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EYE-TRACKING TECHNOLOGY IN AUTOMOTIVE INDUSTRY

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Abstract. The research paper “Eye-tracking technology in automotive industry” describes the implementation of eye-tracking technology into the development of new vehicles and their decision-making process. This objective technology tracks the eye movement of a participant, detects where the subject is looking during an interval of an experiment, and thus offers a wide range of applications. It can be used to detect distractions while driving on a simulator under a certain workload or to record objective data during an otherwise subjective customer-oriented clinic. In this topic, we evaluate areas of the vehicle which are the most interesting for customers, and therefore provide support and recommendations for new vehicle designs.

Keywords: Eye tracking, customer interest, driver distraction, eye fixation.

1. Introduction

The eye-tracking technology offers nearly limitless possibilities of applications in research and commercial sectors. Its applications might vary from marketing research studies, medicine (diagnosis of psychological conditions), to design assessment of vehicle design. In the automotive industry, eye-tracking technology can be used to gather objective data to verify subjective results, and eventually influence the decision-making process of developing or modifying new vehicle design. Because this methodology can evaluate areas of the vehicle which are the most interesting for customers, it serves as an objective source of customer voice.

Besides customer clinics and design related topics, eye tracking is a great tool to assess distraction levels while driving on a simulator or in any vehicle on the road under a certain workload. Thus, it can evaluate the safety of given tasks or the infotainment system's architecture. For instance, while driving in a car, subjects were told to carry out several tasks, one of them was to turn on the Wi-Fi Hot-spot. This task number 7 proved to be one of the most difficult as illustrated in Figure 1. It took on average 37.8 seconds to accomplish. In those time intervals, 72.9 % of total eye fixations were on central display (infotainment)! Only a quarter of eye fixations remained on the road in front of drivers. Therefore, we can conclude that the driver's attention isn't where it should be (on the road). Certain tasks and functionalities in modern vehicles have a high ability to distract a driver and potentially create a dangerous situation. Eye tracking was used in various studies focused on the topic of driver distraction. The study by Ma et al. used gaze monitoring to compare size and positioning of displays on 13 mass produced vehicles [1].

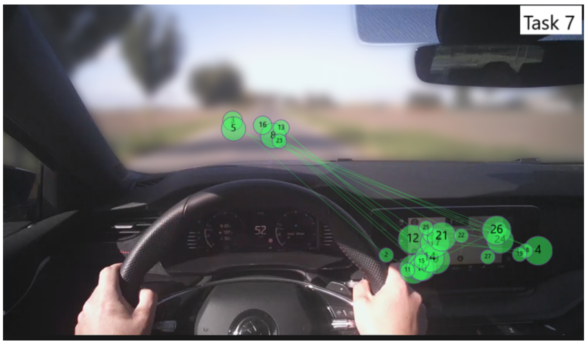

Figure 1. Gaze map of eye fixations while turning on Hot-spot Wi-fi.

2. Eye tracking applications in related studies

As stated in the introduction, eye-tracking technology in the automotive industry is used mostly in the safety area. Another example is a study by Lange et al., where visual demand of in-vehicle touchscreen displays was measured [2]. Kapitaniak et al. performed eye movement recordings and analyses to understand the nature of the complex task of driving a vehicle [3].

A study by Orlický et al. focused on external HMI (Human-Machine Interaction) communication between the pedestrian and autonomous vehicle. To assess different types of communication on the front of the vehicle (LED panels, pictograms, etc.) they used eye-tracking technology [4].

However, the automotive industry has been missing the design or marketing application of this technology, although design and eye tracking are closely related. Eye tracking is widely used to assess customer interest and attraction of various products. It is evident from a study by Djamasbi et al. that eye tracking

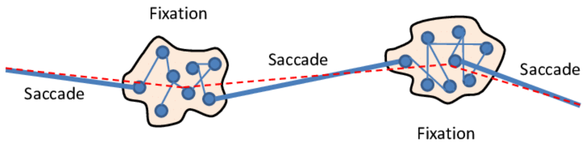

Figure 2. Illustration of basic eye movements.

is applicable also in web design and assessing its visual esthetics. According to this study, Generation Y prefers pages that include a large main image, images of celebrities and a search feature [5]. According to Khalighy et al., this technology proved to be valid as a qualitative data source for product design. A conducted study compared the subjective opinion of 300 participants and 200 participants measured with eye tracking. The comparison confirmed the capability of eye tracking to quantify visual aesthetics, beauty and product design [6]. According to Goyal et al. it is even possible to predict a customer's behaviour and, to a large extent, a purchasing decision by using eye-tracking data [7].

3. Eye movement

Vision is a very sophisticated sense that employs a great deal of brain power. The brain processes images on the retina on which light falls. However, for the image to be sharp, the light must hit the retina at the right angle. Therefore, the eyes (along with their pupils) are constantly moving towards the observed area [8].

The eyes can perform a variety of movements. In terms of eye tracking, we are interested in a gaze, fixation and saccade. When the eye stops for a fraction of a second, it is called a gaze. If multiple gazes occur in close proximity in short succession, this cluster can be considered a fixation. A fixation is defined as a period of approximately 100-600 milliseconds when the eyes are relatively still, focusing on one area, holding the central foveal vision in place so that the visual system can take in detailed information about what is being looked at [8].

As visualized in the Figure 2 below, saccades are transitions, trajectories between fixations. A saccade is always one-directional and lasts for a very short time, between 20 and 40 milliseconds for a healthy individual. The last concept is smooth pursuit, which is when the eye follows an object in motion [8].

All these states of the eyes can be detected and tracked by the eye-tracking technology, which allows the acquisition of a lot of objective data.

4. Eye-tracking technology

The Tobii Pro Glasses 2 50 Hz wireless eye-tracker is used for the experiments. It is a binocular eye tracker functioning on the principle of videooculography. This method senses the position of a pupil using the reflection of infrared light shining on the surface of the eye, using videodetection. Based on the respective

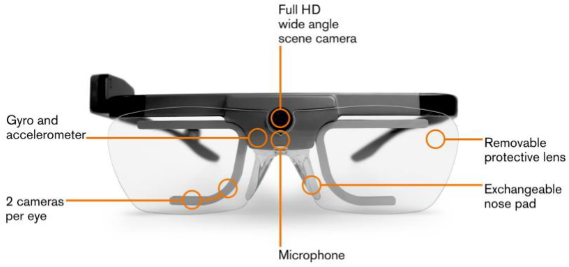

Figure 3. The Tobii Pro Glasses 2.

locations of these two points, the participant's gaze direction vector is calculated, which is then mapped onto the image captured by the eye tracker's front camera. Eye tracker consists of 4 cameras monitoring the eyes (2 cameras per eye) and one FullHD camera for monitoring the environment in front of the participant. An immense advantage of these glasses is their unobtrusiveness and light structure, weighing only 45 grams. Comfortable glasses help the participants forget that they even have glasses and are being measured. Because of that, it is easier to combat the so called "Hawthorne Effect" which implies that a participant might change their behaviour, because they are aware of being observed [8].

The output data of eye tracking are gaze points, which are locations of the visual axis landing on the stimulus. As such, they have an (x, y) coordinate and a timestamp corresponding to its measurement. That is then analyzed in a dedicated software [9].

The software Tobii Pro Lab is used to evaluate raw data recorded by the eye tracker. An algorithm is used to evaluate the recording, which processes raw data from the eye tracker and classifies the individual states of the eye (saccade, fixation, blinking). The I-VT classification algorithm is used in the CIIRC laboratory for standard experiments. This algorithm classifies data based on the velocity of the eye's sampled movement. The velocity threshold is the most important parameter of this classification algorithm as it is the primary parameter used to classify the states of eye movement. Eye movements below the velocity threshold are classified as a fixation, while eye movements at higher speeds are considered saccades. In the CIIRC laboratory, the value of the velocity threshold parameter was set for the experiment to $30° \cdot s^{-1}$, because it proved to have the best reliability and success rate of accurate assessment of eye movements [10, 11].

The accuracy, precision and gaze detection success rate vary according to the situation and conditions in the experiment area. The most important conditions are distance, observation angle and light. The gaze detection success rate is typically between 90 % and 98 %. It can't be 100 % gaze detection, because there is no detection while blinking. According to the table below (Figure 5), eye-tracking functions best in lighting conditions of around 300 lux and when the

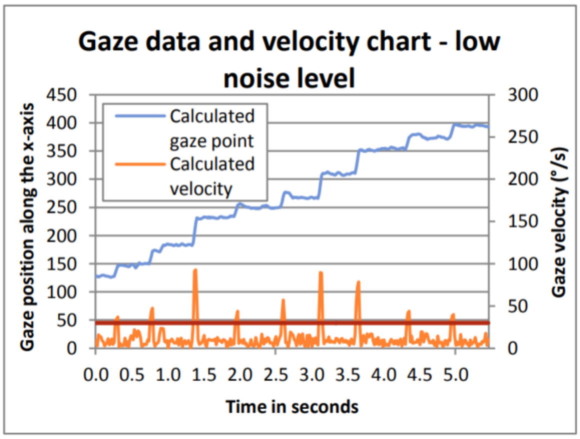

FIGURE 4. Gaze data and velocity graph [9].

Conditions		N	Accuracy (°)	Precision (RMS °)	Detected Gaze (%)
Optimal	≤15°	20	0.62	0.05	99
Large gaze angles	>15°	20	3.05	0.62	92
Lighting conditions	1 lux	20	1.86	0.14	98
	300 lux	20	0.62	0.05	99
	3000 lux	19	0.79	0.22	99
	Black background	20	0.86	0.06	99
Distance to target	0.5-3m	17–20	0.56–0.73	0.11–0.05	98–99
Glasses removal	Reposition	20	0.73	0.09	97

FIGURE 5. Results of binocular accuracy, precision and gaze detection [9].

observing gaze angle is below 15°. The data was published by the eye tracker manufacturer Tobii after a testing measurement with 20 (N) participants in each condition. For this measurement, 300 lux was considered an optimal lighting condition and was fixed for angle measurement [9].

The accuracy of the gaze vector is around 0.6° in these conditions, precision is 0.05 RMS°. As illustrated in Figure 6, the accuracy is the angle a_i difference between the observed stimuli point and the average gaze point location, which is the measured and reported location by the eye tracking. The precision defines the reliability of the technology to measure and detect the same gaze point repeatedly with the same result or only marginal variance [9].

5. The design and methodology of experiments

The analysis of vehicles based on eye-tracking measurements requires robust methodology. When preparing the experiment, it is necessary to determine which locations of the examined vehicle are of importance. The exterior locations of a vehicle can be the front, side and back of a vehicle. In an interior-based experiment, it is usually the dashboard area. However, an interior-based experiment can be divided into several phases – getting into the vehicle, observing the interior with the engine off, observing the interior with the engine on, getting out of the vehicle.

The observed locations such as the front of the vehicle or its dashboard are photographed and di-

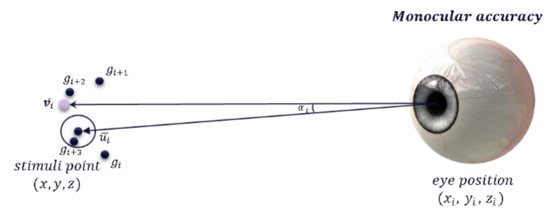

FIGURE 6. Illustration of the accuracy calculations [9].

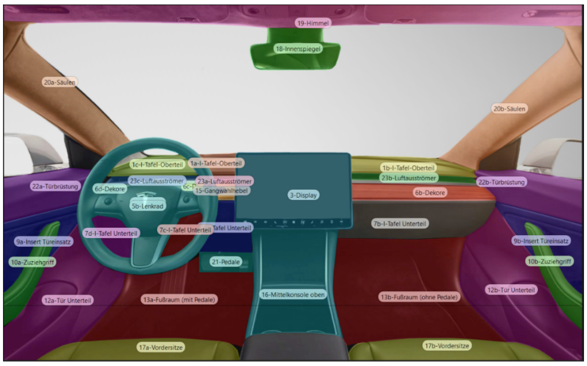

FIGURE 7. Example of Areas of interest (Tesla model 3).

vided in the software into areas of interest (AOI). As shown in Figure 7, this divides the observed image into individual areas. This can then be analyzed in post-processing to determine which areas have seen the most or least fixations.

When working with a participant, a moderator must also ensure that they are not biased, that they do not lead participants into certain areas and that there aren't any distracting or moving objects in the background. We also want to use the glasses to record their first views and impressions to really see what attracts attention at the first moment. The second look would be slightly different, because they already saw the "eye-catching" element. For that reason, participants come to a mark on the floor with their head down so they don't see the vehicle before the start of experiment. Once everything is prepared, the participant can look freely at the observed object.

6. The eye-tracking application

The experiment, which is one of the essentials of this article, is a design assessment of the front masks of selected vehicles. At the customer clinic there were Mid-size vehicles from several manufactures including Ford, Volvo, Mercedes, VW and Peugeot. Some of them also brought a prototype which was actually the point of the customer clinic – to get opinions of potential customers before the prototype cars even start their production. This "voice of a customer" is essential when developing a new product.

The areas of interest (AOI) for these cars were divided as shown in the illustrative drawing (Figure 8).

Obtained data from approximately 50 participants revealed interesting findings. As the following graphs

FIGURE 8. Universal areas of interest of the exterior based study.

and heat maps in Figure 9 show, the examined time intervals are always first 5 seconds and first 20 seconds. This interval has been established by past experiments. When participants have too much time to observe certain objects, they either start to look at the background and surroundings, they start to repeat the previous observing pattern, or they simply get bored and stop. Therefore, a longer interval is not necessary. When examining the first 5 seconds, we get the participants' initial fixations, possible "wow effect", what really drew attention. During the first 20 seconds, participants already have time to visually explore the whole vehicle, focus on several details and thus offer more comprehensive data.

The results showed a lot of data from which it is important to select relevant interpretations. The results of all individual vehicles would take up too much space, so the paper will focus on individual specifics and overall results. An example evaluation is represented by Mercedes-Benz C180. The heat map on the left (Figure 9) shows concentrations of fixations during the first 20 seconds of observing the vehicle. It is clearly noticeable that major clusters of fixations are located on the logo, lights and windshield. However, from the graph we can see that the large areas such as the bumper and hood have more fixations in total, 20 % and 24 % respectively. It is due to their size and also because of the observers' transitions between other surrounding areas of interest. Nevertheless, the hood is a very relevant area. For instance, Ford Mondeo has very distinctive lines on its hood and the heat map indeed shows increased concentrations on that area, as illustrated in Figure 10.

The differences between 5 and 20 second intervals were generally not significant. The attention of participants during this observed interval usually steered from large areas to smaller details. Therefore, we can observe only slightly increasing percentages on logos, mirrors and lights.

Overall, the findings for all eight vehicles outlined some interesting facts. With exceptions, a similar pattern for observing areas (or elements) is seen for all vehicles. The most observed areas and thus most relevant in terms of design are the bumper, hood, lights and logo. Moreover, the windshield tends to have a high observing percentage, however, part of the reason is its transparency into the vehicle interior. The interior draws attention which is unwanted in this particular exterior-oriented measurement.

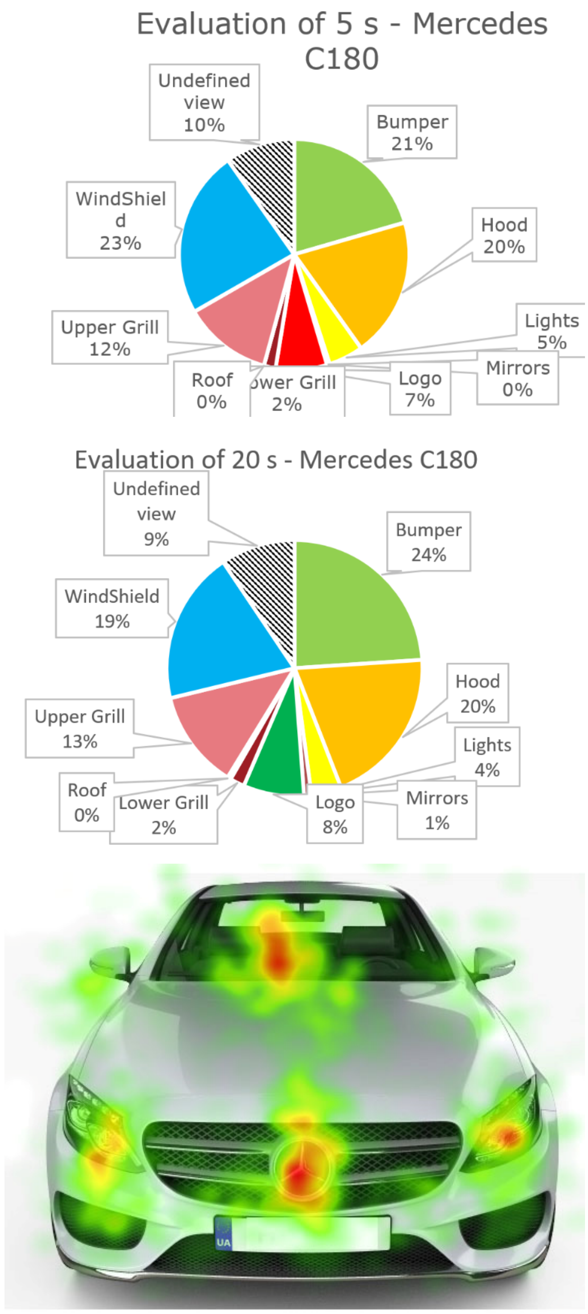

FIGURE 9. Graphs of both intervals and heat map of eye fixations during the first 20 seconds.

Distinctly different elements attract high attention, for example a newly shaped logo. Also observed was axis symmetry of tracking – left and right side of the tracked vehicle. Significant tracking of primarily hidden elements occurred very often, mainly exploring the location of the ACC sensor. Lower observing times were recorded for vehicles with the logo placed in the hood area (Ford, Škoda). Logos on a bumper (e.g. Mercedes) recorded higher observing time – more attention.

Figure 10. Heat map of Ford Mondeo during first 20 seconds.

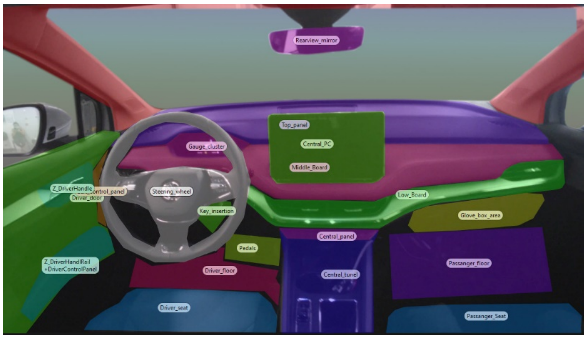

Figure 11. Areas of interest of Enyaq model.

As in the Mercedes-Benz example, overall results determine bumpers, hoods and windshield as the most observed areas. However, compared to their size, lights and logos recorded high fixation rate and customer interest.

6.1. Interior based study

Another study is measuring customer interest in the interior of the Škoda Enyaq vehicle with help of 15 participants. Due to the nature of the study, age and gender division of the participants wasn't considered. Observing parts of the interior were again divided into areas of interest. The experiment consisted of 4 phases described in the previous chapter. The areas of interest were divided as illustrated in Figure 11.

Observation measurement during "getting in" phase was evaluated from the first contact with the outer door handle to driver door closure. Based on the data and heat map in Figure 12, it is apparent that the attention is spread across more areas of interest, though the driver door received the most attention (23.1 %) jointly with the steering wheel (21.4 %). The average observation time (i.e. the time of the process of getting in) was 5.51 seconds. Interestingly, only a few participants actually looked at the driver seat (less than 7 % of total fixations). Majority didn't even look at the area where they were about to sit.

Figure 12. Getting in phase.

On the heat map visualization, the fixation distribution is clearly displayed. The fixation on the heat map corresponds to an observation of unfamiliar surroundings. This phenomenon can be caused by the fact that the Enyaq model was a brand-new addition to the ŠKODA AUTO model line-up, and as such was seen for the first time by the majority of participants.

While "observing the interior with the engine off", the gauge cluster had the highest fixation duration (40.3 %) during the first five seconds, together with the steering wheel (29.9 %) and the central display (15.8 %). Other elements had nearly no fixations. In longer observing intervals of 20 seconds the mentioned elements with high fixation duration remained dominant, but were joined by the central tunnel and driver door.

"Observing the interior with the engine on" had very different results. The number of active areas of interest further decreased. The gauge cluster, which lit up during the ignition and drew more attention, received the biggest fixation time percentage (65.4 %). With ongoing observation time, the attention shifted dramatically towards the central infotainment display (65.1 %), without affecting other areas of interest.

As expected, during the phase "Getting out" attention switched mainly to the driver door. There are also high percentages for dashboard and gauge cluster. This may be due to the fact that the participants wanted to reflexively make sure to turn off the ignition when getting out of the car. In an electric vehicle such as Enyaq it is unrecognizable by noise.

7. Conclusion

The aim of this paper was to introduce the technology of eye tracking and to demonstrate its possible applications in the automotive industry. This technology offers a wide range of possibilities to obtain valuable objective data about potential customers or drivers while operating a vehicle.

The paper described the function of the technology, its accuracy and limitation, eye movement and methodology of the experiment. Furthermore, two studies concerning exterior and interior of vehicles were introduced. The exterior-based study shows the main frontal areas of vehicles that are the most relevant in terms of design.

From previous research, interior data were available also for the Škoda Kodiaq, measured using the same methodology as for Enyaq. Therefore, it was possible to compare these two models. It is the comparison of vehicles with each other that brings the most valuable information about the interior of vehicles. From this evaluation, it is clear that during the entry and exit phases, the distribution of views is very similar. However, during the interior observation phases, a significant difference can be observed in the fixation distribution among the areas of interest. The biggest difference is the length of observation of the infotainment during the "engine on" phase. Both vehicles recorded a majority of fixations on both screens, which means an overwhelming HMI supremacy. But during this phase, the Enyaq model dominates with its infotainment area, which gets 65.1 % of the observation time, compared to the Kodiaq model with only 24.3 %. This result points to a unique and innovative infotainment composition of the Enyaq model. The reason behind this is most likely due to an unusual concept of this element, which is very different from previous models, including the Kodiaq model. Different interior concepts cause different customer behavior.

For the upcoming studies, it is possible to add various car models and scenarios and obtain more data. Another feasible evaluation approach would be using virtual reality. This way, a larger number of experiments focused on vehicle interior could be carried out. The heat maps would be mapped onto 3D models, which could enable testing of prototype solutions digitally in the pre-development phase of creating a vehicle.

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