

# Eye Tracking: A Comprehensive Review of Methods and Applications

Nilo T. Bugtai<sup>1</sup>, Renann G. Baldovino<sup>1,2</sup>, Francisco Emmanuel T. Munsayac Jr. III<sup>1,3</sup>,  
Edison Anit<sup>1</sup> and Charmine Sheena Saflor<sup>1,3</sup>

<sup>1</sup>*Evelyn D. Ang - Institute of Biomedical Engineering and Health Technologies, 0922 Manila, Philippines*

<sup>2</sup>*Gokongwei College of Engineering, De La Salle University, 0922 Manila, Philippines*

<sup>3</sup>*Department of Innovation and Sustainability, School of Innovation and Sustainability, De La Salle University,  
0922 Manila, Philippines*

*nilo.bugtai@dlsu.edu.ph, renann.baldovino@dlsu.edu.ph, francisco.munsayac@dlsu.edu.ph, ed\_anit@dlsu.edu.ph,  
charmine.saflor@dlsu.edu.ph*

**Keywords:** Eye Tracking, Human Eye Movement, Iris Detection.

**Abstract:** Eye tracking has been around for decades, growing alongside the technology that supports it. Early systems were simple and often imprecise, but better cameras and smarter algorithms have made measurements far more reliable. Today, high resolution imaging and modern software can capture even tiny, moment to moment eye movements. This jump in precision does not just improve data quality; it also widens the kinds of questions researchers can ask. As a result, eye tracking studies have expanded quickly, offering clearer insight into how people pay attention, interpret what they see, and make decisions. This review traces that journey from the first basic setups to the most advanced systems available today and shows how these methods are now used across many fields. In recent years, eye tracking has also become increasingly accessible, integrated into consumer devices, and applied in diverse domains such as neuroscience, marketing, education, and virtual reality. These innovations not only enhance experimental accuracy but also democratize the technology, allowing a broader range of users to explore human perception and behaviour with unprecedented detail.

## 1 INTRODUCTION

Eye tracking technology has been studied as early as the 19th century. The initial studies available for eye tracking were based on observations of the researchers with the use of a mirror on the object of fixation and the researchers would then stand behind the participant to be able to observe their eye movements through the mirror [1]. Since then, the studies on eye tracking have been done and continued to develop as time passed. As the technology advances, so does the refinement of gathering data for various data. One of the methods in gathering data from participants is through eye tracking. Eye tracking allows for the researchers to be able to determine habits and other observations through the use of technology, some of these data gathered are gaze estimation, pupil dilation, duration of the time when the patient fixates their gaze on the object and the like. Through the improvement of the technology,

the requirements of the systems present also increase. Eye tracking is a field of research that continues to improve as more applications of eye tracking technology continue to be determined. Some industries that use eye tracking in their research are marketing and design, medicine, and the like [2]. The industries use eye tracking to be able to learn more information about the participants, especially the participants that are within their target market. Eye tracking is often used to detect when participants look away and to identify the items they subsequently fixate on [3]. In this review, the researchers examine the main methods for collecting and using eye tracking data and survey its current applications.

## 2 EYE TRACKING SYSTEMS

This section surveys recent literature on eye tracking systems and methods that are currently used or actively being explored.

## 2.1 Development of Real-Time Eye Tracking Algorithm

This study developed a real time eye tracking algorithm to improve iris detection and gaze classification. Although the circular Hough transform (CCHT) is commonly used for iris detection, its accuracy tends to drop when the subject is not facing the camera directly or when lighting varies. To address this, the authors used a facial landmark detector to locate the eyes and define a region of interest. Within this region, the system tracks eye movements and classifies gaze as left, right, or center, and it also detects eye blinks for potential use in drowsiness monitoring. The software was implemented in Python with OpenCV to keep it lightweight and portable. In testing, the method achieved 100% accuracy for iris detection and 90% for gaze position classification [4].

## 2.2 Saccadelenses: Interactive Filtering of Eye Tracking Trajectories for Exploration

The study repurposed an interactive filtering technique originally developed for geographic trajectory analysis and applied it to eye tracking data [5]. The method, called TrajectoryLenses, lets researchers narrow the dataset for local inspection, closely examine fixation patterns and the movements between fixations, and directly explore the spatial context of the stimulus [5]. To demonstrate the approach, the team ran an eye tracking experiment with a static stimulus and eight participants [5]. TrajectoryLenses provides three complementary filters: one that highlights outgoing trajectories, another for incoming trajectories, and a third that selects paths intersecting a chosen area; these filters can be combined to create stronger, more flexible queries [5]. The authors note that common analysis methods can oversimplify eye tracking records. By adding density based heat maps and flexible filtering, their workflow offers a more detailed and interactive way to explore and interpret the data [5].

## 2.3 iTrace: Tracking the Practical Eye

The researchers created iTrace, an infrastructure for integrating eye tracking into programming environments, and validated it with a live implementation [6]. Studies built on iTrace proceed

as follows. In iTrace Core, the investigator specifies the study and researcher names, assigns a participant ID, and selects a data directory, a combination that makes later processing more straightforward. Calibration then shows nine targets on the screen, and the calibration record is saved as both images and a file. After connecting the needed plugins to the core, tracking is started and the eye tracker feeds data directly to those plugins. The same interface has already been used in two peer reviewed studies, indicating its practicality [6].

## 2.4 Suitability of GA and PSO for Eye Tracking System

The study compared two optimization-based trackers for eye movement, pairing deformable template matching with either a genetic algorithm or particle swarm optimization [7]. Eyes were first detected using Haar like features, then tracked with GAET or PSOET while handling head motion, eye motion, blinks, and zoom, which often reduce accuracy [7]. On a 2.13 GHz machine with 2 GB RAM, both methods were implemented in Java with OpenCV in Eclipse and used a population or swarm size of 10 [7]. GAET produced predictions that closely matched the ground truth but reached only 91 percent accuracy, whereas PSOET achieved 98 percent and finished faster, leading the authors to prefer PSOET for future work [7].

## 2.5 Methods for Eye Tracking Analysis of Multiple Moving Targets

The study explored how eye tracking could be applied to multiple moving targets on a computer screen, tackling both the limitations of current systems and the complexity of tracking dynamic objects. The researchers developed a system that maps eye fixations to moving targets and introduced an algorithm capable of recording the sequence and duration of those fixations. They proposed that this method could reduce the number of areas of interest (AOIs) required for analysis by finding a balance between AOI size and tracking accuracy. To evaluate the system, they carried out a case study in which an air traffic controller completed a conflict detection task with several aircraft displayed on a simulated radar screen. The findings showed that the approach is a promising method for tracking multiple moving targets [8].

## 2.6 Optimization of Real-Time Eye Tracking Using Circular Hough Transform

The study used the circular Hough transform to find circular shapes in images. The authors noticed that eyes move more slowly than a typical 30 frames per second video, so the eye is not really changing position thirty times each second. With that in mind, they suggested adjusting the tracking pipeline so it does not process every single frame, even though this change initially raised CPU load. Because back-to-back frames often show the same motion, many frames are unnecessary. After skipping those repeats, processing time dropped a lot: about 1500 percent for slow eye movements and about 750 percent for fast ones. These gains came from removing frames that did not add new information [9].

## 2.7 A State-of-the-Art Review on Eye Tracking and Head Movement Detection

The paper reviews methods for eye tracking and head movement detection and shows how they are used in human computer interaction, driving assistance, and assistive technologies [10]. The authors group the approaches into two families: sensor based and computer vision-based methods [10]. Sensor based eye tracking measures the tiny electrical potentials produced by eye movements using electrodes, a technique known as electrooculography or EOG [10]. Computer vision methods are divided into six groups: pattern recognition, corneal reflection points, shape-based techniques, dark and bright pupil effects, model-based tracking, and hybrid systems [10]. Pattern recognition covers tools such as template matching, particle filters, rotated images, and prediction algorithms [10]. Corneal reflection methods estimate gaze direction from light reflections captured by the camera, using the vector between the pupil center and the corneal reflection, although they do require calibration [10]. Shape-based tracking identifies the iris or pupil using circular patterns or edge detection. Methods based on dark and bright pupil effects rely on camera images, with the dark pupil detected under normal lighting and the bright pupil effect created through infrared reflection. However, dark brown eyes can pose challenges for the dark pupil method due to low contrast. Model-based tracking incorporates natural head movements to minimize calibration, though the complexity of this approach limits its use in real time. Finally, hybrid methods combine several of these techniques to

improve accuracy and reliability [10]. As presented in Tables 1 and 2, the performance of these eye tracking and head movement detection methods was evaluated and compared.

Table 1: Result of the eye tracking methods.

Study	Detection Accuracy (%)	Angle Accuracy (°)	CPU Time (ms)
Eye Tracking using Pattern Recognition			
Raudonis et al. [11]	100.00	N/A	N/A
Kuo et al. [12]	90.00	N/A	N/A
Yuan & Kebin [13]	N/A	1	N/A
Lui & Lui [14]	94.10	N/A	N/A
Khairofaizal & Nor'aini [15]	86.00	N/A	N/A
Hotrakool et al. [16]	100	N/A	12.92
Shape-based Eye Tracking			
Yang et al. [17]	N/A	0.5	N/A
Yang et al. [18]	N/A	Horizontal: 0.327, Vertical: 0.3	N/A
Mehrubeoglu et al. [19]	90.00	N/A	49.70
Eye Tracking using Eye Models			
Zhu & Ji [20], 1 <sup>st</sup> scheme	N/A	Horizontal: 1.14, Vertical: 1.58	N/A
Zhu & Ji [20], 2 <sup>nd</sup> scheme	N/A	Horizontal: 0.68, Vertical: 0.83	N/A
Eye Tracking using Hybrid Techniques			
Li & Wee [21]	N/A	0.5	N/A
Huang et al. [22]	95.63	N/A	N/A
Coetzer & Hancke [23]	98.10	N/A	N/A

Table 2: Result of the head movement detection methods.

Study	Detection Accuracy (%)	Angle Accuracy (°)
CV-based Head Tracking		
Siriteerakul et al. [24]	N/A	3.32
Zhao et al. [25]	92.86	N/A
Zhao & Yan [26]	90.00	N/A
Accelerometer & Gyro-sensor Based Methods		
King et al. [27]	99.05	N/A
Nguyen et al. [28]	93.75	N/A

### 3 USES AND APPLICATIONS

This section of the paper explores the applications of eye tracking technology. The literature includes examples of how eye tracking is used across various industries, as well as recent advancements in the technology.

#### 3.1 Application in Aviation, Maritime and Construction Industries: A Systematic Review

This review paper systematically explored the literature on eye tracking in the industries of aviation, maritime, and construction. A total of 80 studies met the criteria for inclusion in the review. The researchers observed the distribution of eye tracking studies across various industries and noted the types of eye tracking methods used. They identified gaps in certain industries where more studies could enhance and validate existing eye tracking systems. Additionally, they suggested that future reviews could explore high-risk industries, such as space exploration [29].

#### 3.2 Front Camera Eye Tracking for Mobile VR

The study explored the use of virtual reality (VR) in eye tracking systems. A methodology was proposed that utilizes the captured images taken by the front camera of a mobile phone without any modifications. The system improves images from the front camera, especially when lighting is poor and contrast is low. It uses a processing pipeline that reduces lens reflections from the headset. After calibration, the captured images are used to build a linear mapping between on screen pixels and the estimated iris centroids, enabling real time iris tracking. In tests, the method performed on par with commercial eye trackers, particularly when the eyes are near the center of the headset field of view [30].

#### 3.3 Eye Movement Tracking & English Teaching Application Based on CNN-BLSTM

The study tested a virtual reality eye tracking setup that uses a mobile phone camera [31]. To improve performance, it enhances frames captured under low contrast or poor lighting and runs a processing pipeline that suppresses reflections from the headset lenses. After these adjustments, the system calibrates

the view and maps the estimated iris centroids to the screen's physical pixels, enabling real time iris tracking. In evaluations, its accuracy was comparable to commercial eye trackers, especially when the eyes stayed near the center of the headset's field of view [31].

#### 3.4 Automated Recording and Replay of High Speed Eye Tracking for Cognitive Studies in Software Engineering

The authors propose a data-collection approach that records the entire telemetry stream as it happens and postpones any gaze analysis to a later review. During playback at a slower speed, the system can anchor each gaze sample to the exact source file on screen, down to the specific line and column being viewed. To demonstrate the approach, they built a tool called *Déjà Vu* and evaluated it with three eye trackers running at 60, 120, 150, and 300 Hz. To cover popular development environments, they also ran time tests in Visual Studio and Eclipse. Their findings suggest that *Déjà Vu* is a solid basis for further software engineering research using eye tracking data since it consistently reconstructs sessions and maintains accurate mappings [32].

#### 3.5 Eye Movement Monitoring for Multimedia Content Ranking

The study examines how an eye tracking system can be integrated into teaching at Subotica Tech College of Applied Sciences. The technique uses light reflected from the cornea as a source and compares it to the eye center's trajectory. Eye tracking is highlighted as useful in medicine, marketing, education, usability research, and related fields. Students were tasked with developing software applications, and using eye tracking to evaluate how viewers engaged with their work helped them judge design quality and usability. The authors note that the resulting gaze data enabled students to produce better infographics, applications, and other materials [33].

#### 3.6 Replicating Human Eye Movements Using an IR Camera-Based Wearable Eye-Gaze Tracker

The study examined whether robotic eyes can mirror human eye movements in real time using a model with two degrees of freedom. The researchers built a head mounted eye gaze tracking controller with an

infrared camera that streamed signals to drive the robot's eye motions. By accounting for head movements and capturing both horizontal and vertical movement, the system improved upon previous work and solved frequent gaze tracking issues. The system combined polynomial regression with the pupil center corneal reflection method to translate human gaze into robot commands for image processing. A Wilcoxon test was used to evaluate accuracy, and the results indicated no statistically significant difference between robotic and human motions. For horizontal tracking, the system's accuracy was 99.07 percent, and for vertical tracking, it was 98.91 percent [34].

### 3 CONCLUSIONS

Eye tracking has been used for many years and in many settings, from studying how people watch videos to detecting early signs of drowsiness in drivers. It also supports practical tasks such as evaluating the clarity of on-screen content and controlling robots through gaze. Steady progress over years of research has turned eye tracking from a niche lab tool into something that works in everyday studies and applications. Current work continues to raise both efficiency and accuracy, so systems can detect small eye movements and estimate gaze with greater precision. These gains make trackers more reliable in practice and also lead to richer datasets that researchers can use to test, compare, and validate new methods.

The future research could explore integrating eye tracking with other biometric and behavioral sensors, such as EEG, facial expression analysis, or heart rate monitoring to gain a more holistic understanding of human cognition and emotion. Advances in machine learning and computer vision can further enhance gaze estimation models, enabling adaptive interfaces that respond in real time to user attention and intent. Eye tracking also holds promise for accessibility, helping individuals with mobility impairments interact with digital environments more naturally. Additionally, addressing privacy and ethical considerations in gaze data collection will be crucial as eye tracking becomes more embedded in consumer devices and everyday technologies.

### ACKNOWLEDGMENTS

The researchers are deeply grateful to the Philippine Council for Health Research and Development

(DOST-PCHRD) of the Department of Science and Technology for the financing and assistance that enabled this effort. Their assistance was crucial in advancing this research and assisting us in reaching significant study milestones.

### REFERENCES

- [1] M. Płużyczka, "The first hundred years: a history of eye tracking as a research method," *Applied Linguistics Papers*, vol. 4/2018, no. 25, pp. 101-116, Dec. 2018, doi: 10.32612/uw.25449354.2018.4.
- [2] "Applications & history of eye tracking technology," Gazept, [Online]. Available: <https://www.gazept.com/eye-tracking/?v=a25496ebf095>, [Accessed: 30 Apr. 2024].
- [3] "What is eye-tracking? benefits of eye-tracking in research," [Online]. Available: <https://www.hotjar.com/conversion-rate-optimization/glossary/eye-tracking>, [Accessed: 30 Apr. 2024].
- [4] S. N. S. S. Anwar, A. A. Aziz, and S. H. Adil, "Development of real-time eye tracking algorithm," 2021 4th International Conference on Computing & Information Sciences (ICIS), Karachi, Pakistan, 2021, pp. 1-6, doi: 10.1109/ICIS54243.2021.9676406.
- [5] R. Krueger, S. Koch, and T. Ertl, "Saccadelenses: interactive exploratory filtering of eye tracking trajectories," 2016 IEEE Second Workshop on Eye Tracking and Visualization (ETVIS), Baltimore, MD, USA, 2016, pp. 31-34, doi: 10.1109/ETVIS.2016.7851162.
- [6] B. Sharif et al., "Practical eye tracking with iTrace," 2019 IEEE/ACM 6th International Workshop on Eye Movements in Programming (EMIP), Montreal, QC, Canada, 2019, pp. 41-42, doi: 10.1109/EMIP.2019.00015.
- [7] J. Amudha and K. R. Chandrika, "Suitability of genetic algorithm and particle swarm optimization for eye tracking system," 2016 IEEE 6th International Conference on Advanced Computing (IACC), Bhimavaram, India, 2016, pp. 256-261, doi: 10.1109/IACC.2016.56.
- [8] Z. Kang and E. J. Bass, "Supporting the eye tracking analysis of multiple moving targets: design concept and algorithm," 2014 IEEE International Conference on Systems, Man, and Cybernetics (SMC), San Diego, CA, USA, 2014, pp. 3184-3189, doi: 10.1109/SMC.2014.6974418.
- [9] A. Al-Rahayfeh and M. Faezipour, "Enhanced frame rate for real-time eye tracking using circular hough transform," 2013 IEEE Long Island Systems, Applications and Technology Conference (LISAT), Farmingdale, NY, USA, 2013, pp. 1-6, doi: 10.1109/LISAT.2013.6578214.
- [10] A. Al-Rahayfeh and M. Faezipour, "Eye tracking and head movement detection: a state-of-art survey," *IEEE Journal of Translational Engineering in Health and Medicine*, vol. 1, pp. 2100212-2100212, 2013, Art no. 2100212, doi: 10.1109/JTEHM.2013.2289879.

- [11] V. Raudonis, R. Simutis and G. Narvydas, "Discrete eye tracking for medical applications," Proc. 2nd ISABEL, pp. 1-6, 2009.
- [12] Y. Kuo, J. Lee, and S. Kao, "Eye tracking in visible environment," Proc. 5th Int. Conf. IHH-MSP, pp. 114-117, 2009.
- [13] Z. Yuan and J. Kebin, "A local and scale integrated feature descriptor in eye-gaze tracking," Proc. 4th Int. CISP, vol. 1, pp. 465-468, 2011.
- [14] H. Liu and Q. Liu, "Robust real-time eye detection and tracking for rotated facial images under complex conditions," Proc. 6th ICNC, vol. 4, pp. 2028-2034, 2010.
- [15] W. Khairofaizal and A. Nor'aini, "Eye detection in facial images using circular Hough transform," Proc. 5th CSPA, pp. 238-242, 2009.
- [16] W. Hotrakool, P. Siritanawan and T. Kondo, "A real-time eye-tracking method using time-varying gradient orientation patterns," Proc. Int. Conf. Electr. Eng. Electron. Comput. Telecommun. Inf. Technol., pp. 492-496, 2010.
- [17] C. Yang, J. Sun, J. Liu, X. Yang, D. Wang, and W. Liu, "A gray difference-based pre-processing for gaze tracking," Proc. IEEE 10th ICSP, pp. 1293-1296, 2010.
- [18] X. Yang, J. Sun, J. Liu, J. Chu, W. Liu and Y. Gao, "A gaze tracking scheme for eye-based intelligent control," Proc. 8th WCICA, pp. 50-55, 2010.
- [19] M. Mehrubeoglu, L. M. Pham, H. T. Le, R. Muddu, and D. Ryu, "Real-time eye tracking using a smart camera," Proc. AIPR Workshop, pp. 1-7, 2011.
- [20] Z. Zhu and Q. Ji, "Novel eye gaze tracking techniques under natural head movement," IEEE Trans. Biomed. Eng., vol. 54, pp. 2246-2260, Dec. 2007.
- [21] X. Li and W. G. Wee, "An efficient method for eye tracking and eye-gazed FOV estimation," Proc. 16th IEEE Int. Conf. Image Process., pp. 2597-2600, 2009.
- [22] H. Huang, Y. S. Zhou, F. Zhang, and F. C. Liu, "An optimized eye locating and tracking system for driver fatigue monitoring," Proc. ICWAPR, vol. 3, pp. 1144-1149, 2007.
- [23] R. C. Coetzer and G. P. Hancke, "Eye detection for a real-time vehicle driver fatigue monitoring system," Proc. IEEE Intell. Veh. Symp., pp. 66-71, 2011.
- [24] T. Siriteerakul, Y. Sato, and V. Boonjing, "Estimating change in head pose from low resolution video using LBP-based tracking," Proc. ISPACS, pp. 1-6, 2011.
- [25] Z. Zhao, Y. Wang and S. Fu, "Head movement recognition based on Lucas-Kanade algorithm," Proc. Int. Conf. CSSS, pp. 2303-2306, 2012.
- [26] Y. Zhao and H. Yan, "Head orientation estimation using neural network," Proc. ICCSNT, vol. 3, pp. 2075-2078, 2011.
- [27] L. M. King, H. T. Nguyen and P. B. Taylor, "Hands-free head-movement gesture recognition using artificial neural networks and the magnified gradient function," Proc. 27th Annu. Conf. Eng. Med. Biol., pp. 2063-2066, 2005.
- [28] S. T. Nguyen, H. T. Nguyen, P. B. Taylor and J. Middleton, "Improved head direction command classification using an optimized Bayesian neural network," Proc. 28th Annu. Int. Conf. EMBS, pp. 5679-5682, 2006.
- [29] A. Pranith and C. R. Srikanth, "Iris recognition using corner detection," Proc. 2nd ICISE, pp. 2151-2154, 2010.
- [30] D. Martinez-Marquez, S. Pingali, K. Panuwatwanich, R. A. Stewart, and S. Mohamed, "Application of eye tracking technology in aviation, Maritime, and Construction Industries: a systematic review," Sensors, vol. 21, no. 13, p. 4289, Jun. 2021, doi: 10.3390/s21134289.
- [31] P. Drakopoulos, G. A. Koulieris, and K. Mania, "Front camera eye tracking for mobile VR," 2020 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW), Atlanta, GA, USA, 2020, pp. 642-643, doi: 10.1109/VRW50115.2020.00172.
- [32] Y. Shang, "Research on eye movement tracking and English teaching application based on CNN-BLSTM fusion algorithm," 2023 IEEE 3rd International Conference on Electronic Communications, Internet of Things and Big Data (ICEIB), Taichung, Taiwan, 2023, pp. 379-382, doi: 10.1109/ICEIB57887.2023.10170423.
- [33] V. Zyrianov, D. T. Guarnera, C. S. Peterson, B. Sharif, and J. I. Maletic, "Automated recording and semantics-aware replaying of high-speed eye tracking and interaction data to support cognitive studies of software engineering tasks," 2020 IEEE International Conference on Software Maintenance and Evolution (ICSME), Adelaide, SA, Australia, 2020, pp. 464-475, doi: 10.1109/ICSME46990.2020.00051.
- [34] R. Pinter, S. M. Čisar, L. Szedmina, V. Bulović, and A. Kovari, "Eye movement monitoring for multimedia content ranking," 2022 IEEE 5th International Conference and Workshop Óbuda on Electrical and Power Engineering (CANDO-EPE), Budapest, Hungary, 2022, pp. 81-86, doi: 10.1109/CANDO-EPE57516.2022.10046393.