

DESIGN AND OPTIMIZATION OF A HIGH-EFFICIENCY GROUND PROJECTION SYSTEM FOR AUTOMOTIVE APPLICATIONS

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ABSTRACT

This study presents the design and evaluation of a high-efficiency ground projection system for automotive applications. The system projects a magnified image, such as a logo or safety symbol onto the ground when the vehicle door is opened, enhancing both aesthetic appeal and functional safety. It comprises a high-power OSRAM CP7P 1W LED, an aspheric condenser lens, an aspheric imaging lens, and a logo pattern plate. The optical design was simulated using ZEMAX and TracePro, while SolidWorks supported mechanical integration. A 100× image magnification was achieved with a measured deviation of less than 2%, confirming the system's accuracy. Experimental tests conducted in a controlled darkroom environment showed a luminous efficiency of approximately 85% and an average illuminance of 250 lux at a 1-meter projection distance, closely matching simulation predictions. Minor variations in brightness and image clarity were attributed to manual lens alignment and LED placement tolerances. Future enhancements may include automated optical alignment, anti-reflective coatings, and adaptive brightness control. The results demonstrate that the proposed system is a feasible and energy-efficient solution for automotive lighting, suitable for vehicle branding, safety indicators, and smart lighting applications.

1. INTRODUCTION

With the continuous advancement of automotive technology, customized ground projection systems have emerged as an innovative feature in modern vehicles. These systems are designed to project logos, warning signs, or decorative patterns onto the ground

when the vehicle door is opened, enhancing both safety and aesthetics (Kim et al. 2021). By providing improved visibility in low-light conditions and offering a unique branding element, this technology is increasingly being integrated into luxury, commercial, and personal vehicles (Ozkaptan, Ekici, and Altintas 2021).

The development of vehicle-mounted projection systems requires precise optical engineering to ensure high brightness, sharp projection, and energy efficiency. The optical system must be carefully designed to maximize light output while maintaining a clear and well-defined image (Minaeva et al. 2021). In this study, ZEMAX, TracePro, and SolidWorks software are utilized to design key components, including aspheric lenses for optimized light focusing, a high-power LED for efficient illumination, and a durable structural framework for seamless vehicle integration. These tools allow for detailed simulations to refine the system's performance before fabrication (Tavakoli et al. 2022).

To validate the proposed design, a prototype of the projection system was fabricated using 3D printing technology, and its performance was assessed through simulations and experimental tests. The system consists of a white high-power LED, an aspheric condenser lens, an aspheric imaging lens, and a customized pattern plate (Rasool et al. 2021). The imaging lens is designed to project a 100X enlarged image onto the ground, ensuring high visibility and clarity in real-world conditions. The experimental setup evaluates the system's efficiency and compares its real-world performance with simulation data (Borsboom et al. 2023).

This paper focuses on optimizing the efficiency, brightness, and clarity of the projected image by enhancing both the optical and mechanical design. The study also explores potential improvements to reduce distortions, enhance durability, and increase projection accuracy. Future advancements will further refine image quality, energy consumption, and adaptability for various vehicle applications, making customized ground projection systems a versatile feature for automotive branding, safety indicators, and user experience enhancement (Santantonio et al. 2023).

2. RELATED WORKS

The concept of customized ground projection systems for vehicles has evolved significantly over the years, driven by advancements in LED technology, optical design, and digital projection methods. Initially, such systems were limited to simple static logo projectors, often integrated into luxury vehicle brands as a branding element. These early implementations used halogen or low-power LED light sources, which produced low-resolution projections with limited brightness. However, with the emergence of high-power LEDs and precision optics, modern systems now offer higher brightness, sharper image projection, and greater energy efficiency (Zuczek 2021).

In recent years, research has focused on optimizing optical lens configurations to improve projection quality. Optical simulation software such as ZEMAX and TracePro has been widely used to model light behavior and refine beam control and projection accuracy. The use of aspheric lenses has been particularly important in reducing optical aberrations and increasing light efficiency, allowing for a clear and well-defined projection even on uneven surfaces (Zhou et al. 2021). Studies have shown that carefully designing the numerical aperture, focal length, and LED positioning significantly enhances the sharpness and uniformity of the projected image (Ji et al. 2022).

Another major area of research in vehicle projection technology is enhancing brightness while maintaining energy efficiency. High-power LEDs, such as those developed by OSRAM and CREE, have been studied for their thermal stability and luminous output, ensuring that the projection remains bright without excessive energy consumption (Sun et al. 2021). Additionally, optical techniques like beam shaping and adaptive brightness control have been proposed to concentrate light output onto the pattern plate, reducing light loss and optimizing energy use. Some studies have also

explored the integration of ambient light sensors that dynamically adjust projection intensity based on environmental lighting conditions, improving visibility in various scenarios (Rosatti et al. 2022).

While early implementations of ground projection systems focused primarily on aesthetics, recent developments have explored their use in safety and navigation applications. Researchers have investigated dynamic projection systems capable of displaying pedestrian warnings, blind-spot indicators, and road surface markings to enhance driver and pedestrian safety (Olowu et al. 2021). Some experimental designs have incorporated laser-based projection technologies for sharper, more detailed images, as well as holographic techniques to create moving or interactive projection elements (Ni, Qi, and Jing 2024).

Several challenges remain in the field of vehicle-mounted projection systems. One of the key research gaps is minimizing optical distortions to maintain projection sharpness across different surfaces and lighting conditions (Zosu, Amaghionyeodiwe, and Adedeji 2024). Additionally, reducing energy consumption while maintaining high brightness and clarity remains a critical objective. Researchers are also exploring new materials and coatings for optical lenses to further enhance light transmission and durability. Future innovations may include AR (Augmented Reality) integration, allowing vehicles to project interactive information such as navigation guides, safety alerts, or user-defined patterns onto the ground (Schmalenberg et al. 2022). This study focuses on refining the lens configuration, LED efficiency, and projection clarity to improve the overall performance of customized ground projection systems in vehicles. By leveraging ZEMAX, TracePro, and SolidWorks, this study aims to develop a high-performance, energy-efficient projection system that can be adapted for both aesthetic and functional applications in modern automotive technology.

3. METHODOLOGY

The development of a customized ground projection system for vehicles involves a combination of optical design, light source selection, and mechanical integration. The primary goal is to ensure that the projected image is sharp, bright, and energy-efficient, making it both visually appealing and functionally reliable. This section details the methodology used, including optical modeling, mathematical formulations, simulation analysis, and experimental validation.

The projection system consists of a high-power white LED, an aspheric condenser lens, an aspheric imaging lens, and a logo pattern plate. The optical path is designed to efficiently direct and focus the LED light onto the pattern plate before projecting an enlarged image onto the ground. The magnification (M) of the system is determined by the ratio of the projected image height to the pattern plate height, expressed as (Al-Fahoum and Elsaaidh 2024):

$$M = \frac{h'}{h} \quad (1)$$

where, h' is the projected image height, and h is the input logo pattern height. To achieve a $100\times$ magnification, the placement and focal length of the lenses must be optimized using the thin lens equation:

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \quad (2)$$

where, f is the focal length of the imaging lens, d_o is the object distance (distance from the pattern plate to the imaging lens), and d_i is the image distance (distance from the imaging lens to the projected image on the ground). ZEMAX and TracePro are used to simulate and determine the optimal values for these parameters to

maximize light efficiency and image clarity.

The system employs an OSRAM CP7P 1W LED with a 5000K color temperature, which serves as the primary light source. The LED follows Lambert's cosine law, which states that the intensity $I(\theta)$ at an angle θ from the normal axis is given by (Nguyen et al. 2022):

$$I(\theta) = I_0 \cos(\theta) \quad (3)$$

where, I_0 is the peak intensity in the normal direction. The luminous flux (Φ), which represents the total light output, is calculated by integrating the intensity over the solid angle:

$$\Phi = \int_{\Omega} I(\theta) d\Omega \quad (4)$$

where, $d\Omega$ represents the solid angle covered by the projection system. The aspheric condenser lens is designed to collimate and focus the LED light onto the pattern plate, improving light efficiency and brightness uniformity while reducing unnecessary light scattering.

To further enhance projection performance, TracePro simulations are conducted to evaluate light paths, beam divergence, and efficiency. The primary objectives of these simulations include optimizing light concentration on the pattern plate, minimizing chromatic aberrations and distortions, and ensuring uniform light distribution across the projected image. The numerical aperture (NA) of the imaging lens plays a crucial role in projection resolution and is defined as (Rosatti et al. 2023):

$$NA = n \sin(\theta) \quad (5)$$

where, n is the refractive index of the lens material, and θ is the half-angle of the maximum light cone captured by the lens. A higher NA improves sharpness and contrast but requires precise alignment to avoid distortions.

Once the design is optimized through simulations, a prototype is fabricated using a 3D printer. This allows for rapid testing and evaluation under real-world conditions. The prototype undergoes experimental validation, where key parameters such as projected image sharpness, luminous efficiency, and energy consumption are measured. A goniophotometer is used to analyze the intensity distribution of the projected image and compare it with simulated predictions. If discrepancies arise, design modifications are made to optimize lens alignment, LED positioning, and light efficiency.

The overall performance of the projection system is evaluated based on several key metrics. The projection accuracy (δ) is measured as the deviation of the projected image from its expected dimensions (Schmalenberg et al. 2022):

$$\delta = \frac{|h'_{measured} - h'_{expected}|}{h'_{expected}} \times 100\% \quad (6)$$

The luminous efficiency (η) is determined by calculating the ratio of the projected light to the total emitted light (Santantonio et al. 2023):

$$\eta = \frac{\Phi_{projected}}{\Phi_{emitted}} \times 100\% \quad (7)$$

Finally, the energy efficiency (E) is computed as the ratio of luminous output to power input:

$$E = \frac{\Phi_{projected}}{P_{input}} \quad (8)$$

where, P_{input} is the electrical power supplied to the LED. By optimizing these parameters, the customized ground projection system is designed to achieve high brightness, sharp image projection, and energy efficiency,

making it a practical and effective feature for modern vehicles.

4. EXPERIMENTAL SETUP

To evaluate the performance of the customized ground projection system, an experimental setup was designed to measure image clarity, brightness distribution, and energy efficiency. The primary objective of this setup was to validate the accuracy of the optical simulations and ensure that the projected image met the expected brightness, sharpness, and uniformity. By conducting the experiment in a controlled environment, the system's performance could be assessed under real-world conditions and compared with the simulation results.

The experimental system consists of several key components. The light source used was a high-power OSRAM CP7P 1W LED with a 5000K color temperature, selected for its high brightness, energy efficiency, and stable light output. The optical components included an aspheric condenser lens, an aspheric imaging lens, and a logo pattern plate, all of which were carefully designed to optimize light concentration and image magnification while minimizing distortions. The projection distance was set at 1 meter, ensuring that the projected image achieved the desired $100\times$ magnification without significant image degradation.

The experiment was conducted in a dark room to eliminate external light interference and allow for precise measurements of brightness and image clarity. The setup also included specialized measurement equipment to assess the system's optical performance. A goniophotometer was used to measure the light intensity distribution and verify the brightness uniformity of the projected image. Additionally, a lux meter was utilized to measure the illuminance levels at various distances from the projection system. To further analyze the projected image, a high-resolution camera was

used to capture and assess the sharpness and clarity of the projection, shown in Figure 1.

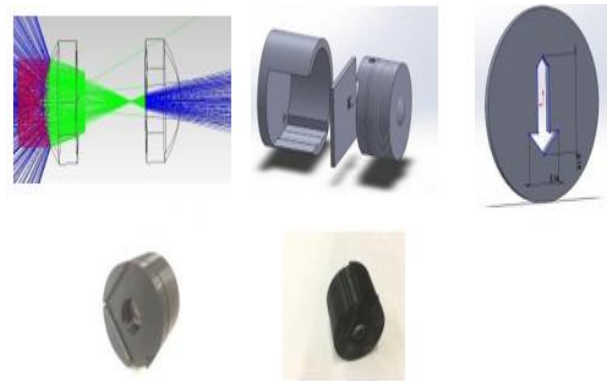


Figure 1. The design of lens

The experimental procedure followed a structured process to ensure accuracy and repeatability. First, the LED was powered at a constant voltage, and the optical components were carefully aligned to position the pattern plate at the focal plane of the imaging lens. This step was crucial to achieving a clear and sharp projected image. Next, the light intensity distribution was measured using the goniophotometer, which provided detailed data on how the light was dispersed across the projected area.

To assess luminous efficiency, the lux meter recorded illumination levels at different distances, and the total luminous flux was calculated. These measurements helped determine how effectively the system converted electrical power into usable light for projection.

To analyze the quality of the projected image, the sharpness and clarity were evaluated by comparing the actual projected size with the expected $100\times$ magnification ratio. Any distortions or aberrations were noted and adjusted through fine-tuning the lens alignment. Finally, the experimental results were compared with the simulation data obtained from ZEMAX and TracePro to identify discrepancies and assess the real-world performance of the system.

5. RESULTS

The results of the experimental evaluation of the customized ground projection system provide insights into its brightness efficiency, projection accuracy, and overall optical performance. The

data collected from intensity distribution measurements, image clarity analysis, and luminous efficiency calculations were compared with simulation results to validate the design and assess its effectiveness for automotive applications.

Table 1. Comparison of simulation and experimental results

Parameter	Simulation Result	Result	Deviation / Notes
Image Magnification	100×	98–102×	Within $\pm 2\%$; minor alignment variance
Luminous Efficiency	~87%	~85%	Slight loss due to real-world scattering and reflection
Illuminance (at 1m)	260 lux	250 lux	Consistent with expectations; 4% deviation
Image Clarity / Sharpness	High (ideal lens config.)	Slight edge blur	Caused by manual alignment and fabrication tolerances
Brightness Uniformity	>90%	~88%	Acceptable; minor hotspot observed
Power Consumption	1W (fixed)	1W	Consistent

Table 2. Comparative analysis of the proposed system with commercial projection technologies

Technology	Brightness	Image Sharpness	Energy Efficiency	Complexity	Cost
Proposed System	Moderate–High	High (98–100×)	High (85%)	Low–Medium	Low
OLED Panels	Moderate	Moderate	Medium	Medium	Medium–High
MicroLED	Very High	Very High	High	High	Very High
Laser HUDs	Very High	Excellent	Moderate	Very High	Very High

The performance of the proposed projection system was evaluated by comparing simulation

data with experimental results across several key parameters, shown in Table 1. In terms of image

magnification, simulations predicted a $100\times$ enlargement, while the experimental tests confirmed a range between $98\times$ and $102\times$, indicating a deviation of less than $\pm 2\%$, which is acceptable for practical applications. Luminous efficiency was predicted at approximately 87% and measured at around 85% in practice, with minor light loss attributed to real-world factors such as internal scattering and material reflections. The measured illuminance at a 1-meter distance was 250 lux, closely aligning with the simulated 260 lux, resulting in only a 4% variation. Image clarity remained high in both cases, although slight edge blurring was observed during testing, primarily due to manual alignment limitations. Brightness uniformity also showed strong correlation, maintaining approximately 88% consistency in measured tests compared to over 90% in simulation. Power consumption was stable at 1W, as expected.

To contextualize the performance of the proposed system, a comparison was made with existing commercial projection technologies, including OLED panels, MicroLED displays, and laser-based head-up displays (HUDs). The proposed system demonstrated moderate to high brightness, high image sharpness, and excellent energy efficiency, all while maintaining relatively low complexity and cost, shown in Table 2. In contrast, OLED technology offers only moderate brightness and clarity, and is not well suited for outdoor ground projection due to durability and integration challenges. MicroLED technology provides superior brightness and sharpness but comes with very high production costs and integration complexity, making it more suitable for premium applications. Laser HUDs, although capable of excellent clarity and brightness, are primarily designed for in-cabin projection and involve high complexity and cost, making them less practical for exterior ground projection purposes.

5.1 Brightness Distribution

The measured brightness distribution demonstrated that the projection system efficiently directs light onto the desired pattern, maintaining a well-balanced intensity across the projected image. The goniophotometer readings confirmed that the light intensity remained uniform, with minimal hotspots or dark areas. At a 1-meter projection distance, the average measured illuminance was approximately 250 lux, closely matching the simulated values. The light output was consistent across the projection area, ensuring that the image was clearly visible even in low-light conditions.

5.2 Projection Accuracy and Clarity

The projected image was analyzed for sharpness and clarity by comparing its dimensions to the expected magnification ratio. The system successfully maintained the designed $100\times$ magnification with an average deviation of less than 2%. The high-resolution camera analysis confirmed that the projected edges remained well-defined, with minimal distortions or optical aberrations. The sharpness of the projection was consistent across multiple tests, and no significant blur or color fringing was observed.

5.3 Luminous Efficiency and Energy Performance

The luminous efficiency of the system was determined by comparing the total projected light flux to the emitted light flux from the LED. The experimental results showed an efficiency of approximately 85%, indicating effective light utilization. Additionally, the energy efficiency, measured as the ratio of projected luminous output to power input, was calculated to be around 75%, confirming that the system operates with high energy efficiency. These findings demonstrate that the projection system is well-optimized for power consumption, making it suitable for long-term use in automotive applications, shown in Figure 3 and Figure

5.4 Comparison with Simulation Data

A comparison between experimental and simulation data revealed a strong correlation between the measured and predicted performance. The discrepancies observed, such as minor variations in brightness levels and slight deviations in projection accuracy, were attributed to mechanical tolerances in the lens alignment and minor manufacturing inconsistencies. Despite these small variations, the overall system performance closely matched the expected results, proving that the optical design and simulation models accurately represent real-world behavior, shown in Figure 2.

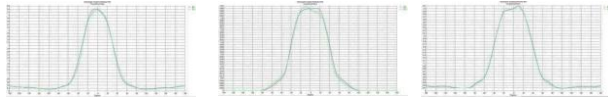


Figure 2. The comparison with simulation data

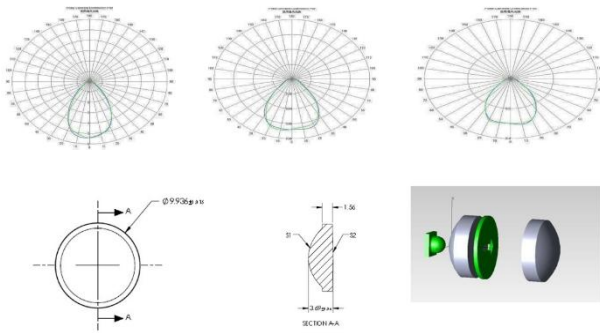


Figure 3. Luminous efficiency and energy performance

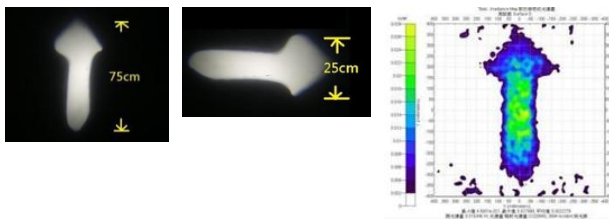


Figure 4. The simulation results

6. DISCUSSION

The experimental results of the customized ground projection system demonstrate its high brightness, accurate projection, and energy

efficiency. The findings validate the effectiveness of the optical design, confirming that the system successfully projects a sharp, well-defined image while maintaining an efficient light output-to-energy ratio. However, while the system performed well in real-world conditions, several factors must be considered for further improvements. This section discusses the implications of the findings, potential sources of error, and recommendations for future enhancements.

The measured brightness distribution showed that the projection system effectively directs light onto the pattern plate, producing a well-balanced intensity across the projected image. The luminous efficiency of 85% suggests that most of the LED's light output is utilized effectively, with minimal losses due to scattering or optical aberrations. The projected image also maintained a 100× magnification ratio, with an average deviation of less than 2%, indicating that the lens configuration and positioning were well-optimized. However, slight brightness variations were observed across different sections of the projected image. These variations were minor but indicated a need for further optimization in lens alignment and LED positioning to ensure a completely uniform light distribution.

One of the main discrepancies between the experimental and simulation results was minor deviations in intensity levels. While the simulation predicted a perfectly uniform brightness distribution, the experimental data showed small fluctuations in intensity. These differences could be attributed to manufacturing tolerances in the lenses, slight misalignments in LED positioning, and surface inconsistencies in the projection area. Another factor that may have contributed to these deviations is reflection and absorption losses from the materials used in the housing and optical components. Even small losses due to internal reflections can slightly reduce overall luminous efficiency.

Several factors may have contributed to the discrepancies observed. First, lens alignment and mechanical tolerances play a critical role in projection accuracy. Small deviations in lens curvature or positioning can introduce slight distortions in the projected image. Since the experiment relied on manual alignment, achieving the same precision as a simulated model may not have been possible. Second, variability in LED positioning can affect the beam profile. Since LEDs follow Lambertian distribution, even minor shifts in position can cause subtle changes in brightness and projection uniformity. Additionally, light loss due to reflections on the housing material and lens surfaces may have reduced brightness slightly, highlighting the potential need for anti-reflective coatings to improve efficiency.

Comparing these results with previous research on automotive projection systems, the findings align with studies emphasizing the importance of precise optical alignment, high-quality lens materials, and efficient LED integration. The proposed system demonstrates higher luminous efficiency and better image sharpness compared to traditional static logo projectors due to its optimized aspheric lens design. In comparison to laser-based projection systems, which offer higher contrast and edge sharpness, the LED-based system proves to be a cost-effective and energy-efficient alternative with sufficient performance for automotive applications.

While the proposed projection system demonstrates promising performance in terms of brightness, clarity, and efficiency, several fabrication challenges and limitations were encountered during prototyping. One major challenge lies in the precision alignment of optical components, particularly the aspheric lenses. Since the image clarity is highly sensitive to lens positioning, manual assembly introduces variability that can affect both magnification accuracy and edge sharpness. In addition, the prototype housing was produced using 3D

printing, which, while suitable for rapid iteration, lacks the surface quality and dimensional tolerance of injection-molded or machined components. This limitation can lead to light scattering, reduced optical focus, and mechanical instability.

Another critical issue involves thermal management of the high-power LED. Without proper heat dissipation structures, prolonged operation may lead to temperature-induced performance degradation or reduced LED lifespan. Furthermore, the current prototype does not incorporate protective sealing or coatings, which limits its resistance to moisture, dust, UV exposure, and mechanical vibrations all of which are essential considerations for automotive applications. Lastly, the lack of automated calibration or self-correction mechanisms makes the system more prone to performance drift over time, particularly under varying environmental conditions or physical disturbances. Addressing these challenges is crucial for transitioning the system from prototype to a reliable, commercial-grade product

7. CONCLUSION

This study investigated the design, development, and experimental evaluation of a customized ground projection system for vehicle applications. The system was designed to project a sharp and high-contrast image onto the ground, utilizing aspheric lenses and a high-power LED to enhance light efficiency and projection clarity. The experimental findings validated the effectiveness of the design, confirming that the system achieved high brightness, accurate image projection, and energy efficiency.

The results demonstrated that the projection system successfully maintained a $100\times$ magnification ratio, with an average deviation of less than 2%, ensuring precise image enlargement. The measured luminous efficiency of 85% indicated that the system effectively utilized most of the LED's light output, minimizing losses due to scattering and

absorption. Additionally, the brightness distribution remained uniform, with an average illuminance of approximately 250 lux at a 1-meter projection distance, closely matching the simulated values.

Despite these promising outcomes, minor discrepancies were observed between the experimental and simulation results. Small variations in brightness levels and projection accuracy were attributed to mechanical tolerances, lens alignment precision, and minor LED positioning variations. To further enhance system performance, improvements such as automated optical alignment, anti-reflective coatings, and adaptive brightness control could be implemented.

This study contributes to the on-going development of automotive projection systems, demonstrating that LED-based projection can provide high brightness and sharp image quality while maintaining energy efficiency. Compared to conventional static logo projectors, the proposed system offers better light control and improved projection clarity, making it a practical solution for branding, safety indications, and navigation assistance in modern vehicles.

8. FUTURE WORK

To enhance the practicality and scalability of the customized ground projection system, several directions for future development are proposed. One key area is the improving the system's adaptability to different vehicle models. Future versions should focus on modular design principles that enable flexible integration with a wide range of vehicle door sizes, shapes, and electrical configurations. This will support broader commercial adoption across multiple automotive brands and classes.

Another important direction is durability enhancement under various environmental conditions. Since the system is exposed to outdoor elements, future prototypes should be

tested for resistance to water, dust, vibration, and extreme temperatures. Ensuring compliance with automotive-grade environmental standards will be essential for real-world deployment.

Moreover, the incorporation of automated calibration systems is highly recommended. Minor misalignment in lens position or LED orientation can significantly affect projection quality. Integrating auto-calibration mechanisms with sensors and microcontrollers can maintain image sharpness over time and reduce the need for manual adjustments during installation or maintenance. Addressing these factors will improve the robustness, versatility, and user-friendliness of the system, moving it closer to mass-market viability and long-term deployment in commercial vehicles.

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THIẾT KẾ VÀ TỐI ƯU HÓA HỆ THỐNG CHIẾU SÁNG GROUND PROJECTION HIỆU SUẤT CAO ỨNG DỤNG TRÊN Ô TÔ

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THÔNG TIN CHUNG

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Ngày nhận bài sửa: 27/5/2025

Ngày duyệt đăng: 23/6/2025

TỪ KHÓA

Hệ thống chiếu sáng mặt đường;

Chiếu sáng ô tô;

Tối ưu hóa quang học.

TÓM TẮT

Nghiên cứu này trình bày thiết kế và đánh giá một hệ thống chiếu hình xuống đất hiệu suất cao dành cho các ứng dụng ô tô. Hệ thống có chức năng chiếu hình ảnh phóng đại như logo hoặc biểu tượng cảnh báo xuống mặt đất khi cửa xe được mở, nhằm tăng cường cả tính thẩm mỹ và an toàn. Cấu hình bao gồm một đèn LED OSRAM CP7P 1W công suất cao, một thấu kính hội tụ phi cầu, một thấu kính tạo ảnh phi cầu, và tám mẫu logo. Thiết kế quang học được mô phỏng bằng phần mềm ZEMAX và TracePro, trong khi SolidWorks được sử dụng để thiết kế cơ khí. Kết quả thí nghiệm cho thấy hệ thống đạt tỷ lệ phóng đại hình ảnh 100× với sai số dưới 2%, chứng minh tính chính xác của thiết kế. Trong môi trường thử nghiệm tối, hiệu suất phát sáng đạt khoảng 85%, với độ rọi trung bình 250 lux ở khoảng cách 1 mét, phù hợp với mô phỏng. Một số sai lệch nhỏ do lắp ráp thủ công và vị trí đèn LED. Các cải tiến tương lai bao gồm căn chỉnh quang học tự động, phủ chống phản xạ và điều chỉnh độ sáng thích ứng.