DE GRUYTER
Adv. Opt. Techn. 2019; aop

Research Article

Marina Budanow* and Cornelius Neumann

Road projections as a new and intuitively understandable human-machine interface

https://doi.org/10.1515/aot-2018-0055
Received October 10, 2018; accepted December 7, 2018

Abstract: Various sensors in nowadays cars are already used to assist the driver or to inform him through several display technologies. However, some information cannot properly be displayed through conventional systems. This article shows the development of an assistance system through projections on the road beginning from human perception and interpretation of different symbols. The results of a simulator study are displayed, where test subjects had to state how they intended to react when seeing certain symbols on the road and how they interpreted these signs. As most promising symbols for all possible actions, two parallel lines were used in a further dynamic field study. The outcome of this study is presented and discussed. Having additional information about the car width displayed on the road, drivers managed challenging situations better without being distracted. Projections on the road showed a big potential of being used in broad traffic as assistance systems.

Keywords: assistance system; HMI; interpretation; projections; symbols.

1 Motivation

Looking at our present cars, there are already various sensors installed in the vehicle (Figure 1).

All of these collect and analyze environmental data and provide the driver with useful information. Much of the information is used to assist the driver directly. The information the driver receives visually is presented on the inside of the vehicle or, in the case of current head up display systems, virtually in close range ahead of the vehicle.

The driver's look is, thus, directed more and more into the vehicle's interior, away from the road in front of him and the traffic.

Head up displays allow only a limited perspective to recognize the presented data. Furthermore, it is not in the direct field of view, but requires (small) eye movements to be correctly resolved and processed by the driver.

In this article, we analyze and experimentally evaluate a different human-machine interaction: the projection of relevant information onto the road ahead of the car to support the driver while driving. This support could shorten the reaction times of the driver, help him to cope better with dangerous situations, and possibly prevent accidents in challenging traffic situations.

Before introducing fundamentally new systems, we decided to answer the key questions: Which projections are feasible concerning legal regulation in the near future? Which technologies enable the necessary sensor technology and resolution for the realization of such assistance systems? Most important, how do potential users experience this way of obtaining information?

2 What are the requirements for light projections on the road?

Nowadays, road projections while driving are allowed neither in the (United Nations) Economic Commission for Europe nor Society of Automotive Engineers regulations.

One thing seems obvious when consulting lawmakers and other experts in the field of automotive lighting regulation: no other color than white is assumable for projections in front of the car in the near future.

Thus, the choice of creating projections on the road is by positive or negative contrast in the white headlamp distribution. In the positive contrast, the light symbols are brighter than the underlying low beam, whereas in the negative contrast, symbols are presented less brightly than the low beam light distribution.

***Corresponding author: Marina Budanow,** Karlsruhe Institute of Technology, Light Technology Institute, Karlsruhe, Germany, e-mail: marina.budanow@gmx.de
Cornelius Neumann: Karlsruhe Institute of Technology, Light Technology Institute, Karlsruhe, Germany

www.degruyter.com/aot

Figure 1: Exemplary presentation of the already implemented sensor systems in nowadays cars.

The latter is easier to implement, but likewise more critical. The projection of symbols is intended to be an additional lighting function that provides the driver with additional information. The omission of currently required light contradicts the basic idea of increasing safety. Furthermore, environmental light sources wash out the negative contrast making the projected information harder to recognize.

Positive contrasted symbols are, therefore, more promising for a new light-based assistance system.

3 The role of human perception

As a system based on human-machine interaction, the light-based assistance system depends on the human perception: The psychophysiological aspect has to be taken into account and be evaluated from the user's point of view. Furthermore, it has to prove its benefit for car drivers before being introduced into broad traffic. It has to be proved that the theoretical benefits can also be observed when the system is tested on naive test subjects. What is logical to the developer does not have to be accepted by potential users.

Like in daily life, where same gestures and symbols can have different meanings in different contexts, similar projections on the road might be understood dissimilarly depending on the environment and the individual. For example, while nodding your head is a sign of approval in most countries, a person from India, Pakistan, and Bulgaria might take it as a sign of disapproval [1]. The understanding depends on the subject, the spoken words, and the communicating individuals.

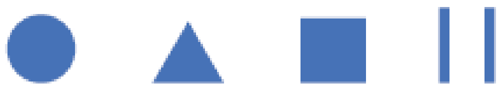
Considering the use of light to project information onto the road, it is the light that acts like a language in a communication between the car driver and the machine. However, what semantics does light have in the case of projections on the road during a trip? What do people understand seeing different symbols on the road ahead when they are driving?

4 The semantics of light

In collaboration with psychologists, we selected some simple symbols to examine exactly these questions under consideration of the following requirements:

- Recognition: the symbols must be sufficiently contrasted to be easily recognized and differentiated from the low beam.
- Quick understanding by simple symbols: the chosen symbols should not distract the driver from traffic due to very long fixation times on the symbol.
- Positive contrast: As already mentioned, the symbol shall support the driver and not omit light in currently required areas
- A contrast perceived as pleasant: A contrast-gradient shall be used that is perceived as pleasant for the driver [2].

With additional regard to technical feasibility and the legal restrictions mentioned above, we decided to use the following symbols in white positive contrast to the dipped beam:



These are the simplest conceivable symbols. Other symbols such as arrows, stars, etc., can be seen as combinations of the symbols and can be used in further considerations if necessary.

As a possible application, we focused on projecting information that cannot quite well be displayed in any other, already existing, system. Arrows, for example, as a navigational information and other discussed projection signs, can easily be displayed using the head-up-display and might even reduce traffic safety due to a higher distraction potential for other traffic participants when projected on the road.

Additionally, the problem of perspective when projecting more complicated symbols on the road is an important issue. The symbols shown above can be displayed easily in a large distance ahead of the car.

Nevertheless, our task was to clarify whether it is intuitively possible to communicate with the driver with these simple symbols and, further, how users interpret certain projections if they appear on the road in front of them while driving.

For this purpose, a simulator study was designed. The mentioned symbols were implemented in a given light distribution and shown to 40 participants in a night drive simulator while simulating a night time drive on a rural road.

The test group consisted of 20 female and 20 male test subjects, aged between 28 and 40 years, and having a driving experience of at least 10 years. They were interviewed about their intuitive reaction to, and interpretation of, the symbols. When the symbols appeared in front of them on the simulated road, they were asked how they would react if this happened on a real drive. Furthermore, the test subjects should explain the reasons for their decision to react, so we could learn how they understood the corresponding symbols.

In all possible driving maneuvers (no change, swerving, acceleration, and deceleration), the symbol of two lines achieved the most explicit results among all test persons (for further information: [3]).

Surprisingly, the triangles were interpreted very ambivalently: different subjects chose to accelerate or decelerate as well as not to react at all. A closer look also showed that some test persons even made different statements in different runs. In the first run, they decided to brake when seeing a triangle; in the next run, they chose to accelerate.

These results left us with the two lines as the most promising symbol for further examination, followed by the rectangle on the second place. The triangles and the circle were dismissed for further tests.

5 The interpretation

In the simulative study, the test subjects were asked about the motivation for their respective statements. If they stated, that they would not react when seeing a specific symbol, they had to answer why they had made this choice. One possible answer was that they felt confirmed by the signal, meaning everything is okay at that moment. Another statement was that they chose not to react because they had no interpretation for this symbol. Comparable answering options were displayed when the test subject selected one of the given response possibilities (swerving, acceleration, and deceleration).

Ambiguous results for interpretation will be discussed below using the example of the triangle (Figure 2).

Figure 2: Picture of a triangle in positive contrast on top of a common low beam that was shown to the test subjects in the simulative study.

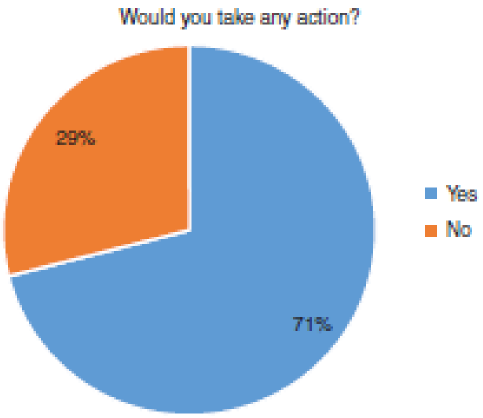


Figure 3: Answers given to the question whether a test subject would react when seeing a triangle on the road ahead of him/her.

Most of the test persons, who stated, that they would not react at all interpreted the triangle as a symbol of confirmation, meaning everything is fine (Figure 3).

On the other hand around two thirds of the test persons decided to react in some way or the other. Out of those, 27% felt warned of a dangerous situation ahead. Another 38% felt under pressure to increase their speed due to a car behind them. Some even interpreted the triangle as an information about an upcoming lane narrowing (27%) or the simple information about the road being clear (16%) (Figure 4).

Consequently, a minority of the test subjects interpreted the symbol as a confirmation, most of the test persons as a warning. Because of different interpretations, the applied actions of the test subjects would have led to a comparable amount of people either accelerating or reducing speed when seeing the projection of a triangle in front of their car. Even with an identical environment, the interpretations evolved in different directions and led to contrary actions.

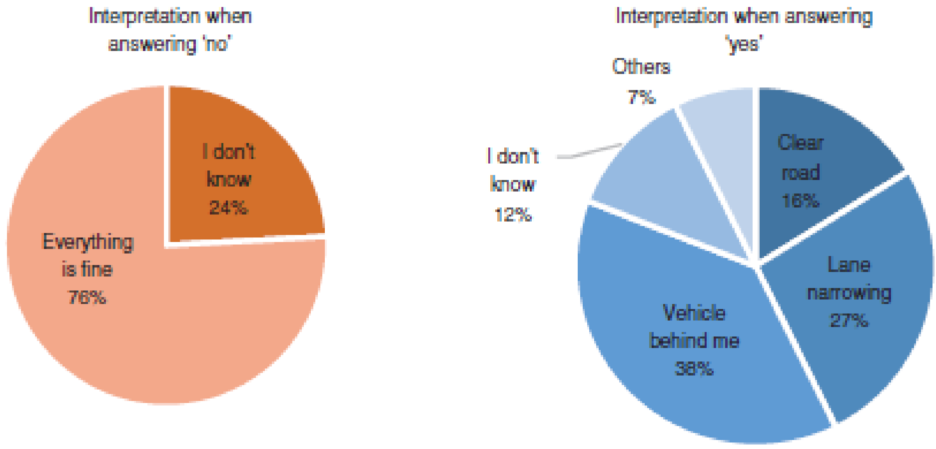


Figure 4: Interpretation of the symbol after the test subjects having stated they either would not react (left) or would react in any way (right) when seeing a triangle on the road in front of the car.

Figure 5: Picture of two lines transverse to the driving direction in positive contrast on standard low beam that was shown to the test subjects in the simulative study.

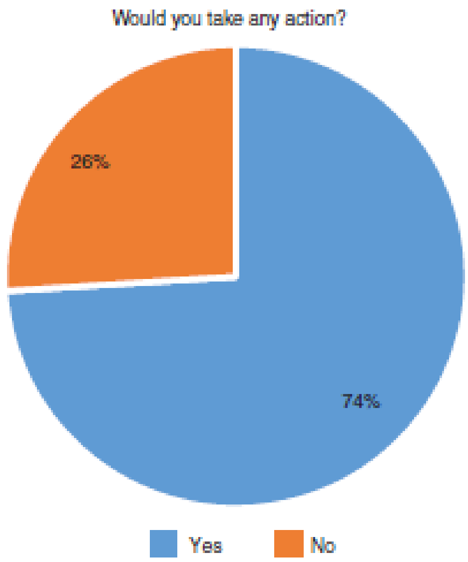


Figure 6: Answers given to the question whether a test subject would react when seeing two transverse lines on the road ahead of him/her.

The most unambiguous symbol happened to be the two parallel lines. Therefore, we want to take a closer look at the lines transverse to the driving direction (Figure 5).

Figure 6 shows that around 26% of the test persons would not react, with half of them not having an interpretation of the symbol (Figure 7). When reacting, 81% of the test persons took the two transverse lines as a warning to a danger ahead or as a distance information (9%) (Figure 7). This is why, out of the 74% of test persons reacting in some way when seeing this symbol, a big majority chose to react by reducing speed [4].

6 Expert study

In a real-time driving test, the gained results were subsequently evaluated. The main subject was to prove if the interpretation from the simulator study is still valid and leads to the same reactions under real driving conditions. As the most promising symbols, the field study focused on the two parallel lines. These signs (Figure 8) are discussed below.

The characteristics of the lines like line width and distance between the beginning of the lines and the car were tested in an expert study with the experts being unbiased employees of lighting technology facilities of different ages and sex.

For the interpretation of the line symbol, the line width played an important role: Depending on the width, the lines were either understood as the car width (see Figure 8) or as lane markings, when being similarly wide as car tires. Having the intention to display the total width of the car, the deviating interpretation of the lines as lane

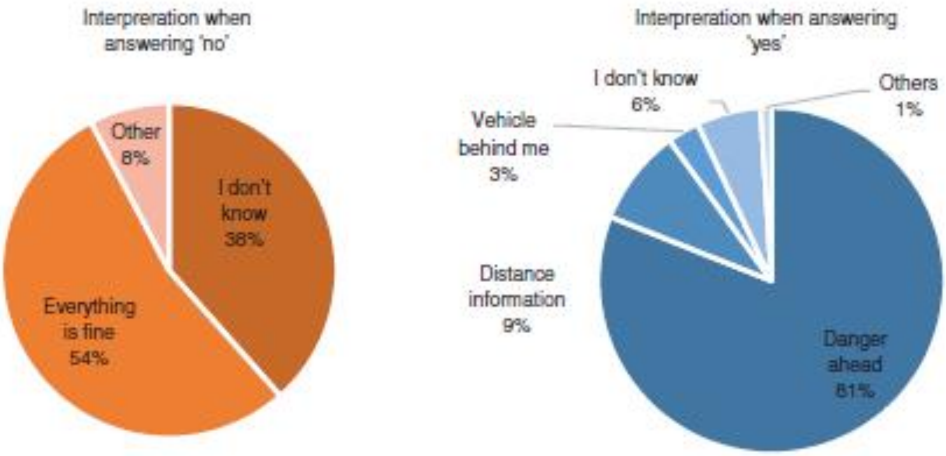


Figure 7: Interpretation of the symbol after having answered they either would not react (left) or would react in any way (right) when seeing the two transverse lines on the road in front of the car.

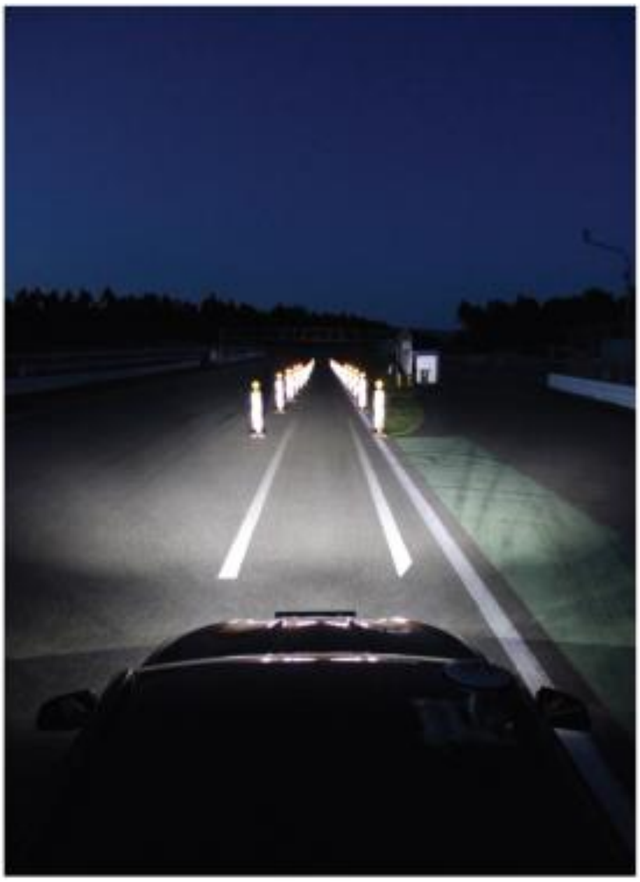


Figure 8: A BMW 5 series equipped with a projector in the radiator grill. Before entering the narrow path, two parallel lines in positive contrast appear and show the car width.

markings could lead to an increased risk of confusion in narrow areas.

To strengthen the association of the lines as belonging to the own car, a projection was chosen to give the driver the impression of the lines starting right ahead of the car. Seeing a break between the own car and the projected lines could be misunderstood as projections from surrounding cars.

Additionally, an alternative to the statically displayed lines was selected in the expert's study: dynamically loading lines that build up in driving direction. The dynamic loading was chosen in a frequency compared to the frequency of the turn indicator.

7 Dynamic field study

In order to carry out a study as close to reality as possible, to ensure repeatability and not endanger other traffic participants, a private test track was chosen as the site for the project. On the track of the Hockenheimring, a 105-m-long construction site was built up following the specifications given for construction zones in Germany. The prepared narrow passage tapered from a width of 3.00 m at the beginning to 2.70 m during the first 20 m (Figure 9).

The vehicle was a BMW 5 Series Touring with a total width of 2.16 m (Figure 10).

The test group consisted of 83 persons. In addition to objectively collected Controller Area Network- and differential Global Positioning System-data of the trip, a subjective questionnaire was handed out after each ride (for further details see [4]).

Each test subject had to complete four laps on the prepared track, passing the construction zone once each lap. In a randomized order, the test drivers either were provided only low beam or low beam with additional guiding lines. Depending on the group, this varied with high beam or low beam with guiding lines, respectively.

Figure 9: The built up construction zone at the Hockenheimring.

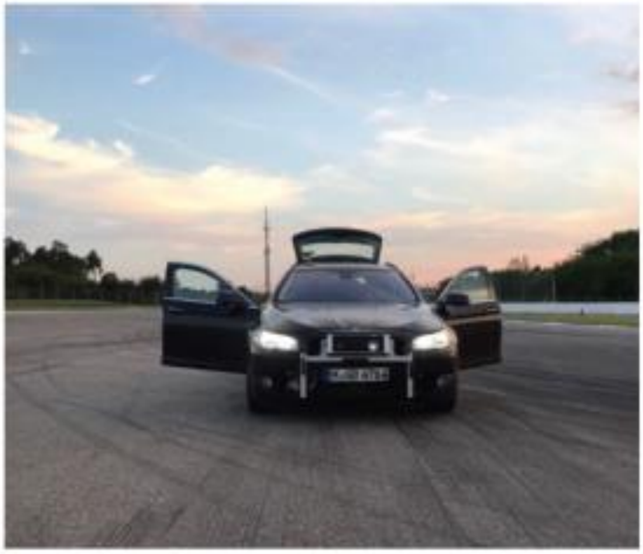


Figure 10: BMW5 series with an external projector implemented in the car's radiator grill for the projection of positive contrasted symbols on top of the car's LED low beam.

The measured results show that the test drivers managed the narrow passage with fewer and less hasty steering movements when the lines are projected onto the road. This was observed with static line projections as well as with the dynamic version. Additionally, in both cases, the speed was more adapted to the usual construction zone speed of 80 km/h (Table 1). These results are proven to be statistically significant by the paired-sample t-test.

These results indicate that the test persons drove more confidently through narrow construction sites when their vehicle width was indicated by projected lines ahead of them on the road. A dependence of age or sex could not be detected during the evaluation.

Particularly, in the first confrontation with this situation, a clear difference in the data was noticeable (Table 2). Comparing rides with common low beam to driving with low beam and additional lines, the average speed went up by 33% while the summed up steering motion and average steering velocity decreased by 62% and 26%, respectively.

These results coincide with the subjectively collected data, in which, among other things, the perception of safety in this demanding situation was inquired. Ninety-seven percent of the test persons stated that they feel safer with additional lines in front of the car. Ninety-two percent claimed that they could handle the situation better than only with low beam.

It hardly made any difference whether the test persons drove with static or dynamic line projections. In the ensuing interviews and spontaneous statements during the ride, however, it was often expressed, that the dynamic lines were rather distracting or even irritating. One reason for this was that the period in which the lines were fully displayed was comparatively short to the time in which they sequentially lit up.

This effect could not be proven in the objectively collected data though.

When compared to laps with common high beam, the average velocity when driving through the construction site with low beam and guiding lines was reduced to a minor extent. Still, a comparably calm driving style concerning steering movements and steering velocity within the restricted area could be observed (Table 3). The differences in steering motion and steering velocity are displayed as not significant by the paired sample t-test.

Nevertheless, the use of high beam is not possible in various situations. There, the guiding lines can help the driver without glaring other traffic participants.

Table 1: Average results of the objective data collected during four rounds.

Average results in 4 rounds	Low beam	Low beam + guiding light	Δ	Δ (%)
Average velocity	55.43 km/h	63.71 km/h	+8.28 km/h	+15
Summed up steering motion	3.86°	2.55°	−1.31°	−35
Average steering velocity	0.35°/s	0.29°/s	−0.05°/s	−16

Table 2: Results of the objective data collected in the first round.

Results in the first round	Low beam	Low beam + guiding light	Δ	Δ (%)
Average velocity	45.11 km/h	59.78 km/h	+15 km/h	+33
Summed up steering motion	6.37°	2.02°	−4°	−62
Average steering velocity	0.39°/s	0.30°/s	−0.1°/s	−26

Table 3: Results of the objective data comparing high beam to low beam with additional guiding lines.

Results in the first round	High beam	Low beam + guiding light	Δ	Δ (%)
Average velocity	54.96 km/h	50.51 km/h	−4.5 km/h	−8.1
Summed up steering motion	1.96°	1.88°	−0.08°	−4.1
Average steering velocity	0.22°/s	0.21°/s	−0.01°/s	−4.5

Table 4: Learning effect differed by the order of functions shown.

Learning effect	Low beam → low beam	Low beam → low beam + static lines	Low beam + static lines → low beam	Low beam + static lines → low beam + static lines
Average velocity	+5.3 km/h	+11.4 km/h	+0.5 km/h	+6.9 km/h
Summed up steering motion	−0.2°	−1.8°	+0.1°	−0.3°
Average steering velocity	−0.05°/s	−0.04°/s	+0.01°/s	−0.02°/s

The first column describes the difference in values when driving with low beam after one other round with low beam. The second column compares the results of rounds with static lines after rounds with only a low beam. In the third column, one round with a low beam follows one round with a low beam and additional lines. In the last column, two rounds with static lines are compared.

Overall, a strong learning effect could be witnessed: With each lap, the test persons drove faster and calmer through the construction site. In dependence of the order of the provided light, this effect is greater or smaller (Table 4).

The greatest effect can be observed in two consecutive laps with additional lines (column 2). The slightest effect is shown during a ride with a low beam after one lap with supporting lines (column 3). A significantly negative effect, i.e. a more restless driving after the removal of the projections, could not be detected in the average results.

Likewise, none of the test subjects stated that they felt distracted from the driving task by the lines in front of the vehicle. In confirmation with the results of Jahn and Neumann [5] and Hamm et al. [6] to the results of our study, no distraction for the driver or other traffic participants can be detected, but only the advantages mentioned in this paper above.

8 Conclusion

Throughout all the experiments, we could observe that communication with the driver through very simple symbols is possible and successful. Drivers approach challenging situations like narrow lanes with more confidence when the car width is displayed by two projected lines on the road. The greatest benefit was experienced in unfamiliar situations. After the first confrontation with the demanding construction zone, a learning effect occurs, and the difference in speed and steering between low beam and additional guiding lines decreases with every lap. As unfamiliar situations are the more common and usually more challenging ones, our results indicate a great benefit in these cases. Insecure drivers are reassured in difficult situations and can cope with these situations more confidently. These systems have the potential to avoid accidents in difficult or even dangerous situations at dusk or at night if the information otherwise provided by daylight is reduced.

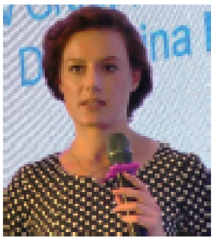
As there was no negative effect observed when removing the guiding lines from the light distribution, no harm is to be expected when a driver has to make a ride without additional projections.

Furthermore, hazard potential due to additional projections can be regarded as very low, as neither the drivers, themselves, felt distracted by the guiding lines, nor other car drivers turned their look away from their lane for too long like those examined by Jahn and Neumann [5].

Overall, these results should have an assuring effect for the legislator. An advantage in assisting car drivers in challenging traffic situations can clearly be demonstrated here, without observable harms for either the driver or other traffic participants.

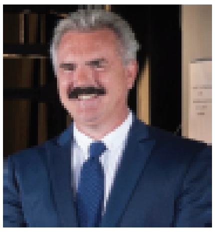
References

[1] K. Dorscheid, Geo.de (https://www.geo.de/geolino/mensch/6703-rtkl-gestik-kultur-mal-anders-gesten-aus-aller-welt), 25.09.5018.
[2] I. Cristea, 'Kontrastbestimmung neuartiger Lichtfunktionen', (Karlsruhe Institute of Technology, Master's thesis, 2017).
[3] M. Budanow, '*Vision Proceedings*' (SIA, Paris, 2016).
[4] M. Budanow, *IFAL Proceedings* (IFAL, Shanghai, China, 2018).
[5] P. Jahn and C. Neumann, *Lux Junior Proceedings* (TUI, Ilmenau, Germany, 2017).
[6] M. Hamm, W. Huhn and J. Reschke, *SAE International* (SAE, Warrendale, PA, USA, 2018).



Marina Budanow
Karlrsruhe Institute of Technology
Light Technology Institute, Karlsruhe
Germany
marina.budanow@gmx.de

Marina Budanow studied Chemistry with specialization on Laser Chemistry at the Goethe University in Frankfurt, Germany, and the Lomonossov Moscow State University, Russia. Since 2015, she works on her PhD in Electrical and Informational Engineering with the subject of 'Development of Driver Assistance Systems Based on Projections on the Road' at the BMW Group in Munich under the supervision of Prof. Cornelius Neumann at the Lighting Institute of the Karlsruhe Institute of Technology.



Cornelius Neumann
Karlsruhe Institute of Technology, Light Technology Institute, Karlsruhe, Germany

Cornelius Neumann studied Physics and Philosophy at the University of Bielefeld, Germany. After his PhD, he worked for the automotive supplier Hella in the advanced development for automotive lighting. During his time at Hella, he was responsible for signal lighting, LED application, and acted as a director of the L-LAB, a laboratory for lighting and mechatronics in a public-private partnership with the University of Paderborn, Germany. In 2009, he became a Professor for Optical Technologies in Automotive and General Lighting and one of the two directors of the Light Technology Institute at the Karlsruhe Institute of Technology, Germany.