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Dariusz LITWIN*, Adam CZYŻEWSKI, Jacek GALAS, Tadeusz KRYSZCZYŃSKI, Piotr WIKLIŃSKI
Łukasiewicz Research Network - Tele and Radio Research Institute
Ratuszowa 11, 03-450 Warsaw, Poland
Barbara RYMSZA, Leszek KORNALEWSKI
Road and Bridge Research Institute
Instytutowa 1, 03-302 Warsaw, Poland
**Corresponding author*. E-mail: dariusz.litwin@itr.lukasiewicz.gov.pl

SMART PHOTONIC GUIDANCE SYSTEM FOR ROAD SAFETY

Summary. Despite the rapid and continuous progress in the construction of vehicles and accompanying improving road infrastructure, the road safety issue remains very serious. Especially, it concerns intersections and road junctions where nearly 30% of road accidents take place. The paper is focused on a new intelligent path displaying support system to be installed on intersections of complex geometry combined with multiphase traffic lights. It consists of optical projection of two different horizontal signs, i.e. strips designating lanes for the green-light directions and perpendicular blocking lines for the red-light directions.

1. INTRODUCTION

For road safety, the human factor is crucial. The nature of human beings (despite good will and experience) is such that people are always inclined to make mistakes. In some circumstances, even small mistakes may lead to fatal consequences. Inevitably, it also concerns road users. Interestingly, almost half of the road accidents (according to the road police database) take place at straight parts of the roads, where the number of necessary maneuvers to be performed by the driver is the smallest. The phenomenon can be explained by psychological factors or a poor vehicle's technical condition. On the contrary, these segments of roads are the longest, which has an obvious effect on statistics.

Psychological studies reveal that people in a hurry are inclined to take unjustified risk in many areas of transport, which concerns pilots and motorists [1]. The decisions made by them can be either conscious or subconscious. Nowadays, psychologists are inclined to the opinion that there is a single mechanism at both conscious and subconscious levels, which is in contrast to Freud who though that subconsciousness had its own and independent nature [2]. It means that regardless of whether the driver is conscious of the aim or not, the way he or she tries to achieve it remains similar. Therefore, it is possible to observe in the motorist unconscious behavior.

The "chameleon effect" is an unconscious behavior [3]. The phenomenon consists in looking alike the environment - in this context to behave like other drivers. The herd instinct is very useful in some situations, however may be dangerous on the road. Being constantly overtaken by several speeding cars, it is much easier to exceed the speed limit. Another undesired element is strong desire to "reach the base", i.e., place of destination. The closer to the trip end, the driver has stronger feeling to be there. In such a situation, the motorist subconsciously increases speed and is more likely to maneuver in an unsafe way. Especially, the most dangerous, in this context, are overtaking in inadequate visibility conditions and "in and out of traffic" driving including overtaking into oncoming traffic, which results in forcing cars off the road.

Another collection of issues includes some physiological reasons. Motorists often perform small but eventually dangerous mistakes like activating the left direction indicator and then turning right. If the driver is tired and/or has not slept well for long enough, his/her brain may partly go to sleep [4]. It is not classified as falling asleep at the wheel. In this case, a group of neurons that have been used too extensively or too frequently “disconnect” for a short time and are inactive while the body as a whole is theoretically conscious of events on the road [4, 5]. Unfortunately, the driver is not aware of this state and is more likely to perform unexpected mistakes. The phenomenon is called “the local sleep” [6, 7]. Therefore, the limited trust rule should be then applied not only to other road users but first of all to ourselves. The importance of sleep has been discussed by many teams, leading to the recommendations that proper sleep should decrease the risk of accidents [8-12]. Especially in the case of professional drivers, acute and chronic insufficient sleep can be monitored by biomarkers [13]. Then, the sleep debt status can be evaluated more objectively to modify driving schedule simultaneously decreasing the threat of the local sleep effect.

Despite using the biomarkers, it is crucial to develop technology capably to prevent or at least decrease the threat of accidents. The influence of a collection of different factors like weather conditions, perception performance of motorists, and in particular, traffic organization on road safety is investigated at several research centers [14-16].

According to the road police database, intersections and road junctions appear to be particularly dangerous places where nearly 30% of road accidents take place. Except external factors, other issues like individual skill, experience, and the aforementioned physiological aspects affect motorists' behavior. In such places, it happens that a car crosses an intersection after the motorist is misled by the neighboring green light activated for the left-hand turn. In our survey, which included experienced drivers (10-40 years of driving), 62% of the responders admitted such event. A good and the simplest solution here would be a temporal increase of the red light intensity (a blink), so that the driver's attention could be kept on his or her direction instead of neighboring lanes. Another potential reason for entering an intersection at the red light is when a car column slowly moves through an intersection (a traffic jam). In such conditions, drivers incline to focus on the preceding vehicle and can easily miss the change of the traffic light. This is difficult to confirm by a survey as the motorists perform the action subconsciously, and frequently, the mistake remains unnoticed, though some of our responders have mentioned the issue.

Correctly chosen traffic path (especially in the case of left-hand or right-hand turns) may contribute to safe crossing of an intersection, increasing smoothness of traffic, and consequently the intersection capacity. Difficulties in recognizing the intersection geometry occur mostly from sunset to dawn (which partly comes from the eye physiology), during bad weather conditions like heavy rain, snow, fog, mist, and especially when the road surface is covered by snow or slush. Our survey showed that 83% of the responders confirmed being confused on complex intersections. Therefore, it is extremely important to avoid unintuitive solutions and instead create simple and standardized crossings easy to follow. Where necessary, the motorists should be supported by advanced technology including smart illumination. The solution described in this paper has been developed to support motorists (and simultaneously protect pedestrians) on complex geometry intersections equipped with multiphase traffic lights.

2. SYSTEM DESCRIPTION

Thanks to the observation of the geometry of a collection of intersections, literature research [17], and regulations [18-20], the authors have proposed and implemented an intelligent, auxiliary horizontal sign system called the SPIKer. The system helps motorists in finding the proper, safest, and most effective path through the intersection. The system can also be used when the traffic is temporarily reoriented because of accidents or construction works.

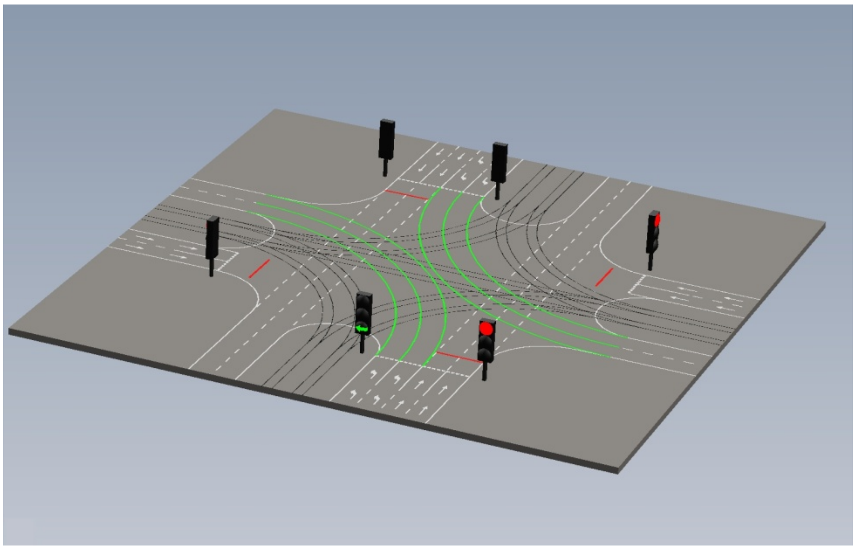

Fig. 1. The idea of the SPIKer system

The idea of the SPIKer system is presented in Fig. 1. The LED lamps that emit green, yellow or red light are crucial elements of the system. The lamps are placed above the intersection and have the ability to project in the precisely designed places lines and/or spots of the width/diameter equals to 10÷15 cm. The color of the emitted light is correlated with the standard traffic signals already installed at the intersection. The idea consists in optical projecting of two different horizontal signs, i.e., for the green light directions: strips designating lanes, and for red light directions: perpendicular blocking lines.

A red strip or a collection of aligned dots are projected perpendicularly to the incoming vehicles for the red light direction, which constitutes the explicit and suggestive signal not to enter the intersection. Potential crossing the red line, which in this case can be interpreted simultaneously literally and figuratively, is a strong psychological barrier, stronger than a standard traffic light. The latter can be easily misinterpreted as part of advertisement installation, which often utilizes LEDs of high luminance and unfortunately similar color or can be just ignored because of one of the previously outlined reasons.

For example, green dots designate the path for vehicles turning left when, and only when, for this direction the traffic light is green. It is assumed that the path will be displayed through the entire intersection. The motorist performing the turn will be sure all the time that he or she is driving correctly and safely and that the traffic light is green. Such a configuration combined with perpendicular red barriers prevents from misinterpretation of lights and increases the safety level of passing the intersection.

The color dots are projected by individually adjusted small projectors. The optical system of each of them is achromatic and is designed to work with LEDs emitting different wavelengths. It includes two lenses, parameters of which have been optimized by using ZEMAX platform as well as the Institute of Applied Optics-INOS original software utilities (INOS has joined the Tele and Radio Research Institute-ITR on 1st of November, 2019 as a part of the restructuring process of the Łukasiewicz Research Network, the ITR has been a member of which). The schematic view of a single projector with the optical setup is presented in Fig. 2. In addition, the individual projectors have been outfitted with the zoom feature. Thanks to the function, the dot diameter can be flexibly adjusted regardless of the projector position with respect to the road surface.

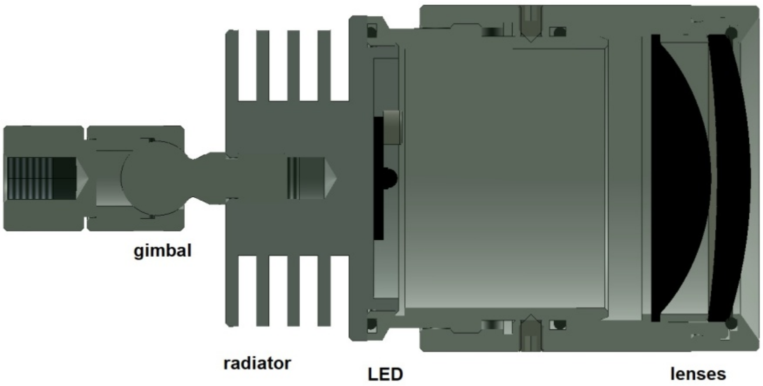

Fig. 2. The schematic view of a single projector with the optical setup

The system of projected lines has the ability to change the line curvature. Therefore, the color line can match any shape of the lane. The curvature can be modified by dedicated software that controls configuration of the optical elements of the system. Being mounted on a ball joint, each projector can be individually angularly adjusted, so that its light beam can precisely image a spot of light in the desired place on the road. One of the expected benefits of the proposed system will be its resistance to weather conditions. Displayed lines will be clearly visible on snow. In the case of frosted surfaces, small ice crystals will scatter the light, visualizing the lines. To increase visibility on dark surfaces, the light spots are correlated with the classical horizontal lines placed on the road surface. In this case, the markings may also be coated with a special suspension of artificial microcrystals producing a similar effect as frost. The advantage of the system is that there is no need to build in any structure into the road surface. Our system can be mounted quickly without interfering in the road traffic. In addition, the solution is recommended to the areas where snowfall is considerable and frequent. A snow layer may cover the optical systems placed within the road surface and prevent the emitted light from being seen.

The system based on displaying color spots appears to be simpler and more practical, especially in designing the configuration of projectors so that the dot pattern can perfectly fit the intersection geometry. The light can be very effectively focused, so that the light spot can be well seen during daylight when the sunlight is not too strong. The lamp equipped with the set of single projectors is presented in Fig. 3.

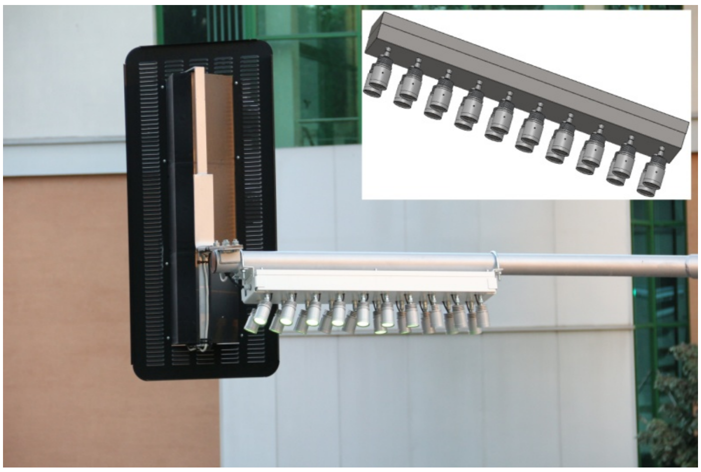

Fig. 3. The lamp equipped with the set of single projectors mounted over the intersection

Another optical system has been designed for displaying straight lines (a simplified arch projector) blocking entrance to the intersection for incoming cars seeing the red light. Properly deployed lamps will not cause undesired situations when the driver is exposed to glare. Potentially, it is possible that a truck or coach may overshadow the light path. In such a case, the truck that shadows the path becomes a reference vehicle the other motorist can follow. The illuminating systems used in our experiments have been designed to utilize LEDs. However, we also tried to apply lasers including commercially available laser torches. Nevertheless, for safety measures, high costs, and limited lifetime, we decided to resign from using them.

The SPIKer system has been successfully validated as a real-scale model constructed over the intersection within the area of the Road and Bridges Research Institute, Warsaw, Poland. The construction included a collection of projectors generating green and red dotes aligned to designate turns and blocking lines, respectively. In addition, we have mounted alternative system for projecting continuous red lines. The systems have been controlled by means of standard traffic light electronic units. The lamps of the SPIKer system have been tested against their resistance to harsh weather conditions. The individual projectors and the lamps, as a whole, have been subjected successively to the water-penetration resistance test. The components have been also imaged by a thermal camera, which allows us to check the temperature pattern and its dependence in time. The investigations concerned mainly the projectors as their power consumption is meaningful due to their large number.

To check the temperature pattern and its dependence in time, the lamp has been imaged by a thermal camera. The study revealed that the electronic components worked properly, and any “hot spots” have not been discovered.

The SPIKer system has been also tested against its effectiveness taking into account the parameters of the road surface and weather conditions. The light dots have been projected on different surfaces like asphalt, concrete and paver partly with presence of standard horizontal road markings. In all these cases, the visibility was similar and satisfactory according to the later described survey. The tests have been conducted in daylight and at night. The example of the system operation at night is presented in Fig. 4. The readability of SPIKer system has been checked from two points of view: a motorist seated in a passenger car and pedestrian. At night, the headlights of a car were on and SPIKer’s lanes were clearly visible so that the motorist could safely follow them. The closing tests of SPIKer have been performed in simulated differentiated weather conditions including rain (wet road surface), snow (road surface has been covered by white powder), and fog (generated by two steam machines). The results are presented in Fig. 5 and 6. Interestingly, the SPIKer system excellently worked in haze in contrast to the horizontal signs that almost disappeared.

Fig. 4. The night view of intersection equipped with the SPIKer system

Fig. 5. The visibility of the SPIKer system in a fog

Fig. 6. The visibility of the SPIKer system dotes on the wet road

3. DISCUSSION

The aforementioned solution consisting in projecting lanes belongs to the class of experimental marking. In other words, elements of such system do not appear in any traffic regulation books. In this case, perception and understanding of the marking by road users depend on several factors from graphics (symbol shapes, and colors) to external impulses and human behavior in particular situations [21]. Human perception depends on focusing, memory, and experience. As experimental marking is not widely applied (some drivers may never encounter it during all their careers), the memory and experience of drivers do not reach the desired level. Experimental marking should be designed in such a way that the motorist who sees it for the first time would know intuitively how to react. Therefore, in many countries, special collection of procedures concerning the perception of such signs including eye-trackers and road simulators has been implemented. The prototype installation has allowed us to perform a survey among motorists for readability and perception of the information displayed by the SPIKer. The survey included six questions concerning the SPIKer functionality, readability of the displayed lines and dots, and their influence on safety level on the intersection. The respondents agreed that the SPIKer was functioning well and is perceived as a clear guidance aid at the intersections of complex geometry. They pointed out that the system as a whole should well contribute to the road safety and is a good support for the classical traffic lights (86% and 76% were in favor of green paths and red bars, respectively). The difference in visibility between signs in the form of lines and dots was also evaluated. The responders preferred dotted path to lines - 83% and 76%, respectively. They did not mention any issue with the illumination system itself, as it produces mild LED light in the direction almost parallel to the surfaces of the car mirrors, and therefore, potential residual reflections do not affect the motorist's sight. Thanks to the displayed perpendicular red bars, the system tells the drivers not to enter the intersection at the red light. The road operators and operation-maintenance companies that took part in the project indicate that the most important advantage of the system is that it can be installed without any road surface modifications, and in addition, it remains effective independently from any winter road maintenance works.

4. CONCLUSION

The SPIKer system constitutes a successful solution in the area of road safety. It has been validated as a real-scale model constructed over an intersection at the premises of the Road and Bridges Research Institute, Warsaw, Poland. Using the prototype installation, a survey for readability and perception of the information displayed by the SPIKer has been carried out among motorists. The majority of them responded in favor of the system, clearly indicating that it is a readable road facility that effectively helps motorists to choose the right path through any intersection despite its complex geometry. The responders suggested that the system may indicate an entrance to ferry, toll collection points at motorways, or show an emergency bypass in case of an accident or construction works. In these cases, the green lines would guide the motorist through the right lanes, increasing their sense of safety and comfort of driving. On the contrary, the red light barriers may prevent the motorists from entering intersections or railway crossings or other crucial lines in the traffic system. The relatively high probability of passing through the intersection when the light is red is because (among other factors) the traffic lights [22] can be placed above the intersection or/and at the side of the road and large vehicles can also obstruct them. The accompanied well-known phantom effect during a sunny day deteriorates the situation. The popular use of cell phones, including text messaging, decreases fragile conscious attention, especially when it is affected by the aforementioned local sleep phenomenon. Therefore, the suggestive red light barrier becomes, in this context, a valuable element of the road safety.

From the technological point of view, the road maintenance companies underline that no road surface modifications are required and the system is not sensitive to winter road maintenance works. Thanks to the tests performed in different weather conditions like simulated fog and rain (Figures 5, 6) on different surfaces (asphalt, concrete, and paver including projection on existing horizontal signs), it can be confirmed that the SPIKer is ready to be implemented on public roads for further evaluation.

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The second project, "Experimental road signs in context of the road user behavior" (RID-I/36/5/NCBR/2016), was funded jointly by NCBiR and General Directorate for National Roads and Motorways – GDDKiA.

References

1. Beaty, D. *The Naked Pilot*. Airlife Publishing. The Crowood Press Ltd, 1995.
2. Bargh, J.A. & et al. Automaticity in Social-Cognitive Processes. *Trends in Cognitive Sciences.* Vol. 16. No. 12. 2012. P. 593-605.
3. Chartrand, T.L. & Bargh, J.A. The chameleon effect: the perception-behavior link and social interaction. *J Pers Soc Psychol.* 1999. Vol. 76(6). P. 893-910.
4. Cirelli, C. & Tononi, G. Is Sleep Essential? *PLOS Biology*. 2008. Vol. 6(8). P. 1605-1611.
5. Diekelmann, S. & Born, J. The Memory Function of Sleep. *Nature Reviews Neuroscience.* 2010. Vol. 11(2). P. 114-126.
6. Vyazovskiy, V.V. & Olcese, U. & Hanlon, E.C. & Nir, Y. & Cirelli, C. & Tononi, G. & et al. Local Sleep in Awake Rats. *Nature*. 2011. Vol. 472. P. 443-447.
7. Quercia, A. & Zappasodi, F. & Committeri, G. & Ferrara, M. Local use-dependent sleep in wakefulness links performance errors to learning. *Frontiers in Human Neuroscience*. 2018. Vol. 12. No. 122. P. 1-17.
8. Maycock, G. Sleepiness and driving: the experience of UK car drivers. *J. Accident Analysis & Prevention*. 1997. Vol. 29(4). P. 453-462. DOI: http://dx.doi.org/10.1111/j.1365-2869.1996.00229.x.
9. Watson, N.F. & et al. Recommended amount of sleep for a healthy adult: a joint consensus statement of the American Academy of Sleep Medicine and Sleep Research Society. *J Clin Sleep Med*. 2015. Vol. 11(6). P. 591-592.

10. Duan, Z. & Xu, J. & Ru, H. & Li, M. Classification of driving fatigue in high-altitude areas. *Sustainability*. 2019. Vol. 11. No. 817. P. 1-10. DOI: https://doi.org/10.3390/su11030817.
11. Lal, S.K. & Craig, A. A critical review of the psychophysiology of driver fatigue. *J. Biological Psychology.* 2001. Vol. 214. No. 55(3). P. 173-194.
12. Dawson, D. Fatigue research in 2011: from the bench to practice. *Accid Anal Prev* 45(Suppl):1-5. 2012. Vol. 212. DOI: http://dx.doi.org/10.1016/j.aap.2011.09.016 213.
13. Laing, E.E. & et al. Identifying and validating blood mRNA biomarkers for acute and chronic insufficient sleep in humans: a machine learning approach. *SLEEP J.* 2019. P. 1-18.
14. Cafiso, S. & D'agostino, C. & Kieć, M. & Pappalardo, G. Surrogate measure of safety from road inspection data - experimental test on Polish roads. *Roads and Bridges - Drogi i Mosty.* 2017. Vol. 16(2). P. 115-130. DOI: 10.7409/rabdim.017.008. Available at: http://www.rabdim.pl/index.php/rb/article/view/v16n2p115.
15. Kamińska, J.A. & Chalfen, M. The effect of distances between vehicles on time and speed in simulated traffic flow. *Roads and Bridges - Drogi i Mosty*. 2017. Vol. 16(3). P. 163-176. DOI: 10.7409/rabdim.017.011. Available at: http://www.rabdim.pl/index.php/rb/article/view/v16n3p163.
16. Hazim, N. & Bazlamit, S.M. & Salem, Z.A. & Alghazawi, O. & Odeh, I. Determinations of critical gap and follow-up time at roundabouts in Jordan. *Roads and Bridges - Drogi i Mosty.* 2019. Vol. 18(3). P. 227-234. DOI: 10.7409/rabdim.019.015. Available at: http://www.rabdim.pl/index.php/rb/article/view/v18n3p227.
17. Gaca, S. & Suchorzewski, W. & Tracz, M. *Inżynieria ruchu drogowego. Teoria i praktyka*. WKŁ. Warsaw. 2008. ISBN: 978-83-206-1707-8. [In Polish: *Road Traffic Engineering. Theory and Practice*].
18. Chodur, J. & Gaca, S. & Tracz, M. *Wytyczne projektowania skrzyżowań drogowych*. Generalna Dyrekcja Dróg Publicznych i Autostrad – GDDKiA. Warsaw. 2008. [In Polish: *Guidelines for the Design of Road Intersections*. General Directorate for National Roads and Motorways].
19. *Ustawa z 21 marca 1985 r. Prawo o ruchu drogowym, z dalszymi zmianami* (Dz.U. 1985 Nr.14, poz. 60). [In Polish: *Legislation of 21 March 1985 About Public Roads, with further changes*].
20. *Ustawa z 20 czerwca 1997 r. Prawo o ruchu drogowym, z dalszymi zmianami* (Dz.U.1997 Nr 98, poz.602. [In Polish: *Legislation of 20th June 1997 r. about traffic code, with further changes*].
21. Skuza, W. Widoczność znaków we współczesnym otoczeniu drogi. *Nowa Elektrotechnika*. 2006. Vol. 9(25). P. 16-19. [In Polish: The road sign visibility in modern road environment].
22. Shiffrin, R.M. & Schneider, W. Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. *Psychological Review*. March 1977. Vol. 84(2). P. 127-190. DOI: 10.1037/0033-295X.84.2.127.

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