation	1	150
10	LED	1	25
11	Wire		40
12	Connectivity		500
	Total		5,205

5. CONCLUSION

Glare while driving poses a significant safety concern for motorists. It occurs when our eyes are suddenly exposed to bright lights, such as the headlights of other vehicles, leading to a temporary loss of vision known as the Troxler effect. This can greatly increase the risk of accidents, particularly at night. Despite the importance of reducing glare by controlling headlights, many drivers fail to do so promptly. As a solution to this problem, the concept of an automatic headlight control prototype has been proposed. This device allows drivers to use high beams with headlight direction upward when necessary but automatically switches headlight to roated down when it detects an approaching vehicle from the opposite direction. Implementing such a system in all vehicles has the potential to not only prevent accidents but also enhance overall driving safety and comfort. However, our proposed system is energy efficient, improves safety, helps drivers feel comfortable driving, is easy to implement, and reacts quickly to keep drivers safe on the road.

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