

Fast measurement of headlamps by means of a developed fuzzy luxmeter based on a fuzzy mapping algorithm

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Abstract: The importance of an automobile's headlamps in the dark is inferable from the results of studies. Various regulations are available in order to arrange the required illuminance values at certain positions on the road. The designed and produced headlamps have to satisfy the requirements of these regulations. Manual measurement tools, such as the luxmeter (which are based on point-by-point measurements), have traditionally been used. This traditional way has been considered inefficient in terms of awkward setup procedures, complexity, the continuous intervention of human operators, and costs. In this study, in order to overcome these problems, a new approach for measuring the illuminance values is proposed. Combining a digital still camera with a fuzzy mapping algorithm, a fast and economic tool to measure the illuminance values of the entire measuring screen is developed. The proposed method was tested on two different brands of headlamps and its effectiveness has been proved.

Key words: Fuzzy luxmeter, opto-electronic conversion function, measurement of headlamp, fuzzy mapping algorithm

1. Introduction

Concurrently with the thorough proliferation of vehicles into human life, many studies have been conducted for solving problems that better illuminate the road while decreasing the dazzling effect on the drivers and pedestrians coming from opposite directions, especially when traveling at night. However, these issues have not been solved completely.

According to the US National Highway Traffic Safety Administration, the nighttime fatality rate is nearly three times higher than the daytime rate, with people traveling approximately three times more during the daytime than at night [1,2]. The reasons for this incompatibility can be poor visibility, the dazzling effect of oncoming vehicle headlamps, fatigue, and alcohol. Fatigue and alcohol depend on the human factor, whereas poor visibility and the dazzling effect are proportional to the quality of the headlamps.

As expected, some restrictions should be maintained during the headlamp production phase so as to guarantee safe driving. There are some regulations reported by the International Economic Commission of Europe (ECE) related to headlamps [3]. ECE regulations state the required illumination that is significant for road lighting and the protection of the oncoming vehicles from the dazzling effect at certain directions. There are also some standards for analyzing the quantity of road lighting with luminance measurements, one of which is EN 23201-3 [4].

In order to fulfill these regulations, it is necessary to set up experimental headlamp luminance measure-

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ments at certain points in a designed laboratory. Although such testing systems are available on the market, they are not efficient seeing as they involve awkward setup procedures, complexity, the continuous intervention of human operators, and costs. Thus, testing headlamp luminance is best realized by the operator that yields an operator-dependent test using a luminance, or lux, meter [5]. A patent entitled "Illuminance measurements of vehicle lamp" [6] is one of the methods for illuminance measurements.

During the present day, in order to decrease the effect of the operator, automated tools have been developed for the measurement and assessment of headlamps in the automotive industry [7–9]. The development process is parallel to high dynamic image processing. An increased demand for image processing is available in many applications; for example, computer-aided diagnosis in medical images, character recognition, and industrial inspection in textiles [10–13]. There are many image analysis methods available in the literature. One of these that has been successfully applied during the last decades is fuzzy set theory. Fuzzy set theory, which was introduced after the middle of the 20th century [14], has been applied to many areas (from control theory to image analysis) due to its being capable of dealing with the uncertainty associated with vagueness and ambiguity [15–18].

Although there are manufactured cameras, such as Fuji Finepix F10, which are specifically available in the market in order to measure luminance, alternative solutions using digital still cameras are required. This is due to the fact that, besides being expensive, the specifically manufactured luminance measurement cameras require an awkward setup procedure. However, developments in high dynamic range imaging provide reasonable cost solutions when used with digital still cameras. Using a digital camera has significant advantages. One of them is their ability to capture the entire scene, which, in turn, speeds up the measurement process; likewise, it allows multiple measurements that can be recorded digitally. Another (and, arguably, the most) important advantage of using a digital camera is that it can measure a small area light source, since the field of view (FOV) of a digital camera's pixel is approximately 150 times smaller than that of a luminance meter (i.e. approximately around 1°) [19].

The opto-electronic conversion function (OECF), which is defined as the relationship between input log luminances and the corresponding digital output levels for an opto-electronic digital image capture system, is used to calibrate the digital still camera [20]. The calibration assigns digital output values to different luminance values (candela per square meter) that can be converted into the illuminance values (lux), which are required for ECE regulations.

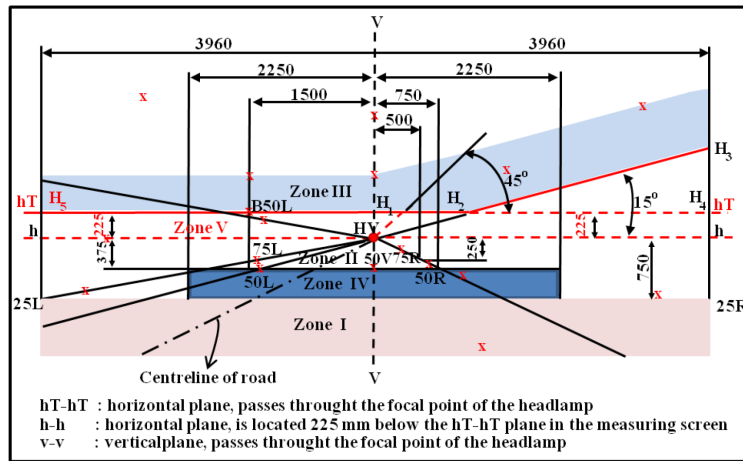
The main purpose of this study is to make a contribution to the automotive industry by suggesting a novel measurement method for headlamps that is not only very effective, but also less time consuming, easy-to-use, and economical. Software called Fuzzy Luxmeter, which has a user-friendly interface, is developed in this study. By using this software, which is based on high dynamic image analysis by means of a fuzzy mapping algorithm, it is very effective to test whether headlamps comply with the required ECE regulations with high accuracy. Because of the fact that the measurement of headlamps demands very high precision in radiance as well as positioning of the headlamp and measuring device, a goniophotometer is usually used in the headlamp industry. The proposed Fuzzy Luxmeter, which is a reliable tool for determining the illumination patterns of the headlamps to be tested by means of collaborated digital still camera, is developed considering the mentioned positioning problem. We expect that the proposed method will provide a very economical way to increase the measurement speed of the headlamps and be less time consuming during the headlamp design process.

The paper is structured as follows. Section 2 presents a review of the ECE regulations. Section 3 describes the manual measurement of the headlamp illuminance values in all directions using a TES-1332 luxmeter in a

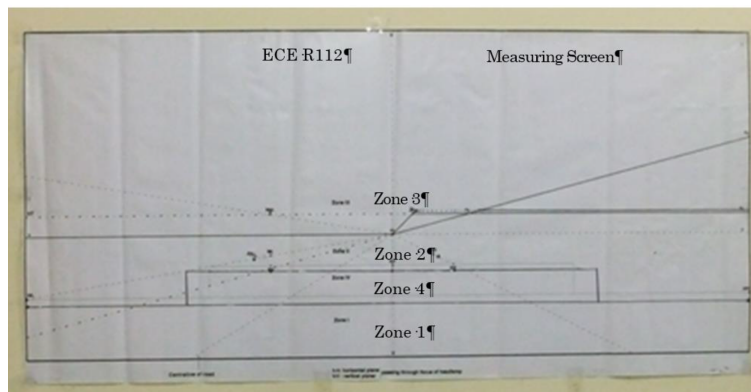
test laboratory. Section 4 details the fuzzy mapping algorithm. Section 5 explains the proposed fast, economical, and effective headlamp illuminance measurement method. Section 6 presents the experimental results of the proposed method and discussions of those results. Section 7 concludes the study.

2. Review of the ECE regulations

Light distribution of a low-beam headlamp is required in order to satisfy the ECE regulations for both right-hand traffic and left-hand traffic. [3] is valid for right-hand traffic, which is more common than left-hand traffic. This regulation, R112, defines the shape of the illumination line, which, in turn, is an asymmetric cut-off line between dark and light regions and the acceptable values of illumination in certain regions. The cut-off line is drawn as the flat red line in Figure 1(a). Above the line should be as dark as possible so as not to disturb the coming drivers' eyes, whereas below the line, there should be as much light as possible in order to lighten the road much better. Figure 1(a) illustrates the ECE regulation lines whose dimensions are shown in millimeters on a screen at 25-m distance for right-hand traffic. The dazzling effect that the headlamps can cause for the coming drivers can be evaluated with the luminous intensity (cd) in specific directions and luminance (cd/m²) at the driver's eye. The evaluation of this effect is realized with the illuminance (lux) measurements at the points 25 m away as indicated in ECE regulation no.R112.



(a)



(b)

Figure 1. (a) The ECE regulation lines and measurement points. (b) The measuring screen set up in the test laboratory.

The illumination of the screen should meet the regulation ECE no.R112. To check the illumination, the points marked in red in Figure 1(a) are used. Figure 1(b) shows the screen, which is covered with a matt sheet on which zones and measurement points are drawn and which is set up in the test laboratory.

3. Manual measurement process using TES-1332 luxmeter in a test laboratory

The headlamp to be tested is to be fixed to a table located 25 m away from the measuring screen as indicated in ECE regulation no.R112. Figure 2(a) shows the table on which the tools are to be placed (e.g., the headlamp to be tested, the power source, a digital camera, and a notebook).

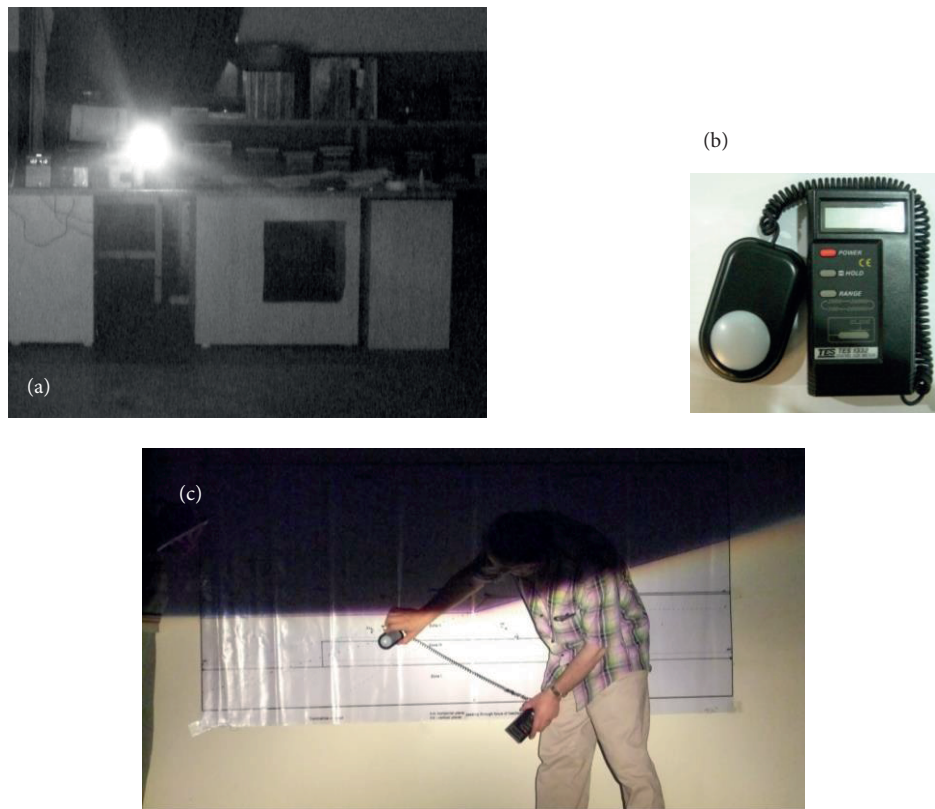


Figure 2. (a) The table on which the tools, such as the headlamp to be tested, the power source, the digital camera, and the laptop, are to be placed. (b) The TES 1332 luxmeter used for manual measurement. (c) An example of the measuring process performed by the authors during test operation in the test lab.

The illuminance values of all measurement points seen in Figure 1(a) are measured one by one using the TES-1332 seen in Figure 2(b). Figure 2(c) is an example of the measuring process during test operation. The process is realized by two people, i.e. while one reads the TES-1332 value, the other stores the data. As is seen, the process takes more labor even though only certain points are to be measured. Even if the measuring points are sufficient according to ECE regulation no.R112, the illuminance value of the entire screen should be measured in the case of a leakage beam that causes a dazzling effect from oncoming vehicle drivers.

The proposed method, which is stated in Section 5, decreases the labor force and process time needed to measure the entire screen.

4. Fuzzy mapping algorithm

A fuzzy mapping algorithm is used because of the fact that fuzzy set theory has the capability of dealing with the uncertainty associated with vagueness and ambiguity [15–18]. The raw image can get rid of this ambiguity and vagueness in the image data by using a fuzzy mapping algorithm. The developed fuzzy mapping algorithm consists of four main parts: image fuzzification, rule base, inference system, and image defuzzification shown in Figure 3. Membership functions, which are used in both fuzzification and defuzzification processes, are also a vital part of the algorithm. The algorithm calculates the crisp gray level output value of each pixel according to the crisp red (R), green (G), and blue (B) input values.

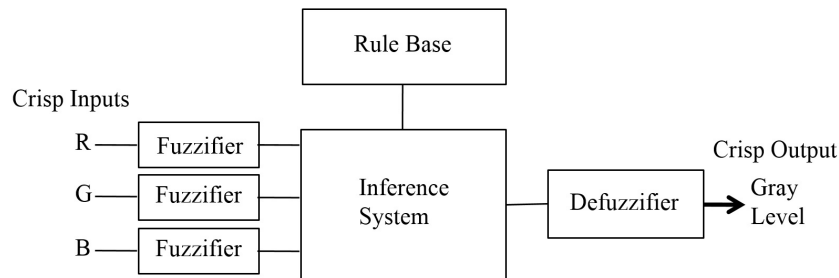


Figure 3. The structure of the fuzzy mapping algorithm.

During the first step (i.e. the fuzzification process) the crisp R, G, and B digital values of each pixel are converted into linguistic expressions in the membership plane. The degree of membership is decided upon by using the membership functions. S (small), M (medium), and L (large) are the linguistic expressions (i.e. fuzzy sets).

The membership functions for R, G, B, and gray level are portrayed in Figures 4(a), (b), (c), and (d), respectively. Since the input image to fuzzification process and output image obtained after defuzzification process are 8-bit quantized, boundaries of the membership functions are always between 0 and 255. S, M, and L fuzzy sets representing the degree of membership of each variable are decided according to experience for each R, G and B input values and gray level output. The inference system, which associates between the rule base and the linguistic expressions, infers the rules to be executed. The Table shows the rule base in which the rules have the IF-THEN-ELSE structure. Unlike conventional rule bases, it is a three-dimensional rule base. Thus, the rules are decided on according to human experience and thoughts, i.e. the basis of fuzzy logic theory.

Table. Rule base.

R	S			M			L			
L	G	S	M	L	S	M	L	S	M	L
S		S	S	M	S	M	M	M	M	L
M		S	M	L	M	M	L	M	L	L
L		M	M	L	M	L	L	L	L	L

During the defuzzification process (i.e. the last step of the algorithm), the Mamdani method in which the fuzzy sets obtained after applying each inference rule to the input data are joined using minimum and maximum functions for “and” and “or” operations, respectively, is used. The output image is achieved using the center of area (COA) method, which calculates the crisp gray level value.

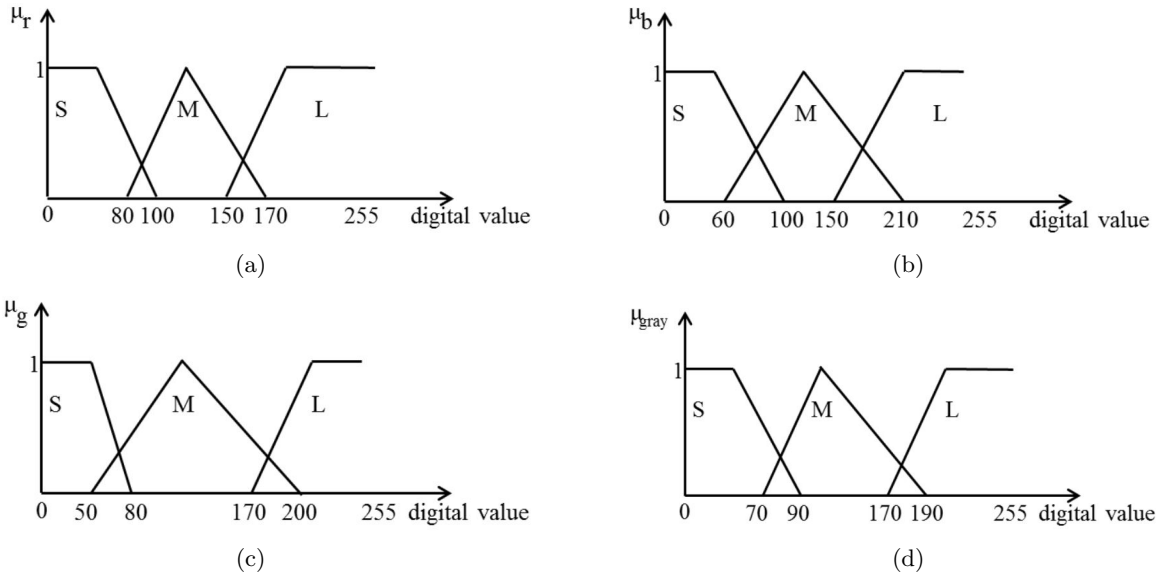


Figure 4. The membership functions for the: (a) R input value. (b) G input value. (c) B input value. (d) Gray level output value.

5. The proposed method

In this section, the proposed method for the automatic illuminance measurement of an automobile headlamp using a digital still camera instead of the other expensive cameras produced specifically for measuring luminance is clarified. The measuring/testing process is composed of three main parts: experimental setup, OECF curve, and the Fuzzy Luxmeter. The flowchart of the testing process is given in Figure 5.

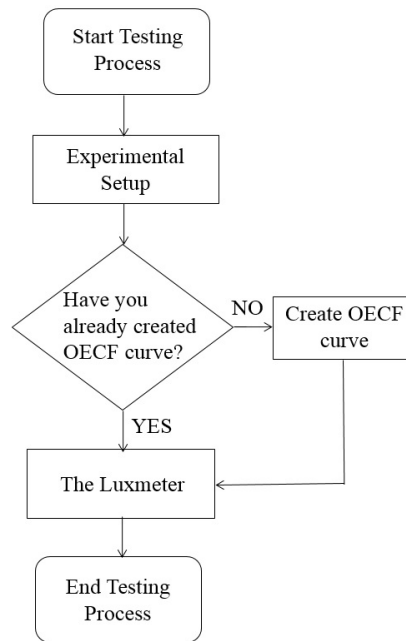


Figure 5. Flowchart depicting the testing process.

The experimental setup illustrated in Figure 6 is established in the test lab according to the international ECE regulations mentioned in Section 2. The measuring screen is placed 25 m away from the headlamp, with the position of the headlamp being adjusted in accordance with the breaking point, HV point, in the middle of the measuring screen. A Casio EX-Z2 digital camera of which the F-number is 6.3 mm is placed just behind the headlamp on a tripod in order to avoid vibrations. The connection between the Casio EX-Z2 and the Fuzzy Luxmeter is realized by means of a laptop whose operating system is Windows 7.

The second part of the proposed method, which, in turn, is relevant to the third part (i.e. the Fuzzy Luxmeter), is to create an OECF curve using the Casio EX-Z2. The measurement method for camera calibration is described by ISO 14524 [20]. Camera calibration is performed according to this ISO standard. However, 20 patches are located in the test chart instead of 12 patches, which is mentioned in the standard. A 2-D line plot of the measured 20 data creates the OECF curve. By creating the OECF curve, the illuminance value of the cells on the measuring screen can be easily calculated according to the digital gray level value, which is obtained using a fuzzy mapping algorithm. Figure 7 depicts the OECF curve of the digital camera. The maximum illuminance value that can be measured using the Casio EX-Z2 in the test laboratory is 429 lx. This measurement corresponds to the digital gray level value-255.

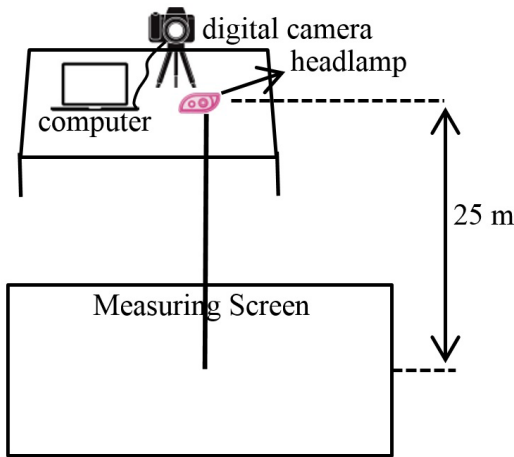


Figure 6. Experimental setup for illuminance measurement in the test lab.

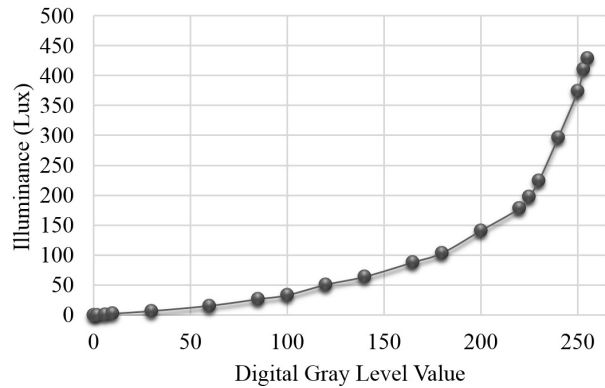


Figure 7. OECF curve of the digital camera.

The Fuzzy Luxmeter, which has a user-friendly interface (as shown in Figure 8), is the last part of the testing process. The Fuzzy Luxmeter has an easy-to-use design and can work either in real-time mode or calibration mode.

The calibration mode is used to calculate the accuracy rate of the software by using the values measured by means of the software and the values measured using the TES-1332 luxmeter, the true ones. In calibration mode, the Fuzzy Luxmeter divides the uploaded image taken by the digital still camera (at a resolution of 3072×2304 pixels) into 40 columns and 18 rows, meaning that 720 cells are available for measuring the illuminance value. The illuminance value of each cell is estimated by assigning the average value of its comprised pixels' illuminance values to the cell. The uploaded image is divided into these fixed values because the manual measurement taken by using the TES-1332 luxmeter is realized by using the same fixed cells on the measuring screen as seen in Figure 2(c). The calculated illuminance values are compared with the true ones; the performance is evaluated as:

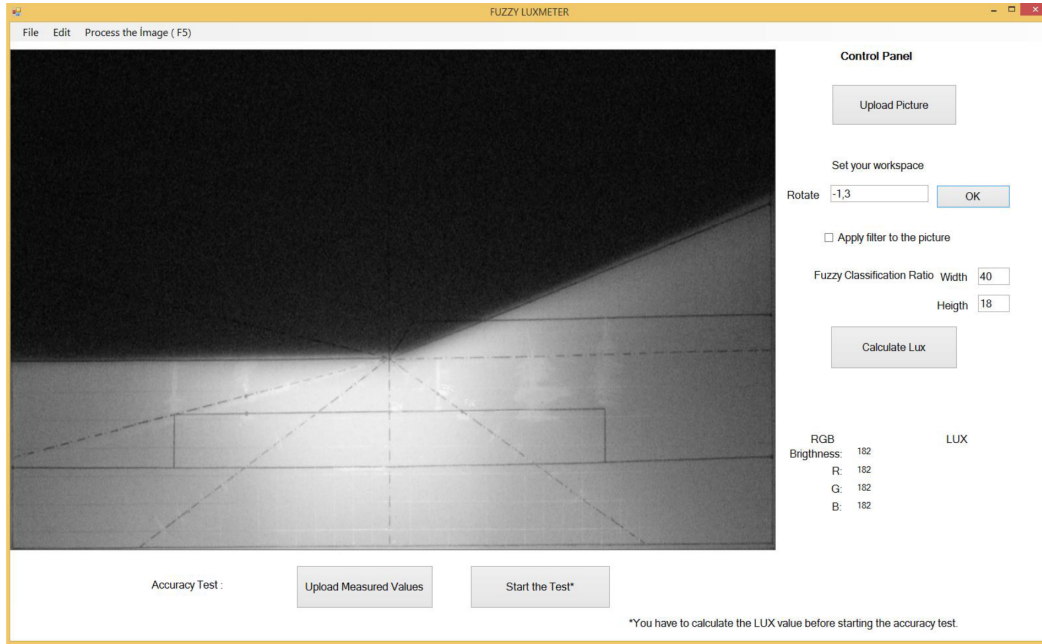


Figure 8. A screenshot of the developed Fuzzy Luxmeter.

$$P = \frac{(Im - It)}{It} \times 100, \quad (1)$$

where P, Im, and It correspond to the performance index, the measured illuminance value, and the true illuminance value, respectively. Eq. (1) is known as the deviation ratio. As indicated in the agreement [21], at a selected cell, the deviation ratio has to be less than 20%, which is required by the headlamp industry.

Once the calibration mode is completed and, additionally, if the positions and angles of the digital camera and/or measuring screen are not changed, using real-time mode, the illuminance values of every pixel of the uploaded image are estimated instead of dividing the image into 40 columns and 18 rows, in turn creating an illuminance map in another window.

6. Results and discussion

Experiments were performed using two different brands of headlamp (Brand-A and Brand-B) for verifying whether the illuminance values at the certain positions given by ECE regulations were satisfied. Instead of measuring only the illuminance values at certain positions, the illuminance values of the entire measuring screen were measured first manually and then using the Fuzzy Luxmeter.

A digital still camera, Casio EX-Z2, was used to obtain the image of the measuring screen. The images were taken without flash and their resolution was 3072×2304 . The first experiment was carried out with the Brand-A headlamp. The beam of the headlamp was projected onto the measuring screen, which was itself divided into 40 columns and 18 rows. The illuminance values were measured manually by means of the TES-1332 luxmeter and uploaded to the Fuzzy Luxmeter as an Excel file.

Once the true illuminance values were recorded, calculations were performed by the Fuzzy Luxmeter with the uploaded measuring screen image. The original measuring image taken by the digital camera is shown in Figure 9(a). As measured manually, the original image is divided into the same fixed values as seen in Figure

9(b) and the illuminance value of each cell was calculated in order to evaluate the deviation ratios using Eq. (1). Furthermore, a new window showing the illumination value of each cell was created by the Fuzzy Luxmeter with each cell painted the color blue according to its illuminance value, as in Figure 9(c). It is important to note that the darker blue cells have a higher illuminance value while the white ones have a lower one.

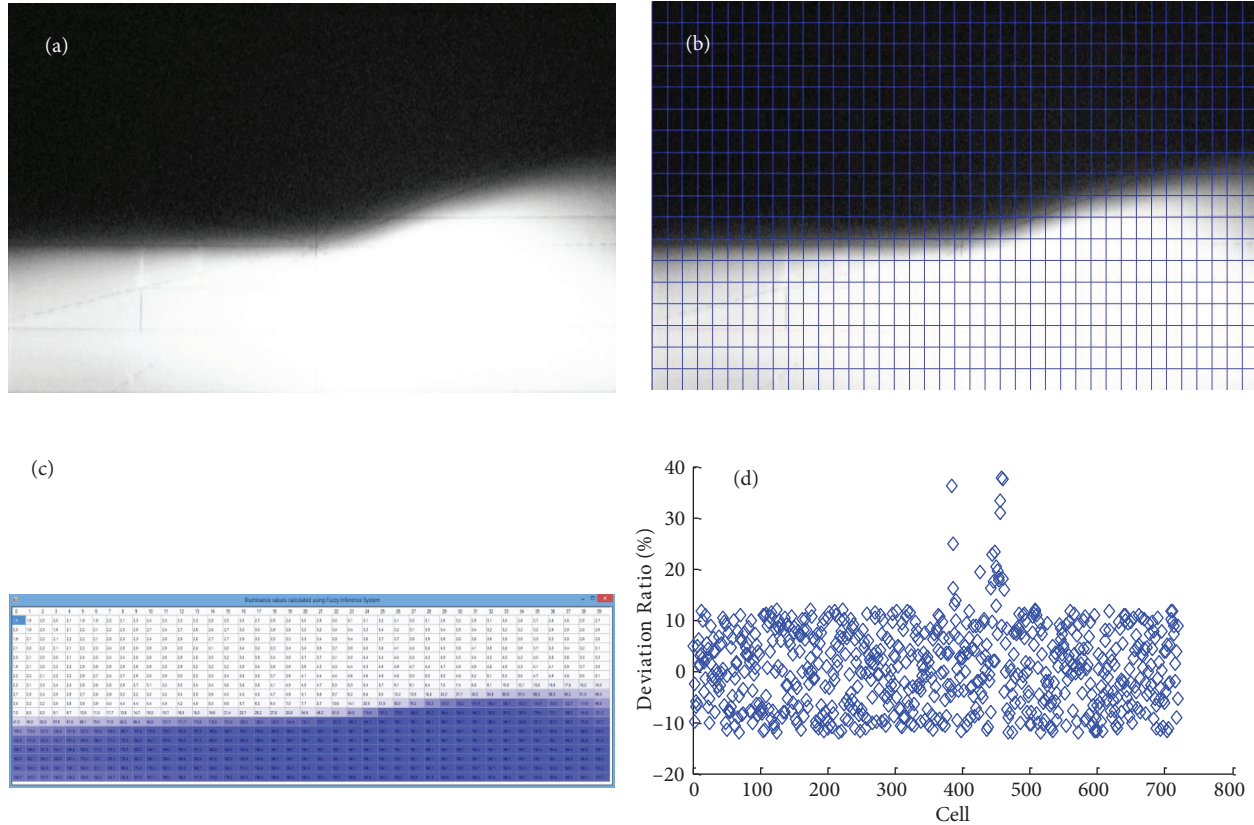


Figure 9. (a) Original image of measuring screen on which the Brand-A headlamp is reflected. (b) Divided image for measurement. (c) The Fuzzy Luxmeter result window. (d) Deviation ratios for the Brand-A headlamp.

The performance evaluation is carried out by calculating the deviation ratio for each cell. Figure 9(d) shows the deviation ratios of the cells where the 1st and 720th cells correspond to the upper left and bottom right ones, respectively.

As can be seen from Figure 9(d), the deviation ratios are within the range between $\pm 12\%$, excluding only a few cells. Indeed, the exclusive ones correspond to the asymmetric cut-off line between dark and light regions where the true illuminance values of the cells can be measured erroneously during manual measurement. This is due to the fact that performing a measurement on the upper and lower sides of the cell provides different illuminance values. As a result of this, the size of the TES-1332 luxmeter is smaller than the size of the cell.

The Brand-B headlamp was used in the second experiment by following the same steps as the first. The figures seen in Figure 10 are related with the Brand-B headlamp. As in Figure 9(d), Figure 10(d) has some cells whose deviation ratios are higher than 20%, although the ratios are within the range between $\pm 11\%$. The reason why this is so is the same as that given in the first experiment above.

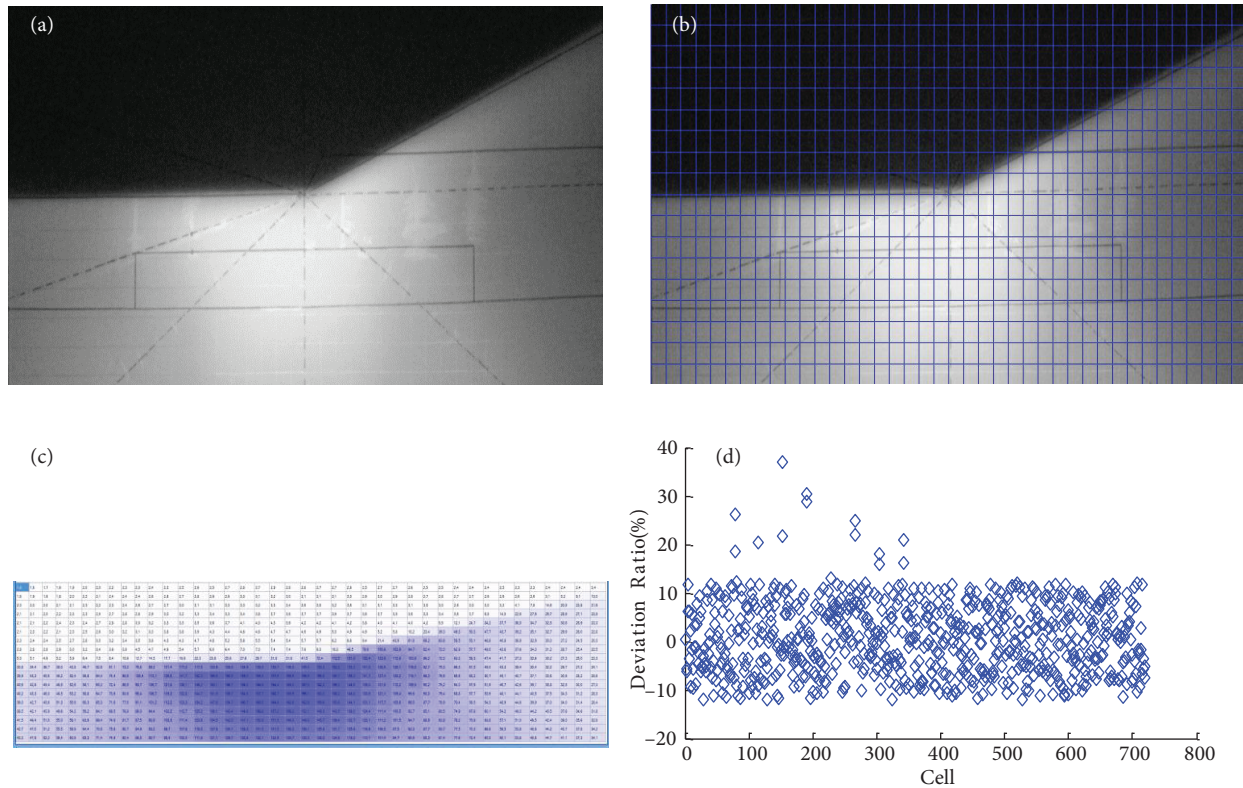


Figure 10. (a) Original image of measuring screen on which the Brand-B headlamp is reflected. (b) Divided image for measurement. (c) The Fuzzy Luxmeter result window. (d) Deviation ratios for the Brand-B headlamp.

When the measurements near the asymmetric cut-off line between the dark and light regions were performed heedfully by the TES-1332 luxmeter and the Fuzzy Luxmeter, the derivation ratios of the cells were within a range between $\pm 12\%$ and $\pm 11\%$ for the first and second experiments, respectively.

7. Conclusion

While developing a fast, economical, and effective method for measuring the illuminance values of automobile headlamps for the purpose of determining whether they satisfy the requirements given by ECE regulations, some contributions have been made in this study. First, a new approach for measuring the illuminance values of the headlamp in all directions was suggested. Second, a fuzzy mapping algorithm was applied to such an industrial application. Third, an economical, fast, and effective measurement method whose effectiveness was evaluated and proved was proposed. Last, but not least, by using the proposed method, it is possible to measure the entire measuring screen pixel-by-pixel, which, in turn, provides a method for effectively catching the leakage beams that cause the dazzling effect on oncoming vehicle drivers, while the TES-1332 luxmeter and other such luxmeters can only measure the cells obtained by dividing the measuring screen into 40 columns and 18 rows.

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