Investigation of the Effects of Road Conditions on Road Lighting and Visibility Level

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Abstract—**In this study, the developed system uses two different software substructures, which are "Road Lighting" and "Visibility Level". The "Road Lighting" function makes mapping and photogrammetric measurements, while the "Visibility Level" function tests the visibility of a critical object. It was confirmed that irregularities on road surfaces adversely affect road illumination. The obtained numerical results were graphically reproduced. According to international standards, the acceptable interval for luminance values is 1.5-2.0 cd/m^2. With larger, heterogeneous, wet or irregular areas in the surfaces, the illumination level and luminance increase in lightened areas, and the illumination level of distribution becomes heterogeneous.**

***Index Terms*—Road lighting, luminance,visibility level**

I. Introduction

Road lighting is a practical tool in providing efficient and safe traffic movement and making driving conditions more comfortable [1]. The impact of road lighting on reducing night-time fatal accidents is even higher [1]–[2].

According to CIE-115 standard, the luminance level used in the calculation of road lighting [3]. The road is an M2 class road by CIE-115 standards and the luminance of an ideal road should be 1.5 cd/m^2. Quality criteria for road lighting classification based on road surface luminance is present in accordance with CIE-1995 standards. Road surface luminance has been based on standardized lighting classes, using certain static luminance levels in the certain road types [4]–[5]. It is also accepted that visual conditions might be inadequate even at luminance levels higher than the recommended values based on luminance concept for night-time road lighting conditions [6]–[8]. Therefore, a different criterion is needed to provide efficient and safe road lighting conditions. In recent recommendations on road lighting, the visibility factor has been proposed as a criterion [6], [9]–[10].

II. Methods and Materials

In investigations on photometric measurements, cameras have been used for defining photometric quantities [11]–[12]. Pixel RGB values and photometric quantities are related mathematically by image processing algorithms to pictures. Illuminance and luminance values are obtained from the algorithm.

A. Visibility Level

The visibility level, VL, quantifies the observer's ability to see an object more or less easily [3]. For a given driver with a given acuity and a given contrast sensitivity, the ability to detect a given achromatic object in a given traffic situation mainly depends on three parameters: object luminance, background luminance and adaptation luminance [13]. Its visibility is calculated from [14]

$$V_L = \Delta L_{actual} / \Delta L_{threshold} \tag{1}$$

where VL is visibility level, which indicates how much the contrast of the target is above threshold contrast; ΔL_{actual} is the different in luminance between the target and its background; and $\Delta L_{threshold}$ is the luminance difference needed between the target of a certain angular size and its background for the target to be just visible[14]–[15]

$$\Delta L_{actual} = L_f - L_b \tag{2}$$

where L_f: The target luminance (cd/m^2) L_b:The background luminance (cd/m^2).

According to Adrian's theory [15]–[17] this threshold value (ΔL_e) is taken from empirical equations:

$$\Delta L_e = k.\left(\frac{\sqrt{\Phi}}{\alpha} + \sqrt{L}\right)^2 * \frac{a(\alpha, L_f) + t_g}{t_g} * F_{CP} * AF \tag{3}$$

where k: factor for the probability of perception (k = 2.6 for 100% probability) Φ: Luminous flux function (lm) L: Luminance function (cd/m^2) F_{cp}: Contrast polarity factor AF: Age factora(a;L_b): Parameter depending on size of target and background luminance t_g: Observation time (s)

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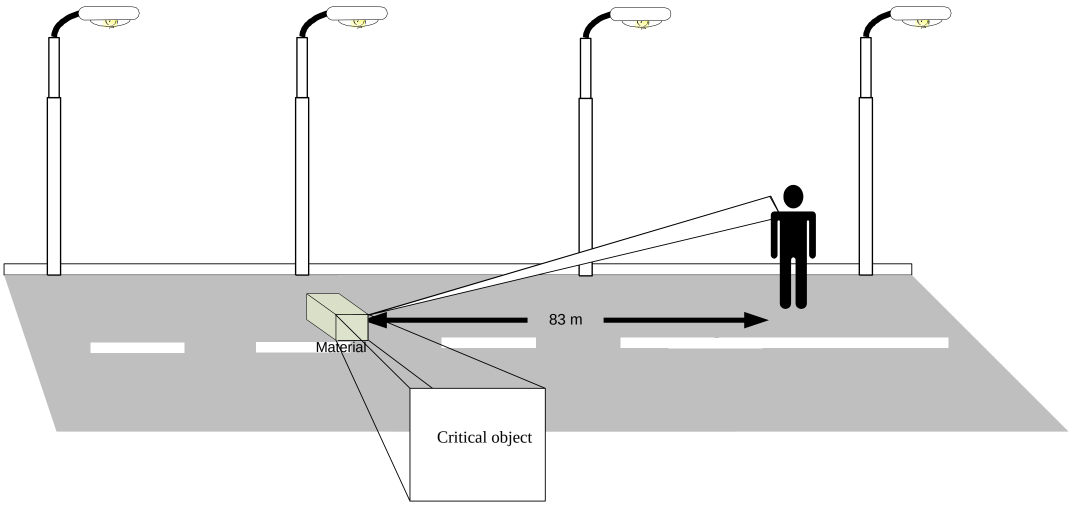


Fig. 1. Calculation of the critical object visibility

Visibility of the critical object of 20x20 cm is calculated (see Fig. 1). Small target represents a critical object which is the most difficult to perceive but still dangerous for a normal size vehicle [21]–[22].

III. Working Principle Of the System

The developed system uses two different software substructures, which are “Road Lighting” and “Visibility Level”. The “Road Lighting” function makes mapping and photogrammetric measurements, while the “Visibility Level” function tests the visibility of a critical object.

In the “Road Lighting” software, a mathematical correlation between pixel values and illumination level was established by means of using image processing techniques on a photograph of the road. CIE- No 115, titled “Recommendations for the Lighting of Roads for Motor and Pedestrian Traffic” of the International Commission on Illumination (CIE) considers luminance as the principal criteria in road lighting. The illumination level and luminance are directly proportional. By means of the mentioned correlation, the mapping of the road is made based on luminance. Road irregularities adversely affect road lighting. These adverse effects prevent a homogeneous distribution of light. A software interface was developed in order to calculate the illumination level and luminance values, based on the pixel values on the photographs (see Fig. 2). By means of such software, the user is able to not only see the illumination level and luminance values of any point on the photograph in the text box area, but also visually assess the compatibility of these values according to photogrammetric codes thanks to the developed color map.

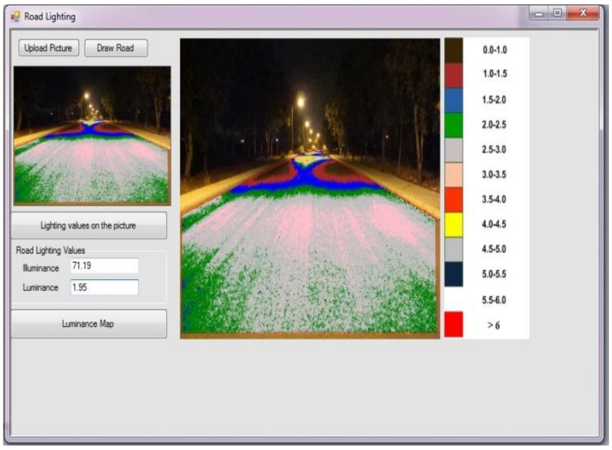


Fig. 2. Road lighting software interface

In order to calculate the visibility of the critical object on the road, another interface for “Visibility Level” software was also developed(see Fig. 3).

By means of this software, the user can also investigate the effects of road irregularities on the visibility of a critical object. In the developed software, the luminance values of the road and the critical object on the road are measured, and these values are shown in the textbox areas. By also taking into consideration other factors affecting visibility, such as age, the angular position of the object and duration of observation, the visibility of the critical object is calculated. The adverse effects of road irregularities on the visibility of a critical object have been experimentally shown.

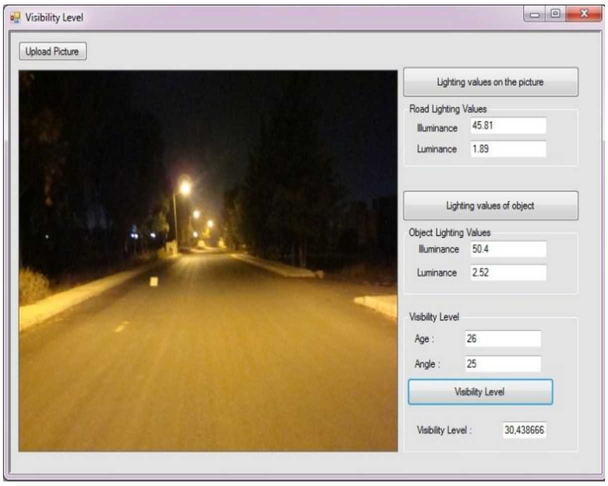


Fig. 3. Visibility Level software interface

A. *Effects of Road Irregularities on Luminance*

Irregularities in road structures affect road lighting. IRC(Ideal road lighting condition) with a homogeneous structure and an ideal reflectivity have acceptable conditions regarding lighting Roads with non-homogeneous structures and irregularities, on the other hand, constitute negative conditions regarding lighting and reduce the visibility of a critical object.


(a) (b)
(c) (d)

Fig. 4. Test roads a. IRC b. Heterogeneous asphalt road c. Irregular surface asphalt road d. Wet surface asphalt road

The photographs of an asphalt road with a heterogeneous surface, an asphalt road with an irregular surface, and an asphalt road with a wet surface were applied separately to the developed “Road Lighting” software (see Fig. 4.). The heterogeneous substructure is the same for all three roads, and the experimental methods were tested for different defects on these roads.

By means of the “Road Lighting” software, these roads were mapped according to luminance based on illumination measurements and analyses.

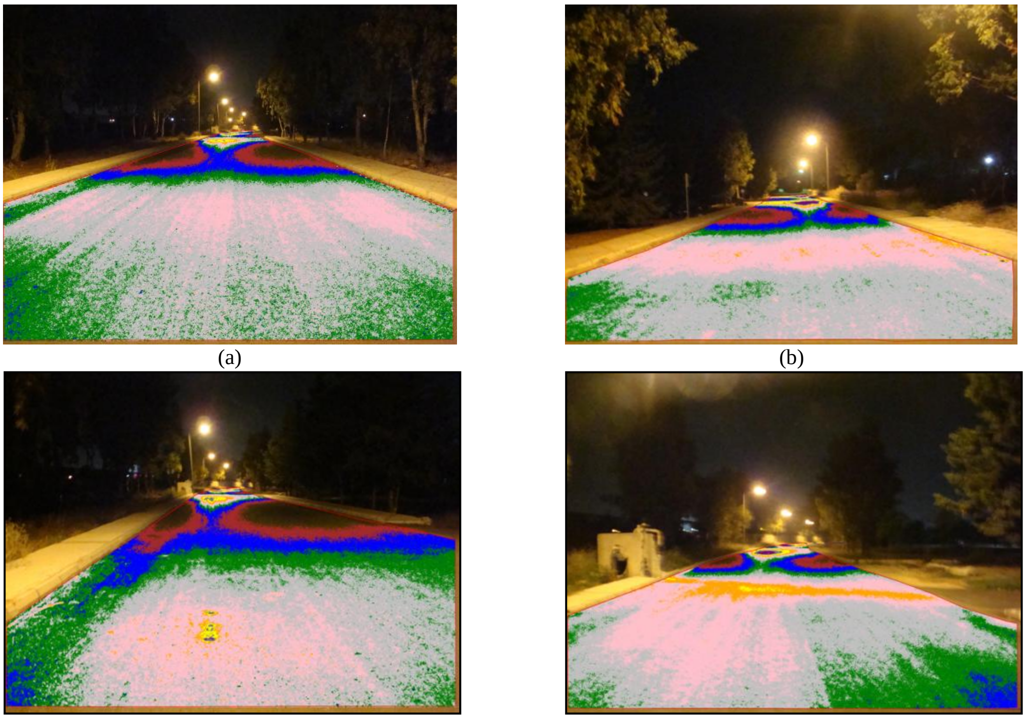


Fig. 5. Luminance map of the roads: (a) Luminance map of the IRC, (b) Luminance map of the heterogeneous asphalt road, (c) Luminance map of the irregular surface asphalt road, (d) Luminance map of the wet surface asphalt road

In Figure 5, the photographs of the roads that were mapped by means of the developed software according to luminance are shown. The blue – green parts of the color-mapped roads show the zones which are ideally illuminated according to CIE-115 standard [3], while the silver – brown points indicate the zones which are nearly ideally illuminated. The black points, on the other hand, indicate places where the road lighting is insufficient, and the yellow points indicate the over-illuminated areas.

From the evaluation results taken from the "Road Lighting" software, it was seen that the heterogeneous road lighting is caused by asymmetrical reflections of curvatures on the road surface, and therefore, these curvatures adversely affect the illumination of the road by creating a different vision to the ideal one. The yellow points in the silver areas at the luminance-based mapping of the roads with irregular surfaces are formed as a result of the distortions on the road surfaces. Such areas increase based on the amount of corrosion. The wet areas on the roads with irregular and wet surfaces affect the reflection coefficient of the roads and therefore, adversely affect the road lighting. They result in luminance and glare areas, and therefore, they also corrupt the lighting of other areas. The zones indicated in yellow and orange on the luminance-based maps are due to wet. These zones are normally 2.5-3.0 cd/m^2; however, due to their effect on the reflection coefficient of the wet surface, they appear to be 3.5 - 4.5 cd/m^2.

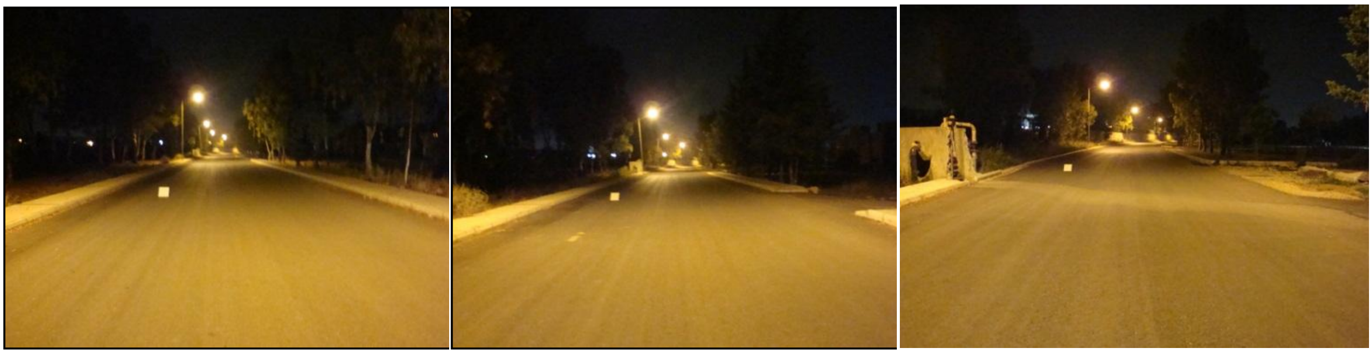
TABLE I: COMPARISON OF VALUES OF ROADS LUMINANCE

IRC	Heterogeneous asphaltroad	Irregular surface asphalt road	Wet surface asphalt road
2,11	2,15	2,53	2,06
1,9	2,3	2,44	1,94
1,75	1,79	1,71	1,73
1,32	1,78	1,3	2,52
1,05	1,11	0,98	2,32

The software-based evaluation of luminance and lighting levels of road irregularities were compared against the ideal values (see. Table I). These table clearly show that road irregularities adversely affect road lighting. The wet surface, which corresponds to 20% of the whole surface, increases average illumination by 30.012% due to reflections, and therefore, causes heterogeneous lighting because of local increases in illumination. The irregular surface, which corresponds to 5% of the whole surface, increases average illumination by 10.209% due to reflections, and therefore, caused heterogeneous lighting because of local increases in illumination. For these reasons, luminance increases too. It was seen that the major reason for the increase in illumination is that irregular surfaces reduce the dark asphalt color to a lighter tone, which eventually also increases luminance. On roads with heterogeneous surfaces, on the other hand, thereflection differences on certain regions of the road cause a nearly ideal illumination level on the whole surface, and on the other hand, at the regions where it is dominant, causes an increase of 0.45–1.65 cd/m^2, and in regions where it is not dominant, causes a decrease of 0.86–2.34 cd/m^2. The overall adverse effect of these heterogeneous luminance values on general lighting was determined by means of the software. After all these evaluations, it was seen that road irregularities increase luminance.

B. Effects of Road Irregularities on the Visibility of Critical Objects

Since road irregularities adversely affect lighting, they also affect the visibility of critical objects. Excessive or insufficient lighting may decrease the visibility of a critical object.



(a) (b) (c)

Fig. 7. Critical object photographs on the test roads (a) Critical object photograph on the heterogeneous asphalt road, (b) Critical object photograph on the irregular surface asphalt road, (c) Critical object photograph on the wet surface asphalt road

In the “Visibility Level” software, the visibility level of a critical level with a reflection coefficient of 0.25 was calculated by also considering age and the angular position of the object.

TABLE II: VISIBILITY LEVEL OF A CRITICAL OBJECT ON A ROAD WITH HETEROGENEOUS SURFACES

Road luminance	Object luminance	Age	Angular position of the object	Visibility level
2.31	3.11	26	25	26.58

By the previous studies, it was concluded that the visibility level should be greater than seven in order to assume that the critical object is visible [6], [16]–[20]. As a result of the measurements made on the road with heterogeneous surfaces, it was seen that the critical object was visible (see. Table II).

TABLE III: VISIBILITY LEVEL OF A CRITICAL OBJECT ON A ROAD WITH IRREGULAR SURFACES

Road luminance	Object luminance	Age	Angular position of the object	Visibility level
2.62	3.11	26	25	15.01

The results of the measurements made on the road with an irregular surface showed that the critical object is visible, yet has a lower level of visibility in comparison to the previous road (see. Table III).

TABLE IV: VISIBILITY LEVEL OF A CRITICAL OBJECT ON A ROAD WITH WET SURFACES

Road luminance	Object luminance	Age	Angular position of the object	Visibility level
2.90	3.11	60	25	5.60

The results of the measurements made on the road with a wet surface showed that the visibility level of the critical object is lower than the desired threshold (see. Table IV). Therefore, the critical object cannot be assumed to be visible.

IV. CONCLUSION

In this study, it was confirmed that irregularities on road surfaces adversely affect road illumination. The obtained numerical results were graphically reproduced. According to international standards, the acceptable interval for luminance values is 1.5-2.0 cd/m^2 [3]. With larger, heterogeneous, wet or irregular areas in the surfaces, the illumination level and luminance increase in lightened areas, and the illumination level of distribution becomes heterogeneous.

According to the obtained results, it was also seen that road irregularities increase luminance. The increase in luminance decreases the visibility level of a critical object, occasionally with very low visibility levels in comparison to the values defined by the standard.

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