

Eye-Tracking Accuracy in Robot Controls: Separating Genuine Issues from Artificial Barriers

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Abstract

Eye-tracking technology has been extensively researched for its potential as an input modality in human-robot interaction. It has undergone significant advancements in recent years, leading to enhanced accuracy. However, despite these improvements, the narrative of eye-tracker inaccuracy, which originated in 2001, remains prevalent in current literature. This critical review aims to investigate the validity of these longstanding claims and determine whether they are supported by substantial evidence or simply perpetuated through repeated citation. By examining influential and representative studies that state limited accuracy, we aim to determine the contemporary relevance of this assertion in various contexts. While not exhaustive, this review identifies key areas in which the inaccuracy claim may still be significant, particularly in specific robotic control applications. Our objective is to provide a nuanced understanding of eye-tracking accuracy and advocate for a contextual approach to evaluating it in modern robotic systems.

Keywords: Robotics, Eye-Tracking, Metrology.

Introduction

The accuracy of eye tracking has improved significantly, reducing errors from over 1° [1] to less than 0.6° with modern devices such as the Tobii Pro Glasses 3. This advancement has mitigated the impact of head movements, slippage and involuntary eye movements, such as lens jitter, which were a significant issue in earlier systems used to control robotic arms. Consequently, the idea that limited accuracy is a general problem with eye-tracking technology is being questioned.

Our previous work indicated that the narrative of insufficient or limited accuracy is frequently echoed by other researchers. In light of the diverse research backgrounds influencing eye-tracking-based robotic controls, it is crucial to adopt distinct perspectives rather than merging these statements into a generalized assumption. The present paper explores specific viewpoints that contribute to claims of limited accuracy in eye-tracking-driven controls, assesses the current validity of these claims, and estimates the accuracy deficiencies reported in the reviewed studies.

Analysis of Accuracy Claims

The present analysis identified 20 such publications in which limited accuracy was

cited as a motivator for research. In four studies it was found that the claim for insufficient eye-tracking accuracy is not valid due to outdated nature of the works cited. The references used are between 10 and 20 years old. The studies in question addressed the technological challenges of that era [2-5].

In the context of systematic reviews and circumstances involving environmental and user-specific influences, user intent recognition, and 3D-gaze estimation, concerns regarding limited accuracy remain valid. It is mandatory that reviews state findings without initial interpretations. Therefore, in the included reviews the statement of insufficient eye tracking accuracy was found [6,7]. Important for new works is that these statements should be evaluated critically on their applicability.

Eye tracking outcomes are influenced by environmental factors, including illumination, as well as user-specific parameters such as ocular morphology and visual impairments [8,9]. Additionally, insufficient accuracy can result from errors in the calibration process [10,11]. Even though calibration might be good, the accuracy of the measurement may deteriorate over time due to the occurrence of slippage [12]. Slippage has been observed to occur at a higher frequency in cases where the eye-tracking glasses are not properly fitted to the participant's head. Accuracy errors in eye tracking glasses are worsened when the user

is forced to look through the periphery of the glasses [13].

In the context of user intent recognition, the accuracy of the eye tracker directly impacts the performance of trained machine learning models. These models often exhibit limited accuracy in predicting correct tasks or objects [14-18]. Given the reduced gaze accuracy, the gaze is consequently tracked next to the original fixation point, resulting in an inability to precisely match gaze patterns with objects or the environment. This mismatch can potentially lead to incorrect indications regarding the designated objects, which, in turn, may result in erroneous task predictions. In the majority of cases, the authors refer to prediction accuracy. Finally, issues with the accuracy of 3D-gaze estimation can be found in the depth measurements [19]. These accuracy errors can occur due to calibration drift and head movements [20]. Especially in robot control, such errors are complex to handle, particularly in the context of 3D-gaze estimation, which is used to track gaze behavior on small object features, obtaining information for user intent recognition based on hand-eye coordination. The depth information is used to instruct the robot to plan grasps or to move to a distinct location. Errors have been shown to result in unsuccessful task performance.

These rationales suggest that while the statement of insufficient or limited accuracy is applicable, it must be contextualized within specific scenarios. This review is not exhaustive and acknowledges that the scope of evaluated contexts does not encompass all potential influences on eye-tracking accuracy. It is important to note that additional biases may exist due to experimental setup, device specifications, and the diverse range of application settings.

Conclusion

The present analysis demonstrates that the extensive claim regarding the lack of accuracy in eye-tracking technology is not universally applicable. Our findings emphasize the importance of acknowledging and accounting for differing contexts and backgrounds in future reviews, in order to derive meaningful conclusions from accuracy metrics. The objective of this work is to emphasize the importance of differentiation by providing specific examples to illustrate the necessity for it. Further research is needed to identify additional contextual differences. It is assumed that analogous observations may be applicable to other research domains involving eye-tracking, where these results could be extrapolated.

It is therefore essential to define what is meant by 'inadequate accuracy'. In consideration of the extensive range of applications, it is not possible to establish a universal threshold. However, evidence suggests that in fields such as user intent recognition and 3D-gaze estimation, sub-millimetre accuracy is essential, as retrieving precise information from small object details is critical for effective control strategies. Conversely, in domains where less nuanced interaction is sufficient, errors up to a few centimetres are tolerable (e.g., in scenarios where gaze needs to align only with coarse bounding boxes to infer intent, supplemented by LLM techniques).

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