STAG: Smart Tools and Applications in Graphics (2023)
G. Manfredi, G. Caggianese, N. Capece, and U. Erra (Editors) *Poster*

A Gaze Detection System for Neuropsychiatric Disorders Remote Diagnosis Support

A. Cangelosi[1,2], G. Antola[1], A. Lo Iacono[1], A. Santamaria[1], M. Clerico[3], D. Al-Thani[4], M. Agus[4], C. Calì[5,6],

[1] Polytechnic University of Turin, Corso Duca degli Abruzzi, 24, 10129 Torino, Italy
[2] Intravides SRL, Corso Massimo D'Azeglio 52, 10026 Torino, Italy
[3] Laboratory of Neuroimmunology, Department of Clinical and Biological Sciences, University of Turin, Orbassano (TO), Italy
[4] Division of ICT, College of Science & Engineering, Hamad Bin Khalifa University, Doha, Qatar
[5] Department of Neuroscience "Rita Levi Montalcini", University of Turin, Corso Massimo D'Azeglio 52, 10126 Turin Italy
[6] Neuroscience Institute Cavalieri Ottolenghi, Regione Gonzole 10, 10043 Orbassano (TO), Italy

Abstract

Accurate and early diagnosis of neuropsychiatric disorders, such as Autism Spectrum Disorders (ASD) is a significant challenge in clinical practice. This study explores the use of real-time gaze tracking as a tool for unbiased and quantitative analysis of eye gaze. The results of this study could support the diagnosis of disorders and potentially be used as a tool in the field of rehabilitation. The proposed setup consists of an RGB-D camera embedded in the latest-generation smartphones and a set of processing components for the analysis of recorded data related to patient interactivity. The proposed system is easy to use and doesn't require much knowledge or expertise. It also achieves a high level of accuracy. Because of this, it can be used remotely (telemedicine) to simplify diagnosis and rehabilitation processes. We present initial findings that show how real-time gaze tracking can be a valuable tool for doctors. It is a non-invasive device that provides unbiased quantitative data that can aid in early detection, monitoring, and treatment evaluation. This study's findings have significant implications for the advancement of ASD research. The innovative approach proposed in this study has the potential to enhance diagnostic accuracy and improve patient outcomes.

CCS Concepts

• ***Applied computing*** → ***Health informatics;*** • ***Human-centered computing*** → *Pointing devices;*

1. Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder characterized by socialization, communication, and behavioral impairments [LMS09]. Early and accurate detection of ASD is crucial for implementing appropriate treatment and improving patient outcomes. Intervention at an earlier stage has been shown to be more effective, leading to better speaking and behavioral skills, as well as higher IQ scores [HMCM09; DRM*10]. However, timely and accurate diagnosis remains a challenge due to the complexity of clinical markers and the subjective nature of traditional assessments. In this context, the use of real-time gaze tracking and recognition (gaze detection) has emerged as an innovative strategy to support ASD diagnosis across patients of all cognitive levels and ages [PCH*11]. Gaze detection technology enables accurate monitoring and recording of eye movements, providing valuable information on visual-related cognitive activities and differences in attention mechanisms. For example, it can reveal whether a child primarily focuses their gaze on specific facial regions such as the mouth or eyes of a speaker [KJS*02; CIN*18]. Gaze analysis allows for the extraction of quantitative data, in contrast to the subjective nature of conventional diagnostic methods [FKP*18; BAQ23]. However, technical challenges to be faced include accuracy and calibration issues, environmental noise and interference, eye fatigue, and experimental setup. Although eye trackers have become more user-friendly, with the potential for remote usage [HCKH15], inaccuracies and low data quality raise concerns in experts[HCKH15; HNKH17]. To overcome the aforementioned issues, we propose a novel tracking system that is not only reliable and accurate but also easy to set up, and portable in a way that it could be directly incorporated into complex systems. The framework provides gaze recognition, tracking, and recording in a way to accurately measure and interpret eye movements in real-time. The system contains a calibration and a verification module, allowing for an accurate identification and quantification of pupil movements and the detection of abnormalities associated with the ASD condition. The main features of the system are the following:

- **a quantitative data analysis tool of recorded signals** (E.g. speed of movement): the proposed processing component goes beyond simple qualitative observation and it allows to formulate a diagnosis based on semi-objective analysis;

DOI: 10.2312/stag.20231306

- **a processing tool for checking the consistency between proposed pattern and followed trajectory**: we provide a preliminary evaluation of trajectory accuracy and preliminary guidelines for determining normal and abnormal gaze patterns;
- **a proof-of-concept implementation of the system:** we exploit the capabilities of state-of-the-art smartphones (in this case iPhone) equipped with *RGB-D camera* and we implement live, as well as remote analysis routines to support the diagnosis. Our prototype does not require spatial constraints between the visualization screen and the acquisition camera, providing a flexible experimental setup that easily allows for remote use.

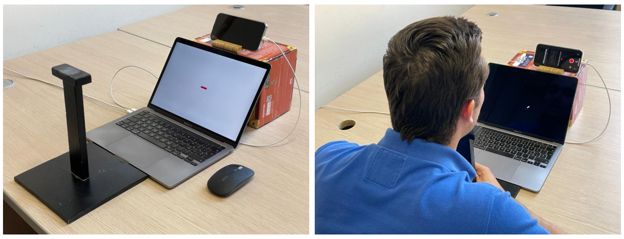

Figure 1: *Gaze detection setup: the system is composed by a smartphone with an RGBD camera integrated, and a screen with a user interface where the gaze is tracked.*

2. Methodology

Experimental Setup The configuration in Figure 1, for this preliminary analysis, includes the following components:

- An RGB-D camera, such as that already incorporated in many of the latest smartphones [BSK*19], is used in this study, specifically the one on the iPhone 13. The combination of the RGB-D camera and the Record3D application enable the grayscale, depth-related and contextually also color, eye and pupil imaging. The minimum working distance, on the other hand, is 150 *mm*, that can be considered adequate for most gaze tracking scenarios;
- A computer with a screen displaying a user interface where the user gaze is tracked. The screen is critical in the calibration phase but also in the application phase for the child to view the pattern to be tracked or watched.

Tools and Methods To capture images *Record3D* app on the iPhone is used:

- *Depth camera* provides grayscale images with 640*x*480 resolution, where pixel values were obtained in meters relative to the camera position;
- *RGB camera* captures color images focused on the eyes and pupils to detect markers

The acquired data is processed using *Python*: specific libraries, such as *OpenCV*, are leveraged for image processing and extraction of gaze tracking features. The *pin-hole camera model* and *perspective projection model* are applied to calculate the three-dimensional position of the pupils, with the origin centered on the camera itself. The *Direct Linear Transformation* (DLT) model [AKH15] and calibration parameters are used for correlation between pupil position and objects displayed on the screen. The observed position on the screen is obtained by linearly combining the calibration parameters with the position of the pupils in space. For face point detection and tracking, the *MediaPipe MeshFace* [LTN*19] model is used, which leverages machine learning techniques to create a three-dimensional representation of the face and identify key points such as the eyes, nose, and mouth. Finally, *Matlab* is used for visualization, filtering and data analysis.

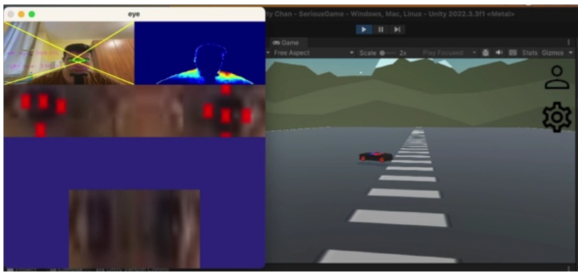

Figure 2: *Gaze detection in action: a serious game is used to attract the focus of the user while tracking eyes gaze.*

Figure 2 shows the system in action: the framework records the gaze of the user while she is following a virtual object in a serious game scenario. A demo of the system can be found in this link.

3. Results and Conclusion

Calibration and testing procedures were performed on a cohort of 17 subjects, all of whom had no reported underlying medical conditions. The age range of the participants fell between 18 and 24 years. The test consisted of asking the participant to follow with his or her eyes the motion of an object that appears on the screen in random positions and bounces according to a deterministic law, always maintaining the same speed of $15 pixel/frame$ ($8.7\ cm/s$) for a period of 30 *seconds*(see Fig. 2). The preliminary results showed that the proposed gaze tracking system achieves remarkable accuracy (average error of 48 pixels) in detecting and recording eye movements while observing a screen, compared to setups specifically designed for this task. Despite some limitations, the system is of interest to domain experts and hence could benefit from further development through the integration of machine learning techniques and experimentation with telerehabilitation, in particular for ASD. Furthermore, aside the signal processing aspects, AI-powered computer vision algorithms could be exploited to further improve the accuracy of the gaze tracking system and evaluate the application of gaze tracking through mobile devices in remote rehabilitation of autism spectrum disorders. This study opens up new perspectives for the use of gaze tracking as a clinical assessment and therapy tool in the field of autism spectrum disorders, offering more accessible and convenient support than traditional methods.

Acknowledgments This work was supported by the GFI grant from the University of Torino to CC and is part of the project NODES, which has received funding from the MUR–M4C2 1.5 of PNNR with grant agreement number: ECS00000036.

References

[AKH15] ABDEL-AZIZ, YOUSSET I, KARARA, HAUCK MICHAEL, and HAUCK, MICHAEL. "Direct linear transformation from comparator coordinates into object space coordinates in close-range photogrammetry". *Photogrammetric engineering & remote sensing* 81.2 (2015), 103–107 2.

[BAQ23] BANIRE, BILIKIS, AL THANI, DENA, and QARAQE, MARWA. "One size does not fit all: detecting attention in children with autism using machine learning". *User Modeling and User-Adapted Interaction* (2023), 1–33 1.

[BSK*19] BREITBARTH, ANDREAS, SCHARDT, TIMOTHY, KIND, COSIMA, et al. "Measurement accuracy and dependence on external influences of the iPhone X TrueDepth sensor". *Photonics and Education in Measurement Science 2019*. Ed. by ROSENBERGER, MAIK, DITTRICH, PAUL-GERALD, and ZAGAR, BERNHARD. Vol. 11144. International Society for Optics and Photonics. SPIE, 2019, 1114407. DOI: 10.1117/12.2530544. URL: https://doi.org/10.1117/12.2530544 2.

[CIN*18] CAMPISI, LISA, IMRAN, NAZISH, NAZEER, AHSAN, et al. "Autism spectrum disorder." *British Medical Bulletin* 127.1 (2018) 1.

[DRM*10] DAWSON, GERALDINE, ROGERS, SALLY, MUNSON, JEFFREY, et al. "Randomized, Controlled Trial of an Intervention for Toddlers With Autism: The Early Start Denver Model". *Pediatrics* 125.1 (Jan. 2010), e17–e23. ISSN: 0031-4005. DOI: 10.1542/peds.2009-0958. eprint: https://publications.aap.org/pediatrics/article-pdf/125/1/e17/1008520/zpe00110000e17.pdf. URL: https://doi.org/10.1542/peds.2009-0958 1.

[FKP*18] FRAZIER, THOMAS W., KLINGEMIER, ERIC W., PARIKH, SUMIT, et al. "Development and Validation of Objective and Quantitative Eye TrackingBased Measures of Autism Risk and Symptom Levels". *Journal of the American Academy of Child Adolescent Psychiatry* 57.11 (2018), 858–866. ISSN: 0890-8567. DOI: https://doi.org/10.1016/j.jaac.2018.06.023. URL: https://www.sciencedirect.com/science/article/pii/S0890856718313327 1.

[HCKH15] HESSELS, ROY S, CORNELISSEN, TIM HW, KEMNER, CHANTAL, and HOOGE, IGNACE TC. "Qualitative tests of remote eyetracker recovery and performance during head rotation". *Behavior Research Methods* 47 (2015), 848–859 1.

[HMCM09] HOWLIN, PATRICIA, MAGIATI, ILIANA, CHARMAN, TONY, and MACLEAN Jr., WILLIAM E. "Systematic Review of Early Intensive Behavioral Interventions for Children With Autism". *American Journal on Intellectual and Developmental Disabilities* 114.1 (Jan. 2009), 23–41. ISSN: 1944-7515. DOI: 10.1352/2009.114:23-41. eprint: https://meridian.allenpress.com/ajidd/article-pdf/114/1/23/2023450/2009_114_23-41.pdf. URL: https://doi.org/10.1352/2009.114:23-41 1.

[HNKH17] HESSELS, ROY S, NIEHORSTER, DIEDERICK C, KEMNER, CHANTAL, and HOOGE, IGNACE TC. "Noise-robust fixation detection in eye movement data: Identification by two-means clustering (I2MC)". *Behavior research methods* 49 (2017), 1802–1823 1.

[KJS*02] KLIN, AMI, JONES, WARREN, SCHULTZ, ROBERT, et al. "Visual Fixation Patterns During Viewing of Naturalistic Social Situations as Predictors of Social Competence in Individuals With Autism". *Archives of General Psychiatry* 59.9 (Sept. 2002), 809–816. ISSN: 0003-990X. DOI: 10.1001/archpsyc.59.9.809. eprint: https://jamanetwork.com/journals/jamapsychiatry/articlepdf/206705/yoa10221.pdf. URL: https://doi.org/10.1001/archpsyc.59.9.809 1.

[LMS09] LEVY, SUSAN E, MANDELL, DAVID S, and SCHULTZ, ROBERT T. "Autism". *The Lancet* 374.9701 (2009), 1627–1638. ISSN: 0140-6736. DOI: https://doi.org/10.1016/S0140-6736(09)61376-3. URL: https://www.sciencedirect.com/science/article/pii/S0140673609613763 1.

[LTN*19] LUGARESI, CAMILLO, TANG, JIUQIANG, NASH, HADON, et al. "Mediapipe: A framework for perceiving and processing reality". *Third workshop on computer vision for AR/VR at IEEE computer vision and pattern recognition (CVPR)*. Vol. 2019. 2019 2.

[PCH*11] PIERCE, KAREN, CONANT, DAVID, HAZIN, ROXANA, et al. "Preference for Geometric Patterns Early in Life as a Risk Factor for Autism". *Archives of General Psychiatry* 68.1 (Jan. 2011), 101–109. ISSN: 0003-990X. DOI: 10.1001/archgenpsychiatry.2010.113. eprint: https://jamanetwork.com/journals/jamapsychiatry/articlepdf/210964/yoa05050_101_109.pdf. URL: https://doi.org/10.1001/archgenpsychiatry.2010.113 1.