IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received March 1, 2022, accepted March 23, 2022, date of publication April 1, 2022, date of current version April 26, 2022.

Digital Object Identifier 10.1109/ACCESS.2022.3164075

Eye-Tracking Assistive Technologies for Individuals With Amyotrophic Lateral Sclerosis

HILARY O. EDUGHELE[1], YINGHUI ZHANG[1], FIRDAUS MUHAMMAD-SUKKI[2], QUOC-TUAN VIEN[3], (Senior Member, IEEE), HALEY MORRIS-CAFIERO[1], AND MICHAEL OPOKU AGYEMAN[1], (Senior Member, IEEE)

[1]Centre for Advanced and Smart Technologies (CAST), Faculty of Arts Sciences and Technologies (FAST), University of Northampton, Northampton NN1 5PH, U.K.

[2]School of Engineering and the Built Environment, Edinburgh Napier University, Edinburgh EH14 1DJ, U.K.

[3]Faculty of Science, and Technology, Middlesex University, London NW4 4BT, U.K.

Corresponding author: Michael Opoku Agyeman (michael.opokuagyeman@northampton.ac.uk)

The article is funded by University of Northampton.

ABSTRACT Amyotrophic lateral sclerosis, also known as ALS, is a progressive nervous system disorder that affects nerve cells in the brain and spinal cord, resulting in the loss of muscle control. For individuals with ALS, where mobility is limited to the movement of the eyes, the use of eye-tracking-based applications can be applied to achieve some basic tasks with certain digital interfaces. This paper presents a review of existing eye-tracking software and hardware through which eye-tracking their application is sketched as an assistive technology to cope with ALS. Eye-tracking also provides a suitable alternative as control of game elements. Furthermore, artificial intelligence has been utilized to improve eye-tracking technology with significant improvement in calibration and accuracy. Gaps in literature are highlighted in the study to offer a direction for future research.

INDEX TERMS Amyotrophic lateral sclerosis, artificial intelligence, assistive technology, eye-tracking.

I. INTRODUCTION

Amyotrophic lateral sclerosis (ALS) is a neurodegenerative disease that predominantly affects the motor system, but with increasingly identified extra-motor manifestations [1]. Individuals with ALS maintain full consciousness throughout the illness, but as they develop progressive quadriplegia with bulbar muscle atrophy, it becomes more difficult for them to interact and articulate their everyday needs. This communication barrier for ALS patients has been labelled as an extreme communication obstacle [2], a window of opportunity is however available as they retain control of their eye movements for some time. Thus, eye-tracking technology has been utilized in varying ways to make communication possible. Eye-tracking involves the measurement of either the point of gaze or the motion of an eye, relative to the head and it has a vast range of applications in numerous fields such as psychology, neuroscience [3], [4], military weaponry, assistive technologies [5] to enhance communication with disabled patients [6], computer games [7], [8], remote health [9], security and access control using facial recognition and iris detection [10], driver fatigue monitoring products such as meitrack [11], [12], in the advertising industry to analyse customer interest, and in other notable fields. Throughout history, many researchers have contributed to the study of eye-tracking. Figure 1 illustrates the evolution of eye-tracking. In the 20th century, saccadic masking was discovered by Dodge [13], where the eye is essentially blindfolded as it travels from one fixation point to the next. Although this was based primarily on the self-observation of his eyesight and reports from a test subject, who indicated that they were unable to see texts when they moved their gaze. However, self-observation proved insufficient in unpacking the mechanics of what was going on, necessitating the development of a new method to study this further. The next step in eye movement research was the development of photographic methods, which eventually replaced self-observation methods. Dodge and Cline created photographic equipment that used the surface of the cornea as a reflector to record eye movements. Rather than photographing the eye directly, the reflection from the cornea was measured. The bright light lines provide a clear record of eye movement. Due to the greater clarity compared to photographing the eyes directly, the images obtained could be magnified significantly while preserving the accuracy of the measurement. Another early user of the photographic technique to record

The associate editor coordinating the review of this manuscript and approving it for publication was Yeliz Karaca.

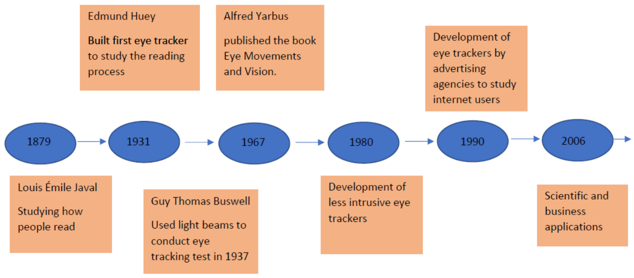

FIGURE 1. Eye tracking evolution.

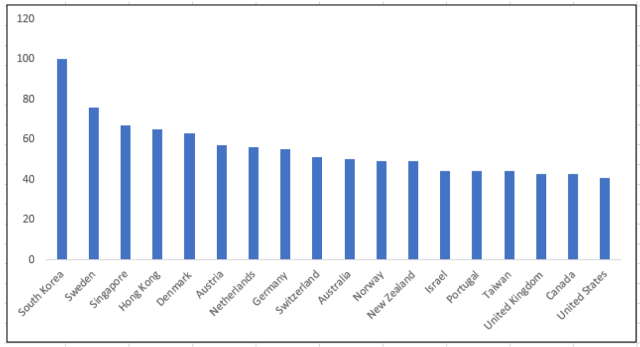

FIGURE 2. Eye tracking internet search by country from 2004 to 2021.

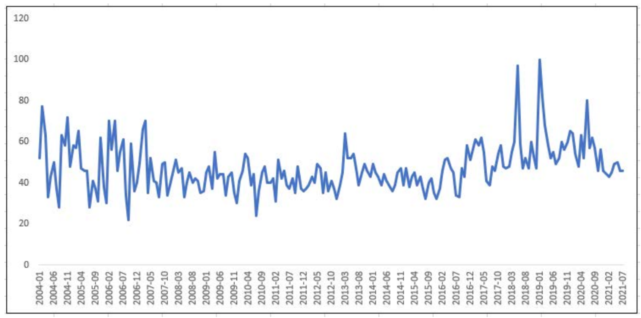

FIGURE 3. Eye tracking internet search worldwide from 2004 to 2021.

eye movements was Judd [13]. He created a kinetoscope eye-tracker to solve the difficulty of photographing the eye with sufficient quality. A tiny particle was deposited on the cornea and moved with the eye, making it easier to monitor eye movements. It could also take binocular recordings and measure eye movements between fixations. It worked by snapping a series of photos in quick succession. Photographic techniques were also utilized to explore specific pathologies or medical disorders, allowing for comparisons of eye movements in healthy participants and a variety of sick individuals. Around the mid-twentieth century, eye-tracking methods that measured muscular activity rather than eye movement were created. Electrooculography (EOG) is an electrical method of measuring the corneoretinal standing potential, which exists between the front and rear of the eye. It is based on the dipole principle of the eye. Electrodes are implanted at the top and bottom of the eye, as well as to the left and right. One of the electrodes detects the positive or negative side of the retina when the eye moves. Because the resting potential is constant, any potential observed provides information about the position of the eye [13]. Eye-tracking has been utilized in numerous studies and consist of a wide range of applications. In Figure 2 the chart shows the number of times from the year 2004 to 2021 the "eye-tracking" keyword was searched on the google scholar database. Figure 3 shows the number of eye-tracking search query by country. The aim of the chart is to identify the popularity of the technology amongst researchers. This paper presents a review of existing eye-tracking software and hardware and charts a course for its application as an assistive technology to aid ALS patients. The paper also includes Table 1 to show various research studies, their goals, technology used, the findings and possible future research direction.

The rest of this paper is organized as follows. Section II presents a comparison of related literature. Section III shows how eye tracking can be utilized as assistive technology. Section IV gives a background of some of the eye tracking software available in the field. Section V presents eye tracking techniques and algorithms. Section VI highlights some drawbacks in eye-tracking technology. Section VII discusses some relevant artificial technology techniques used in eye tracking. Section VIII shows some of the applications of eye tracking software. Section IX discusses some possible directions future of research. Finally, Section X concludes this paper.

A. RESEARCH QUESTIONS

The literature review seeks to answer the following research questions:

- The number of eye-tracking research articles in noteworthy publications such as IEEE access from 2017
- The contributions eye tracking technology has made to improve the study of severe disabilities such as Motor Neurone Disease (MND)
- The frequent eye-trackers used in eye tracking research and comparisons between them
- The eye-tracking techniques used in eye tracking studies
- The applications of eye-tracking technology

II. COMPARISON OF RELATED SURVEY

A. TECHNIQUES

Eye-tracking techniques can be distinguished into four broad categories, the most accurate and invasive technique highlighted is based on the insertion of a contact lens equipped with magnetic search coils or mirrors [14].

In the case of the magnetic search coils, a thin copper wire is inserted into a silicon annulus. When a person moves his or her eyes, the lens is attached to a mechanical or optical device, such as a coil that measures the variation of an electromagnetic field. However, due to the method's invasiveness, even though the eye is anaesthetized, the duration of an experiment is restricted to 30 minutes, limiting the method's use [14].

FIGURE 4. Electrooculography (EOG).

Another technique analysed is Electrooculography (EOG) [14], which involves corneoretinal and measured with usage of skin electrodes situated within the vicinity of the eye. This approach is often considered to be inconvenient and uncomfortable for the subjects. Another drawback is that it can only be used for laboratory research, and mobility is prohibited. Figure 4 illustrates the EOG eye movement measurement, courtesy of MetroVision, Pérenchies, France [15]. The last technique and referred to as the most popular and comfortable, due to a lack of direct eye contact is the video-based eye-tracking (VOG) technique [14]. The system relies on digital cameras to capture the movement and position of the eyes. The accuracy of VOG based eye-tracking systems is dependent on the resolution of the images captured and up until recently were generally expensive and complex.

In their paper, authors [16] describe two types of imaging methods widely used in eye-tracking: visible and infrared spectrum imaging. The passive technique of visible spectrum imaging captures ambient light reflected from the eye. The contour between the iris and the sclera, known as the limbus, is often the best feature to track in these images. The pupil, iris, and sclera are the three most important parts of the eye. The use of unregulated ambient light as the source, which may include several specular and diffuse components, complicates visible spectrum eye-tracking. By deliberately lighting the eye with a consistent and monitored infrared light that is not visible to the patient, infrared imaging prevents unregulated specular reflection. Another advantage of infrared imaging is that the pupil, not the limbus, is the image's strongest feature contour. Infrared light is strongly reflected by both the sclera and the iris, but visible light is strongly reflected by only the sclera. Since the pupil contour is smaller and more sharply defined than the limbus, it is preferable to track it. The pupil is, therefore, less likely to be occluded by the eyelids due to its size. The main drawback of the infrared imaging techniques is that they cannot be used outdoors during daylight due to the ambient infrared light. Bright-pupil or dark-pupil techniques are commonly used in infrared eye-tracking. The bright-pupil technique uses a light source that is on or very close to the camera's axis to illuminate the pupil. Owing to the photo reflective aspect of the back of the eye, the pupil is clearly demarcated as a bright area because of such illumination. Dark-pupil techniques use an off-axis source to illuminate the eye so that the pupil is the darkest part of the picture, while the sclera, iris, and eyelids all reflect more light. The first-surface specular reflection of the illumination source of the cornea is apparent in both methods. The dependent measure is usually the vector between the pupil centre and the corneal reflection centre, rather than the pupil centre alone. Since both the camera and the source shift at the same time, the vector difference is less vulnerable to headgear slippage. In the context of remote video-based eye-tracking, both visible and infrared spectral imaging methods have been used. The fact that a remote eye-tracking device can be used invisibly is the single most appealing feature. A remote system's drawback is that it can only detect eye movements while the user is within a relatively small operating area. The three-way trade-off between cost, versatility, and efficiency must be considered when designing remote eye-tracking systems. A pan-tilt camera, for example, can increase the flexibility of tracking eye movements over a large area, but such cameras are very costly. Additionally, by using a zoom camera to capture a high-resolution image of the eye, the accuracy of eye tracking can be enhanced, but at the expense of a smaller operating area and a higher cost.

B. DEVICES

Low-cost eye-trackers present new opportunities for researchers, in a paper [17] a usability test was carried out to ascertain the accuracy of an open-source remote eye-tracking device and a state-of-the-art commercial eye-tracker. The result obtained from nine participants tested four times showed that both devices were equally stable over time, but the commercial tracker was more accurate, with a mean error of 31 pixels versus 59 pixels for the low-cost method. This means that low-cost eye-tracking may be a feasible option when usability studies do not need to differentiate between specific words or menu items that participants are looking at, but rather between broader areas of interest [17]. The devices used in the study were the free and open-source ITU Gaze Tracker 30 Hz, monocular eye-trackers running with a modified Sandberg Nightcam 2 web camera that had a 16 mm lens mounted, 2 Sony HVL-IRM infrared lamps were also used to illuminate the eyes which all amounted to a total cost of about $71.72 and the Tobii T60, 60 Hz, binocular eye-tracker valued at the time at $21,515.55. The research was carried out on a PC with an Intel®CoreTM2 2.6 GHz processor and 3 GB of RAM, as well as Windows XP SP3. The T60 eye-tracker's 17'' TFT monitor was used as the display. The computer was 60 cm away from the user's head and had a resolution of 1280 $\times$ 1024 pixels. The performance of the low-cost eye-tracker Gazepoint GP3 was evaluated based on pupil dilation by researchers [18]. Their findings suggest that the Gazepoint GP3 is a simple and low-cost tool that can be used in psychological studies that require pupil diameter data. The eye-tracker performs well in classifying mental workloads under various background luminance conditions, but it is not a reliable method for frequency domain analysis, which may be due to linear interpolation of low-quality readings. According to the authors [18], Gazepoint GP3 is suitable for use pupillary indicators of cognitive workload but Gazepoint GP3 is only capable of collecting pupil diameter data.

Some webcam eye-tracking systems were reviewed by researchers [19], in their findings they reported that TurkerGaze [20], a webcam eye-tracker for image saliency deployed on Amazon Mechanical Turk. The system necessitates calibration, which is done during a game process in which users fix their gaze on a particular target. PACE is a stand-alone desktop application created by Huang *et al.* [21] that performs eye tracking using the interactions of users. From their findings, the authors [19] introduced their system SearchGazer, a self-calibrated client-side eye-tracking library that extends WebGazer [22] and trains a regression model which maps eye features to gaze locations and search page elements during user interactions. In addition to predicting the gaze of a user within any device display which has a browser that supports access to the webcam, SearchGazer also identifies gaze periods over regions of interest on the search results page for analysis. According to the authors, a few lines of JavaScript code are enough to integrate SearchGazer in any search page and perform eye-tracking once the user starts interacting with the page [19].

Vidal *et al.* [23], looked into wearable eye-tracking and reviewed some video-based eye-trackers including, Mobile Eye by Applied Science Laboratories, the iView X HED by SensoMotoric Instruments, and the Dikablis by Ergoneers GmbH. In their analysis they deduced that despite the portability of these systems they however require some supplementary headgear and laptop for video processing. Further study was conducted on the Tobii Glasses launched by Tobii technology, which includes a pair of glasses as well as a compact processing and data storage device that fits in the palm. According to the researchers, the system is portable and can be used in mobile settings, but it can only monitor eye movements at a low frequency and for up to 1 hour. The SensoMotoric Instruments developed, SMI GazeWear was also analysed, the system which has similar operating time limitations but allows for the acquisition of eye movement data from both eyes (binocular tracking). Several open-source projects are working on developing low-cost hardware and software for video-based eye-tracking in conjunction with these efforts. Research into the eye movements of infants [24] has used open-source software, openEyes [25], Opengazer, and the ITU Gaze-Tracker for the study. These open-source projects enable researchers to adapt equipment to situations and easily prototype ideas without imposing significant constraints. Eye-trackers that use video need a lot of processing power. This means they cannot be used for long periods on only batteries. According to manufacturers, the average running time is between 2 and 4 hours. To be used in day-long trials, mobile eye-trackers must require low power consumption.

Titz *et al.* [26] conducted research on the comparisons of eye-trackers by correlating their eye-metric data, and from their findings, they deduced that the low-cost eye-tracker EyeTribe when compared to a far more expensive device (SMI-RED 120-Hz), the EyeTribe can be relied upon for pupillometry research. They also recommended, using a mixed model for analyses to account for individual variations in pupil size between participants. In the simple case of a correlation between the two eye-trackers earlier mentioned, discrepancies between participants account for around 9% of the variance, which cannot be explained by calibration efficiency. The findings are more varied for the x and y coordinates: the association between the two eye-trackers is only strong when the variation between the participants is considered. A portion of this variation is due to poor calibration. Calibration accuracy may be used in the regression model for researchers interested in gaze behaviour. The findings will be more reliable this way, and they will be easier to generalize to studies using other eye-tracking devices.

C. ALGORITHMS

Pupil detection algorithm (PDA) was explored by researchers in [27] where they deduced that the increase of computing power over time has led to the diversification on the subject. According to their studies, the algorithms for detecting pupils can be broadly divided into two types: feature-based and model-based approaches [28], [29].

Detecting and localizing image features related to the location of the eye pupil are part of feature-based approaches. An ellipse is the best shape approximation of an infrared (IR) video camera's eye pupil image. Several techniques, including least-squares ellipse fitting (LSFE) [30], voting-based methods, such as the circular Hough transform (CHT) [31], [32], and searching-based methods, such as the random sample consensus (RANSAC) paradigm [33], [34], may then be used to match an ellipse to the feature points.

By minimizing the number of square algebraic distances of the feature points to the conic defined by the ellipse coefficients, the LSFE algorithm fits a conic (ellipse) to a set of data points. A parameter accumulator is used in the CHT algorithm. Every edge pixel in the eye image votes for the parameters of all circles in which it can be a part [19]. The accumulator's maxima lead to circles that have been discovered [31]. The circular Hough transform involves a three-dimensional (3D) accumulator since a circle is fully represented by three parameters.

The RANSAC algorithm [33], [34], is an iterative method that selects several small but random subsets of input data, fits each subset to a model, and finds the model that best fits the input set of data points. The algorithm calculates the number of feature points (inliers) that best approximate the ellipse model from the input data set. The consensus set is the collection of input points. An ellipse is fitted to the largest consensus set after a certain number of iterations. Any time a new largest consensus set (represented by the percentage of inliers) is found, the number of algorithm iterations can be reduced until the total number of inliers remains constant. The projection method algorithm (PROJ) [35], [36], and the curvature algorithm [37] are two other feature-based approaches.

Model-based approaches do not specifically detect features, but rather find the best fitting model that is consistent with the eye image, which can be represented by either a circle or an ellipse [29]. The outcome of ellipse fitting is improved in the Starburst algorithm [28], [29] by a model-based optimization using a Nelder–Mead Simplex search [29] that does not depend on feature detection. Starburst is a hybrid algorithm that uses both feature-based and model-based methods. To evaluate a collection of candidate feature points, the algorithm employs the RANSAC paradigm.

Chang *et al.* [38] researched the use of Electrooculograms (EOG), based eye-tracking as a means of communication of individuals with ALS. They developed an EOG-based eye-writing system comprising of a series of computational algorithms to reconstruct eye movement traces and to recognize 10 Arabic numbers and conducted a test with 18 healthy individuals and three ALS patients more accurately. A new method for eliminating crosstalk between horizontal and vertical EOG components was also used. After a brief practice session, all study participants were asked to eye-write specially designed patterns of ten Arabic numbers three times. For the healthy participants, the system had a mean recognition rate of 95.93 %, while the three participants with ALS had recognition rates of 95%, 66.67%, and 93.33%. One of the ALS participants' low recognition rates was mostly due to miswritten letters, which decreased as the experiment progressed. The authors [38], concluded that their proposed eye-writing system is a viable human computer interface (HCI) resource for allowing individuals with ALS to communicate.

D. COMPARISON OF EYE-TRACKING WITH OTHER RELATED TECHNOLOGY

There are technologies prevalent with similar operating mechanisms or incorporated with eye-tracking technology. Some Virtual Reality (VR) devices such as the HTC VIVE Pro Eye for instance contain eye-tracking functionalities and in comparison to conventional eye-tracking devices, they offer researchers novel possibilities in conducting human behaviour and perception studies. The combination of these technology gives users the functionality of the VR system's body motion tracking as well as the eye tracker's gaze monitoring features. All experimental conditions can be controlled specifically, while the subject is in a virtual environment that reacts to the subject's movements and behaviours. The use of eye tracking and virtual reality allows researchers to compute a subject's gaze in 3D space and watch where they are gazing during experiments [39]. In contrast to real-world eye tracking, defining areas of interest in 3D space and tracing points with time to establish when the regions were looked at, is simple in VR eye-tracking. With the advantages of more natural stimuli, more natural movement, controlled environment, and controlled data gathering, the combined technique of eye tracking and VR can address numerous research problems in a fundamentally novel way [39]. Comparison can also be drawn between Brain-Computer Interface (BCI) and eye-tracking technology. There have been studies that explicitly compare eye-trackers and Brain-Computer Interface (BCI). When comparing eye-trackers to P300 BCI, Pasqualotto *et al.* [40], found that eye-trackers had a significantly higher information transfer rate and System Usability Scale ranking, as well as a significantly lower cognitive workload [40]. As a result, eye-trackers are more appropriate when there is no ocular involvement, which can be solved by BCI. Electro-oculography, eye-trackers, and auditory BCI for Augmentative and Alternative Communication (AAC) were all tested by a standard low-tech AAC user in the locked-in stage, the technology was viable but none were considered an additional use, though, auditory BCI was recognized as favouring independence from eye control but more tiring [41]. A study in robotic technologies in a social environment compared the two concepts (BCI and eye-tracking), in a means to analyse their use as a non-physical operating mechanism of robots. The study used real-time BCI paradigm, Steady-State Visually Evoked Potential (SSVEP), and according to the findings of this study, both SSVEP and eye tracking appear to be viable options for immersive control in an HMD. In terms of interface usability, the two methods differed in several ways. There were no differences in task success during the skill test or in the responses to the interfaces questionnaire. Though the eye tracker had a substantially shorter delay in triggering gestures (1s vs. 3s with SSVEP), however during the skill test, all individuals using ET were unable to make even a single coherent gesture; while, all SSVEP participants made at least one coherent gesture [42].

III. EYE-TRACKING ASSISTIVE TECHNOLOGY

As earlier highlighted, Eye-tracking as an assistive technology would be beneficial particularly for individuals with severe disability and incapable of regular movements. In a paper [57], the authors present a human-machine interface centred on eye-tracking, applied as an assistive tool for disabled individuals. The EyeAssist system, which was developed gave the disabled patients the ability to communicate by implementing a predictive keyboard that enables easy text typing. The algorithm employed was the OpenOffice dictionary, in addition to a T9-like writing approach. EyeAssist was also developed to support the implementation of additional plug-ins to enhance many functionalities, including the inclusion of the popular snake game that can be controlled with the eyes. The researchers tested the software by changing the grid size from 3×3 to 4×5 and calculating the error rate over 100 calibration trials to determine the system's accuracy. The device was tested by taking two calibrations, one as a guide and the other as a test to determine the number of cells that were correctly matched. Each trial was made up

TABLE 1. Eye-tracking technology used in disease research, findings, and future research direction.

Research	Disease/Research goal	Technology	Findings	Future direction
Scott et al. [43]	ALS and other locked-in diseases	Optical sensors/ emitters	Because EyeLive does not rely on a traditional camera, it lowers eye fatigue, improves accuracy, boosts mobility, and it is user friendly	In the future, tracking eye movements may enable us to track our interactions with computer simulations in virtual reality. Wearable eye-trackers could become a useful tool for evaluating the performance of employees.
Sharafia et al. [44]	Lung Cancer	C-CAD with eye-tracking with graph clustering	Providing a paradigm-shifting CAD system, called Collaborative CAD (C-CAD), that unifies CAD and eye-tracking systems in realistic radiology room settings	Not stated
Hansen & Ji. [45]	Autism Spectrum Disorder (ASD)	Tobii eye-tracking system	Children with ASD were drawn to video games in the same manner that other children were	• IR light is useful for eye-trackers because it may be used to alter light conditions, obtain higher contrast images, and stabilize gaze estimates while remaining unseen to the user. Systems that use infrared light have a practical restriction in that they are not always reliable when used outside. Future eye-tracking devices should be able to work outside as well. Structure from motion approaches on face feature points are now being used in this direction. These approaches are still in their infancy, and further research is required. • Current gaze models either utilize a strong prior model (hardware calibration) with little session calibration or a weak prior model (more calibration points) with little hardware calibration. Another future direction will be to develop non-calibrated procedures. Given existing eye and gaze models, this does not appear to be possible. To achieve calibration-free gaze tracking, new eye models and theories must be established.

TABLE 1. *(Continued.)* **Eye-tracking technology used in disease research, findings, and future research direction.**

Chennamma & Yuan. [46]	Amyotrophic Lateral Sclerosis (ALS)	EyeTribe connected to the notebook	Eye-tracking based ECAS version is well suited to identify those ALS patients with substantial cognitive impairment	Future eye tracking advancements should focus on standardizing which eye movement metrics are utilized, how they are referred to, and how they should be understood in the context of interface design.
Sorate & Chhajed. [47]	To study the behaviour of the infant	Head-Mounted Eye-Tracker	Image processing algorithms The most frequent recurrences of the infant's gaze were most often in the direction of hand movements and crawling, but the least frequent were in the leg movements	Not stated
Eibenberger, Eibenberger, & Rucci, [48])	ASD due to genetics of their early development	magnetic scleral search coil	The use of eye-tracking technology is advantageous in areas such as automated testing sessions and the record of more visual attention metrics	Not stated
McCamy et al. [49]	Attention Deficit Hyperactivity Disorder (ADHD)	Leap Motion and Tobii X1 Light	Teachers can use this approach to keep track of their pupils' progress and behaviour	Not stated
Chen et al. [50]	Strabismus Recognition	A gaze deviation (GaDe) image	The CNNs are a powerful option for extracting features from eye-tracking data	Not stated
Rana et al. [51]	Tetraamelia syndrome	Eyewriter	The device is independent of the lighting condition of the room, and provides a speaking option for disabled users but is however not as efficient as high-end eye-trackers such as the Tobii eye-tracker	The authors suggest the following could serve as future research work • EyeWriter based paralyzed patient monitoring in a hospital. • EyeWriter based automated wheelchair • EyeWriter based home automation • Eyewriter based virtual computer • EyeWriter based drone control system • EyeWriter based VR application
Wanluk et al. [52]	smart wheelchair	raspberry Pi	The camera's lens distortion has a substantial impact on the motion direction accuracy. Because the web camera must be placed close to the eyeball, the focal length is short. The larger the distortion, the shorter the focal length. We designed the measuring system by moving the circle along the x and y directions of the screen and letting the algorithm detect the position to evaluate the accuracy of motion direction recognition	Not stated.

TABLE 1. *(Continued.)* **Eye-tracking technology used in disease research, findings, and future research direction.**

Lazarov et al. [53]	Attention to Threat in Post-traumatic Stress Disorder	Eye-Tracking Indices	Enhanced threat detection, hypervigilance, and attentional avoidance were shown to have minimal support in the findings. In PTSD, however, consistent evidence for continuous threat attention has emerged. The findings also suggest that continuous threat attention could be a focus for therapeutic intervention.	More eye-tracking research is needed to further deepen the understanding of attentional biases in PTSD.
Hunter et al. [54]	Early-onset epilepsy/Autism spectrum disorder	Tobii ×60 eye-tracker	The main findings demonstrated that, in comparison to typically developing children, CWEOE exhibited aberrant social attention. This was a task-specific finding, as CWEOE saw facial characteristics in a pattern similar to controls during the social preference test but not during the face region preference task.	Future research focusing on specific cognitive and social dimensions in age groups would add to the findings' credibility. Another drawback of the current study is that, whereas the facial region preference paradigm has been widely utilized in infants and preschool-aged children, it has never been used in adults. The social preference test has only been verified in babies. As a result, it may have lacked the developmental appropriateness to test social attention in infants and preschoolers, where the social brain is still growing.
Arslan et al. [55]	The usability of electronic chart display and information systems (ECDIS)	Tobii Pro Glasses 2 with gaze sampling frequency of 100 Hz	This study shows that eye-tracking, as a usability assessment tool, has a lot of potential for enhancing the effectiveness of ECDIS, and the authors suggest that manufacturers and researchers use it at the product research and development stage.	A possible future research direction of the study could compare or reveal the quality or usefulness of the various ECDIS models employed in the experiment as this area was not within the scope of the study. Comparing functionality, practicability, simplicity of use, and other factors that influence system usability necessitates more testing.
Martinez-Marquez et al. [56]	Application of eye-tracking technology in high-risk industries	Mobile / remote based eye-trackers	The results of this research show that industries such as the aviation industry have been using eye-tracking technology for longer and therefore have more pertinent articles than other industries, such as construction. Regardless, there has been an increase in the usage of eye-tracking technology in the mentioned industries. The main countries using such technology can also be seen to be dependent on their location and industry resources.	Future work is necessary for the creation of acceptable experimental and industrial standards for eye-tracking systems, to overcome limitations in terms of data quality and algorithmic variability, an acceptable translation must be achieved. Future research on the application of Eye-tracking in other high-risk areas, such as space exploration, mining, and oil and gas. More research into the similarities and differences between different uses of eye-tracking in the aviation, maritime, and construction industries could also be beneficial.

of M×N tests, where M×N refers to the grid-scale. The average number of mismatched cells across all trials was used to calculate the error rate. The experiments were carried out using a standard webcam with a resolution of 800×600 pixels and a personal computer. The processing was done at a rate of 22 to 25 frames per second (maximum rate of the cam). The

TABLE 2. Eye-tracking software.

Eye-tracking Software	Programming language	Cost	webcam supported	OS supported
Optikey [67]	C#	Free	Nil	Windows 8 / 8.1 / 10
GazePointer [69]	C++	Free	Yes	Windows
pyGaze [65]	Python	Free	Yes	Windows / Linux
openGazer [71]	C++ / Python	Free	Yes	Windows / Linux
ITU Gaze Tracker [14]	C#	Free	Yes	Windows
Ogama [62]	C#	Free	Yes	Windows
GazeParser [75]	Python	Free	-	Windows / Linux
openEyes [25]	Matlab	Free	Yes	Windows /Linux /macOS
TurkerGaze [19]	JavaScript	Free	Yes	Linux

TABLE 3. Eye tracking hardware.

Hardware	Gaming	Mobile	VR Support	Head movement Sync
Eyegaze [76]	-	Yes	-	Present
Blickshift [77]	Present	Yes	Present	Present
FOVE [78]	Present	-	Yes	Present
Ergoneers [79]	Present	Yes	Present	Present
Varjo [78]	Present	-	Yes	Present
LooxidVR [76]	Present	Yes	Present	Present
TM5 mini [76]	Present	-	-	-
Tobii Pro Glasses 3 [80]	Present	Yes	-	Present
Tobii Pro Glasses 2 [81]	Present	Present	Present	Present
Htc vive pro eye [82]	Present	Present	Present	Present

researchers combined their implementation with a proposal for eye detection [58] to improve eye detection and tracking. The algorithm was split into two parts. The aim of the first step is to extract the eye region in the YCbCr domain, where the Cr portion takes very low values compared to the value in the skin regions. By sliding a M×N window across the image, the area belonging to the eye can be selected as the window with the lowest sum of Cr values. The gap l between the eyes, which can be retrieved after classification and detection, can be used to pick M and N values.

IV. EYE-TRACKING SOFTWARE

There is a lot of open-source eye-tracking software available that researchers can utilize to carry out various forms of studies about eye-tracking. These open-source software have various features and capabilities. In this section, some of the various open-source software available would be discussed. Table 2 shows a comparison of some noteworthy eye-tracking open-source packages suitable for research in areas where high-end eye-tracking tools are difficult to attain. Table 3 shows a comparison of eye-tracking hardware used in the research.

A. EXPERTEYES

ExpertEyes [59] is an open-source hardware and Java-based software package designed to provide portable high-definition eye-tracking at a low cost. It was developed for difficult recording environments, and all processing is done offline to allow for the optimization of parameter estimation. Drift correction, data cleaning, trial and event tagging, and data export are some of the features available. ExpertEyes is cross-platform compatible, unlike some other open-source software that are limited to certain operating systems. ExpertEyes, however, isn't suitable for real-time or gaze-contingent designs, and data processing takes a long time. The temporal resolution is constrained by the hardware used (currently 60 Hz), ruling out tasks requiring rapid eye kinematics. ExpertEyes proved valuable in an experiment which involved the collection of behavioural data from fingerprint experts. ExpertEyes was used due to its portability and workability outside of a lab environment. The open-source software enabled the researchers, take two video streams from two cameras to generate x and y coordinates to indicate where the participant is gazing at in the scene camera [60]. Figure 5 shows an image of the Experteyes head-mounted eye-tracker.

B. ITU GAZE TRACKER

ITU Gaze Tracker [17] is an open-source eye-tracking program. It supports both head-mounted and remote setups that work with low-cost web cameras and basic camcorders. Using infrared illumination, the software monitors the users' pupil and corneal reflections. The device employs an interpolation-based method to map eye features from camera images to the point of focus. The ITU Gaze Tracker [61] can track one or two corneal reflections as well as the pupil centre. The software was created to operate with low-cost webcams that have an infrared light built in. The software does, however, contain initial support for remote setups that utilise more expensive video cameras. By thresholding the image and extracting points in the contour between the pupil and the iris, the pupil centre may be computed. After that,

FIGURE 5. ExpertEyes head-mounted eye-tracker [58].

the points are fitted to an ellipse using the RANSAC process, which eliminates any probable outliers. A crosshair is drawn on the image to approximate the pupil's centre [61].

C. OGAMA

Open Gaze and Mouse Analyzer (OGAMA) [62] is an open-source application written in C#.NET. Slideshow design, recording of gaze and mouse data, database-driven pre-processing and filtering of gaze and mouse data, creation of attention charts, areas-of-interest definition, and replay are some of its key features. The software allows users to import eye-tracking recordings in ASCII format. The result of the data produced can be used directly with a variety of statistical software packages. OGAMA is a stand-alone program that runs on Microsoft Windows platforms and is designed to manage data from a variety of psychology and usability testing studies. OGAMA has been used in conjunction with GP3 to identify attention deficit disorder in children [63]. Data-controlled preprocessing, or filtering eye and mouse movement, are some of the key features of OGAMA. Measured data can also be exported into video format, text, or module. Data can be displayed and analysed in a variety of modules [64].

D. PYGAZE

The PyGaze [65] toolbox is an open-source Python software package. It's made to make eye-tracking experiments as simple as possible in Python syntax, with programming ease and script readability without sacrificing functionality or versatility. PyGaze can be used to display visual and auditory stimuli, collect responses through keyboard, mouse, joystick, and other external hardware, and detect eye movements in real time using a custom algorithm. Eye-trackers from a variety of brands (EyeLink, SMI, and Tobii systems) are supported. PyGaze is unique in that it provides an easy-to-use layer on top of the numerous software libraries available to execute eye-tracking experiments. PyGaze supports several operating systems and eye-tracking hardware devices from various manufacturers, the application is mostly platform and eye-tracker independent. The functionality of many existing Python libraries is merged into a single package, allowing stimulus presentation and communication with several brands of eye-trackers to be done with a single collection of routines. PyGaze includes functions for quickly implementing complex paradigms including forced retinal positions, areas of interest, and other gaze-dependent experiments that can be generated by capturing and processing real-time gaze samples. PyGame and PsychoPy are libraries for interacting with screen displays, keyboards, cursors, joysticks, and other external devices, as well as internal timing. However, PsychoPy has the disadvantage of requiring a graphics card that supports OpenGL drivers and multitexture. Pygaze tests can be written and tested on a computer without the use of an eye-tracker. The klieg algorithm, which calculates the velocity of eye movement based on repeated samples to detect saccades was used a study [66]. The research concluded that pygaze is the ideal software and that it bridges the gap between complex programming and time-consuming programming. It is the most effective eye-tracking package available [66].

E. OPTIKEY

Optikey [67] is a free and an open-source Windows-based assistive on-screen keyboard. It's made to work with a low-cost eye-tracking device to give people with motor and speech disabilities, such as those with Amyotrophic Lateral Sclerosis (ALS) or Motor Neuron Disease (MND) the ability to use the keyboard, mouse, and speech. The Optikey software enables users to select characters on the on-screen keyboard using dwell selection, as well as physical buttons and assistive devices (such as Glassouse, or assistive switches). Optikey can be operated with a mouse or a webcam if an eye-tracking device is unavailable. An experiment based on the prediction of mental fatigue during eye typing was conducted using Optikey and Tobii eye-tracker 4C by Bafna *et al.* [68]. Machine learning (ML) was utilized to predict fatigue levels on a six-point Likert scale and correlation analysis was performed using the data from these trials and the fatigue levels. Figure 6 shows the optikey typing interface.

F. GAZEPOINTER

Gazepointer [69] is a computer human interaction application that calculates a person's point of gaze to guide the mouse pointer using a computer vision algorithm. Gazepointer is a low-cost, software-based solution that explores the use of the eyes as a pointing device. The software was created with OpenCv, MATLAB, and Qt, and it can be used on both Windows and Linux operating systems. The OpenCV developed algorithms can be ported to Mac and Android operating systems. The system's motivation is to improve users' computer interaction experiences by tracking eye gestures and minute pupil movements, which results in the pointer moving in conjunction with them. Gazepointer extracts human visual focus from webcam video frames, performs human eye

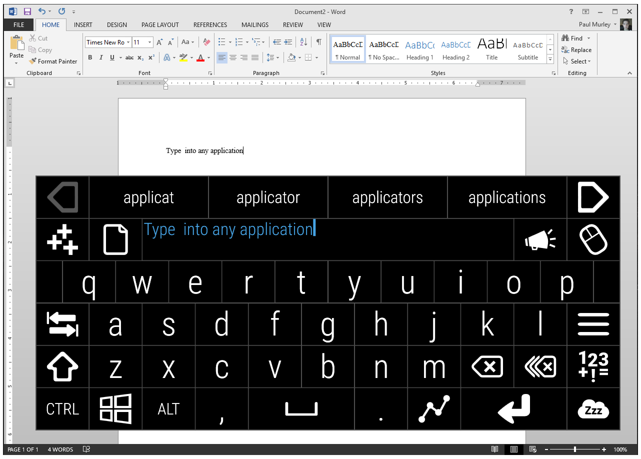

FIGURE 6. Optikey typing into apps feature [67].

motion detection, and calculates the point of gaze as a result. Niu *et al.* [70] found that GazePointer can only identify the region in which the user is looking, not the specific point of gaze which limits its use as a result.

G. OPENGAZER

OpenGazer [71] is a webcam-based open-source program that estimates head posture, facial gestures, and gaze direction. This data can then be passed on to other programs. OpenGazer, for example, when combined with Dasher, helps users to write with the eyes. OpenGazer aspires to be a low-cost software alternative to expensive commercial eye-trackers. Piotr Zieliski created the first edition of Opengazer with the help of Samsung and the Gatsby Charitable Foundation. Emli-Mari Nel has continued OpenGazer's research and development, which was funded by the European Commission as part of the AEGIS project until 2012, as well as the Gatsby Charitable Foundation [71]. OpenGazer can be utilized by the public in everyday human-computer interaction [72]. OpenGazer was used as a reference point for a webcam gaze interaction system that uses a novel feature-based technique that involves the automated detection of the iris bounding box and iris segmentation using binarization [73]. OpenGazer has been successfully utilized for the summarization of documents and online content recommendation systems [74].

V. EYE-TRACKING ALGORITHM AND TECHNIQUES

Eye-tracking systems usually employ some form of algorithm to carry out the objectives of the system. Regression, neural networks (NN), naive bayes classification, and support vector machine (SVM) are some of the algorithms and techniques that have been applied to eye-tracking systems [83]. In classification, object recognition, image querying, SVM are highly efficient and widely used ML approaches or techniques [84]. In addition, in eye-tracking techniques, SVM was used in conjunction with a range of feature extraction and face recognition algorithms. To detect repeated patterns of eye movements, electrooculography (EOG) was used to detect signal-saccades, fixations, and blinks. To train the model, the SVM classifier, the person-independent and leave-one-person-out strategies were combined with the minimum repetition, minimum redundancy, and maximum relevance features. The accuracy rate in all categories was 76.1%, according to the evaluation results [85]. If the model matching algorithm or the Haar face detection algorithm fails to detect the eyes, an SVM and the Zernike movement (ZM) are used [86]. In the case of upside-down images or ambiguous visibility due to lighting problems, ZM was particularly helpful in reducing troublesome views. Similarities between a template and another image are found using template matching. This approach was used to sort objects where the prototype is a miniature image or a portion of an image, this method is used to classify complex images and the objects they relate to [87]. Table 4 has been adapted from Klaib et al [83] research, to highlight the merits and demerits of various eye-tracking techniques, the inclusion, however, of examples of devices which employ these techniques is necessary for researchers seeking to conduct research using the various techniques.

If the template matching technique or the Haar face identification algorithm fails to detect the eyes, an SVM and the Zernike movement (ZM) will be utilized [87]. In the instance of upside-down images or hazy vision due to lighting concerns, ZM proved extremely beneficial in decreasing undesirable views. Similarities between a template and another image are found via template matching. This method was used to sort items if the template is a small image or a portion of a picture. Ahuja often employed this technique to recognize complex images and the objects they refer to [95]. Gradient orientation pattern is a vector-based technique for creating an image that can track the human eye in real time. To aid in the matching of eye images, a template updating algorithm was employed. The template algorithm was used to create a new template in each frame based on the image of the eye, and then use the matching algorithm to improve the results [96]. Light fluctuations that occur during the tracking process are also helped by the template algorithm. The capacity to offer considerable matching results and handle intricate lightning variations is one of the advantages of adopting the gradient orientation pattern. However, if a frame is not matched, it will be discarded, which is a shortcoming of this methodology. Liu and Liu [97] provided another study that looked into the applications of template matching with eye-tracking in complex scenarios where identifying and capturing eye movements can be problematic. Ghazali *et al.* [98] developed a framework for a proposed eye detection and tracking algorithm. In the algorithm after the image is captured, the next process is to search for the human face in the entire image. Afterward, the eye filter is utilized to point out the location of the eye. After successfully detecting the location of the eye, the on-line trained classifier is used to detect and track the eye movement. If any step lost the target, then go to the first step.

TABLE 4. Eye-tracking techniques.

Techniques	Merits	Demerits
Scleral Search Coil e.g EyeContact [88]	• High temporal and spatial resolution. • High accuracy	• Invasive method. • Rarely used clinically. • May cause Intraocular pressure. • Wear the coil for a short period of time. • Does not work on sensitive eyes. • Anaesthesia of the eye. • Complicated settings.
Infrared Oculography (IOG) e.g EyeLink 1000 optical system [89]	• Used in light and darkness. • Handles blinking accurately	• Unable to quantify torsional eye movement. • Limited movement of the head. • Invasive method.
Electro Oculography (EOG) e.g EOG based ALS system [90], e.g wireless EOG-based Human Computer Interfaces [91], JINS MEME [92]	• Medical fields and laboratories. • Very high temporal and spatial resolution. • Used ML to found accuracy. • Analyse the data in real time by using microcontroller.	• Not used daily. • Affected by the noise around the eye. • Invasive method. • Complicated settings
Video Oculography (VOG) e.g Free Visual Exploration (FVE) [93], EyeSeeCam [94]	• Use visible light or infrared light. • Clinical observation of eye movement disorders. • Video recording system is easily handled. • Uncomplicated settings. • Can allow head movement and fully remote recording. • Use of ML techniques to gain higher accuracy. • Not expensive.	• Limited spatial resolution. • Recording with closed eyes is not possible.

A. FACE DETECTION

Face detection research has progressed significantly in recent years, with advances such as colour–space-based identification, neural network-based detection, and feature-based identification. The Adaboost-based face detector described by Viola and Jones is a milestone in tackling face detection challenges [99] when it comes to algorithm time consumption, detection accuracy, and resilience. The primary premise of their identification approach is to filter objects and reject background using a sub window that can be re-scaled to scan a picture or video frame according to a collection of values of Harr-like attributes. Figure 7 shows the basic Harr-like characteristic.

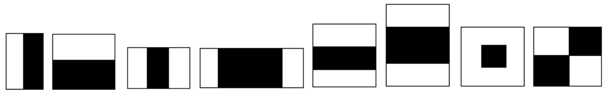

FIGURE 7. Harr-like characteristic [78].

B. EYE LOCATION ALGORITHM

For many computer vision applications, such as facial recognition, the recognition of facial expressions, and monitoring of fatigue, locating the eyes is often the first and most essential step. The accuracy with which the eyes are located has an impact on the proceeding processing and analysis of the system. D'Orazio *et al.* [100] research looked into this field, their proposed eye location algorithm is an example of an appearance-based technique. This technique convolutes a frontal face image with a trained eye filter, then analyses the response result to determine the maximum value [101]. Convolution in the spatial domain appears to become element-wise multiplication in the frequency domain, according to the convolution theorem (as shown in Equation 1).

$$g(x, y) = f(x, y)h(x, y) = F^1(F(u, v)H(u, v)) \tag{1}$$

where h(x, y) is the eye filter kernel, f(x, y) is the image of the face and g(x, y) is the convolution result in time domain. The aim is that g(x, y) is synthetically generated with a bright peak at the centre of the eye and small values everywhere else. So g(x, y) could be a two-dimensional Gaussian function, written as

$$g(x, y) = e^{(x-x_0)+(y-y_0)^2/\sigma^2} \tag{2}$$

where x_0 and y_0 are the locations of left or right eye, σ is the x and y spreads of blob.

VI. EYE-TRACKING DRAWBACKS

While eye-tracking technology has tremendous applications and advantages as seen in this study, it is necessary to take cognisance of the drawbacks. One of the biggest drawbacks of eye-tracking technology is that not all eye types can be tracked appropriately. Contact lenses, glasses, and pupil colour all have an impact on the capacity of an eye-tracking device to record eye movements. Due to this, not everyone (usually 10–20% of the sample) is eligible to take part in an eye-tracking study. As a result, the appropriate representation of samples will be affected [102]. Calibration in eye-tracking poses some issues particularly for individuals with central visual field loss, where eccentric fixation and misdirected eye movements can contribute to higher calibration errors and erroneous estimate of the user's point of view [103]. Another drawback of eye-tracking technology can be seen in the area of mobile eye-tracking. In mobile eye-tracking technology, dynamic Area of Interests (AOIs) are only visible if they are in the participant's field of view when using mobile eye tracking with wearable glasses. This situation necessitates identifying and annotating AOIs for each participant separately. As a result, establishing AOIs in mobile eye tracking is time-consuming. This information, on the other hand, is critical for comparing data from multiple individuals [104]. Some researchers state that there is limited research in using mobile eye-tracking to analyse the decision making process for the purchase of goods in high demand by consumers. This is attributed to the burdensome procedure of collecting and evaluating mobile eye tracking data. Researchers face a significant obstacle in annotating fixations of respondents' eyes to an area of interest (AOI) designated for a real and dynamic environment. The position of the objects in the head-mounted scene camera recordings of the surroundings is constantly changing due to the user's head motions. This entails examining each video frame individually to determine which section the user's sight rested on [105].

VII. EYE-TRACKING AND ARTIFICIAL INTELLIGENCE

Artificial intelligence (AI) has been combined with eye-tracking technology in different studies. This is due to the immerse possibilities and the power of AI which includes reduction of human errors, faster processing time, and improved accuracy. AI has been utilized to improve eye-tracking technology. Calibration of eye-tracking devices can be done by NN or parametric interpolation methods of which NN outperform parametric interpolation. Back-propagation is used in NN for learning, and the bipolar sigmoid function is used as the activation function. A simple web camera with backlight compensation is attached to a head fixation device and scans the user's eye [106]. With NN, the process of calibration is quicker since fewer calibration marks are required, and cursor control is more exact. Demjén et al [106], proposed a system using NN to perform calibration of eye-tracking devices that can differentiate areas at the level of desktop icons. The lack of head-pose invariance and the system's relative sensitivity to illumination are the system's key drawbacks. Zemblys et al [107] conducted a study on how ML can aid in the classification of raw gaze samples belonging to fixations, saccades, or other oculomotor events. To conduct the study, they trained a random forest classifier to predict eye-movement events from features used by existing event detection algorithms. From their findings, when compared to existing state-of-the-art event detection algorithms, machine-learning techniques provide superior detection that can match the performance of coding manually. However, a drawback of their technique is that heuristics are required to produce significant events. This is because each sample's classification is independent of the context of the samples around it. ML has been employed to detect readers with dyslexia using eye-tracking measures. The researchers trained a model and assessed its capabilities using a dataset of 1,135 readings from people with and without dyslexia that were recorded with an eye-tracker in a 10-fold cross experiment. Using the most informative features, the model, which is based on a SVM binary classifier, achieved an accuracy of 80.18% [108]. The experiment however is only valid for Spanish language, the study shows that eye-tracking technology may be used to diagnose dyslexia in the future. Highly accurate tracking has been achieved using ML algorithms such as Bayesian models and NN. Santini created an open-source program for real-time head-mounted eye-tracking that can detect an eye pupil and estimate the gaze [109]. By changing algorithms, the software can be adjusted to meet the needs of developers. Using Bayesian models, the software provides progressive settings, gaze estimation, and blinking detection. Using a single camera with video processing capabilities and a micro-controlled board [110], MATLAB-Simulink was effective in recognizing winks and blinks. Furthermore, ML algorithms were tested in an EOG and proven to be accurate. The goal of the study was to enhance and improve the EOG interface. An eye wearing device was developed to gather and analyse signals in real time using a microcontroller. The signals were processed using wavelet transform and neural network for real-time and trustworthy output. Fuhl *et al.* [111] suggested a system that achieved 92% dependability by combining ML techniques with a VOG strategy to improve eye-tracking accuracy. Zou and Zhang [112] proposed a novel methodology for eye Electrooculography decoding to achieve voiceless communication for patients with amyotrophic lateral sclerosis (ALS) using deep learning. The researchers utilized the deep Convolutional Neural Network (CNN) framework and proposed a deep CNN, called CNN-word, for automating the decoding of EOG-based words, which can continuously analyse the dynamics within an EOG word by automatically learning stroke-to-character-to-word constructions. From their findings, using the CNN the average accuracy of EOG word recognition among all users is 90.58%. Deep Neural Networks (DNNs) are effective tools for identifying and tracking aspects of interest, and they have recently been applied to eye tracking. The ability of a DNN to anticipate keypoints localising the eyelid and pupil under the types of demanding picture variability seen in mobile eye-tracking were tested in a study by Biswas *et al.* [113]. Rotations, blur, exposure, reflection, and compression artefacts are five typical sources of visual variation in mobile eye-tracking that we mimic with varied degrees of perturbation. Features produced from a DNN (ResNet50) were used to compute the distance of each perturbed video from the films used to train DNN to assess the relative performance reduction across domains in a common space of image variation [113]. The study suggests beneficial advancements for training data augmentation but the association between model feasibility and distance from the training set is currently too low to be employed as a frame-by-frame quality assessment. Calculating distance from a training set, on the other hand, could be beneficial in determining whether a new data session is likely to cause issues. Research in psychophysics and neuromarketing applications benefit greatly from real-time gaze tracking. Because of the high-end processing hardware specialised for processing infrared camera photos, many modern eye-tracking devices are pricey. In their study Zdarsky et al [114] provide a deep learning-based method for analysing video frames from

TABLE 5. AI algorithms used in eye-tracking research.

Algorithms	Merits	Demerits
Convolutional Neural Networks [115]	• High accuracy	• Poorly regulated parameters such as sample size may affect accuracy of the results if they are not appropriately controlled.
Support Vector Machine [116]	• The use of SVM for prediction analysis is feasible using eye-tracking data	• Due to the small sample size, generalizability is limited.
Random Forest (RF) [117]	• Doesn't require scalability, features can be used in their current state	• The RF algorithm is incapable of learning the sequence and context information directly from raw data and provides the final output without any postprocessing.
Artificial Neural Network (ANN) [114]	• It has been demonstrated that the ANN-based prediction model generates a high correlation coefficient between the original and forecasted data.	• The prediction model's statistical power and reliability are hindered by the short sample size. To validate the provided data, a study with controlled illumination conditions is required.
Deep learning [118]	• The accuracy and performance of detection systems have been increased due to deep learning.	• In state-of-the-art detection systems, search efficiency is still a serious concern.

low-cost web cams. Facial markers crucial to gaze placement were retrieved using DeepLabCut (DLC), an open-source toolbox for identifying areas of interest from movies, then predicted the point of glance on a computer screen using a shallow neural network. This architecture had a median inaccuracy of around one degree of visual angle when tested for three extreme positions. Their findings add to the emerging field of deeplearning techniques to eye-tracking, establishing the groundwork for additional research by psychophysics or neuromarketing experts. Table 5 shows AI algorithms used in eye-tracking research.

VIII. EYE-TRACKING APPLICATIONS

Eye-tracking has been a fundamental tool in various form of research. It can be used to develop applications and collect data in a range of sectors, including healthcare and medicine, psychology, marketing, engineering, education, and gaming, as well as boost human-computer interactions by allowing users to navigate and operate their devices with eyes. This section presents various eye-tracking applications.

A. TRANSPORTATION

Eye-tracking has been applied to devices used to enhance the safety of drivers and road users in general. Eye-tracking systems have proven a convenient performance indoors when surrounding light is controlled, and the eye region of interest (ROI) can be detected by using focused images. These techniques are used in a driving scenario, where the light can vary quickly while the vehicle is in motion, so a continuous reflection of lights on the eye cannot be assured. The detection of driver's fatigue [119], monitoring of drowsiness [120], detection of drowsiness in real time [121], driving-assistance systems [122], and accident prevention [123] all benefit from eye tracking research. Many researchers have expressed interest in creating intelligent systems for activating alert systems when the driver's eyes are not visible for several seconds. To detect visual changes, the Viola Jones face detector and tracking-learning detection algorithms have been utilized in other systems [124], Neshov and Manolova proposed a hybrid algorithm that combines these two algorithms [120] while Anjali *et al.* [123] created a device to reduce car accidents by detecting closed eyes as a sign of driving weariness and alerting drivers with a buzzer and vibration if the detection is positive. The system was created with a front-facing camera that collects real-time video using OpenCV and a Raspberry Pi. It can detect the eyes in low, medium, and high light. Yan *et al.* [125], also used grayscale image processing and PERCLOS to assess if the driver is suffering from exhaustion or drowsiness promptly. The rapid sort method is used to confirm the black pixel distribution range. This method can be applied even if the driver is wearing glasses or a breathing mask. Eriksson *et al.* [126] investigated the utility of gaze time on screen as a measure of engagement in a screen-mediated learning context, and the results revealed little about the drivers' engagement when utilizing eye-trackers while driving an expensive car [126]. Khushaba *et al.* [127] devised a feature extraction approach called fuzzy mutual information-based wavelet packet transform (FMIWPT) to classify the driver drowsiness condition into one of the predefined drowsiness levels. During a simulated driving test, FMIWPT retrieved the most relevant features required to identify the driver's drowsiness/fatigue states and maximized the quantity of drowsiness-related information collected from an EEG, electrooculogram (EOG), and electrocardiogram (ECG) signal set. The authors also evaluated EOG, ECG, and EEG signals for feature extraction and discovered that EEG and ECG signals are better for this than EOG signals. Other attempts were made to use a camera to monitor the driver's eyes and detect signs of driving drowsiness early enough to prevent an accident [128]. Eye-tracking technology was further applied by researchers in the University of Missouri: The first application is based on developing a better collision avoidance warning system, while the second application was focused on evaluating the driver's physical behaviour in real time using the driver's eyes when a crash occurs. They discovered that the collision avoidance system's alert causes a distraction, which can cause an accident. To avoid such accidents, they employed a vehicle-assisted safety system to monitor how people's pupils altered in response to their physical reactions and created a two-way communication channel between a driver and a vehicle [129]. Furthermore, car manufacturers have been scouring the globe for methods to incorporate IoT into vehicles for entertainment and, more importantly, for the safety of elderly and special-needs drivers. Many firms, including Volkswagen, GM, and Audi, have set their sights on eye-tracking in smart cars. To ensure the safety of drivers on the road, sensors were utilized to detect eye blinks. Drowsiness and sleepiness have been detected via eye-tracking [130]. Using eye-tracking techniques, Noland *et al.* [131] conducted a survey to assess quantitatively how people interpret and rank images used in public contexts for urban planning. Different rating levels for urbanist components such as images, people, pedestrian elements, greenery, buildings, automobiles, and parking were found in their findings. They also demonstrated how to extract more value from visual preference surveys for transportation and urban planners, which can be used to reduce motor vehicle traffic in cities in the future. Various approaches for making driving safer for old persons have been investigated, including the use of IoT to swiftly obtain assistance during an emergency for instance when a stroke happens while driving, Park *et al.* [132] demonstrated how stroke can be identified and how a medical doctor or relative can be notified. The authors, for example, demonstrated how older people can employ wearable devices with sensors to assist them to stay safe during a stroke. Visual, physical, and cognitive distractions are the three forms of driving distractions classified by the US National Highway Traffic Safety Administration [133]. Several studies have looked into using eye-tracking to determine the sort of distraction [134]–[136]. In a real-world driving situation, cognitive distraction is frequently accompanied by visual and manual distraction [137]. Checking the level of visual and manual distraction can also assist in determining the level of cognitive distraction of car assistive systems. Future Research looks into discovering cognitive distraction from a manual or visual distraction using eye-trackers. Checking the level of visual and manual distraction can also aid in determining the level of cognitive distraction.

B. HEALTH CARE

Several studies have proved that eye-tracking can be applied in varying elements of medical care. Mental illnesses for instance can be catered for with eye-tracking technology. Studies shows that mental disorders such as bipolar disorder [138], Alzheimer disease [139], ADHD [140], mild cognitive impairment [141], Autism [142]. Eye-tracking could be used to help people with autism, with the development of augmentative and alternative communication (AAC) policies. Individuals with autism, have poor communicative and language abilities, and analysing their gaze can aid in the customization of AAC design [143]. Wanluk *et al.* [144] used eye-tracking technology to develop a smart wheelchair for individuals with mobility disabilities. The smart wheelchair comprises four features which include an imaging processing module, wheelchair-controlled module, SMS manager module, and appliance-controlled module. The coordinate of the eye movement is wirelessly transmitted to wheelchair-controlled module to control the movement of a wheelchair. The wheelchair-controlled module is a two-dimensional rotating stage that is installed to the joystick of the electrical wheelchair to replace the manual control of the wheelchair. The eye movement is also used to control the cursor on the raspberry Pi screen to send messages to mobile phones. NajiKhosravan *et al.* [145] created an algorithm that integrates CAD with eye-tracking devices by utilizing a variable collaborative-computer aided diagnosis (C-CAD) system. To integrate eye-tracking data into a network model that can be used in a radiology room, the researchers used graph clustering. The technology also includes a three-dimensional deep learning algorithm, built within a new multi-task platform that can split and recognize suspicious areas at the same time. The researchers put their approach to the test on patients with lung cancer in front of a panel of radiologists. The findings revealed that their method improves accuracy, efficiency, and applicability in an actual radiology environment. Lauermann *et al.* [146] created an evaluation methodology to assess the impact of eye-tracking technology on the quality of OCT-A images in patients with age-related macular degeneration (AMD). The results of the study revealed that adopting active eye-tracking technology improves image quality in OCT-A imaging in terms of involuntary movement in AMD patients when the acquisition time is longer. Speaking and writing are challenging for patients with amyotrophic lateral sclerosis (ALS). A software program based on the Edinburgh Cognitive and Behavioural ALS Screen [147] has been created that uses neuropsychological screening instruments. It tracks eye movements using an infrared sensor called Eye-Live and a pre-programmed user interface. It does not rely on a shared camera; instead, it uses infrared sensors embedded in a pair of glasses to determine the direction of the eye glance. Current entry-level systems for people with ALS have a number of flaws: They are costly, inflexible under varied lighting conditions, and necessitate specialized care. Other low-cost systems exist Optikey as earlier mentioned to enable patients with ALS to communicate utilizing eye-tracking technology.

C. EDUCATION

Eye-tracking has been shown to have advantageous applications in the field of education. Inoue and Paracha employed eye-tracking technology to analyse the extent to which fluent and non-fluent readers complete the processing of texts and images to enhance their reading results [148]. Rasmussen and Tan investigated reading progress using an eye gaze-tracker and speech recognition to create word probabilities to improve the language model's likelihood. According to their findings, the tracking error rate for speech recognition was 34.9%, whereas the error rate for combining eye gaze tracking with speech recognition was 31.2%, a 10.6% improvement [149]. Guarnera *et al.* created the iTrace eye-tracking infrastructure, which allows software engineers to work under more realistic conditions by enabling an eye-tracking option in several integrated development environments [150]. Using eye-tracking data, Najar *et al.* compared the behaviours of beginners and experienced students while studying examples to raise learning levels using an intelligent tutoring system [151].In a digital assessment game, video-based pupil monitoring eye-trackers were utilized to explore the allocation of the attention generated by the eye-tracker regarding an individual's locus of attention. In terms of measuring and evaluating cognitive level, inspiring an interface design, discovering a behavioural response based on user data, improving teaching quality by improving the teaching framework, promoting the use of technology, and improving educational standards, eye-tracking technology has proven its efficiency and effectiveness. However, other areas, such as designing an adaptive system based on the need for user's cognitive load levels estimated from eye-tracking data, are lacking substantial contributions. Having a method like this will improve training by enhancing knowledge transfer and retention while maximizing the trainee's time. Adding gamification techniques to educational systems, utilizing eye-tracking technology for individuals with severe disabilities could increase learning engagements.

IX. FUTURE DIRECTION AND RESEARCH

There are other interesting areas where eye technology research can be utilized, such as the gaming industry, recommendation-based adverts and marketing, education, and assistive technology. According to recent research, the advertising industry will focus more on attention metrics in the future, rather than impressions, and eye-tracking technologies are the best way to evaluate attention [152]. The nutrition label can provide consumers with additional information about a product's healthiness, and so the design qualities can boost the likelihood that consumers will pay attention to this label visually, this data can be collected and analysed with eye-tracking technology. As a result, future research might investigate how different design methods affect healthy food selection. In terms of accuracy and responsiveness of actions, researchers on computer games have found that eye-tracking gives players greater control of inputs and completion of game actions than standard input devices (e.g., mouse, keyboard, and game controllers) [153]. There are various advantages of using eye-tracking in games. For starters, it informs game developers of the player's visual concentration. It also analyses the player's core skills to determine his or her strengths and limitations, as well as how to develop them. With Eye-tracking, the player gets more realistic engagement, giving them a deeper experience and the capacity to be more engaged with the game. In terms of future research, eye-tracking can be integrated into the field of augmented and virtual reality-based games to create a more fluid and immersive environment. Further research can be done to explore how eye-tracker enhanced games can be improved. ML algorithms are highly powerful tools that can change the way systems are implemented. However, there are several drawbacks to using ML algorithms in eye-tracking systems. The significant dependency between selected features, sample size, and data quality with accurate findings is one of these restrictions, and it has been proved that if the images used for training and/or testing CNNs are of low quality, the results will be inferior to those utilizing higher quality images [154]. In addition, the quality of sample images is affected by the calibration of operational parameters of a handheld device's camera. Furthermore, the nature and structure of the obtained data, as well as the successful labelling of training data, aid pre-processing and post-processing in the generation of higher quality data. Because of their ability to independently adapt and learn from past data, spot trends, and provide trustworthy choices with minimal human interaction, ML algorithms such as SVM and NN are useful to incorporate with eye-tracking systems. This integration will most probably result in more precise and reliable eye-tracking findings. Some of the eye-tracking concerns can be solved with algorithms that use ML methods. Syncing between head movement and head-rotation data is one of these challenges. Noisy data is another issue that must be addressed, particularly when multiple IoT devices are used together. Another research gap that future research can address is the case of reducing dwell time for eye-tracking communication systems such as gaze to text software. In a study [155], non-disabled individuals were found to be able to type at a maximum rate of 19.9 words per minute (wpm). This typing speed is slow when compared to speaking (150 wpm) and typing on a standard keyboard (40 wpm). Working at such a slow pace may make it difficult and demotivating to use gaze-to-text systems on a regular basis. Future research can look into reducing the dwell time of gaze-to-text systems in order to increase the typing speeding user.

X. CONCLUSION

A systematic literature review was performed to investigate the use of eye-tracking technology as an assistive technology for individuals with ALS. One major finding from the systematic literature review is that eye-tracking technology has shown substantial contributions in various research areas particularly in health care, education and industrially. Eye-tracking has been able to provide valuable support for individuals with severe disabilities by being a useful tool for human computer interaction. Some of the limitations of conducting eye-tracking research have also been highlighted, which include the expensive nature of commercial eye-trackers. The paper introduces some cheaper but valuable alternatives and open-source eye-tracking software. Another finding shows that gamification and eye-tracking can be successfully combined to increase motivation and engagement of tasks.

Eye-tracking can also serve as a much-needed alternative to the control of gaming elements which could be beneficial to individuals with severe disabilities. In the area of calibration and event detection, NN and ML proves superior to existing detection algorithms. Eye-tracking research in assistive technology for people with motor neuron diseases is becoming increasingly important as the demand for assistance for those with severe disabilities increases. This review examines some of the most commonly used software and hardware in the area, as well as eye-tracking techniques, their limits, and cutting-edge technologies such as ML algorithms that can help enhance the field. There were also some research gaps discovered. As a result, this discovery can help future researchers who want to improve eye-tracking technology. The study backs the use of eye-tracking in assistive technology studies for those with severe disabilities.

A. DATA STATEMENT

"Pre-existing data underpinning this publication are openly available at http://10.24339/8c3d57d4-b1d2-46b5-8082-32d5bfe3d4d91. Further information about data processing, and additional new supporting data are available from the University of Northampton Research Explorer at http://doi.org/10.15129/a1234b56"

REFERENCES

[1] P. Masrori and P. Van Damme, "Amyotrophic lateral sclerosis: A clinical review," *Eur. J. Neurol.*, vol. 27, no. 10, pp. 1918–1929, 2020.

[2] D. R. Beukelman, S. Fager, L. Ball, and A. Dietz, "AAC for adults with acquired neurological conditions: A review," *Augmentative Alternative Commun.*, vol. 23, no. 3, pp. 230–242, Jan. 2007.

[3] P. S. Holzman, L. R. Proctor, and D. W. Hughes, "Eye-tracking patterns in schizophrenia," *Science*, vol. 181, no. 4095, pp. 179–181, Jul. 1973.

[4] P. Maurage, N. Masson, Z. Bollen, and F. D'Hondt, "Eye tracking correlates of acute alcohol consumption: A systematic and critical review," *Neurosci. Biobehav. Rev.*, vol. 108, pp. 400–422, Jan. 2020.

[5] A. Al-Mahmood and M. O. Agyeman, "On wearable devices for motivating patients with upper limb disability via gaming and home rehabilitation," in *Proc. 3rd Int. Conf. Fog Mobile Edge Comput. (FMEC)*, Apr. 2018, pp. 155–162.

[6] R. G. Bozomitu, L. Niüta, V. Cehan, I. D. Alexa, A. C. Ilie, A. Pasarica, and C. A. Rotariu, "New integrated system for assistance in communicating with and telemonitoring severely disabled patients," *Sensors*, vol. 2019, p. 19, Jan. 2026.

[7] M. O. Agyeman, A. Al-Mahmood, and I. Hoxha, *A Home Rehabilitation System Motivating Stroke Patients with Upper and Lower Limb Disability*. New York, NY, USA: Association for Computing Machinery, 2019, doi: 10.1145/3386164.3386168.

[8] A. Al-Mahmood and M. O. Agyeman, *Design an IoT Serious Games Based on A Wearable Device: For Home Rehabilitation With Arduino and Raspberry Pi*. New York, NY, USA: Academic, 2019.

[9] M. O. Agyeman and M. Jegatheeswaran, *Design and Implementation of a Smart Health Monitoring System*. New York, NY, USA: Academic, 2019.

[10] N. Guliani, M. K. Shukla, A. K. Dubey, and Z. A. Jaffery, "Analysis of multimodal biometrie recognition using iris and sclera," in *Proc. 6th Int. Conf. Rel., Inf. Technol. Optim.*, Sep. 2017, pp. 472–475.

[11] F. Zhou, A. Alsaid, M. Blommer, R. Curry, R. Swaminathan, D. Kochhar, W. Talamonti, L. Tijerina, and B. Lei, "Driver fatigue transition prediction in highly automated driving using physiological features," *Expert Syst. Appl.*, vol. 147, Jun. 2020, Art. no. 113204.

[12] I. García, S. Bronte, L. M. Bergasa, N. Hernandez, B. Delgado, and M. Sevillano, "Vision-based drowsiness detector for a realistic driving simulator," in *Proc. 13th Int. IEEE Conf. Intell. Transp. Syst. (ITSC)*, Sep. 2010, pp. 887–894.

[13] A. Fletcher, S. Dunne, and J. Butler, "A brief history of eye movement research," Apr. 2021. [Online]. Available: http://psyarxiv.com/yb4zq

[14] K. Harezlak and P. Kasprowski, "Application of eye tracking in medicine: A survey, research issues and challenges," *Comput. Med. Imag. Graph.*, vol. 65, pp. 176–190, 2018.

[15] A. T. Duchowski and A. T. Duchowski, *Eye Tracking Methodology: Theory and Practice*. Cham, Switzerland: Springer, 2017.

[16] D. W. Hansen and A. E. Pece, "Eye tracking in the wild," *Comput. Vis. Image Understand.*, vol. 98, no. 1, pp. 155–181, 2005.

[17] S. A. Johansen, J. San Agustin, H. Skovsgaard, J. P. Hansen, and M. Tall, "Low cost vs high-end eye tracking for usability testing," in *Proc. Extended Abstr. Hum. Factors Comput. Syst.*, vol. 11, 2011, pp. 1177–1182.

[18] P. Mannaru, B. Balasingam, K. Pattipati, C. Sibley, and J. T. Coyne, "Performance evaluation of the gazepoint GP3 eye tracking device based on pupil dilation," in *Proc. Int. Conf. Augmented Cognition*, Cham, Switzerland, 2017, pp. 166–175.

[19] A. Papoutsaki, J. Laskey, and J. Huang, "Searchgazer: Webcam eye tracking for remote studies of web search," in *Proc. Conf. Conf. Hum. Inf. Interact. Retr.*, 2017, pp. 17–26.

[20] P. Xu, K. A. Ehinger, Y. Zhang, A. Finkelstein, S. R. Kulkarni, and J. Xiao, "Turkergaze: Crowdsourcing saliency with webcam based eye tracking," 2015, *arXiv:1504.06755*.

[21] M. X. Huang, T. C. Kwok, G. Ngai, S. C. Chan, and H. V. Leong, "Building a personalized auto-calibrating eye tracker from user interactions," in *Proc. CHI*, 2016, pp. 5169–5179.

[22] A. Papoutsaki, P. Sangkloy, J. Laskey, N. Daskalova, J. Huang, and J. Hays, "Webgazer: Scalable webcam eye tracking using user interactions," in *Proc. IJCAI*, 2016, pp. 3839–3845.

[23] M. Vidal, J. Turner, A. Bulling, and H. Gellersen, "Wearable eye tracking for mental health monitoring," *Comput. Commun.*, vol. 35, no. 11, pp. 1306–1311, 2012.

[24] J. M. Franchak, K. S. Kretch, K. C. Soska, J. S. Babcock, and K. E. Adolph, "Head-mounted eye-tracking of infants' natural interactions: A new method," in *Proc. Symp. Eye-Tracking Res. Appl.*, Austin, TX, USA, 2010, pp. 21–27.

[25] D. Li and D. J. Parkhurst, "OpenEyes: An open-hardware open-source system for low-cost eye tracking," *J. Mod. Opt.*, vol. 53, no. 9, pp. 1295–1311, 2006.

[26] J. Titz, A. Scholz, and P. Sedlmeier, "Comparing eye trackers by correlating their eye-metric data," *Behav. Res. Methods*, vol. 50, no. 5, pp. 1853–1863, Oct. 2018.

[27] R. G. Bozomitu and C. Rotariu, "Development of an eye tracking-based human-computer interface for real-time applications," *Sensors*, vol. 19, no. 16 p.3630, 2019.

[28] D. Li, D. Winfield, and D. J. S. A. Parkhurst, "Hybrid algorithm for video-based eye tracking combining feature-based and model-based approaches," in *Proc. IEEE Comput. Soc. Conf. Comput. Vis. Pattern Recognit. Workshops*, Sep. 2005, p. 79.

[29] D. Li, "Robust algorithm for video-based eye tracking," in *Proc. Vis. Hum.-Comput. Interact. Workshop*, Ames, IA, USA, 2005, pp. 1–5.

[30] A. W. Fitzgibbon, M. Pilu, and R. B. Fisher, "Direct least squares fitting of ellipses," in *Proc. 13th Int. Conf. Pattern Recognit.*, Vienna, Austria, 1996, pp. 253–257.

[31] N. Cherabit, A. Djeradi, and F. Z. Chelali, "Circular Hough transform for iris localization," *Sci. Technol.*, vol. 2, pp. 114–121, Dec. 2012.

[32] H. L. Rhody, *Hough Circle Transform; Chester F* (Carlson Center for Imaging Science). Rochester, NY, USA: Rochester Institute of Technology, 2005.

[33] M. A. Fischler and R. Bolles, "Random sample consensus: A paradigm for model fitting with applications to image analysis and automated cartography," *Commun. ACM*, vol. 24, no. 6, pp. 381–395, 1981.

[34] L. Swirski, A. Bulling, and N. Dodgson, "Robust real-time pupil tracking in highly off-axis images," in *Proc. Symp. Eye Tracking Res. Appl.*, Santa Barbara, CA, USA, 2012, pp. 28–30.

[35] G. J. Mohammed, B. R. Hong, and A. A. Jarjes, "Accurate pupil features extraction based on new projection function," *Comput. Informat.*, vol. 29, no. 4, pp. 663–680, 2012.

[36] Z.-H. Zhou and X. Geng, "Projection functions for eye detection," *Pattern Recognit.*, vol. 37, no. 5, pp. 1049–1056, May 2004.

[37] D. Zhu, S. T. Moore, and T. Raphan, "Robust pupil center detection using a curvature algorithm," *Comput. Methods Programs Biomed.*, vol. 59, no. 3, pp. 145–157, Jun. 1999.

[38] W.-D. Chang, H.-S. Cha, D. Y. Kim, S. H. Kim, and C.-H. Im, "Development of an electrooculogram-based eye-computer interface for communication of individuals with amyotrophic lateral sclerosis," *J. NeuroEng. Rehabil.*, vol. 14, no. 1, pp. 1–13, Dec. 2017.

[39] V. Clay, P. König, and S. U. König, "Eye tracking in virtual reality," *JEMR*, vol. 12, no. 1, Apr. 2019.

[40] E. Pasqualotto, T. Matuz, S. Federici, C. A. Ruf, M. Bartl, M. O. Belardinelli, N. Birbaumer, and S. Halder, "Usability and workload of access technology for people with severe motor impairment: A comparison of brain-computer interfacing and eye tracking," *Neurorehabil. Neural Repair*, vol. 29, no. 10, pp. 950–957, 2015.

[41] I. Käthner, A. Kübler, and S. Halder, "Comparison of eye tracking, electrooculography and an auditory brain-computer interface for binary communication: A case study with a participant in the locked-in state," *J. NeuroEng. Rehabil.*, vol. 12, no. 1, pp. 1–11, Dec. 2015.

[42] S. Kishore, M. González-Franco, C. Hintemüller, C. Kapeller, C. Guger, M. Slater, and K. J. Blom, "Comparison of SSVEP BCI and eye tracking for controlling a humanoid robot in a social environment," *Presence, Teleoperators Virtual Environ.*, vol. 23, no. 3, pp. 242–252, Oct. 2014.

[43] N. Scott, R. Zhang, D. Le, and B. Moyle, "A review of eye-tracking research in tourism," *Current Issues Tourism*, vol. 22, no. 10, pp. 1244–1261, Jun. 2019.

[44] Z. Sharafi, Z. Soh, and Y.-G. Guéhéneuc, "A systematic literature review on the usage of eye-tracking in software engineering," *Inf. Softw. Technol.*, vol. 67, pp. 79–107, Nov. 2015.

[45] D. W. Hansen and Q. Ji, "In the eye of the beholder: A survey of models for eyes and gaze," *IEEE Trans. Pattern Anal. Mach. Intell.*, vol. 32, no. 3, pp. 478–500, Mar. 2010.

[46] H. R. Chennamma and X. Yuan, "A survey on eye-gaze tracking techniques," 2013, *arXiv:1312.6410*.

[47] P. Sorate, B. Vpkbiet, and G. J. Chhajed, "Survey paper on eye gaze tracking methods and techniques," *Int. Res. J. Eng. Technol.*, vol. 4, no. 6, pp. 465–468, 2017.

[48] K. Eibenberger, B. Eibenberger, and M. Rucci, "Design, simulation and evaluation of uniform magnetic field systems for head-free eye movement recordings with scleral search coils," in *Proc. 38th Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. (EMBC)*, Aug. 2016, pp. 247–250.

[49] M. B. McCamy, J. Otero-Millan, R. J. Leigh, S. A. King, R. M. Schneider, S. L. Macknik, and S. Martinez-Conde, "Simultaneous recordings of human microsaccades and drifts with a contemporary video eye tracker and the search coil technique," *PLoS ONE*, vol. 10, no. 6, Jun. 2015, Art. no. e0128428.

[50] Z. Chen, H. Fu, W. L. Lo, and Z. Chi, "Artificial intelligence in medical applications," *J. Healthcare Eng.*, vol. 2018, p. 15, Jun. 2018.

[51] M. M. Rana, M. W. Islam, and M. J. Hossain, "Eyewriter based pc control system for paralyzed and disabled patients," in *Proc. Int. Conf. Adv. Electr. Electron. Eng. (ICAEEE)*, Nov. 2018, pp. 1–4.

[52] N. Wanluk, S. Visitsattapongse, A. Juhong, and C. Pintavirooj, "Smart wheelchair based on eye tracking," in *Proc. 9th Biomed. Eng. Int. Conf. (BMEiCON)*, Dec. 2016, pp. 1–4.

[53] A. Lazarov, B. Suarez-Jimenez, A. Tamman, L. Falzon, X. Zhu, D. E. Edmondson, and Y. Neria, "Attention to threat in posttraumatic stress disorder as indexed by eye-tracking indices: A systematic review," *Psychol. Med.*, vol. 49, no. 5, pp. 705–726, Apr. 2019.

[54] M. B. Hunter and R. Chin, "Impaired social attention detected through eye movements in children with early-onset epilepsy," *Epilepsia*, vol. 62, no. 8, pp. 1921–1930, 2021, doi: 10.1111/epi.16962.

[55] O. Arslan, O. Atik, and S. Kahraman, "Eye tracking in usability of electronic chart display and information system," *J. Navigat.*, vol. 74, no. 3, pp. 594–604, May 2021.

[56] 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, 2021.

[57] A. Armanini and N. Conci, "Eye tracking as an accessible assistive tool," in *Proc. 11th Int. Workshop Image Anal. Multimedia Interact.*, vol. 11, Apr. 2010, pp. 1–4, 2010.

[58] L. P. G. Kourkoutisnad and J. Hadjileontiadis, "Automated iris and gaze detection using chrominance: Application to human-computer interaction using a low resolution webcam," in *Proc. Int. Conf. Tools Artif. Intell.*, Oct. 2007, pp. 536–539.

[59] F. J. Parada, D. Wyatte, C. Yu, R. Akavipat, B. Emerick, and T. Busey, "ExpertEyes: Open-source, high-definition eyetracking," *Behav. Res. Methods*, vol. 47, no. 1, pp. 73–84, 2015.

[60] C. Yu, T. Busey, and J. Vanderkolk, "Discovering correspondences between fingerprints based on the temporal dynamics of eye movements from experts," in *Proc. Int. Workshop Comput. Forensics. November.* Berlin, Germany: Springer, 2010, pp. 160–172.

[61] J. San Agustin, H. Skovsgaard, and E. Mollenbach, "Evaluation of a low-cost open-source gaze tracker," in *Proc. Symp. Eye-Tracking Res. Appl.*, 2010, pp. 77–80.

[62] A. Voßkühler, V. Nordmeier, L. Kuchinke, and A. M. Jacobs, "OGAMA (Open gaze and mouse Analyzer): Open-source software designed to analyze eye and mouse movements in slideshow study designs," *Behav. Res. Methods*, vol. 40, no. 4, pp. 1150–1162, Nov. 2008.

[63] C. Costescu, A. Rosan, N. Brigitta, A. Hathazi, A. Kovari, J. Katona, R. Demeter, I. Heldal, C. Helgesen, S. Thill, and I. Efrem, "Assessing visual attention in children using GP3 eye tracker," in *Proc. 10th IEEE Int. Conf. Cognit. Infcommun.*, Oct. 2019, pp. 343–348.

[64] T. Ujbanyi, J. Katona, G. Sziladi, and A. Kovari, "Eye-tracking analysis of computer networks exam question besides different skilled groups," in *Proc. 7th IEEE Int. Conf. Cognit. Infcommun.*, Oct. 2016, p. 000.

[65] M. S. E. S. Dalmaijer and S. Van der Stigchel, "Pygaze: An open-source, cross-platform toolbox for minimal-effort programming of eyetracking experiments," *Behav. Res. Methods*, vol. 46, no. 4, pp. 913–921, 2014.

[66] S. Akshay, Y. J. Megha, and C. B. Shetty, "Machine learning algorithm to identify eye movement metrics using raw eye tracking data," in *Proc. 3rd Int. Conf. Smart Syst. Inventive Technol. (ICSSIT)*, Aug. 2020, pp. 949–955.

[67] J. Sweetland. (Jun. 2021). *Optikey/Optikey Github*. Accessed: Jun. 5, 2021. [Online]. Available: https://github.com/OptiKey/OptiKey/wiki

[68] T. Bafna and J. P. Hansen, "Eye-tracking based fatigue Cognit. assessment: Doctoral extended abstract," in *Proc. 11th ACM Symp. Eye Tracking, Res. Appl.*, May 2019, pp. 1–3.

[69] M. U. Ghani, S. Chaudhry, M. Sohail, and M. N. Geelani, "GazePointer: A real time mouse pointer control implementation based on eye gaze tracking," in *Proc. Multi Topic Conf.*, Dec. 2013, pp. 154–159.

[70] C. Niu, J. Sun, J. Li, and H. Yan, "A calibration simplified method for gaze interaction based on using experience," in *Proc. 17th Int. Workshop Multimedia Signal Process. (MMSP)*, Oct. 2015, pp. 1–5.

[71] E. Nel, D. MacKay, P. Zieliński, O. Williams, and R. Cipolla, "Opengazer: Open-source gaze tracker for ordinary webcams," 2012. [Online]. Available: http://publications.eng.cam.ac.uk

[72] N. Bee and E. André, "Writing with your eye: A dwell time free writing system adapted to the nature of human eye gaze," in *Proc. Int. Tutorial Res. Workshop Perception Interact. Technol. Speech-Based Syst.*, Berlin, Germany: Springer, 2008, pp. 111–122.

[73] O. Ferhat, A. Llanza, and F. Vilarino, "Gaze interaction for multi-display syst using natural light eye-tracker," in *Proc. SAGA-Int. Workshop Solutions Autom. Gaze Data Anal.*, 2015, pp. 1–5.

[74] S. Xu, H. Jiang, and F. C. M. Lau, "User-oriented document summarization through vision-based eye-tracking," in *Proc. 14th Int. Conf. Intell. User Interface*, Feb. 2009, pp. 7–16.

[75] H. Sogo, "GazeParser: An open-source and multiplatform library for low-cost eye tracking and analysis," *Behav. Res. Methods*, vol. 45, no. 3, pp. 684–695, Sep. 2013.

[76] A. F. Klaib, N. O. Alsrehin, W. Y. Melhem, H. O. Bashtawi, and A. A. Magableh, "Eye tracking algorithms, techniques, tools, and applications with an emphasis on machine learning and Internet of Things technologies," *Expert Syst. Appl.*, vol. 4, Oct. 2020, Art. no. 114037.

[77] M. Trefzger, W. Titov, and T. Schlegel, "Analysis and comparison of the gaze behavior of e-scooter drivers and cyclists," in *Proc. INFORMATIK*, 2021, pp. 1–5.

[78] N. Stein, D. C. Niehorster, T. Watson, F. Steinicke, K. Rifai, S. Wahl, and M. Lappe, "A comparison of eye tracking latencies among several commercial head-mounted displays," *I-Perception*, vol. 12, no. 1, 2021, Art. no. 2041669520983338.

[79] I. Hooge, R. Hessels, D. Niehorster, G. Diaz, A. Duchowski, and J. Pelz, "From lab-based studies to eye-tracking in virtual and real worlds: Conceptual and methodological problems and solutions," *J. Eye Movement Res.*, vol. 12, no. 7, pp. 1–6, 2021.

[80] S. Knust. (Sep. 2020). *5 Advancements in Eye Tracking for Consumer Research|Tobii Pro*. Accessed: Jan. 16, 2022. [Online]. Available: https://www.tobiipro.com/blog/advancements-eye-tracking-consumer-research/

[81] D. C. Niehorster, R. S. Hessels, and J. S. Benjamins, "GlassesViewer: Open-source software for viewing and analyzing data from the tobii pro glasses 2 eye tracker," *Behav. Res. Methods*, vol. 52, no. 3, pp. 1244–1253, Jun. 2020.

[82] A. Sipatchin, S. Wahl, and K. Rifai, "Eye-tracking for clinical ophthalmology with virtual reality (VR): A case study of the htc vive pro eye's usability," in *Healthcare*, vol. 9, no. 2, p. 180, 2021.

[83] A. F. Klaib, N. O. Alsrehin, W. Y. Melhem, H. O. Bashtawi, and A. A. Magableh, "Eye tracking algorithms, techniques, tools, and applications with an emphasis on machine learning and Internet of Things technologies," *Expert Syst. Appl.*, vol. 1140, p. 37, Dec. 2020.

[84] S. Tong and E. Chang, "Support vector machine active learning for image retrieval," in *Proc. 9th ACM Int. Conf. Multimedia*, 2001, pp. 107–118.

[85] A. Bulling and H. Gellersen, "Toward mobile eye-based human-computer interaction," *IEEE Pervasive Comput.*, vol. 9, no. 4 pp. 8–12, Sep. 2010.

[86] C. Singh, N. Mittal, and E. Walia, "Face recognition using Zernike and complex Zernike moment features," *Pattern Recognit. Image Anal.*, vol. 21, no. 1, ppp. 71–81, 2011.

[87] H. Singh, J. Bhatia, and J. Kaur, "Eye tracking based driver fatigue monitoring and warning system," in *Proc. India Int. Conf. Power Electron. (IICPE)*. New Delhi, India, 2011, pp. 1–5.

[88] E. Whitmire, L. Trutoiu, R. Cavin, D. Perek, B. Scally, J. Phillips, and S. Patel, "EyeContact: Scleral coil eye tracking for virtual reality," in *Proc. ACM Int. Symp. Wearable Comput.*, Sep. 2016, pp. 184–191.

[89] D. L. Kimmel, D. Mammo, and W. T. Newsome, "Tracking the eye non-invasively: Comparison of the scleral search coil and optical tracking techniques in the macaque monkeys," *Frontiers Behav. Neurosci.*, vol. 6, p. 49, Dec. 2012.

[90] A. Larson, J. Herrera, K. George, and A. Matthews, "Electrooculography based electronic communication device for individuals with als," in *Proc. Sensors Appl. Symp.*, 2017, pp. 1–5.

[91] M. Lin and B. Li, "A wireless EOG-based human computer interface," in *Proc. 3rd Int. Conf. Biomed. Eng. Informat.*, Oct. 2010, pp. 1794–1796.

[92] N. Barbara and T. A. Camilleri, "Interfacing with a speller using EOG glasses," in *Proc. IEEE Int. Conf. Syst., Man, Cybern. (SMC)*, Oct. 2016, Art. no. 0041069.

[93] B. C. Kaufmann, D. Cazzoli, M. Koenig-Bruhin, R. M. Müri, T. Nef, and T. Nyffeler, "Video-oculography during free visual exploration to detect right spatial neglect in left-hemispheric stroke patients with aphasia: A feasibility study," *Frontiers Neurosci.*, vol. 15, p. 269, Oct. 2021.

[94] M. Morrison, H. Kerkeni, A. Korda, S. Räss, M. D. Caversaccio, M. Abegg, E. Schneider, and G. Mantokoudis, "Automated alternate cover test for 'HINTS'assessment: A validation study," *Eur. Arch. Oto-Rhino-Laryngol.*, vol. 4, pp. 1–7, Dec. 2021.

[95] K. Ahuja and P. Tuli, "Object recognition by template matching using correlations and phase angle method," *Int. J. Adv. Res. Comput. Commun. Eng.*, vol. 2, no. 3, pp. 1368–1373, 2013.

[96] W. Hotrakool, P. Siritanawan, and T. Kondo, "A real-time eyetracking method using time-varying gradient orientation patterns," in *Proc. Electr. Eng./Electronics Comput. Telecommun. Inf. Technol. (ECTI-CON)*, 2010, pp. 492–496.

[97] H. Liu and Q. Liu, "Robust real-time eye detection and tracking for rotated facial images under complex conditions," in *Proc. 6th Int. Conf. Natural Comput.*, Aug. 2010, pp. 2028–2034.

[98] K. H. Ghazali, M. S. Jadin, M. Jie, and R. Xiao, "Novel automatic eye detection and tracking algorithm," *Opt. Lasers Eng.*, vol. 67, pp. 49–56, Dec. 2015.

[99] P. Viola and M. Jones, "Rapid object detection using a boosted cascade of simple features," in *Proc. IEEE Conf. Comput. Vis. Pattern Recognit.*, vol. 1, Kauai, HI, USA, Dec. 2001, pp. 511–518.

[100] T. D'Orazio, M. Leo, G. Cicirelli, and A. Distante, "An algorithm for real time eye detection in face images," in *Proc. 17th Int. Conf. Pattern Recognit.*, 2004, pp. 278–281.

[101] D. S. Bolme, B. A. Draper, and J. R. Beveridge, "Average of synthetic exact filters," in *Proc. IEEE Conf. Comput. Vis. Pattern Recognit.*, Jun. 2009, pp. 12–2105.

[102] H. Khachatryan and A. L. Rihn, "Eye-tracking methodology and applications in consumer research," *Proc. Electron. Data Inf. Source UF/IFAS Ext*, 2014, pp. 1–5.

[103] K. Love, A. Velisar, and N. Shanidze, *Eye, Robot: Calibration Challenges Potential Solutions for Wearable Eye Tracking Individuals with Eccentric Fixation*. New York, NY, USA: Association for Computing Machinery, 2021. [Online]. Available: https://doi.org/10.1145/3450341.3458489

[104] K. Kurzhals, *Image-Based Projection Labeling for Mobile Eye Tracking*. New York, NY, USA: Association for Computing Machinery, 2021. [Online]. Available: https://doi.org/10.1145/3448017.3457382

[105] M. Meißner, J. Pfeiffer, T. Pfeiffer, and H. Oppewal, "Combining virtual reality and mobile eye tracking to provide a naturalistic experimental environment for shopper research," *J. Bus. Res.*, vol. 100, pp. 445–458, Jul. 2019.

[106] E. Demjén, V. Abosi, and Z. Tomori, "Eye tracking using artificial neural networks for human computer interaction," *Physiol. Res.*, vol. 60, no. 5, p, p. 841, 2011.

[107] R. Zemblys, D. C. Niehorster, O. Komogortsev, and K. Holmqvist, "Using machine learning to detect events in eye-tracking data," *Behav. Res. Methods*, vol. 50, no. 1, pp. 160–181, Feb. 2018.

[108] L. Rello and M. Ballesteros, "Detecting readers with dyslexia using machine learning with eye tracking measures," in *Proc. 12th Int. Web All Conf.*, May 2015, pp. 1–8.

[109] T. Santini, W. Fuhl, D. Geisler, and E. Kasneci, "EyeRecToo: Open-source software for real-time pervasive head-mounted eye tracking," in *Proc. 12th Int. Joint Conf. Comput. Vis., Imag. Comput. Graph. Theory Appl.*, 2017, pp. 96–101.

[110] S. R. Rupanagudi, V. G. Bhat, B. S. Ranjani, A. Srisai, S. K. Gurikar, M. R. Pranay, and S. Chandana, "A simplified approach to assist motor neuron disease patients to communicate through video oculography," in *Proc. Int. Conf. Commun. Inf. Comput. Technol. (ICCICT)*, Feb. 2018.

[111] W. Fuhl, M. Tonsen, A. Bulling, and E. Kasneci, "Pupil detection for head-mounted eye tracking in the wild: An evaluation of the state of the art," *Mach. Vis. Appl.*, vol. 27, no. 8, pp. 1275–1288, Nov. 2016.

[112] J. Zou and Q. Zhang, "Eyesay: Eye electrooculography decoding with deep learning," in *IEEE Int. Conf. Consum. Electron. (ICCE)*, Jan. 2021, pp. 1–3.

[113] A. Biswas, K. Binaee, K. J. Capurro, and M. D. Lescroart, *Characterizing Performming Deep Neural Networking for Eye-Tracking*. New York, NY, USA: Association for Computing Machinery, 2021, doi: 10.1145/3450341.3458491.

[114] N. Zdarsky, S. Treue, and M. Esghaei, "A deep learning-based approach to video-based eye tracking for human psychophysics," *Frontiers Hum. Neurosci.*, vol. 15, Oct. 2021, Art. no. 685830.

[115] Y. Yin, C. Juan, J. Chakraborty, and M. P. McGuire, "Classification of eye tracking data using a convolutional neural network," in *Proc. 17th IEEE Int. Conf. Mach. Learn. Appl. (ICMLA)*, Dec. 2018, pp. 530–535.

[116] X. Ding, X. Yue, R. Zheng, C. Bi, D. Li, and G. Yao, "Classifying major depression patients and healthy controls using EEG, eye tracking and galvanic skin response data," *J. Affect. Disorders*, vol. 251, pp. 156–161, May 2019.

[117] Y. Mao, Y. He, L. Liu, and X. Chen, "Disease classification based on eye movement features with decision tree and random forest," *Frontiers Neurosci.*, vol. 14, p. 798, May 2020.

[118] J. N. Stember, H. Celik, E. Krupinski, P. D. Chang, S. Mutasa, B. J. Wood, A. Lignelli, G. Moonis, L. H. Schwartz, S. Jambawalikar, and U. Bagci, "Eye tracking for deep learning segmentation using convolutional neural networks," *J. Digit. Imag.*, vol. 32, no. 4, pp. 597–604, Aug. 2019.

[119] J. Xu, J. Min, and J. Hu, "Real-time eye tracking for the assessment of driver fatigue," *Healthc Technol. Lett.*, vol. 5, no. 2, pp. 54–58, 2018.

[120] N. Neshov and A. Manolova, "Drowsiness monitoring in real-time based on supervised descent method," in *Proc. 9th IEEE Int. Conf. Intell. Data Acquisition Adv. Comput. Syst., Technol. Appl.*, Bucharest, Romania, 2017, pp. 660–663.

[121] P. J. Murphy, A. L. Duncan, A. J. Glennie, and P. C. Knox, "The effect of scleral search coil lens wear on the eye," *Brit. J. Ophthalmol.*, vol. 85, no. 3, pp. 332–335, 2001.

[122] S. Said, S. AlKork, T. Beyrouthy, M. Hassan, O. Abdellatif, and M. F. Abdraboo, "Real time eye tracking and detection a driving assistance system," *Adv. Sci., Technol. Eng. Syst. J.*, vol. 3, no. 6, pp. 446–454, 2018.

[123] K. U. Anjali, A. K. Thampi, A. Vijayaraman, M. F. Francis, N. J. James, and B. K. Rajan, "Real-time nonintrusive monitoring and detection of eye blinking in view of accident prevention due to drowsiness," in *Proc. Int. Conf. Circuit Power Comput. Technol. (ICCPCT)*, Mar. 2016, pp. 1–6.

[124] J. J. Bengoechea, A. Villanueva, and R. Cabeza, "Hybrid eye detection algorithm for outdoor environments," in *Proc. ACM Conf. Ubiquitous Comput.*, 2012, pp. 685–688.

[125] J. J. Yan, H. H. Kuo, Y. F. Lin, and T. L. Liao, "Real-time driver drowsiness detection system based on PERCLOS and grayscale image processing," in *Proc. Int. Symp. Comput. Consum. Control*, 2016, pp. 243–246.

[126] P. E. Eriksson, T. Swenberg, X. Zhao, and Y. Eriksson, "How gaze time on screen impacts the efficacy of visual instructions," *Heliyon*, vol. 4, Jun. 2018, Art. no. e00660.

[127] R. N. Khushaba, S. Kodagoda, S. Lal, and G. Dissanayake, "Driver drowsiness classification using fuzzy wavelet-packet-based feature-extraction algorithm," *IEEE Trans. Biomed. Eng.*, vol. 58, no. 1, pp. 121–131, Jan. 2011.

[128] H. Singh, J. Bhatia, and J. Kaur, "Eye tracking based driver fatigue monitoring and warning system," in *Proc. India Int. Conf. Power Electron. (IICPE)*, New Delhi, India, 2011, pp. 1–6.

[129] University Missouri-Columbia. *Seeing is Believing: Eye-Tracking Technology Could Help Make Driving Safer Scientists Take a New Look at Importance Keeping Your Eyes Road*. Accessed: Sep. 24, 2019. [Online]. Available: https://www.sciencedaily.com/releases/2019/09/190924133248.htm

[130] A. Anusha and S. M. Ahmed, "Vehicle tracking and monitoring system to enhance the safety and security driving using IoT," in *Proc. Int. Conf. Recent Trends Electr., Electron. Comput. Technol. (ICRTEECT)*, Jul. 2017, pp. 49–53.

[131] R. B. Noland, M. D. Weiner, D. Gao, M. P. Cook, and A. Nelessen, "Eye-tracking technology, visual preference surveys, and urban design: Preliminary evidence of an effective methodology," *J. Urbanism, Int. Res. Placemaking Urban Sustainability*, vol. 10, no. 1, pp. 98–110, Jan. 2017.

[132] S. J. Park, M. Subramaniyam, S. Hong, D. Kim, and J. Yu, "Conceptual design of the elderly healthcare services in-vehicle using IoT," *WCXT SAE World Congr. Exper. Detroit*, vol. 17, pp. 1–5, Dec. 2017.

[133] A. S. Le, T. Suzuki, and H. Aoki, "Evaluating driver cognitive distraction by eye tracking: From simulator to driving," *Transp. Res. Interdiscipl. Perspect.*, vol. 4, Mar. 2020, Art. no. 100087.

[134] Y. Liang and J. D. Lee, "Driver cognitive distraction detection using eye movements," in *Proc. Passive Eye Monit.*, 2007, pp. 285–300.

[135] S. Hurtado and S. Chiasson, "An eye-tracking evaluation of driver distraction and unfamiliar road signs," in *Proc. 8th Int. Conf. Automot. User Interface Interact. Veh. Appl.*, Oct. 2016, pp. 153–160.

[136] Gazepoint. *Eye Tracking Applications: Distracted Driving Studuies*. Accessed: Jun. 16, 2020. [Online]. Available: https://www.gazept.com/blog/visual-tracking/eye-trackingapplications-distracted-driving-studies/

[137] Y. Liang and J. D. Lee, *Comparing Support Vector Machines (SVMs) and Bayesian Networks (BNs) in Detecting Driver Cognitive Distraction Using Eye Movements*. Berlin, Germany: Springer, 2007.

[138] A. García-Blanco, L. Salmerón, M. Perea, and L. Livianos, "Attentional biases toward emotional images in the different episodes of bipolar disorder: An eye-tracking study," *Psychiatry Res.*, vol. 215, no. 3, pp. 628–633, Mar. 2014.

[139] D. Lagun, C. Manzanares, S. M. Zola, E. A. Buffalo, and E. Agichtein, "Detecting cognitive impairment by eye movement analysis using automatic classification algorithms," *J. Neurosci. Methods*, vol. 201, no. 1, pp. 196–203, Sep. 2011.

[140] P.-H. Tseng, I. G. Cameron, G. Pari, J. N. Reynolds, D. P. Munoz, and L. Itti, "High-throughput classification of clinical populations from natural viewing eye movements," *J. Neurol.*, vol. 260, no. 1, pp. 275–284, 2013.

[141] Q. Yang, T. Wang, N. Su, S. Xiao, and Z. Kapoula, "Specific saccade deficits inpatients with alzheimer's disease at mild to moderate stage and in patients with amnestic mild cognitive impairment," *Age*, vol. 35, no. 4, pp. 1287–1298, 2013.

[142] S. Wang, M. Jiang, X. M. Duchesne, E. A. Laugeson, D. P. Kennedy, and Z. Q. Adolphs, "A typical visual saliency in autism spectrum disorder quantified through model-based eye tracking," *Neuron*, vol. 88, no. 3, pp. 604–616, 2015.

[143] K. Gillespie-Smith and S. Fletcher-Watson, "Designing aac systems for children with autism: Evidence from eye tracking research," *Augment. Altern. Commun.*, vol. 30, no. 2, pp. 160–171, 2014.

[144] N. Wanluk, S. Visitsattapongse, A. Juhong, and C. Pintavirooj, "Smart wheelchair based on eye tracking," in *Proc. 9th Biomed. Eng. Int. Conf. (BMEiCON)*, Dec. 2016, pp. 1–4.

[145] N. Khosravan, H. Celik, B. Turkbey, E. C. Jones, B. Wood, and U. Bagci, "A collaborative computer aided diagnosis (C-cad) system with eye-tracking, sparse attentional model, and deep learning," *Med. Image Anal.*, vol. 51, no. 1, pp. 101–115, 2019.

[146] J. L. Lauermann, M. Treder, P. Heiduschka, C. R. Clemens, N. Eter, and F. Alten, "Impact of eye-tracking technology on OCT-angiography imaging quality in age-related macular degeneration," *Graefe's Arch. Clin. Experim. Ophthalmol.*, vol. 255, no. 8, pp. 1535–1542, Aug. 2017.

[147] J. Keller, A. Krimly, L. Bauer, S. Schulenburg, S. Böhm, H. E. A. Aho-Özhan, I. Uttner, M. Gorges, J. Kassubek, E. H. Pinkhardt, S. Abrahams, A. C. Ludolph, and D. Lulé, "A first approach to a neuropsychological screening tool using eye-tracking for bedside cognitive testing based on the Edinburgh cognitive and behavioural ALS screen," *Amyotrophic Lateral Sclerosis Frontotemporal Degeneration*, vol. 18, nos. 5–6, pp. 443–450, Jul. 2017.

[148] A. Inoue and S. Paracha, "Identifying reading disorders via eye-tracking technology," in *Proc. Int. Conf. Adv. Mater. Sci. Eng. (ICAMSE)*, Nov. 2016, pp. 1–5.

[149] M. H. Rasmussen and Z.-H. Tan, *Fusing Eye-Gaze Speech Recognition for Tracking Automation Reading Tutor: A Step Right Direction*. Grenoble, France: Speech and Language Technology in Education, 2013.

[150] D. T. Guarnera, C. A. Bryant, A. Mishra, J. I. Maletic, and B. Sharif, "Itrace: Eye tracking infrastructure for development environments," in *Proc. ACM Symp. Eye Tracking Res. Appl.*, Warsaw, China, 2018, pp. 1–5.

[151] A. S. Najar, A. Mitrovic, and K. Neshatian, "Utilizing eye tracking to improve learning from examples," *Lect. Notes Comput. Sci.*, vol. 8514, pp. 410–418, 2014.

[152] J. L. Orquin and M. Wedel, "Contributions to attention based marketing: Foundations, insights, and challenges," *J. Bus. Res.*, vol. 111, pp. 85–90, Apr. 2020.

[153] J. A. Santana, "A study on the use of eye tracking to adapt gameplay and procedural content generation in first-person shooter games," *Multimodal Technol. Interact.*, vol. 23, no. 2, pp. 1–20, 2018.

[154] J. N. Stember, H. Celik, E. Krupinski, P. D. Chang, S. Mutasa, B. J. Wood, A. Lignelli, G. Moonis, L. H. Schwartz, S. Jambawalikar, and U. Bagci, "Eye tracking for deep learning segmentation using convolutional neural networks," *J. Digit. Imag.*, vol. 32, no. 4, pp. 597–604, Aug. 2019, doi: 10.1007/s10278-019-00220-4.

[155] T. Bafna, "Gaze typing using multi-key selection technique," in *Proc. 20th Int. ACM SIGACCESS Conf. Comput. Accessibility*, New York, NY, USA, 2018, pp. 477–479, doi: 10.1145/3234695.3240992.

HILARY O. EDUGHELE received the bachelor's degree in information technology from Salem University Lokoja, Kogi State, Nigeria, in 2014, and the master's degree in computing (internet technology and security) from the University of Northampton, U.K., in 2019, where he is currently pursuing the Ph.D. degree. He is also an IT Consultant with over five years of experience and has provided IT solutions to government and private sectors. His research interests include augmented and virtual reality technology, artificial intelligence, cyber security, eye tracking technology, and other related areas.

YINGHUI ZHANG received the B.Sc. degree in mathematics from Zhejiang University, the master's degree in relational database system from the Northeastern Heavy Machinery Institute exploring the foundations of NULL-keyword database theory, and the Ph.D. degree in virtual environments (virtual reality) from the University of Hull. He is currently a Senior Lecturer at the University of Northampton. He has led and completed several U.K. and China funded projects his research focuses on. His current research interests include incorporating the brush friction model into the state of art development of physically based simulation, global illumination, and haptic-based virtual environment and its applications in medicine.

FIRDAUS MUHAMMAD-SUKKI received the Ph.D. degree. He is currently a Lecturer at the School of Engineering and the Built Environment, Edinburgh Napier University. He has secured multiple grants from the U.K. and international funding agencies, such as Innovate U.K., Scottish Institute for Remanufacturing (SIR), Scottish Funding Council, British Council - Newton Fund, Chilean Research Council (CONICYT), Ministry of Higher Education Malaysia, and Universiti Teknologi Malaysia. He also carried out a number of non-technical research, including market trend and financial analysis related to renewable technologies for various countries. He has published numerous articles in high impact factor journals, such as *Nature*, *Renewable & Sustainable Energy Reviews*, and *Applied Energy*, as well as presenting in various conferences related to his area. Prior to joining the academia, he was a Communication Engineer in Malaysia's largest telecommunication company. His research interests include the area of renewable energy technology and policies and sustainable resources. He is a MIET and ACGI. He is a C.Eng.

QUOC-TUAN VIEN (Senior Member, IEEE) received the Ph.D. degree in telecommunications from Glasgow Caledonian University, U.K., in 2012. He is currently a Senior Lecturer with the Faculty of Science and Technology, Middlesex University, U.K. He has authored a textbook, coauthored four books, five book chapters, and more than 90 research papers in ISI journals and major conference proceedings. His current research interests include physical-layer security, network coding, non-orthogonal multiple access, RF energy harvesting, device-to-device communications, heterogeneous networks, network-on-chip, and the Internet of Things. He was a recipient of the Best Paper Award from IEEE/IFIP 14th International Conference on Embedded and Ubiquitous Computing in 2016. He serves as a Program Co-Chair for the INISCOM 2018-2022, and a Technical Symposium Co-Chair for the SigTelCom 2017–2021. He also serves as an Editor for the *Wireless Communications and Mobile Computing* and the *International Journal of Digital Multimedia Broadcasting* and a Guest Editor for the *EAI Endorsed Transactions on Industrial Networks and Intelligent Systems* and the *Mobile Networks and Applications*. He is also a Frequent Reviewer of the IEEE journals. He is a TPC member of the IEEE conferences. He was honored as an Exemplary Reviewer of the IEEE COMMUNICATIONS LETTERS in 2017.

HALEY MORRIS-CAFIERO received the B.A. degree in photography and the B.F.A. degree in fine art from the University of North Florida, and the M.F.A. degree in art (concentrations in photography, ceramics and printmaking) from the University of Arizona. She worked at the Memphis College of Art for 14 years starting as a part-time Lecturer and leaving the College as the Vice President of Academic Affairs. During her tenure at the Memphis College of Art, she developed undergraduate and postgraduate courses, managed the national and regional accreditation. She is currently a Senior Lecturer in photography where her specialism is conceptual development, interdisciplinary practices and performative photography as well as creative use of assistive technologies, such as eye-trackers.

MICHAEL OPOKU AGYEMAN (Senior Member, IEEE) received the B.Sc. degree (Hons.) in electrical and electronics engineering from the KNUST, Ghana, the M.Sc. degree in embedded and distributed systems from LSBU, U.K., and the Ph.D. degree in embedded and distributed systems from Glasgow Caledonian University, U.K. He is currently a Professor of computer engineering at the University of Northampton (UoN). He is the Lead of the Centre for Advanced and Smart Technologies (CAST), UoN. He also leads the Centre for Advancement of Race Equality (CARE), UoN. He is also the Program Leader of B.Eng. degree (Hons) in electronics and computer engineering, a Chartered Engineer (C.Eng.) of the IET, and a Chartered Manager (C.Mgr.) of CMI. He represents the research community of UoN at the Academic Senate. He is the Science and Technology Postgraduate Research (PGR) Lead with the Faculty of Arts Science and Technology (FAST) and a Chair of the University's PGR Supervisory Forum. In 2018/2019, he was the Elected Senate Representative for Academic Staff with the FAST, UoN. He holds four teaching qualifications: M.A. in education, PGCAP, PGCert in Digital Leadership, and PGCert in research degree supervision from the UoN. He is the holder of two management qualifications: Executive Master of Business Administration (EMBA) from the UoN and PGDip in strategic management & leadership from the CMI. He has over ten years of experience in embedded systems design. Previously, he was a Research Fellow with Intel Embedded System Research Group, The Chinese University of Hong Kong (CUHK). He is the author of over 80 peer-reviewed publications: five books, two book chapters, over 16 journals, and 32 conference papers. His research interests include three main strands and disciplines: electronics and computer engineering; business and management (neuromarketing, advertising, and marketing research), and pedagogy (education research). His research interests include Electronics and Computer Engineering: high-performance computing, embedded systems, the Internet of Things (IoT), smart farming (with focus on vertical farming), smart grid and smart metering, VLSI, on-chip networking, system-on-chip, computer architecture, multicore and manycore systems, 3D integrated circuits (3D IC), FPGA design, Wireless Networks-on-Chip. Pedagogy (education research): student engagement, problem- and project-based learning, active distance learning, technology enhanced learning, teaching multidisciplinary groups of students, decolonising learning, teaching and assessment, experiences of ethnic Underrepresented Groups in education, equality diversity and inclusion in HE, BAME award, and education gap. Business and Management (strategic marketing): neuromarketing, eye-tracking and the brain's buy button, use of EEG and other embedded sensors for strategic marketing, virtual reality (VR), and digital advertisement and marketing research. He is a fellow of the Higher Education Academy (U.K.). He has won two best papers awards.