# Comparison of Eye Tracking Systems with One and Three Cameras

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**ABSTRACT**

When using eye movements to determine the state of a car driver it is important that the eye tracker is robust, unobtrusive, inexpensive and fully automatic. The objectives of this study are to compare the performance of a one-camera system with a three-camera system and to investigate if the accuracy and availability of the one-camera system is sufficient to monitor driver state. Data from 53 subjects were evaluated and the results indicate that there is not much difference between a single-camera system and a multi-camera system as long as the driver is looking straight ahead. However, with more peripheral gaze directions, the larger coverage that is provided by the additional cameras works in favour of the multi-camera system.

**Author Keywords**

Eye tracker, availability, accuracy, precision.

**ACM Classification Keywords**

H.3.4 Systems and Software: Performance evaluation, H.1.2 User/Machine Systems: Human factors

## INTRODUCTION

Eye movement tracking is an important tool when measuring behaviour in different domains such as neuroscience, psychology, industrial engineering and human factors, marketing/advertising, and Computer Science [1]. In early days, eye tracking technology was both invasive and obtrusive, thus limiting the areas of application. However, today it is possible to use portable eye trackers that allow real-time eye tracking in realistic environments [2].

Eye tracking is mainly used in research to discover new knowledge in the above mentioned domains, but technology is now spreading to consumer products where it is of interest to monitor human state. One example is the automotive industry where eye movements can be used to measure driver behaviour in many different ways. For example, the *gaze direction* has been used to measure visual distraction based on where the driver is looking [3], and the *fixation duration* [4], the *gaze concentration* [5] and the *saccade amplitude* [4] has been found to vary with cognitive distraction. Further, different blink parameters such as the *blink duration* and the *blink velocity* have been used to recognise drowsy driving [6]. Prerequisites for such consumer oriented products are that they are inexpensive, non-obtrusive, fully automated and highly robust. This means that it is necessary to use remote cameras (in contrast to helmet mounted eye trackers), and to lower the cost by using as few cameras as possible.

The objective of this paper is to compare two remote eye tracking systems mounted in the cockpit of a car. In particular, performance of the two systems will be compared in order to determine when it is sufficient to use a one-camera system and when a several-camera system is required.

## METHODOLOGY

The two eye tracking systems were evaluated based on their availability, accuracy and precision. *Availability* (or tracking ratio) is defined as the total amount of logged gaze data divided by the maximum number of gaze data during some time period. This measure is related to the robustness of the system, but it says nothing about its accuracy. *Accuracy* is defined as the angular difference between the mean of all gaze log entries for a specific gaze target and the corresponding true gaze direction. This means that accuracy is related to the offset error of the system, but it says nothing about the robustness of the system. Finally, *precision* is defined as the standard deviation in angle between the tagged gaze log entries for a specific gaze target.

### Participants

53 participants aged between 30 to 60 years, 50% males and 50% females, were included in the evaluation. The participants should have normal visual acuity without

wearing glasses (contact lenses were allowed), facial piercings were prohibited (earrings were accepted), different hair lengths were allowed (participants with long hair were asked to put their hair up) and the body length should lie between 155 and 193 cm (to fit the range of the camera).

### Measurement Setup

The one-camera system used in the study was the Smart Eye AntiSleep system (Smart Eye AB, Gothenburg, Sweden). The system uses a single standard camera of VGA resolution together with IR flash illuminators. The IR illuminators and filters are tuned to frequencies with minimum interference of outdoor light, making the system robust to all natural illumination conditions in automotive applications. Smart Eye AntiSleep measures the driver's head position and orientation, gaze direction and eyelid opening at a rate of 60 Hz. The three-camera system used is the Smart Eye Pro (Smart Eye AB, Gothenburg, Sweden). The system has similar properties as the one-camera system, but also facilitates gaze direction in full 3D.

The data collection took place in a driving simulator at Saab AB in Trollhättan, Sweden. 41 dots at predetermined fixed locations were used as gaze targets, 14 in the cockpit of the car (Figure 1) and 27 outside the vehicle. The dots light up for 2 seconds so that the participant knows where to look. Each participant performed the experiment with and without eyeglasses. The eyeglasses had rather heavy frames and were the same model for each participant. The order of eyeglasses use (with or without mock-up eyeglasses) was randomized for all participants as well as for the sequence of the dots.

### RESULTS

Out of the 53 participants, four were excluded from further analysis due to technical problems during data collection. Additional issues that were excluded from further analyses include incomplete fixation during the 2 seconds that the gaze target was active, erroneous camera calibration and bad initialization.

**Figure 1. The layout of the LED inside the cockpit (small dots: LED; large dots: eye tracking camera location for three-camera system; square: eye tracking camera location for one-camera system).**

### Availability

Availability per participant is presented in Figure 2. It can be seen that availability is really low for several participants. Availability is about 20 percent better for the three-camera system, something that is directly related to the coverage of the cameras (a single camera cannot see the eyes when the participant is looking at several of the peripheral dots).

An ANOVA analysis ($p$ = 0.05) reveals that availability is affected by the location of the current dot and the age and gender of the participant. There is also an interaction between the angular distance of the current dot and the eye tracking system that is used, where availability decreases more with distance for the one-camera system as compared to the three-camera system. There are no significant

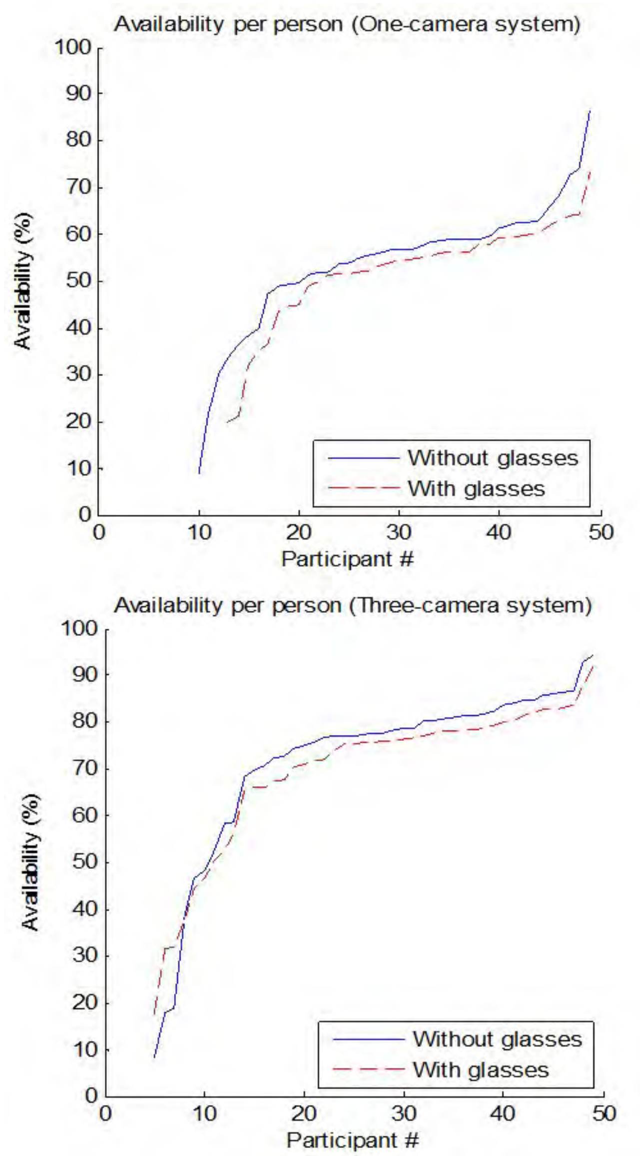


**Figure 2. Availability per participant.**

differences due to the eye glasses. Distance is defined as the angular distance from the active gaze target to the central gaze target that is located in front of the driver.

Availability results when dividing the gaze targets in three regions are presented in Table 1. The regions are defined by ellipses with horizontal radius *r* and vertical radius *2r/3*, where $r \leq 20°$ for the central region, $20° < r \leq 120°$ for the middle region and $r > 120°$ for the outer region.

**Accuracy**

ANOVA results related to accuracy shows that the main differences in accuracy are due to the eye tracking system that is used and the distance from the central region. Figure 3 shows 2D maps of accuracy and availability for the one-camera and the three-camera system. The three-camera system has high accuracy and availability (coloured in blue) in a larger area compared to the one-camera system. The maps are constructed by interpolation between the measured availability and accuracy values in the 41 dots.

**Precision**

Figure 4 illustrates the precision and accuracy of the one-camera versus the three-camera system when the participants are not wearing glasses. In the central area the precision (ellipses) and accuracy (lines) are similar between the two systems, but the three-camera system performs better in peripheral areas. No systematic changes in precision due to glasses versus no glasses could be found.

**DISCUSSION**

The motive for this study was to evaluate eye tracking systems based on one or three cameras in terms of accuracy, availability and precision. The results show that both accuracy and availability decreases with the distance from the central region, and that the decrease is larger for one camera as compared to three cameras.

According to the statistical tests, both accuracy and availability deteriorates with distance from the central gaze target. There are also clear trends that this deterioration is larger for the one-camera system as compared to the three-camera system, and the same trends can be seen for precision. This means that with more cameras, you obtain higher accuracy, availability and precision over a larger area. There was also one unexpected finding, namely that eyeglasses did not significantly affect the tracking performance. This is a result which we cannot explain.

There are a few peculiarities related to the three performance indicators that are used to assess the eye tracking systems. The most important thing to remember is that the three indicators should never be interpreted individually. Availability in itself can be misleading since it is not affected by where the participant is looking. This means that if a participant is looking straight ahead, where the eye tracking system has better performance, instead of at a peripheral gaze target where he/she is supposed to look according to the experimental protocol, this peripheral gaze target will get very high marks on availability. Similarly, accuracy (and precision) is calculated based on data with a certain quality. This means that only high quality data is used in the actual calculations. If the system is unable to measure the gaze direction for most of the time, the calculations will be very unreliable. It would have been possible to punish such unreliable data with a weighting function, but this was not done in this study.

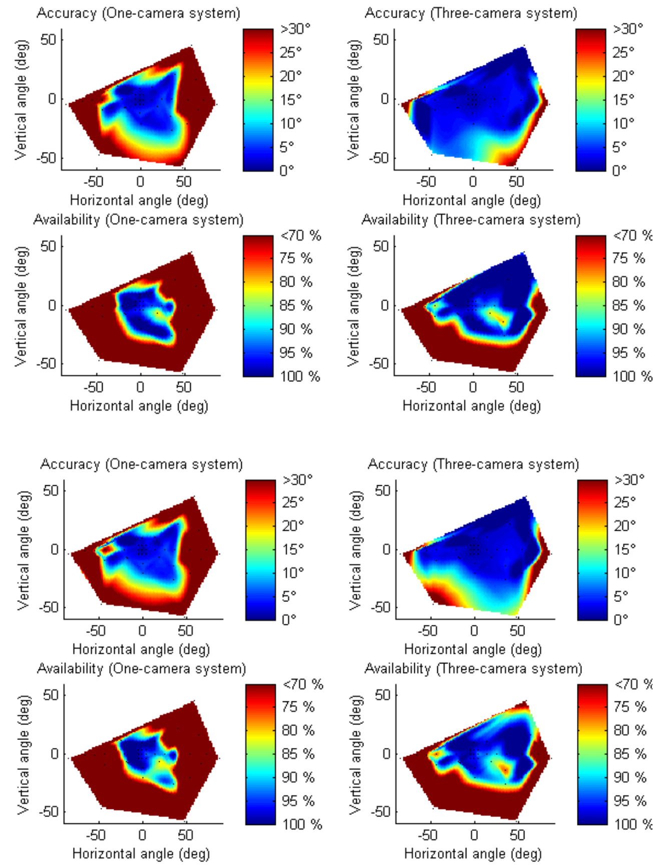


**Figure 3. 2D-maps of accuracy and availability encoded by color. The top four subplots illustrates when the participants are not wearing glasses and the bottom four subplots illustrates when they are wearing glasses.**

| | No glasses | | | | Glasses | | | |
|---|---|---|---|---|---|---|---|---|
| | All | Centre | Middle | Outer | All | Centre | Middle | Outer |
| One-camera system | 53.9 | 84.0 | 63.8 | 5.0 | 52.2 | 86.9 | 60.8 | 2.1 |
| Three-camera system | 71.6 | 84.1 | 82.1 | 37.2 | 69.6 | 85.7 | 80.7 | 30.7 |

**Table 1. Overall availability (mean values) in different regions based on the distance from straight ahead.**

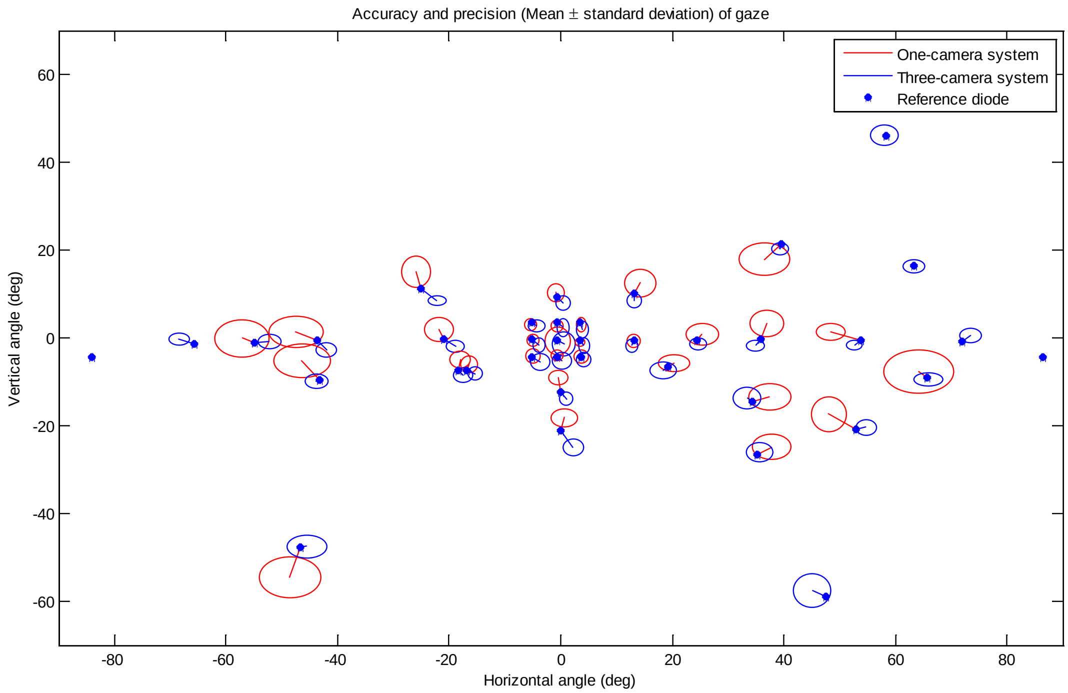


**Figure 4. Precision and accuracy of the measurements for each dot, where the ellipses indicate the average standard deviation across participants and the lines indicate the accuracy (distance from the reference point). Results are omitted in cases where the precision calculations are based on less than 15 % of the data.**

Limitations to this study include that only eye trackers from one manufacturer were included in the evaluation and that the tests were conducted in a static setting in a simulator as compared to a dynamic real-world environment.

Thresholds defining when availability, accuracy and precision levels are acceptable are hard to provide. In general, algorithms for sleepiness warnings only require high quality data in the central region. This could also be sufficient for visual distraction algorithms, but then it is very important that the system only delivers data when tracking is available since the warning system will implicitly assume that lost tracking means that the driver is not looking in the central region.

## CONCLUSION

Advantages with a one-camera system are that it is cheaper, easier to operate and easier to install in a vehicle. A multi-camera system will, on the other hand, provide higher availability and accuracy for areas that are far from the road centre. A one-camera system is thus mostly suitable for in-vehicle applications such as systems that warn drivers for sleepiness or internal distraction while multi-camera solutions are preferable for applications such as visual distraction where it is necessary to know where the driver is looking.

## ACKNOWLEDGEMENTS

We would like to thank VIP - Virtual Prototyping and Assessment by Simulation for financial support. We would also like to thank our industrial partners in this project, Saab Automobile AB, SmartEye AB and Pixcode AB.

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