UNIVERSITY OF NIS FACULTY OF MECHANICAL ENGINEERING

THE EIGHTH INTERNATIONAL CONFERENCE
TRANSPORT AND LOGISTICS

til 2021

INTELLIGENT LED MATRIX LIGHTING SYSTEMS ON MODERN VEHICLES

Andrija VELIČKOVIĆ [1]
Miloš MILOŠEVIĆ [2]
Maša MILOŠEVIĆ [2]
Aleksandra CVETKOVIĆ [2]

[1)] Gama Consalting Prokuplje, Serbia
[2)] Department of Mechatronics, Faculty of Mechanical Engineering Niš, Serbia

Abstract

This paper presents the importance of car headlights for traffic safety and security, their history and significance. Also, the impact of technological advances in industry that have contributed to easier, cheaper and more efficient solutions of lighting systems on vehicles. Then, high-resolution intelligent LED matrix headlights were presented and described in more detail as mandatory equipment of modern vehicles of the future. Special emphasis is placed on different principles of realization of headlights, advantages and disadvantages, as well as a review of different views by engineers, scientists and manufacturers themselves on this modern technological discovery.

Key words*: Headlights, artificial intelligence, sensors, control units, pixel, LED*

1 INTRODUCTION

The lighting system in cars is one of the most influential factors for traffic safety. A large number of traffic accidents occur in conditions of reduced visibility, which may be limited by weather or adverse weather conditions, but also by a number of other factors. For that reason, scientific institutes, car corporations and many other companies invest a lot of effort and a large amount of money in the development of lighting systems in cars.

The main component of a car lighting system and one of the basic elements of the concept of active safety are the headlights. They primarily serve to illuminate the road in front of us, but also to "discover" our position on the road to other drivers. Literally, headlights allow us to see at night and to be visible to those coming from the opposite direction. Until recently, this basic function of headlights was realized only during night driving, however, nowdays, the rule and obligation was introduced to turn them on during the day as well.

For these reasons, during the development of the lighting system, attention is always focused on the realization of a clear and pure beam of light that will provide the driver with maximum clear visibility of the road and other road users to notice the vehicle on the road as easily and quickly as possible. The development of automotive headlights has been a long process and many solutions have been used throughout the history of car lights, from kerosene lamps mounted on carriages to intelligent LED (Light Emitting Diode) high-resolution matrix headlights that are increasingly used in modern cars. Based on information from various sensors, these technological solutions control the operation of the corresponding LEDs arranged in a matrix shape in order to achieve an intelligent distribution of the light effect. A special analysis is focused on the technological and development process, as well as aspects of the use of this modern technological discovery to increase the safety and security of traffic participants.

2 HISTORY OF AUTOMOTIVE LIGHTING SYSTEM DEVELOPMENT

During the 130 years of its existence, cars have undergone numerous transformations [1]. One of the most fascinating aspects of this whole development was the innovation of automobile lighting, which developed at the same time as new technical and technological achievements in the field of light technology.

The first headlights were acetylene lamps and have been used since 1880. In 1898, the first electric headlights were made, which were optionally mounted on vehicles. To this day, they are indispensable but also the most recognizable parts of every vehicle. Standard lamps were introduced in 1940, while halogens were first used in 1962.

In the last two decades, there have been significant changes in automotive lighting, with changes being particularly noticeable in the area of headlights. Headlights have evolved from simple ones with the sole function of being able to turn on and off to more adaptable lighting solutions, and this is an evolution that has significantly accelerated due to the development of LED lights for the automotive market. Over the last 100 years, headlights have changed greatly to meet new safety requirements, but in the last 20 years these changes have been motivated by other factors, such as performance, efficiency and economy, reliability and appearance. For example, in terms of performance and reliability, headlights have progressed from incandescent bulbs through halogen bulbs to headlights with xenon HID (High Intensity Discharge) and LED lights and adaptive beam design. Incandescent bulbs have been in use for the longest time, but due to their low light characteristics and high consumption as well as short lifespan, they had to be pushed out of use and give way to more efficient and economical principles of light generation. Even halogen bulbs, which are still the most popular in today's automotive industry due to their basic advantage reflected in the simple principle of operation and low price, lose their position due to the biggest problem, which is the great loss of energy by overheating and the sensitivity of the bulb. its lifespan would not be significantly reduced. Xenon headlights are much more efficient when it comes to the intensity of light produced compared to halogens. Xenons also have a very long lifespan, but their price is certainly significantly higher than halogens, they are more complex and require a special device for creating and regulating high voltage. Xenon is not suitable as a high beam on a car because it takes a few seconds after ignition to reach full power. Some xenons can contain toxic substances and can be harmful to health. Also, they often lead to blinding of other traffic participants due to the impossibility of their regulation, thus increasing the number of accidents and deaths. The introduction of LED bulbs at the beginning of the 21st century improved the shortcomings of xenon devices, but this evolutionary step did not greatly affect the overall efficiency of the light source. However, further development of LED technology has enabled the cost and efficiency of LED headlights to exceed HID. One of the most successful applications of LED headlight technology is daytime running lights (DRL). These are forward-facing lights that should stay on all the time the car is in use. However, recent developments have shown that the flexibility of LED lights is also used for styling purposes, which includes the use of directional light for dynamic direction indicators based on the successive ignition technology of corresponding other color diodes evenly displaying the light signal from the inside out.

The development of adaptive beam design by introducing LED matrix headlights represents another significant step in their evolution. Adaptive beam shaping allows the light beam control to actually change the direction of the light. Implementations vary, but this is usually accomplished by turning on and off selected diodes in their matrix layout. This greatly increases the performance of the headlight, and dramatically improves safety, not only by improving driver visibility or excessive illumination of traffic signs, but also by reducing the glare of oncoming vehicles. The headlights that form the adjustable beams vary greatly in complexity and can contain only nine to over 80 diodes.

3 INTELLIGENT LED MATRIX LIGHTING SYSTEMS

In the field of autonomous driving [2], in addition to the basic function of road lighting and vehicle marking, various sensors are combined with car headlights in order to increase traffic safety and reduce the occurrence of traffic accidents. LED matrix headlights with high-resolution LED pixels (***Fig. 1***) are new types of headlights that use arrays of LEDs for "pixelated" lighting. By obtaining information from different sensors, they can intelligently control the amount of light of the corresponding diodes in order to achieve an intelligent distribution of the light effect. Due to the complexity of the external environment and road conditions, high-resolution matrix LED headlights are constantly evolving. The main idea is to provide the best conditions for drivers and other road users by changing the appropriate distribution of light according to external information regarding traffic conditions. The variability of the environment requires high reliability, response speed and stability of such systems. To ensure the best behavior, various technologies can be used, and each of the technologies has its advantages and limitations.

Fig. 1 *LED Matrix Headlight of Audi A7 Sportback (source: https://www.manufacturer.lighting/)*

Automotive headlights with high-resolution beam technology provide extremely flexible light distribution benefits in the areas of far and low beams and ADB (Adaptive Driving Beam). By segmented lighting of a specific area, the brightness of each segment is controlled to achieve an intelligent light distribution design. Each part of the area of the light beam whose amount of light can be controlled represents the resolution of the headlight. In the literature [3], the terms pixel resolution, functioning in conditions of difficult visibility, reliability and stability, the fusion with sensors, and customizations are mostly mentioned for the characteristics for high-resolution headlamps.

The most commonly used indicator is the pixel resolution. The number of pixels of high-resolution headlamps is the size of the area where the headlamps can be controlled. This is important in order to be able to follow other parameters that define the current events on the roads, such as the radii of curvature of the road, different situations in which the vehicle can be found, objects with different reflections, etc. However, the resolution of matrix facsimiles is affected not only by the number of pixels of the light source itself, but also by the structure of the entire optical system. Each headlight has different functions, and the requirements for resolution are also conditioned by other functions that need to be realized.

High-resolution headlights require real-time feedback on the information the car has collected. At the same time, the complexity of traffic conditions requires that the system be capable of real-time light correction. It has been noticed that the use of high beams in difficult weather conditions, such as rain, fog, sleet and snow, ie. when there is reduced visibility it leads to erroneous estimates and causes traffic accidents. Therefore, special lighting strategies are needed in situations where the impact of reflected light reflections can directly affect the visibility of oncoming vehicles. Then the advantages of using a high-resolution headlight system come to the fore, which increase the audibility by controlling the brightness intensity. Providing better night lighting in difficult visibility conditions with this technology is one of the most important tasks for autonomous driving . Therefore, high overall reliability and stability is necessary, which is reflected in the nature of a "self-healing" measure. Highly adjustable headlights compensate for the failure of one or more diodes by controlling adjacent diodes. The local dimming of defective diodes caused in this way can be supplemented by the distribution of light from neighboring diodes, which, in addition to traffic safety, also reduces the cost of replacing car lights. Signals from the ambient perception system while driving are required for high-resolution headlights to function. Therefore, fusion is performed with sensors from various systems on the car, especially with newer technology systems such as radar, ultrasound and on-board cameras. This is especially important in autonomous driving as the driving environment conditions become increasingly demanding. The integration of sensors into LED headlights can shorten the system's response time to dynamic changes while driving, for example, light beam shakes can be eliminated in the event of an uneven road surface. Finally, the high-resolution headlamp system should be able to adjust system parameters so that the behavior of the entire system is adapted to the specific needs of the user. Once set, the desired settings should be memorized and reused in similar situations without subsequent driver intervention. The development of Machine Learning and large databases have made travel more intelligent, allowing users to set up a personalized lighting database according to personal needs and desires.

In order to achieve all these set requirements for driving in increasingly complex conditions in modern cars, high-resolution car headlights use the achievements of modern technologies in the field of Digital Light Processing (DLP) based on a set of chipsets based on Optical Micro-Electro-Mechanical (OMEMS) technology that uses a Digital Micromirror Device (DMD) originally developed by Texas Instruments (TI). In DLP projectors, the light is created by microscopically small mirrors laid out in a matrix on a semiconductor chip. These mirrors are so small that DMD pixel pitch may be 5.4 µm or less. Each mirror represents one or more pixels in the projected image. The number of mirrors corresponds to the resolution of the projected image. These mirrors can be repositioned rapidly to reflect light either through the lens or onto a heat sink. TI's latest device can achieve the highest resolution currently on the market using a 1.3 million mirror rotation to achieve light distribution with short switching times and fast response times [4]. On the other hand, the development of microLED and miniLED devices is influencing the development of new types of high-resolution headlights.

The latest high resolution technology presents pixelated LED arrays which are composed of thousands of LED pixels in each LED array composition. High-resolution LED pixel headlamps typically have a Lighting Matrix Manager (LMM) device which provides regulation and control of LED pixels. The components of one High-resolution LED matrix headlamps system are shown in ***Fig. 2***.

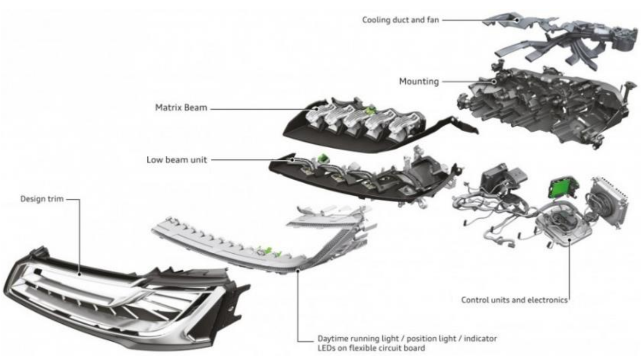

Fig. 2 *Components of LED Matrix Headlight of Audi A7 Sportback (source: https://www.peakpx.com/)*

The intelligent control of the individual light diodes of the High-resolution LED Matrix headlamp is proposed by the Light Control Units (LCU) installed on the headlamp housing. The light is distributed where necessary, via projection modules or reflectors so that the system absorbs different parts of the light to adjust the light distribution.

The main benefits for the driver of the High-resolution LED Matrix headlamp works when the driver switches on the high-beams and selects the headlights 'automatic function. The high-beams headlight can be made to split so that it avoids a car in front but still shines far ahead (***Fig. 3***) regardless of whether other vehicles are moving in the opposite or the same direction. The headlights get their instructions from a computer that processes images of the road taken by an on-board camera. In areas around town, this function only starts working at speeds above 60 km/h, and out of town it's activated at speeds above 30 km/h.

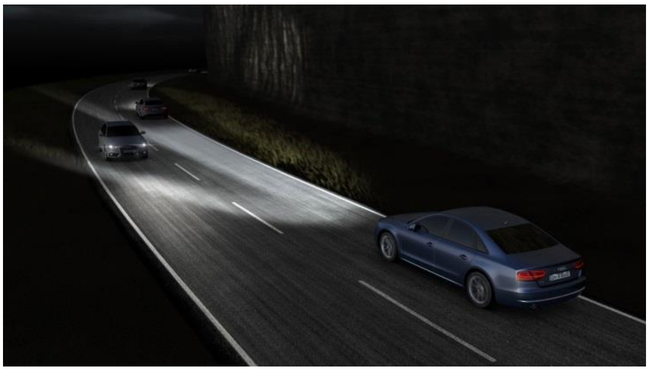

Fig. 3 *Splited high-beams headlight of LED Matrix Headlight (source: https://www.motorauthority.com/)*

In addition, the Matrix LED headlights also function as a cornering light. Using predictive route data supplied by the navigation system, the focus of the beam is shifted towards the bend even before the driver turns the steering wheel ahead (***Fig. 4***).

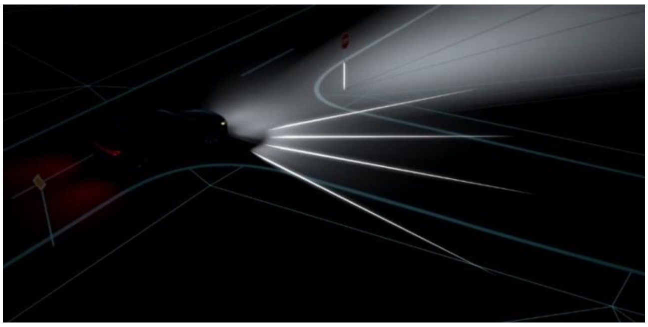

Fig. 4 *Cornering light of LED Matrix Headlight (source: https://www.manufacturer.lighting/)*

In addition to the option of turning off individual diodes in High-resolution LED Matrix headlamps, there is also the option of additional brightness enhancement of certain areas that can draw the driver's attention to certain details on the road. Thus, there is also a marker light that works together with the optional night vision assistant. As soon as a pedestrian is detected in front of the vehicle, individual LEDs flash briefly three times in succession to alert that person, who is then clearly visible to the driver (***Fig. 5***).

Fig. 5 *Marking light of pedestrians of LED Matrix Headlight (source: https://www.motorauthority.com/)*

Moreover, this box beamed onto the road shows up tarmac defects and marks out your position between the lines and your distance from the car in front (***Fig. 6***).

This includes visible markings, to augment where the car is positioned on the road, so that it's easier for the driver to stay in their lane, which is especially useful in lousy weather.
Similarly, this can be also used to highlight obstacles or the edge of the road with brighter light.

Fig. 6 *Marking the distance from the vehicel in front of LED Matrix Headlight (source: https://www.carmagazine.co.uk/)*

Fig. 7 *Displaying patterns on the road of LED Matrix Headlight (source: https://www.caranddriver.com/)*

And finally, on some Audi prototype cars futuristic tech that can display patterns on the road within the "light carpet" the LEDs illuminate was presented. Behind the four projectors and the layers of glass and plastic lenses on the prototype headlights individually controllable light pixels on eight LED modules that enable micromanaging of the shape of the beam pattern of traffic signs (***Fig. 7***).

4 CONCLUSION

This paper gives a detailed overview of the development of the lighting system on vehicles. Advances in technology, as well as new requirements such as increased efficiency and economy and improved performance and reliability, have led to the implementation of LED matrix headlights. These headlights are characterized by arrays of diodes in the form of matrices that emit light individually and that can be independently controlled in terms of controlling the amount of light they emit depending on current needs and driving conditions. For this reason, these matrix headlights have found application in next-generation cars that support autonomous driving. Along with other advanced sensors, intelligent matrix headlights are the basis for self driving cars.

ACKNOWLEDGMENT

This research was financially supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Contract No. 451-03-9/2021-14/200109). The authors are grateful for the support.

REFERENCES

1. Hamm, M., Audi, A.G., *Real Driving Benefits and Research Findings with Digital Light Functions*, ISAL, Darmstadt, Germany, 2019.
2. Hamm, M., Huhn, W., Reschke, J., *Ideas for Next Lighting Generations in Digitalization and Autonomous Driving*, SAE International, Pennsylvania, USA, 2018
3. Wang, L., Ma, J., Su, P., Huang, J., *High-Resolution Pixel LED Headlamps: Functional Requirement Analysis and Research Progress*, Appl. Sci. 2021, 11, 3368, https://doi.org/10.3390/app11083368
4. Knöchelmann, M., Held, M.P., Kloppenburg, G., Lachmayer, R, *High-resolution headlamps–technology analysis and system design*, Adv. Opt. Technol., 2019, 8, 33–46.
5. *https://www.caranddriver.com/*
6. *https://www.motorauthority.com/*
7. *https://www.carmagazine.co.uk/*
8. *https://www.manufacturer.lighting/*

Contact address:
Miloš Milošević
University of Niš
Faculty of Mechanical engineering
18000 Niš
A. Medvedeva 14
e-mail: milos.milosevic@masfak.ni.ac.rs