Design and Implementation of Dynamic Headlight

KARTHIK S 1, HRUTHIK M JAIN 2, PAWAN P 3

2UG students, EEE Department, PESITM, Shivamogga
3Associate professor, EEE Department, PESITM, Shivamogga.

ABSTRACT

The automotive sector is currently in a dynamic change by the introduction of new vehicle concepts, like electric and autonomous vehicles, and innovative driver assistance systems like systems for a precise adaptive headlight adjustment. The continuous adjustment of the headlamps is very important for the correct illumination of the road and prevention of blinding the oncoming traffic, respectively. Hence, a great share of new vehicles possess an automatic headlight adjustment. In some countries, like Germany, these systems are legally required for some kinds of headlights. Nevertheless, there are only a few suppliers for aftermarket products and thus, the product range of automatic headlamp adjustment systems for existing vehicles is low. This paper presents a system concept for the aftermarket that is modular designed and easy to integrate in existing vehicles. In addition, the concept includes a novel approach by the application of a smart tire pressure monitoring system for the detection of the tilt angle of the vehicle.

1. INTRODUCTION

Dynamic headlight systems represent a significant advancement in modern automotive lighting technologies. Unlike traditional fixed-beam headlights, dynamic headlights actively adjust their beam patterns in response to real-time driving conditions, such as vehicle speed, steering angle, and surrounding traffic. This adaptability enhances driver visibility during cornering, reduces glare for oncoming vehicles, and improves overall road safety. As vehicle automation and smart systems become increasingly integrated into automotive design, dynamic headlights stand at the forefront of intelligent lighting innovations. This paper explores the design principles, control algorithms, and performance evaluation of dynamic headlight systems in various driving environments. [3].

The annual number of traffic accidents has decreased in the European Union (EU). The “Annual Accident Report 2018” [1] of the European Commission concluded that the number of injury road accidents has decreased from 1.319 million in 2007 to 1.099 million in 2016. In addition, the annual number of fatalities has decreased from 43,151 (2007) to 25,651 (2016). However, the report [2] of the World Health Organization (WHO) highlights that traffic accidents are the eighth most common cause of death. In absolute numbers, this means 1.35 million deaths worldwide based on road accidents [2].

One aim of the automobile industry is the enhancement of the driving comfort and the reduction of road accidents by the implementation of driver assistance systems (DAS). In [3] the authors emphasize that human errors have a share of 90% in all traffic accidents. This finding and the assessment of the authors of [4] underlines the great potential of DAS and advanced driver assistance systems (ADAS) for the reduction of traffic accidents. [4].

2. PROBLEM STATEMENT

In Conventional static headlights are problematic because they cannot adjust to varying driving conditions, which can compromise safety and visibility on the road. Existing lighting systems often struggle to provide optimal illumination, particularly in challenging environments such as inclement weather or poorly-lit roads. This can increase the risk of accidents. To address these deficiencies, this project aims to develop dynamic headlights that can adapt in real time to dynamic driving scenarios.

The objective is to minimize glare for other road users while optimizing visibility for the driver by leveraging advancements in sensor technology and computing algorithms. However, achieving this goal poses significant technical challenges, including ensuring compliance with regulatory standards, seamlessly integrating with existing vehicle systems, and enhancing the overall driving experience. Through comprehensive research and development efforts, this study aims to contribute to the advancement of automotive lighting technology, ultimately fostering improved road safety and bolstering driver confidence on the streets. [5].

3. BLOCK DIAGRAM

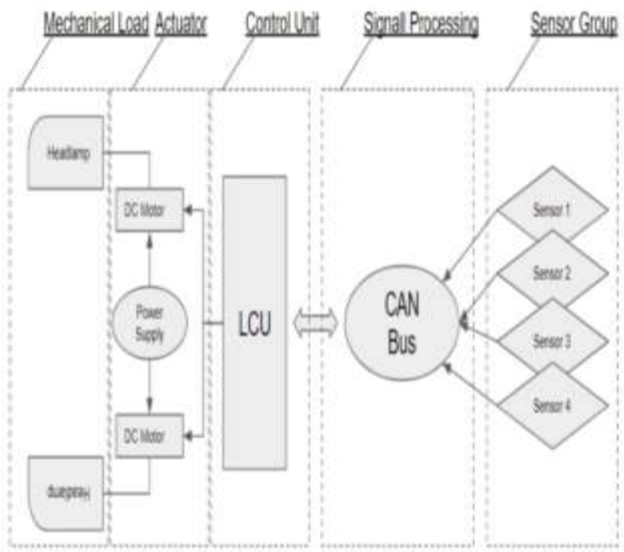

Figure 1: block diagram

To achieve different functions, ILS (Intelligent lighting system) must obtain different vehicle driving information from different sensors. For example, in order to realize the function of turning and lighting the curve, in addition to obtaining the vehicle speed from the vehicle speed sensor, the steering wheel angle sensor to obtain the steering wheel angle, and the vehicle height sensor to obtain the vehicle tilt angle, some special sensors must also be used to obtain the vehicle's actual steering angle ; In order to realize the function of lighting in very complex user environment[6].

Because under normal circumstances, some of the information required by ILS is also used by other control systems, that is, ILS actually needs to share some sensors with other systems. Therefore, the sensor information must be realized through the bus. The information received by ILS, except for a small amount of information such as vehicle speed, vehicle body rotation angle, and vehicle body tilt angle, can be quantified, and most of the information sent back by other sensors can only be qualitative. For example, environmental information outside the vehicle body, such as uneven ground, heavy rain, etc., cannot be accurately quantified. This enables the lighting control Unit (LCU) of ILS to make vague judgments. And a lot of information is interrelated. For example, in the case of rainy weather and road surface water, the corners of the vehicle are significantly different from sunny days ... [7]

The LCU of ILS must not only make vague judgments, but also continuously change as the environment changes. The system parameters are modified, which makes ILS eventually become an adaptive fuzzy system. ILS's actuator is composed of a series of motors and optical mechanisms. Generally, there are projection headlamps, a height-adjusting motor that adjusts the vertical angle of the headlights, a rotary motor that adjusts the horizontal angle of the headlights, a movable light grid that adjusts the basic light type, and some additional lights such as cornering light (or front bending light FBL) and so on[8].

AFS RESEARCH BACKGROUND AND FUNDAMENTAL TECHNOLOGY

The traditional headlight system is composed of a combination of low beam, high beam, running lights and front fog lights. When driving on urban roads and speed limits, low light is mainly used. When driving at high speed on rural roads or highways, high light is mainly used. When driving in fog, you should turn on the fog lights. During daytime, you should turn on. Lamp (this requirement is mandatory in ECE regulations). However, in actual use, there are many problems with the traditional headlamp system. For example, the existing dipped headlights have a poor lighting effect at short distances, especially in urban areas with more complicated traffic conditions. Many drivers often turn on the dipped headlights, high beam headlights and front fog lights at night; There is also a dark area of illumination when the vehicle is turning, which seriously affects the driver's judgment of obstacles on the curve; when the vehicle is driving on a rainy day, the ground area reflects the light of the headlights, generating reflective glare and so on. European automotive lighting research institutions have conducted a special survey on this. The results show that the most hopeful for European drivers is to improve the lighting of flooded roads in rainy weather [9].

The second place is the lighting of rural roads, followed by curved roads. Lighting, highway lighting and urban lighting. The existence of these problems makes it necessary to develop a headlamp with multiple lighting functions, and the switching of these functions must be realized automatically for safety reasons. Therefore, Europe and Japan have successively developed this type of headlamp system that automatically adapts to the driving state of the vehicle-AFS (Adaptive Headlamp System). Basically, an AFS provides the following functions: • Town passing beam (Class V) • Basic/Country passing beam (Class C) • Motorway passing beam (Class E) • Wet-road passing beam (Class W) •[10].

3. Working Model

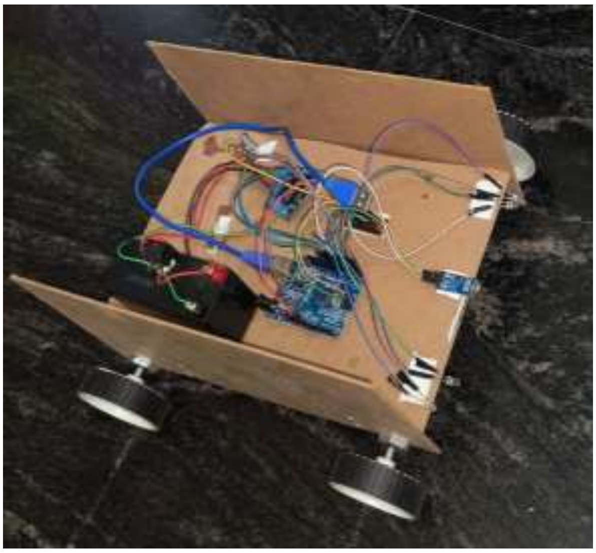

Figure 2: working model

The process of developing dynamic headlights involves many stages to ensure effective and reliable lighting solutions that meet modern driving needs. The process begins with a thorough analysis of requirements, identifying key factors such as safety standards, regulatory compliance, driving conditions, and user preferences. After that, extensive research and development are conducted to explore existing dynamic headlight technologies, prototype different configurations, and evaluate performance feasibility. Next, various sensors, including inertial sensors are integrated to gather real-time data on the vehicle's surroundings, enabling informed decision-making. Sophisticated algorithms are then developed to analyze sensor data and dynamically adjust the headlight beam pattern in response to changing driving conditions [11].

Hardware components, such as led arrays, actuators, controllers, and power management systems, are designed and implemented, ensuring compatibility with existing vehicle architectures and safety standards. Software development is crucial in controlling the operation of dynamic headlights, including sensor data processing, algorithm execution, and communication with vehicle systems. Extensive testing and validation under real-world driving scenarios, along with compliance with safety regulations, are essential steps to ensure performance, reliability, and safety. Integration with other vehicle systems, deployment in production vehicles, and ongoing maintenance and support complete the process, delivering innovative and adaptive lighting solutions that enhance road safety and driving experience [12].

4. RESULT

1. Enhanced Visibility, Especially on Curves and Hills:

Adaptive Bending/Swiveling Headlights: Studies show that systems that "bend" or "swivel" the light beam in response to steering input or road curvature significantly improve illumination around corners and over hills. This allows drivers to see further into turns, perceive potential hazards earlier, and react more effectively. Some research indicates a 2-3% reduction in nighttime crashes along curves due to these systems.

Increased Illumination of Gaze Point: Various studies on swivel-beam headlamps have demonstrated up to a 300% increase in the illumination of the driver's gaze point when navigating curves, directly addressing the problem of "blind spots" with traditional headlights [12].

2. Glare Reduction for Oncoming Drivers:

Adaptive Driving Beam (ADB) / Matrix Headlights: These advanced systems are a major focus of recent research. They use arrays of individually controlled LEDs or laser diodes to dynamically adjust the light pattern, selectively dimming portions of the beam that would otherwise cause glare to oncoming or preceding vehicles, while maintaining high-beam illumination elsewhere [13].

Improved Glare Control: Research shows that ADB systems can effectively manage glare, leading to a reduction in discomfort and disability glare for other drivers. This is crucial for preventing temporary blindness and associated accident risks[14].

3. Accident Prevention and Safety Improvements:

Reduced Nighttime Accidents: The overarching goal of dynamic headlights is to reduce the high percentage of road traffic accidents that occur at night or in low-visibility conditions. Research supports this by showing that improved visibility and glare control contribute to a safer driving environment [15].

Automatic High/Low Beam Switching: Intelligent systems that automatically switch between high and low beams based on detecting other vehicles are shown to reduce driver fatigue and improve concentration, especially on unlit roads. Simulations have shown high success rates (e.g., 98% success rate in detecting approaching vehicles at 90 degrees) for proposed intelligent headlight systems [16].

Driver Fatigue Reduction: By automating beam control and enhancing visibility, dynamic headlights reduce the cognitive load on drivers, contributing to less fatigue and improved alertness during nighttime driving[17].

5. CONCLUSION

The integration of adaptive headlights with automatic high beam and low beam functionality, adaptive lighting for curve roads, and automatic up-down adjustment on slopes and downhill roads represents a significant advancement in automotive lighting technology. Through sophisticated sensor systems and intelligent control algorithms, this project has successfully addressed key challenges in nighttime driving, inclement weather conditions, and varied road geometries. The results demonstrate tangible improvements in road safety, including enhanced visibility, reduced glare for other road users, and improved driver awareness of the surrounding environment. By providing drivers with optimal illumination tailored to the driving conditions, adaptive headlights contribute to accident prevention and mitigate the risks associated with limited visibility and driver fatigue. In conclusion, the successful implementation of adaptive headlights with automatic high beam and low beam control, adaptive lighting for curve roads, and automatic up-down adjustment on slopes and downhill roads represents a significant step forward in improving road safety and enhancing the driving experience.

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