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Automotive lighting: method of assessing the visibility of objects in the light of car headlights

***Abstract**. An improved method for assessing the visibility of road objects in the light of car headlights in the examination of traffic accidents is proposed. This method is based on the results of processing of experimental studies with cars of category M1, in the headlights of which the lamps H1, H4, H7 are installed. Visibility assessment is carried out according to the parameters that significantly affect the processes of distinguishing objects in the dark and the speed choice by the driver according to the requirements of traffic safety.*

Streszczenie.** Zaproponowano ulepszoną metodę oceny widoczności obiektów drogowych w świetle reflektorów samochodowych podczas badania wypadków drogowych. Metoda ta opiera się na wynikach badań eksperymentalnych z samochodami kategorii M1, w reflektorach których zainstalowane są lampy H1, H4, H7. Ocena widoczności jest przeprowadzana zgodnie z parametrami, które znacząco wpływają na proces wyróżniania obiektów w ciemności oraz na wybór prędkości przez kierowcę zgodnie z wymogami bezpieczeństwa ruchu. **Ulepszona metoda oceny widoczności obiektów drogowych w świetle reflektorów samochodowych

Keywords: car headlights, visibility of objects on the road, automotive lighting and road safety.
Słowa kluczowe: in the case of foreign Authors in this line the Editor inserts Polish translation of keywords.

Introduction

Over the past 25 years, the optical systems of headlights, used sensors, software and electronic components of intelligent lighting systems of the vehicle have significantly improved [1, 2]. According to analytical reports on the development of the global automotive lighting market, three main types of lighting sources are currently used in the vehicle: halogen, xenon and LED (Table 1), and some cars with halogen sources make up 70-80% [3, 4].

To measure a person's visual reaction to light, photometric parameters such as luminous intensity, luminous flux, illumination, brightness and luminous efficiency are used [5, 6, 7]. The light quality of car headlights can be assessed by its range, width, comfort (coverage of the driver's point of view) and the level of inconvenience for other road users in accordance with international requirements (for example, Regulations R1, R2, R8, R20, R48, R98, R99 of the United Nations Economic Commission for Europe).

Table 1. Key indicators of automotive head lighting systems for vehicles of category M1

Indicator/Type of headlights	Halogen	Xenon	LED
Service life, hours	up to 1000	up to 3000	10k...100k
Rated voltage, V	12	85, for pulse to turn on (10-20 kV)	12
Rated power, W	55-65	35	up to 20
Luminous flux, lm	1k-1,65k	2,8k-3,2k	0,8k...1,7k and more
Value	low	high	high

In the dark, according to traffic safety conditions, it is necessary that the visibility distance of road objects (S_V) is greater than the stopping distance of the vehicle (S_0)

$$S_V \geq S_0 + S_S, \quad (1)$$

where: S_S – safety interval to obstacle.

The illumination required to detect an obstacle depends on the transparency of the atmosphere and the color contrast of the objects of difference. It can be approximately determined by the empirical formula [8]

$$E_n = 0.2 + 0.01 \cdot S_0. \quad (2)$$

The total luminous intensity of the headlights and the illumination necessary to detect an obstacle at a distance of S_V, are related by the dependence [9]

$$I = E_n \cdot S_V^2. \quad (3)$$

How much the visibility of road objects is deteriorating by the driver from headlights of oncoming cars is estimated by the glare coefficient

$$C_S = \left(I_S + I_F\right) / I_S, \quad (4)$$

where: I_F – the light intensity of the oncoming car headlights, which gets into the driver's eyes, I_S – light intensity, causes a glare effect.

The visibility distance of road objects depends on the illumination of the road E created at a distance d and the illumination necessary to detect an obstacle

$$S_V = d\sqrt{E / E_n}. \quad (5)$$

Identification method and construction of the structure of the visibility distance assessment system

An adaptive system for assessing the visibility distance of road objects in the dark was developed on the basis of the method of identifying nonlinear objects with fuzzy knowledge bases [10] in the neuro-fuzzy editor Anfis [11] of the Fuzzy Logic Toolbox of the Matlab computing environment [12]. The system was built in two stages (Fig. 1): the first is structural identification; the second is parametric identification.

At the stage of structural identification, the structure of the dependence of the visibility distance on the influence factors (Fig. 2) was built based on the "if-then" rules. Parametric identification was carried out by selecting such knowledge base parameters that ensure maximum approximation of the simulation results and experimental data.

All factors affecting the visibility distance (Fig. 2) are considered as linguistic variables defined on the corresponding universal sets and evaluated by fuzzy terms.

As can be seen from fig. 2, the neuro-fuzzy network of the system consists of five layers. Each node of the first layer represents one term with a Gaussian membership function [12]

$$\mu_j\left(x_i\right) = \exp\left(-\frac{1}{2}\left(\frac{x_i - c_{ij}}{\sigma_{ij}}\right)^2\right), \quad (6)$$

where: $\mu_j(x_i)$ – membership function of a fuzzy set a_{ij}; c_{ij} and σ_{ij} – the coordinate of the maximum and the concentration coefficient – the parameters of the membership function.

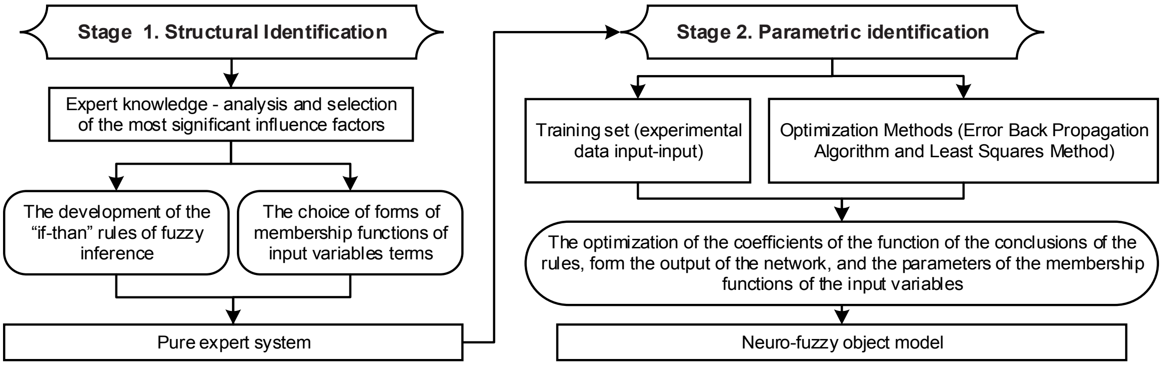

Fig. 1. Stages for setting the visibility distance assessment system

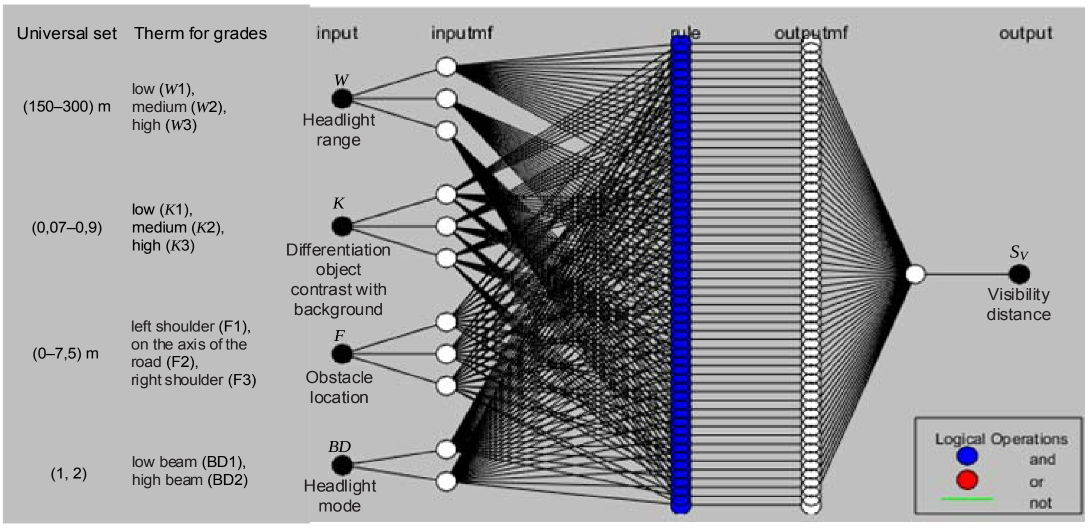

Fig. 2. Structure of the system for assessing the distance of visibility

The number of nodes of the second layer is equal to the number of rules of the fuzzy Sugeno knowledge base [11] (for this case, as can be seen from Fig. 2, the number of rules is m = 3*3*3*2 = 54). Each node of the second layer is connected to those nodes of the first layer that form the antecedents of the corresponding rule. The node output is the degree of fulfillment of the τ_r rule embedded in it, equal to the product of the input signals.

All fifty-four nodes of the third layer determine the relative degree of fulfillment of the corresponding fuzzy rule τ_r*. The nodes of the fourth layer determine the contributions of fuzzy rules to the output of the S_V network.

(7) $$\tau_r{}^* = \tau_r \, / \sum_{j=1,m} \tau_j ,$$

(8) $$S_{Vr} = \tau_r{}^* \cdot \left(b_{0,r} + b_{1,r} \cdot W + b_{2,r} \cdot K + b_{3,r} \cdot F + b_{4,r} \cdot BD \right),$$

where: $b_{q,r}$ – coefficients of the consequent function of the r-th rule (r = 1, 2, …, 54; q = 0, 1, 2, 3, 4).

A single fifth layer node aggregates the contributions of all the rules

(9) $$S_V = S_{V1} + \ldots + S_{Vr} + \ldots + S_{Vm} .$$

Recommendations for assessing the contrast of the object of distinction with the background K are given in table. 2. The "if-then" rules of fuzzy inference were generated in the neural-fuzzy Anfis editor of the Matlab computing environment in automatic mode.

Table 2 – Recommended values of the contrast parameter of the object of distinction with the background [6]

Road surface		Indicator K (silhouette visibility)			
type	state	pedestrian in light clothes	pedestrian in dark clothes	pedestrian in light clothes with reflective elements	pedestrian in dark clothes with reflective elements
Asphalt-concrete, cement-concrete	Dry	0.8	0.1	0.9	0.4
	Wet	0.72	0.07	0.82	0.25
	Covered in snow	0.08	0.75	0.35	0.88
Dirt road	Dry	0.7	0.2	0.84	0.3
	Wet	0.75	0.5	0.87	0.48
	Covered in snow	0.08	0.75	0.35	0.89

An experimental study of performance indicators for car headlights in the dark and parametric identification of the system

Experimental studies have been carried out since 2003, including with the on-site road traffic accidents or in road conditions close to the road traffic accidents [6, 13, 14]. The studies were carried out according to the current method [6, 15] in the following sequence: selection of equipment and measuring equipment; selection of headlight operation modes for road tests; measuring selected performance indicators of lighting systems. During the experiments, 3 observers with visual acuity 0.9...1.0 were in the cars.

Auxiliary tools (Fig. 3): light meter U116, 20-meter tape measure, vest with reflective elements, a reflector, chalk for marking the roadway, numbered chips, a lantern. Each experiment was carried out 2 times in the forward and reverse directions of the road, and the value of the visibility distance was measured 3 times to obtain reliable averaged data.

Sixty-eight vehicles of the M1 category from 1991-2015 of the year of production in the headlamps of which installed H1, H4 and H7 halogen lamps with European light distribution took part in the tests. All vehicles were in technically sound condition. Generalized experimental data on determining the visibility distance of an object on the road under the headlights of an oncoming vehicle, obtained for a 95% confidence level, presented in Figure 4.

Fig. 3. Aids to experimental research

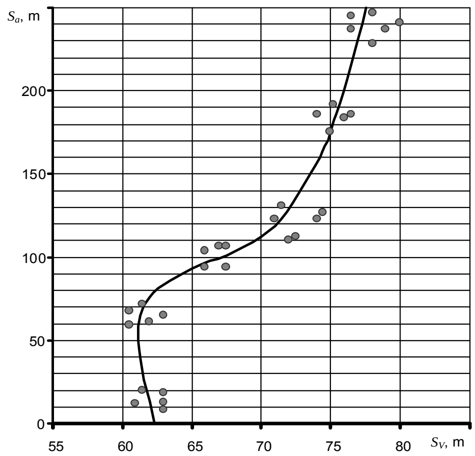

Fig. 4. Dependence of the visibility distance S_V on the distance between cars S_a

After analyzing the obtained graphical dependence (Fig. 4), it can be noted that from the moment cars approach a distance of 200-250 m under the influence of dazzling brilliance of headlights, the process of reducing the visibility distance of objects begins. At a distance of 0.2 km, drivers lose their visibility to one degree or another, with S_a = 110 m, the range of visibility decreases by 15%, with S_a = 70 m, by 23%. Further rapprochement of cars practically does not affect the change in visibility.

It was also found that it is necessary to distinguish between objects the illumination increases with increasing distance to it (Fig. 5), that is, it is not true to consider the value of illumination constant. The higher the illumination created by the lighting system at characteristic points remote from the car at equal distances, the more efficient the lighting system. At the same time, the lower the illumination sufficient to detect a test object, the better the light distribution of the lighting system [6].

A series of planned full-scale experiments was carried out to determine the visibility distance of test objects on the road in the dark, which allowed us to obtain the dependences of the visibility distance on the characteristics of the distinguishing object for headlights of various cars in the dipped and main beam modes, an example of which is shown in Figure 6.

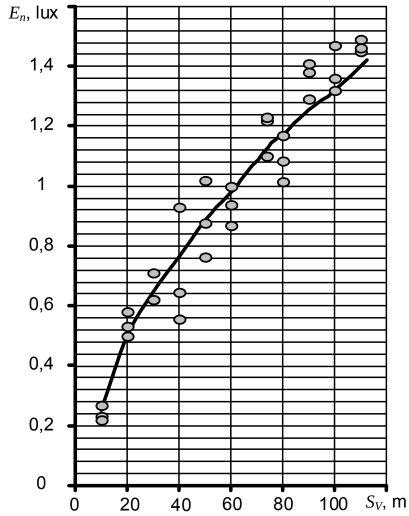

Fig. 5. Experimental dependence of the visibility range S_V of the critical illumination of an object E_n

Table 3 – Experimental database (fragment)

W, m	*K*	*F*, m	*BD*	S_V, m
151	0.07	2	1	37.1
182	0.2	7.5	1	51.8
223	0.5	3	2	155.6
285	0.7	7	2	250.8
179	0,2	3,75	2	94,5

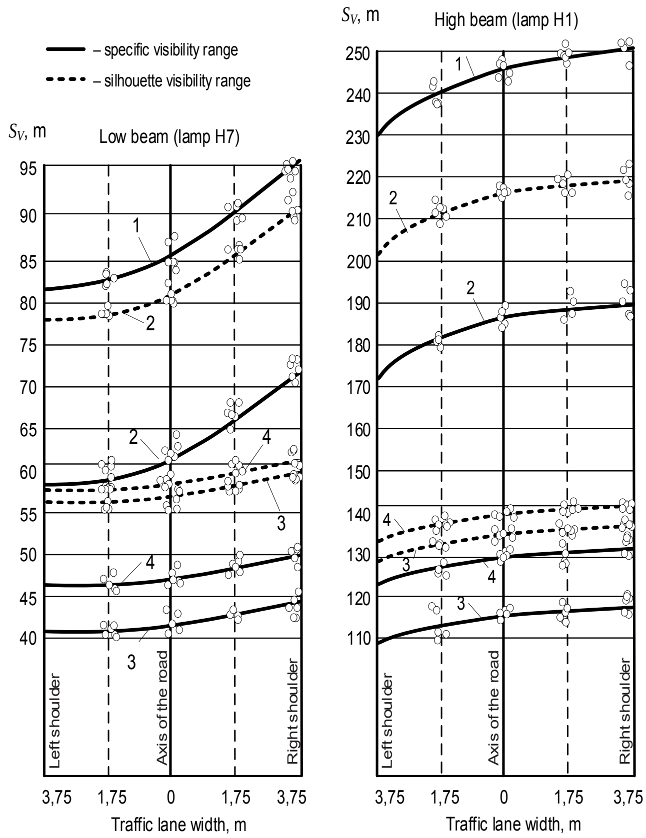

Fig. 6. Experimental dependence of the visibility range on the characteristics of the object of discrimination for headlights with lamps H7, H1 (Opel Astra G): 1 – test object (general visibility) 2 – a pedestrian in light clothes; 3 – a pedestrian in dark clothes; 4 – a pedestrian in clothes with reflective elements.

The experimental data obtained by the authors correlate well with other results of studies of the performance of the headlamps of vehicle headlights [5, 9, 16].

During the experiment in road conditions in order to create training and test samples for the parametric identification of the neuro-fuzzy system, the values of the factors of influence on the visibility distance of road objects in the dark were recorded (see Fig. 2) and the visibility distance itself. As a result, an experimental database was obtained (700 input-output data pairs), a fragment of which is presented in Table 3. The training database (420 pairs of input-output data) and test samples (280 input-output data pairs) were formed from the resulting database.

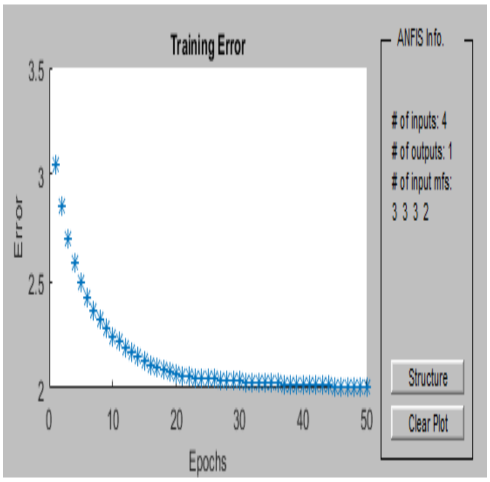

Fig. 7. The learning process of an adaptive neuro-fuzzy system

The learning process of an adaptive neuro-fuzzy system for identifying the visibility distance from a sample of input-output experimental data in Anfis Editor Matlab using the back-propagation error algorithm in combination with the least squares method is shown in Figure 7.

As can be seen from Figure 7, the training was completed in the 20th era and in the future the forecasting error is practically unchanged.

A comparison of the error in predicting the visibility distance of road objects in the light of car headlights by various methods is presented in table 4.

Linear model for predicting the visibility distance (Table 4) has the form

$$S_V = -166.4264 + 0.4449 \cdot W + 87.202 \cdot K + \\ + 2.1607 \cdot F + 85.7719 \cdot BD. \quad (10)$$

Nonlinear model for predicting the visibility distance (Table 4) has the form

$$S_V = 62.7768 - 0.4504 \cdot W - 69.2353 \cdot K - 5.7786 \cdot F - \\ - 0.0002 \cdot W^2 - 36.7703 \cdot K^2 + 0.1491 \cdot F^2 - \\ - 25.6635 \cdot BD^2 + 0.3414 \cdot W \cdot K + 0.0088 \cdot W \cdot F + \\ + 0.5129 \cdot W \cdot BD + 1.6619 \cdot K \cdot F + \\ + 73.2922 \cdot K \cdot BD - 0.0001 \cdot F \cdot BD. \quad (11)$$

From table 4 it can be seen that an adaptive neuro-fuzzy system for identifying the visibility distance of road objects is the most accurate (the average forecast error is 1.31%, the maximum is 4.69%) and can be recommended for use in auto technical examination of road traffic accidents that occurred in night time.

Table 4 – Error predicting the distance of visibility of road objects by various methods

Parameter	Neuro-fuzzy model	Existing fuzzy model [6]	Linear model	Nonlinear model
RMSE	2.0079	3.1506	18.9018	4.0818
Average relative error	1.31%	4.16%	34.92%	23.76%
Maximum relative error	4.69%	10.4%	1014.41%	107.55%
Number of data pairs of training and test samples	700	78	700	700

Conclusions

1. Currently, vehicles use three main types of light sources: halogen, xenon and LED, with some cars with halogen sources accounting for 70-80%. This contributes to the presence of dazzling brilliance of headlights of oncoming cars at night, significantly reduces the visibility of the road and road objects (by almost 25%) and reduces the safe speed of vehicles on the roads of the general network.

2. An improved method allows to determine the distance of visibility in specific road conditions and significantly reduce the time spent by an automotive expert to interrogate the participants of the incident and witnesses, conduct an in-depth analysis of the situation and conduct a full-scale investigative experiment. Using the proposed approach minimizes the modeling error, narrows the range of possible expert decisions, and thereby increases the objectivity of decision making.

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