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The preferred placement of the external Human Machine Interface for the safety communication between automated vehicles and vulnerable road users

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Abstract- This paper explores the preferred placement for an external Human Machine Interface (eHMI) on automated vehicles (AVs) to enhance the safety of communication with vulnerable road users (VRUs) in six scenarios: VRUs crossings at crosswalks in front of two types of vehicles, a passenger car and a van, with the distance difference at three conditions, 50m, 25m, 0~5m. For the selected scenarios, potential eHMI positions include the front grille (including the headlamp position), front windscreen, engine cover, side windows, side doors, and the upper space of the wheels for effective communication under three different distance scenarios for each type of vehicle. With this research survey and post-processing of the collected data, the top two rated areas are the upper middle of the front grille (max 46.51%) and the upper middle of the front windscreen (max 44.19%) for both vehicles, the passenger car and the van. These placements aim to provide intuitive visual cues to convey AV intentions, such as yielding or proceeding with caution. Feedback based on user experiences will be used to guide the development of eHMIs with better performance. Regarding to the application of the eHMI module on self-driving vehicles, it seems that more efforts should be put on the regulation aspects, so that people would not be confused by the different exterior maker lights in the near future.

Keywords: eHMI, external human machine interface, vulnerable road users, placement, safety

I. INTRODUCTION

Vulnerable road users (VRUs) can be defined as "non-motorized road users such as pedestrians and cyclists as well as motor cyclists and persons with disabilities or reduced mobility and orientation" [1]. It is well known that most fatalities result from road accidents and are detrimental to VRUs. The 2018 road safety statistics of the EU found that over 46% of all road fatalities in 2017 involved VRUs [2]. Even worse, the road and safety department of Australia recorded over 1000 fatalities involved in road accidents, 370 (33%) of whom were VRUs. In its most recent report on road safety, the World Health Organization (WHO) reported over 1.19 million road accident-related deaths in 2021. Although there was a decrease compared to prior years, VRUs still accounted for 50% of these fatalities [3,4]. It is paramount that the objective set by WHO to reduce road accidents by 50% compared to 2011 should be achieved in 2021, but only a few countries achieved this goal [4]

To achieve this goal, several factors need to be streamlined; these include improving road architecture, putting safe vehicles on the road, and legislature to ensure that road users themselves abide by road safety guidelines [5]. Other research, including Daniel J. Fagnant et al., suggest that autonomous vehicles might be the way forward, considering that over 90% of road accidents are caused by human error, according to the National Highway Traffic Safety Administration [6]. One can note that autonomous vehicles also have their shortcomings, e.g., the difficulty in recognizing humans and other road objects compared to human drivers [7]. For the VRUs, it's difficult for them to get the intention of the self-driving vehicles; most of the time, they would have eye contact or gesture communication with the driver in a traditional vehicle. As a result, there is a need to enhance communication between VRUs and automated vehicles [6,8].

Visual cues are a major tool for communication between VRUs and drivers, as any misinterpretation or miscommunication could be fatal. Otte Dietmar et al. identified a major cause of accidents involving VRUs to result from either lack of adequate information, information evaluation (misjudgment or misinterpretation of information of others), and planning based on the evaluation of information received. In a mixed road situation, drivers were more likely to stop completely when the road user looked at the driver, further highlighting the need for these visual cues

[9]. Research conducted by J Uttly et al. highlighted the major non-verbal communication tools as the use of hand and head movements [10]. The experiment highlighted that hand movements were rarely used between the pedestrian and the driver (17% and 12%, respectively). On the other hand, head movements accounted for 83% of the driver's interaction with the pedestrian and 42% on the side of the pedestrian, all within a sample of 52 recorded interactions. This stresses the importance of the role of communication between VRUs and drivers.

Gaining a better understanding of these visual and non-verbal communications in urban environments is important, in particular concerning the transition towards automated vehicles. The recent breakthrough to SAE level 3 by automakers like Mercedes-Benz [11,12] adds pressure to ensure that the replacement of body language with driverless vehicles can be as efficient as possible. The lack of reduced participation of the driver at SAE level 3 exponentially increases not only out of safety concerns, but also greatly affects legislature and how blame is assigned in case of accidents caused by such vehicles [13,14].

Automated vehicles require means of communication that replace the human-human interaction between drivers and pedestrians. This is done through an external Human Machine Interface (eHMI), and several concepts have been developed in which different concepts were classified into different groups: eHMI with simple cues, others that give detailed information or constant feedback, concepts designed for several situations, and concepts mimicking human behavior or animatronics [15].

Further taxonomy of the communication categories are visual forms of communication which include text, anthropomorphic interfaces, symbols, abstract shapes, and other visual communication not yet explained. The second category comprises speech and abstract audio signals and auditory interface. Lastly, the body language of the vehicle serves as an interface for communication, such as deceleration, kneeling, or braking, as these are essentially gestures used by the vehicle to communicate its intent. Another category of communication that is not related to the automated vehicles themselves includes haptic signals sent to devices like wearables or sent to phones or tablets of the pedestrian [16].

In light of the above, this research paper aims to discover the ideal placement of an eHMI for VRUs. In the chapters that follow, a methodology for data collection is outlined using a survey. This data will inform the decision for the eHMI placement.

II. Methodology

A survey is a good way to collect people's preferences on this topic for further research. The online survey tool Qualtrics was used to conduct this research. Two types of simplified vehicles were used in the survey as in this simplified way, participants can't be distracted by the vehicle's shape, stylish design, or other factors. The visible surfaces of the vehicle were split into mesh patches decomposing the surface of the vehicle 3D model for the participants to select during the research survey (Figure 1, left). The car body was split into six parts: the front grille, engine cover, windscreen, side windows, side doors, and the roof. All these areas were further split into small pieces for the participants to choose their preferred areas freely and conveniently.

To make the participants more familiar with the project and smoothen their workflow, the instructions on the aims of the project, basic eHMI knowledge introduction, and how to select/deselect an area were explained in the survey prior to the actual survey questions. The participants could click or tap to select their ideal area(s) for the placement of the eHMI module on the vehicle body. The predefined surfaces will become visible by turning green (Figure 1, right). They were also informed that more than one area could be chosen, and they could always reselect or deselect one area by clicking or tapping it again. After they completed all six scenarios, the submitted data were recorded online. Participants could leave their email addresses if they want to participate in future field tests on eHMI.

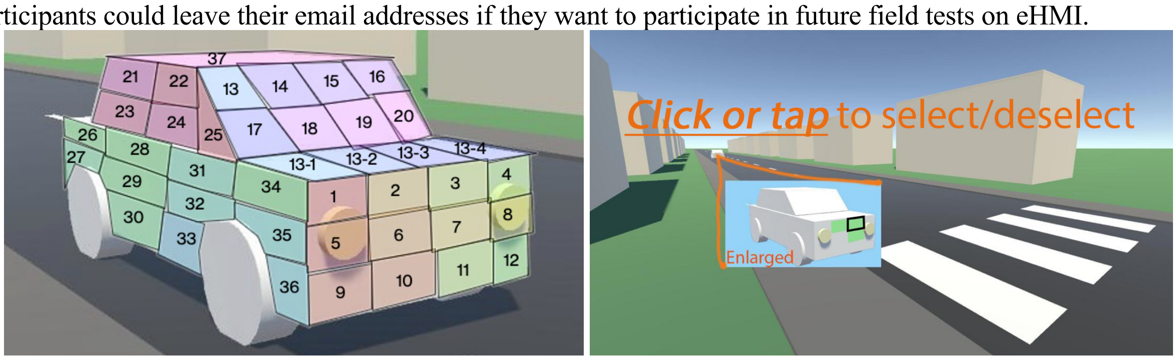

Figure 1. The split of the selectable areas on the test vehicle (left) and how to select in the survey (right).

The above-mentioned six scenarios are shown below in Figure 2, the pictures show a representation of the point of view of the pedestrian or cyclist. The scenarios were designed based on two factors: the type of self-driving vehicle (passenger car and van) and the distance to the crosswalk (here, we chose 50m, 25m, and 0~5m). The distance selection is based on the common speed limitation in urban areas in Europe, 50km/h, with which on the dry road, the reaction distance is about 21m, the braking distance is about 14m, the stopping distance is about 35m in total, while on the wet road, the stopping distance is about 41m in total [17]. The VRUs are assumed to stand on the sidewalk and look in the direction that the test self-driving vehicles are approaching. The vehicles will show their intention to the VRUs. The participants were acting as a VRU, and they decided their preference for the placement of the eHMI module, which would be used for future self-driving vehicles.

After all the responses were submitted, the survey data was exported, and a heat map of responses was calculated. Then, the heatmaps were imported to Unity (version 2022.3.28f1) to generate the test results on the related areas on the vehicles' bodies, the results of which will be shown in Figures 3 and 5 in the results and discussion parts of this paper.

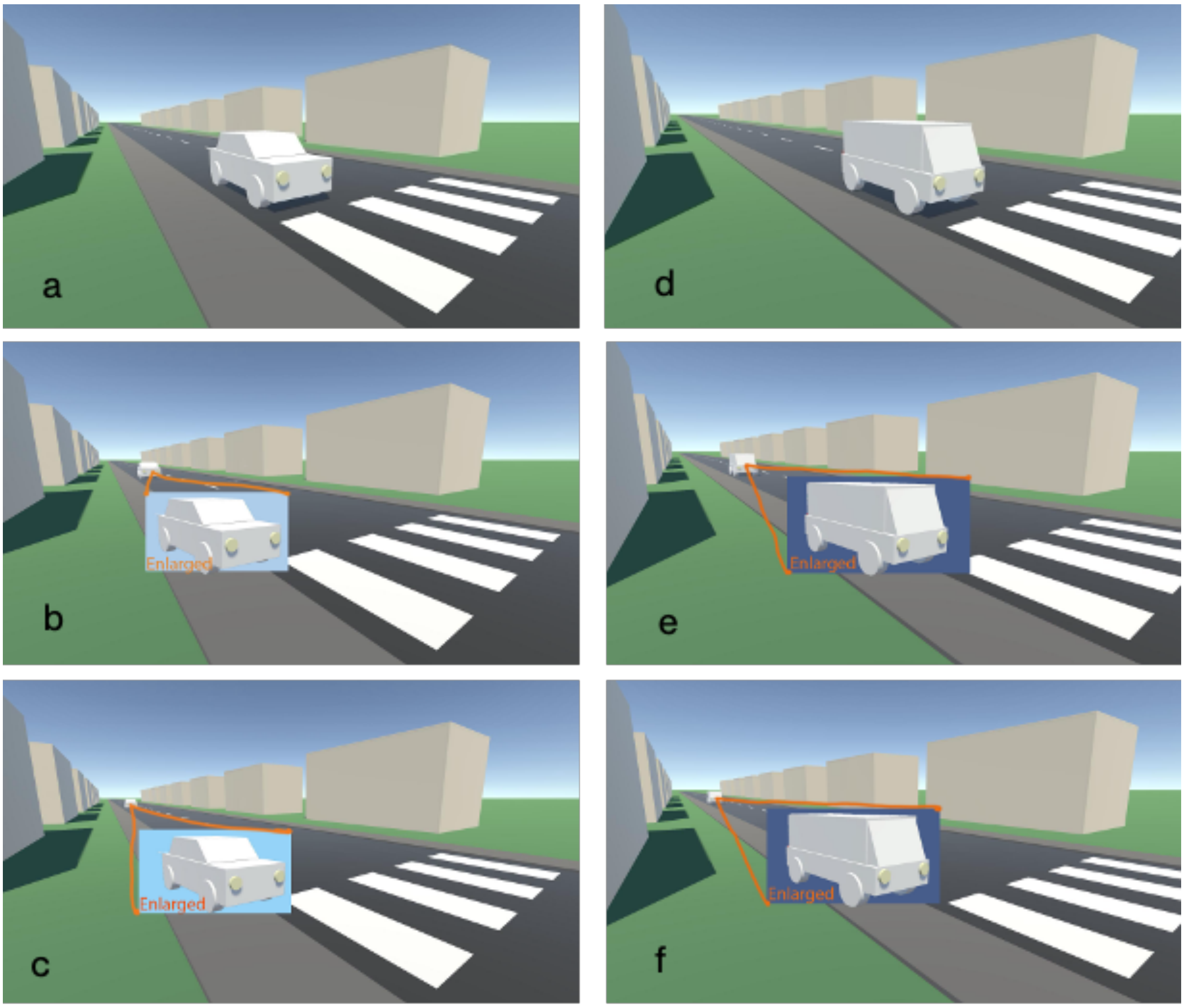

Figure 2. The six scenarios designed for the project, a, b, and c are the passenger cars with different distances to the crosswalk: 0-5m, 25m, 50m; d, e, and f are the vans with different distances to the crosswalk: 0~5m, 25m, 50m.

III. Results and Discussion

A. Participants in this research

The survey was carried out online, and 43 participants joined the research, including 26 males, 16 females, and 1 preferred not to say. The average age of the whole group is 34.5 years. The age group can be divided into three groups: 18-30 years (46.5%), 31-45 years (41.9%), and 45-65 years (11.6%).

B. The Passenger car

As discussed in the above paragraph, the car body was split into six parts: the front grille, engine cover, windscreen, side windows, side doors, and the roof. Figure 3 compares the heatmap of the different areas on the passenger car bodies under different scenarios: g-0~5m; h-25m; i-50m, in which the grille and windscreen are the top 2 rated areas (see Figure 4).

On the one hand, the upper middle areas of the grille attracted the most participants' selection, regardless of the distance of the vehicles to the crosswalk. Even under the long distance of 50 m, the upper middle parts are the most rated areas to have the eHMI module. This also means people prefer to get information from the front of the vehicles compared to the side window areas and the side door parts.

On the other hand, the second part from the right of the windscreen is the most popular place to amount this eHMI module, while there are only slight differences when the distance to the crosswalk is considered: as the car is approaching, the favorite place moved from the upper right to the lower right side of the windscreen eventually. This probably means that with the car approaching at a faraway distance of 50m, participants prefer to see the eHMI module at a higher place, where they could get the communication information easier compared to the lower position. In contrast, at a closer distance of 0~5m, it's much easier for the participants to see the eHMI module at a lower position. At the same time, the second right lower place is also the place of a traditional driver's seat. This implies that participants prefer to keep their habits of communicating with a vehicle as someone is in the driver's seat and expect the communication information to come from there. The left side of the windscreen is also the side where the participants are assumed to be. Also, the right side of the windscreen is a little further away from the VRUs than other areas under the designed scenarios, so it would not be easier for people to see and recognize the information delivered by the eHMI module. The reasonable explanation would be that even if there is no driver in the driver's seat, people are subconscious to look at the driver's seat position as if it were a traditional car with a driver.

Besides the most rated two parts, other parts also attracted some people's interest, especially the upper space of the front wheel. This is also the place close to the headlamp corner. The other three areas, including the window area, engine cover, and roof, do not seem to be preferred place for eHMI,

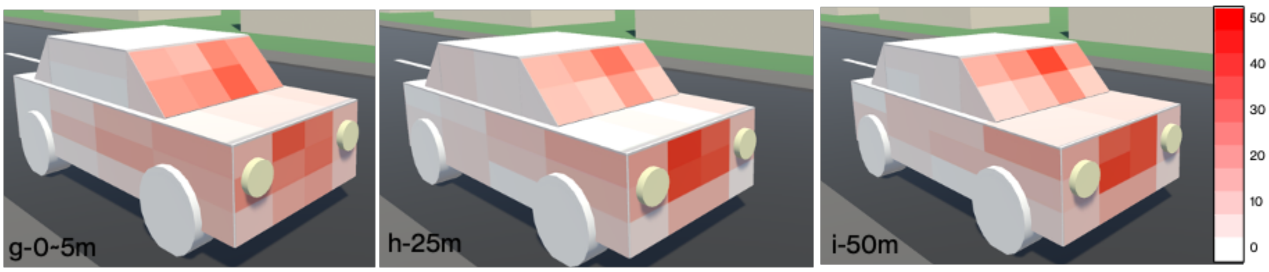

Figure 3. The heatmap of the different areas on the passenger car bodies under different scenarios: g-0~5m; h-25m; i-50m

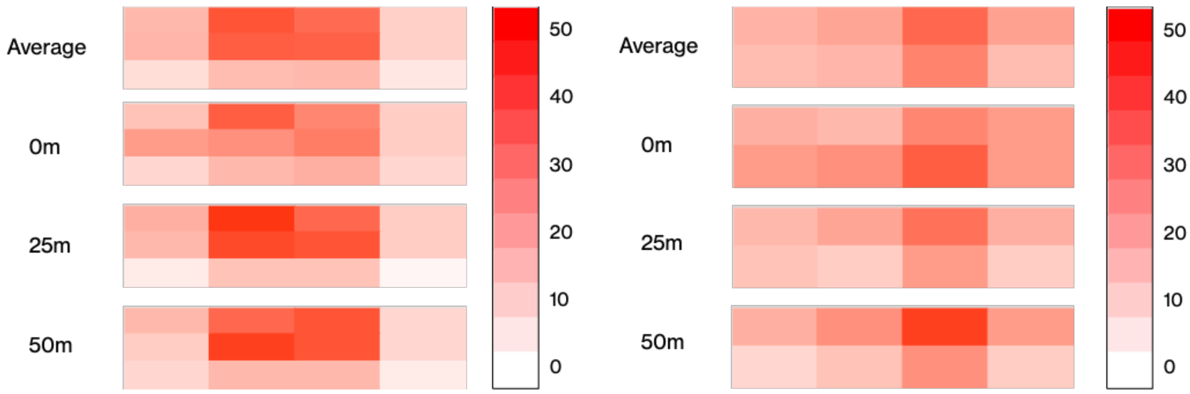

Figure 4. The comparison of different scenarios of passenger car at the top 2 rated areas: the grille (left) and the windscreen (right)

Figure 4 shows the average performance of the results, which were calculated from the three scenarios under different distances. It confirms that the upper middle four areas of the grille and the second part from the right of the windscreen are the favorite areas. The second part from the right of the windscreen is also the driver's seat if this is a traditional car with a driver inside. This implies that people still have the intention to have contact with the driver, even if they have already been told that this is a self-driving vehicle and there wouldn't be any driver inside the vehicle.

C. The Van

The van was also split into five different areas for the research survey, including the front grille, the front windscreen, the side surface of the van body, and the lower side surface of the van body. Figure 5 compares the heatmap of the different areas on the van bodies under different scenarios: j-0~5m; k-25m; l-50m, in which the grille and windscreen are the top 2 rated areas (see Figure 6).

As shown in Figure 5, the most popular areas are the upper middle areas of the grille, and the windscreen is the second most popular area out of the five areas. For the grille areas, as the van was approaching closely to the crosswalk, participants focused mainly on the left side of the upper middle of the grille, which is closer to the participants where they are assumed to stand. This is similar to results obtained for the passenger car, as was shown in Figure 3 and has been discussed in the above part B. Regarding the front windscreen, people prefer the upper of the windscreen, where they can have a good view and be more visible when it's a little far away from the crosswalk. The middle areas become more popular as the van is approaching in the k-25m scenario; it seems these areas will be easier for them to get the delivered information by the van. Their interests move to the upper right side of the front windscreen when the distance becomes around 0 m, which probably means they made their choice subconsciously as they were encountering a traditional van with a driver, even though they were told at the beginning there was no driver with the self-driving vehicle.

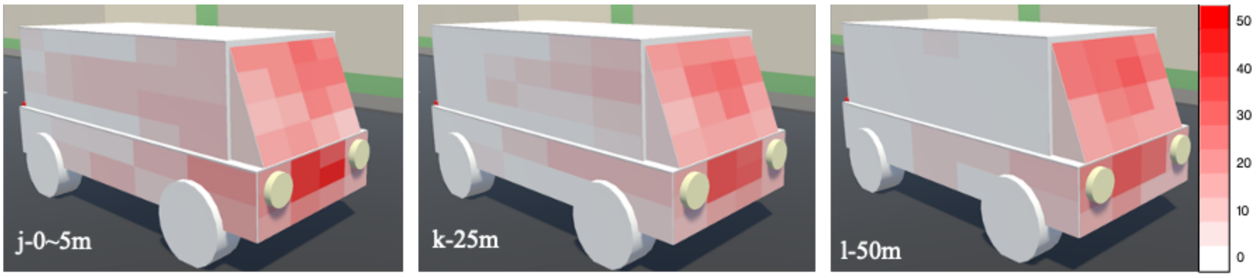

Figure 5. The heatmap of the different areas on the van bodies under different scenarios: j-0~5m; k-25m; l-50m

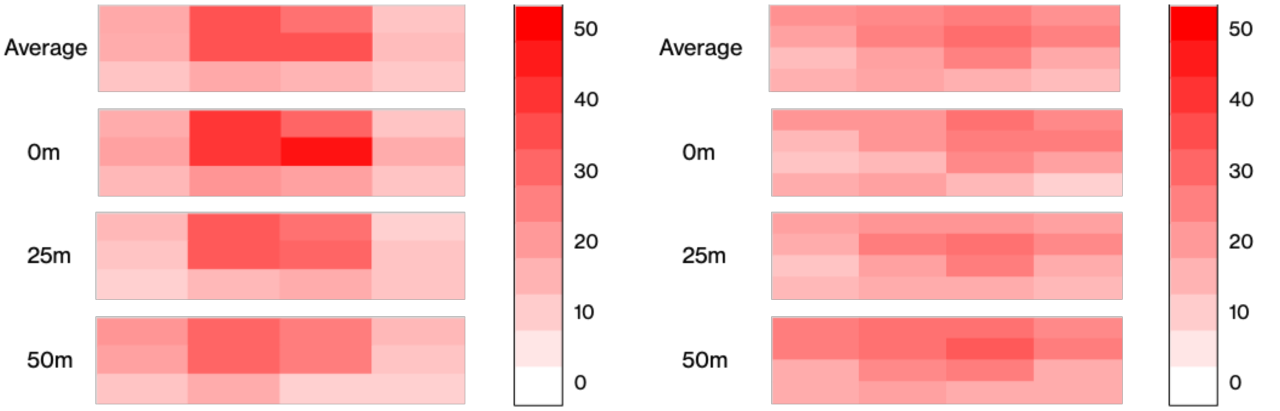

Figure 6. The comparison of different scenarios of van at the top 2 rated areas: the grille (left) and the windscreen (right)

Similarly, the most rated 2 parts were taken out for further discussion. Firstly, the grille areas, from far away (50m) to around 0m, the focused areas do not seem to change in an obvious way, even with the average results. Secondly, the results on the windscreen do change a lot with the change of the distance. When the van is approaching at 50m, a faraway distance, the upper left areas were the favorite areas compared to others. A probable explanation is that these areas have the better visibility compared to other areas from the participants's view. Consider the average results, the upper middle areas seem to be the best choice to amount the eHMI module for better communication.

IV. PERSPECTIVES

The above figures show that for both passenger car and van, the most rated areas to place the eHMI module are the upper middle of the front windscreen and the front grille. At the same time, there are several self-driving cars already running on public roads, with or without the eHMI module. That doesn't mean self-driving vehicles do not need an eHMI module at all. As from December 2023, Mercedes-Benz became the world's first automaker to secure permits for special exterior marker lights (kind of eHMI) for automated driving in California and Nevada[11]. Also, in the Chinese market, Huawei and Zeekr also demonstrate their latest eHMI module on their newly launched models [18,19]. Regarding to the application of the eHMI module on self-driving vehicles, it seems that more efforts should be put on the regulation aspects, so that people would not be confused by the different exterior maker lights in the near future.

V. SUMMARY AND CONCLUSION

eHMI is becoming more and more popular and important when the safer communication between self-driving vehicles and VRUs is taken into account, the VRUs represent the pedestrians and cyclists, and we are all one of the VRUs in our daily life in the modern city traffic system. Explicit communication methods can be used to ensure road safety at certain scenarios. With this research survey and post-processing of the collected data, the top two rated areas are the upper middle of the front grille (max 46.51%) and the upper middle of the front windscreen (max 44.19%) for both vehicles, the passenger car and the van. The visibility of the eHMI module might be the most important factor for the participants in all scenarios.

Based on the present research results and the development of the self-driving technologies, the regulation part will become increasingly important in the near future, which is also the main task we will address for the next step of this research project.

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