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INFLUENCE OF VARIOUS ANGLES AND DISTANCES ON LUMINANCE MEASUREMENT RESULTS

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Abstract. The behaviour of drivers in nocturnal conditions is primarily influenced by the early detection of obstacles within the roadway. A reliable approach to evaluate night-time traffic environments is through luminance analysis. This study aimed to investigate the impact of conducting luminance measurements at reduced distances compared to those specified by standard guidelines. Additionally, the study examined the effect of the measurement angle of the luminance analyser on the recorded luminance values. The findings indicate that the measurement angle is a critical factor for ensuring accurate luminance readings, while the distance between the analyser and the measured surface has minimal influence on the results. Statistical analysis confirms that reliable data can be obtained even when deviating from standard measurement conditions. These results suggest that luminance analysis is feasible and applicable across a wide range of traffic scenarios.

Keywords: Luminance, lighting, luminance analysis, brightness, luminance analyser.

1. Introduction

Addressing traffic safety is a persistent issue that necessitates continuous scrutiny. Key strategic documents issued by the European Commission [1], along with national reports [2], indicate that reducing traffic accidents remains a primary priority. When assessing road user behaviour, particular emphasis is placed on the clarity and intelligibility of transport infrastructure [3]. This aspect is crucial not only during the daytime but also in conditions of reduced visibility [3]. Traffic accident statistics reveal that, in 2023, 118 out of 455 fatal accidents in the Czech Republic occurred under low visibility conditions [4]. This figure represents over one-fourth of all fatal accidents recorded that year. These statistics are especially significant considering that traffic volume at night is markedly lower than during daytime hours.

The behaviour of drivers in nocturnal conditions is primarily influenced by the early detection of obstacles within the roadway. A reliable approach to evaluating nighttime traffic environments is luminance analysis. This method not only assesses the adequacy of illumination in traffic areas but, more importantly, evaluates the visibility and detectability of obstacles or individuals on and around the roadway. The methods for measuring the luminance of specific sections of the traffic area are defined in European and Czech standards, which outline the conditions for conducting these measurements and their subsequent evaluation. The area under consideration is measured over a relatively long distance of 60 m, determined based on the range of vehicle headlights and the braking distances of vehicles. This measurement is applicable in ideal situations on straight road sections, where ambient luminance is assessed without significant geometric changes in road alignment (both horizontal and vertical). However, if a situation arises that necessitates measuring the luminance of the road and its adjacent surroundings in areas with directional curves, the investigator must assess the area at a shorter distance than specified in the standards.

The aim of this study is to assess the effect of measuring luminance at distances closer than those defined under standard conditions. Additionally, the study aims to evaluate the influence of the measurement angle and the scanning process of the area under consideration by the luminance analyser on the resulting luminance values. This analysis seeks to contribute to the optimization of measurements under nocturnal conditions, thereby assisting users in obtaining the most accurate values.

2. Survey of studies on lighting and luminance measurement methods

In the field of photometry and luminance measurement, numerous studies and research endeavours have addressed various aspects of illumination and its impact on traffic safety. Specifically, attention has been directed toward analysing human perception of the environment under different lighting conditions, considering visual adaptation to these scenarios [5]. Concurrently, research has also focused on the influence of external light sources, such as vehicle headlights, assessing how different lighting sources affect the visibility and recognizability of objects. Significant differences can be observed among halogen, xenon, and LED headlights, as their luminance and technology directly influence the illumination range and light dis-

Camera type	NIKON D7500
Sensor type	CMOS Nikon DX 15.7 × 23.5 mm
Number of pixels	21.51 mil. pixels
Image size	Large – 5568 × 3712, Medium – 4176 × 2784, Small – 2784 × 1856
Effective number of pixels	20.9 mil. pixels
A/D converter	12 bits / 4096 levels, or 14 bits / 16384 levels
Shutter speed	1/8000–30 sec. + Bulb
ISO sensitivity	100–51200

Table 1. Specification of the LDA camera.

tribution. These factors are closely related to the recognizability of objects in the traffic environment. Additionally, the colour of light plays a crucial role in distinguishing individual objects [6].

Object distinctiveness is currently under investigation, particularly at pedestrian crossing points. At these locations, it is crucial to achieve the required lighting intensity, as this directly influences both the luminance and visibility of obstacles. In this context, obstacles are defined as pedestrians moving within the roadway [7]. The employed methods also consider the impact of the background, where various distractions or ambient light sources may significantly affect measurement outcomes, potentially leading to the oversight of pedestrians [8].

A study conducted by Seoul National University in the Republic of Korea investigates the influence of traffic area lighting efficiency under adverse weather conditions, such as rain or fog. The findings indicate that distance plays a crucial role in object recognition, which directly impacts the effectiveness of road lighting [9].

Road lighting can be designed dynamically so that the lighting brightness is automated and adjusted based on the speed and intensity of traffic. Such an approach can enhance the efficiency of lighting systems and improve safety in the area [10].

Elements located on the roadway, specifically horizontal road markings, are another critical factor that enhances driver orientation in nighttime traffic areas. These road traffic markings convey information regarding the trajectory of the road, thereby facilitating predictions about its direction and elevation. However, this element is also subject to significant variation, which depends not only on the quality of workmanship but also on the adequacy of ambient lighting [11].

The issue of measuring the luminance of LED luminaires using various measuring devices is also examined. Concurrently, the study recommends standardizing the parameters to obtain relevant values. Furthermore, an alternative method for measuring luminance from outside the traffic area is proposed, which may yield comparable results to traditional measurement methods [12].

The study conducted by Aalto University, Finland, focuses on the integration of spatial laser scanning and luminance analysis. By combining the outputs of these measurement instruments, the research facilitates the mapping of illumination in traffic areas and the creation of a spatial representation of luminance [13].

It is important to reference studies that outline methods for conducting nighttime safety inspections, which often involve a significant degree of subjectivity in their evaluations [14]. Additionally, a related concern is the uniform distribution of luminance in traffic areas, as it has been shown to be a critical factor in ensuring the safety of road users [15].

Most scientific studies predominantly concentrate on the influence of the surrounding environment and the ways in which users perceive the nocturnal setting. Consequently, the emphasis is primarily placed on the quality of the light source and the subjective perception of the night environment. The present study aims to enhance the measurement process and seeks to provide an objective evaluation of the methodology and quality of the data collected.

3. Method of data processing and comparison

Experimental measurements of luminance values from different positions were conducted following the defined procedure according to ČSN EN 13201 [16]. The basis for the luminance measurement involved defining a grid of measurement points and positioning the measuring device at a predefined location. In general, the measurement area in the longitudinal direction is determined by the distance between luminaires situated in the same row. If there are multiple rows of luminaires in the measured area, the measurement field must be located between the two luminaires in the row with the largest spacing. For measurements with a luminance analyser, the device is positioned 60 m in front of the start of the measured area. Additionally, the height of the centre of the device lens is set to 1.5 m above road level, with a measurement angle of $89 \pm 0.5°$relative to the normal to the road surface. These parameters reflect the observation conditions of a driver in a vehicle [16]. The focus of the measurements was the road surface beneath the light source, where the light cone impacting the road was observed. The measurements were conducted using the LDA luminance analyser, with specifications of the LDA settings during the measurements provided in Table 1 [17].

Lens type	TOKINA 50 mm f/1,4 FF Opera for Nikon F
Focal length	50 mm
Aperture range	f/1.4–f/16
Filter thread diameter	72 mm

Table 2. Specification of the LDA lens.

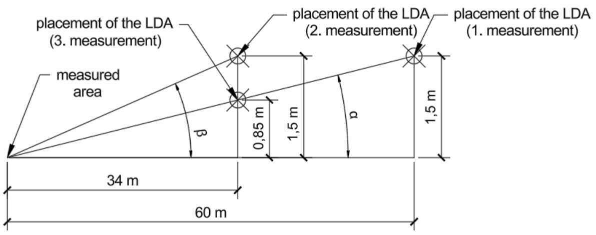

Figure 1. Schematic placement of the luminance analyser.

The LDA luminance analyser is equipped with a Nikon bayonet mount, allowing compatibility with a wide range of lenses tailored to specific measurement requirements. Table 2 presents the specifications of the lens utilized for the present measurements.

The measurement site was selected to ensure safe luminance analysis without the need for traffic restrictions. The location chosen is a road lighting installation in Studničkova Street, Prague. The light source consists of a high-pressure sodium lamp, which is commonly used for road lighting. A specific measurement area was defined directly beneath the light source, where the light cone is projected. For the purposes of this study, will be presented only the assessment of measured luminance values from a uniform viewing axis.

For the first measurement, the luminance analyser was positioned 60 m from the centre of the measurement area, with the centre of the analyser's lens placed at a height of 1.5 m above the road surface. In the second measurement, the instrument was positioned 34 m away, maintaining the lens at the same height of 1.5 m above ground level. This distance was determined with respect to the vehicle's braking distance under wet road conditions. The third measurement was conducted at a distance of 34 m, but with the lens placed at a height of 0.85 m above the road surface. This lower height corresponds to a measurement angle aligned with the original measurement specifications, as outlined in ČSN EN 13201. The various positions of the luminance analyser are illustrated in Figure 1.

To capture the complete light scene within the measurement area, multiple photographs must be taken at varying exposure durations. The exposure times utilized for the measurements conducted with the luminance analyser included 1/2 s, 1 s, 3 s, 5 s, 8 s, and 10 s. The data outputs from the luminance analyser are subsequently imported into the LumiDISP software, which calculates and determines the luminance values for each pixel in the photographs. These

Figure 2. Luminance image from the first position.

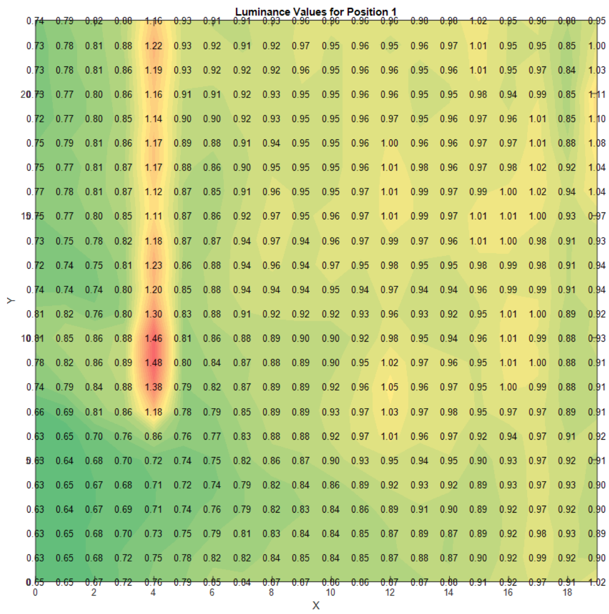

Figure 3. Measured luminance values from the first position.

luminance images are then merged into a single comprehensive luminance image, effectively minimizing any overexposed or underexposed areas, Figure 2.

In the LumiDISP program, an array was specified to calculate the average luminance value for each designated element within the array. Additionally, the program facilitated the visualization of a graphical waveform illustrating the luminance distribution across a designated strip. This figure can be converted into a tabular format, in which each cell corresponds to the calculated average luminance value for that specific area, Figure 3.

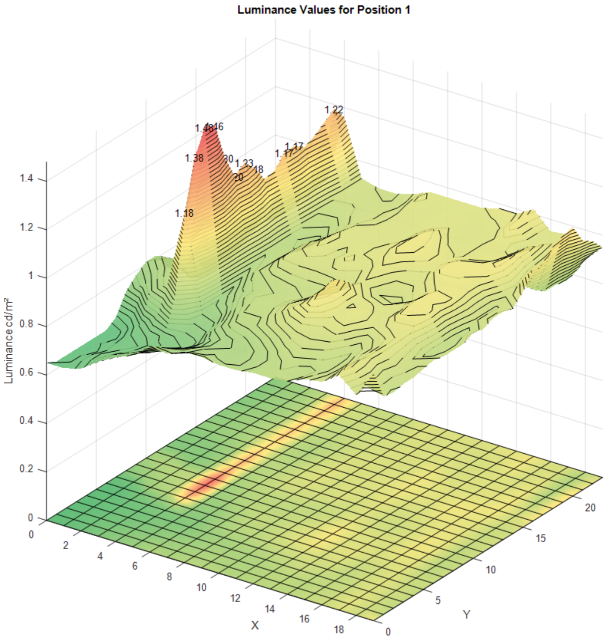

FIGURE 4. Two-dimensional and three-dimensional display of measured values from the first position.

First measurement Figure 2 presents a luminance photograph illustrating the luminance distribution within the measured area of the traffic space. Each pixel is assigned a colour level corresponding to its luminance. The colour representation of the luminance photograph may be adjusted according to output requirements.

The measured luminance values are displayed in Figure 3. For enhanced clarity and interpretation, the measured luminance values have been mapped to a colour scale to depict the effect of the light cone within the measured area.

Figure 4 presents both two-dimensional and three-dimensional representations of the luminance distribution within the measured space. The z-axis represents the luminance values, expressed in $\mathrm{cd\,m^{-2}}$. The figure illustrates the impact of horizontal road markings present in the measured area on the resulting luminance levels. This effect is attributed to the higher reflectivity of the road markings, which locally increases the brightness by reflecting more of the incident light.

To enhance clarity and facilitate comparison, the following measurements are presented in a consistent format. This approach simplifies the identification of differences and similarities between the results and improves the reliability of subsequent analyses.

Second measured In this measurement, it is already possible to discern the horizontal road markings, specifically the parking lane. At the same time, a local extreme can be observed that exceeds the measured values in all measurements. This deviation may be caused by a failure to maintain the correct measurement angle with the luminance analyser (see Figures 5, 6 and 7).

FIGURE 5. Luminance image from the second position.

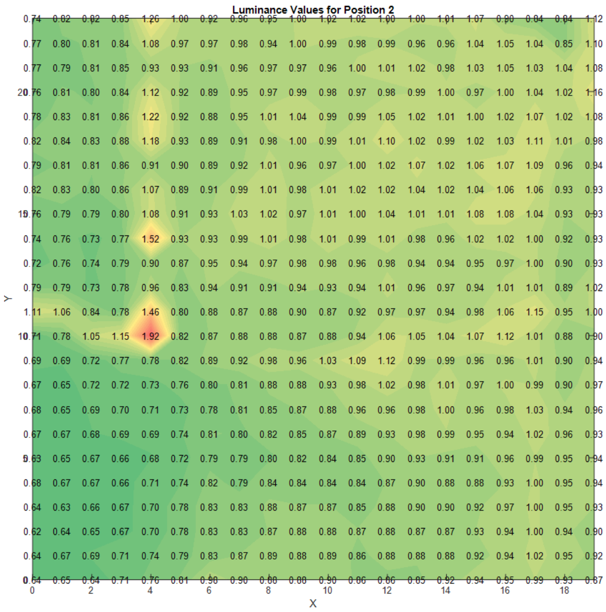

FIGURE 6. Measured luminance values from the second position.

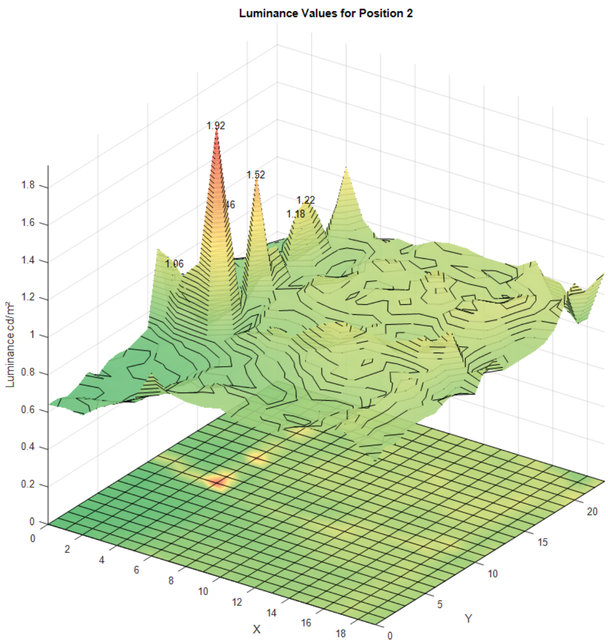

FIGURE 7. Two-dimensional and three-dimensional display of measured values from the second position.

Third measured This measurement is similar to the second measurement in terms of capturing the overall luminance distribution in the area of interest. However, it provides a more valid measurement in detecting and recording the effect of horizontal road markings on luminance levels (see Figures 8, 9 and 10).

FIGURE 8. Luminance image from the third position.

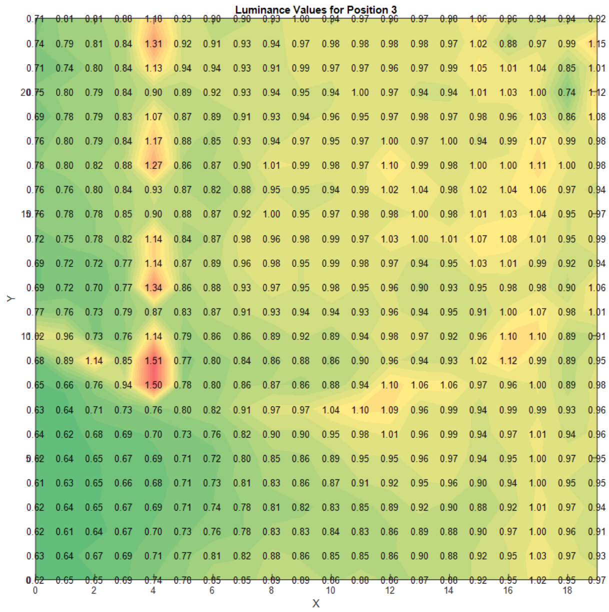

FIGURE 9. Measured luminance values from the third position.

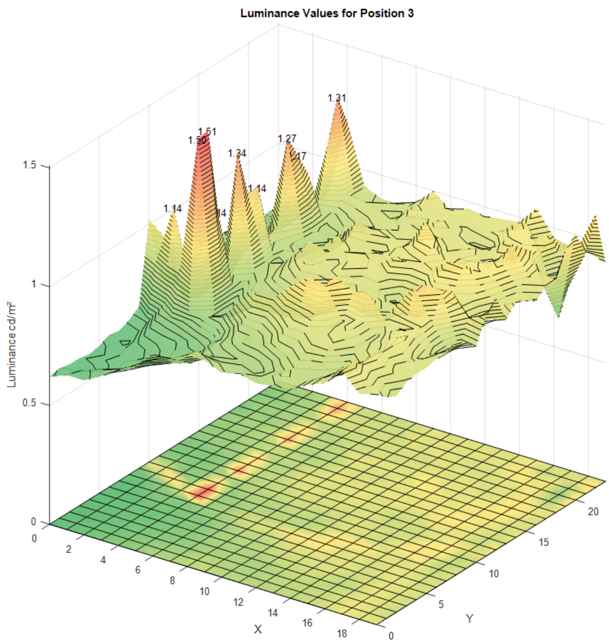

FIGURE 10. Two-dimensional and three-dimensional display of measured values from the third position.

3.1. Comparison of measurements

The scatter of all measured luminance values in the study area ranges from 0.6 to 2.0 $cd\,m^{-2}$. The Figures 12 and 14 compare the measured values at the location of the luminance analyser with the previously defined parameters. The individual values represent the absolute differences in average luminance attributable to a predefined regular grid of measurement points. To enhance clarity, the difference results have been rounded to one decimal place. For accurate correlation and interpretation of the data, the tables should be examined from top to bottom to maintain the measurement direction. Comparisons of the measurements were first conducted between the initial and second measurements, followed by comparisons between the initial and third measurements.

(1.) **First and second measurements**
The dominant difference was primarily attributed to the horizontal road markings present in the measured area. In other instances, the influence could be ascribed to road geometry or surface conditions. By executing the command to obtain a frequency of 0, a total of 346 cases were identified in the table where relative agreement existed between the two measurements, while 134 cases demonstrated discrepancies. Subsequently, the command for calculating the average value of luminance differences was applied to provide an overall summary. The average value of the absolute differences in average luminance across the entire measured area is recorded as 0.0478 $cd\,m^{-2}$ (see Figures 11 and 12).

(2.) **First and third measurements**
In this comparison, the presence of horizontal road markings is crucial to the results. A more distinct gap in the roadway extends from the horizontal road markings through the measured area. When analysing the measurements, relative agreement was found in 408 cases, while discrepancies were observed in 72 instances. The average value of the absolute differences in mean luminance across the entire table representing the measured area corresponds to 0,0319 $cd\,m^{-2}$ (see Figures 13 and 14).

3.2. Summary of verification measurement results

The primary factors influencing the results of luminance measurements were predominantly the horizontal road markings delineating the parking lane within the measured area. The condition of the roadway, such as the presence of a pothole in the measurement zone, could also impact certain measured values. Occasional

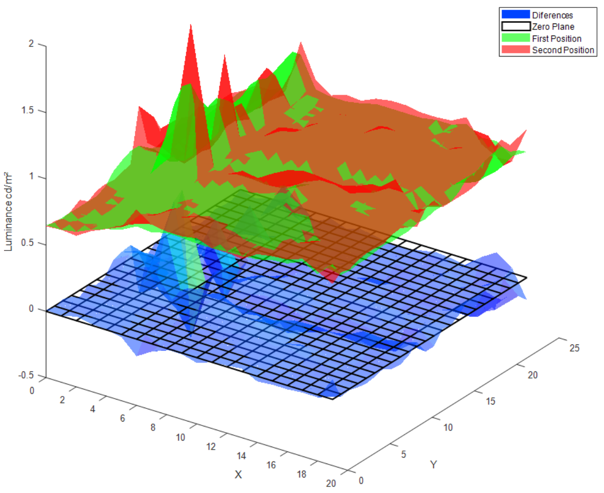

Figure 11. Comparison of luminance values in three-dimensional display for the first and second measurement.

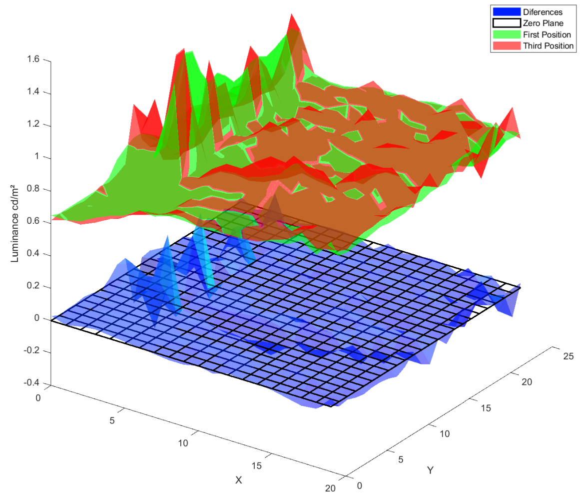

Figure 13. Comparison of luminance values in three-dimensional display for the first and third measurement.

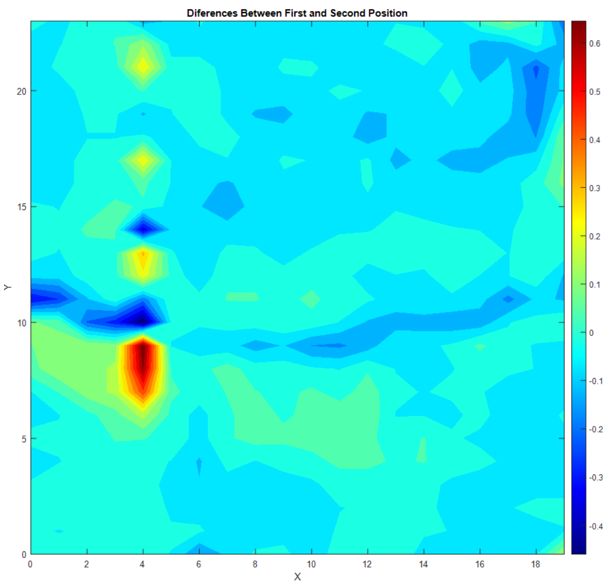

Figure 12. Comparison of brightness values in two-dimensional display for the first and second measurement.

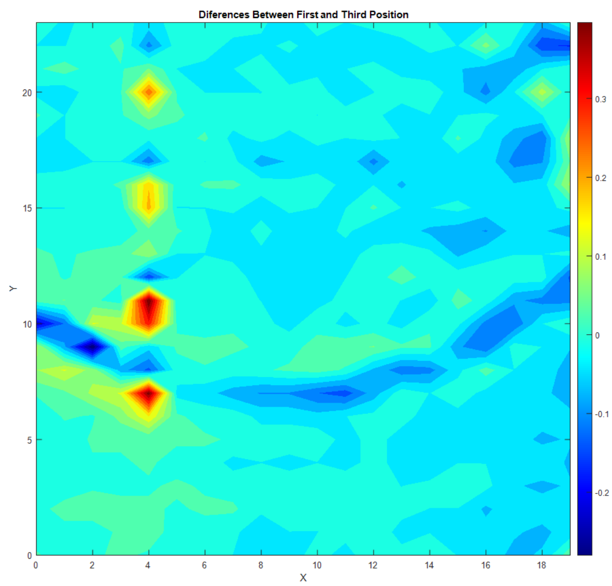

Figure 14. Comparison of luminance values in two-dimensional display for the first and third measurement.

discrepancies in the recorded luminance values may arise from potential inaccuracies in configuring the luminance analyser to the specified parameters for a given measurement. These factors must be considered when interpreting the measured data to ensure the highest accuracy of the results.

4. Discussion

During the measurement process and subsequent post-processing, several limitations were identified that may affect the accuracy of the results. The limited number of measurements taken from various directions and angles of the luminance analyser may have reduced variability and, consequently, the reliability of the data. This limitation could be addressed by expanding the measurements to encompass additional directions and positions, thereby providing a more comprehensive and precise analysis of the luminance distribution in the traffic area. Furthermore, the delineation of the computational areas in the LumiDISP software may have impacted the accuracy of the resulting luminance values. To mitigate this issue, it is necessary to accurately synchronize the boundary points of the delineated measurement area in the traffic space with the corresponding boundary points in the delineated calculation area in the LumiDISP software. Additionally, the measurements did not incorporate detailed information about the light source, which could enhance the thoroughness of the analysis.

5. Conclusion

Based on the conducted study, it is concluded that the measurement angle is crucial for achieving consistent luminance values, while the distance of the analyser is of negligible significance. Statistical analysis confirmed that reliable measurement results can be obtained when the correct measurement angle is maintained. This demonstrates that surface luminance measurements depend primarily on the measurement angle and the angle of incidence, rather than on the distance from the analyser. The validation of the luminance measurements was carried out to enhance safety in traffic areas and to expand the possibilities of its application. This paper also indicates that luminance analysis is feasible even when normative requirements cannot be fully met. While it is essential to base measurements on applicable standards, adaptations can be made for specific measurement conditions without significantly impacting the results.

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