“I am going this way”: Gazing Eyes on Self-Driving Car Show Multiple Driving Directions

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Figure 1: Eyes on the car with five gazing directions.

ABSTRACT

Modern cars express three moving directions (left, right, straight) using turn signals (i.e., blinkers), which is insufficient when multiple paths are toward the same side. As such, drivers give additional hints (e.g., gesture, eye contact) in the conventional car-to-pedestrian interaction. As more self-driving cars without drivers join the public roads, we need additional communication channels. In this work, we discussed the problem of self-driving cars expressing their fine-grained moving direction to pedestrians in addition to blinkers. We built anthropomorphic robotic eyes and mounted them on a real car. We applied the eye gazing technique with the common knowledge: *I gaze at the direction I am heading to.* We found that the eyes can convey fine-grained directions from our formal VR-based user study, where participants could distinguish five directions with a lower error rate and less time compared to the conventional turn signals.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in interaction design**.

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KEYWORDS

Anthropomorphic car-to-pedestrian interaction, Eye gazing technique, Communication capability, Real-world VR-based evaluation

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1 INTRODUCTION

People live in the city and continuously interact with their surroundings [24]. Their spatial perception enables them to understand their position in space and know the relationship between themselves and cars. When there is a perception limitation, pedestrians seek more specific information from drivers, such as eye contact or gestures. Unlike modern cars, a self-driving car does not have a driver to make these nonverbal communications possible. Many researchers discovered how an external Human Machine Interface (eHMI) could convey a car's intent, status, and perception to pedestrians and investigated the efficiency by measuring pedestrians' reactions, such as their response time and the number of non-collision decisions [20].

There are numbers of nonverbal communications, including eye contact, touching, hand gestures, and facial expression methods. Among them, especially, the eyes are effective in communication. Eye gazing has been applied in biological development [49], attention-drawing [31], memory fostering [22], impression formation [28], trust improvement [4], and video conferencing [6]. In car-to-pedestrian interaction, eyes on a car can make the car's information understood by pedestrians. Applying the anthropomorphic design with common sense in car-to-pedestrian interaction can imitate an interaction between a pedestrian and a driver. Ito et al. [27] mentioned two interpretations of eye gazing directions. The first one is that eye gaze shows the direction of objects attracting attention. The second one that eye gaze shows its moving direction. Some researchers [8, 10] applied the first interpretation. They attempted to use eyes on the car to show the car's perception to pedestrians (whether the eyes are recognizing a pedestrian or not). Our study focuses the second interpretation and discovering how a car displays its intention to pedestrians and distinguishability in eye gaze, which is how a car conveys its fine-grained driving direction (different turning degrees) intention.

We defined five turning directions in the experimental stage. We built two robotics eyes and mounted them on a real car. While our car has autonomous driving functionality, we manually drove it for safety reasons. We shot the moving car with a 360-degree camera and built a VR system that plays back the video for the evaluation. The results show that our eye communication could convey five different turning directions, and participants distinguished them with a lower error rate and less time compared to the standard turning signal (i.e., blinkers). We conducted a post-test interview and concluded the feedback into eight views, including the eye system's strengths, weaknesses, opportunities, and threats (SWOT) [25]. In summary, our work made three major contributions:

- We applied the anthropomorphic robotics eye prototype with multiple gazing directions on a self-driving car and showed the car's fine-grained driving intention using common knowledge in human nonverbal communication. This design can improve the car-to-pedestrian interaction efficiency, which increases road safety with self-driving cars.
- We conducted a real-world VR-based experiment on the capability to communicate with a self-driving car with robotic eyes.
- Our user study results showed that pedestrians could distinguish five different directions using the robotic eye gaze with a lower error rate and in a shorter timeframe. We summarized eight views based on SWOT analysis from the interview.

2 RELATED WORK

2.1 The research in car-to-pedestrian interaction

The general pipeline of exploring car-to-pedestrian interaction contains three steps: (1) determine a research field (scope), like how color effect pedestrians to make a decision. (2) plan a related study site (scenario), like the "intersection" and "parking lot." (3) design a corresponding user task and evaluation metric, like "cross or not cross the road," then count the safe interaction and task completion time [48]. The research trend includes the color of eHMI, information type, and pedestrian demographics analysis. Researchers hypothesize that different types of color can show multiple levels of precision when attempting to convey similar information, for example, the comparison of white and turquoise in eHMI to notice the automated driving system is engaged [16], how combining the 729 colors from the RGB spectrum can express "please cross / not cross" intention properly [3], and testing the different levels of comprehensibility with mixed color and animation patterns for the yielding intention [12]. On the other hand, researchers investigated which information shall be displayed on eHMI, including the car's intention [1, 32, 44], perception [17], and status [19, 36], as the car's status and intention are significant while perception has a negative effect when mixed all information [20]. Lastly, the pedestrian demographics analysis is often aimed to discover how pedestrians' age [13], gender [7, 42], and characteristics [2] impact their decisions.

Previous research is often conducted based on a similar scenario with the core task, where there is an intersection and a pedestrian cross. The major limitation of such a scenario is having a binary decision: crossing or not crossing. In real-world car-to-pedestrian situations, much more sensing, negotiation, and communication are happening. With the city's rapid development, more complex scenarios and infrastructure will be constructed in the future city's public traffic ecosystem [14]. Since the previous research results do not cover all situations and problems, we would like to expand to have multiple directions in car-to-pedestrian situations. Some research projects were conducted in a spacious area, for example, having a parked car in a parking lot and asking a participant to distinguish the stationary car's "ready to start" status [16]. In another study, the researcher drove a car in random directions and conducted a qualitative analysis of pedestrian behavior and feedback from the interview [18]. However, they do not research the car's specific (rather realistic) moving direction. There are two cases we can think of in the real-world scenario where pedestrians need to understand the car's intention accurately for their safety: (1) there are more than two roads toward the vehicle's same side [1], such as the near left lane or far left lane in a multi-lane Intersection and a half or quarter turn in a roundabout, and (2) the vehicle needs a wide space to turn. In these cases, the turn signal is not enough to let pedestrians know where the car wants to go exactly, which leads to a chaotic and panicking situation. Our exploration set up a site with multiple turning directions for the car and investigated the higher capability of car-to-pedestrian communication.

2.2 The anthropomorphic design with common sense

Mirnig et al. [35] raised three strategies of how self-driving cars could communicate with pedestrians based on human-robot interaction (HRI) paradigms: (1) machine-like car-to-pedestrian communication, (2) anthropomorphic car-to-pedestrian communication, (3) social robot proxy-to-pedestrian communication. Our project is focused on using anthropomorphic car-to-pedestrian communication. The primary goal of anthropomorphic designs is to have a positive influence on people [33]. In addition, the anthropomorphic designs communicate via intuitive information that can be used in multi-language community. There are several existing anthropomorphic designs in the car, for example, applying projection techniques and providing the gestures or postures [37, 38] to show the car's intention of stopping or turning, putting the 3D anthropomorphic virtual assistants on the car to play a driver's role [30], embedding haptic systems with multiple sensors on the car that can transfer feeling of touch from the car to the driver inside of the car [38], and adding social elements in front of the car such as a face with simple facial expressions (e.g., smile) to convey the yielding intention [45] or a set of eyes to have eye contact [9, 10, 43].

There are two pitfalls: the difficulty of applying traditional nonverbal methods [29] on the car and designing measurements to prove that anthropomorphic designs decrease the risk. The traditional non-verbal methods, including eye contact, gestures, and facial expressions, are difficult to apply directly to self-driving cars [35] since we do not know how they can be mapped to robotic status in different contexts. We use "common knowledge" by assigning human-like features and behavior to the eyes [15]. Research proved the critical role of common knowledge in human-human interactions [41] and human-automation interaction [39, 40, 47]. In addition, we need metrics to prove that anthropomorphic designs can decrease the danger in car-to-pedestrian interactions. The majority of the above projects have either not conducted user studies or conducted in computer graphics virtual reality environment (CG-VR) [26]. VR evaluation can reduce the experiment risk, expense, and time [5]. However, the CG models in VR look different from the real car. Hence, to utilize the benefits of VR while keeping the realistic environment, we conducted user study in Real-world VR enviornment (RW-VR) [26]. We mounted two robotic eyes in front of the car, where the blinkers were placed, and took various 360-degree videos to play in a VR environment. There are already several projects researching eyes on the car. The roles of the eyes in these studies focused on conveying the car's perception to a pedestrian. For example, a car manufactured by Jaguar Land Rover gives pedestrians a sense of security using its eyes when it has identified them [43]. In one project, "eyes on the car," the researcher showed that when a car is looking at a pedestrian, the car has noticed the pedestrian [10]. Research seldom delved into using eyes to convey the purpose of the car itself, especially the multiple turning direction. Based on research investigating the essential eyeball expression and the possibility of displaying various turning angles using the eye [11, 23, 34], we proposed the common idea: *I gaze at the direction I am heading to*, and applied the gazing technique to show fine-grained driving directions.

3 SYSTEM DESIGN

We built a physical anthropomorphic prototype of robotic eyes and mounted them on a real car. We built a pair of robotics eyes with the black plastic eyeball and the transparent hemispheric acrylic cover. The diameter of an eye was 30cm. The eyeball can reach 45 degrees at max toward all directions (figure 2 (a)). The motion track is a partial hemisphere similar to the human eye's movement. Then, we embedded the eyes on a 4-seat golf car with self-driving capability. We mounted the eyes on the aluminum frame of the car. The car was considered as a level 3 automation (i.e., Conditional Driving Automation). It can perform lateral, longitudinal control, object and event detection, and response (OEDR) tasks. However, in the case of failure, the driver must take up the control in this level 3 automation [46]. In our study preparation, we drove the car manually for the safety (figure 2 (b)). We covered the windshield with a one-way window film so that the driver is invisible from the outside while they can see outside clearly. We developed a module for the operator to control the motion of the eyes by pressing a button. The same set-up was used in [8].

4 USER STUDY

4.1 Test goal and participants

We conducted a user study in a VR environment to assess the strength and limitation of applying the eye contact technique in car-to-pedestrian interaction compared to the standard turn signals (i.e., blinkers). We used a within-subject test to control the individual variability. Participants' task is to observe the self-driving car, distinguish its turning direction, and make a correct *evade* decision to avoid collision in a limited time frame. We designed the task and the questionnaire focusing on the followings. (1) Does applying the eye system improve the accuracy of pedestrians' recognition on cars' fine-grained directions? (2) Does applying the eye system improve the time efficiency for pedestrians to make a decision? (3) Does applying the eye system improve pedestrians' subjective feeling (i.e., trust, safety, and confidence) in the interaction?

We recruited 16 participants (eight females and eight males between 18- and 50-year-old) from the Japanese general public. The same participants participated in the study described in [8] before our study. So, they all have seen the self-driving car with the eyes. However, the meaning of eyes was completely different in the two studies. We explicitly explained to the participants that the eye behaviors are completely different in this study. We provided an

[1]There are multiple directions on the car's left in Matsugasaki-dori: https://www.google.com/maps/@35.0441539,135.7766262,20.17z

(a) The eye looks upward.

(b) The self-driving car with robotic eyes.

Figure 2: The apparatus for eyes on the car.

honorarium of $35 to each participant for this study. They confirmed that they did not have VR-sickness (carsickness) during the audition process. This study is approved by the research ethics board in our institution.

4.2 Test scenario

We defined five moving directions for the car (two sub-directions for the left and the right in addition to the straight moving direction) and hypothesized that pedestrians can distinguish the car's five moving directions (Figure 3 (a) left part). We assigned the angle between direction 3 with directions 1 and 5 to be 45 degrees (robotics eye's maximum moving angle) and direction 3 with directions 2 and 4 to be 22.5 degrees (Figure 3 (a)). The turning direction of the car is symmetric, so we focused on the half (dot square in Figure 3 (a) left part).

We determined several critical points and lines. We chose an open space with a tunnel, where the car moves out. In our scenario, the car starts from the point A and drives out of the tunnel. Meanwhile, the eyes or the turn signals activate as the car passes the point B, where the pedestrian can see the car from any positions (e.g., the black dashed line connecting the person at 5 to the point B in figure 3 (a) right). At the point C, the car starts turning toward the direction 4 or 5. The pedestrian stands at the position 4 or 5, nine meters far from the point C. We did not tell participants the details including the number of moving directions, distance from the car, where they stand, and the meaning of the eyes.

We have three preset look-at directions (3, 4, and 5 in Figure 3 (a) right part) that can be controlled with our eye control module. By pressing the corresponding button, the eyes automatically look at the predefined direction within 0.2 seconds. For example, if the operator presses the button 3, the eyes will look straight (figure 3 (b)), while the button 4 or 5 will make the eyes look at the car's slight and sharp left (figure 3 (c) and (d) respectively).

4.3 Computer support and test environment

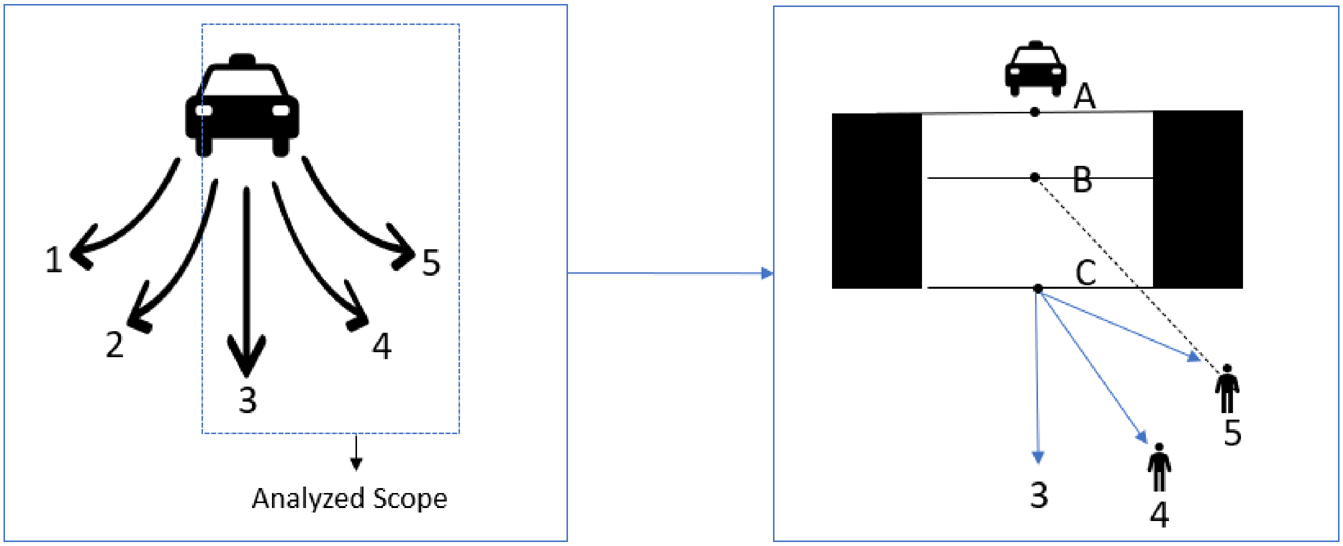
The evaluation had taken in the VR simulation. We performed three steps to prepare the environment. (1) We took the 360-degree videos using RICOH THETA Z1 with the self-driving car in the real-world. Based on the scenario we set up, there are eight conditions (2 car directions x 2 pedestrian positions x 2 signal types). We drove the car eight times with the controlled speed. The video started from the point A (Figure 3 (a)) until the car completed its turn. We trimmed the videos into 4.5 seconds and imported them into the VR simulation. The video in the VR ended as soon as the car's front wheel passed the tunnel (Figure 4 (b), the beginning of actual turn). We chose the stop timestamp to make the pedestrian feel the car is about to come, but they do not know the final result. The participants played as a pedestrian in the VR.

(2) The participant's task is to observe the car, distinguish the car's intended direction, and decide to evade the car or not. Each task is 8-second long from the beginning of the video. As soon as the car activates eyes or blinkers, a counter progress bar (having 3-second to drain out) shows up for the participant to make an evade decision within the time limit (Figure 4 (b), the white part of the progress bar represents the elapsed time). If the participant pulls the controller's trigger, it means that they want to evade the car; if no actions, it means that the participant do not want to evade.

(3) We constructed a specially equipped usability laboratory (Figure 4 (a), and we invited all participants to come to the lab. We prepared the HTC VIVE Pro 2 Full Kit to visualize the VR content in the 5K fidelity, the four-square meter of the VR active area, and the Alienware Aurora desktop with NVIDIA GeForce GTX 3080 GPU.

4.4 User study procedure

The evaluation contains three stages: 1) instruction with the VR tutorial and training (15 min), 2) the main test (10 min), 3) questionnaire



(a) Five directions and study site definition.

(b) Eyes gaze straight. (c) Eyes gaze to direction 4. (d) Eyes gaze to direction 5.

Figure 3: User study scenario and eye corresponding movement in the pedestrian's perspective.

and interview (15 min). The entire study takes approximately 40 minutes. In the stage one, we provided an overview to participants and they signed the consent form only if they agree to continue. They were invited into a repetitive VR tutorial with step-by-step instructions. They proceeded to the VR training, where the participants try eight actual tasks. We do not collect their error rates in this step. In the stage two, they started the main test which includes 48 tasks taking about 7 minutes. Participants are notified that they can stop anytime when they feel uncomfortable. Finally, participants will complete a short questionnaire and a semi-structured interview.

4.5 Measurement

The VR system recorded each task's accuracy for all tasks. The participant only makes the decision when they feel dangerous and want to evade. Therefore, the VR system only records the reaction time if the participant chooses to evade. Then, we computed the error rate of all interactions (failure / all interactions) and the average time to make correct evade decisions. The conditions are summarized in table 1. Table 1 contains four cases. In C4P4 and C5P5, the car goes in the pedestrian direction, which is the same-direction case. In cases C5P4 and C4P5, the car does not go in the pedestrian direction, which is the different-direction case. All cases

(a) The specially equipped usability laboratory.

(b) View in VR.

Figure 4: The user study environment.

are considered dangerous because incorrectly evading sometimes crashes into cars that were not originally in the same direction.

A questionnaire measured the proportion of users who prefer using the eye system over the standard turn signals based on their satisfaction and understandability from a Likert scale. In the interview, the instructor asked: "Imagine one day in the future, the self-driving car is common on the road. Which signal type would you prefer and trust more?", and participants were asked to explain the reason. The instructor will encourage the participants to talk about their preferred signal's strengths, weaknesses, opportunities, and threats. We conducted a SWOT analysis based on their feedback and drew eight different perspectives in the discussion.

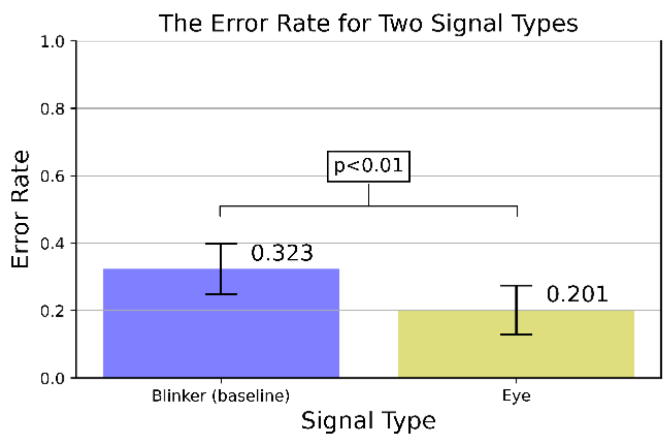


Figure 5: The error rate for two signal types.

5 RESULT

5.1 Error rate

The car direction distinguishing error rate was 0.323 for the blinker type and 0.201 for the eye type (Figure 5). We analyzed our data using the paired t-test and found the statistical significance ($p<0.01$, SD of blinkers=0.1496 and SD of eyes=0.1146). The data indicated that the participants could recognize the car's turning intention more accurately through our proposed eye gazing system.

Our paired t-tests for C4P4 and C5P5 cases showed the statistically significance ($p<0.01$) between the blinker and the eye types (Figure 6, in C4P4, blinker's M=0.29 SD=0.3467 vs. eye's M=0.042 SD=0.1283, and in C5P5, blinker's M=0.34 SD=0.3417 vs. eye's M=0.052 SD=0.1000). This means that the eye system could significantly reduce the error rate when the car goes in the participants' direction. In the C4P5 case, participants made more erroneous decisions through the eye system (M=0.12, SD=0.1350) than blinker (M=0.063, SD=0.2550); however, the paired t-test revealed that there is not statistically significance between the two ($p>0.05$). In the C5P4 case, there was no statistically significance between eye (M=0.58, SD=0.4033) and blinker (M=0.59, SD=3800, $p>0.05$).

5.2 Decision time

We measured the decision time only when the participant made correct evade decisions (Figure 7). The total number was 183 for the eye type, and the average completion time was 1.1737 seconds (SD=0.2174). The total number was 131 for the blinker type, and the average completion time was 1.3816 seconds (SD=0.3524). The paired t-test showed statistically significant difference ($p<0.01$). The result showed that participants spent less time differentiating the car's driving direction.

5.3 Questionnaire

Figure 8 shows the participants' subjective feelings (on a Likert scale) to the questions asking how noticeable each signal type is (Q1-2 in the upper two rows), and results indicate eye is clearer to see on the car than the blinker. Q3-6 asked whether the signal type helped understand the car's intention (in the middle four rows),

Table 1: Test condition statement with error rate

Participants' answer	Condition 1 (C4P4): Car goes direction 4, Pedestrian stands at position 4	Condition 2 (C4P5): Car goes direction 4, Pedestrian stands at position 5	Condition 3 (C5P4): Car goes direction 5, Pedestrian stands at position 4	Condition 4 (C5P5): Car goes direction 5, Pedestrian stands at position 5
Evade	✓	Error	Error	✓
Stand	Error	✓	✓	Error

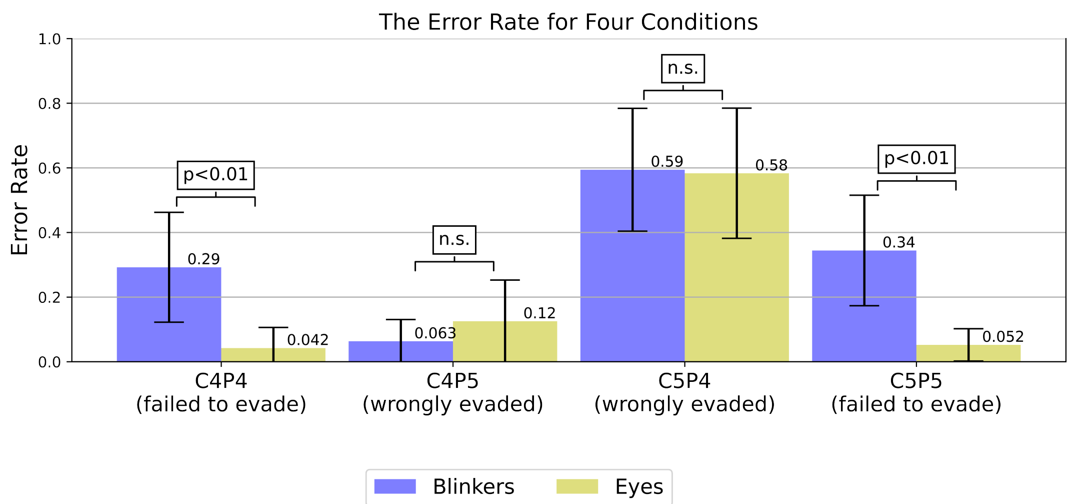


Figure 6: Error rate for four difference cases.

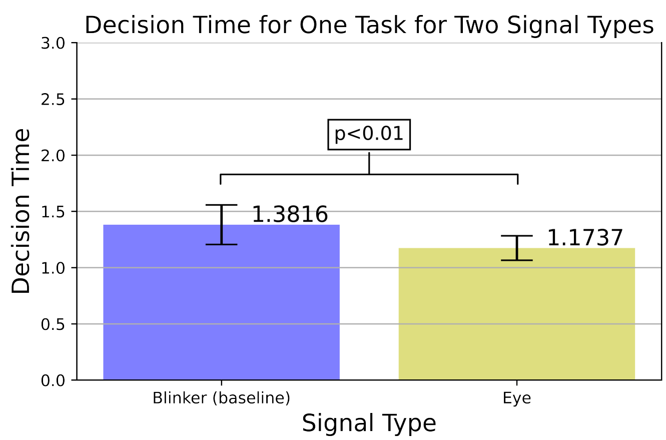


Figure 7: Average decision time for two signal types.

and the answers showed both blinkers and eye could show the general direction (turn left), while eye can show the more detailed direction (slight left and sharp left). In Q7-8, participants felt that the pedestrian's position does not affect the effectiveness of the eyes.

5.4 Interview results

We asked participants for their thoughts on the application of the eye system. Our participants reported diverse views on the current advantage and disadvantages of the eye system, highlighted the potential concerns, and raised promising opportunities. Through our SWOT analysis, we categorized the feedback to the eight views to apply the robotic eyes in the car-to-pedestrian interaction.

Easy to understand the car's turning intention: the relationship between a car's turning direction and eye movement is intuitive, and the eyes can look at a different angle providing its intention in high resolution than simple turn signals. Eyes are more straightforward for anyone such as children.

The attractive design: we designed the robotic eyes to be attractive and cute (like ones from Japanese animations). This design may be more acceptable to people compared to mechanical robotic eyes presented in various media (e.g., Terminator eyes). The size is big and noticeable as we mounted them in the front of the car.

The environment limitation: the eyes can hardly be seen at night, and in bad weather, such as rainy, foggy, and snow. Some ways can improve this limitation (e.g., set bright color on the eyes); however, this may not look adorable anymore (e.g., scary cat eyes in the night). We need further considerations to overcome this limitation.

Hard to get pedestrian's trust: pedestrians are worried about the technical issues, like the malfunction of the eyes or mismatching between the eyes' movement and the car's moving direction.

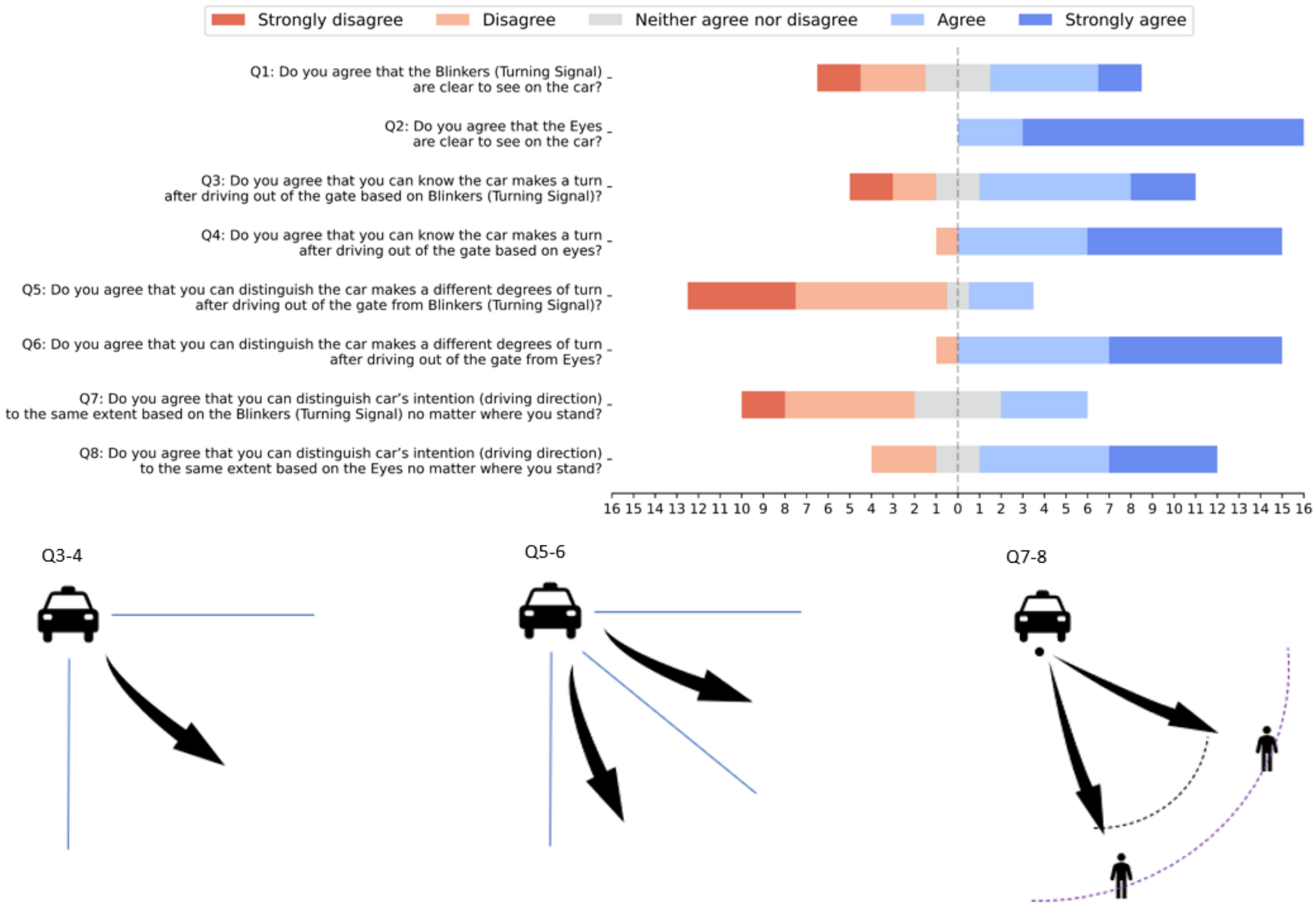


Figure 8: Likert scale answers to the questions asking the noticeability, understandability of blinker and eyes.

The ethics thread: the eyes are similar to an actual creature's eye, making participants be empathic, feel anxious, or make them think of being watched. For example, if the car with the attractive eyes gets into an accident, people may be more empathetic and not being objective when discussing the accident. Or some people may think that they are being watched by everyone and every car. We need further discussions on this topic.

The ambiguity of information conveys: applying eyes in the modern traffic may be confusing in the mixed traffic environment (e.g., confusing corners with self-driving and human-driving cars and many pedestrians). Eye gazing can convey different feelings and meanings in various contexts and situations, such as perception (I noticed you), decision (I move to that direction), or status (I am busy and want you to avoid me).

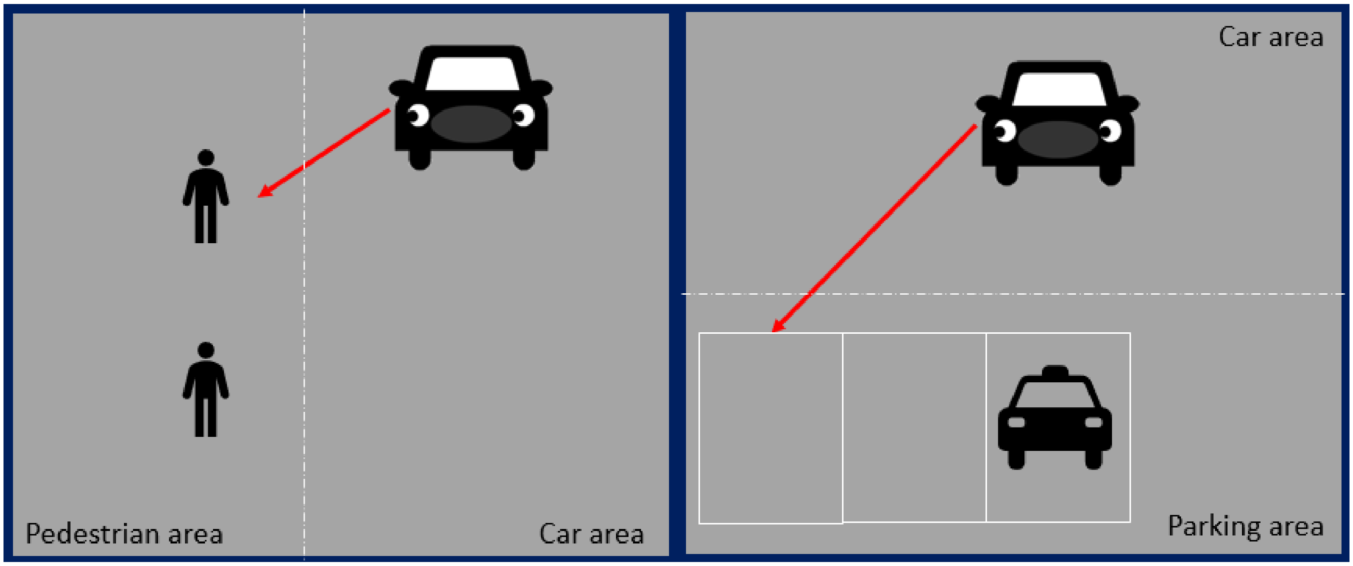
The colorful motions: for the eyes to be seen more friendly, we may need to change its mounting height (e.g., when we talk to children we knee down and adjust our eye height). Further, we can add different animation (eye-movement) patterns and possibly adjusting its iris color to convey more detailed information.

The future opportunity: it would be better if the eyes are mixed with other eHMIs (i.e., using both blinkers and eyes. Setting up the two-step system, like moving eyes after blinking and making a turn, can increase the social acceptance of self-driving cars and increase the pedestrian safety.

6 DISCUSSIONS

6.1 The decision time decrease

The result shows that the eye system decreased the time for a correct evade decision by around 0.2 seconds. Our interpretation is as follows. The car tuning is a process that takes several seconds. Without eyes, the participants need to rely on the observation of the car's actual movement to make a decision (rotation of the wheels and motion of the car body). On the other hand, the rotation of the eye gaze occurs faster than the actual turning process, so the participants can make a decision much faster. An interesting observation was that some (mostly with more than 20-year of driving experience) achieved the high accuracy in both blinker and eye conditions. They habitually observed the car's body motion, tire rotation, and turning speed, so they were successfully made correct decision even in the blinker condition.



(a) Self-driving car picks a customer.

(b) Self-driving car picks a parking space.

Figure 9: The potential application.

6.2 The difference between four cases

Our analyses found that the eyes work well in C4P4 and C5P5 cases but not in C4P5 and C5P4 cases. Moreover, noticeably large errors in C5P4 and less errors in C4P5. A possible interpretation is as follows. People are sensitive to eyes directly looking at them (C4P4 and C5P5). In these cases, the participants immediately felt danger and make an evade decision. On the other hand, when the eyes are not directly looking at them, the participants relied on other information to make a decision. In this particular experimental setup, the result suggests that the participants predicted that the car is moving rather straight (C4) rather than making an sharp turn (C5). This results in less incorrect evade decision in C4P5 (the participant is in P5 and predicts that the car is heading C4, making correct decision not to evade), and more incorrect evade decision in C5P4 (the participant is in P4 and predicts that the car is heading C4, making wrong decisions). Another possible interpretation is that large eye motion (C5) causes anxiety of participants, making them to make evade decision regardless of participant's position. It is shown in the following comment from a participant: *"When the eye moves in a larger range, there will be a feeling that the car will turn more urgently, so before distinguishing the direction of the eyes, I subconsciously choose to evade it."* (P7)

6.3 The user's preference

The user's preference matched with the error rate: the average error rate with the eye condition were lower than blinkers and the majority (fourteen participants) preferred eyes over blinkers (two chose blinkers). It seems that the eye system has a high user acceptance rate, while it may be difficulty to accept novel and non-typical objects for the rest of two participants. In the interview, we received some concerns from eye-preferred participants (View 4, 5, and 6 presented above) and their unbelieving of entire replacement of the driver hints by eHMI in a self-driving car. One of the participants who preferred blinkers explained: *"It made me feel anxious when I found no driver. I cannot trust the eyes. What if the car goes left, but the eye misdirects to the right? Nobody could guarantee the eye movement is the same as a car's moving unless the blinker is controlled by the driver."* (P3) However, the majority of participants tend to hold the positive idea of the eye system, even if they agreed that the eye system has ethical limitations and conveys ambiguous information. One participant mentioned that: *"The ambiguity problem (View 6) may be solved automatically when the eye system is widely applied in our daily life. Blinkers meet the same problem. Blinking has multiple functions, like turning at an intersection, changing lanes, entering a parking lot, passing another vehicle, and merging with traffic. However, people can infer the meaning of blinker according to different scenarios."* (P16)

7 LIMITATIONS

There are some fundamental limitations with the physical eyes as communication method such as weather conditions, ethics problems, and different expectations depending on individual's common senses. The solution contains a mixing eHMI design, lightening the eyes, and enriching the eye movement patterns.

There was also a limitation with our experimental setup. (1) The individual difference: some participants with lousy eyesight, contact lenses, or long eyelashes would be misled [50]. (2) The psychology factor: a particular group of people would be under-sensitive, over-sensitive, or anxious when facing the eye-gazing line in conventional human interaction [21]. These influence their accuracy when the eyes on the car are looking or not looking at them. (3) The VR limitation: even though we replaced the entire scene with a real-world video shot by a 360-degree camera, the immersions between the VR evaluation and the real-car evaluation are very different. The procedure of video cutting, camera placement angle, and the video taking condition (weather, time) all influence the visualization fidelity. There is still a huge gap. Because pedestrians and vehicles travel from morning to night, additional daylight and weather conditions need to be considered when shooting the videos for future VR evaluation.

8 POTENTIAL APPLICATIONS

Based on test results, user feedback, and the characteristics of the eyes, this study showed that eyes can be helpful to find out the moving direction of a self-driving car and making it easier for pedestrians to dodge in an open space. Other than that, we proposed a specific potential application sites for our eye system (Figure 9). The eyes might be also helpful for pedestrians to find out to whom a car (taxi) is trying to pick up (Figure 9 (a)), and to find out at which parking space a car is trying to enter (Figure 9 (b)).

9 CONCLUSION

We identified a problem that a blinker can convey only three directions, which is not enough when there are more than three possible paths to go. We explored how self-driving cars can tell fine-grained directions to pedestrians by using an anthropomorphic design and the eye gaze. For our experiment, we built a real-size physical prototype of the robotic eyes, mounted on a real self-driving car, and defined a scenario with five moving directions. We drove the car, shot the 360 videos, and developed a VR system. The results proved that the eye could convey different directions in a higher resolution than blinkers. Specifically, in our experiment, we tested slight and sharp turns and showed that reduced the error rate to a different extent when pedestrians stand in different positions. We conducted a post-test interview and found that most participants hold the positive impression for the eyes while they also expressed some concerns of applying the eyes in real traffic scenarios. While we have a long way to develop and apply the eyes on self-driving cars, we presented the benefits of having eyes in a real car and discussed potential improvements.

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