CNN-Based Adaptive Automatic Headlight Control System for Night-Time Driving Safety

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***Abstract*—Night driving is often challenging because of the glare of oncoming vehicles. The glare of the oncoming vehicle's headlights may temporarily impair the driver's vision. The chances of road accidents may thereby increase. Existing automatic headlight control systems use light-dependent resistor technology to detect the amount of light. The amount of light is then compared with the threshold value. If the amount of light is high, the system switches to high beam. If the amount of light is low, the system switches to low beam. The system may give incorrect results because of the interference of streetlights. A CNN-based adaptive automatic headlight control system has been designed to provide improved automatic headlight control for vehicles out of the use of convolutional neural networks (CNNs). This system contains a camera mounted at the top of the vehicle that will take images of the roadway ahead of the vehicle. The CNNs then process these images and are able to identify the glare from the lights of oncoming vehicles. Ultrasonic sensors will also assist in providing accurate readings for the distance between vehicles, and the headlight beam patterns can be modified to accommodate the distance between vehicles. The testing of this system has provided proof that a CNN-based automatic headlight control system for vehicles is feasible. The system is cost-effective compared to other intelligent vehicle safety systems.**

Keywords - Automatic Headlight Control, Convolutional Neural Network (CNN), Night-time Driving Safety, Vehicle Detection, Glare Reduction, Intelligent Transportation Systems.

I. INTRODUCTION

Road safety during nighttime driving is a major problem encountered in different regions of the world. The major contributing factor to nighttime driving accidents is glare from high-beam headlights of vehicles traveling towards you. If a driver is exposed to high beam headlight glare, he may be in a state of impaired vision, which reduces his ability to see the road and vehicles clearly. Such a state may lead to road traffic accidents. Therefore, it is essential to design an intelligent headlight control system to assist drivers in maintaining road safety during nighttime driving.

In regular vehicles, drivers manually switch between high- and low-beam headlights according to the road conditions and approaching vehicles. However, drivers generally fail to switch between high- and low-beam headlights while driving vehicles. Such a situation may lead to vehicles being in high-beam mode in the presence of an approaching vehicle on the road, which may cause glare to other drivers. Therefore, several automatic headlight control systems have been proposed.

The majority of the existing automatic headlight control systems utilize the Light Dependent Resistors (LDRs) or light intensity sensors for the detection of the headlight beam and control the beam intensity accordingly. However, all existing headlight control systems utilize a threshold control mechanism to control the headlight beam intensity in accordance with the light intensity. However, these systems are not reliable in all cases, as the light intensity sensor may detect streetlights, reflective surfaces, etc., apart from the headlight beam.

Recently, various changes have been incorporated into artificial intelligence and computer vision techniques. Image-based systems are more efficient for object or light detection. The CNN model is more efficient for image classification problems than other models. The CNN model is considered to be a very effective method in detecting the headlight beam of an oncoming vehicle by processing and analyzing images taken by the camera along the roadway. Apart from visual detection, the measurement of the distance between two vehicles is also important in deciding the level of the headlights. Ultrasonic sensors have the potential to measure the distance between vehicles in real time. The visual detection and measurement of the distances between vehicles can improve the accuracy of automatic headlight systems.

In this study, a CNN-based adaptive automatic headlight control system is proposed to improve the safety level during nighttime driving. The proposed system was able to capture images in real time from the camera, and a CNN model was used to detect the status of the headlights of vehicles moving in the opposite direction. The distance between two cars was also being monitored by an ultrasonic sensor while they were switching between high-beam and low-beam lighting modes based on the Artificial Neural Network model and the ultrasonic sensor information. The relay module has been used to automate the headlight systems. The proposed system has been designed in such a way that it minimizes the glare resulting from high beam headlights, improves the vision of the driver, and maximizes the safety of the driver on the road. The results obtained during experimentation under different night driving conditions prove that the proposed system provides reliable beam switching with a minimum change in the headlights.

II. LITERATURE SURVEY

Accidents that occur on the road during the night hours are mainly due to the glare of headlights and poor visibility. Many researchers have proposed an automatic control system for the headlights to enhance safety for drivers and prevent accidents. A report by Ministry of Road Transport and Highways states that in India, the majority of accidents occur between the hours of darkness as a result of many variables such as; poor visibility and improper use of high-beam headlights [1].

Al-Subhi et al. suggested a vehicle headlight control system using Arduino microcontrollers and LDRs/Ultrasonic sensors. This system will automatically switch a vehicle’s high beam into a low beam when another vehicle approaches [2]. In the same way, an automatic headlight dimmer was created by Kalaimathi et al and associates with the use of an Arduino as well as a light dependent resistor (LDR) as a measure for the amount of bright light coming from an oncoming vehicle so that the headlights could be turned down appropriately [3].

An automatic brightness adjustment system has been developed by Narendiranath Babu et al. which uses both LDR and ultrasonic sensors to detect incoming vehicles' headlights and brightness in order to decrease glare when driving at night by adjusting the amount of emitted light from your headlamps based on how much light is coming from other driver's vehicles and how far away they are from you [4]. An automatic vehicle headlight management system was proposed by Lakshmi et al. to manage vehicle headlights with the help of Arduino and LDR sensors to avoid accidents caused by glare [5].

A system for controlling the intensity of vehicle headlamps by incorporating various sensors to enhance visibility and avoid glare was proposed by Deshpande et al. [6]. A case study by Balaji demonstrates how intelligent headlight systems can be utilized to prevent accidents, as well as emphasizes the significance of headlights having the ability to turn on or off automatically while driving [7].

An IoT-enabled accident detection and notification system was also developed by Sharma and Sebastian which incorporates both accident detection sensors and communication modules that will automatically notify emergency services about an accident [8]. Pasala et al. suggested an automatic smart street lighting system using NodeMCU and LDR sensors to control light intensity according to environmental lighting conditions [9]. Vijaya Kumar et al. suggested an automatic brightness control system for vehicles using IoT technology to improve vehicle lighting efficiency [10].

Currently Artificial Intelligence (AI) and Deep Learning (DL) techniques are currently being implemented in many different parts of Computer Vision Systems. Howard et al. proposed an efficient CNN model known as MobileNet for mobile vision applications [11]. Tan and Le proposed a model known as EfficientNet to improve CNN performance [12]. Grigorescu et al. recently wrote a paper on the use of Deep Learning for Object Recognition and Environmental Perception in Autonomous Driving Applications [13]. Also, Redmon and Farhadi have developed an Object Detection Method using DL called YOLOv3, which will be useful for Vehicle/Object Detection in Computer Vision [14].

LeCun, Bengio, and Hinton published a comprehensive review of the many types of deep learning applications both for image recognition and for artificial intelligence in their research publication [15].

From the literature review, most of the existing systems are based on sensor techniques such as LDR and ultrasonic sensors for the control of the headlight of the vehicle. However, with the advancements in computer vision and CNN techniques, the accuracy of detecting the vehicles and environmental conditions is higher compared to the existing techniques. Therefore, the proposed method of using CNN techniques in image detection with the distance measurement sensors will improve the performance of the automatic headlight control of the vehicle.

This proposal outlines the implementation of a smart automatic headlight control system utilizing an intuitive CNN-based method for accurate high/low beam headlight control on automobiles during nighttime hours through the use of ultrasonic distance measurement techniques.

III. PROPOSED SYSTEM

Currently, many of the existing automatic headlight control systems utilize sensor-based technologies to control the intensity of vehicle headlights during nighttime driving. In these types of systems, Light Dependent Resistors (LDRs) or other types of sensors are used to measure the intensity of light emitted by the headlights of an approaching vehicle. If the light level goes over a specific limit, the vehicle's headlight will automatically change to lower beam so that it does not shine in the eyes of the driver of an approaching vehicle. In some types of headlight control systems, ultrasonic sensors are also used along with LDR sensors to calculate the distance between vehicles while driving during nighttime. The data collected by these sensors is then used to process a microcontroller like Arduino.

Despite the fact that these systems are simple and inexpensive, there are various shortcomings associated with them. An example of a random LDR sensor is that it only detects the intensity of the light; therefore, it does not know if the light is coming from an approaching vehicle. This is a flaw in the reliability of the system due to having difficulties and being untrustworthy when detecting headlights. Another limitation of thresholding is that a headlight may go on/off when switching beams from high beam to low beam and vice versa. This may be annoyingly constant for drivers.

To overcome these limitations, an intelligent automatic headlight control mechanism is proposed, which utilizes computer vision techniques along with distance sensors. In this technique, a camera is used to take images of the road during nighttime driving. Researchers use a Convolutional Neural Network to analyze images of a vehicle's headlight condition and classify the condition into three categories: high beam, low beam, or no beam. Ultrasonic sensors are used to determine the distance between two vehicles and, in conjunction with the classification of headlight conditions, aid in effective decision making about controlling the headlights of the vehicle(s). The proposed technique utilizes both headlight condition classification and distance measurement to make a reliable decision regarding headlight beam control.

The architecture of the proposed system is illustrated in Fig. 1. which shows that the proposed system consists of four main functional blocks: image acquisition, headlight condition classification, distance measurement and headlight control. In the image acquisition block, images are acquired using a camera. These acquired images are then passed through a CNN-based headlight classifier. At the same time, the distance between two vehicles is measured using an ultrasonic sensor. With these two values, it is decided whether to change the headlight state to low beam or not to avoid any glare and to improve safety while driving.

Table I displays the hardware utilized by the proposed system. Various types of sensors, microcontroller devices, electronic switch devices, etc. were used in order to implement the proposed system.

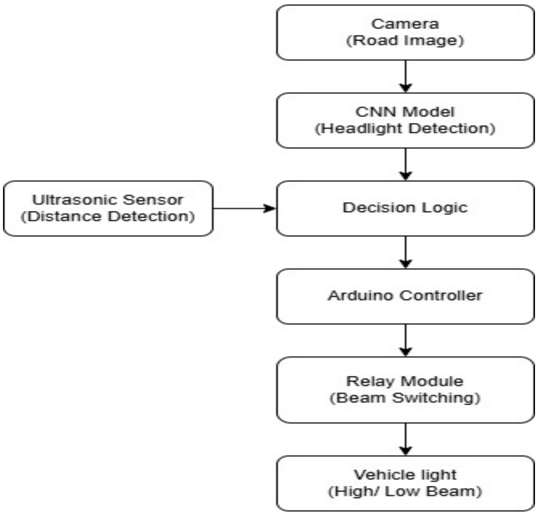

Fig. 1. CNN-based automatic headlight control system's block diagram.

TABLE I. DEVICES FOR THE PROPOSED SYSTEM

Name of the Device	Type of Device
Camera	Image Sensor
Ultrasonic Sensor	Distance Sensor
Arduino Microcontroller	Controller
Relay Module	Switching Device
LED Bulbs	Output Device
Power Supply	Power Source
Connecting Wires	Electrical Connector

A) System Architecture

The suggested CNN-based adaptive auto headlamp control system consists of 3 modules (image acquisition/glare detection, distance measuring, and auto headlamp control). The camera is attached to the vehicle to capture the road while driving at night. The image acquired by the camera is then sent to the CNN model to detect glare from the headlights of an oncoming vehicle.

The distance between two vehicles is measured by an ultrasonic sensor. The output of the CNN model and ultrasonic sensor is combined and then sent to the decision logic module. The headlight is controlled using a relay module based on the output from combined modules. The Arduino microcontroller sends this output to each of the combined relay modules to set the headlight either on high or low beam thereby reducing the number of times a headlight has been turned off/on.

The workflow for this proposed system can be seen in Fig. 2.

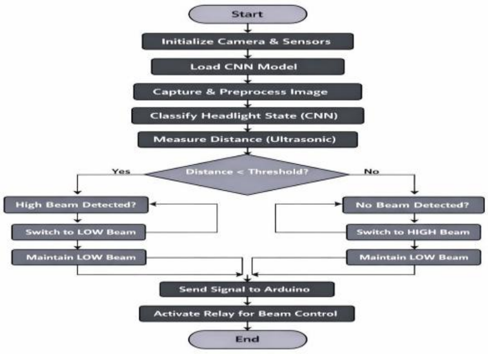

Fig. 2. Workflow of the designed CNN-based automatic headlight control system

B) Image-Based Headlight Detection

The image-based headlight detection system detects glare from oncoming vehicles with a Convolutional Neural Network (CNN) model trained to classify captured images of the road into specific classes. The camera of the image-based headlight detection system captures images of the road in real-time and are pre-processed before being sent to the CNN. The CNN is then used to classify the image based upon the processed image:

1)High Beam

2)Low Beam

3)No Beam

The classes of the CNN model classify the different headlight conditions that can be encountered when driving at night. The CNN model examines the intensity of the headlights in the image to determine the headlight condition of the approaching vehicle. The intensity of the headlights in the image provides better detection of the headlight condition of the approaching vehicle than that of the light sensor-based detection system.

C. Measurement of Distance between Vehicles Using Ultrasonic Sensor

Although information regarding headlight glare is obtained through visual sensing, it is important to understand that the distance between two vehicles is an important factor in determining the intensity of the headlights. An ultrasonic sensor is used to calculate how far apart two vehicles are.

The ultrasonic sensor works on the principle that ultrasonic waves are emitted and then measured for their time of reflection. The distance between two vehicles can be determined using (1).

$$Distance = Speed\ of\ Sound \times Time / 2 \qquad (1)$$

If the distance between two vehicles is less than a specified value, then it indicates an approaching vehicle.

D. Decision Logic and Headlight Control

The output values obtained from the CNN model and the ultrasonic sensor are utilized in the decision logic to decide the appropriate headlight beam according to the headlight condition detected. The steps taken in the decision logic are listed in Table II.

If the CNN model finds that a light's condition is in 'high beam glare', then the car will turn its lights to low beam if it determines that the value detected is below a defined threshold level. If the CNN model has detected that the vehicle is using low beams, the vehicle will continue to use low beams. If the CNN model does not detect any headlights, but the detected value is greater than the threshold limit, the vehicle's headlights will switch to high beams.

The headlight of the vehicle can be adjusted to be in the (high) or (low) mode using an Arduino controller based on the output of the decision making process.

TABLE II. LIST OF INPUT CONDITIONS TO REGULATE HEADLIGHT ILLUMINATION

Ultrasonic Sensor (Distance)	CNN Detection Output	Inference on Headlight (Output)
Distance ≥ 50 cm	No Beam Detected	Headlight ON (High Beam)
Distance < 50 cm	High Beam Detected	Headlight Switch to Low Beam
Distance < 50 cm	Low Beam Detected	Headlight Maintain Low Beam

E. Advantages of the designed System

The benefits of the designed automatic headlight control system over the current conventional systems are as follows:

- Accuracy of detection of glare
- High reliability in the operation of the designed system.
- Avoiding changes in the state of the headlights unnecessarily
- Cost-effectiveness of the designed system

The system proposes utilizing automated headlight control through the use of intelligent technology that relies on the combination of computer vision systems and distance sensors.

IV. EXPERIMENT AND RESULT

A. Experimental Setup

The effectiveness of the proposed CNN-based Headlight Control System was tested and verified using a model created using both hardware and software technology. A camera, ultrasonic sensor, Arduino board, relay and LED headlights comprise what the new system uses to mimic how a car's headlight system works. Hardware usage of the proposed system is shown in Fig. 3.

The camera captures images of the road at night while driving and utilizes a pre-trained Convolutional Neural Network (CNN) to process the images and identify the headlight condition of any oncoming vehicles. Images can be classified as high beam, low beam or no beam. Before being processed with the CNN, images are normalised and resized using the proposed system. Resizing will occur at 224 x 224 pixel size as per the input size used to train the CNN model.

This research project employs a Convolutional Neural Network (CNN) model that uses transfer learning. The model uses the MobileNet V2 architecture as its base feature extraction network, with additional, fully connected layers for classification purposes. The model is trained on a dataset consisting of a variety of different types of images of headlight conditions; as a result, throughout the training process of the CNN model, it can learn different features that are associated with high-beam glare, low-beam headlights, and a vehicle with no headlights on.

In addition to the camera, the ultrasonic sensor is also used in the system. Using ultrasonic waves to transmit between the two vehicles, measurements of the distance between them are accomplished by calculating how long the reflected ultrasonic wave takes to return to the transmitter. The values of the distance are sent to the control system by using serial communication between the Arduino and the processing unit.

From the outputs of the CNN model and the ultrasonic sensor, the decision logic module is able to make a decision on whether the headlight of the approaching vehicle is on or off. This is then sent to the Arduino microcontroller, which is able to control the headlight beam by using a relay module.

Fig. 3. Hardware Implementation of proposed system

B. Experimental Result

The project was able to test the system with various night drive scenarios to assess how well the system could automatically adjust the intensity of the headlights based on glare detected by vision. Scenarios were created that include visual examples of each different car proximity condition found (i.e., no cars nearby, an oncoming car with low beam headlights, and an oncoming car using high beam headlights).

When there is a glare from an oncoming vehicle's (high beam) headlamps, the camera-based system will switch from high beam to low beam if the vehicles are within a predetermined distance of one another, thus reducing glare and increasing visibility for the other driver. If the CNN detects low beams from an oncoming car, the system stays with low beams, as the glare from these beams is already within an acceptable level. If no headlights from other cars are detected, and the distance between cars is wide enough, the system turns to high beams to improve visibility.

The results indicate that by utilizing visual detection of headlights via a CNN model and distance detection via an ultrasonic sensor, the reliability of an automatic headlight control system can be increased. This is because the proposed system is able to more effectively differentiate between glare coming from streetlights and glare coming from headlight sources, as opposed to a traditional light sensor-based system that might mistake streetlight glare for headlight glare. The various testing scenarios, along with the corresponding output, are summarized in Table III. Real-time tests of three test platforms for the proposed automatic headlight control system were completed and the results obtained from the three test vehicles are shown in Fig. 4.

TABLE III. TESTS PERFORMED WITH VARIED DISTANCE AND CNN DETECTION AND RESULTS POSTED.

Scenes	Distance from Approaching Vehicle (cm)	CNN Detection Output	Scenario Description	Headlight State
Scenario 1	80	No Beam	No approaching vehicle detected	High Beam ON
Scenario 2	45	Low Beam	Vehicle approaching with low beam	Maintain Low Beam
Scenario 3	40	High Beam	Vehicle approaching with high beam glare	Switch to Low Beam

Fig. 4. Real-time testing of the proposed automatic headlight regulate system using a vehicle prototype.

V. CONCLUSION

A new adaptive automatic headlight control system based on CNN is proposed to improve the safety of driving at night. In the proposed system, the headlight of the vehicle is detected by a camera, and the distance is detected by an ultrasonic sensor. In the proposed system, a CNN model is used to classify the detected headlight type as high beam, low beam, and no beam. The detected distance by the ultrasonic sensor is the distance between the vehicles. Based on the detected headlight type and distance, the headlight beam level is automatically controlled to minimize the glare caused by the headlight of another vehicle. The outcome of the experiments shows that the newly developed system successfully detects the brightness of the lights and adjusts the beam of the headlights accordingly. It was further determined that the performance of the newly developed system was superior to that of a light intensity sensor and a deep-learning model image detection system currently in use.

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