Visual scanning behaviour in a parking lot

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Abstract— **With the growth of autonomous vehicles the question arises how pedestrians will communicate with driverless vehicles in traffic situations where traffic rules are not formalized. Pedestrian-driver communication proves to be important in the decision about "who will go first". A parking lot is a typical situation where no clear set of traffic rules is applied and thus may cause confusion about priority. The aim of this paper was to examine in what way pedestrians look at manually driven cars or drivers in cars in a parking lot. An eye-tracking study is conducted with pedestrians in the parking lot of a local supermarket in Delft, where 43 participants were tested. The participants were asked to walk two rounds on the parking lot as they would normally do while wearing the Tobii Pro Glasses 2. This head mounted eye-tracking device was used to investigate what pedestrians look at during interactions with cars driving around the parking lot as well as parked cars with the driver behind the wheel. The results show that eye contact is part of the visual scanning behaviour of pedestrians at a parking lot.**

I. INTRODUCTION

Traffic signals and road markings provide an explicit guideline for those operating in and around the roadways. Some decisions, such as determinations of "who will go first", are made by implicit negotiations between road users. In these situations, behaviours such as eye contact, posture and gesture may play a crucial role between vehicles and pedestrians [1]. Looking at different traffic situations, research has been done on pedestrian-driver interaction in environments where traffic rules are formalized [2]. With the introduction of autonomous vehicles (AVs) on the road, nonverbal communication, such as eye contact, is often impossible, either because there is no driver in the AV or because the driver of the AV is engaged in a non-driving task.

The aim of this research was to examine in what way pedestrians look at manually driven cars or drivers in cars at a parking lot. Based on the results of this research, a hypothesis can be formulated on how AVs should take eye contact into account during interactions with pedestrians at a parking lot. In this paper, a visual analytic method is applied to analyze the behaviour of pedestrians in a real-world eye tracking experiment.

This research has been conducted as part of the Bachelor End Project for Mechanical Engineering students at the Delft University of Technology in the third year of their Bachelor studies.

II. THEORY

With the development of AVs in our society, extensive research is being done on how AVs and pedestrians will communicate. However, most of these studies focus on pedestrian-driver communication on a crosswalk or intersection [3] [4] [5] [6] [7], where road user interaction is largely defined by a clear set of formal traffic rules. Little is known about what kind of communication takes place when there are no formalized traffic rules, such as a parking lot.

Research on car-pedestrian interactions at crossings or intersections has shown that communication between cars and pedestrians mainly consists of non-verbal communication, such as posture, gestures, and eye contact [1] [2] [8] . At the point of crossing, in more than 90% of the cases, pedestrians use some form of attention to communicate their intention of crossing. The most prominent form of attention is to look at the direction of the approaching vehicle. [2]

Looking deeper into the specific role of eye contact while crossing, research suggests that eye contact contributes to the safety of the driver and pedestrian. Research [9] about the influence of pedestrians' eye contact during a crossing, shows that making eye contact can increase the time to collision. Furthermore, "in the encounters where the pedestrians got eye contact with the driver, pedestrians stated that they felt safe for a longer while compared with other encounters" [8].

Research has been done on crossings or intersections but the information on research in a parking lot is scarce. Although there are a number of similarities between the interactions, there are also many differences between a parking lot and a pedestrian crossing. In a parking lot cars can come from any given direction. This requires both the pedestrians and the driver to pay attention to ensure their safety [9]. This research focuses on the visual scanning behaviour of pedestrians during car interactions in a parking lot.

III. METHODS

A. Participants

Forty-three participants (21 male, 23 women) with an average age of 47.1 years (SD = 16.9) participated in the experiment. All participants provided an informed consent approved by the Human Research Ethics Committee (HREC).

B. Measurement apparatus

During the experiment, the Tobii Pro Glasses 2 were used, which are portable head-mounted glasses with integrated eye tracking. Tobii Pro Glasses 2 can be used to study the visual attention of individuals [10]. The acquired eye movement data were analyzed with the supported software Tobii Pro Lab.

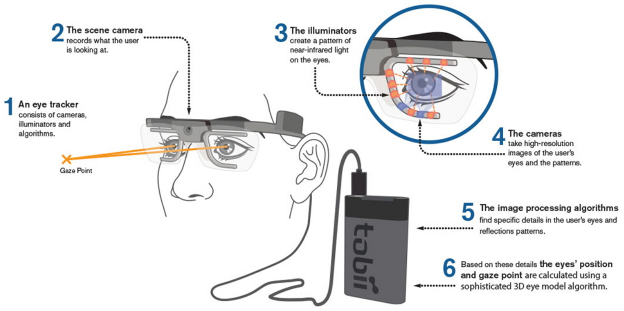

Fig. 1. The wearable Tobii Pro Glasses 2

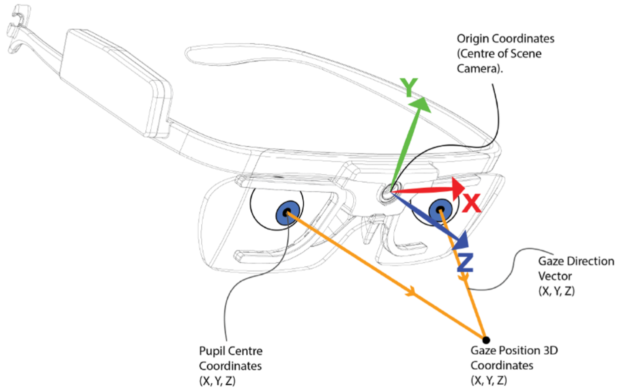

Fig. 2. The X, Y and Z axis of the Tobii Pro Glasses 2

Figure 1 shows how the eye tracker works. The Tobii Glasses contain several light sources which result in a reflection of near-infrared light on the eyes. Two cameras per eye capture an image of the users eyes showing the reflection of the illuminators. The image is used to measure the reflection of the light source on the cornea and in the pupil. Then a vector is calculated, formed by the angle between the cornea and pupil reflections. The direction and magnitude of this vector are used to calculate the gaze direction vector. The obtained result is a raw data point, consisting of the position of the eyes in space and a gaze point [10].

The Tobii Velocity Threshold Fixation filter is used to filter out the fixation points out of the raw eye tracking data. The filter classifies the eye movement type based on the directional shifts of the eye [11]. The different types of eye movement can be classified as:

- **Fixation**: The eye is kept aligned with the point of interest for a certain duration [12].
- **Saccade**: The eye is moving rapidly from one point of interest to another [12].
- **Unclassified**: The eye can be found, but the movement cannot be classified.
- **Eyes not found**: The eye cannot be found.

In dynamic situations, where either the participant or the target object is moving, an alteration of the standard Tobii Velocity Threshold Fixation filter is required. This is done by adjusting the Velocity Threshold parameter in the Tobii Pro Lab software. If the directional shift of the eye exceeded the threshold, the sample is classified as a saccade sample; if not, the sample is seen as part of a fixation. The X, Y and Z coordinates of the Tobii Pro Glasses 2 are given in Figure 2.

C. Procedure and instructions

Before the experiment, a pilot test was conducted to determine where pedestrians would look at during car interactions. The results of the pilot test also indicated a distinction between the different kinds of car interactions in a parking lot. The pilot test consisted of three volunteers following the indicated path (Figure 3) in the parking lot for two consecutive rounds. During the analysis of the pilot test different values for the Velocity Threshold parameter were compared. A velocity threshold of 100 degrees per second was chosen for the experiment.

The experiment was conducted in the parking lot of a local supermarket in Delft. The participants were asked if they wanted to participate as they were leaving or entering the supermarket. The first 10 participants were asked to walk one round and the rest of the participants were asked to walk two rounds on the parking lot as they would normally do while wearing the Tobii Pro Glasses 2. Figure 3 shows a map of the parking lot and the indicated path. Before starting the experiment, each participant was asked to sign an informed consent form and fill out a demographic questionnaire. Next, the Tobii Pro Glasses 2 were calibrated, by asking the participant to focus on a black spot on a white paper. Then, the experiment commenced and the participant started walking the indicated path. The experimenter would walk behind the participant with a laptop, on which the real time wireless feed of the field of view of the participant was shown. Staged interactions, in which the driver (one of the experimenters) was instructed to avoid any eye contact with the participant, were added alongside non-staged interactions, to investigate whether there is a difference in the visual scanning behaviour when people are unable to make eye contact.

During both rounds two different non-staged interactions might occur:

- **Driving Car (DC)**: A car is driving around in the parking lot.
- **Parked Car (PC)**: A car is parked with the driver behind the steering wheel; the car is visually (rear lights on) and audibly running.

At the start of the second round, one or two staged interactions were instituted by one of the experimenters. These two staged interactions were:

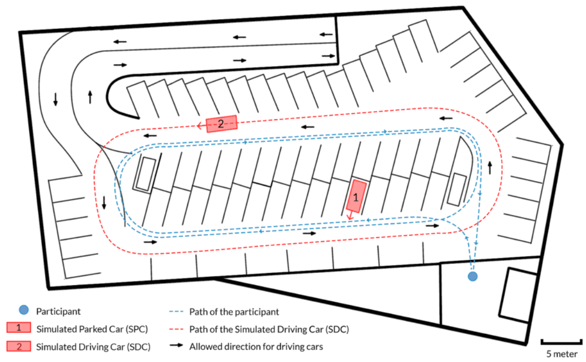

Fig. 3. The overview of the parking lot and the two different staged interactions

- **Staged Driving Car (SDC)**: The experimenter drove around in the parking lot, passing by the participant while avoiding eye contact.
- **Staged Parked Car (SPC)**: The experimenter waited for the participant to approach the parked car, which was visually (rear lights on) and audibly running, and then drive backwards while avoiding eye contact.

These four different interactions are defined as the 'Times of Interest' (TOIs). The testing results are imported in Tobii Pro Lab in order to be analyzed. The software allows for marking different TOIs. Table 1 shows the different TOIs used in this experiment with their start and end marker. Some TOIs could occur multiple times during a recording. A recording is defined as the total time a participant takes to walk the given path.

TABLE I
TIMES OF INTEREST (TOI)

TOI type	Description
Driving Car (DC)	This TOI indicates a driving car in the field of view of the Tobii Glasses. It can occur multiple times during the same recording.
Parked Car (PC)	This TOI indicates that a parked car with running engine is in the field of view of the Tobii Glasses. It can occur multiple times during the same recording.
Staged Parked Car (SPC)	This TOI indicates a staged parked car is in the field of view of the Tobii Glasses. This TOI can only occur one time in the same recording.
Staged Driving Car (SDC)	This TOI indicates that a staged driving car is in the field of view of the Tobii Glasses. It can occur multiple times in the same recording.

The manual annotation of the markers was conducted independently by two experimenters, based on which the inter-rater reliability of the annotation was estimated. Specifically, the recording was played back at 6.25 frames per second (1/8th speed), with every frame accounting for 20 milliseconds. The experimenter manually placed markers by pressing keys on the keyboard, assigned to indicate the start and end of the different TOIs. After the TOIs were determined, the recording was played back at 3.125 frames per second (1/16th speed) and when a gaze point was fixated on a specific area a marker, assigned to this specific area would be placed. These markers are named the Areas of Interest (AOI). During the pilot test, it was determined that five different AOIs would be used to analyze the visual scanning behaviour in the parking lot. Table 2 indicates the AOI markers.

TABLE II
AREAS OF INTEREST (AOI)

AOI type	Description
Wheels	The participant is looking at the wheels of the car.
Lights	The participant is looking at the lights of the car.
License Plate	The participant is looking at the license plate of the car.
Driver	The participant is looking at the driver.
Eye Contact	The participant is looking at the eyes of the driver and the driver is visibly looking back at the participant.

D. Data processing

After the recordings were analyzed and both the TOIs and AOIs were determined, the data were imported to Matlab. Because the amount of TOIs per participant are not consistent, the interaction durations and counts were compared per TOI type to normalize the results. The average AOI count does not take the possibility of multiple TOI interactions per participant into account and had to be normalized by looking at the percentage in comparison to the total AOI count per TOI type. This correlation was investigated using a script which extracts the recording data from the raw data and relates this to the data from the Tobii Pro Lab software.

Recording data

- Acceleration in meters per second squared (X,Y,Z)
- Rotation in degree per second (X,Y,Z)
- Gaze sample in percentage (%)

Data from Tobii Pro Lab

- Eye Movement type: Fixation, Saccade, Unclassified or Eyes Not Found
- Interaction duration of TOIs in milliseconds (ms)
- TOI and AOI markers with time stamp (ms)

IV. RESULTS

A. Data quality assessment

1) Gaze sample: A threshold was set at a gaze sample during the TOIs of at least 45%. For participants with a lower gaze sample, gaze points could not be determined. For this reason, participants 4, 8, 25 and 31 were excluded, leaving 39 participants for further analysis. The mean gaze sample for the remaining 39 participants during the TOIs was 67.8% (SD = 12.97).

2) Reliability manual annotation: To compare the inter-rater reliability and repeatability of the annotation method two experimenters independently analyzed the same recording. The instructions of when to place a marker for a TOI and AOI were identical and as described in the Methodology. The inter-rater reliability is shown in Figure 4.

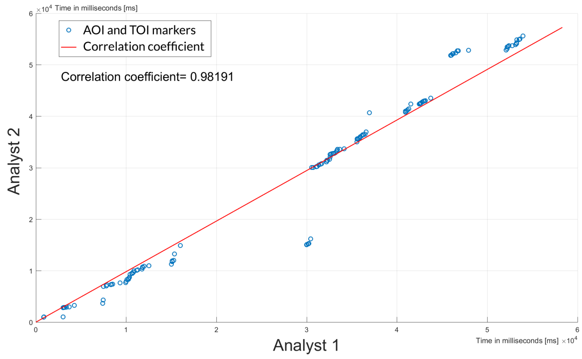

Fig. 4. Inter-rater reliability for manual annotation method

B. Duration of interactions

The results show that there was a mean TOI count of 12.33 per participant (SD = 5.51) with an mean TOI duration of 4.41 seconds (SD = 1.60). The results show that 26 of the 39 participants made eye contact at least once during the course of a recording. With respect to the total sample size of 380 interactions eye contact is made 101 times with an mean duration of 0.36 seconds (SD = 0.22).

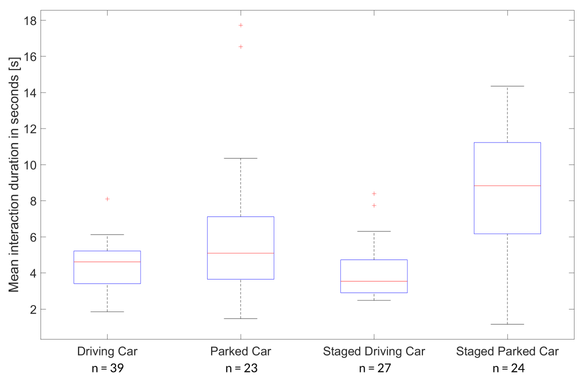

Fig. 5. Mean interaction duration per TOI type for all participants

Table 3 shows that the mean interaction duration for both the Parked Car and the Staged Parked Car TOIs are longer than the Driving Car and Staged Driving Car TOIs. When comparing this with the mean interaction count per TOI type (Figure 5 and 6) it can be seen that the Driving Car

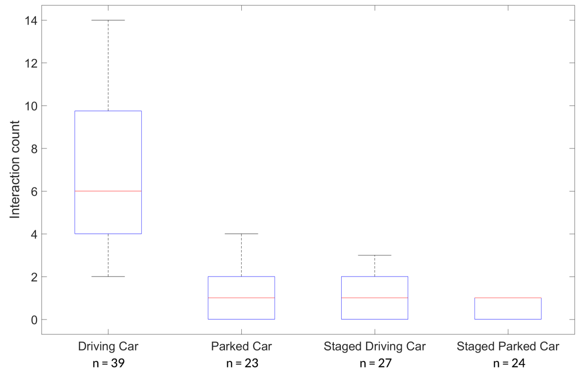

Fig. 6. Interaction count distribution per TOI type for all participants

TABLE III

MEAN INTERACTION DURATION AND COUNT PER TOI TYPE

	Driving Car	Parked Car	Staged Driving Car	Staged Parked Car
Mean Interaction Duration (s)	4.34	6.08	4.04	8.80
Standard Deviation (s)	1.26	4.10	1.57	3.68
Mean Interaction Count (n)	7.00	1.03	1.10	0.62
Standard Deviation (n)	3.40	1.09	0.94	0.49

interactions occurred more often, but the interactions had shorter mean durations than the Parked Car interactions.

C. Areas of Interest (AOI)

Table 4 and Figure 7 show the mean AOI count distribution per TOI type. When comparing the AOI count distribution for different TOI types it can be seen that the percentage of the Wheels AOI is higher during the Driving Car TOIs than the Parked Car TOIs. Also the percentage of the Lights AOI count is higher for both Parked Car TOIs than for the Driving Car TOIs. Comparing the two non-staged interactions show that Eye Contact is more relevant during the Driving Car TOI than during the Parked Car TOI.

TABLE IV

MEAN AOI COUNT PERCENTAGE PER TOI TYPE

	Driver	License plate	Lights	Wheels	Eye contact
Mean count percentage (%)	49.4%	5.6%	23.5%	18.5%	3.0%
Standard Deviation (%)	3.6%	1.9%	5.8%	6.7%	3.7%

A one-way ANOVA measure was conducted to compare the mean AOI counts to the TOI types for all interactions with a significance level α of 0.05.

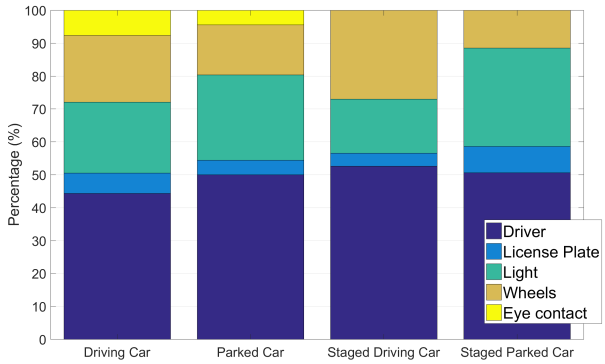

Fig. 7. Mean AOI count distribution per TOI Type for all participants

- **Driver:** F(3, 109) = 14.952, p <0.001.
- **License plate:** F(3, 109) = 6.168, p <0.001.
- **Lights:** F(3, 109) = 12.013, p <0.001.
- **Wheels:** F(3, 109) = 13.742, p <0.001.
- **Eye contact:** F(3, 109) = 20.564, p <0.001.

A post hoc Tukey-Kramer measure was conducted to analyze the correlation between the different groups with respect to the mean AOI count with a significance level α of 0.05. The results of this analysis can be seen in Table 5.

TABLE V
POST HOC TUCKEY-KRAMER ANALYSIS

Group	Driver	License plate	Lights	Wheels	Eye contact
DC-PC	p <0.001	p <0.05	p <0.001	p <0.001	p <0.001
DC-SDC	p <0.001	p <0.05	p <0.001	p <0.001	p <0.001
PC-SPC	p <1	p <1	p <1	p <1	p <1
SDC-SPC	p <1	p <1	p <1	p <1	p = 1

D. Head movement

When comparing the TOIs with the head movement data from the Gyro and Accelerometer of the Tobii, it can be seen that the head movement of the participant decreased when the walking path was obstructed, forcing the participant to slow down its pace or come to a standstill. The largest decrease in acceleration and rotation was seen in the Y direction. In certain cases (Participants 6, 15, 21, 22, 27, 28 and 29) eye contact was made for a relatively long duration (Figure 8) during this period.

When the AOI markers are plotted as a sequence with respect to time (Figure 8) it can be seen that eye contact often occurs during the middle or the end of a TOI interaction. The Eye Contact AOI is often preceded by other AOIs, indicated with different colors.

V. DISCUSSION

A. Interpretation of results

The aim of this research was to examine in what way pedestrians look at manually driven cars or drivers in cars at a parking lot. The ANOVA measure shows that the difference between the mean AOI counts during the different TOIs is significant for all TOIs. The post hoc Tukey-Kramer analysis shows that eye contact is significantly different (p <0.001) for the Driving Car and Parked Car TOI. The higher percentage of the Eye contact AOI during the Driving Car interaction could imply that eye contact is more relevant in interactions with Driving Cars than with Parked Cars. This could be explained by the fact that eye contact is often used as an indicator of safety, ensuring the pedestrians that the driver has seen them. In dynamic situations, the risk is higher and thus the need for ensuring safety might be higher [13]. By looking at the wheels pedestrians are able to make an estimation of the distance and velocity of the driving car. The significant difference (p <0.001) for the Wheels AOI during the Driving Car and Parked Car TOI might indicate that this estimation is used to assess the risk in dynamic situations.

It should also be stated that during the Driving Car interactions the car would approach the participant from the front, due to the indicated walking path being against traffic direction. During the Parked Car interactions this was not always the case. This might have obstructed the possibility to establish eye contact during the Parked Car TOIs. The significant (p <0.001) difference between the Driving Car - Parked Car TOIs with respect to the Driver AOI could indicate the participant would look at the driver more often if eye contact could not be established. For future research this could be investigated by using a controlled set-up in which eye contact can be an manipulable parameter.

The mean interaction duration for a Parked Car TOIs is longer than for a Driving Car TOIs, while the mean interaction count for the Driving Car TOIs is higher than the Parked Car TOIs. This can be explained by the different dynamics of the interactions. Due to the velocity of the Driving Cars they did not remain in the field of view of the participant as long as the Parked Cars, which were stationary. If the rear lights indicated that the car would drive backwards, the participants often slowed down its pace or fully stopped moving, resulting in a longer interaction duration. The significant difference (p <0.001) for the Lights AOI when comparing the Driving Car and Parked Car interaction could be explained by the focus on the rear tail lights during the Parked Car interaction, which indicate the actions of the car [8].

The decrease in head movement in the Y-direction (Figure 2 and 8) is due to the bobbing of the head while walking [14]. When a participant was unable to move along the indicated path the bobbing of the head stopped. The prolonged eye contact in the cases mentioned in the results might be

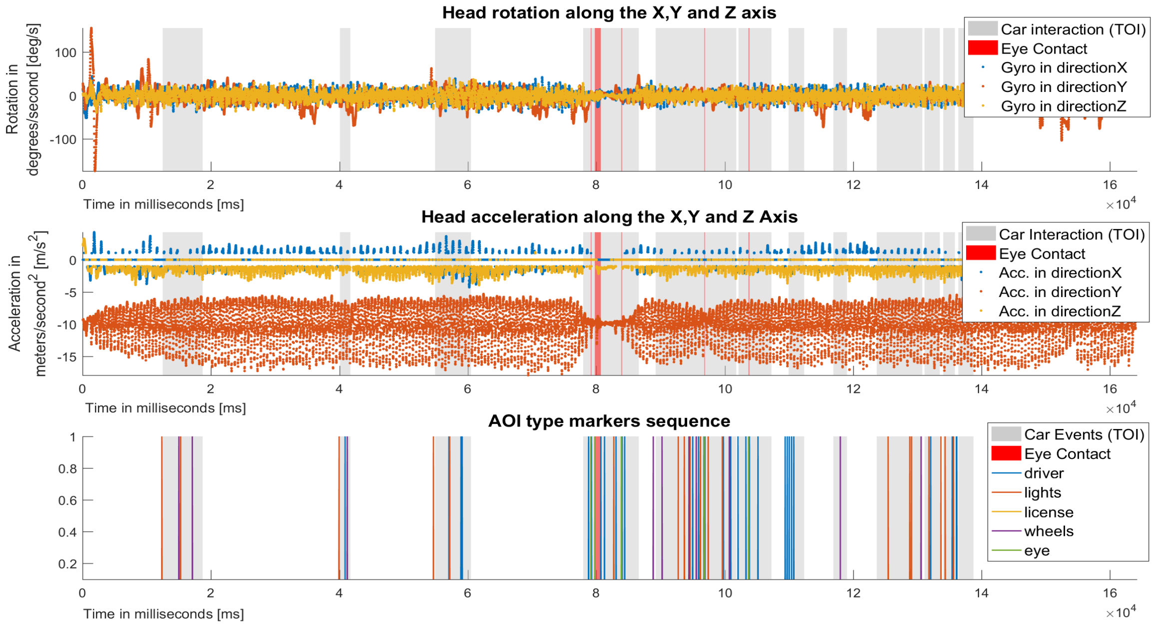

Fig. 8. Acceleration, rotation, TOIs and AOIs for participant 29

a form of nonverbal communication where the participant establishes eye contact to determine the intentions of the driver.

B. *Data quality*

The obtained gaze samples during the TOIs are low. However, in comparison with other research using Tobii Pro Glasses 2 in dynamic situations, the same gaze samples were found [15]. There are multiple factors to be taken into account that might be responsible for this low sample frequency. The dynamic interactions in the parking lot combined with rapid head movements of the participants could have contributed to a low sample frequency. The lightning conditions in the parking lot were sub-optimal against expectation. The lack of diffuse light caused a contrast which might have influenced the gaze sample.

A reason for the difference between the results of the inter-rater reliability of manual annotation could be the human factor of subjectivity. The definitions of the different AOIs and TOIs should be more extensive, to reduce the factor of human subjectivity. Comparing the results of the inter-rater reliability a consensus could not be made regarding a specific TOI, since the definitions of the TOIs were not extensive enough. This led to a different interpretation of the same interaction. Regarding the Eye Contact AOI, it was difficult to make a clear distinction if the driver was also looking back at the participant. A future research could be conducted where both the driver and the pedestrian would wear an eye tracking device. By comparing the gaze points of both eye tracking devices a more decisive result wheter eye contact was established could be obtained.

VI. CONCLUSION

This research shows that eye contact is part of the visual scanning behaviour of pedestrians at a parking lot. By looking at the wheels and the lights of a car, a pedestrian can asses its actions. Establishing eye contact with the driver ensures the pedestrian that they are seen and provides them with a sense of security. When eye contact could not be established pedestrians tend to look at the driver more often. Based on these findings the recommendation of this research is that for the development of driverless AVs eye contact should be taken into account and further analyzed.

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