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Research Article

Adaptive Headlight Management and Information System for Optimized Intensity and Direction in Electric Vehicles

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ABSTRACT

This paper presents Adaptive Headlight Management Information System for Optimized Intensity and Direction in Electric Vehicles, aimed at optimizing road illumination while minimizing glare for other road users. The system integrates three primary components: the Vital Illumination Sensing System (VISS), the Headlight Adjusting System (HAS), and the Light Intensity Adjusting System (LIAS). The CISS, which consists of a PIXY2 microcontroller and a camera, detects oncoming vehicles and evaluates their headlight intensity using machine learning algorithms. The microcontroller then adjusts the intensity of the vehicle's own headlights through the LIAS, which uses a DC-DC boost chopper to vary the duty cycle according to the required light intensity.The HAS controls the headlight's direction by using a servo mechanism to adjust its angle, ensuring that the light is directed precisely on the road, especially during turns or inclines. The system dynamically predicts the necessary adjustments by processing data from the PIXY2 microcontroller and applying image processing algorithms. Additionally, the integration of IoT communication protocols, such as Wi-Fi and GPRS, enables real-time data transmission to the user interface, allowing the rider to receive notifications about headlight status, intensity adjustments, and anomalies.By continuously adjusting the headlight intensity and direction based on real-time vehicle and road conditions, the system enhances road safety, conserves energy, and reduces glare for other road users. This innovative approach represents a significant step forward in the development of intelligent lighting systems for electric vehicles.

Keywords: Adaptive Headlight Management System, IoT (Internet of Things), Machine Learning, Glare Reduction, Energy Efficiency, Visibility Optimization.

INTRODUCTION

Vehicle lighting systems, particularly headlight intensity control, have become crucial in enhancing road safety and energy efficiency. Adaptive headlight systems, which adjust the intensity and direction of vehicle headlights based on environmental factors, such as the presence of oncoming vehicles and road conditions, play a significant role in reducing glare for other drivers while maintaining optimal road illumination for the vehicle. One of the primary concerns of headlight systems is glare, which can cause temporary blindness for oncoming drivers and increase the risk of accidents. O'Neal et al., [1], highlight that headlamp glare is a significant contributor to accidents, especially during night driving. The traditional solution has been to employ manual adjustments, such as dimming or tilting headlights, which have their limitations in terms of speed and accuracy. To address this, several researchers have explored the use of adaptive lighting systems, where headlight intensity is adjusted automatically based on the proximity and type of oncoming vehicles [2,3]. These systems typically utilize sensors and machine learning algorithms to detect oncoming vehicles, measure their distance, and adjust the light intensity accordingly. Adaptive systems offer several advantages over traditional manual systems. For instance, Lima et al., [4] propose a system where headlights adjust not only for oncoming traffic but also for varying road conditions, ensuring that drivers receive optimal lighting without causing discomfort for others. Similarly, Bormann et al., [5] examine the design of such systems and their ability to improve night-time safety by dynamically changing the headlight intensity in response to different driving conditions. This reduces glare while maintaining proper illumination, thereby enhancing overall road safety. In the context of energy efficiency, Koehler et al., [6] point out that adaptive lighting systems can contribute significantly to reducing power consumption in electric vehicles. By adjusting the headlight intensity based on the distance to oncoming vehicles, these systems ensure that only the required amount of light is emitted, conserving energy while still providing sufficient illumination for the driver. This is particularly crucial for electric vehicles, where efficient energy use is essential to maximizing range.

Machine learning (ML) and Internet of Things (IoT) technologies have significantly advanced the capabilities of adaptive headlight systems. [7,8] explore the use of ML algorithms to predict headlight adjustments based on the type and distance of oncoming vehicles. These algorithms analyze input from various sensors and adjust headlight intensity in real-time, ensuring a seamless and effective system. Additionally, IoT connectivity enables real-time updates to headlight adjustments, providing continuous communication between the vehicle's lighting system and external devices or other vehicles, further improving safety [9].Several studies have also focused on glare reduction. Zhang et al. [10] emphasize that while headlight intensity adjustments are crucial, ensuring that headlights are properly directed to avoid glare is just as important. Adaptive headlight systems that tilt or swivel based on the vehicle's angle or lean during turns are particularly beneficial in these contexts. Gu et al. (2010) demonstrate that such systems can significantly reduce glare, especially when integrated with dynamic steering adjustments, ensuring that headlights illuminate the road in the desired direction.

While these advancements offer clear benefits, challenges remain. A significant issue is the cost and complexity of integrating adaptive systems into vehicles. Pérez et al., [11] note that while the technology behind adaptive headlights has matured, the cost of implementation remains high, particularly for retrofitting older vehicles. Moreover, the development of accurate sensors and the refinement of machine learning models to predict headlight adjustments in diverse environmental conditions remain ongoing challenges.

OBJECTIVES

The Optimizing Headlight Intensity and Direction with Adaptive Control Systems for electric vehicles is designed to monitor and detect the light source/power of the vehicle's front lamp as well as the type of oncoming vehicle. The system integrates microcontroller 101a with camera 101b to form the Central Illumination Sensing System (CISS) 101, which identifies oncoming vehicles using a YOLO-based machine learning algorithm. The microcontroller, along with the camera, also detects the size of the opposite vehicle's headlights and predicts their light intensity through an image detection algorithm. A key feature of the system is the integration of microcontroller 101a with the Light Intensity Adjusting System (LIAS) 103, which adjusts the headlight illumination accordingly. The system utilizes machine learning algorithms (MLA) and image processing to determine the required intensity based on factors such as vehicle turn and inclination.

Additionally, the Headlight Adjusting System (HAS) 102 is implemented to modify the direction of the headlight by controlling the relevant servo motors 102a, ensuring optimal illumination of the road. The CISS 101 identifies the required light intensity to maintain proper visibility and uses appropriate machine learning algorithms to predict the necessary adjustments. Machine learning algorithms (MLA) also help to analyze the street conditions, anticipate the required light intensity, and communicate necessary adjustments to the LIAS 103. Furthermore, the system integrates an IoT communication protocol (WiFi Mesh Network) to update the headlight intensity data and provide real-time information about the remaining lifespan of the headlight, enabling proactive maintenance and ensuring safety.

DETAILED DESCRIPTION

Figure 1 illustrates the Optimizing Headlight Intensity and Direction with Adaptive Control Systems for Electric Vehicle, X and Y axes. Light intensity and headlight angle data are displayed on the user interface via Wi-Fi communication.

Fig 1: Machine Learing- based Headlight Intensity Altering device for Electrical vehicles

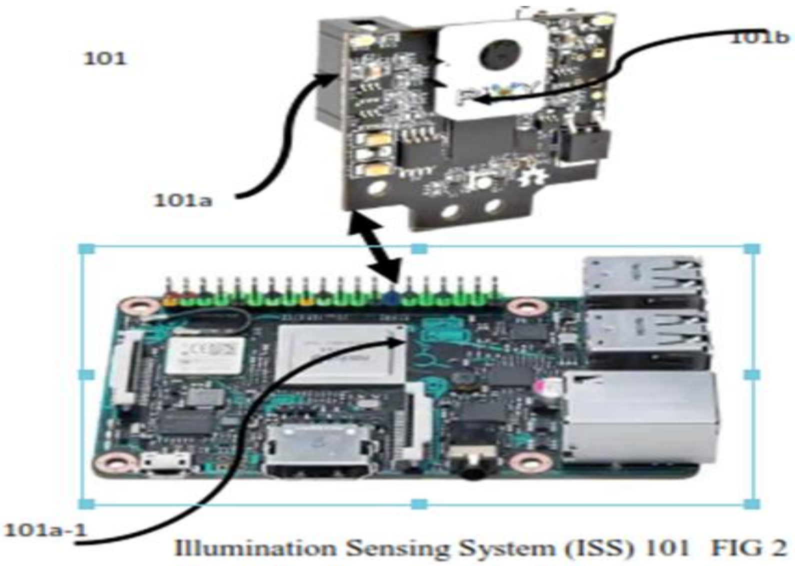

Fig 2: Illumination Sensing System (ISS) 101

Figure 2 depicts the Component Layout of the Vital Illumination Sensing System (VISS) 101, where the PIXY2 microcontroller 101a is integrated with the Raspberry Pi 101a-1, which works together to determine the approaching vehicle's type, illumination, distance, and relative speed. The PIXY2 101a and microcontroller 101a-1 operate in a symmetric configuration to execute the necessary algorithms for predicting and maintaining the required light intensity. The microcontroller 101a-1 is further integrated with a General Packet Radio Service (GPRS) module 101c, allowing it to communicate with the user interface. When a vehicle is detected or light is identified, the microcontroller, via the GPRS or Wi-Fi module, sends updates about the light source, vehicle type, and light-emitting status. Additionally, the system can detect anomalies in light intensity and send alerts to the user through a Wi-Fi mesh network. Figure 3 illustrates the Component Architecture of the Headlight Adjusting System (HAS) 102, where the microcontroller 101a integrates with the servo-mechanism to position the headlight as needed. The servo mechanism comprises two motors placed perpendicular to each other, with a toothed wheel gear assembly between the headlight and the motors. These motors rotate the headlight along the X and Y axes. When a light source is detected, the microcontroller 101a identifies the oncoming vehicle and adjusts the intensity of the headlight to reduce glare. If the ambient road illumination is insufficient, the microcontroller commands the servo mechanism to re-focus the headlight, ensuring proper road visibility.

Fig 3: Headlight Adjusting System (HAS) 102

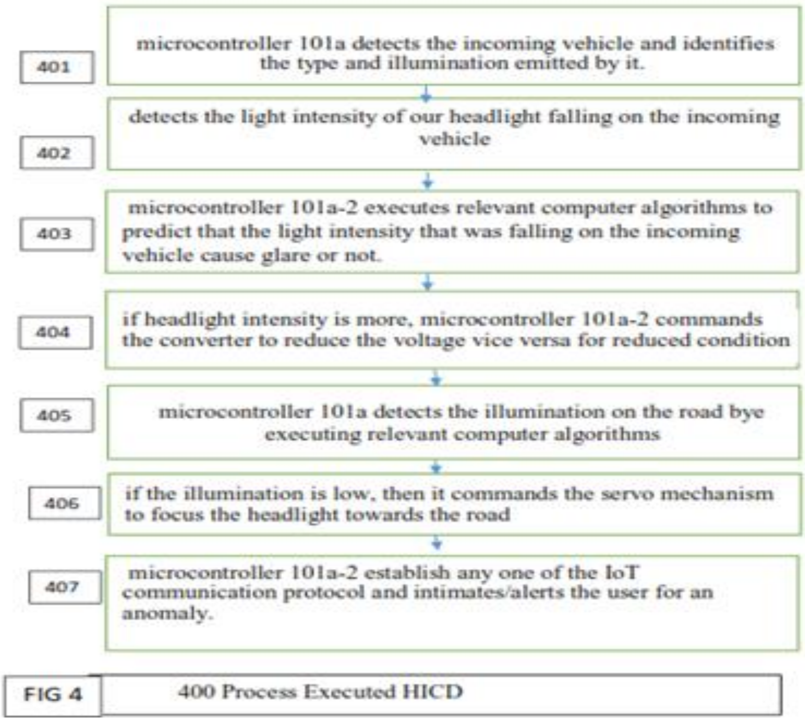

Fig 4: 400 Process Executed HICD

Figure 4 depicts the 400 Process Flow executed in the headlight intensity changing system. The process starts with step 401, where the microcontroller 101a detects the incoming vehicle, identifies the vehicle type, and determines the illumination emitted by it. In step 402, the system detects the light intensity of the headlight falling on the oncoming vehicle. Step 403 involves the microcontroller 101a-1 executing relevant algorithms to determine if the light intensity causes glare. In step 404, if the intensity is too high, the microcontroller commands the converter to reduce the voltage accordingly. During step 405, the microcontroller detects the ambient illumination on the road. In step 406, if the illumination is insufficient, the system commands the servo mechanism to adjust the headlight direction. Finally, in step 407, the microcontroller 101a-1 establishes one of the IoT communication protocols and alerts the user about any detected anomalies.

It is to understood that the headlight intensity of a two-wheeler should be dynamically adjusted based on the distance to oncoming vehicles to ensure proper road illumination while minimizing glare as suggested by Gu, W. S., et al.,in 2010. For motorcycles, the headlight should remain at 100% intensity when the distance to an oncoming motorcycle exceeds 100 meters, and it should be reduced to 50-60% when approaching within 50 meters. For cars, the intensity should be 60-70% when within 100 meters and increased to 100% when the distance exceeds 150 meters. In the case of heavy vehicles like trucks and buses, the headlight intensity should be 50% when approaching within 150-200 meters to prevent glare, with 100% intensity used when the distance is greater than 200 meters. These adjustments should be made dynamically using IoT and machine learning systems that calculate the optimal intensity, ensuring both safety for the rider and comfort for other road users. The system should also adjust the headlight angle based on the vehicle's movement and inclinations, further enhancing visibility and reducing glare. The tabulated comparision is as shown in Table-1 by considering Formula for Intensity Adjustment Based on Distance by use a simple inverse square law for adjusting light intensity with respect to distance:

$I_{(d)} = \frac{I_0}{d^2}$ - (1) Where: I(d)= Intensity at distance d I_o = Initial intensity (100% at reference distance) d = Distance to oncoming vehicle

Table:1 Bechmarked Intensity Adjustment

Distance to Oncoming Vehicle	Motorcycle (Lux)	Car (Lux)	Heavy Vehicle (Lux)	Adjustment Logic
0 - 50 meters	100%	60-70%	40-50%	Full intensity for motorcycle, moderate for car/bus
50 - 100 meters	90%	70%	50%	Reduce intensity as vehicle approaches
100 - 150 meters	70%	80%	60%	Adjust intensity based on glare reduction needs
150 - 200 meters	60%	100%	70%	Full intensity for clear visibility at larger distances
>200 meters	50%	100%	100%	Full intensity remains for far distance

RESULTS

A comprehensive test setup has been implemented to evaluate the system's impact, incorporating multiple parameters. A Lux Meter measures headlight intensity before and after adjustments, assessing changes in light output. Camera/Visual Analysis evaluates glare reduction using discomfort or glare indexes. A Power Meter tracks energy consumption, highlighting efficiency improvements. Vehicle Sensors measure headlight direction, tilt angles, and vehicle speeds for real-time operational data. Ambient Light Sensors assess surrounding light conditions, ensuring proper system adaptation. Temperature Sensors monitor variations around the headlights, ensuring safe operation. Finally, the Speed of Adjustment measures the system's responsiveness to driving conditions. These parameters provide a thorough evaluation of the system's safety and energy efficiency in electric vehicles.

Table 2: summarizing the Lux values before and after adjustment for the headlight intensity at various driving conditions

Condition	Before Adjustment (Normal Conditions)	After Adjustment (Post-Adjustment)
Low Beam (Standard)	300 to 500 Lux	150 to 300 Lux (for glare reduction)
High Beam (Standard)	1,000 to 1,500 Lux	800 to 1,000 Lux (for optimal road illumination)
Oncoming Vehicle Detected	High Beam: 1,000 to 1,500 Lux	Low Beam: 300 to 500 Lux (glare reduction)
Urban Area (Low Speed)	300 to 500 Lux	150 to 300 Lux (reduced glare in well-lit areas)
Vehicle Turning (Inclined Position)	High Beam: 1,000 to 1,500 Lux	Low Beam: 300 to 500 Lux (adjusted angle and reduced intensity)
Clear Road (No Oncoming Traffic)	1,000 to 1,500 Lux	800 to 1,000 Lux (optimized for road visibility)
Glare Threshold (for safety)	Above 1,500 Lux (may cause glare)	Below 1,500 Lux (system adjusts to reduce glare)

Table 2 summarizes the headlight intensity (Lux values) for a two-wheeler before and after applying an IoT-based, machine learning-driven adaptive system under various driving conditions. In normal conditions, the low beam intensity ranges from 300 to 500 Lux, and the high beam from 1,000 to 1,500 Lux. The system reduces intensity to 150 to 300 Lux for glare reduction, particularly in urban areas or when an oncoming vehicle is detected. For optimal road illumination, the high beam is adjusted to 800 to 1,000 Lux. Intensity is also lowered to 300 to 500 Lux during turns or when an oncoming vehicle is detected. In urban areas, it further drops to 150 to 300 Lux, while on clear roads without oncoming traffic, the intensity stays between 800 and 1,000 Lux. The system ensures the intensity does not exceed 1,500 Lux, reducing glare, improving visibility, conserving energy, and enhancing safety for all road users. Table 3 show that summarizing the optimal values for headlight angle/position adjustment on a two-wheeler which are programmed in to the microcontroller

Table-3: summarizing the optimal values for headlight angle/position adjustment on a two-wheeler which are programmed in to the microcontroller.

Adjustment Type	Optimal Range	Achived Range	Conditions/Notes
Vertical Tilt Adjustment	1° to 3° downward	2.3°	Normal riding conditions
	1° to 2° upward	2.1°	For inclines or uphill riding
Horizontal (Lateral) Angle Adjustment	10° to 30° (for turns)	18°	During turns or leaning while cornering
Inclination-based Adjustment	1° to 3° based on vehicle tilt	2.1°	Adjusts to rider's lean during turns
Headlight Beam Pattern	130°	130°	Ensures proper road coverage without glare

CONCLUSION

Optimizing Headlight Intensity and Direction with Adaptive Control Systems for Electric Vehicle, offers an innovative solution to enhance both energy efficiency and road safety. By leveraging advanced machine learning algorithms and IoT communication protocols, the system continuously monitors and adjusts the headlight intensity based on real-time data, ensuring optimal illumination while minimizing energy consumption. The integration of a Vital Illumination Sensing System (VISS), Headlight Adjusting System (HAS), and Light Intensity Adjusting System (LIAS) enables seamless adaptation to dynamic driving conditions, such as vehicle turns, inclines, and the presence of oncoming vehicles. This not only reduces glare and prevents accidents but also contributes to the sustainability of electric vehicles by conserving power. The system's IoT connectivity further enhances its functionality, allowing for real-time updates and alerts. In summary, this technology represents a substantial pace advancing in the progress of smarter, safer, and more energy-efficient electric vehicles.

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