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Combination of the Adaptive Front Light System and Matrix Headlight System

Suresh A[1], Nandhakumar P V [2], Arsath Rahuman M[3], Mohanraj S[4], Nagarjun K[4]

[1]Assistant Professor, Department of Mechanical Engineering, Chennai Institute of Technology, Chennai-600069, India.

[2]Assistant professor, Department of Automobile Engineering, Karpaga Vinayaga College of Engineering and Technology, Chengalpattu, India.

[3] Assistant professor, Department of Mechanical Engineering, Sri Muthukumaran Institute of Technology, Maangadu, Chennai, India.

[4]Student, Department of Mechanical Engineering, Chennai Institute of Technology, Chennai-600069, India

Email ID: suresha@citchennai.net, Email ID: pvnandha@gmail.com, Email ID: m.arsathrahuman@gmail.com

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ABSTRACT

Driving at night, especially on curved roads, presents substantial safety challenges due to the limitations of traditional headlight systems. Poor illumination compromises driver visibility, increasing the likelihood of accidents. This study explores the integration of two innovative technologies—the Adaptive Front Lighting System (AFS) and the Matrix Headlight System—to address these issues and enhance nighttime driving safety.

The AFS employs real-time sensor data to adjust the headlamp direction dynamically, ensuring optimal illumination on curves and critical areas. Simultaneously, the Matrix Headlight System uses advanced control over individual light segments to deliver precise light distribution while mitigating glare for oncoming vehicles. Together, these technologies form a cohesive and intelligent lighting solution that adapts responsively to diverse road conditions and driving scenarios.

By overcoming the inherent shortcomings of conventional lighting systems, this integrated approach significantly improves visibility and comfort during nighttime driving, particularly on complex and challenging roadways. Ultimately, this advancement aspires to lower the prevalence of night-time traffic accidents, fostering safer and more efficient driving environments worldwide.

Keywords: *Headlamps, AFS (adaptive front-lighting system), Matrix Headlight System, Sensor, Automobiles.*

1. INTRODUCTION

Numerous researchers have identified the Advanced Front-lighting System (AFS) as a viable solution to the shortcomings of traditional static headlamps. Static headlamps are limited in their ability to illuminate specific areas for drivers during nighttime driving, proving inadequate for navigating curved roads and intersections. This limitation has sparked a growing interest in AFS technology. Notably, more than 80 percent of road traffic accidents occur in low-light and adverse weather conditions, highlighting the urgent need to focus on the development of advanced intelligent lighting systems featuring multi-functional swiveling headlamps. The main objective is to improve visibility for drivers, which is expected to significantly enhance road safety and driving comfort. Research has shown that swivel-beam headlamps can boost the illumination at the driver's point of focus by as much as 30% when the vehicle approaches a turn. Furthermore, the added corner lighting can enhance the driver's ability to detect obstacles by 58%. The existing fixed headlamp design offers illumination solely in a linear direction, failing to account for road angles or the spacing between vehicles. Consequently, drivers often face insufficient lighting and an unclear perspective of the roadway. To remedy this challenge, it is essential to investigate innovative technologies. One promising advancement is the Adaptive Front Light System (AFS), which is currently under research by experts globally. The AFS modifies the orientation and spread of the low beams in response to the vehicle's turns or corners, as well as the proximity of oncoming and nearby vehicles.

The combination of Adaptive Front Light Systems (AFS) and Matrix Headlight Systems represents a significant advancement in automotive lighting technology, enhancing safety and visibility during night driving. AFS adjusts the light beam based on vehicle dynamics, while matrix headlights provide high-resolution, customizable illumination patterns. Together, they optimize lighting conditions, improving driver comfort and reducing glare for oncoming traffic.

Adaptive Front Light Systems (AFS)

AFS utilizes an electric control unit to adjust the light angle based on steering and speed, enhancing visibility in curves (Vitca et al., 2023). The system employs LED segments that can be individually controlled, allowing for tailored illumination in various driving scenarios (Vitca et al., 2023).

Matrix Headlight Systems

High-density matrix headlights enable precise light projections, dynamically masking areas to avoid glare while maintaining visibility ("Dynamic Model-Based Safety Margins for High-Density Matrix Headlight Systems", 2023). These systems can adjust brightness and color, improving adaptability to environmental conditions and driver behavior (Kim & Lee, 2023).

Integration Benefits

The integration of AFS and matrix systems leads to improved safety by reducing accidents and driver fatigue through optimized lighting (Sandra et al., 2023). Advanced sensor technologies enhance the responsiveness of these systems, ensuring that lighting adapts in real-time to changing conditions (Sandra et al., 2023).

While the combination of AFS and matrix headlights offers numerous advantages, challenges remain in ensuring seamless communication and control between the systems, which may require sophisticated vehicle communication networks to manage the increased data flow effectively (Kim & Lee, 2023).

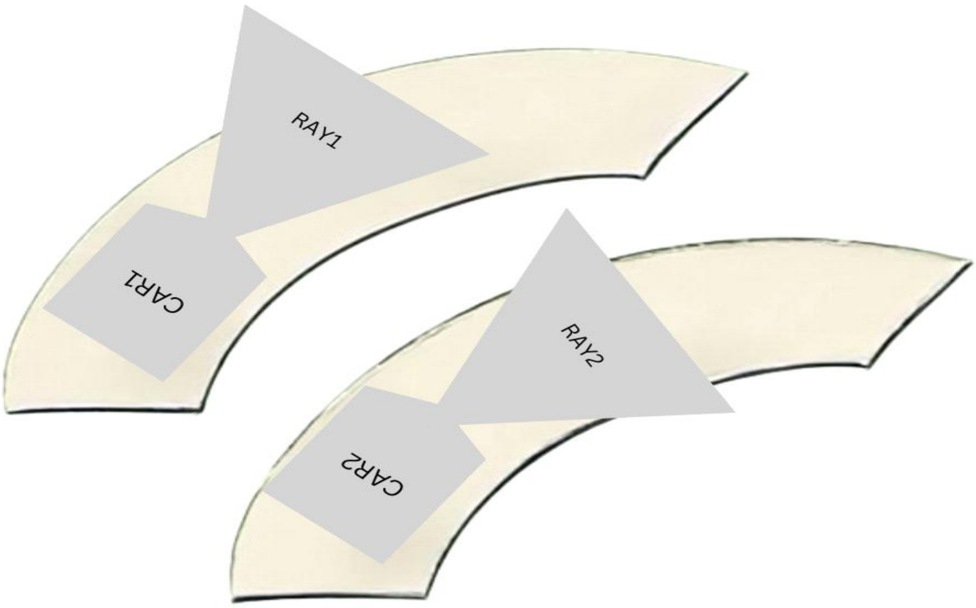


FIGURE1: Car1 without (AFS), Car 2 with (AFS)

When driving at night, the Adaptive Front Light System (AFS) modifies the light distribution to suit the curvature of the road, thereby enhancing visibility. As illustrated in Figure 1, Car 1 does not feature the AFS, whereas Car 2 is equipped with this technology. By automatically adjusting the headlamp direction in line with the vehicle's trajectory and considering the distance to other vehicles, AFS significantly improves the driver's visibility during night-time travel.

A newly developed adaptive front-lighting system has been launched, leveraging CCD technology to outperform conventional systems. This cutting-edge AFS utilizes CCD image recognition to collect corner data from a predetermined distance. It then adjusts the angles of the dipped headlights based on this information, ensuring compliance with regulatory standards and providing optimal illumination when navigating corners, thus eliminating potential blind spots. This sophisticated system effectively predicts and responds to cornering conditions through the application of CCD technology.

2. GENERAL PROBLEM

The central challenge is to create a system capable of assessing road conditions to pinpoint situations where an adaptive road lighting system could improve visibility. This initiative aims to substantially increase safety and comfort for those using the roads. The primary goal of this proposed project is to investigate ways to upgrade existing static vehicle lighting systems, transforming them into more dynamic and responsive solutions that can adjust to the ever-evolving road environment.

3. METHODOLOGY

The creation of a highly sensitive system designed to detect the rotation of headlights is essential, followed by the processing of sensor data through a microcontroller, which then controls the motors linked to the headlights. The proposed Adaptive Front Light System is illustrated through a block diagram. To maintain optimal visibility of the road and any potential obstacles during night-time driving on winding roads, it is vital to adjust the headlight direction accordingly. This system employs a camera (image sensor) to collect data about the curves, converting the RGB image into the HSV colour space. From this processed image, the rotation angle for the headlamp, functioning as an angle sensor, is determined. This data is relayed to the controller, which processes the information and modifies the PWM width. The final output is transmitted to the servo motor, facilitating the horizontal movement of the headlights.

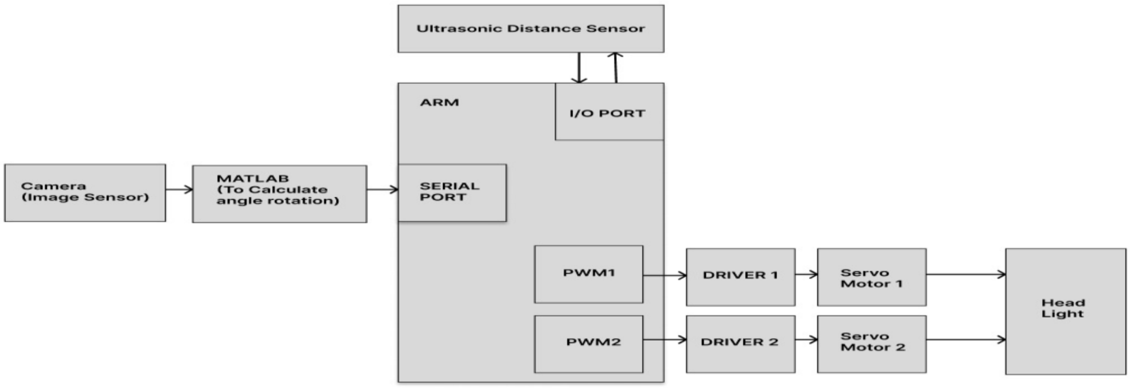


Figure 2: The flow model of the connection of the altered AFS

To achieve optimal visibility of the road and potential hazards while navigating curved roads at night, it is crucial to properly adjust the headlights. This system employs a camera equipped with an image sensor to collect data about the curves ahead. The captured RGB image is transformed into the HSV colour space. From this processed image, the necessary rotation angle for the headlamp, functioning as an angle sensor, is determined. This information is relayed to the controller, which interprets the data and modifies the PWM width accordingly. The final output is transmitted to the servo motor, allowing for the horizontal adjustment of the headlights. The development of a highly sensitive system for detecting the rotation of headlights, followed by the processing of sensor output using a microcontroller, and subsequently controlling the motors connected to the headlights, is crucial. The proposed Adaptive Front Light System is represented by a block diagram. To ensure clear visibility of the road and any obstacles during night-time travel on curved roads, it is essential to adjust the direction of the headlights accordingly. In this system, a camera (image sensor) is utilized to gather information about the corners, and the RGB image is then converted into the HSV plane. From this image, the angle of rotation for the headlamp, acting as an angle sensor, is calculated. This information is transmitted to the controller, which processes the input and updates the PWM width. The resulting output is then sent to the servo motor, enabling the horizontal rotation of the headlights.

4. SOFTWARE AND HARDWARE REQUIREMENTS:

1. Ultrasonic distance sensor
2. PC with MATLAB
3. Servo motor
4. ARM Controller

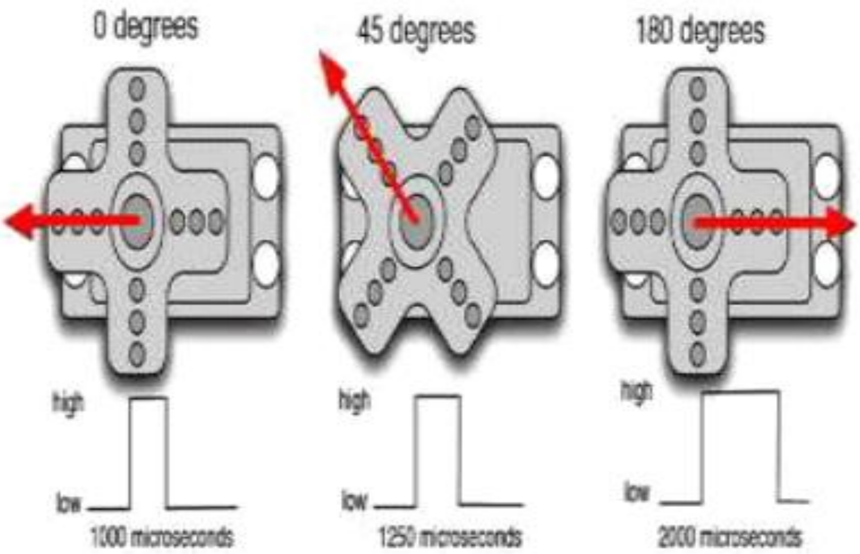


FIGURE 3: PWM (Pulse Width Modulation)

5. PRINCIPLE OF OPERATION

5.1. Vertical adjustment of light based on distance measurement

The ultrasonic sensor employed in this system features two signal pins: the trigger pin and the echo pin. To activate the ultrasonic module, a trigger pulse lasting 10µs must be sent. Following this trigger pulse, an echo pulse is produced, with its duration being directly related to the distance separating the vehicles. This echo pulse is detected on the echo pin.

The ON width of the echo signal indicates the distance to the obstacle. As this distance diminishes, it is necessary to decrease the speed correspondingly. Consequently, the program will modify the ON width of the PWM (Pulse Width Modulation) signal in direct relation to the distance from the obstacle. This adjusted output is then sent to the controller, which updates the PWM width to adjust the vertical position of the headlight.

The vertical servo PWM variable can be determined by applying the following formula: 18000 + (150 - (ultrasonic count - 50)) * 60.

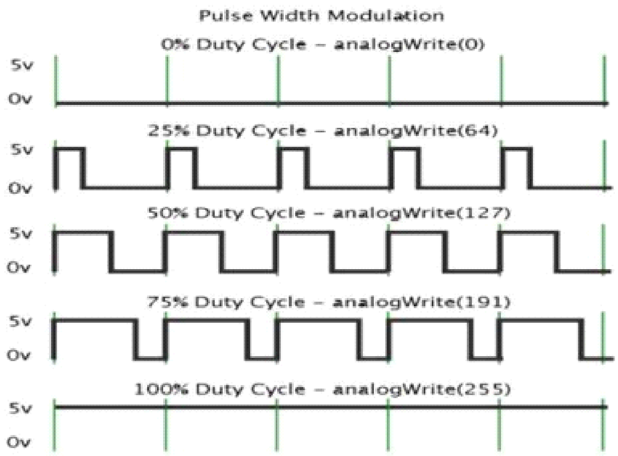


FIGURE 4 PWM Outputs

The PWM signal for the vertical servo motor is based on the ultrasonic count. The ultrasonic sensor outputs a minimum width of 50 and a maximum width of 200. To modify this range, we have deducted 50 from all values, resulting in a new range of 0 to 150. To preserve the relationship where the headlight angle is elevated when the object is distant and lowered when the object is closer, we subtract the measured count from 150. By multiplying this count by 60, we ensure it remains within the thousands range and encompasses the entire vertical movement of the motor. A count of 18000 positions the motor at its lowest point, while any further count incrementally elevates the motor to a higher angle

5.2. Front lights equipped with a servo-controlled camera for horizontal movement:

The controller unit processes the input from the camera and modifies the PWM width as needed. This adjusted output is then sent to the servo motor, which controls the horizontal movement of the headlight. For optimal performance, the servo motor requires a PWM pulse with a 20ms period, a minimum active time of 1ms, and a maximum active time of 2ms.

The initial PWM output operates at a 25% duty cycle, indicating that the signal remains active for 25% of the total period and inactive for the remaining 75%. Following this, PWM outputs at duty cycles of 50%, 75%, and 100% are introduced, each representing a unique analog signal value that corresponds to 10%, 50%, and 90% of the maximum output strength.

5.3. MATLAB Script for Adaptive Front Light system and working:

Matrix Initialization:

- The LED matrix (led Matrix) is initialized as an 8x16 grid with all elements set to 0, simulating an inactive headlight system. The matrix size reflects a simplified version of a vehicle's headlight array.

Adaptive Front Lighting Function:

- The Adaptive Front Lighting function modifies the LED matrix based on the steering angle, simulating how real headlights adjust their beam direction.
- **Adjustment Logic**: The function calculates an Adjustment Factor based on the steering angle, which reduces the brightness of LEDs on the opposite side of the turn. For a right turn (positive angle), LEDs on the left side are dimmed, and vice versa for a left turn (negative angle).
- The adjustment is applied progressively across the matrix, with LEDs farther from the turn direction being dimmed more significantly.

Simulation and Visualization:

- The initial LED matrix is uniformly set to 80% brightness, simulating a steady light distribution.
- The script then simulates a 30° right turn, adjusting the matrix accordingly.
- Both the initial and adjusted matrices are visualized using imagesc, with a grayscale colormap and color bar to illustrate the brightness levels before and after the adaptive adjustment.

5.4. Result obtained for existing AFS: (MATLAB SCRIPT) as shown in figure 4.

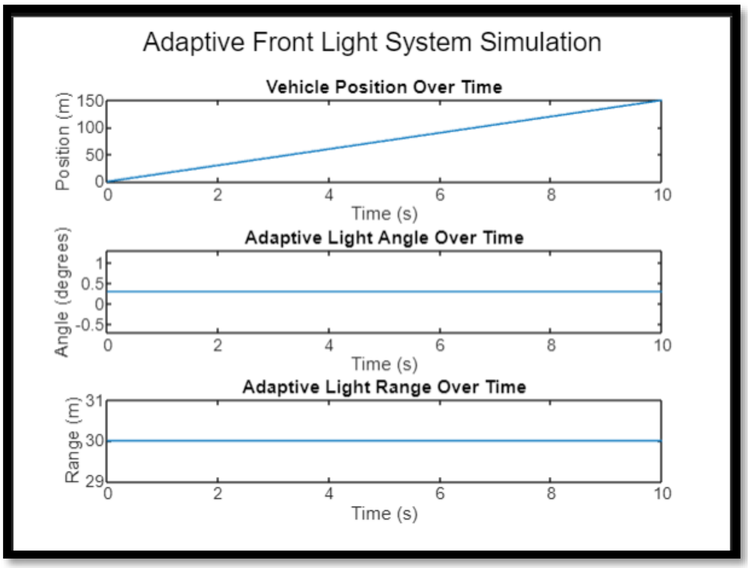


FIGURE 5 Result Obtained for AFS in MATLAB

5.5. Software Flowchart:

The Philips Flash utility software facilitates the uploading and execution of code. To compile for the ARM7 (LPC2148), the

ARM Keil tool employs the µVision4 software as explained in Figure 6.

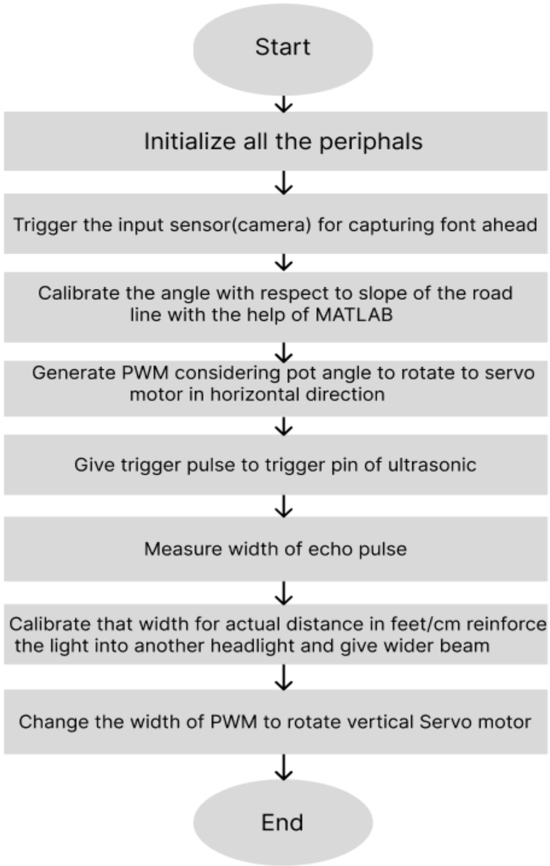


FIGURE 6: Flow chart of the software working

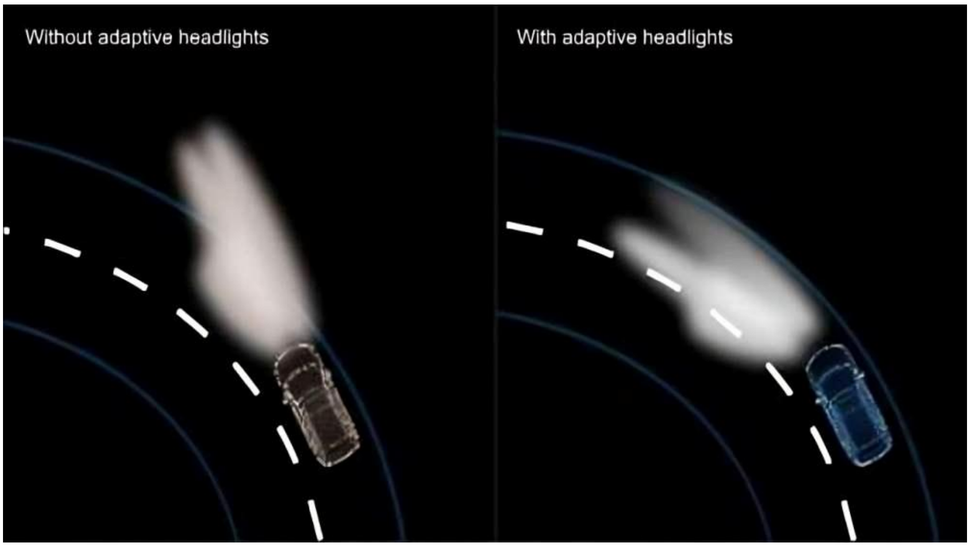


FIGURE 7: Conventional vs. Adaptive Headlight.

6. MATRIX LED LIGHTING:

Matrix LED lighting systems have been engineered to deliver intelligent front illumination with dynamic control and rapid beam adjustment in response to varying driving conditions, addressing the shortcomings of conventional adaptive headlights. These systems operate on a simple principle—pixel-level digital management of the high beam. As depicted in figure 8. In contrast to gas-burning and arc-type lamps, LEDs are semiconductor devices that emit light by allowing an electric current to flow through a p-n junction in a forward-biased configuration. The current through the LEDs can be adjusted to control light intensity with precision and dynamism. LED headlight modules provide exceptional dimming capabilities, enabling high beam LEDs to be reduced in intensity for use as daytime running lights. Furthermore, the compact design, solid-state characteristics, and versatility in optical control of LEDs offer unparalleled design flexibility and engineering potential in advanced adaptive driving beam systems, making them a favored option despite the complex engineering they require.

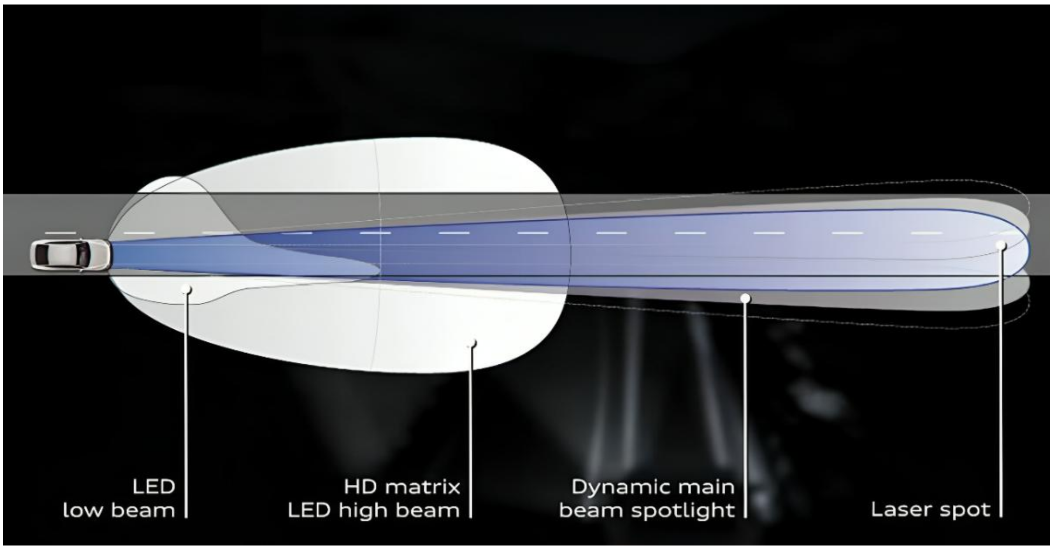


FIGURE 8 Matrix Led Lighting

6.1. MATLAB Script for matrix headlight system and working:

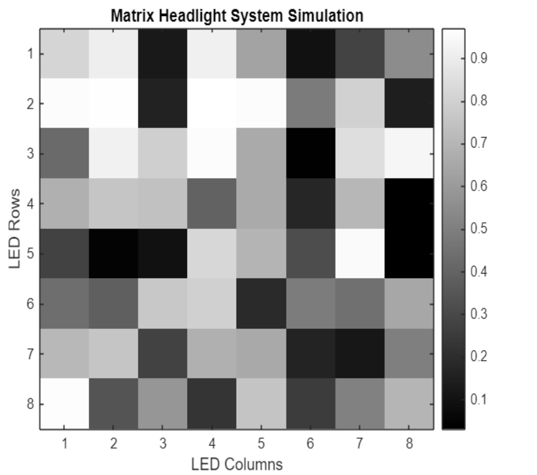
The below MATLAB script is designed to simulate the operation of a matrix headlight system using an 8x16 LED grid. Each element in the LED matrix array corresponds to an individual LED, where the value ranges from 0 (off) to 1 (fully on). The script begins by initializing the LED matrix with random brightness levels using the rand () function, creating a varied pattern of illumination across the grid. This randomization simulates a starting condition for the headlight system.

The initial state of the LED matrix is visualized with the imagesc function, which displays the grid as an image where each LED's brightness is represented by a grayscale color. A color bar is added to indicate the scale of brightness values.

To mimic an external condition, such as detecting an oncoming vehicle or obstacle, the script simulates an adjustment by dimming the left half of the matrix to 20% of its original brightness. This represents a typical adaptive feature of matrix headlights, where certain sections of the light are dimmed to prevent glare or to adapt to road conditions.

After this adjustment, the updated LED matrix is displayed again, allowing for a visual comparison between the initial and adjusted lighting states, highlighting how the system dynamically adapts to external factors.

6.2. Result obtained for existing Matrix Headlight system: (MATLAB SCRIPT) as shown in figure 9.



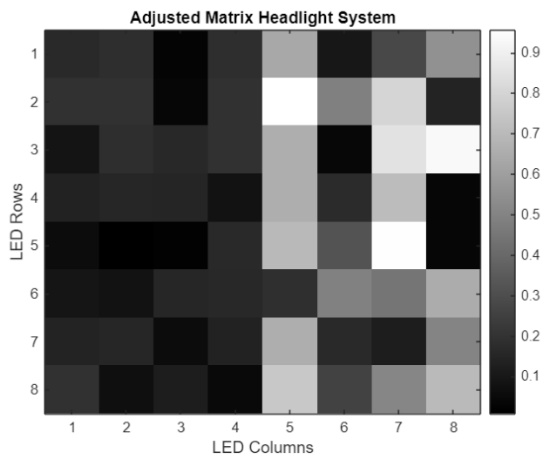


FIGURE 9 Result obtained for existing Matrix Headlight system (MATLAB)

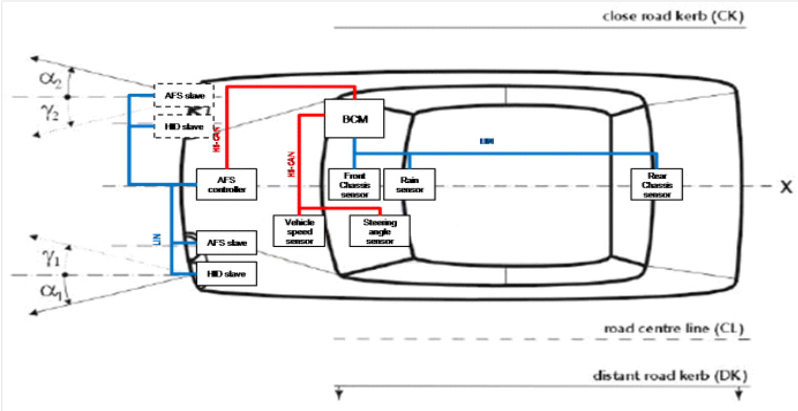


FIGURE 10: Automotive Network Structure

Result obtained for combined matrix and AFS Lighting system: (MATLAB SCRIPT) as shown in figure 11.

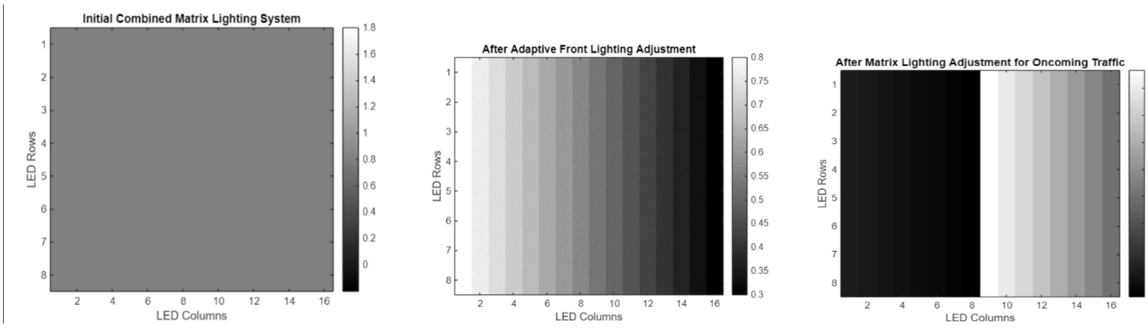


FIGURE 11: Result for combined lighting system

7. MATLAB SCRIPT FOR COMBINED LIGHTING SYSTEM AND WORKING:(MATRIX AND AFS LIGHTING SYSTEM)

LED Matrix Initialization:

The script begins by defining an 8x16 LED matrix (LED matrix) and initializing it with zeros. This matrix represents the headlight system, where each element corresponds to an individual LED.

Adaptive Front Lighting Function:

The function adaptive front lighting dynamically adjusts the LED brightness based on the vehicle's steering angle.

Adjustment Logic:

The brightness is scaled by an Adjustment Factor derived from the absolute value of the steering angle. A higher angle results in a greater reduction in brightness on the side opposite to the turn, simulating the realignment of the headlight beam during steering.

For a right turn (positive angle), the LEDs on the left side are dimmed progressively, and for a left turn (negative angle), the right-side LEDs are dimmed accordingly.

Matrix Lighting Adjustment Function:

The Matrix Lighting Adjustment function modifies the LED matrix based on road conditions, such as oncoming traffic or obstacles.

Road Condition Logic:

For **oncoming traffic**, the left half of the matrix is dimmed to reduce glare.

For **obstacles**, the center columns of the matrix are dimmed to avoid directly illuminating the obstacle.

On an **open road**, no adjustment is made, maintaining full brightness across the matrix.

Simulation Process:

The script first sets all LEDs to 80% brightness, representing a default headlight state.

It then applies the adaptive front lighting function with a steering angle of 30° (simulating a right turn) and displays the adjusted matrix.

Finally, the script simulates an oncoming traffic scenario by dimming the left side of the matrix using the Matrix Lighting Adjustment function and displays the resulting matrix.

Visualization:

The script uses images to visualize the LED matrix at each stage of the simulation. A grayscale colormap is applied to represent LED brightness, and a colour bar is included to indicate brightness levels.

8. CONCLUSION

In summary, the Adaptive Front-Lighting System (AFS) faces limitations in night-time functionality, primarily due to its inability to illuminate road signs effectively, which can compromise safety. To address this challenge, a hybrid approach integrating matrix LED technology with AFS is proposed. This system would dynamically adjust headlamp illumination to enhance the visibility of road signs by selectively controlling light distribution. Future research will focus on developing a robust, integrated AFS-matrix lighting system tailored to diverse and complex driving conditions, including wet road surfaces, highways, rural roads, and urban environments, ensuring safer and more efficient vehicle lighting solutions.

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