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INVESTIGATIONS ON THE DYNAMICS OF MOTOR VEHICLE DRIVING IN NIGHTTIME CONDITIONS

KRZYSZTOF STRYJEK[1], GRZEGORZ MOTRYCZ[2], BEATA ŚWIECZKO-ŻUREK[3], TOMASZ WRÓBEL[4]

[1] POLSAD
[2] Military Institute of Hygiene and Epidemiology
[3] Gdańsk University of Technology, Faculty of Mechanical Engineering
[4] Automotive Industry Institute (PIMOT)

Summary

The article describes investigations on vehicle driving in nighttime conditions. Apart from a comparison with the impact of conventional vehicles' road illumination systems on the test results obtained, the good points of new driver's aids such as thermal imaging cameras have been presented. The systems of this kind are increasingly often installed in advanced vehicles and they really improve the driving safety.

Keywords: night vision, vehicle, stress, dipped beam, safety

1. Introduction

The type, distribution, and intensity of the light emitted by motor vehicle headlamps have a critical impact on the driving safety [1, 2]. The motor vehicle and headlamp manufacturers have been developing their products for many years for the best visibility during nighttime drives to be achieved. The insufficient illumination has also an impact on driver's efficiency and stress related to vehicle driving, especially during a dynamic drive with a high speed. When driving on an inadequately illuminated road, the driver is not certain as regards the course of the road and the potential obstacles that can be present on it. The driver is forced to function under continuous stress, which adversely affects his/her

[1] POLSAD, ul. Holenderska 14, 99-300 Kutno, Poland; e-mail: krzysztof.stryjek@polsad.net.pl

[2] Wojskowy Instytut Higieny i Epidemiologii (Military Institute of Hygiene and Epidemiology), ul. Kozielska 4, 01-163 Warszawa, Poland; e-mail: gmotrycz@wihe.waw.pl

[3] Gdańsk University of Technology, Faculty of Mechanical Engineering, ul. Gabriela Narutowicza 11/12, 80-233 Gdańsk, Poland; e-mail: beazurek@pg.gda.pl

[4] Automotive Industry Institute, ul. Jagiellońska 55, 03-301 Warszawa, Poland; e-mail: t.wrobel@pimot.eu

concentration and causes additional tiredness. Such a situation especially takes place in the case of drivers of emergency service vehicles (fire-fighting vehicles, ambulances, etc.), who very often must intervene in nighttime conditions. The ensuring of adequate conditions of driving an emergency service vehicle is often critical not only for the time of arrival at the incident place but also for the safety of the crew when travelling to that place.

The authors would like not only to draw reader's attention to the potential risks arising from the vehicle driving in nighttime conditions but also to review the engineering solutions being now introduced as driving aids, such as thermal imaging and night vision systems. At present, this area of technology, previously reserved for military applications, increasingly often finds application in passenger cars.

The results of the tests carried out at various road illumination intensities and described herein may also be utilized for the training of emergency service vehicles drivers, who have to move with high speeds in nighttime conditions. The measurements were made with the use of GPS-based measuring techniques, with a gyroscopic module and acceleration sensors incorporated in the basic test apparatus, thanks to which the vehicle dynamics could be fully analysed and the impact of specific environmental conditions on driver's behaviour could be defined.

2. Object of the tests

The tests were carried out on a Renault Clio 2.0 16v passenger car with F4R 730 engine of 1 998 cm^3 capacity and 169 hp (metric) maximum power output. The maximum output torque of 200 Nm was attained at an engine speed of 5 400 rpm.

The vehicle was provided with standard main-beam and dipped-beam headlamps and a special structure for the mounting of four additional main-beam headlamps with 100 W bulbs each on it (Fig. 1). Such a solution is exclusively allowed for use at sports events (motorcar rallies), but the additional lighting is often used in special vehicles as well, e.g. in fire-fighting vehicles

a) sports headlamps b) standard (mass-produced) headlamps

Fig. 1. Number of lights (by: Krzysztof Stryjek)

2.1. Testing of the dynamics of vehicle driving

To determine the impact of the illumination intensity on the dynamics and efficiency of vehicle driving, pilot tests were first carried out with the test runs being done on a predefined road section with different types of the vehicle's road illumination system. The driver had to travel the predefined road section (about 1 500 m long) within as short a time as possible, depending on the visibility at a specific road illumination type. The tests were performed on a road closed for the normal traffic. Approximate values of the speed with which the vehicle, provided with sports headlamps in this case, was driven on the test road section have been presented in Fig. 2.

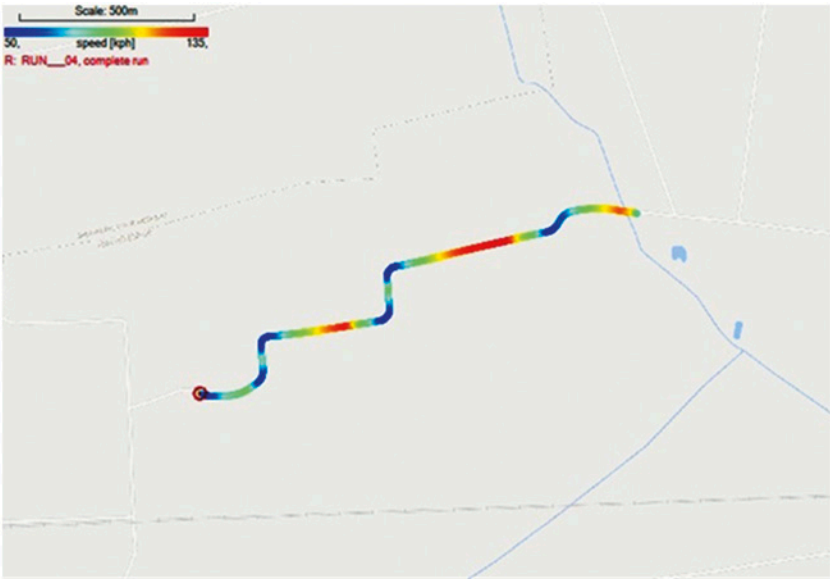

Fig. 2. Example test run on the test road section, with the drive speeds having been shown (by: Krzysztof Stryjek)

The measurements were carried out with the use of a measuring apparatus based on the global positioning system (GPS) and manufactured by Race-Technology LTD, presented in Fig. 3. This device was additionally provided with a gyroscopic module and acceleration sensors. The dedicated software made it possible to carry out a subsequent in-depth analysis of the data recorded.

Fig. 3. GPS unit made by Race-Technology LTD installed in the vehicle (by: Krzysztof Stryjek)

For the differences in the road illumination in individual cases to be quantitatively determined, the intensity of the illumination on the road ahead of the vehicle was measured. The measurements were carried out at a height of about 80 cm above ground, with keeping the measuring head aligned with vehicle's longitudinal centreline. The measurement results have been given in Table 1.

Table 1. Comparison of the intensity of illumination ahead of the vehicle

Distance from the vehicle [m]	Dipped beam [lx]	Main beam [lx]	Sports headlamps [lx]
10	50	660	1 750
25	25	115	421
50	4	35	108
100	–	2	37

3. Analysis of the test results

When analysing the measurement results given in Table 1, one can notice that the values of the intensity of the light emitted by headlamps of individual types fundamentally differ from each other. The main-beam (also referred to as "driving-beam" or "upper-beam") headlamps provide road illumination to a distance about twice as long as that comparably illuminated by the dipped-beam (also referred to as "passing-beam", "meeting-beam", or "lower-beam") headlamps. The sports headlamps additionally make it possible to double the length of the illuminated road section as against the main-beam headlamps. The visual

Fig. 4. Comparison between the road illumination by dipped-beam and main-beam headlamps (by: Krzysztof Stryjek)

Fig. 5. Comparison between the ranges of road illumination. From the top: sports headlamps, main-beam headlamps, dipped-beam headlamps (by: Krzysztof Stryjek)

differences in the road illumination have been presented in Fig. 4. Fig. 5 shows a comparison between the ranges of road illumination by lights of individual types, from sports through main-beam to dipped-beam headlamps, with the illuminated road section having been shown as viewed from the side.

During the test drives, the vehicle speed and acceleration were measured. Example measurement results, obtained for the test drives with standard main-beam and sports headlamps being on, have been presented in Fig. 6.

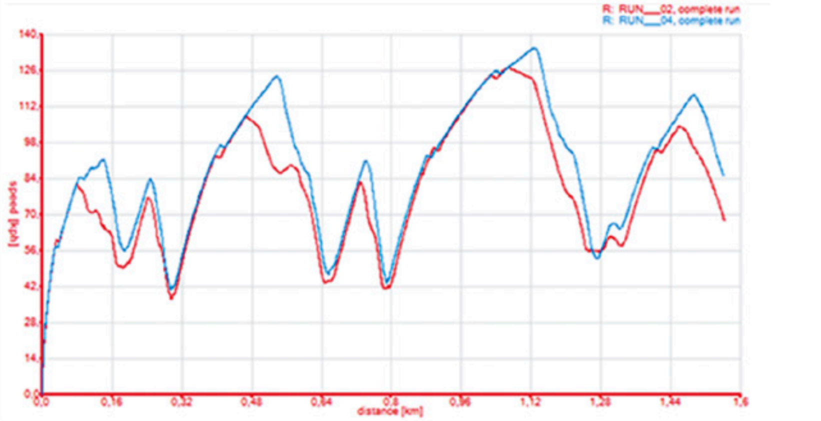

Fig. 6. Curves representing the vehicle speed vs. distance travelled, recorded during test drives: blue curve – test drive with sports headlamps on; red curve – test drive with main-beam headlamps on (by: Krzysztof Stryjek)

It can be noticed that the additional illumination of the road enables the driver to make better assessment of the driving safety and to utilize wider ranges of vehicle speed. In Fig. 6, characteristic areas can be seen, e.g. between 480 m and 640 m of the test road section, where the driver was capable to move with higher speeds. In the worse road illumination conditions, the driver markedly reduced the vehicle speed and had problems with choosing the optimum points to apply brakes: in most cases, he/she applied brakes too early and with varying brake pedal effort.

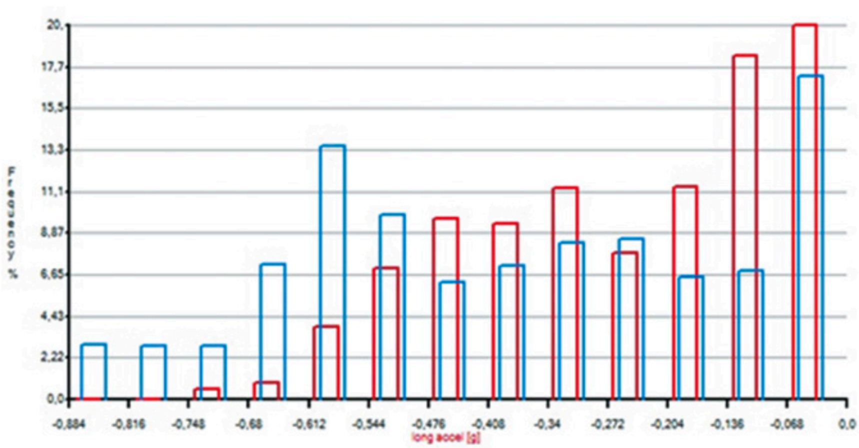

Fig. 7. Statistics of vehicle decelerations recorded during test drives: blue curve – test drive with sports headlamps on; red curve – test drive with main-beam headlamps on (by: Krzysztof Stryjek)

According to the principles the sports vehicle drivers are taught when being trained, the driver, when applying brakes, should attain a full and uniform deceleration of about 8-11 m/s^2 for dry asphalt road surfaces. When analysing the statistics shown in Fig. 7 as pertaining to the test drives at limited lighting, an observation can be made that for a significant part of the braking time, the driver used brakes in an unrepeatable way. This was caused by reduced visibility, due to which the driver could not properly identify the optimum points where the brakes should be applied. Hence, the vehicle moved with lower dynamics and the driver reduced vehicle speed, waiting for the instant of noticing a change in the course of the road (e.g. a bend). The graph also shows that when the vehicle was driven with merely the main-beam headlamps on, not only the driver applied brakes too early before the approached bends but also the vehicle deceleration was too low in comparison with that attainable at the actual tyre-road adhesion and in the actual traffic situation if realistically assessed, e.g. in normal (daylight) conditions.

The statistics of applying vehicle brakes with specific intensities, as presented in Fig. 7, are used at the assessment of individual sports driver's way of driving. A properly reacting driver should always brake in a way that would make it possible to generate a uniform maximum deceleration. The bigger the proportion of intermediate deceleration values in the deceleration graph, the lower degree of driver's confidence in his/her way of vehicle driving. The measurements carried out may also be considered in relation to the driving of emergency service vehicles in nighttime conditions. The lack of adequate road illumination will result not only in lower dynamics of driving but also in a growing hazard to the crew due to imprecise and unrepeatable driver's behaviours.

4. Nighttime driving assistance systems

A nighttime driving assistance system was first presented in 2000 in the Cadillac DeVille model. At present, night vision systems to assist vehicle driving in difficult conditions are provided as standard in premium-class passenger cars. Such vehicles are equipped with additional thermal imaging cameras and additional software to analyse the image obtained. The system of this type not only offers the driver a possibility of viewing the image produced by a night vision camera but also recognizes potentially dangerous situations, e.g. having noticed a human silhouette it warns the driver by displaying additional graphic warning symbols (Fig. 9).

The principle of operation of the night vision system is based on the use of a thermal imaging camera for the monitoring of the space ahead of the vehicle and displaying the silhouettes of pedestrians or animals on the display of the instrument cluster or directly on the windscreen. Depending on the mode of operation, the night vision system may be either:
- active, or
- passive.

The active system employs an infrared radiation source placed on the vehicle front (usually in the bumper or the radiator grille) to illuminate the road ahead of the vehicle and to capture the reflected radiation. Actually, separate infrared projectors are used for this purpose, which illuminate the road ahead of the vehicle to a distance of 150 m. The emitted radiation is reflected from the objects detected, thanks to which thermal contrast is generated between the objects and the background radiation registered by the infrared camera.

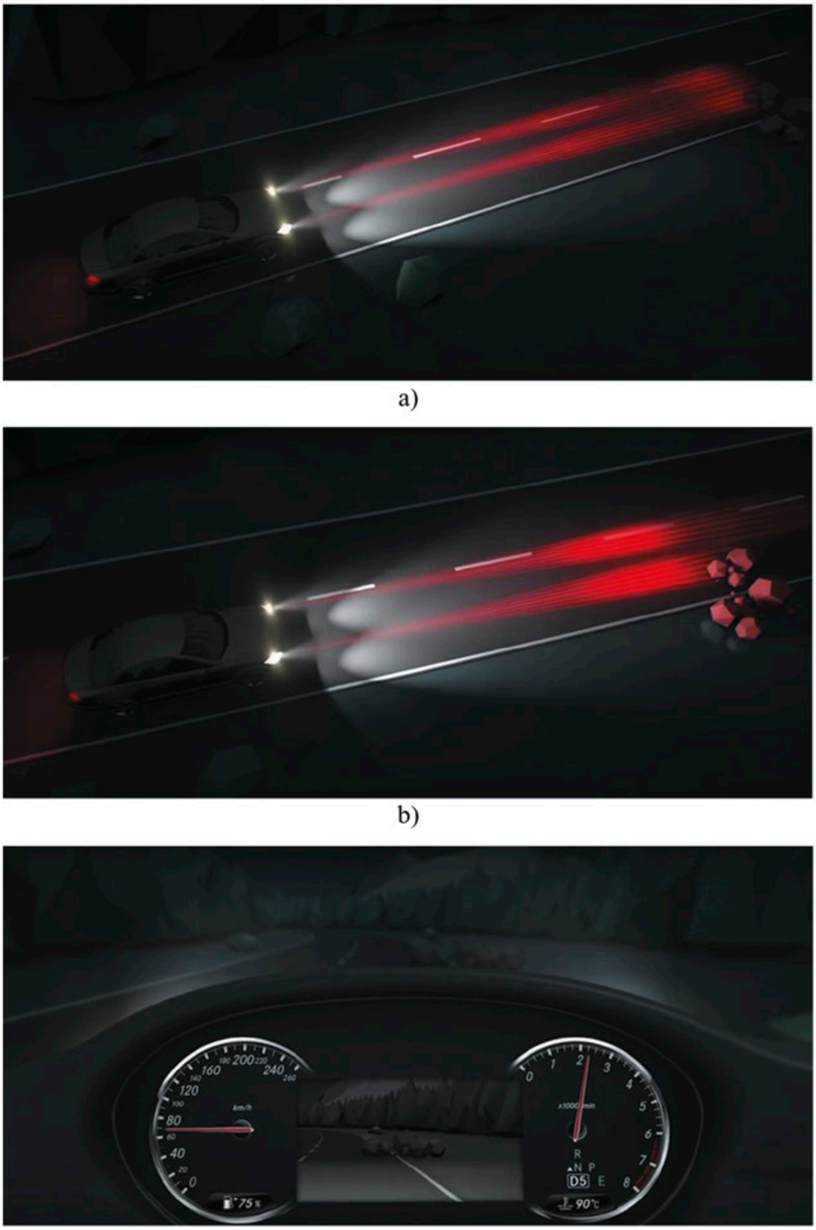

Fig. 8. Schematic presentation of the functioning of the active system (night view / night vision system; source: Mercedes Benz)

In the passive system, a thermal imaging (infrared) camera detects the thermal radiation emitted by physical objects (a human, animal) in the range of the temperatures that can be encountered in the vehicle driving conditions.

Fig. 9. Example of signalling the recognition of animals and humans by night vision systems in BMW vehicles (source: www.bmw.pl)

Each of the systems presented has both good and bad points.

The active system

Good points: higher resolution of the image; better image of inanimate objects; better functioning in warmer weather conditions; smaller sensor capable of being incorporated in the rear-view mirror unit.

Bad points: the system does not work in rainy and foggy conditions; lower contrast of the image in the case of animals; shorter visibility range (150-200 m).

The passive system

Good points: longer visibility range (about 300 m); higher contrast of the image in the case of animate objects.

Bad points: lower resolution of the image; worse functioning in warmer weather conditions; bigger dimensions of the sensor.

The related tests were carried out with the use of a BMW X5 vehicle provided with the Night Vision system [7]. In the BMW Night Vision system, the thermal imaging camera detects humans and animals present ahead of the vehicle much before they become visible for the human eye in the light of vehicle headlamps. The image detected is sent by the system to the central monitor in the vehicle. The image registered by the thermal imaging camera covers a belt extending to a width of several ten meters to the vehicle sides and to a distance of several hundred meters ahead of the vehicle. The BMW Night Vision system offers the driver special advantages during drives on dark and insufficiently illuminated roads.

Fig. 10. Arrangement of the infrared camera in the vehicle (by: Grzegorz Motrycz)

The system is automatically activated at every engine start after the nightfall; it may also be activated manually on the central monitor. The warning area of the humans recognition system consists of two zones:

- central zone (covering the area just in front of the vehicle);
- extended zone (covering the area on the right and left side of the vehicle).

In the case of animal recognition, the system does not differentiate one of these two zones from the other. The range and dimensions of the zones are fitted to the vehicle driving style. Thanks to the cameras placed in the front vehicle part, the system makes it possible to detect and indicate the presence of a pedestrian or animal close to the road. The system operates in two stages. Initially, a mark representing the silhouette of the object detected appears on the monitor screen. This takes place as early as at a distance of several hundred meters from the possible pedestrian. Although the lack of clear-cut contours makes it impossible for the driver to identify the silhouette as a pedestrian or animal, but the driver is preliminarily warned about a possible hazard. At the second stage, the system automatically recognizes the silhouette and a message with a warning sign is displayed on the monitor (Fig. 11).

Fig. 11. View of recognized pedestrians displayed by the BMW Night Vision system (source: BMW Poland)

5. Tests in nighttime conditions

The system functioning was verified on a non-trafficked road in the conditions of full darkening (Figs. 12 and 13). The test road section was so selected that adequate safety was ensured for the test crew and possible outsiders.

Fig. 12. Preparation of the vehicle for testing the night vision system; illustration of the test conditions (test vehicle lent by BMW Poland)

Fig. 13. Situation of the experiment site (source: https://www.google.pl/maps)

The vehicle was provided with a GPS system, which recorded the parameters related to the vehicle dynamics (vehicle speed, acceleration, location on the road). When a pedestrian was noticed by the driver, the latter recorded this fact by depressing a marker. For this task to be more difficult for the driver, the pedestrian wore dark clothes with no reflective elements, as presented in Fig. 14. The tests were carried out within the territory of Poland, during one of autumn nights, at a moonlight illumination of about 1-5 lx.

Fig. 14. The type of pedestrian's clothes used during the tests

It should be remembered that the driver's eye receives the light signal reflected from the obstacle rather than that incident on it. According to the literature, the necessary minimum height of the illuminated area of a non-contrast obstacle may be said to be about 0.25 m. This is determined by the distribution of the intensity of illumination depending on the height above the road surface (Fig. 15 and 16).

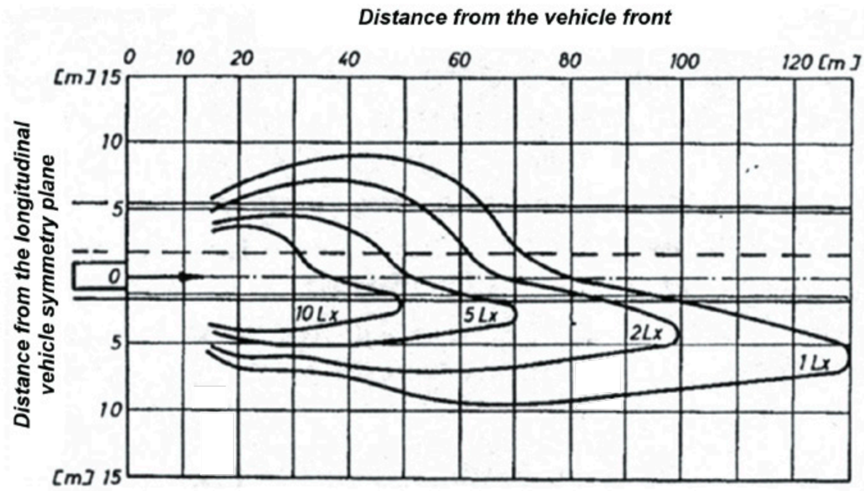

Fig. 15. Intensity of the road surface illumination by autonomic headlamps of the vehicle [5]

Thus, the obstacle in the nighttime driving conditions will become noticeable when it comes within the reach of the dipped beam, which would illuminate it to a height of not less than about 0.25 m above the road surface.

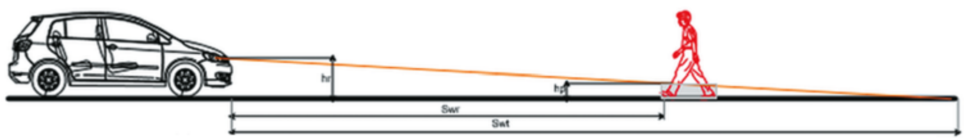

Fig. 16. Intensity of the illumination of an obstacle at different heights above the road surface

For the dipped beam to illuminate an obstacle part with a height of h_p [m], the obstacle should be within a distance of s_{wr} from the vehicle front. At the average height of the headlamp axis above the road surface level [1], this distance is

$$s_{wr} = s_{wt} \cdot \frac{h_r - h_p}{h_r} \; [m] \tag{1}$$

where:

h_r – height of the headlamp axis above the road surface level;

h_p – minimum height of the illuminated area of the obstacle;

s_{wt} – distance between the vehicle front and the obstacle at the instant when the obstacle is reached by the 10 lx illumination field boundary line.

The distance ahead of the vehicle, available to the driver for the carrying out of a defensive manoeuvre, is

$$s_s = s_{wr} \cdot \frac{v_s}{v_s \pm v_{pr}} \quad [m] \tag{2}$$

where v_s is the vehicle speed and v_{pr} is the obstacle speed component parallel to the vehicle speed; for the obstacle moving towards the vehicle, there should be "plus" in the denominator of equation (2). If the obstacle moves away from the vehicle, the sign "plus" should be replaced with "minus".

When the obstacle moves in a direction perpendicular to the direction of vehicle motion, v_{pr} = 0; hence

$$s_s = s_{wr} \tag{3}$$

The measurements were carried out when the pedestrian moved along the road shoulder, both towards the oncoming vehicle and in the opposite direction. During the tests, the vehicle moved with a speed of 80 km/h. The test results have been presented in Table 2.

Table 2. Detection of the pedestrian by the vehicle system

Item	Distance between the vehicle and the pedestrian when detected [m]	Direction of pedestrian's motion relative to that of vehicle's motion
1	254	Opposite (towards the vehicle)
2	302	The same (away from the vehicle)
3	321	Opposite (towards the vehicle)
4	220	The same (away from the vehicle)
5	280	Opposite (towards the vehicle)
6	315	The same (away from the vehicle)
7	269	Opposite (towards the vehicle)
8	310	The same (away from the vehicle)
9	277	Opposite (towards the vehicle)
10	287	The same (away from the vehicle)

The results of the tests carried out in real conditions confirmed the technical data claimed by the manufacturers. The detection of a pedestrian by the thermal imaging system took place when the distance to the pedestrian was as long as about 300 m. An additional good point of the system was the fact that the system effectiveness was not affected by the type of pedestrian's clothes (e.g. absence of reflective elements). The system capability of effectively detecting a pedestrian appearing at a distance of several hundred meters offers the driver adequate time for a reaction, even if the vehicle is driven with high speeds. For a comparable pedestrian recognition to be obtained with the use of conventional lighting systems, very high power capacity of the light sources would be required, which would result in a risk of frequent dazzling of other road users as well.

6. Conclusions

The impact of the road illumination conditions on the safety of vehicle driving is extensively described in the literature. The authors of this article looked at this issue in a somewhat different way and carried out pilot investigations on the impact of road illumination on the dynamics of vehicle driving in nighttime conditions. According to the findings from the investigations, the road illumination has a critical impact not only on the dynamics but also on the accuracy and precision of vehicle driving, which directly translates into the driving safety. The pilot tests and their results may be helpful in particular for the drivers of civilian emergency service vehicles, such as ambulances or fire-fighting vehicles, who very often fulfil their tasks in nighttime conditions as well.

The preliminary results of testing the passenger cars' thermal imaging systems in real conditions confirmed the technical data claimed by the manufacturers. The detection of a pedestrian by the thermal imaging system took place when the distance to the pedestrian was as long as several hundred meters, regardless of the type of pedestrian's clothes. Thus, the system offers the driver adequate time for a reaction, even if the vehicle is driven with high speeds, which means a real significant improvement in the safety of driving in nighttime conditions.

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http://archiwummotoryzacji.pl

References

[1] Lewandowski P, FOKT K. Wpływ niesprawności świateł mijania pojazdu na rozkład plamy świetlnej na przykładzie samochodu osobowego marki Skoda Fabia (The impact of deficiency of dipped headlights on the distribution of light in Skoda Fabia). Problemy Kryminalistyki No. 282/2013.

[2] Błaszczyk J. Wpływ całodobowego oświetlenia pojazdów na bezpieczeństwo ruchu drogowego (The impact of 24-hour use of vehicle lights on the road safety). Zeszyty Naukowe Wyższej Szkoły Zarządzania Ochroną Pracy w Katowicach. 2010; 1(6).

[3] Chun-Che W, Shih-Shinh H, Li-Chen F, Pei-Yung H. Driver assistance system for lane detection and vehicle recognition with night vision. Conference paper, September 2005.

[4] http://autokult.pl/25854,systemy-bezpieczenstwa-i-wspomagania-jazdy-kiedy-i-jak-dzialaj-oraz-czy-warto-im-zaufac

[5] Opis i rekonstrukcja wypadków drogowych (Description and reconstruction of road accidents). Educational materials for participants in the post-graduate course "Diagnostics, Mechatronics, and Automotive Expertise; Insurance", Warszawa 2006.

[6] Aleksandrowicz P. Problemy widoczności nieoświetlonych przeszkód w ruchu drogowym. Część 1 (Problems of the visibility of unlit obstacles to the road traffic. Part 1). Logistyka. 2015; 3.

[7] BMW Company's materials: Documentation of the vehicle used for the tests.