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Relationship between 3D Eye-Gaze and the TrueDepth Measured by Vive Pro Eye

Kenta Kato and Oky Dicky Ardiansyah Prima

Graduate School of Software and Information Science Iwate Prefectural University (Japan)

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g236s002@s.iwate-pu.ac.jp

■ About Me

KENTA KATO received the master's degrees in Software and Information Science from the Iwate Prefectural University, Japan, in 2018. I am currently a doctoral student at the Iwate Prefectural University developing 3D eye tracker. I am a member of the Information Processing Society of Japan.

Contents

■ Background :: Head-Mounted Display (HMD)-type devices

Expanding Virtual Reality (VR)

With the general consumer availability of VR HMDs, 3D content has become more accessible.

These contents are used for product design, new training methods, and other applications that are difficult to reproduce in a real environment.

Walmart, "VR Headsets Train Associates In-Store,"

Youtube, <https://www.youtube.com/watch?v=F1FQ5cYpvh4>

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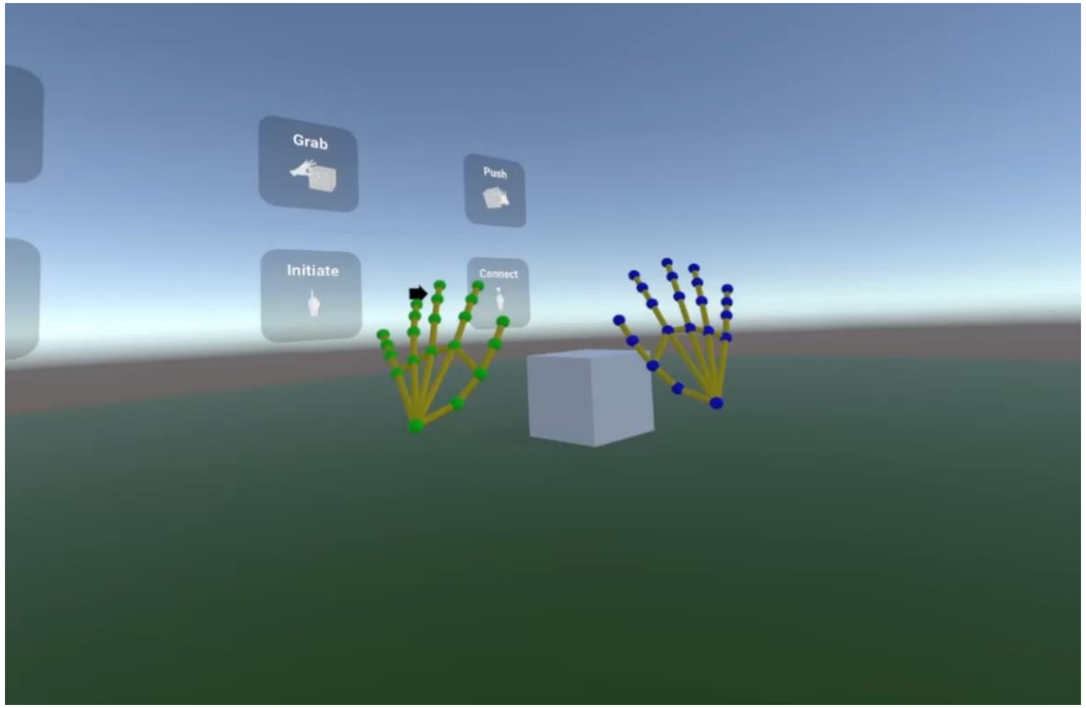
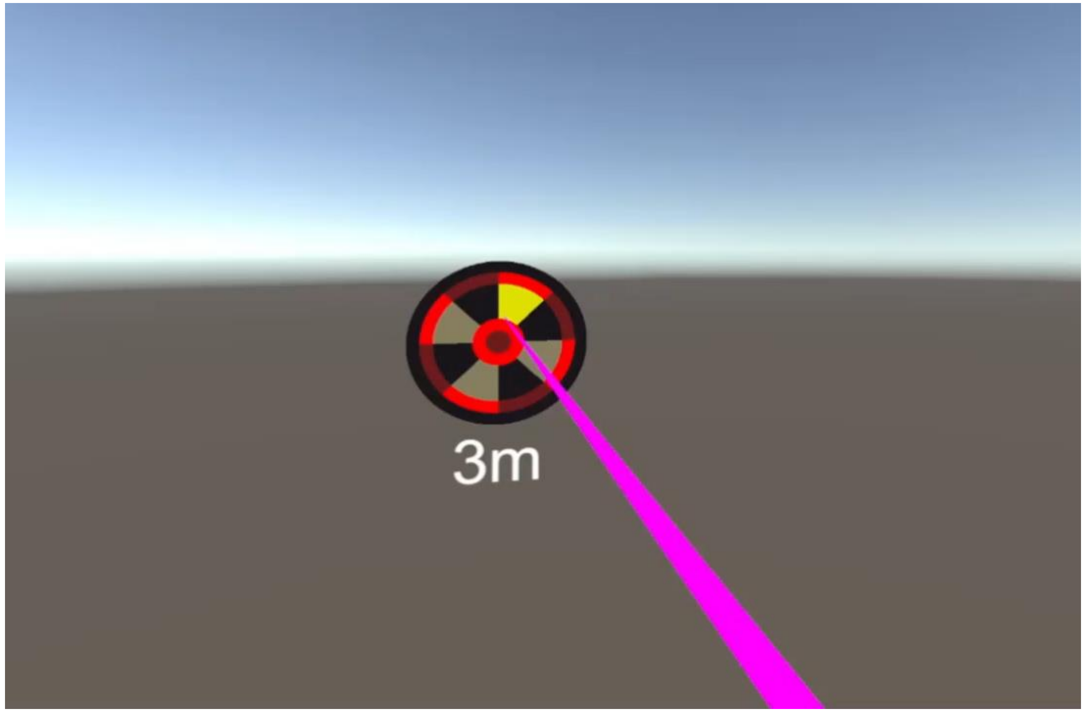
■ Background :: Interactions

Hand Tracking



3D content can be manipulated by inputting the **hand movements** through controllers and hand gestures.

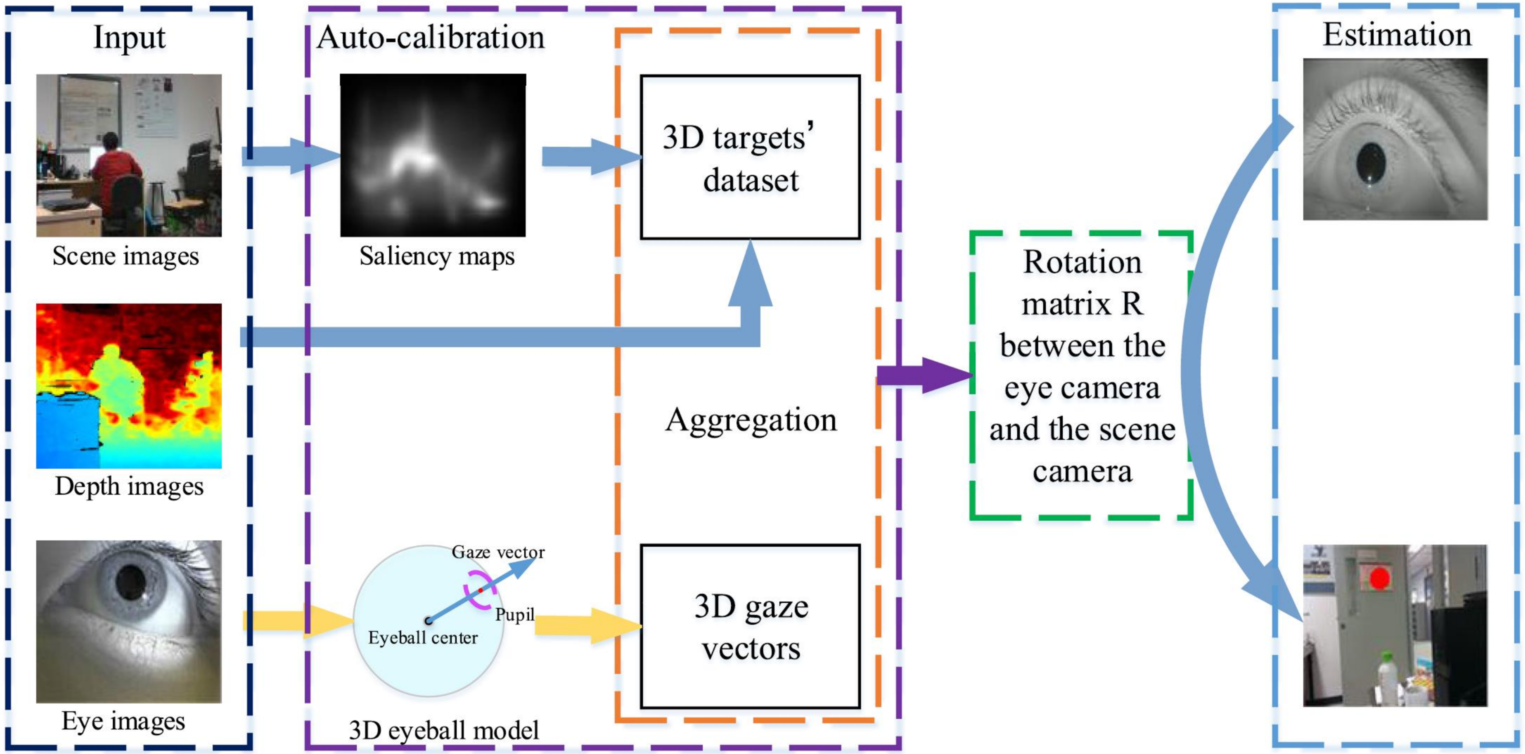
Eye-Gaze Tracking



3D content can be manipulated by inputting the **eye-gaze direction** acquired from the camera image.

■ Background :: Automated 3D Eye-Gaze Measurements

***Liu et al (2020)* [1]**



An automatic 3D eye-gaze measurement using 3D salient pixels of RGB-D images and eye-gaze vectors achieved an **average angular error of 3.7°** and an **average depth error of 55.9 mm** in the 1m~4m range.

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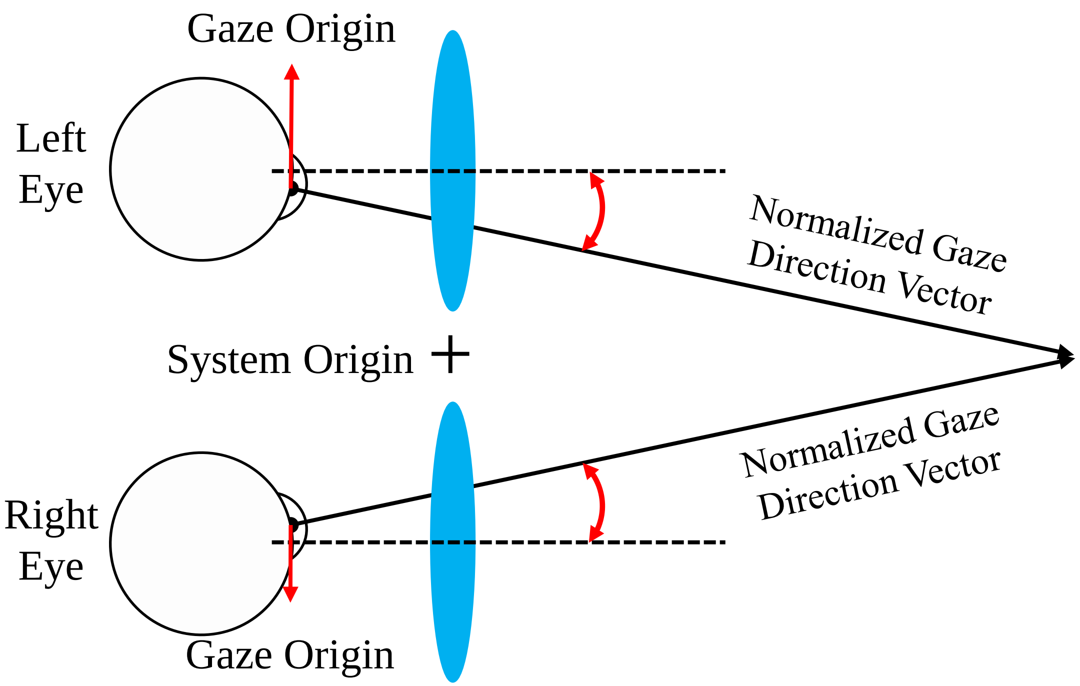
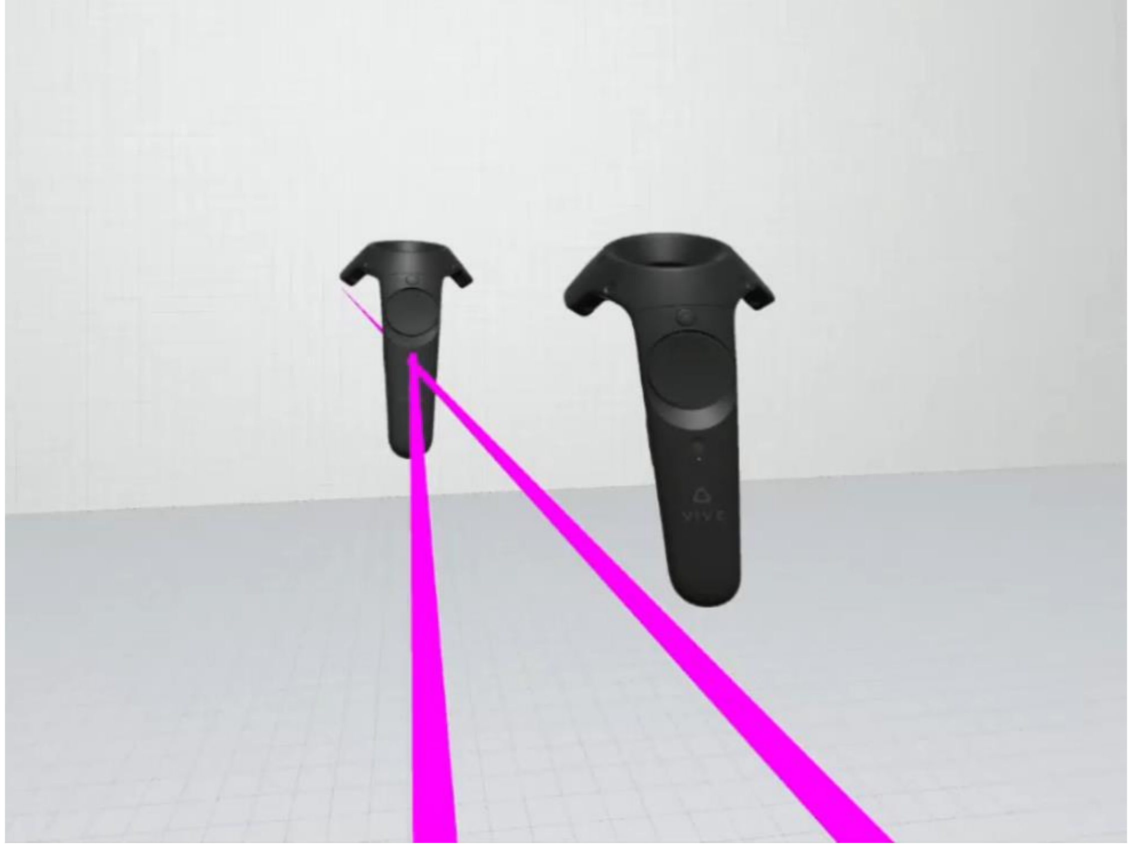
■ Background :: Vive Pro Eye

Eye-Gaze in 3D Coordinates

There is currently a lack of rigorous research investigating the accuracy of 3D eye-gaze with the Vive Pro Eye and the impact of gazing distance and direction on the accuracy.

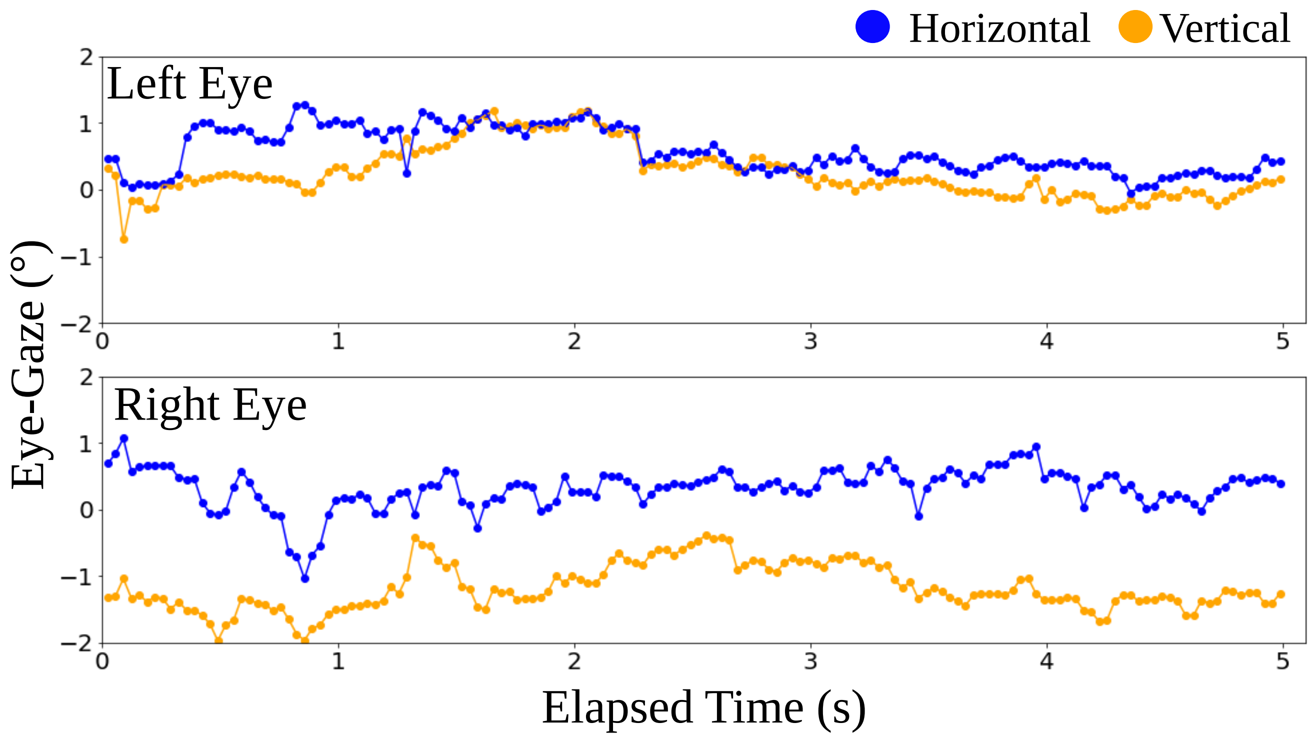


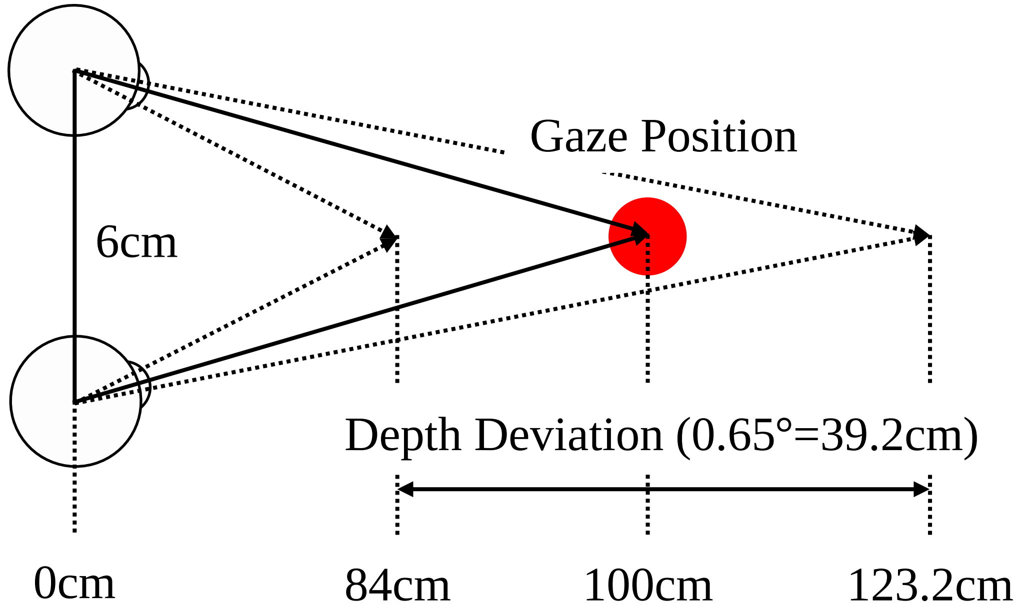


■ Background :: Stability of 3D Eye-Gaze

***Otero-Millan et al (2014)* [2]**

Since our eyes never remain completely still as we try to align our eye-gaze with the object, 3D eye-gaze measurement is less stable than that of 2D eye-gaze.





※ This is an example of gazing at a center visual target (x: 0°, y: 0°) 1 m in front for 5 seconds.

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■ Research Aims

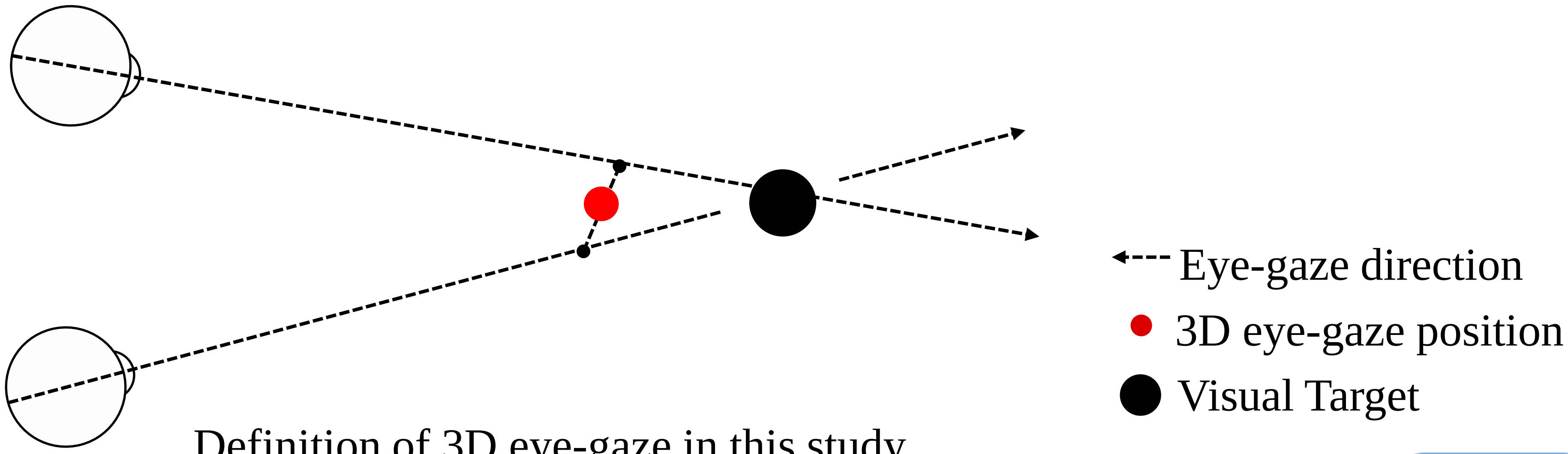
The aim of this study is to evaluate the gaze measurement capability of the Vive Pro Eye in terms of 3D gaze measurement.

- To analyze the distribution of eye-gaze information in 2D and 3D acquired using the Vive Pro Eye.
- To analyze the influence of small involuntary eye movements on eye-gaze depth position during fixation.
- To characterize the eye-gaze at any given direction and distance.

■ How to Assess 3D Eye-Gaze

Concepts

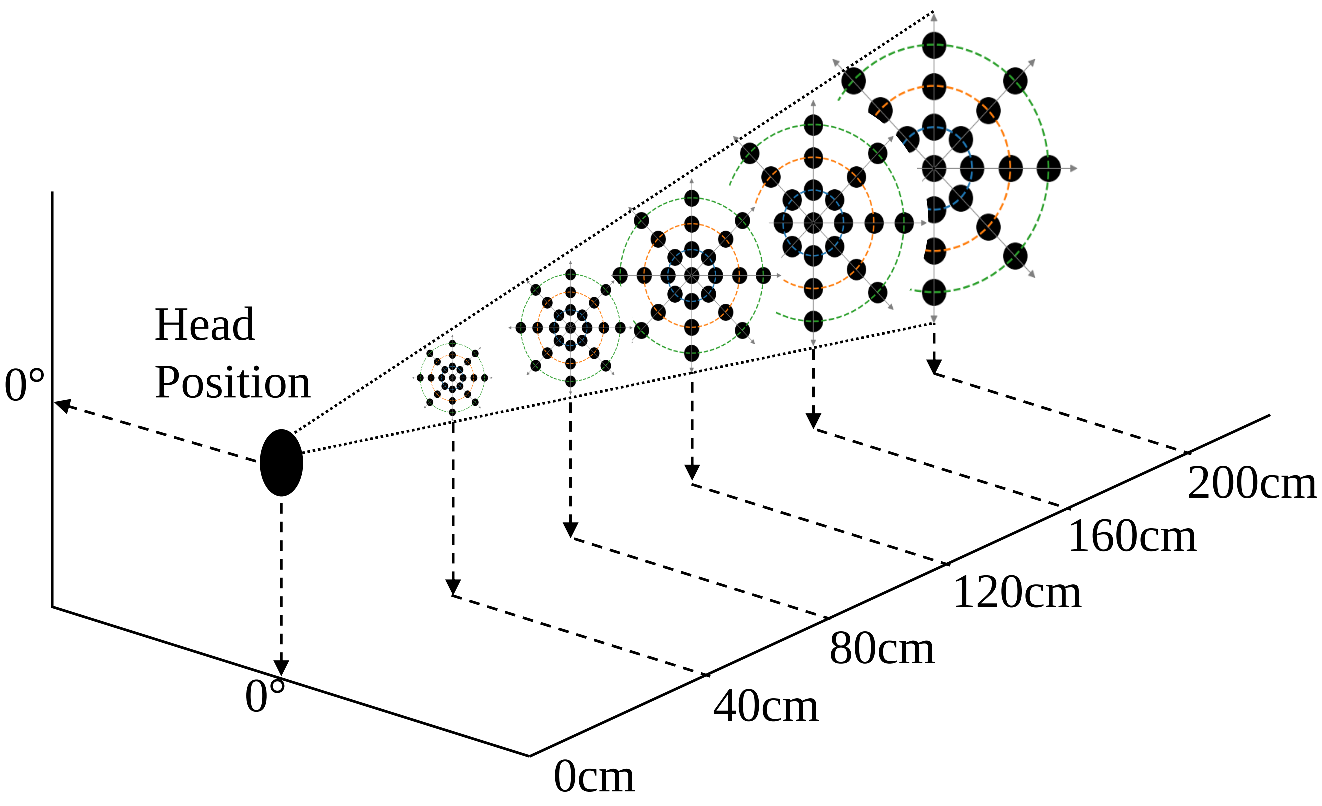
We measure the 3D eye-gaze position when gazing at each visual target placed in 3D space and compare the real positions.
The midpoint of the line segment connecting the closest points of the binocular eye-gaze vector is calculated as the 3D eye-gaze position.



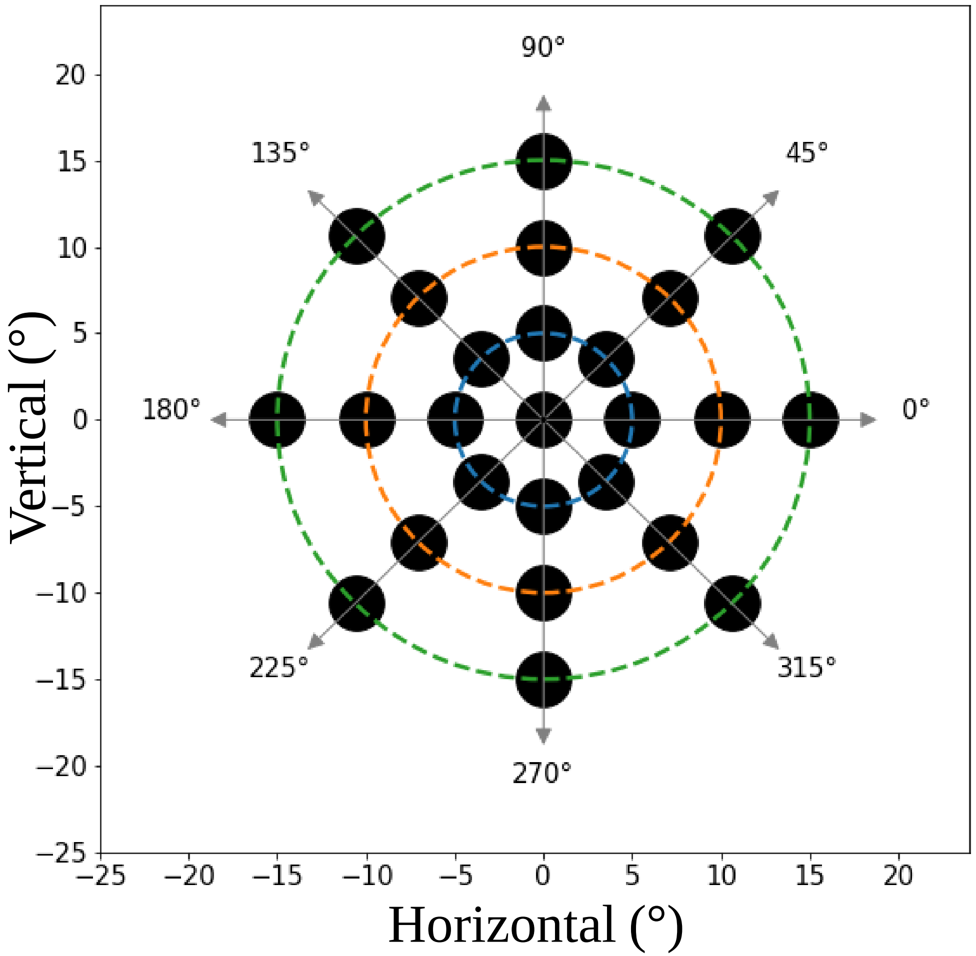
Definition of 3D eye-gaze in this study

■ How to Assess 3D Eye-Gaze

Visual Targets



Arrangement of planes containing the visual targets.



Visual targets placement for each plane

Visual Targets
10° viewing angle
20° viewing angle
30° viewing angle

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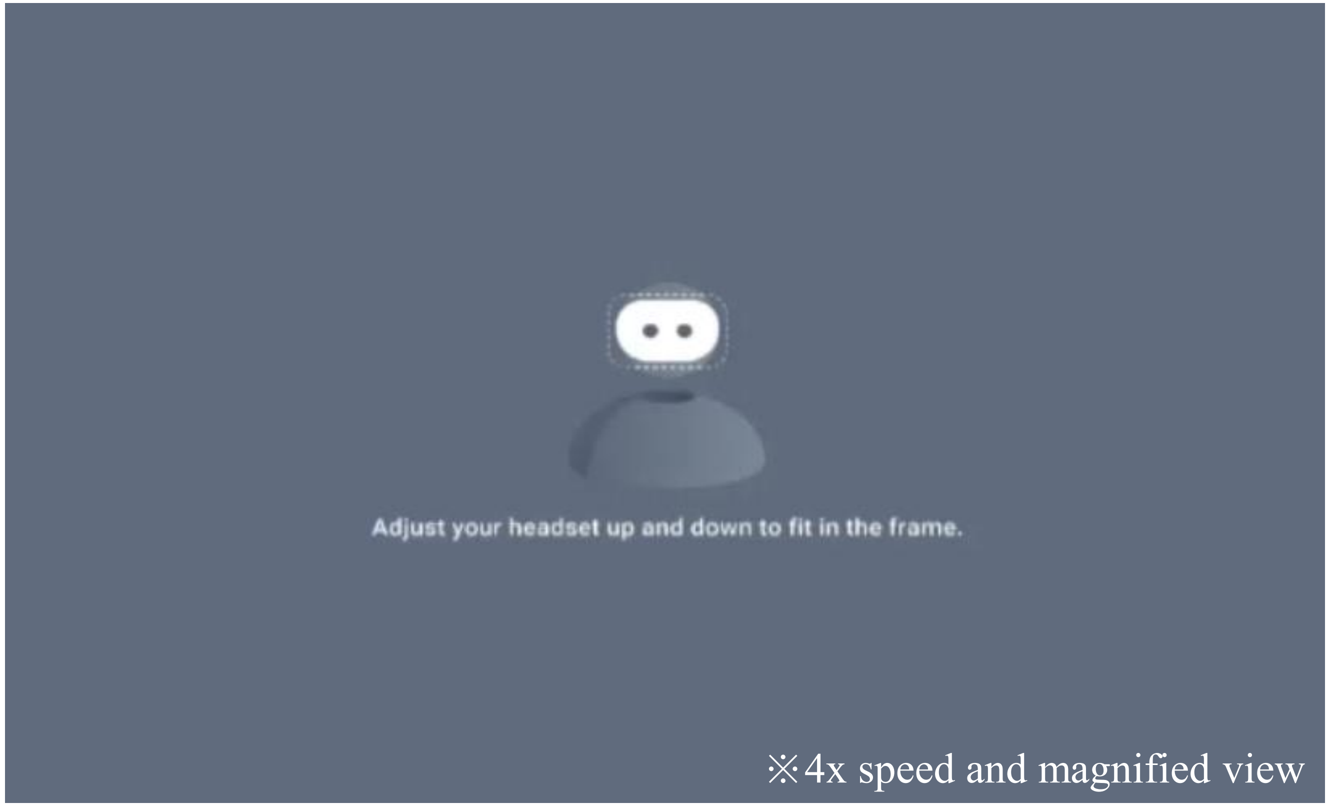
■ Eye-Gaze (2D) Calibration using Vive Pro Eye

Procedure

Correct with standard Vive Pro Eye 5-point eye-gaze calibration to obtain an accurate eye-gaze vector.

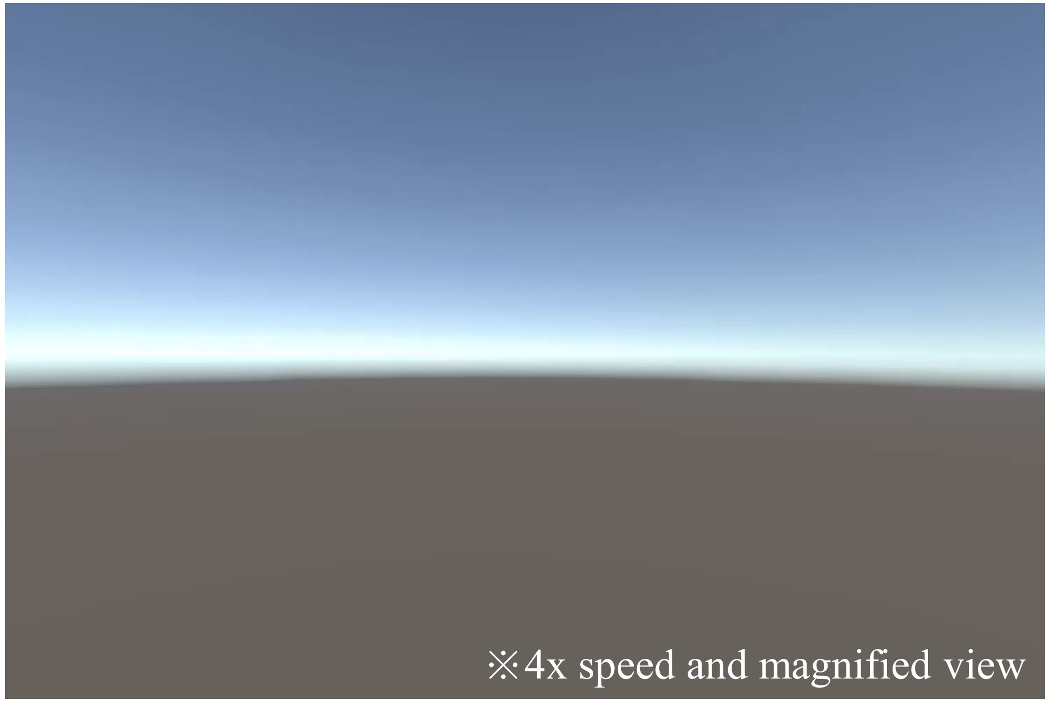


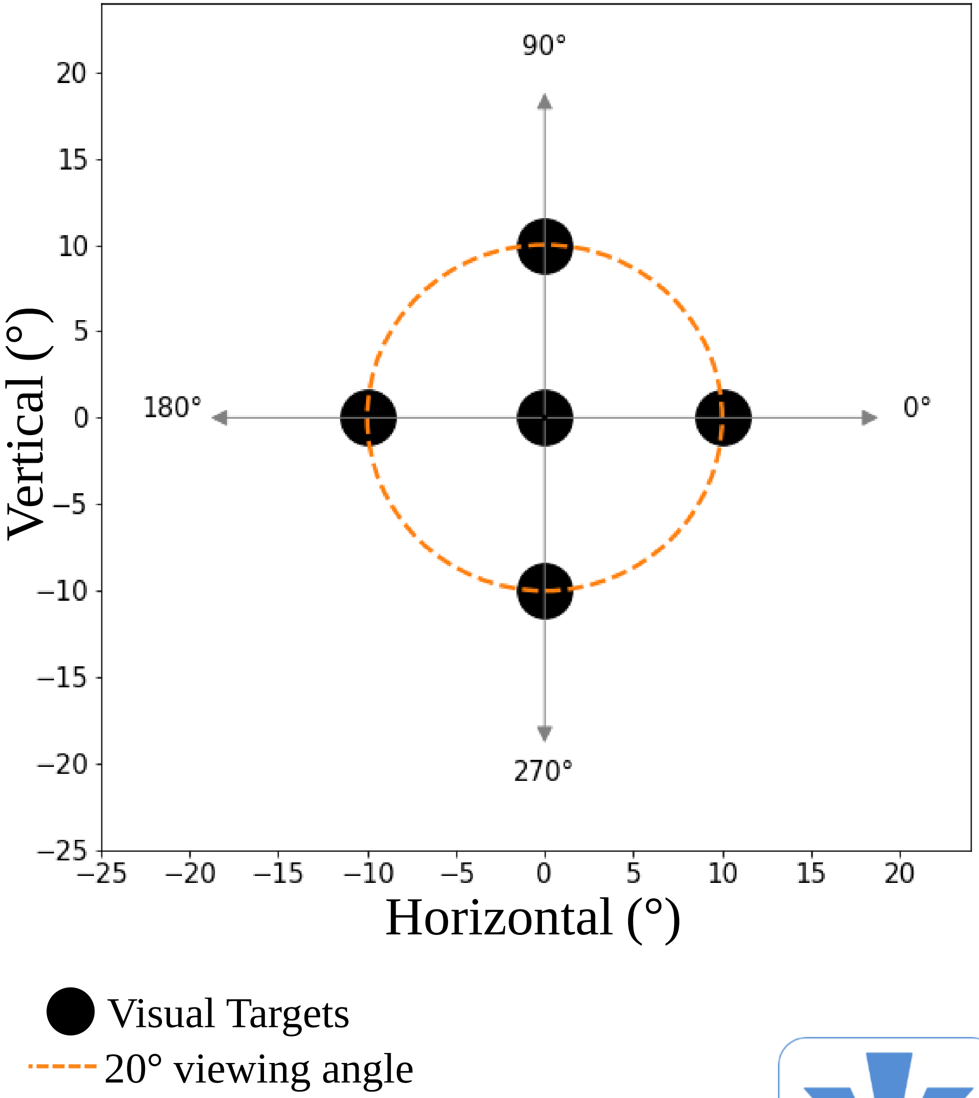
※4x speed and magnified view

■ Accuracy Validation of Eye-Gaze (2D) Calibration

Procedure

Validate the eye-gaze accuracy using the 5-point validation target created for this experiment.
※ If binocular eye-gaze accuracy is greater than 1°, return to Vive Pro Eye standard calibration.

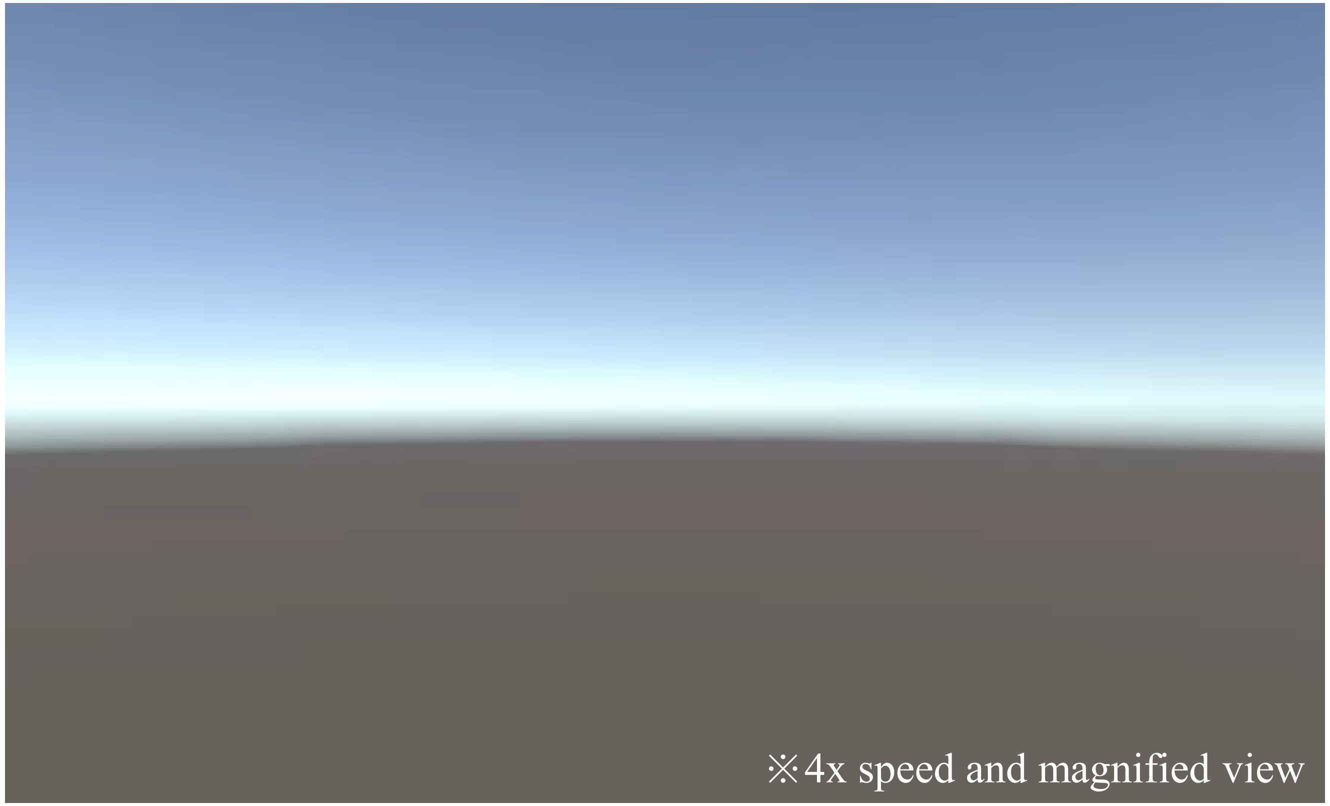




■ Eye-Gaze (3D) Measurement in This Study

Procedure

When the subject triggers the controller, each target performs a gaze measurement for 3seconds.
The measurement is terminated after 125 trials.



■ Experiments

Subjects

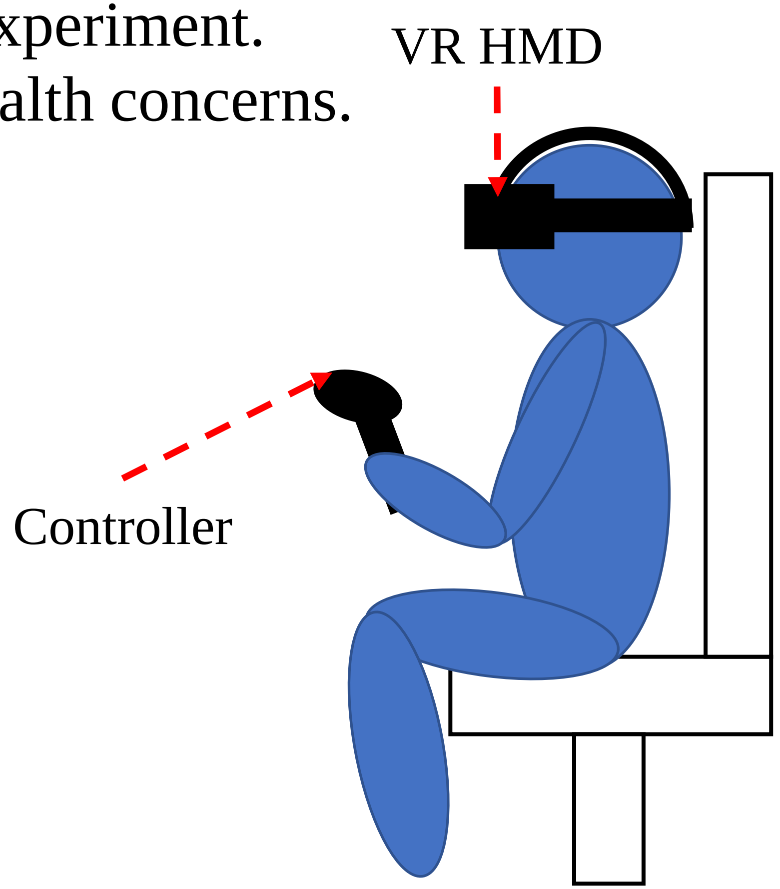
8 subjects (7 male and 1 female) participated in the experiment.
Their visual acuity is 1.0 or over and they have no health concerns.

Hardware

VR-HMD : Vive Pro Eye
Computer : Ryzen 9 3900 3.1GHz processor
DDR4 64GB RAM
NVIDIA Geforce RTX 2060
Super graphics card

Software

VR System : Unity3D 2019.4.31f1
VR Platform : SteamVR 1.21.12
Eye-Gaze Data : SRanipal Runtime 1.3.2.0



Subjects during the experiment

■ Results

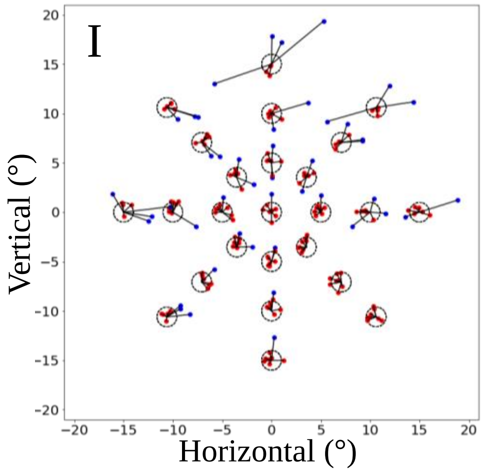
2D Eye-Gaze Accuracy

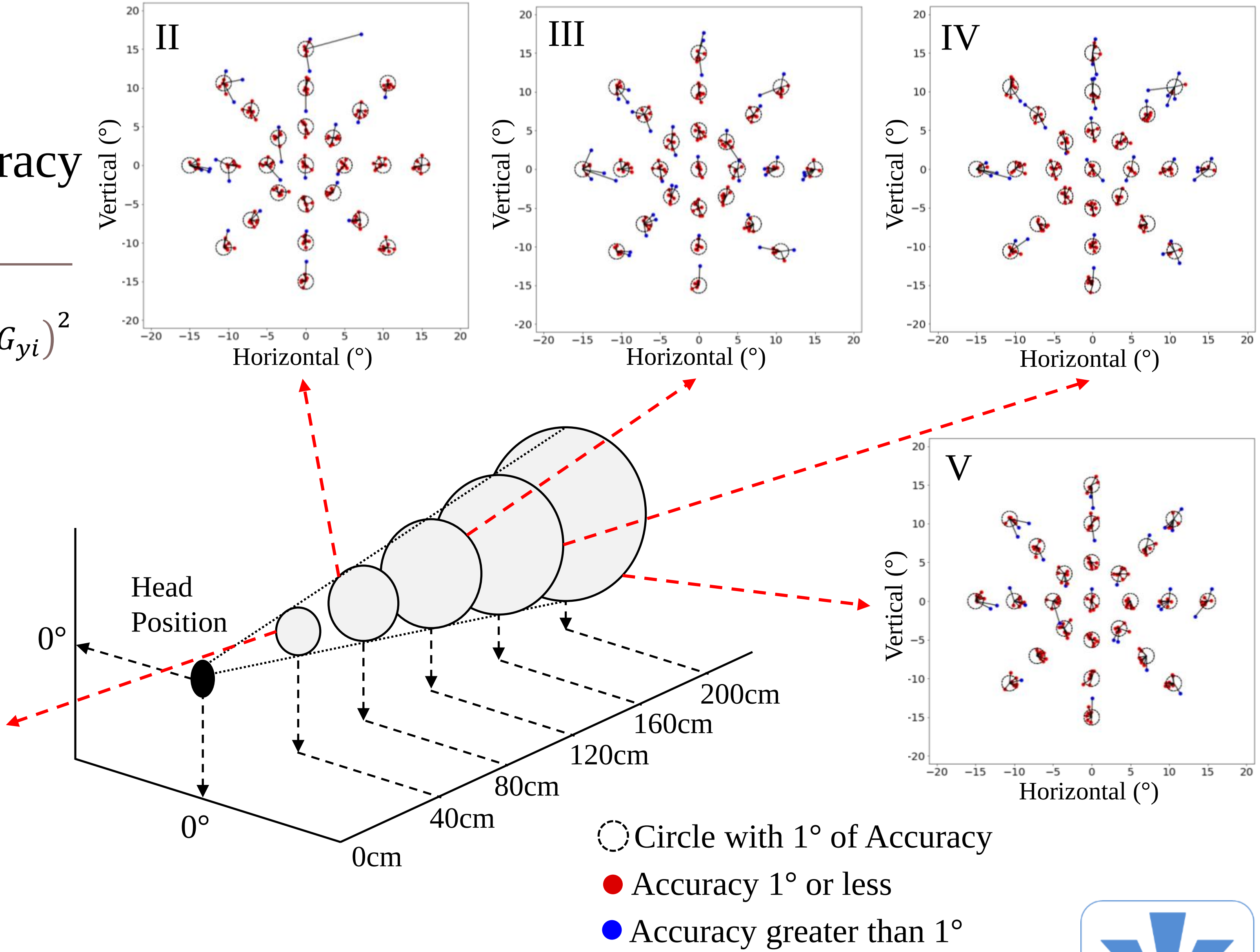
The 2D gaze measurement accuracy $Accuracy_{2D}$ are measured by

$$Accuracy_{2D} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(T_{xi} - G_{xi})^2 + (T_{yi} - G_{yi})^2}$$

i-th Visual target position (T_{xi}, T_{yi})

i-th 3D eye-gaze position (G_{xi}, G_{yi})

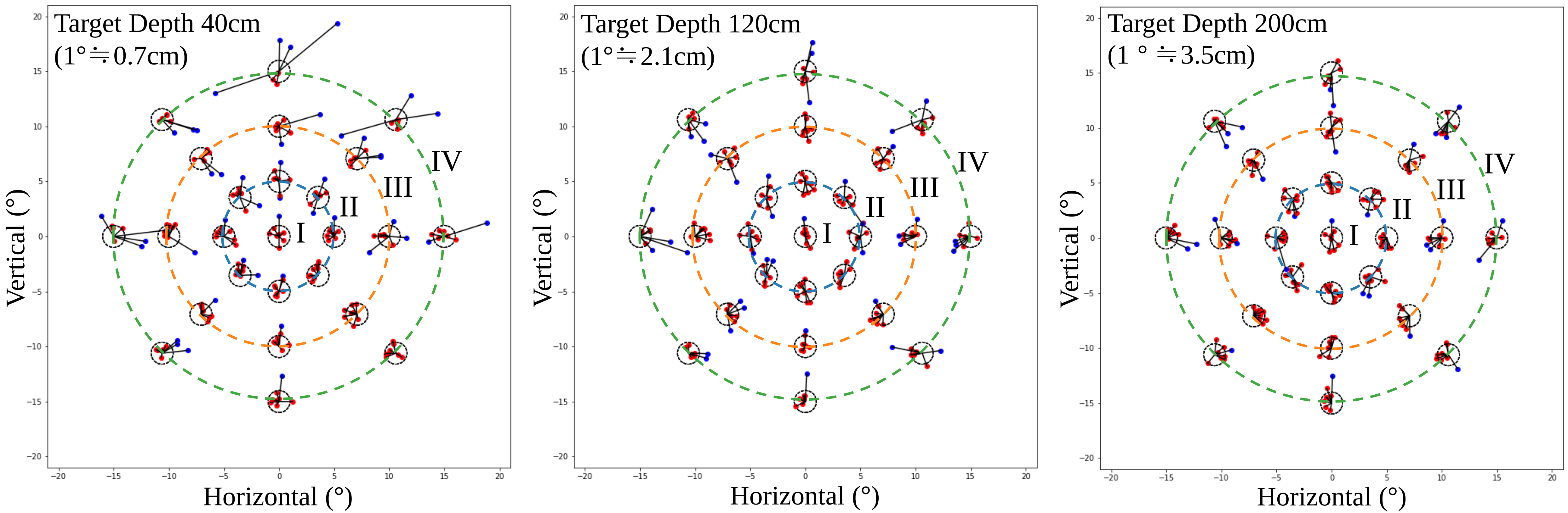




■ Results

2D Eye-Gaze Accuracies

◌ Circle with 1° of Accuracy
● Accuracy within 1°
● Accuracy 1° and over



There was a statistically significant difference in mean accuracy score between at least four groups (I ~ IV) in **viewing angles** ($F(3, 28) = 3.379$, $p =$ **0.0321**).

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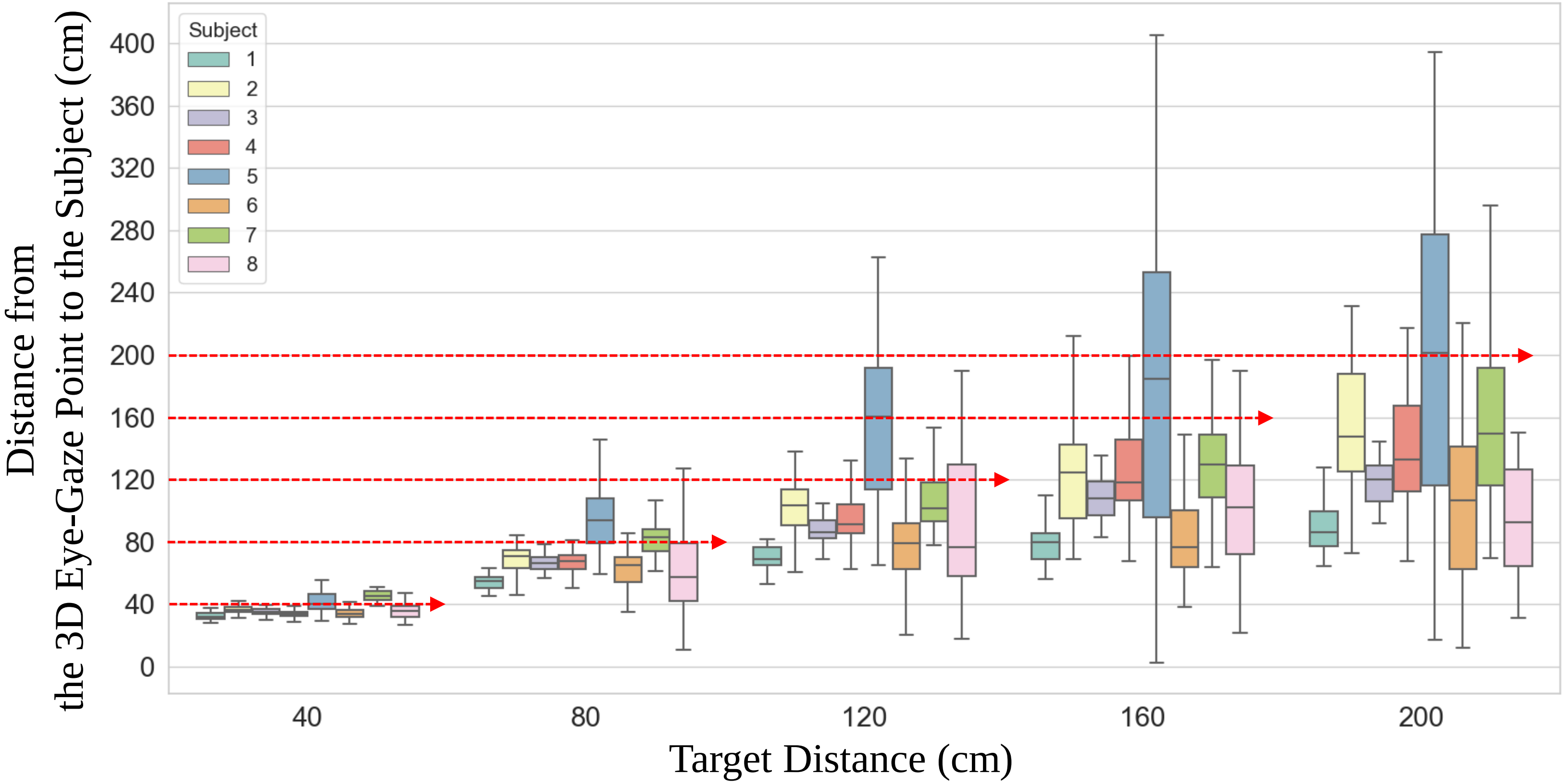
■ Results

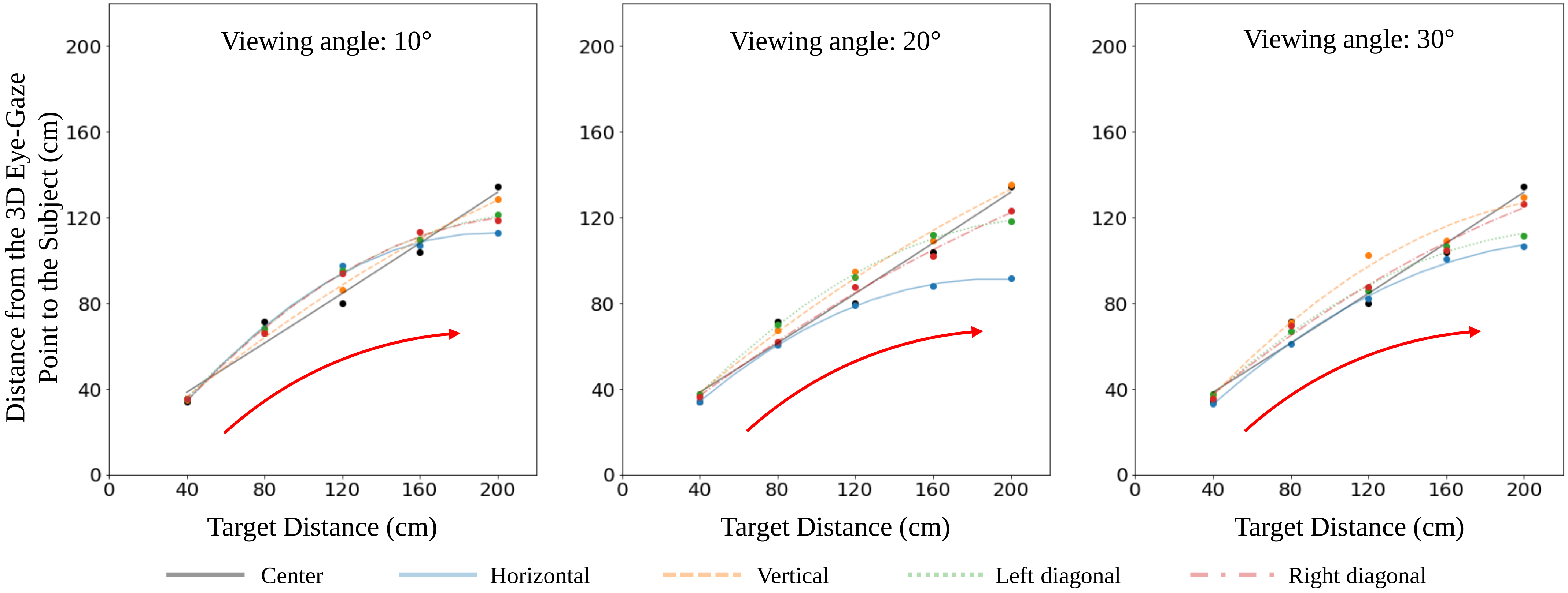
3D Eye-Gaze versus TrueDepth



The distribution of each subject's 3D eye-gaze increases with gazing distance.
This trend was not observed from the accuracy of the 2D eye-gaze.

■ Results

3D Eye-Gaze versus TrueDepth



The 3D eye-gaze to the centrally located visual targets increases linearly, whereas the rest of the eye-gaze shows logarithmic growth.

■ Conclusion

- The estimated distance from the 3D eye-gaze measurement point to the subject tends to be closer than the actual distance (TrueDepth).
- We found that 3D eye-gaze to a centrally located visual target increased **linearly**, while the rest of the eye-gaze increased **logarithmically**.
- Small involuntary eye movements were found to affect the stability of the 3D eye-gaze measurement. The distribution of eye-gaze points was found to increase with gazing distance.

■ References

1. M. Liu, Y. Li, and H. A. I. Liu, "3D Gaze Estimation for Head-Mounted Eye Tracking System With Auto-Calibration Method," in IEEE Access, 8, pp. 104207-104215, 2020. https://doi.org/10.1109/ACCESS.2020.2999633
2. J. Otero-Millan, S. L. Macknik, and S. Martinez-Conde, "Fixational Eye Movements Binocular Vision," Frontiers in Integrative Neuroscience, 8(52), pp. 1-10, 2014.