The Adaptive Headlight System for Cars.

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***Abstract*—This study reviews the design and operation of a microcontroller-based Adaptive Headlight System (AHS) for automobiles. The primary aim of the system is to provide an affordable and efficient method for improving night-time visibility and reducing accidents caused by blind spots or poor lighting conditions. The proposed setup uses a microcontroller to control stepper motors that adjust the headlights' orientation based on vehicle inputs. The system also responds to the indicator signal, allowing the headlights to pivot in the direction of a turn. In addition, a photo diode sensor monitors ambient light levels and automatically switches on the headlights when the surrounding illumination drops below a preset threshold. By automating these functions, the AHS reduces driver workload and enhances road safety through adaptive and intelligent lighting control**

I. INTRODUCTION

Road accidents during night-time have become increasingly common in recent years. Most vehicles are equipped with headlights that illuminate the road directly ahead but fail to provide sufficient lighting around curves or bends. Limited visibility and the inability to detect objects at the edges of turns remain significant challenges for drivers during night travel. Although several safety mechanisms have been developed to reduce the impact of accidents after they occur, relatively few technologies focus on preventive measures that help avoid such incidents altogether [1].
One of the leading causes of accidents, particularly on curved or hilly roads, is the presence of blind spots areas around the vehicle that are not visible to the driver through direct sight or mirrors. These blind spots can result from several factors, including improper mirror adjustment, the thickness of the A-pillars, and the vehicle's height and width. Additional causes include poor road design, weather-related visibility issues, and inadequate street lighting, particularly on highways [2], [3]. Such limitations often reduce the driver's ability to anticipate potential hazards and react in time.
Another major issue contributing to night-time accidents is temporary blindness, or dazzling, caused by the headlights of oncoming vehicles. This phenomenon occurs when the beam from an opposing vehicle's high beam directly strikes the driver's eyes, momentarily impairing vision and reducing reaction time. The problem is especially critical on curved roads, where standard headlights project light tangentially to the curve, often into the path of approaching drivers. As a result, the probability of head-on collisions increases dramatically when a driver is momentarily blinded [4].
Additionally, accidents often occur when drivers neglect to switch on their headlights under low-light or foggy conditions. This underscores the need for an intelligent and cost-effective headlight system that can automatically adapt to real-time driving environments. Such a system should address key challenges, including blind spot illumination, glare reduction, and improved visibility [5].
The Adaptive Headlight System (AHS) proposed in this work provides an efficient solution to these issues. The system automatically adjusts the direction and intensity of the headlight beams according to vehicle motion and external lighting conditions. This ensures that curves and bends are properly illuminated, enabling the driver to detect obstacles or pedestrians earlier and respond safely. High-beam glare can also cause a temporary visual impairment known as the Troxler effect, which reduces reaction time and increases the risk of collisions [6]. To mitigate this problem, the system integrates an automatic headlamp control mechanism using a photo diode sensor that activates the headlights when ambient light intensity falls below a predefined threshold.
Currently, adaptive headlight technology is largely confined to luxury automobiles such as BMW, Audi, and Volvo. However, implementing a photo diode-

based automatic control unit behind the rear-view mirror can make this technology accessible to low- and mid-segment vehicles. Although only about 25% of total driving occurs at night, statistics indicate that nearly 55% of road accidents happen during this period, emphasizing the urgency of developing affordable adaptive lighting systems [7].

Adaptive headlights not only enhance safety but also contribute to overall driving comfort by automatically adjusting beam direction, intensity, and leveling according to environmental conditions. These systems rely on sensor data processed through microcontroller-based algorithms, ensuring precise and real-time headlight control [8].

II. LITERATURE REVIEW

Several studies have been conducted on adaptive headlight systems to improve night-time driving safety, reduce glare, and enhance visibility under various road conditions. Researchers have explored a variety of techniques involving sensors, actuators, and control algorithms to dynamically regulate headlight direction and intensity.

Nkrumah et al. [1] proposed an intelligent headlight system that automatically adjusts light intensity based on real-time traffic data to enhance safety during night driving. Tole et al. [3] designed a smart headlight model integrated with fog detection sensors to maintain proper illumination in low-visibility conditions. Similarly, Gökova [2] analyzed the evolution of automotive lighting technologies and their impact on driver safety and comfort.

Further developments in steering-based adaptive headlights were presented by T. K. et al. [4], who implemented servo-driven mechanisms to achieve dynamic horizontal rotation of headlamps according to steering input. Nkrumah et al. [5] conducted a comprehensive review of adaptive headlight beam control methods, emphasizing the role of sensor fusion in achieving optimal illumination and glare reduction. Zhang et al. [6] optimized headlight beam distribution using real-world traffic and eye-tracking data, showing how human perception could be incorporated into design. Raju et al. [8] developed an adaptive headlight management system for electric vehicles that optimized beam direction and intensity for energy efficiency. More advanced architectures, such as Adaptive Front Lighting Systems (AFS) combined with Matrix LED headlights, have also been reported [9]. These systems enable selective beam shaping, allowing the light to adapt to road curvature and the position of oncoming vehicles in real-time.

While luxury vehicles from brands like BMW, Audi, and Volvo already feature such technologies, cost and complexity remain barriers for low- and mid-range models. To address this gap, low-cost microcontroller-based systems that use sensors such as gyroscopes, light sensors, and stepper motors have been explored [7], [10]. However, most of these designs are either expensive or lack precise automation.

In this context, the present study proposes a cost-effective, sensor-integrated adaptive headlight system capable of both automatic beam adjustment and light-intensity regulation. This approach bridges the gap between affordability and performance, making adaptive lighting technology accessible for all vehicle categories.

III. METHODOLODY

3.1. Proposed System

The main objective of this project is to design and develop an adaptive headlight system which is cost-effective, easy to retrofit in low and mid-end vehicles. The methodology followed is shown in figure 1. The proposed AHS is developed using servo motors attached with the headlights for swiveling operations and placing of gyroscope sensor in the body of the car for levelling the headlights and using the light sensor to dynamically control the high and low beam.

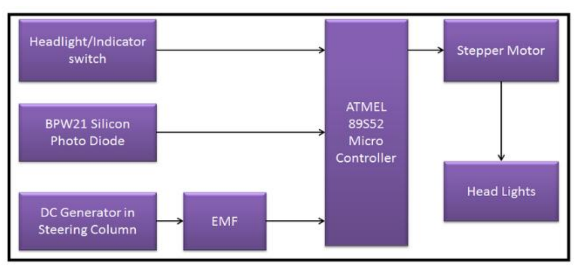

Figure 1. Block diagram representation of the proposed system

3.2. Experimental setup

The experimental setup of the adaptive headlight system consists of the following components as listed in table 1.

Table 1. List of Components

S. No	Name
1	At Mega 328P
2	BH-1750
3	MPU 6050
4	MG 995 servo
5	Automotive relay switch
6	LM-2596
7	12v Battery
8	L298N driver

1.1.1. Component description

The AT mega 328P is a microcontroller-based board having 54 I/O pins with 16 analog pins, 16 MHz crystal oscillator, and 15 PWM pins. This micro controller has voltage regulator that keeps the voltage constant at 5v. Arduino IDE is a proprietary software platform of arduino boards for easy programming. The automotive relay is utilized to activate the multiple connection through a single switch. The servo motor MG995 servo is a low cost and also good in performance which has a torque of 9.4kg/cm (4.8v) to 11kg/cm (6v) is utilized for performing levelling operations efficiently. The BH-1750 ambient light sensor measuring ranges up to 50000lux is used to detect the intensity of the light from oncoming vehicle. The MPU 6050 is a gyro sensor with three axis detection sensor which is combination of both 3- axis gyroscope and 3-axis accelerometer used to detect data of pitch axis and send the data to controller to adjust the headlight and for levelling operation. This is a low-cost sensor which is easy to interface with the board and has a good efficiency compared to the other gyro sensors.

VI. SYSTEM ARCHITECTURE

The prototype setup is shown in figure 2. In this system the arduino mega 328P acts as a main controller which controls the head light, sensors, servo motor and the relay switch. The total system is connected with the 12-v dc battery and the battery output is connected with the LM 2574 switching voltage sensor where the 12v dc is regulated to the required 5v dc. The board and sensors require the 5v dc supply. The power supply unit to the servo motor has been separately bypassed with the L298N driver to supply 6v and the supply to the headlights are given directly from the power unit. The light sensor and gyroscope are interfaced with the arduino. The light sensor is placed in front of the vehicle to detect the oncoming vehicle light lux intensity. Once the intensity is measured, the sensor sends the value to the arduino board and the board sends the signal to relay. The automotive relay switch is used here to respond the light intensity data and accordingly it switches between high or low beam of light. The servomotor is used to perform the swivelling and levelling operation and it is achieved by interfacing the potentiometer and servo with the help of arduino. The steering position or angle is measured using the potentiometer and accordingly the servomotor will swivel the headlight. The swivelling angle is set up to 43 degrees in right and 34 degrees in the left. The gyroscope sensor has been placed in the vehicle and it measures the pitch axis for the leveling operation. According to the signal received from the sensors, the microcontroller processes the signal and will send appropriate commands to the servo for headlights appropriately. Both swivelling and levelling operation are shown in figure 3.

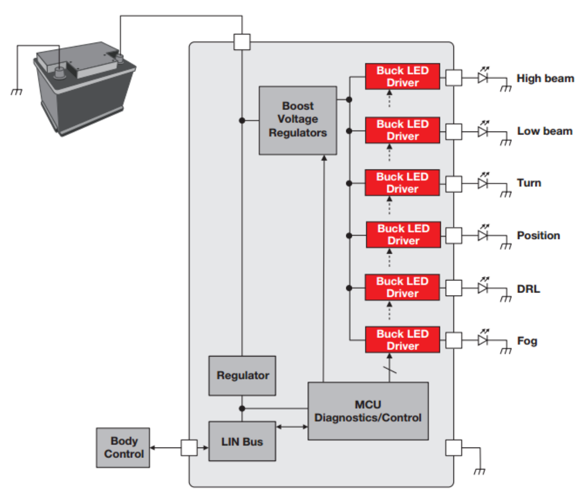

Figure 2. System architecture design of adaptive headlight system

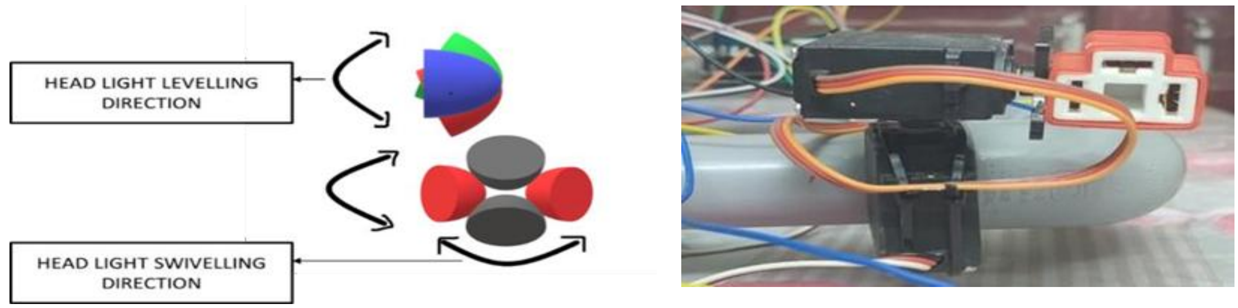

Figure 3. 3D and real time representation of Headlight mechanism.

V. CONCLUSION

The Adaptive Front Lighting System (AFS) automatically adjusts a vehicle's headlights to improve visibility and safety during night driving. By using inputs such as steering angle and distance from oncoming vehicles, the system regulates both the horizontal and vertical movement of the headlights to ensure optimal light distribution. The design focuses on cost-effectiveness, reliability, and ease of integration, making it suitable even for low-cost vehicle models. Overall, the AFS offers a practical and efficient solution for enhancing night-time driving safety and reducing the risk of accidents compared to traditional fixed-beam headlights.

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