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Adaptive Headlight System

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Abstract - *This paper introduces an Adaptive Headlight System (AHS), which enhances night-time and low-light driving safety by dynamically adjusting headlight direction and intensity based on real-time conditions like steering angle and presence of other vehicles. The system is designed using analog components making it easier to implement and more economical. It includes an automatic dimming module and a steering-based headlight adjustment module. The dimming module is designed using a light dependent resistor, op-amp IC, transistor and relay, and the headlight adjustment module is developed using a potentiometer, timer IC and servo motor. A switch is also included for overriding the automation. This design aims to improve the driving safety and comfort thus ensuring a smooth and safe travel experience for travelers.*

Key Words: Automatic headlight dimming, steering based adjustment, Light dependent resistor, Op-amp, Relay, 555 timer IC, Servo motor

1. INTRODUCTION

There's always a risk imposed by the improper use of high beam headlights while driving at night. It causes discomfort and reduces the driver's line of sight which can lead to catastrophic consequences. There also exists the problem of limited illumination in curved roads which is a hazard to the vehicle's occupants. The strict placement of the headlights at the front of the vehicle limits the field of vision in sparsely lit roads. The glare effect might also disorient the driver and combined that with slow reaction time to switch from low beam to high beam, it seems optimal to automate the whole process.

The Adaptive Headlight System (AHS) uses sensors to detect the light intensity from oncoming vehicles and thus activate its dimming mechanism. The placement of the dimming sensors can be made in a way that it would avoid interference due to the presence of ambient lighting such as that from street light. A manual switch is also included for overriding the automation process if necessary. The system also makes use of an automated steering mechanism to turn the headlights along with the vehicle's path. All these systems combined would ensure a smooth and safe travel experience for travelers.

1.1 Objectives

Our mission is to enhance night-time driving safety and comfort by developing a system that automatically adjusts headlights based on traffic conditions and vehicle movement. By providing features like automated dimming, steering-linked illumination and manual control for special cases, we aim to improve visibility, reduce glare, and ensure a safer driving experience for all road users. Main features of this system are:

1. Automatic Dimming System - detects oncoming traffic and automatically dims the vehicle's headlights to reduce glare.

2. Steering Based Adjustment – headlights are rotated and adjusted as the steering wheel is turned. This provides illumination on curved roads, allowing for easier navigation of tight corners and obstacles.

3. Manual Override - allows the driver to switch to high beam headlight manually. This feature ensures that the system adapts to all driving scenarios.

1.2 Motivation

According to the Insurance Institute for Highway Safety (IIHS), half of the car accidents on U.S roads occur at night. Moreover, the number of accidents caused by glare from high beam account for 12 to 15% of all traffic accidents. On December 08, 2025, 'The Times of India' reported an accident that caused the death of three young men as their vehicle collided with a tractor due to the blinding lights from the oncoming vehicle (Source Website: https://timesofindia.indiatimes.com). This project aims to design a system that automatically adjusts the headlights based on the surrounding conditions. This system includes features of automatic dimming, steering based adjustment and manual override, thus making driving more comfortable and safe.

2. RELATED WORK

The project journal by J. Ahmad, R. Yousuf [1] focuses primarily on the sensing of light intensity using analog components which included general-purpose operational amplifiers and a ldr. This highlighted the cost difference between digital dsp based sensing units and analog sensing units. It also showcased a similar layout of voltage divider network output being fed into an Op-Amp and compared with the ldr output.

R. K. Mahadevan and M. Gurusamy[2] implements a system using potentiometer and servo motor. It contains the idea of servo motor being used to swivel the headlight in the direction of steering and the potentiometer output variations are detected and processed into the ATmega 2560 microcontroller which correspondingly gives the signal to the servo.

J. Aishwarya et al. [3], proposed a headlight dimming system implemented with the help of an LDR where the luminosity is measured and the high beam headlight is turned off. The system is implemented using two LEDs symbolizing high and low are toggled corresponding to the input of the LDR module.

R. Muralikrishnan [4], presents a layout design of how the comparator configuration could be implemented and modulated in a way that it could accurately and sensitively detect the light from oncoming vehicle. It also accurately describes the appropriate position of the module for prompt sensing.

S. Shreyas et al. [5], introduces a design to eliminate the issue of blind spots in accordance with the controlled input from Atmel AT89S52 microcontroller unit which drives the stepper motors connected to the headlights. The steering column movement is measured by a DC generator which produces a varying EMF which is then decoded with the help of an algorithm. With the help of this, basic physical movement measurement could be achieved using a potentiometer to give the necessary varying voltage output.

T. D. Admiral [6] discusses pulse width modulation, a concept needed for servo motor rotations, during implementation with the help of a 555 timer IC with a variable potentiometer connected between the discharge pin (pin7) and the threshold voltage pin (pin6).

K. M. Raza [7] further describes the generation of PWM from a 555 timer IC for a DC motor.

Overall, from the literature survey, it can be concluded that an analog system can be designed instead of digital systems which will make the product cost efficient and such a system is valid and relevant for implementation in older vehicles, unlike their newer released counterparts which come with in-built adaptive headlight systems.

3. METHODOLOGY

The working of the system modules has been repersented as a flowchart as seen in Fig -1 and Fig -2.

Module 1: Automatic Dimming System with Manual Override

The process begins by checking whether the switch provided for overiding the automation is turned ON. If the switch is activated, the system directly keeps the headlight in high beam mode. Otherwise, the LDR detects the intensity of the oncoming vehicle's light. The detected light intensity is then compared with a predefined threshold value. If the intensity exceeds the threshold, the operational amplifier produces a +Vsat output, which turns the transistor ON. This energizes the relay into the Normally Open (NO) state, causing the headlight to switch to low beam mode. If the detected light intensity is below the threshold value, the operational amplifier output becomes –Vsat, turning the transistor OFF. As a result, the relay remains in the Normally Closed (NC) state, and the headlight stays in high beam mode. This process continues repeatedly to ensure automatic dimming based on surrounding light conditions.

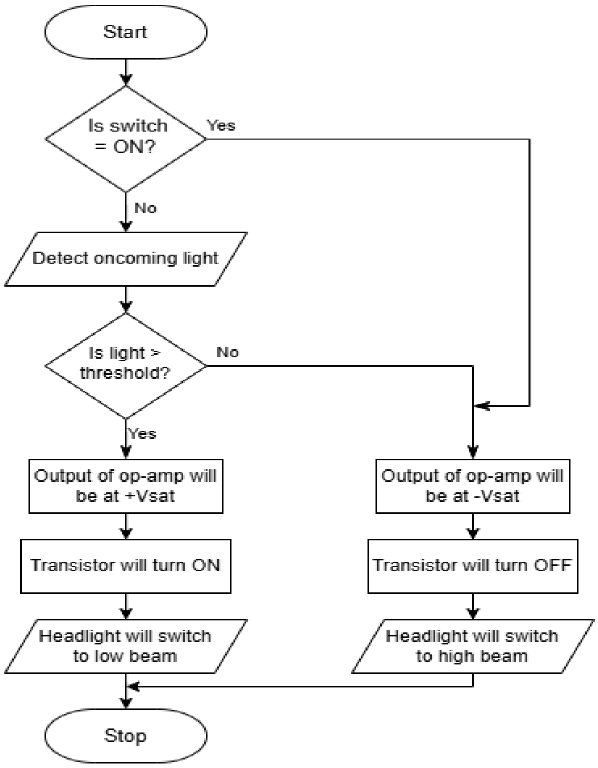

Fig -1: Flowchart of Automatic Dimming System with Manual Override

Module 2: Steering Based Adjustment Module

The steering-based adjustment process starts by detecting the steering movement using a potentiometer. The output from the potentiometer is provided as input to the 555 timer IC to vary the duty cycle of the PWM signal. This PWM signal is then sent to the servo motor. Based on the received PWM signal, the servo motor rotates accordingly, which changes the position of the headlight. As the steering angle changes, the headlight direction also adjust, improving visibility while turning the vehicle.

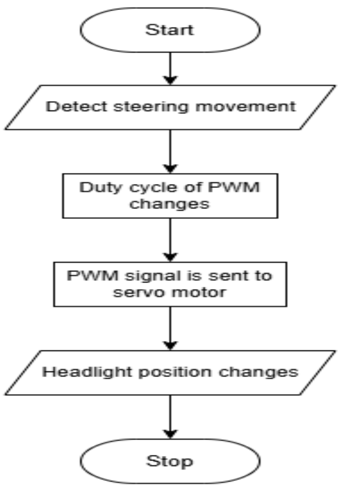

Fig -2: Flowchart of Steering Based Adjustment

4. BLOCK DIAGRAM

The block diagram of the system is as shown in Fig -4. The system contains two modules: (i) Automated headlight dimming with manual override, (ii) Steering based adjustment.

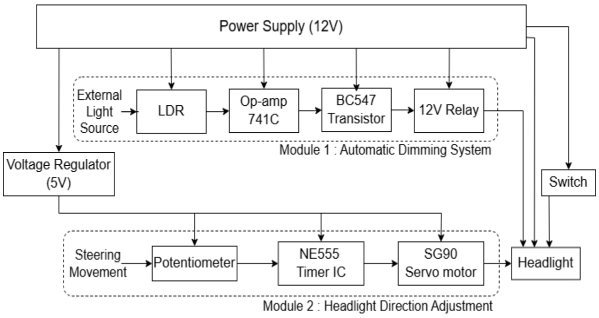

Fig -4: Block Diagram

The first module consists of a LDR, op-amp, transistor and relay. The LDR is combined with resistors forming a voltage divider network. A potentiometer is also added in the network to adjust the sensitivity of detection. The op-amp (uA741C) in comparator configuration is utilized to compare the change in voltage provided by the LDR sensor. The output of op-amp activates the base of an NPN silicon transistor (BC547). The transistor has it's emitter pulled to ground and the capacitor short circuited to one of the coil terminals of the 12V relay. The other terminal of the relay is connected to the 12V supply. When the base gets activated with positive input from the op-amp, the transistor turns on and the relay coil gets energized. This toggles the relay switch from high beam to low beam. It also includes an manual switch for overriding the automation.

The second module consists of a potentiometer, 555 timer IC, servo motor and resistors & capacitors to adjust the pulse output of the timer. The potentiometer is used to analyze the movement of the steering, and its output is connected to pin 5 of 555 IC. The 555 timer IC used here is in symmetrical astable configuration. The output from the timer is directly connected to the microservo which does not need any additional drivers. The servo motor needs high pulse with durations between 2ms and 1ms. These durations are provided by the resistor-capacitor combinations. The servo rotates when variation in pulse width occurs, which can be provided by the timer with the help of a potentiometer connected to the control voltage pin (pin5).

5. SYSTEM HARDWARE

The main hardware components that have been used in this system are:

1. **Light Dependent Resistor (LDR)** – It is a passive electronic sensor used to detect light. It works on the basis of photoconductivity principle, in which it's resistance decreases when exposed to bright light and it's resistance increases when there is no oncoming light. In this sytem it has been employed to sense the light intensity from oncoming vehicle.

2. **μA741C Operational Amplifier** – It is a general purpose operational amplifier which is designed for wide range of analog applications including summer amplifiers, integrators and general feedback applications. In this system, the op-amp operates in comparator configuration to compare the LDR sensor input with a threshold value that is set using a potentiometer.

3. **BC547 Transistor** – It is a NPN Bipolar Junction Transistor (BJT) designed for low power switching and signal amplification. It consists of three terminals: emitter, collector, and base. Here, it acts as a switching device according to the base voltage from the operational amplifier, i.e., depending on the output voltage of the op-amp, the transistor switches ON or OFF.

4. **12V Relay** – A single pole double throw (SPDT) relay is a kind of electrical switch. It has two switching positions, Normally closed (NC) and Normally open(NO). At first position switch connects the one output terminal and second position switch connects to the other output terminal. In this system, when transistor is on, it energizes the relay causing to switch from NC to NO. This activates low beam and turns off high beam. and when transistor is off, relay switches to NO condition activating high beam.

5. **NE555 Timer IC** – The NE555 timer IC is used to generate clock cycles or pulses with custom frequencies. Here, it is configured in astable mode generating a pulse-width modulated (PWM) output signal with varying timing and duty cycle according to its input received from the potentiometer.

6. **SG90 Servo Motor** – The SG90 is a servo motor designed for applications that require precise angular positioning. The motor operates with three connections: power, ground, and signal, and it relies on Pulse Width Modulation (PWM) for control. The rotation angle is determined by varying the duty cycle of the PWM signal, allowing accurate positioning.

7. **Switch** – A switch is an electrical component that is used to connect or disconnect the conducting path in an electrical circuit, interrupting the electrical current or diverting it from one conduction to another. In this system it is used to override the automation. When switch is ON, the headlight will remain at high beam and will not switch automatically.

8. **Transformer and Voltage Regulator** – A 12-0-12 center tapped transformer was used as step down transformer to give 12V, 0V and 12V output. Voltage regulators were used to provide a constant fixed DC supply in the circuit. The linear voltage regulators used here are LM7812 (+12v DC regulator), LM7815 (+15v DC regulator), LM7915 (-15v DC regulator) and LM 7805 (+5v DC regulator).

6. RESULT AND DISCUSSIONS

The implemented system was tested successfully in both breadboard and PCB stages, and the final prototype demonstrated reliable performance in automatic headlight dimming and steering-based beam adjustment under varying operating conditions.

6.1 Breadboard Implementation

The circuit was drawn in Proteus software and initially implemented in breadboard level to test and verify the circuit design. The hardware implementation contains a transformer, a 555 timer IC, a uA741 general purpose op-amp, a switch, voltage regulators 7812, 7815, 7915 and 7805, a 5V DC Buck converter, a 12V DC Buck converter, SPDT relay 12V, SG-90 micro servo motor, 1N4007 diodes, 10k and 47k potentiometers, capacitors, resistors, BC547 transistor and a LDR. The circuit is powered by 12V AC step down transformer which is rectified by a bridge rectifier and filter capacitors are regulated to provide +12V, +15V, -15V, 5V DC supply.

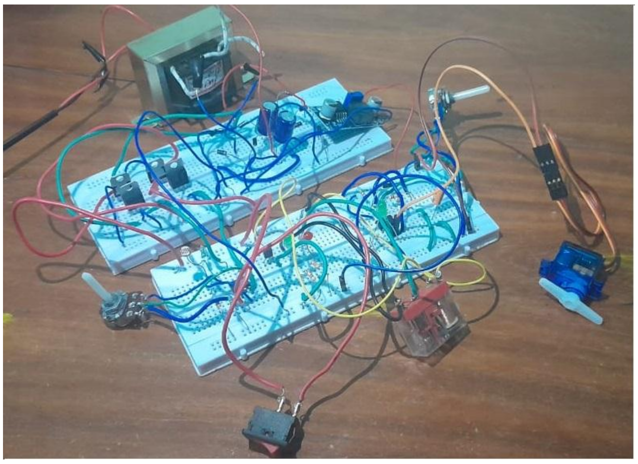

Fig -5: Breadboard Implementation

6.2 PCB Implementation

After successful testing and validation on breadboard, the PCB layout of the system was designed using Proteus software. The designed layout is as shown in Fig -6 and was then implemented on the printed circuit board as seen in Fig -7.

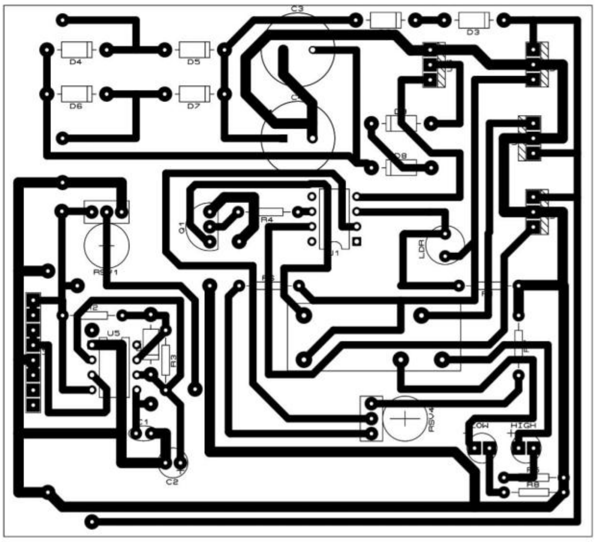

Fig -6: PCB Layout

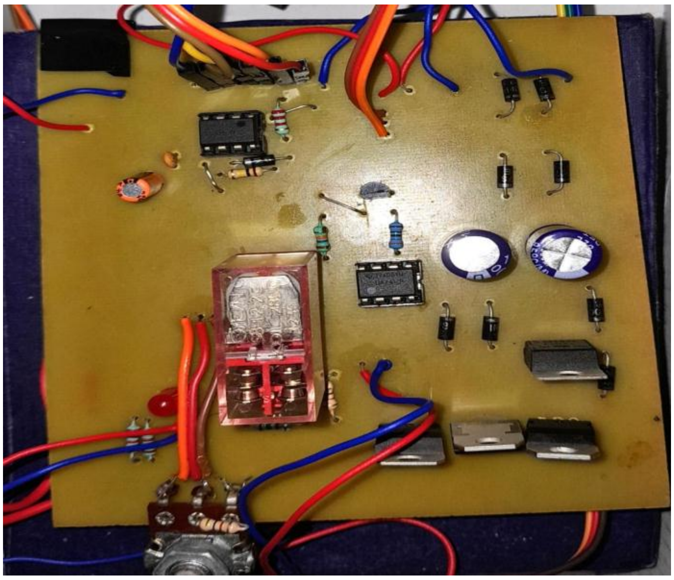

Fig -7: PCB Implementation

6.3 Final Product

After the fabrication of the PCB, the board and other connections were placed inside a casing. Fig-9 shows the automatic dimming of system, i.e., when no oncoming light is detected, the high beam light is ON, and when oncoming light is detected, it switches to low beam.

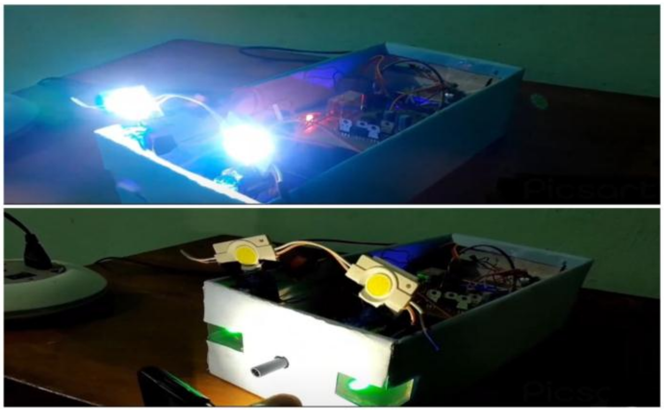

Fig -8: Final Product at high beam and low beam

7. FUTURE SCOPE

This proposed system can be improved by adding smarter features and modern technologies to make driving safer, easier, and more comfortable.

The system is currently designed using analog systems which have their limitations with respect to interfacing more accurate sensors and actuators within the vehicle. On the integration of microcontroller the capability handling of this system could increase up to 70%.

Moreover, with the use of advanced sensors, camera, and AI we can integrate many more features into this system. Pedestrian detection, weather adaptiveness, slope adjustments and vice versa can also be included in the system.

Wireless communication between vehicles (V2X and V2V) can be implemented. Dedicated short range communication has already been in use inside vehicles which helps the system to better understand it's surroundings and adapt accordingly. Cloud based data processing can also help improve and monitor the systems's control and working.

Dynamic power adjustments with Adaptive cruise control can be included to further reduce power consumption in vehicle by tracking the speed of the vehicle, traffic conditions and road curvature to adjust the brightness accordingly. Also it may be possible to implement the system integrated with a solar energy power source which would make it a sustainable product.

8. CONCLUSION

This paper presents an adaptive headlight system, which offers a practical and effective solution to improve road safety for all vehicle owners. The automatic dimming of headlights in response to oncoming traffic and providing enhanced illumination on roads ensures better visibility in various driving conditions, such as night-time and curved roads. The easy installation, without the need for microcontrollers or complex programming, makes it accessible for both modern and older vehicles. With significant potential for both individual and commercial users, this system addresses a growing market need and offers a simple yet impactful way to enhance driving safety and comfort.

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