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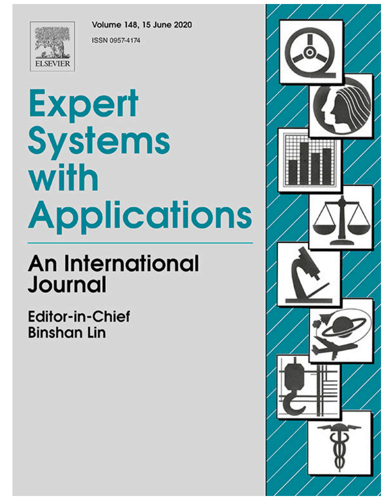

Review

Eye Tracking Algorithms, Techniques, Tools, and Applications with an Emphasis on Machine Learning and Internet of Things Technologies

Ahmad F. Klaib, Nawaf O. Alsrehin, Wasen Y. Melhem, Haneen O. Bashtawi, Aws A. Magableh

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Eye Tracking Algorithms, Techniques, Tools, and Applications with an Emphasis on Machine Learning and Internet of Things Technologies

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Abstract: Eye tracking is the process of measuring where one is looking (point of gaze) or the motion of an eye relative to the head. Researchers have developed different algorithms and techniques to automatically track the gaze position and direction, which are helpful in different applications. Research on eye tracking is increasing owing to its ability to facilitate many different tasks, particularly for the elderly or users with special needs. This study aims to explore and review eye tracking concepts, methods, and techniques by further elaborating on efficient and effective modern approaches such as machine learning (ML), Internet of Things (IoT), and cloud computing. These approaches have been in use for more than two decades and are heavily used in the development of recent eye tracking applications. The results of this study indicate that ML and IoT are important aspects in evolving eye tracking applications owing to their ability to learn from existing data, make better decisions, be flexible, and eliminate the need to manually re-calibrate the tracker during the eye tracking process. In addition, they show that eye tracking techniques have more accurate detection results compared with traditional event-detection methods. In addition, various motives and factors in the use of a specific eye tracking technique or application are explored and recommended. Finally, some future directions related to the use of eye tracking in several developed applications are described.

Keywords: Eye Tracking Techniques; Eye Tracking Applications; Electrooculography; Infrared Oculography; Internet of Things; Machine Learning; Scleral Coil; Video Oculography, Cloud Computing, Fog Computing, Choice Modeling, Consumer Psychology, and Marketing.

1. Introduction

Eye tracking is the process of tracking the movement of the eyes to know exactly where a person is looking and for how long. Eye tracking systems measure the eye position, movement, and pupil size at a specific time to detect areas in which the user has an interest. Eye trackers have been used in different research areas including visual systems (Barr, 2008) (Hristozova, Ozimek, & Siebert, 2018) (Moreno-Esteva, White, Wood, & Black, 2018) (Ulutas, Özkan, & Michalski, 2020); psychology and neuroscience (Maria, et al., 2019) (Migliaccio, MacDougall, Minor, & Della Santina, 2005); psycholinguistics and healthcare (Park, Subramaniyam, Hong, Kim, & Yu, 2017) (Chen, Fu, Lo, & Chi, 2018); user experience and interaction (Lukander, 2016); professional performance, consumer research, and marketing (Hang, Yi, & Xianglan, 2018); the economy, clinical research, and education (Colliot & Jamet, 2018); sports performance and research, product design, and software engineering (Obaidellah, Al Haek, & Cheng, 2018) (Zohreh Sharafi, 2015); transportation (Noland, Weiner, Gao, Cook, & Nelessen, 2017); and virtual reality (VR) (Clay, König, & König, 2019). Eye trackers have also been increasingly used for rehabilitative and assistive applications. With the help of scientific research, valuable information can be inferred and used to benefit elderly and special needs patients in particular who need technology to make their lives easier. Eye tracking systems use software algorithms for pupil detection, image processing, data filtering, and the recording of eye movement by means of a fixation point, fixation duration, and saccades.

The recent increase in the development of eye tracking applications is because of recent technological advancements in both hardware and software. Equipment that were once cumbersome, time-consuming, and expensive have recently been transformed into devices that are inexpensive, unobtrusive, and wearable, which produce data that can be rapidly analyzed through special software. Current innovation in computing capabilities allows machine learning (ML) algorithms to be integrated with eye tracking devices and adds learning functionalities from captured data to generate smarter eye tracking devices. A large variety of hardware and software approaches have been implemented by research groups or companies based on technological progress (Sarkar, Sanyal, & Majumder, 2017) (Verma, 2011).

Users have become accustomed to new and innovative technologies connected to the Internet, a field widely known as Internet of Things (IoT), and eyewear technologies such as goggles and glasses are examples of such innovations. Goggles are safety glasses surrounding the eye to prevent exposure to particulates, water, or chemicals. iMotions eye tracking glasses are used to collect and analyze real-world eye tracking data using glasses from Tobii, Pupil Labs, Argus Science, and Senso Motoric Instruments (SMI). iMotions allows for advanced analysis using tools such as heatmaps, gaze replays, and areas of interest (AOI) to generate certain output metrics such as the time to first fixation and time spent. iMotions also provides automated gaze-mapping from dynamic environments to static scenes for a simpler aggregation and analysis (Haywood, 2019). Research and improvements in this area are progressing to include eye tracking devices, the applications of which have been put into real use.

ML is a process that allows machines to learn and adapt through experience. Artificial intelligence (AI) refers to a wider concept in which machines can execute tasks smartly. AI applies several algorithms and techniques such as deep learning and ML to solve actual problems and smartly execute tasks. AI and IoT are perfect examples of two technologies that complement each other and should be tightly integrated.

Connecting devices and remotely monitoring and controlling them is not an efficient way to enable the devices to make smart decisions or take actions on their own. The real value is obtained when devices learn from each other and from their specific use. This occurs when devices can tune their responses, change their behavior, or adapt based on what they have learned over time. To allow devices to be smartly connected, learn from each other over time, and take actions on their own, it is necessary to implement ML and artificial intelligence algorithms and techniques to create a field called Artificial Intelligence of Things (Bunz & Janciute, 2018).

This paper mainly focuses on 1) representing the major algorithms and techniques used for eye tracking and the benefits of incorporating ML and IoT in various eye tracking technologies, 2) researching and addressing the most well-known and novel applications in eye tracking, 3) organizing the literature related to eye tracking using a structured approach to bring together all studies to date on how ML and IoT technologies along with their applications help people working in the field of eye tracking. In addition, the results from this study may contribute to the further development of the technologies in this field. The initial sections of this paper are directed toward people who are completely new to eye tracking as well as inexperienced researchers. Section 8 is intended for researchers experienced in eye tracking, where we provide our discussions and present some future directions.

Despite the progress made in the various aspects of eye tracking research, only few surveys exist that review the growing body of literature, with a focus on using ML algorithms along with IoT technologies and their applications. Majaranta and Bulling reviewed state-of-the-art research in eye tracking and gaze estimation technologies along with some of their challenges and real-life applications (Majaranta & Bulling, 2014). In addition, the authors designed some solutions and provided some guidelines on matching user requirements with different features of eye tracking systems to find a suitable system for each task. Regarding eye tracking, various principles used to measure the eye movements have also been reviewed (Singh & Singh, 2012).

Majaranta and Bulling (Majaranta & Bulling, 2014) have also explored different visual features in eye images, factors involved in the selection of an eye tracking method, and applications of an eye tracking technique. Kiefer et al. investigated the utilization of an eye tracking methodology as input to spatial cognition, cartography, and geographic information science along with its challenges and opportunities for future research (Kiefer, Giannopoulos, Raubal, & Duchowski, 2017).

In medical applications, Kok and Jarodzka (2017), Harezla and Kasprowski (2018) have reviewed state-of-the art research related to the application of eye tracking technology in medicine. They have provided insight into such studies and the ways in which eye imaging is employed in medical applications. The authors showed that more extensive studies on cue processing and medical decision-making are needed. Al-Moteri et al. provided an overview of eye tracking technology and how it helps in understanding and improving a diagnostic interpretation. In addition, they focused on how eye tracking has been used to understand medical interpretations and encourage medical education and training, the perceptual and cognitive processes involved in medical interpretation, and how eye tracking will be used in future medical applications (Al-Moteri, Symmons, Plummer, & Cooper, 2017) (Thevenot, López, & Hadid, 2018).

In education and training, Rosch and Vogel-Walcutt reviewed eye tracking applications as tools for measuring cognitive load and how such measurements can be used for enhancing real-time training (Rosch & Vogel-Walcutt, 2013). For multimedia learning, Alemdag and Cagiltay explored how eye tracking technology has been used with relevant variables to study the cognitive processes during multimedia learning (Alemdag & Cagiltay, 2018). In addition, Beach and McConnel reviewed a state-of-the-art research on the ways in which eye tracking methodologies are being used to understand the learning process of teachers (Beach & McConnel, 2019), whereas Colliot and Jamet have used eye tracking techniques to investigate the effects of using a video recording of a teacher on the learning experience of students when applying an e-learning module (Colliot & Jamet, 2018). Finally, Chen et al. reviewed the advantages of using eye tracking technologies for application in learning and education (Chen, Lai, & Chiu, 2010).

In the area of human–computer interaction (HCI), various studies (Majaranta & Bulling, 2014), (Drewes, 2010), (Shimata, Mitani, & Ochiai, 2015), (Poole & Ball, 2006) have explored state-of-the-art research in using eye tracking to evaluate the usability of HCI or to lead to a system interaction when using eye movements as an input mechanism. In addition, the authors provided future opportunities for the use of eye tracking in HCI research along with suggestions to overcome some of the challenges and complexities faced by advanced interactive systems to enable effective applications. In addition to the above areas, researchers have provided several reviews on using eye tracking techniques in tourism (Scott, Zhang, Le, & Moyle, 2017), software engineering (Sharafia, Soha, & Gu´eh´eneuc, 2015), online shopping and visual marketing (Hang, Yi, & Xianglan, 2018), and control and command intelligent systems (Bazrafkan, Kar, & Costache, 2015).

In this review article, we focus on using ML, IoT, and cloud computing with eye tracking techniques. A classification of different ML algorithms that use eye tracking data along with the research goal, as well as the strengths and limitations of the algorithms, are presented. In addition, we present healthcare, medical, HCI, accessibility, education, e-learning, and car assistant eye tracking applications. Moreover, this research covers possible future directions of eye tracking techniques and applications using ML and IoT, as well as other research areas that may be interesting to readers, such as the fields of gaming, marketing, advertising, and VR.

The reminder of this paper is organized as follows. Section 3 provides some background and definitions for eye tracking concepts and gaze estimation techniques along with the structure of the literature considered. Eye tracking techniques using ML algorithms are described in section 4. Section 5 presents eye tracking techniques that apply IoT. Section 6 shows the use of cloud computing with eye tracking. Some eye tracking applications are presented in section 7. Section 8 presents our viewpoints and experience, limitations of current eye tracking applications, and possible directions for future studies.

2. Collection and Selection of Papers

2.1. Data Sources

In this study, we do not follow a typical review of individual papers; instead, we provide a systematic qualitative approach, which reviews state-of-the-art research on improving eye tracking algorithms, techniques, tools, and applications. Several well-known digital library databases were selected for the literature search, and the selection was based on their relevance to the computer science community and the availability of papers for download. We focused on collecting papers from IEEEXplore, ACM Digital library, SCOPUS, Citeseer, Citebase, Microsoft Academic, DBLP Computer Science Bibliography, ScienceDirect (Elsevier), and Springer. To ensure the quality of this review, only academic papers published in peer-reviewed journal were included. The search was performed on the search engines of the abovementioned libraries on different days. To establish a clear cut-off date, we limited our search to papers published until June 1, 2020. To produce a more homogeneous result, papers published after this date were not considered, which will also enable any future updates to this study to achieve greater precision in terms of coverage and development.

2.2. Search Strings

To build our search string, we use the Population, Intervention, Comparison, Outcome, Context (Barbara, 2004) criteria to frame the search keywords. These criteria have been adapted from (Kitchenham & Charters, 2007) based on the context of computer science. This approach helps researchers define the relevant terms based on key words that have been used in previous studies and to gain expert insight. Each search query consists of a variation of the words "eye tracking," followed by words related to stimuli and/or strategy. The details of the search queries are as follow:

(1) **Eye tracking**: To ensure that the search results are related to eye tracking or eye trackers, the first keyword in every search query must be "eye track," "eye-track," or "gaze," depending on the context.

(2) **Stimuli**: To make sure we find papers related to a specific topic, we included terms such as "applications," "tools," "algorithms," "approaches," and "techniques."

(3) **Strategy**: Because our focus is to find papers related to ML and IoT, we include "machine learning," "artificial intelligence," "Internet of Things," "IoT," "cloud computing," "fog computing," and "edge computing" into the search queries

2.3. Paper Inclusion and Exclusion Criteria

Inclusion and exclusion criteria set the boundaries for the review. They are determined after the research question is set, and usually before the search is conducted; however, it is necessary to scope searches to determine the appropriate criteria. Numerous factors can be used as inclusion or exclusion criteria. Table I shows the main inclusion and exclusion criteria.

2.4. Selection of the Main Studies

The above string of keywords was applied to the above-listed databases in accordance with some predefined inclusion and exclusion criteria, which are listed in Table I.

Table I. Inclusion Criteria
Relative to subject: Articles were included if they only related to Eye Tracking algorithms, techniques, tools, and applications
We include only published articles
We use articles written only in English
We include peer reviewed articles from 2000 - 2020
We focus on articles that describe the intervention in detail
We focus on articles that use rich descriptions
We focus on articles that are fully available
We focus on articles that describe the outcomes clearly

As a result of the search strategy, a good number of studies have been identified. First, the duplicates and redundancies were removed, and the abstracts of the remaining papers were reviewed to target those studies that are directly related to the topic. The full text of each article was reviewed at the end of the screening process. In total, 180 research articles, published between 2000 and 2020 (30 from 2019 and 8 from 2020), as shown in Figure 1, were selected.

The aim of this paper is to give insight into those studies and the ways in which they utilize eye imaging in medical applications. First, the eye tracking methods and algorithms, along with the eye movement characteristics, are described. Attention was focused specifically on the VOG technique based on eye image processing, which is commonly used in current eye tracking solutions. Based on this knowledge, the experiments used in the aforementioned studies were detailed.

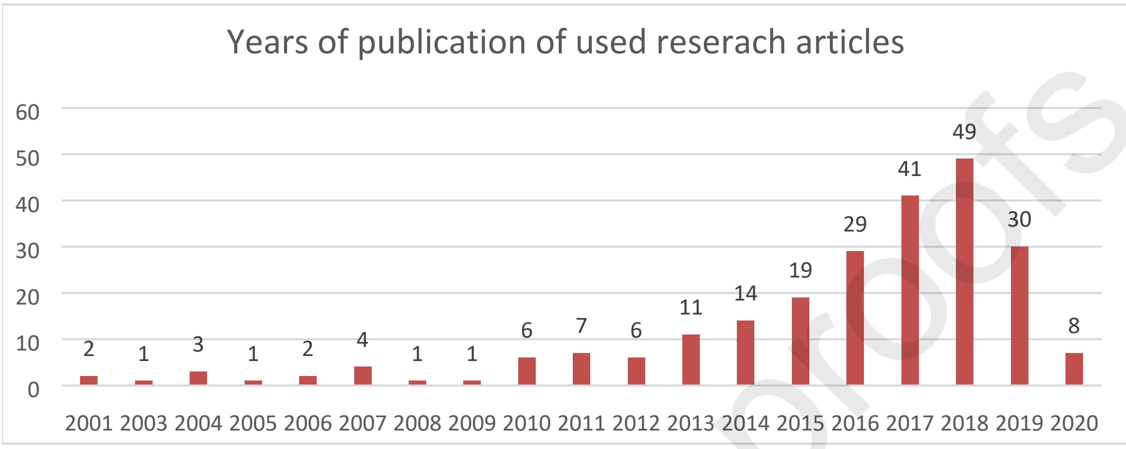

Figure 1. Years of publication of research articles considered

Although they provided answers for many questions, there are other unanswered questions, for which additional studies are required. The presented survey may prove helpful in this regard.

There are several methods for measuring eye movement; the some uses video images to extract the eye position. Other methods use search coils, or they are based on an electro-oculogram.

2.5. Literature Structure

Because eye tracking techniques require a precise procedure to track the eye gaze, it is important to study novel approaches to widen the use of eye tracking on a higher level. Figure 2 shows the structure of our review paper in which we group the literature on eye tracking techniques and applications using the IoT along with ML algorithms and cloud/fog computing.

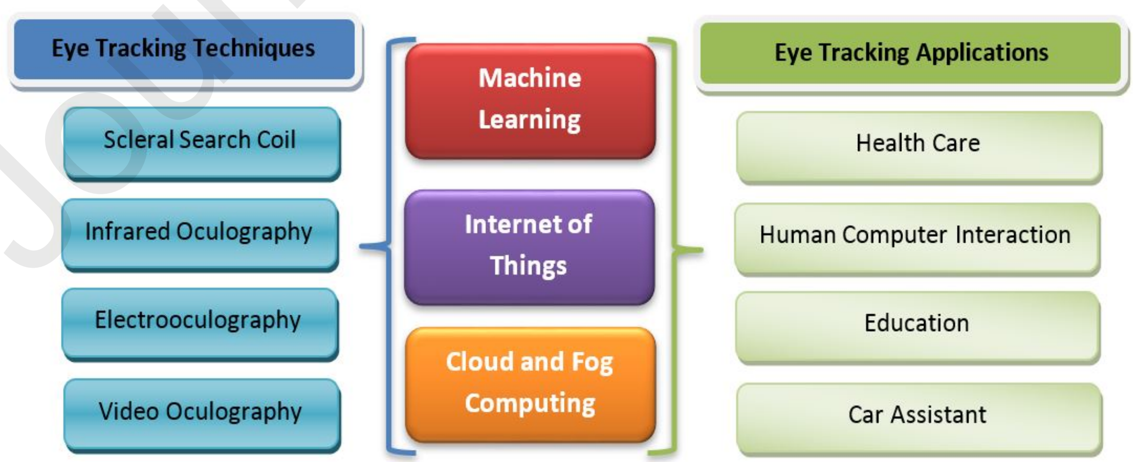

Figure 2. Structure of our review paper in which we group the literature on eye tracking techniques and applications using ML and IoT.

3. Background and Definitions

3.1. Eye Tracking Concept

The human eye consists of the retina, pupil, cornea, sclera, iris, and other components. The activities of these components can be captured as signals to be used in different applications (Majaranta & Bulling, 2014). Eye detection is the process of locating the eye and measuring the eye gaze. There are several methods that are used for gaze tracking, such as shape-based, feature-based, appearance-based, and hybrid methods (Hansen & Ji, 2010).

3.2. Gaze Estimation Techniques

The main goal of gaze tracking is to pinpoint the gaze direction toward different objects. Gaze estimation techniques can be applied for determining the gaze position, which relies on connections between data from the image and gaze direction. In general, eye movements are classified into saccade and fixations, whereas gaze estimation techniques can be classified into feature- and appearance-based techniques (Hansen & Ji, 2010). A saccade occurs when the gaze moves quickly between objects, and a fixation is when the gaze is directed to a specific object for a brief period of time.

Feature-based gaze estimation techniques are applied by detecting a set of varied features of the eyes, insensitive to disparities in lighting and viewpoint, and the iris and pupil need to be clear to be properly detected, including the contour of the pupil, with no cornea reflections. In addition, 3D and geometry-based methods must be applied. An appearance-based gaze estimation technique, by contrast, is applied by extracting image contents and mapping them to positions on a screen. Therefore, finding the point of regard, relevant features, and personal variations are key steps in this technique. Examples of this technique are manifold, and include a gray scale unit, cross ratio, Gaussian interpolation, and morphable models (Chennamma & Yuan, 2013) (Sorate, Vpkbiet, & Chhajed, 2017).

3.3. Eye Tracking Techniques

Four eye tracking techniques have been the focus of most studies in this field and in developing novel eye tracking applications. They are the scleral search coil technique, infrared oculography (IOG), electrooculography (EOG), and video oculography (VOG).

3.3.1. Scleral Search Coil Technique

The scleral search coil technique was first introduced by Robinson in 1963 (Robinson, 1963) and uses a contact lens with mirrors attached to a wire coil that moves in a magnetic field. The field induces a voltage in the coil to produce a signal that represents the eye position. An integrated coil in the contact lens allows detecting the orientation of the coil in a magnetic field. The eye movements can be recorded by monitoring the infrared wavelength range that is reflected by the mirror and recorded by eye trackers for accurately moving an image in line with the eye movement. A scleral search coil is shown in Figure 3.

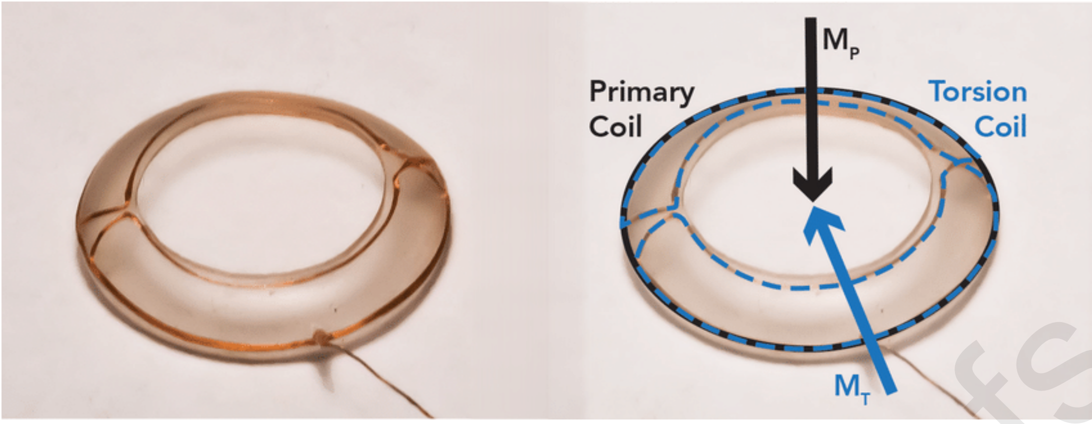

Figure 3. Scleral Search Coil contact lenses (Dietz, Schork, & André, 2016)

The Helmholtz approach is a major approach in the scleral search coil technique. However, it cannot be used for head movements. Head movements can be attained by other popular approaches such as a Rubens coil geometry, which is an older approach that can cover similar magnetic fields as a Helmholtz and Merritt geometry and reduces the error rate (Eibenberger, Eibenberger, & Rucci, 2016).

The original coil search technique has been extended to include a reference coil, digital data acquisition panels, and a receiver program with a goal to enhance the scleral coil in terms of the cost and reliability. The extended technique is considered inexpensive and robust. The hardware may benefit from different operational amplifiers to reduce noise, which will be tested in future developments (Eibenberger, Eibenberger, Roberts, Haslwanter, & Carey, 2015).

The number of experiments that use a scleral coil is less because the coil is prone to breakage, and can only be worn for a short period of time and does not work on sensitive eyes or patients who blink excessively (Murphy, Duncan, Glennie, & Knox, 2001). Intraocular pressure is created when wearing coil contact lenses. Patients who suffer from glaucoma or ocular hypertension should be treated with care if required to wear coil lenses.

The advantages of this technique are high accuracy, good resolution, 3D data representation, and high sampling rate, whereas the main disadvantages are its complicated implementation, invasiveness, and the need for expensive gear. Therefore, many medical labs refrain from using this approach (McCamy M. B., et al., 2015) (Vincent, Alonso-Caneiro, & Collins, 2017).

3.3.2. Infrared Oculography

The infrared oculography (IOG) technique measures the strength of an infrared light that is mirrored from the sclera, which provides a variety of information about the eye position. Light can be produced from a pair of glasses. This approach relies mainly on light and pupil detection algorithms. To solve the issue of head movement sensitivity, a reference point, which is known as a corneal reflection or glint, is included using an infrared light source when this technique is applied. Figure 4 shows the infrared light used and the typical setup of an infrared oculography technique that is known to produce fewer disturbances than an EOG.

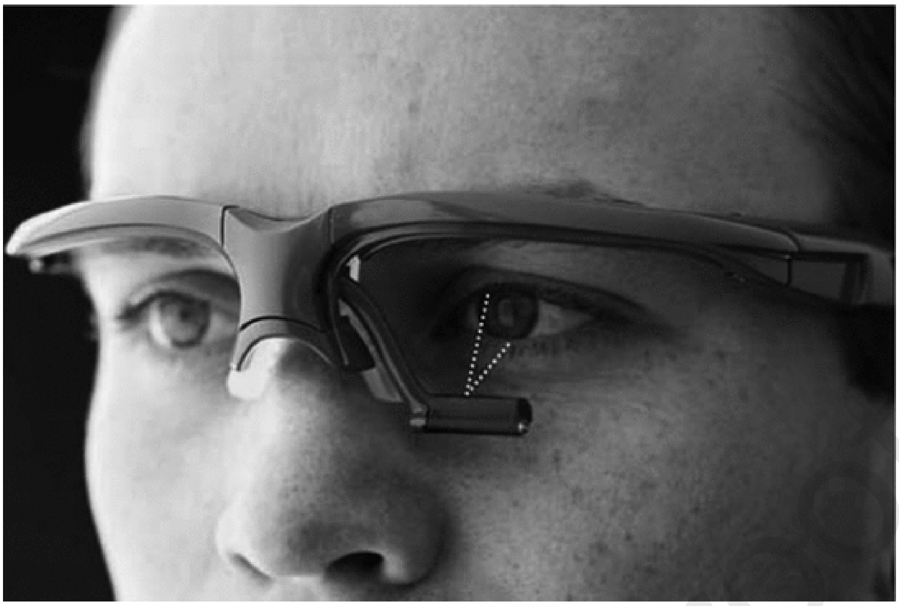

Figure 4. Infrared oculography approach setup (Kurzhals, Brian, Burch, & Weiskopf, 2016)

The IOG technique has been widely studied and researched using many different algorithms and commercial applications such as the Starburst algorithm (Păsărică, Bozomitu, Cehan, Lupu, & Rotariu, 2015) (Mestre, Gautier, & Pujol, 2018) (Wang & Ji, 2017) , circular Hough transformation, FREDA (Martinikorena, Cabeza, Villanueva, Urtasun, & Larumbe, 2018), low pass filtering (Lupu, Bozomitu, & Cehan, 2014), Haar-like features (Santini, Fuhl, Geisler, & Kasneci, 2017) (Wilson & Fernandez, 2006), K-means (Santini, Fuhl, Geisler, & Kasneci, 2017), random sample consensus (Picanço & Tonneau, 2018), ExCuSe (Wilson & Fernandez, 2006), ElSe (Wilson & Fernandez, 2006), Pupil labs (Fuhl, Tonsen, Bulling, & Kasneci, 2016), Euclidean distance (Bobić & Graovac, 2016) binocular-based (Sesma-Sanchez & Hansen, 2018), Camshift algorithm (Li, Li, & Qin, 2014), a pupil center corneal reflection (Park, Jung, & Yim, 2015) and Swirski (Santini, Fuhl, Geisler, & Kasneci, 2017). The use of pupil recognition allows an improved emphasis on the pupil rather than the iris and sclera of the eye (Picanço & Tonneau, 2018) (Păsărică, Bozomitu, Cehan, Lupu, & Rotariu, 2015) (Fuhl, Tonsen, Bulling, & Kasneci, 2016). An advantage of the IOG technique is its ability to smoothly handle eye blinking. However, it is unable to quantify torsion movement (Lupu & Ungureanu, 2013) (Chennamma & Yuan, 2013) (Sorate & Chhajed, 2017).

3.3.3. Electrooculography

Electrooculography (EOG) is a practicable and inexpensive technique for human–computer interaction. In this approach, sensors are attached to the area that surrounds the eyes to detect an electric field that occurs while the eyes are rotating by measuring fluctuations in the skin. Horizontal and vertical eye movements are documented disjointedly using electrodes. However, the signal can be altered without eye movements. Figure 5 shows a wearable EOG device with sensors attached.

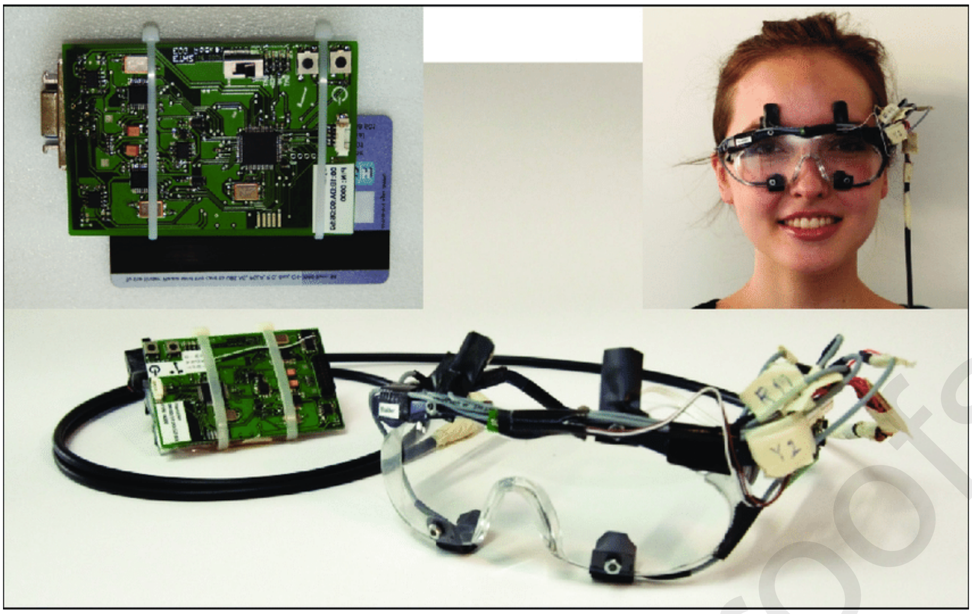

Figure 5. Electrooculography device (Coutrot, Hsiao, & Chan, 2018)

EOG is not an approach for daily use; its application can be beneficial to medical fields and laboratories. This approach is linearly relative to eye movements, and it can use head movements for tracking (Chennamma & Yuan, 2013) (Sorate, Vpkbiet, & Chhajed, 2017). The EOG eye gaze interface is easy to use owing to its simple arrangement. However, the use of EOG is limited because of eye drifts and eye conditions (Tsui, Jia, Gan, Hu, & Yuan, 2007) (Constable, et al., 2017). A solution has been developed for this problem. Users can use a pointer and switcher to easily turn on/ off the call device or to forward a 1-bit signal to a PC with a high level of firmness and fineness (Tsui, Jia, Gan, Hu, & Yuan, 2007).

3.3.4. Video Oculography

A typical setup consists of a video camera that records the movements of the eyes and a computer that saves and analyses the gaze data. The VOG approach can either use visible or infrared lights. The VOG is a non-invasive system that performs the eye tracking remotely. There are two ways to implement video eye tracking based on the number of cameras used: the first approach uses a single camera, whereas the other uses multiple cameras (Majaranta & Bulling, 2014). Both types of eye trackers, remote or head mounted, have a major drawback if used in HCI systems owing to changes in the head position. For remote trackers, this can be resolved by using two stereo cameras or one wide-angle camera to search for the person in front and another to point to the person's face and zoom in. An example of VOG using two cameras is shown in Figure 6.

Figure 6. Video oculography using two cameras (Bulling & Gellersen, 2010)

Single camera systems: Single camera systems capture limited-field and high-resolution images that are fixed at a single point. This method uses an infrared light source to produce a corneal reflection that will be used as a reference point for the gaze estimation. The pupil-glint vector remains constant to the eye and head movement, whereas the glint clearly changes its position when the head moves. Several commercial systems use a single camera and one infrared light. The main difficulty in this approach is the limited view required to sufficiently capture high-resolution images. Better results can be gained by adding multiple light sources to the setup (Chennamma & Yuan, 2013) (Sorate, Vpkbiet, & Chhajed, 2017).

Multiple Camera Eye Tracker: A large field of view is required for free head motion. Multiple cameras are utilized to achieve this goal either through wide-angle lens cameras or movable narrow-angle lens cameras. One camera is used for the eye and the other camera is used to capture the head location. All the data collected from these cameras are combined and used to estimate the point of gaze. Eye tracker systems use two cameras to form a stereo vision system for calibrating the computation of the pupil center, which is achieved using 3D coordinates.

Videos generated from these cameras, such as VOG, were introduced to find solutions for many problems faced by image-based eye tracking techniques. Some of these problems include the difficulty in detecting the eyes due to head movement, unclear eyes because of blinking, or bent eyelashes. VOG helps in increasing the accuracy of eye tracking systems and observing eye movement disorders. The video system can be easily handled, and it allows head movements and a fully remote recording. However, the video recording system is expensive and requires more storage and devices with high computational capabilities. In addition, when recording closed eyes, the eye torsion cannot be measured (Chennamma & Yuan, 2013) (Sorate, Vpkbiet, & Chhajed, 2017).

Many studies have used the VOG approach with different algorithms and tools such as EyeScout (Khamis, et al., 2017), Goggles (Kong, Lee, Lee, & Nam, 2018), a morphology approach (Kong, Lee, Lee, & Nam, 2018), the position of the corneal reflection (Abdulin, Friedman, & Komogortsev, 2017), a charged coupled device (Sakatani & Isa, 2004), GazePath (Van Renswoude, Raijmakers, Koornneef, Johnson, & Hunnius, 2018), bright-pupil algorithm (Goni, 2004), Matrox imaging library (Goni, 2004), polynomial-base VOG models (Murphy, Duncan, Glennie, & Knox, 2001), glint positioning (Ding, Z; Luo, J; Deng, H., 2018), a Haar method with a 6D optical tracker (Migliaccio, MacDougall, Minor, & Della Santina, 2005), Tobii (Klaib, Alsrehin, Melhem, & Bashtawi, 2019), and a pupil framework to automate the analysis of the gaze data (Picanço & Tonneau, 2018) on the pupil

Table II. A summary of the eye tracking techniques along with their advantages and disadvantages

Techniques	Advantages	Disadvantages
Scleral Search Coil	- Very high temporal and spatial resolution. - Invaluable research tool. - Highly accurate.	- Invasive method. - Rarely used clinically. - May cause Intraocular pressure. - Wear the coil for a short period of time. - Doesn't work on sensitive eyes. - Anesthesia of the eye. - Complicated settings.
Infrared Oculography (IOG)	- Used in light and darkness. - Handling blinking smoothly.	- Unable to quantify torsional eye movement. - Limited movement of the head. - Invasive method.
Electro Oculography (EOG)	- Medical fields and laboratories. - Very high temporal and spatial resolution. - Used Machine learning to found accuracy. - Analyze the data in real time by using microcontroller.	- Not used daily. - Inexpensive. - Affected by the noise around the eye. - Invasive method. - Complicated settings.
Video Oculography (VOG)	- 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 machine learning techniques to gain higher accuracy. - Not expensive.	- Limited spatial resolution. - Recording with closed eyes is not possible. - Invasive and noninvasive.

of the dark eye with up to 12 reflections of the cornea (Mestre, Gautier, & Pujol, 2018). According to a previous study, we summarize the advantages and disadvantages of the four most popular eye tracking techniques in Table II.

4. Eye Tracking using Machine Learning

ML is an approach to learn from previous data using a variety of algorithms and find predictions to eventually come up with a model that shows accurate results. Several algorithms and techniques have been introduced to eye tracking, including regression, neural networks, naive Bayes classification, and a support vector machine (SVM).

An SVM is an extremely effective and commonly used ML approach in classification, object recognition, and image querying (Tong & Chang, 2001). In addition, SVM was used with a variety of feature extraction and face recognition algorithms in eye tracking techniques. With electrooculography (EOG), it was used to detect signal-saccades, fixations, and blinks to detect repetitive patterns of eye movements. The minimum repetition, minimum redundancy, and maximum relevance features were combined with the SVM classifier and the person-independent and leave-one-person-out strategies, to train the model. Evaluation results showed an accuracy rate of 76.1 % across all categories (Bulling, Ward, Gellersen, & Troster, 2011).

An SVM and the Zernike movement (ZM) have been used if the template matching algorithm or Haar face detection algorithm is not able to detect the eyes (Singh, Mittal, & Walia, 2011). ZM was especially helpful in reducing problematic views, specifically in the case of upside-down images or unclear visibility owing to lighting issues.

Template matching finds similarities between a template and another image. This method was employed to sort items where the template is considered as a miniature image or part of an image. This technique was typically used by Ahuja to identify complicated images and the things they reference (Ahuja & Tuli, 2013). Gradient orientation pattern is a technique that uses vectors to generate an image that will be used to track the human eye in real time. A template update algorithm was also included to help match eye images. The reason behind using the template algorithm was to build a new template in each frame based on the image of the eye, and then enhance the results by using the matching method (Hotrakool, Siritanawan, & Kondo, 2010). The template algorithm also helps with light fluctuations that occur during the tracking process. A benefit of using the gradient orientation pattern is its ability to deliver significant matching results and handle complex deviations in lightning. However, as a limitation to this approach, if a frame is not matched, it will be rejected. Another study that explored the applications of using template matching with eye tracking was proposed by Liu (Liu & Liu, 2010) under complex situations where detecting and capturing eye movements may be difficult.

ML algorithms such as Bayesian models and neural networks were used to deliver highly accurate tracking. An open source software was developed by Santini for real-time head mounted eye tracking, to detect an eye pupil and estimate the gaze (Santini, Fuhl, Geisler, & Kasneci, 2017). The software can be customized to match developer requirements by swapping algorithms. The software delivers progressive settings, gaze estimation, and blinking detection using Bayesian models. MATLAB-Simulink has been successful in detecting winks and blinks using a single camera with video processing capabilities and a micro controlled board (Rupanagudi, et al., 2018). Moreover, ML algorithms have been used in an EOG and have found good accuracy levels. The aim is to improve and enhance the EOG interface. An eyewear tool was developed to analyze data in real time using a microcontroller, to capture and analyze signals. For real-time and reliable results, researchers used a wavelet transform and neural network to process the signals. Fuhl et. al. in (2016) proposed a system that obtained 92% reliability by applying ML techniques to a VOG approach that results in higher accuracy during the tracking process. Table III shows a classification of the ML algorithms that use eye tracking data along with their specific applications, strengths, and limitations.

5. Eye Tracking using Internet of Things

Developments in mobile communication devices, information technology, sensors, and data have led to a significant enhancement in IoT and novel innovative technologies and services. An IoT micro-sensor was used to integrate objects into wireless networks that allow objects to interact with one another and to interact with other objects, leading to reliable and continuous exchanges of relevant information improving the quality of a user's life. The expansion of IoT has taken over the scope of homes, health care, environmental monitoring, inventory management, intelligent transportation, and numerous other fields (Haslgrübler, Fritz, Gollan, & Ferscha, 2017).

At present, important facilities such as the monitoring of vehicle dynamics and smart navigation are being provided using IoT, which can connect anything electronic to an existing Internet connection. IoT can be used as a car assistant, to reduce car accidents that occur owing to driver drowsiness. IoT is also used to monitor eye and head movements (Murauer, Haslgrübler, & Ferscha, 2017). When a tracking system detects an abnormal eye blinking rate, the driver will be alerted to stay awake. To benefit from the use of IoT in eye tracking, Tourch7 was incorporated using EyeDee technology (Morozkin, Swynghedauw, & Trocan, 2017).

Many applications have been developed that use an eye tracking mechanism with IoT, to enhance the quality of life. For example, in education, assessing the social interactions of students is a key part of measuring their visual attention. An interactive framework was developed by Kangas et al. that tracks and analyzes students' eyes during the learning process, triggering students to focus more to increase their attention and interaction (Kangas, et al., 2016). This framework can fully benefit by modern interaction technology, allowing the learning to increase to a higher level.

Another example of using an eye gaze mechanism with IoT technology is the development of assistive systems that help elderly and special needs people to direct and control any device in their smart homes. This approach focuses on usability and reliability, which are the most important aspects of such systems (Haslgrübler, Fritz, Gollan, & Ferscha, 2017) (Kangas, et al., 2016) (Gill & Vogelsang, 2016) (Bissoli, Lavino-Junior, Sime, Encarnação, & Bastos, 2019).

A lensless smart sensors(LSS) is a low-power, low-cost visual sensing technology that adds optical and thermal sensing capabilities to an IoT device in a form that cannot be achieved with a traditional lensed system. An LSS captures information-rich scene data in a tiny form using a revolutionary new approach to optical sensing, and enables users to experience augmented reality without sacrificing style, design, or comfort, by providing invisible eye tracking hardware to the outside world. It uses both appearance- and feature-based algorithms to accurately track the user's gaze from a wide field of view and across the entire range of eye motion from an extremely close distance (Gill & Vogelsang, 2016) (Abraham, et al., 2017).

Internet shopping and advertising on social media are on the rise these days. It is important to track and analyze the user's interests and interaction. Using IoT to track customers will help increase online shopping. SMI Eye Tracking Glasses and pupil Labs have been used to track a customer's eyes to track the customer's focus and know when the customer interacts (Haslgrübler, Fritz, Gollan, & Ferscha, 2017).

A Midas touch problem occurs when users unintendedly select objects just by gazing at them. Solutions to this problem include gaze fixation, blinking, and external triggers. Researchers have proposed a gaze-mediated interaction method, called DualGaze (Mohan, Goh, Fu, & Yeung, 2018), which does not rely on an external trigger or separate menu to confirm a selection. It is an interaction method that requires users to perform different gaze gestures to select and confirm an object. When a user looks at an object to select, a confirmation flag pops-up adjacent to the object to confirm to which point the user is looking at.

Table III. A classification of different machine learning algorithms that use eye tracking data along with the research goal and the algorithm strengths and limitations.

Machine Learning Algorithm	Research Goal or Task	Strengths	Limitations
Regression	Analyzing visual world eye tracking data using multilevel logistic regression in psycholinguistic research (Barr, 2008), (Ahmad, 2018), automatic classification of health information (Pian, Khoo, & Chi, 2017), analysis of eye movement data using mixed effect modeling with Poisson regression (Huang, Luh, Sheu, Tzeng, & Chen, 2012), and improving eye tracking calibration accuracy using symbolic regression (Hassoumi, Peysakhovich, & Hurter, 2019).	A generalization of logistic regression, known as multinomial logistic regression, can be used to handle polytomous variables.	Robust standard errors are not available for multilevel regression approaches. The implementation of an empirical logit transformation with multinomial data is not clear.
Convolutional Neural Networks	The use of deep learning to semantically segment medical images (Stember, et al., 2019) (Krafka, et al., 2016), classification of eye tracking data (Yin, Juan, Chakraborty, & McGuire, 2018), strabismus recognition (Chen, Fu, Lo, & Chi, 2018), fetal ultrasound plane detection (Cai, Sharma, Chatelain, & Noble, 2018), and confusion prediction (Salminen, et al., 2019). Deep neural networks for human-level saccade detection (Bellet, Bellet, Nienborg, Hafed, & Berens, 2019), feature extraction to develop a hybrid eye tracking on a smartphone (Brousseau, Rose, & Eizenman, 2020).	Highly accurate even when the size of the training set is small. CNNs are a good tool when developing eye tracking systems for VR and AR.	Feature selection, sample size, and data analysis are important steps during the learning and may affect the accuracy of the results if they are not appropriately controlled.
Deep learning	A collaborative computer aided diagnosis (Khosravan N. , et al., 2019), eye gaze estimation in augmented spaces (Lemley, Kar, & Corcoran, 2018), how are learning strategies reflected in the eyes (Catrysse, et al., 2017), video saliency prediction (Jiang, Xu, Liu, Qiao, & Wang, 2018), event detection (Zemblys, Niehorster, Komogortsev, & Holmqvist, 2018), egocentric visual perception (Hristozova, Ozimek, & Siebert, 2018), surgical robot control (Li, Hou, Wei, Song, & Duan, 2018), eye-blinking detection on smartphones (Han, Kim, & Park, 2018).	Deep learning has improved the accuracy and performance of detection methods.	Lack of large datasets for training more sophisticated deep learning models. The efficiency of a search is still a significant issue in state-of-the-art detection methods.
Artificial Neural Network (ANN)	Eye-center detection (Ibrahim, Zin, & Ibrahim, 2018), driver fatigue (He, Li, Fan, & Fei, 2016), temporal data processing (Malakhova, Shelepin, & Malashin, 2018), and predicting mental workload in nuclear power plants (Wu, Liu, Jia, Tran, & Yan, 2019).	The ANN-based prediction model is proven to generate high correlation coefficient between the original and predicted data.	The small sample size reduces the statistical power and reliability of the prediction model. A field study that controls the lighting conditions is necessary to validate the generated results.
Naïve Bayes	Classify individual eye tracking patterns with the help of basic eye tracking metrics using naive Bayes classifier (Bhattarai & Phothisonothai, 2019), better understanding of children's visual cognitive behaviors (Moreno-Esteva, White, Wood, & Black, 2018), successful collaboration in a pair programming (Villamor & Rodrigo, 2018), Gaussian naive Bayes was used for Autism Spectrum Disorder (Thapaliya, Jayarathna, & Jaime, 2018), prediction of human intention and emotion analysis (He, et al., 2018), and predicting levels of learning (Parikh, 2018).	Works better for small sample size and the training is fast.	Cannot incorporate feature interactions
Support Vector Machine	Detecting readers with dyslexia (Rello & Ballesteros, 2015), eye-state classification (Dong, Zhang, Yue, & Hu, 2016), gaze latent support vector machine for image classification (Wang, Thome, & Cord, 2016) (Wang, Thome, & Corda, 2017), classifying major depression patients and healthy controls (Xinfang, et al., 2019), content-based discovery for Web map service (Hu, et al., 2016), evaluating orthodontic treatment from the lay perspective (Wang, et al., 2016), measuring learning attention in eLearning (Liu, Chang, & Huang, 2013), eye-gas estimation for face detection and head pose estimation (Cabrera-Quir´os, 2014), identification of literacy skills (Lou, Liu, Kaakinen, & Li, 2017), on-board estimation of alertness of drivers (George, 2012), classification of the age of toddlers (Dalrymple, Jiang, Zhao, & Elison, 2019), and personalized control system (Yoo, Yeon, & Jeong, 2016).	Using SVM to predict Dyslexia using eye tracking measures is feasible	To efficiently use an SVM, the size of the dataset should be significant. Limited generalizability owing to the sample size.
Random Forest (RF)	Event detection (Zemblys, Niehorster, Komogortsev, & Holmqvist, 2018) (Zemblys R. , 2016), pupil localization (Kacete, Seguier, Royan, Collobert, & Soladie, 2016) (Markuˇs, Frljak, Pandˇzi´, Ahlberg, & Forchheimer, 2014)blinking detection (Marcos-Ramiro, 2014).	RF can use the features as they are. There is no need to scale, center, reduce, or transform them in any way	RF algorithm cannot learn the sequence and context information directly from the raw data and produces the final output without the need for any post-processing.
Hidden Markov Model (HMM)	Using HMM and discriminant analysis (DA) models to suggest a method that focuses on the scan path of the interest and the state of mind of people depending on variations (Coutrot, Hsiao, & Chan, 2018), analysis of fixation sequences during visual inspection of front panels in a home appliance facility (Ulutas, Özkan, & Michalski, 2020), classification of mobile eye tracking data (Kit & Sullivan, 2016).	HMM may help discover human visual behavior patterns. It may also be used to assess whether operator gender has an influence on visual behavior or not.	HMMs are dependent on the structure of the visual content, and thus computer vision tools may be required to detect and track region of interests (ROIs) as they move.

pressed "Enter." Gazing at the object will then confirm the selection, which leads to an intentional confirmation of the object in less time and a correct selection. This also addresses the Midas touch problem in VR. Evaluation results have shown that DualGaze improves the familiarity of use and is significantly more accurate while maintaining a comparable selection speed. There are several classifications for an eye action. Xiao et al. (Cohn, Xiao, Moriyama, Ambadar, & Kanade, 2003) provided a three-category classification: blink, flutter, and non-blinking for only the right eye. The classification will be used to determine the input for the tracking to obtain the right time for detection.

Electrography and VOG have been highly discussed in the medical field and both have been widely studied for many different applications. Their differences show that electrography is suitable for eye tracking while a patient is sleeping, and for certain 3D tracking purposes. Although this is due to enhancements in technology and the focus on a more reliable low-cost technique, VOG has also been proven to be more efficient in many different fields, with advances in VOG found even as low sampling rates have faded owing to the use of high-end image sensor systems (Kong, Lee, Lee, & Nam, 2018).

6. Cloud Computing and Eye Tracking

There are several challenges to state-of-the-art of eye tracking research, including slow and local computations of huge data aggregations and analysis, a massive number of distributed mobile users, limited research laboratories, a merging of eye tracking with augmented reality systems, and the fact that next-generation interactive systems and applications will be ubiquitous. These challenges are preventing the development of online processing and pervasive usage. Distributed technologies and cloud computing represent solutions to some of these problems, allowing instant access to large amounts of eye tracking data of a massive numbers of users at once (Vrzakova & Bednarik, 2013). The eye tracking research community expects cloud based eye tracking applications to be available in the near future. This places more pressure on considering the current challenges and special requirements from HCI aspects, through parallel computing, embedded and network systems, and hardware optimization. Many other important topics, such as ethical and privacy issues, along with other social implications of pervasive cloud based eye tracking, need to be carefully examined in future research. We argue that combining eye tracking research with cloud computing will allow efficient data storage, sharing, processing, modeling, and evaluation. In addition, it may help with conducting a wide range of usability studies and questionnaires along with eye tracking and interaction analyses to access and generate useful information at any time and location.

Future interactive applications and pervasive cloud-based eye tracking solutions will force designers and developers to focus more on design principles, hardware requirements and improvements, intelligent display management, an immediate interaction response, auto-calibration systems, and application requirements and development.

EyeCloud (DAO, 2014) was one such attempt combining distributed algorithms with eye tracking into a cloud-based structure. A cloud-based structure uses a parallel computation to send/receive messages through different nodes, adding network latency to the overall latency. When the network latency is less than the processing time in the cloud structure. In addition, the efficiency and performance of the EyeCloud depends on designing distributed algorithms along with the problem itself. Some problems might be distributed while others might not. For example, it might not be possible to deploy an online fixation detection algorithm on each node in parallel, and thus each slave node handles a certain number of concurrent eye tracker tasks. Otherwise, a real-time heatmap rendering algorithm is required to divide computations into small tasks, each of which is computed on a slave node. Therefore, running as many tasks as possible in parallel leverages cloud computing. In addition, there are other factors that should be carefully considered, such as the number of nodes, the ways to distribute/merge data and/or tasks among these nodes, and a time segment. EyeCloud showed that cloud computing can achieve better handling than a single computer by decreasing the running and delay times.

We should not use cloud computing (DAO, 2014):

- when computational requirements are complex, particularly when using a large amount of data with a long upload time;
- when the number of nodes required for analysis is not too large;
- when the cloud requires many communication messages, which can lead to a slow computation speed.

A cloud-based approach represents a centralized model, which may be a problem that can be solved through fog computing, which is a decentralized architectural pattern that brings computing resources and application services closer to the edge. Fog computing complements the cloud and improves its efficiency by reducing the amount of data that is transferred to the cloud for processing and analysis while also improving security, a major concern in the IoT industry. IoT nodes are closer to the action, but they do not have sufficient computing and storage resources to conduct analytics and ML tasks. By contrast, although cloud servers have the required horsepower, they are far from being able to process data and respond in real time (Dickson, 2016). To the best of our knowledge, studies combining eye tracking with fog computing do not exist; however, some attempts can be found in fog computing with sustainable smart cities (Perera, Qin, Estrella, Reiff-Marganiec, & Vasilakos, 2017), fog computing trends, architectures, requirements, and research directions (Naha, Garg, Georgakopoulos, Jayaraman, & Gao, 2018).

Real-time synchronization, security, offline and batch processing, classification with feedback, and design of cloud-based distributed algorithms represent some future directions for combining eye tracking with cloud and fog computing.

7. Eye Tracking Applications

Eye tracking is a valuable tool for any type of research on human behavior. It can be used to develop applications in a variety of fields, such as healthcare and medicine, psychology, marketing, engineering, education, and gaming, as well as enhancing human–computer interactions using the eyes for navigation and control. Herein, we focus on four application fields owing to their real values and based on our interests and experience.

7.1. Healthcare and Medical Applications

Eye tracking techniques have been widely used as a research tool in healthcare and medical applications. Healthcare researchers have recently shown that using eye tracking techniques in medical decision-making achieved better results. In general, the quality and performance of appropriate medical procedures and treatments along with use of advanced technologies make the study of the human mind and body much easier, and therefore enhance the process of medical decision-making. In addition, the information provided by these technologies is useful in revealing abnormalities in people's feelings and intentions.

The evolutions of current technologies indicate that eye tracking systems can help people who suffer from certain medical issues (Kok & Jarodzka, 2017). Eye tracking provides a rich source of data in an orderly time range that help a set of medicinal theories to resolve issues regarding the inability to deduce cognitive processes. In addition, it allows for a precise diagnosis or monitoring of wellbeing.

Patients suffering from amyotrophic lateral sclerosis (ALS) face difficulties in speaking or writing. A software tool that uses neuropsychological screening instruments based on the Edinburgh Cognitive and Behavioral ALS Screen has been developed (Keller, et al., 2017). It uses an infrared sensor, called EyeLive, to track the eye movements through a predefined user interface. It does not use a mutual camera-based approach, instead it uses the infrared sensors built upon a pair of glasses to identify the direction of the eye gaze. Current entry level systems for people suffering from ALS have certain problems: They are expensive and are not robust under different lighting conditions, and they require special calibrations. To address these challenges, Zhang et al. have proposed an eye-gesture communication system, called GazeSpeak, that has certain characteristics, including a low-cost design, robustness, easy learnability, a high user satisfaction, portability, the capability of running on smartphones, and a higher bandwidth than an e-tran board (Zhang, Kulkarni, & Morris, 2017). In addition, it decodes eye gestures into predicted spoken words in real time and enables communication with different interfaces for speakers and translators. Moreover, it outperforms eye gaze transfer (both low-tech and common use) in terms of both connection speed and ease of use, with a low rate of misrepresentation.

NajiKhosravan et al. developed an algorithm that uses a variable collaborative-computer aided diagnosis (C-CAD) system to integrate CAD with eye tracking systems (Khosravan N. , et al., 2019). The authors used a graph clustering to convert eye tracking data into a graph model, which can be used in an actual radiology room. In addition, the system includes a 3D deep learning algorithm designed into a new multi-task platform to concurrently split and recognize suspicious areas. The authors test their system on lung cancer patients in the presence of multiple radiologists. The results showed that their system improves the accuracy, efficiency, and applicability in a real radiology room setting.

To study the behavior of infants during normal interactions, an eye tracking system was used to record their gaze while they were playing with their mothers. Franchak et al. studied the infants' visual exploration during spontaneous, unconstrained, natural interactions with their caregivers, objects, and obstacles (Franchak, Kretch, Soska, & Adolph, 2011). The results revealed that the visual exploration of infants was opportunistic and depended on the availability of information and the limitations of their bodies. The most frequent recurrences of the infants' gazes were most often in the direction of hand movements and crawling, but the least frequent were in the direction of leg movements. Assistive systems were researched by Enkelejda et al. to help individuals with glaucoma and evaluate their functional ability in everyday tasks (Kasneci, Black, & Wood, 2017). The authors conducted standardized experimental studies and used the results to develop customized solutions.

Individuals with autism spectrum disorder (ASD) suffer from the integration of audiovisual methods. Finke et al. aimed to monitor the behavior of children with and without ASD through the use of video games and by controlling their faces and reactions using the Tobii eye tracking system (Finke, Wilkinson, & Hickerson, 2017). The results of their study showed that children with ASD were attracted to video games in the same way as ordinary children (Hansen & Ji, 2010). Itziar et al. used an eye tracking system to determine if infants suffer from ASD owing to genetics in their early development. The preliminary results of the study showed the advantages and limitations of using eye tracking to register visual attention measures and how the complexity of the observed features present a great number of challenges regarding the quality of data obtained through eye tracking (Lozano, Campos, & Belinchón, 2018).

Another attempt to support the rehabilitation of cognitive functions, this time in children with attention deficit hyperactivity disorder, was developed by Garcia et al. (Garcia-Zapirain, de la Torre Díez, & López-Coronado, 2017). The authors used a technological platform based on the .NET framework and two physiological sensors: a hand recognition sensor (Leap Motion) and eye tracking device (Tobii X1 Light) to provide children the ability to build their learning and attention skills. Evaluation results showed that the system can help children with attention deficit and learning problems.

Lauermann et al. (Lauermann, et al., 2017) developed an evaluation model to evaluate the impact of eye tracking technology on the quality of optical coherence tomography angiography (OCT-A) image in patients with age-related macular degeneration (AMD). The evaluation results showed that using active eye tracking technology improves the image quality in OCT-A imaging in terms of the involuntary movement of AMD patients in cases of a higher acquisition time. Table IV summarizes a list of some diseases that use eye tracking technology along with the main findings and eye tracking techniques used.

Many researchers have developed medical solutions for elderly and special needs assistance through ML and eye tracking technologies. Songpo and Jeremy developed a human–robot-interaction (HRI) modality based on 3-D gaze data that helps users with motion impairment express what tasks they want the robot to perform by directly looking at an object of interest in the real

Table IV. A list of diseases that use eye tracking technology along with the main findings

Study	Disease/Research Goal	Device/Sensor	Main findings
(Scott, Zhang, Le, & Moyle, 2017)	ALS and other locked in diseases	Optical sensors/ emitters	EyeLive does not use a common camera-based approach, so it reduces eye strain, increases accuracy, enhances mobility, and improves user-friendliness
(Sharafia, Soha, & Gu´eh´eneuc, 2015)	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.
(Kitchenham B. , 2004)	Glaucoma	Mobile	Glaucoma patients might be supported through development of personalized solutions that combine VR technology with eye-tracking algorithms, in which the tracking should be done under standardized experimental conditions.
(Hansen & Ji, 2010)	Autism Spectrum Disorder (ASD)	Tobii eye-tracking system	ASD children were attracted to video games in the same way as ordinary children
(Chennamma & Yuan, 2013)	Amyotrophic Lateral Sclerosis (ALS)	EyeTribe connected to the notebook	• Feasibility and reliability of a mobile eye-tracking screening tool to help ASL patients. • It can be easily administered even at the patient's bedside in a timeframe of usually less than one hour. • Eye-tracking based ECAS version is well suited to identify those ALS patients with substantial cognitive impairment.
(Sorate & Chhajed, 2017)	To study the behavior 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.
(Robinson, 1963)	Age-related macular degeneration	Multimodal retinal imaging including OCT-A	Using active eye-tracking technology improved image quality in OCT-A imaging. regarding presence of motion artifacts at the expense of higher acquisition time.
(Eibenberger, Eibenberger, & Rucci, 2016)	ASD due to genetics of their early development	NA	Using eye-tracking involves advantages such as: automate testing sessions, register more visual attention measures, provide concrete answers to the role of some areas of interest.
(McCamy M. B., et al., 2015)	Attention Deficit Hyperactivity Disorder (ADHD)	Leap Motion and Tobii X1 Light	• help children with attention deficit and learning issues. • Teachers may utilize this system to track the progression of their students and see their behavior.
(Chen, Fu, Lo, & Chi, 2018)	Strabismus Recognition	A gaze deviation (GaDe) image	• The authors proposed a CNNs-based method for strabismus recognition. • The CNNs is a powerful alternative in feature extraction of eye-tracking data.

world (Li, Zhang, & Webb, 2017). Their method uses a binocular eye tracker to detect the pupil and gaze vector to estimate the eye gaze, and then interprets the human gaze and converts it into an effective interaction modality. The evaluation results demonstrated the efficiency and effectiveness of gaze-based HRI, which is expected to help users who suffer from impaired mobility in their daily lives.

Elderly people often cannot remember where they leave certain objects, and thus they use a visual search more frequently than others. Thus, a visual search plays a key role in their ability to complete everyday activities. There have been several studies analyzing eye movements during a visual search. First, it is necessary to detect whether a user is searching for an object, and then the required assistance can be provided. Dietz et al. proposed an eye tracking multimodal approach to support the visual search process and assess elderly people (Dietz, Schork, & André, 2016). In addition, the authors used a head mounted display (HMD) technique to explore multiple strategies that provide the user with the location of the desired object. Pupil Pro has been applied to manage a head mounted tracker with dual cameras: an infrared camera and a camera for the surrounding view. Furthermore, the authors showed that, based on the initial experiments, using an eye tracking mechanism can help in addressing some of the challenges faced by a visual search.

Eye imaging and eye movement visualization and metrics used in medical applications were studied by Harezlak and Kasprowski (Harezla & Kasprowski, 2018); they highlighted that eye tracking applications in the medical field that may have significant potential are yet to be explored and investigated, particularly for children, such as the use of eye tracking in therapy and in games with gaze contingent interfaces, which may have a positive effect on their vision.

An SVM classifier has been used to help elderly people automatically detect objects visually, to identify the point in time when they need assistance. Dietz et al. developed a complete mobile eye and head tracking device. Their evaluation results using Google glass eye tracking have demonstrated the feasibility of the approach and achieved a recognition rate of 97.55% with a leave-one-user-out evaluation method (Dietz, et al., 2017). The authors used Google glass over Tobii or Pupil Lab owing to the feedback it provides to the users. Klaib et al. proposed a model that utilizes a VOG approach through Tobii technology with added voice interfaces using the Azure cloud to help control home appliances. It does not use wearable technology through VOG with multiple cameras, which delivers several advantages: an accurate gaze estimate, a portability of the video recording system, and fully remote recordings. It traces the user through reflected infrared light patterns and calculates the gaze position automatically. The flexibility and reliability in interacting with the system, and the accuracy in the movement of the pointer, make this model a reliable solution for simplifying some daily tasks of the elderly and special needs users (Klaib, Alsrehin, Melhem, & Bashtawi, 2019).

The current literature has demonstrated that eye tracking data is a powerful tool to provide valuable information on healthy or unhealthy aging processes along with normative values for some oculo-metrics (Marandi & Gazerani, 2019). However, most of the eye tracking data were generated in a laboratory environment, which may differ when generated in a real-life situation. Thus, it is important to study the importance of eye tracking data in natural situations and how they impact elderly people.

The current literature has shown that combing both head- and eye-movement data will provide a better understanding of the gaze patterns, visual information, and visual scanning strategies along with the necessity to fill in the lack of information (Paraskevoudi & Pezaris, 2018). However, further research needs to be conducted to study the effects of head verses eye movements and their impact on several applications for elderly people.

The human eye generates different patterns of eye movement across a scene, which is called the scan path (Kurzhals, Brian, Burch, & Weiskopf, 2016). Gaze plots for elderly people tend to cause visual clutter as the number of people in a scene and the length of the scan path increases. Therefore, better visual analysis techniques are required for the data generated from a long eye tracking sequence. Furthermore, a comprehensive comparison between different visual analysis techniques that combine an automatic and visual scan path is needed because standard approaches do not work well (Kurzhals, Brian, Burch, & Weiskopf, 2016) and have not been used for an extended evaluation of visualization techniques. For modeling a scan path, Coutrot et al. used hidden Markov models and discriminant analysis models to suggest a method focusing on the scan path of interest and the state of mind of people depending on the variations. The evaluation results showed that the suggested algorithm achieves a classification accuracy of 81.2% (Coutrot, Hsiao, & Chan, 2018).

Eye tracking is a highly useful tool in virtual reality (VR) (Clay, König, & König, Eye Tracking in Virtual Reality, 2019), and provides an innovative way to interact with VR content. It achieves a high level of privacy and security using biometric identifiers through retinal scanning and identification systems, as well as adding the extra functions of connection and feedback to an experience. In addition, it reduces the GPU load and generates high-quality content through foveated rendering, which is a process that renders a specific part of the screen where the user is currently looking in full resolution. Additionally, it provides more natural interactions between a human and applications, which helps developers in understanding how their application is being used. However, it has certain limitations, such as the subjects wearing glasses are not always able to participate in the experiment. Moreover, additional time is needed to calibrate and validate the eye tracker, which may hinder the experiments, particularly in longer sessions for elderly people who have slow natural movements and experience motion sickness. Owing to the rapid developments in VR technologies, however, we expect that solutions to these limitations will soon be addressed.

In contrast to the use of eye tracking in many healthcare and medical applications, there are still some limitations owing to eye movements reflecting the cognitive processes, although cognitive processes cannot be directly inferred from eye tracking data. To interpret eye tracking data properly, theoretical models must be used as the design basis of the experiments as well as for analyzing and interpreting the eye tracking data (Kok & Jarodzka, 2017).

7.2. Human–Computer Interaction (HCI) and Accessibility

Using eye tracking technology to interact with computers implies extracting information from the area the user is gazing or looking at, which goes back at least to the early 1990s. The most common tasks applied through eye tracking in the HCI field are pointing, moving screen objects, selecting menus, dragging, and dropping (Bulling & Gellersen, Toward mobile eye-based human-computer interaction. , 2010).

To analyze infer-facial expressions using partially occluded faces while the user is involved in a VR experience, Hickson et al. showed an algorithm that uses an infrared gaze tracking camera inside a VR equipment with a HMD to capture a set of images of the user's eye. Experiments showed that these images are sufficient to decide which subset of facial expressions the images belong to without the use of any fixed external camera. The accuracy of classifying an expression was 74%, and the accuracy of classifying a facial action unit was 70% (Hickson, Dufour, Sud, Kwatra, & Essa, 2019).

Researchers have investigated the applicability of using eye tracking technology with a small smart phone or tablet screen. Using eye movements to interact only with a smartphone was investigated by Dybdal et al. (Dybdal, Agustin, & Hansen, 2012). The authors used finger-strokes and accelerometer-based interactions with gaze-gestures and dwell-time selection strategies. The results showed that a touch interaction is better than a gaze interaction in terms of completion time of the accelerometer and the error rate.

There has been a shift from studies on tools that focus on desktop graphical applications to the development of end-user development (EUD) research for web environments (Tzafilkou & Protogeros, 2017). Currently, eye tracking and mouse technologies are being used to monitor end-user behaviors in real time. Tzafilkou and Protogeros have explored the correlation between eye movements and end-user perception and acceptance in modern web-based EUD environments. The authors have tried to see whether the end-user sense and acceptance are reflected in the eye behavior when interacting with a web-based and database-driven EUD system. The authors developed a prototype based on a natural language approach to help end-users create mobile-based database applications. Evaluation results showed significant associations between eye behavior, perception, and acceptance (Tzafilkou & Protogeros, 2017).

The IPad's front camera and eye/head tracking technology were used to enhance the lives of people with special needs. The Haar Cascade algorithm was used to detect facial features. Light colored eyes were found to gain the best results with 90% accuracy. Face detection accuracy was 100% in both light and dark environments (Lopez-Basterretxea, Mendez-Zorrilla, & Garcia-Zapirain, 2015).

Activity recognition based on eye movement was investigated by Bulling et al. The authors recorded eye movement using an EOG system and then assessed the repetitive patterns of eye movements. The authors used eight study groups to evaluate their proposed method using five activity classes. Two classifiers, a person-independent classifier, and an SVM were used. Evaluation results showed a precision of 76.1% and a recall of 70.5% (Bulling, Ward, Gellersen, & Troster, 2011).

Visualization techniques for eye tracking data were investigated by Blascheck et al, who reviewed a large number of research papers focusing on visualization techniques and classified them into point-based methods and methods based on AOI, to help researchers apply qualitative analysis methods based on their classification. In addition, they managed to contact the main experts of eye tracking techniques to check their use of visualizing techniques in analyzing eye tracking data, and as a result, have managed to identify the main obstacles that can be avoided, and this led to an increased use of visualizations in eye tracking research (Blascheck, et al., 2017).

Aspects and issues related to eye-movement technology, guidelines for developing eye tracking applications, and various opportunities and challenges for developing systems using eye tracking technology were introduced by Chandra et al. (Chandra, Sharma, Malhotra, Jha, & Mittal, 2015). Bulling et al. showed that subjects with or without bifocal glasses show similar fixation results if they do not have any vision issues, but the results changed and incurred a small error if corrected using lenses. In addition, they showed that input from Eye Tribe© requires less time compared to input from a mouse (Bulling, Ward, Gellersen, & Troster, 2011).

Within an increase in the number of smartphones worldwide and the human disdain for wearing extra special hardware (Khamis, Alt, & Bulling, 2018), we expect that the development of special smartphones or handheld devices for tracking human eyes to enhance the interaction between them will further improve in the coming years. Such inexpensive specialty devices should be designed to make the eye tracking systems more robust and comfortable and allow the camera to see the users' eyes even if they do not hold them in a suitable way or when a part of their faces are occluded. In addition, using gaze interaction techniques to leverage eye behaviors is a more promising direction for handheld devices, particularly for those who do not require a manual calibration, such as gaze-gestures. Moreover, the training systems should be developed that use eye tracking to measure user interactions with programs to evaluate where, how, and when the instruction can be altered. A complete holistic view on the past, present, and future of eye tracking techniques applied on handheld mobile devices can be found in (Rosch & Vogel-Walcutt, 2013) (Khamis, Alt, & Bulling, 2018). Table V shows a comparison between recent studies using eye tracking technology in HCI along with the algorithm, device, and datasets applied.

HCI allows people to interface with systems, whereas assistive systems use HCI to help people with special needs who cannot move their arms or have special needs in different areas such as the work environment, social interaction, normal activities, and education. Eye tracking techniques detect the direction of the eyes to control the cursor movements on the screen. Some technologies such as an intelligent wheel chair (Gautam, Sumanth, Karthikeyan, Sundar, & Venkataraman, 2014), head control (Cognolato, Atzori, & Müller, 2018), voice recognition software, single-switch access, sip and puff switch, oversized trackball mouse, adaptive keyboard, and joystick have been developed as different control interfaces to help take care of people with special needs. However, some people have severe motor disabilities and are unable to move their limbs freely or speak clearly. Therefore, eye tracking technology can be used and represents a promising source of data in an assistive system (Koester & Arthanat, 2018) (Deepika & Murugesan, 2015).

Gautam et al. proposed an EOG-based method with an optical-type eye tracking system to support a mechanical wheelchair for physically challenged people (Gautam, Sumanth, Karthikeyan, Sundar, & Venkataraman, 2014). User eye movements have also been translated into the screen position. The computer input system sends an instruction to the software when the user looks at a convenient angle of the pupil by applying Daugman's segmentation algorithm. An electric powered

Table V. A comparison between recent studies that use eye tracking technology in HCI

Reference	Algorithm	Goal	Device	Dataset/Users
(Păsărică, Bozomitu, Cehan, Lupu, & Rotariu, 2015)	Supervised Learning using a CNN	Classifying facial expressions	IR gaze tracking camera inside a VR equipment with an HMD	The authors collected data from participants in a controlled setting.
(Picanço & Tonneau, 2018)	Finger-strokes and accelerometer-based interactions with gaze-gestures and dwell-time selection strategies	Does using eye movements only is feasible to interact with the small screen of a smartphone?	Cameras of small screens of smart phones and tablets	11 subjects in a controlled environment
(Martinikorena, Cabeza, Villanueva, Urtasun, & Larumbe, 2018)	Prototype EUD tool based on a natural language approach, called 'simple talking').	explore the correlation between eye movements and end-user perception and acceptance in modern web-based EUD environments.	Explored the correlation between eye movements and end-user perception and acceptance in modern web-based EUD environments	NA
(Lupu & Ungureanu, 2013)	Person-independent (leave-one-person-out) and support vector machine classifiers	Investigate the eye-movement data to recognize activity	EOG system using saccades, fixations, and blinks	Eight study groups using five activities classes.

wheelchair that combines electro encephalography (EEG) and eye movements was developed by Taher et al. to help people with severe disabilities. The developed wheelchair does not affect the security of the patients and achieved a success rate of 88.66% (Taher, Amor, & Jallouli, 2015). Meena et al. have developed another tool, called EMOHEX, to help people in need of a wheelchair. It was built using a duel control panel to determine the intention of the user such that they can identify the detection of any command button of an eye tracking system (Meena, et al., 2016). The evaluation results demonstrated the feasibility and stability of the system.

An algorithm having five stages when applied using a personal computer and a low-cost webcam was developed by Ghude et al., allowing users to easily handle a computer. It can detect eye movements efficiently and accurately in real time (Ghude, Tembe, & Patil, 2014). Another study was proposed by Deepika and Murugesan to facilitate the interactions between computers and users with special needs using video-based eye tracking technology (Deepika & Murugesan, 2015). VOG and EOG methods along with a webcam have been used to control the movements of the cursor on the screen using the human eye. Videos gained from a webcam were processed to locate the center of the iris to estimate the eye gaze. The proposed system performed well under good lighting conditions with an accuracy of 97%, but in dark areas the accuracy was 87%.

Some research focused on people with hand disabilities who cannot use a mouse or keyboard while controlling a computer. Dagnew and Kaur proposed a system that calculates the pixel value and sclera detection to apply an eye detection (Dagnew & Kaur, 2016). Another approach proposed by Haritha used eye detection and a tracking camera to capture images using the isophone center applied in eye tracking and eyeblink detection methods (Haritha, et al., 2016). An eye tracking system using steady state visual evoked potentials technology was used for the initial selection and to activate the exact target (Stawicki, Gembler, Rezeika, & Volosyak, 2017).

Another system was developed by Utaminingrum et al. to support people with special needs by adjusting and recognizing eye movements when considering the decision of both the left and right eyes (Utaminingrum, Fauzi, Sari, Primaswara, & Adinugroho, 2016). The Haar Cascade algorithm has also been applied for monitoring the area of the eyes. In addition, a Hough Circle Transform was also used to make a decision regarding the handling of the eye movement position. The accuracy reached more than 80%.

To enhance and facilitate the lives of individuals with upper-limb disabilities, an eye-control approach was proposed by Tunhua et al. based on Kinect 2.0. This approach has been utilized to express the critical points of the eyelid. Indirect control was made to ensure a smooth and gradual movement of the cursor to a fixation point, which reduced the difficulty of calibration and interference from eye jitter on the control. This system provided good stability and high efficiency using a real-time control speed that reached a frame rate of 19.9 fps (Wu, Wang, Lin, & Zhou, 2017). Beibin et al. modified the DBSCAN algorithm to be able to recognize fixations and saccades, and it can handle noise, fixed structure, and smooth continuation movements that traditional fixation identification algorithms cannot. However, it still needs some arbitrary thresholds (Li, et al., 2016). Königa and Buffalo proposed the Cluster Fix algorithm, which uses a K-means cluster analysis to measure the variation between fixations and saccades. It can detect even small saccades that are often difficult to detect, and distinguish them from noisy fixations. In addition, it can detect the beginning and end of saccades using the transition times between the fixations and saccades along with four criteria: the distance, velocity, acceleration, and angular velocity (Königa & Buffalo, 2014).

Training special needs people to control their eye gaze under real scenarios could be the next step toward helping them to master this method. A simulation-based environment, such as VR, may be a solution that can be widely used in training for real-task scenarios, and it provides a completely immersive environment for medical skills training and for people with intellectual disabilities (Zhang & Hansen, 2019).

7.3. Education and E-learning

The use of eye tracking techniques in education and learning has several applications, such as assessing the level of understanding of readers and measuring the interest, attention, and other aspects of users. Most studies have indicated that the use of eye tracking data in such applications succeeds in detecting changes in the cognitive progress and assessing the concentration of learners, which allows the use of this information to enhance the educational process (Rosch & Vogel-Walcutt, 2013) (Sun, Li, Zhang, & Zou, 2017).

Eye tracking technology has been used by Inoue1 and Paracha as a tool to assess the extent to which fluent and non-fluent readers complete the processing of texts and images to improve their reading outcomes (Inoue & Paracha, 2016). Reading progress has also been studied by Rasmussen and Tan using an eye gaze tracker through speech recognition to generate word probabilities to increase the likelihood of the language model. Their experimental results showed that the tracking error rate for speech recognition was 34.9%, whereas the error rate for combing eye gaze tracking with speech recognition was 31.2%, which is an improvement of 10.6% (Rasmussen & Tan, 2013).

Software developers have worked with programs that consist of different source code files, each of which typically contains thousands of lines of code. They spend most of their development time accomplishing activities such as file switching, code folding, and content scrolling (Minelli, Mocci, & Lanza, 2015). While they read, understand, and debug code, they constantly moving their eyes between multiple files and elements, which increases the development time and makes the process of capturing the context of what developers are looking at difficult. Sharafi et al. evaluated the use of eye trackers in software engineering to study model comprehension, code comprehension, debugging, collaborative interaction, and traceability. Their results have provided evidence on the uses and contributions of eye trackers in empirical software engineering studies using Engineering Village rather than applying a manual search. Finally, they reported the limitations of current eye tracking technology, threatening the validity of previous studies, along with suggestions for mitigating these limitations (Zohreh Sharafi, 2015). Similarly, Obaidellad and Al Haek focused on expressing how different experiments using eye tracking are steered and used to collect different information. They used 63 studies focusing on program comprehension and debugging, non-code comprehension, collaborative programming, and requirements traceability research. Their results showed that most of the participants used programing languages and materials, and that eye trackers and attention tracking tools have been utilized (Obaidellah, Al Haek, & Cheng, 2018).

Guarnera et al. developed an eye tracking infrastructure, called iTrace, that enables an eye tracking option in some integrated development environments and allows software developers to work under more realistic conditions (Guarnera, Bryant, Mishra, Maletic, & Sharif, 2018). In addition, the authors presented several use cases using different gaze patterns along with a video demonstration of where iTrace can be used (Guarnera, Bryant, Mishra, Maletic, & Sharif, 2018). Najar et al. investigated the using of eye tracking data to compare the behaviors of novices and advanced students while studying examples to increase the learning level using an intelligent tutoring system (Najar, Mitrovic, & Neshatian, 2014). They found that advanced students paid more attention to database schema than novices. Video-based pupil monitoring eye trackers have been used to investigate the allocation of the attention generated from the eye tracker regarding an individual's locus of attention in a digital assessment game.

Eye tracking technology has proven its efficiency and effectiveness in terms of measuring and evaluating the cognitive level, inspiring an interface design, discovering a behavioral response according to the user data, improving the teaching quality by improving the teaching framework, promoting the application of technology, and improving the educational standards. However, some areas lack significant contributions, particularly for developing an adaptive system based on the need of user's cognitive load levels calculated from eye tracking data. Having such a personalized system will improve the training by increasing the knowledge transfer and retention while utilizing the time of the trainee. In addition, current eye tracking systems and analysis tools have some issues related to system cost and software integration that limit the development of commercialized devices or tools for general use (Rosch & Vogel-Walcutt, 2013).

7.4. Car Assistant

Most eye tracking systems have been applied indoors and have shown a convenient performance when the surrounding light is controlled, and the eye region of interest (ROI) can be detected by using focused images. When these techniques are applied to a driving scenario, the light can change quickly when the car is moving, and thus it cannot be guaranteed that there will be continuous reflection of lights on the eye. In addition, tracking the behaviors of eye-movement is important for driver fatigue detection (Xu, Min, & Hu, 2018), drowsiness monitoring (Neshov & Manolova, 2017), real-time drowsiness detection (Murphy, Duncan, Glennie, & Knox, 2001), driving-assistance systems (Said, et al., 2018), and accident prevention (Anjali, et al., 2016). Many researchers showed interest in developing intelligent methods for activating alarm systems when the eyes are not exposed for several seconds while driving.

In general, the Viola Jones face detector and tracking-learning detection algorithms have been used to detect changes in the appearance of a scene (Bengoechea, Villanueva, & Cabeza, 2012). Neshov and Manolova suggested an algorithm that combine these two algorithms (Neshov & Manolova, 2017). Another system was developed by Anjali et al. to prevent car accidents by detecting closed eyes for driver fatigue and to alert drivers using a buzzer and vibration upon a positive detection (Anjali, et al., 2016). The system was developed using a camera mounted in front of the driver, which captures real-time video using OpenCV and Raspberry Pi. It can detect the eyes at medium and high illumination. In addition, grayscale image processing and PERCLOS have been used by Yan et al. to determine if the driver suffers from fatigue or drowsiness in a timely manner (Yan, Kuo, Lin, & Liao, 2016). The quick sort method is used to confirm the distribution range of black pixels. This study can be used even when the driver is wearing glasses or a respiratory mask. Eriksson et al. explored the usefulness of the gaze time on screen as an engagement measure in screen mediated learning context, and the generated data showed very little about the engagement of the drivers when using gaze trackers while driving an expensive car (Eriksson, Swenberg, Zhao, & Eriksson, 2018).

For driver drowsiness or fatigue, Khushaba et al. developed a feature extraction algorithm, called fuzzy mutual-information - based wavelet packet transform (FMIWPT), to classify the driver drowsiness state into one of the predefined drowsiness levels. FMIWPT extracted the most relevant features required to identify the driver drowsiness/fatigue states and maximized the amount of drowsiness-related information extracted from a set of electroencephalogram (EEG), electrooculogram (EOG), and electrocardiogram (ECG) signals during a simulation driving test. The authors have also compared EOG, ECG, and EEG signals for feature extraction and found that EEG and ECG signals are more suitable than EOG signals for this purpose (Khushaba, Kodagoda, Lal, & Dissanayake, 2011). Other attempts were made to monitor the driver's eyes using a camera and detect symptoms of driver fatigue early enough to avoid an accident (Singh, Bhatia, & Kaur, 2011) (Nguyen, Chew, & Demidenko, 2015) (Muñoz-Leiva, Hernández-Méndez, & Gómez-Carmona, 2019).

Researchers from the University of Missouri have announced two new applications of eye tracking technology: The first application focused on designing a better collision avoidance warning system, whereas the second application focused on a real-time evaluation of the driver's physical behavior using the driver's eyes as a crash occurs. They observed that the alert generated from the collision avoidance system itself creates a distraction that may be a hinderance to the driver and cause an accident or crash. Therefore, they used a vehicle-assisted safety system to watch how people's pupils changed in response to their physical reactions and built a two-way communication channel between a driver and a vehicle to avoid such collisions (Missouri-Columbia, 2019).

Moreover, automakers have been widely looking for ways to incorporate IoT in the vehicle for entertainment and particularly for the safety of elder users and special needs drivers. Eye tracking in smart cars has been a goal of many companies, including Volkswagen, General Motors, and Audi. Sensors were used to detect eye blinks to guarantee the safety of drivers on the road. Eye tracking has been used to detect drowsiness and sleepiness (Anusha & Ahmed, 2017) (Park, Subramaniyam, Hong, Kim, & Yu, 2017).

Noland et al. used a survey to evaluate quantitatively the ways in which individuals process and rank images used in public settings for urban planning, using eye tracking techniques. Their results have shown different ranking levels for urbanist components such as images, people, pedestrian features, greenery, buildings, cars, and parking. In addition, they showed a way to extract greater value from visual preference surveys for transportation and urban planners and can be used in the future to reduce motor vehicle traffic in cities (Noland, Weiner, Gao, Cook, & Nelessen, 2017).

Different methods have been explored for making driving for elderly people a safer experience using IoT to quickly gain assistance during an emergency. Park et al. (Park, Subramaniyam, Hong, Kim, & Yu, 2017) showed how a stroke can be detected and that a medical doctor or relative can be informed when such an incident occurs while driving. For example, the authors showed that elderly people can use wearables that are connected to sensors to help them stay safe when experiencing a stroke.

The US National Highway Traffic Safety Administration classifies three types of driver distraction: visual, manual, and cognitive distractions (Le, Suzuki, & Aoki, 2020). Visual distraction occurs when the driver looks away from the roadway, for example, when looking at the dashboard. Manual distraction occurs when the driver takes a hand off the steering wheel to eat or drink, for example. Finally, cognitive distraction is defined as a task that involves thinking about something other than driving. Using eye tracking approaches to detect the types of distraction is a common task. However, observing a cognitive distraction from an external behavior, such as eye tracking, is harder, and it is easier to discover the visual distraction using eye tracking approaches. Moreover, combining different types of distractions makes the process of identifying the distraction more difficult. Several researchers have investigated the use of eye tracking to detect the type of distraction (Liang & Lee, Driver Cognitive Distraction Detection Using Eye Movements, 2007), (Hurtado & Chiasson, 2016), and (Gazepoint, 2020). In a real driving environment, cognitive distraction often occurs with visual and manual distraction (Liang & Lee, Comparing Support Vector Machines (SVMs) and Bayesian Networks (BNs) in detecting driver cognitive distraction using eye movements, 2007). Thus, we believe that discovering a cognitive distraction from a manual or visual distraction might be a future direction for researchers. In addition, checking the level of visual and manual distraction may help in discovering the level of cognitive distraction.

7.5. Choice Modeling, Consumer Psychology, and Marketing

New marketing and adverting strategies require involving users in the design and evaluation of products and services. This gives insight into customer satisfaction, engagement, and the determination of the design decisions. In addition, the ability to open new possibilities in both lab and real-world neuromarketing tests allows researchers to collect objective data coming from the customers' eyes and brain when they interact with a product or service. Portable eye tracking devices allow individuals to automatically interact with their environment normally. This helps in understanding how specific features appear to be understood by humans and using that knowledge further to make better decisions.

One of the metrics for measuring the impact of ads is the number of clicks, which is the number of times users have clicked on a digital advertisement to reach an online property (Orquin & Wedel, 2020) (Hang, Yi, & Xianglan, 2018) (MetricHQ, 2020). However, it does not precisely reflect the effectiveness of an ad campaign. This is because some non-human resources, such as software tools and applications can generate automatic clicks, which may make this metric inaccurate. With eye tracking technology, online advertisers can exactly measure the number of clicks, which can be achieved by calculating the number of ad views when they appear on the page using some measurements such as the ROI. In fact, using eye tracking to assess the interest of an audience and to give insight into how users interact with ads, requires every computer and mobile device to be embedded with eye tracking technology (Wedel, Pieters, & Lans, 2019) (Bulling & Wedel, 2019). We believe that, in the future, devices will be associated with such technology and many applications will benefit from such features.

Khushaba et al. conducted a pilot study that explores the nature of decision-making by examining the associated brain activity and EEG of people, to understand how the brain responds while undertaking choices designed to elicit the subjects' preferences (Khushaba, et al., 2012). Similarly, Khushaba et al. (Khushaba, et al., 2013) helped in improving the design and presentation of products according to consumer preferences by using an Emotiv EPOC wireless EEG headset to collect EEG signals from participants and a Tobii-Studio eye tracker system to relate the EEG data to the specific choice of options. Their study differs from others in that they did not concentrate on what customers like or dislike, but observed and evaluated the cortical activity of the different brain regions and the interdependencies among the EEG signals from these regions and provided a way to quantify the importance of different features that contribute to the product design based on mutual information.

Uggeldahl et al. (Uggeldahl, Jacobsen, Lundhede, & BøyeOlsen, 2016) investigated the eye movement during the completion of choice sets based on a sample of 200 respondents. They interpreted the respondents' stated certainty of choice as a measure of their "true" certainty of choice. Their evaluation results confirmed that the frequency of the respondents' gaze shifts between alternatives is related to the stated certainty of choice and can be used to explain systematic variations in the error variance. The error variance is larger for choices in which the respondents more frequently shift their gaze between the alternatives. Moreover, they found that using eye movement information in the choice model improves the model performance as compared to other models such as a benchmark approach.

Another research conducted by Rash et al. (Rasch, Louviere, & Teichert, 2015) combined eye tracking with facial electromyography to provide a better understanding of the choice process, which should lead to an improved prediction performance. Their evaluation results indicate the existence of an effect on the stated choice experiments for trivial product categories and provide insight into drivers and the contexts of affective choice processes. Among others, the best and worst task frames show the influence of an integral affect in discrete choice experiments. Their recommendations express the need for future joint investigations of cognitive and affective processes in consumer choice tasks. Better understanding of these processes should lead to valuable insight into how real-time marketing actions influence decisions, ways to improve the predictive performance of choice models, and novel ways to help consumers and organizations make better decisions.

Yegoryan et al. (Yegoryan, Guhl, & Klapper, 2020) related the visual attention derived from eye tracking to the probability of attribute non-attendance (ANA) and preference heterogeneity to test, understand, and validate ANA in a marketing context. Their model concentrated on two applications in which individuals chose durable products and when making product choices in durable categories owing to higher stakes. Their findings show that the use of eye tracking to augment the ANA models is informative in uncovering individual-level behavior and that most respondents indeed ignore some attributes, which has implications for willingness-to-pay estimates, segmentation, and targeting.

Meißner et al. (2019) concentrated on using VR settings with eye tracking to provide a unique opportunity for shopper research regarding the use of augmented reality to provide shopper assistance. They outlined how research in retailing and decision-making can benefit from the use of mobile eye tracking in VR. Furthermore, the study exemplified how the environment interacts with the user in real time by showing additional product information as reactions to the user's pure eye movements. Similar to other researchers, the authors expected that, in the near future, eye tracking technology will be integrated into many electronic devices, such as mobile phones, tablets, or laptops, and will generate large quantities of eye tracking data that can be used to obtain insights into the underlying search and choice processes of consumers (Meißner, Pfeiffer, Pfeiffer, & Oppewal, 2019) (Wedel, Pieters, & Lans, Eye tracking methodology for research in consumer psychology, 2019) (Meißner, Oppewal, & Huber, 2020).

Current consumers and marketplaces are different from the past, and they are likely to be different from the future. These differences are due to major societal forces, customer needs, purchasing behavior, and changing lifestyles that have created new opportunities and challenges and have significantly changed marketing management. Learning more about consumers and the ways to use neuroscientific tools to discover the brain or physiological reactions to reach a better understanding of the consumer needs are the key to implementing and exercising marketing concepts and imagination, and these be exciting areas for a marketing evolution in the future.

8. Discussion and Future Directions

Eye tracking has proven itself to be valuable in many areas, particularly medical and diagnostic fields. In this paper, we discuss eye tracking techniques, tools, and applications to further focus and entice researchers to find suitable techniques for their specific applications.

When choosing an eye tracking system, one should pay attention to different factors, such as the gaze tracking system, its features, the accompanying software and accessories, eye tracking manufacturing devices, software utilizing raw eye data, and the suitability of the system for a specific purpose, including the spatial and temporal resolution (accuracy), camera angle, freedom of head movements, tolerance to ambient light, tolerance to eye glasses and contact lenses, and possibility to track only one or two eyes. Here, we classify the above studies into four areas shown below.

8.1. Future Directions of Techniques and Applications

Techniques. There are various techniques that can be used for building an eye tracker system. We provide a clear description on electrooculography, a scleral search coil, infrared oculography, and VOG. There is no perfect method that can be used for solving all problems in different life sectors and environments because each method has advantages and limitations, and thus we should choose the best candidate method based on the problem specifications, environment, cost, and usability, among other factors. For example, we can use the scleral search coils method if accuracy is a must. The electrooculography method can be used if the available resources are limited. Infrared oculography or VOG methods provide flexibility, whereas VOG is extremely expensive in terms of time complexity. Table VI represents the eye tracking applications, techniques, and algorithms and criteria used for each method.

Applications. Different areas of eye tracking applications have been presented in this paper, including in the healthcare and medical fields, HCI and assistive technologies, learning and education, and vehicle manufacturing. A list of comprehensive review papers on the use of eye tracking in different applications is shown in Table VII. In our review of the literature, we noted that eye tracking appears to be a valuable tool for medical diagnoses, providing automatic hints to observers during an imaging checkup. The use of eye movements along with ML algorithms can help predict most diagnostic errors before their occurrence (Brunyé, Drew, Weaver, & Elmore, 2019). However, each person brings a unique set of individual differences to the diagnostics, clearly impacting the visual search and decision-making processes. In addition, most current studies have used static eye tracking images during an image interpretation. Many medical images are becoming more complex and dynamic (Brunyé, Drew, Weaver, & Elmore, 2019), and the use of dynamic video frames may indeed help in providing valuable information for tracking a ROI moving across a free observation scene during playback. Furthermore, using a combination of different attributes generated from eye movements may become the focus of future research. More information regarding the applications of eye tracking in healthcare along with some future directions can be found in (Liu, et al., 2018) and (Harezla & Kasprowski, 2018).

Eye tracking technology has been and will continue to be one of the main parts of next-generation vehicles, significantly improving driving safety. ABI reported that "the global shipments of factory-installed driver monitoring systems (DMS) based on interior facing cameras reached 6.7

Table VI. List of eye tracking applications and techniques along with algorithms and criteria used.

Applications	Techniques	Algorithms and criteria used
Healthcare and Medical Applications	EOG, IOG, Machine Learning	Deep learning algorithm, KNN, Random Forest, SVM, Naïve Bayes
HCI and Accessibility	EOG, IOG, Machine Learning	Boosted Deep Belief Network, Haar Cascade algorithm, SVM
Education	VOG	Duplicate, Irrelevant, Improper format, Unavailable, Foreign language
Car Assistant	VOG	Viola Jones face detection algorithm, Haar Cascade algorithm, Tracking, Learning Detection Algorithm

Table VII. A list of eye tracking applications clustered based on the field, research goals, and major findings.

Reference	Area of application – survey	Overall Research Goals/Major Findings
(Brunyé, Drew, Weaver, & Elmore, 2019)	Understanding and improving diagnostic interpretation – medical	• Provided an overview of how the eye-tracking technology has been employed in the perceptual and cognitive processes involved in medical interpretation • Provided an overview of how the eye-tracking technology has been used to understand medical interpretation and enhancing medical education and training. • Provided some future directions and challenges of using eye tracking technology in medical applications.
(Bobić & Graovac, 2016), (Meng-LungLai, et al., 2013) (Ashraf, et al., 2018)	Tools for training, exploring learning, medical education – education	• Provided a clearer solution for implementing eye-tracking systems into a training environment. • Suggested future studies based on the review findings. • Discussed how the eye movement measures can be used to indicate the processes of learning.
(Alemdag & Cagiltay, 2018)	Multimedia learning – education	• Provided a systematic review of employing the eye-tracking technology in the area of multimedia learning.
(Borys, 2014) (Wedel, Attention Research in Marketing: A Review of Eye Tracking Studies, 2013) (Higgins, Leinenger, & Rayner, 2014)	Advertising and Marketing	• Showed on-going trends, metrics, and technical challenges of employing eye tracking method into research. • Presented a systematic review of the state-of-the-art research of employing eye tracking in digital marketing, online advertising, advertisements, and shopper marketing • Integrated recent findings in the field and serves as a practical guide for online and traditional marketers for future research planning and development. • Examined key findings on eye movements when viewing advertisements.

million by the end of 2019." In addition, DMS solutions are expected to play an important role in developing human-machine interactions (HMIs) that will allow smart dashboards and contextual HMIs in an interior vehicle environment to be used for safer driving. Moreover, we believe that, to develop high-accuracy car-assistance systems and models, high-quality eye tracking data should be generated and certain factors should therefore be considered. Some of these factors are the quality of the capturing device or camera, the eye detection and eye tracking algorithms, the lighting conditions, the training models, and the specialized fixation- or saccade-classification algorithms applied. Therefore, we encourage researchers to consider these factors and explore their effectiveness and efficiency to develop more reliable and efficient car-assistance systems and models.

A popular feature in new vehicles that generate an alert from a collision avoidance warning system before a crash can also create a distraction that may itself cause an accident. For instance, there is no need to generate an alert if the driver knows about the crash prior to its occurrence. Therefore, a multi-way communication channel needs to exist between the driver and vehicle. In addition, observing how the driver's eyes and behaviors are changing while they respond to an alert generated by a vehicle collision avoidance warning may help engineers design safer systems that decrease driver distractions.

It is believed that the symptoms of driver fatigue can be detected sufficiently early to avoid car accidents by monitoring the movements of the eyes and blink pattern (Sommer, et al., 2009). Some of the symptoms are an inability to keep the eyes open or eye burn. Other symptoms were described by Lees et al. (Lees, et al., 2018) and could be measured using an EEG. However, using such a device to measure driver fatigue is an uncomfortable and intrusive technique that should be addressed in future research (Rost, et al., 2015) (Jap, Lal, & Fischer, 2011). In addition, it is important to calculate the delay when the driver becomes fatigued and the time for the symptoms to start showing in the human eyes. For instance, generating a crash alert within an acceptable delay allows the driver to take an action that may help prevent an accident. We believe that combining data generated from eye tracking along with other facial behavior such as yawning, head movements, and positioning may help in detecting the fatigue level for the driver.

8.2. Future Directions of using ML with Eye Tracking

ML algorithms have been used to solve problems and benefit different companies by making predictions and helping them make better decisions. Future studies using ML with eye tracking can be conducted in different areas. First, the performance of existing ML algorithms can be enhanced and their accuracy verified using larger datasets and various learning techniques. Second, along with the use of a communication protocol, the implementation can be optimized to achieve higher processing rates. Third, focus can be given to detecting other events for eye-movement (such as a smooth pursuit and nystagmus in medical applications), which may be achieved by including other training sets and using other ML approaches.

The use of ML techniques with eye tracking algorithms can predict most diagnostic errors prior to their occurrence, making it possible to automatically calibrate the input images and integrate the feedback of the trainees. Using eye tracking for the detection task, on top of the diagnosis and segmentation in medical applications, for example, represents a promising future direction for handling cases that are missed by radiologists. In addition, a real, larger, and suitable public dataset with richer features is needed to learn the relationship between fixation patterns and confusion because certain features may be impactful. Such type of dataset utilizes two head mounted eye-facing cameras for both eyes, which may be necessary to learn further details regarding the challenges of eye tracking in AR/VR environments and systems. In addition, it will help in implementing deep learning models for augmented spaces. Moreover, high-quality dataset images make the training of deep learning systems easier.

Therefore, more eye tracking analyses using ML algorithms in the context of a user study are needed. Other future agenda will be to develop technologies that focus on delivering fast and accurate predictions and handling voluminous data. In addition, the transfer of successful learning of similar tasks from other domains into the eye tracking domain also represents an area of future research. A real promise of ML is that it will have a single algorithm that can detect and distinguish between all events that exist in the literature on psychological and neurological eye-movement. We encourage other researchers to validate and further develop new ML-based architectures to improve techniques for prediction from eye tracking data to make better decisions.

ML algorithms are extremely powerful tools that hold the potential to revolutionize the way things work. However, applying ML algorithms into eye tracking systems have certain limitations. Some of these limitations are the high dependency between the selected features, sample size, and data quality with accurate results, and it has been proven that if the images used for training and/or testing CNNs is low, the results will be inferior compared to the results using higher quality images (Stember, et al., 2019). In addition, the calibration of operational parameters of the camera of a handheld device will affect the quality of the captured images. Moreover, the nature and structure of the collected data along with the successful labeling of training data help with the pre- and post-processing to generate higher quality data.

Incorporating ML algorithms, such as an SVM and neural networks, with eye tracking techniques is important owing to their ability to independently adapt and learn from previous data, to identify patterns and produce reliable decisions with minimal human intervention. This incorporation is certainly going to yield more accurate and trustworthy eye tracking results. Algorithms relying on ML methods can solve some of the eye tracking issues. Some of these issues include synching between head movement and head-rotation data. Noisy data represent another issue that should be addressed specially when different IoT devices are applied together.

8.3. Future Directions of Using IoT with Eye Tracking

Eye tracking technology is producing high data rates with different data types generated from different sensors and cameras. If this extensive amount of data continues to be compiled, eye tracking will be the new direction for big data. This will require developing new aggregation models, understanding different techniques, and applying evaluation approaches beyond a statistical analysis and a visual inspection, to extract patterns and behaviors from the data. Challenges facing big data on eye movements, the techniques useful to address such challenges, and the potential scenarios for such big data were described in (Blascheck, Burch, Raschke, & Weiskopf, 2015).

With the decreasing costs of gaze trackers, pervasive eye tracking is likely to become a reality and has been widely used to improve the design and usability of different systems and applications, such as web pages, and to explore and understand how users are guided by such applications (Shokishalov & Wang, 2019). However, collecting such data can reveal personal attributes and the privacy will be an issue.

Most of the existing literature on IoT smart home platforms focused on the functionalities provided by smarter connected devices; however, this does not address the privacy concerns or management. Some attempts have focused on dealing with only the data necessary to accomplish a task, which has moderated the privacy issue. Dasgupta et al. (Dasgupta, Gill, & Hussain, 2019) proposed a framework to assist smart home users and manufacture IoT devices to make informed privacy management decisions. In addition, this framework has helped practitioners and researchers interested in the privacy of IoT-enabled smart systems. Moreover, Dasgupta et al. (Dasgupta, Gill, & Hussain, 2019) showed the current emerging trends in IoT in different industry sectors and discussed the key privacy challenges that limit the growth of IoT to reach its potential in the context of smart homes. We believe that pervasive eye tracking has numerous benefits; however, as with most technologies, moving forward with little care will benefit the public in the coming years (Liebling & Preibusch, 2014).

We also focus on the current major IoT issues that lead to a lack of trust in eye tracking techniques, such as privacy and usability concerns for the elderly and people with special needs. Another issue facing eye tracking research is the limited collaboration among different wireless devices in several fields.

Products with more powerful GPUs accelerate the image recognition speeds, which allows the progress in eye tracking technology to be significantly accelerated. Researchers and developers benefit from such developments, and their implementations and experimentations are increasing in frequency. In addition, this development enables the collection of larger and broader datasets to train the recognition algorithms more quickly.

Eye tracking has increased the communication bandwidth between the user and device, changing the way devices and humans are communicating with each other. Eye tracking allows a device to be aware of what the user is interested in at any given point in time. In addition, it provides easier and faster ways to obtain data to train algorithm models without taking anything else away. We believe that eye tracking will be a standard feature of a new generation of devices, such as smartphones, laptops, and desktop monitors. These products will be less expensive and more potent. In addition, new open source software platforms will be adopted in commercial products in a wide array of consumer segments, which have driven the progress of eye tracking technology.

We believe that a new paradigm of eye tracking will make personal computers much more productive and intuitive. Because vision is the most used sense among human beings, eye gaze always presents a smarter user interaction in comparison with a mouse, keyboard, or voice. Being able to digitally track and measure gaze-based data, there will be a significant impact on how we make our intentions known to computers.

The accuracy of the eye tracker systems generally depends on the quality of the collected data along with the number of subjects involved to capture more heterogeneity. In general, a high sampling rate generates high-quality data. In this regard, focusing on manufacturing and working with better-quality instruments represents a future direction to enhance the accuracy of the results. In addition, a robust eye tracking technology with advanced data analysis tools is needed to better understand the eye movement patterns and improve the mobility and quality of life of elderly people. Table VIII shows a list of currently used eye tracking devices along with their characteristics, whereas Table IX shows a list of eye tracking software currently used along with their characteristics and applications.

8.4. Other Future Directions of Eye tracking

We identified other interesting areas where eye tracking is being used. Here, we provide some future eye tracking directions that may be interesting to researchers and the gaming, marketing, advertising, and VR industries.

Gaming: In the past decade, researchers on computer games have indicated that eye tracking provides better input control and task completion compared with traditional input devices (e.g., mouse, keyboard, and gamepad) in terms of action accuracy and responsiveness (Santana, 2018). Using eye tracking in games has several advantages. First, it lets game devices know where the player is visually focused. Second, it adds some reality to the player's interaction and provides the player with a richer experience and an ability to extend himself/herself into the game. Third, it identifies the player's strengths and weaknesses according to the player's fundamental skills and learns how to improve them. Finally, it allows the player's map to provide more awareness and vision-related skills to be accumulated. As a future direction, we expect researchers to study how eye tracking can improve a game instead of replacing a traditional input. In addition, we plan to study the player's attention and integrate it with the core to enhance the games.

Marketing and Advertising: Recent research recommends that the ad industry will focus more on attention metrics in the future, and not on impressions, and the best way to track attention is using eye tracking technologies_(Orquin & Wedel, Contributions to attention based marketing: Foundations, insights, and challenges, 2020) (Hang, Yi, & Xianglan, 2018). Orquin and Wedel (Orquin & Wedel, Contributions to attention based marketing: Foundations, insights, and challenges, 2020), (Bulling & Wedel, 2019), (Orquin & Loose, 2013) and Zuschke (Zuschke, 2020) provided some other research directions: (1) The relationship between attention and the consumer decision-making was studied. (2) The ways to improve eye-movement metrics that consider visual attention, pupil dilation, blinks, and facial expressions as a coordinating mechanism of the body, head, and eye movements were determined. (3) How social media and video marketing will change the potential role of eye tracking in the attribution of advertising was considered. (4) Privacy issues of the consumer data were explored, such as the identity parameter, gaze point, age, gender, and duration of view. Finally, (5) how mobile devices will be used to track human eyes in a virtual environment for observing shopping behavior will be studied. Moreover, it is interesting to see whether the active role of visual attention that has been applied in a testing environment will occur similarly in a real-life environment. Consumers can obtain more information regarding the healthiness of a product using the nutrition label, and thus the design properties can increase the chance that consumers will visually pay attention to this label. Therefore, future research can analyze how different design strategies will affect the selection of healthy food.

Virtual Reality: The current evolution in hardware manufacturing, software development, end-user requirements and specifications, as well as research professionals, have allowed the interactions of VR and eye tracking technology to be an area of future research. Tracking eye movements with sufficient precision provides researchers with a significant amount of information on a subject's behavior in a virtual environment. In addition, it provides an opportunity to analyze a subject's behavior in relation to the objects the subject is looking at, as well as the location of these objects. We see a significant potential of combining VR with eye tracking in the next coming years (Meißner, Pfeiffer, Pfeiffer, & Oppewal, 2019) (Clay, König, & König, Eye Tracking in Virtual Reality, 2019).

9. Conclusion

Eye tracking has proven itself to be valuable in many research areas. This study discussed the eye tracking techniques and applications with a focus on modern approaches such as ML, IoT, and cloud computing.

A classification of different ML algorithms that use eye tracking data along with the research goal and the strengths and limitations of the algorithm are presented. In addition, we summarize different lists that cover eye tracking applications and techniques along with the algorithms and criteria used, diseases that can be identified using eye tracking technology, and the main findings. A comparison between recent research that uses eye tracking technology in HCI, eye tracking software, and devices that are currently applied along with their characteristics is given with a further focus on enticing researchers to find a suitable technique for their specific application. Moreover, we present eye tracking applications such as healthcare, medicine, HCI, accessibility, education, e-learning, next-generation car assistants, driver drowsiness or fatigue, consumer research, and neuromarketing.

This study revealed that ML and IoT are important parts in evolving eye tracking applications owing to their ability to learn from existing data, make better decisions, flexibility of use, and ability to eliminate the need for manually re-calibrating the tracker during the eye tracking process. In addition, it was discovered that eye tracking techniques achieve more accurate detection results compared with traditional event-detection methods. In addition, various motives and factors in the use of a specific eye tracking technique or application were explored and recommended. Finally, it provides some limitations and future directions related to the use of eye tracking techniques in the development of several applications, using ML, IoT, and other recent research areas such as gaming, marketing, advertising, and VR as a key that might open new opportunities and spark some new ideas to researchers in this area to move forward in the future.

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Table VIII. A list of eye tracking devices currently used along with their characteristics

Devices	Synchronization with Head movements	Different Head mount options/ comfortable	Integrating with other products	Gaming	Mobile	Real-time processing	Data Analysis	Multi-sensor integration	Support VR
EyeSeeCam	✓	✓	✓		✓			✓	
Tobii Pro Glasses 2	✓		✓	✓				✓	✓
iMotion		✓	✓			✓	✓	✓	
LooxidVR	✓	✓	✓	✓	✓	✓		✓	✓
FOVE	✓	✓	✓	✓		✓		✓	✓
Varjo	✓	✓	✓	✓		✓		✓	✓
OmniView-TX™	✓	✓	✓			✓	✓	✓	
OmniView-RD™	✓		✓	✓		✓	✓	✓	✓
Eyegaze Edge®	✓		✓		✓	✓		✓	
EyeTech			✓		✓	✓			
TM5 mini		✓		✓		✓		✓	
Ergoneers	✓	✓	✓	✓	✓	✓	✓	✓	✓
Blickshift	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table IX. A list of eye tracking software currently used along with their characteristics and their applications

Software/hardware	Hardware	Supported Platforms	Applications
EyeSeeCam	Goggles		Medical
Tobii Pro Glasses 2	Mobile portable device – like laptop	Unity	Professional performance, consumer behavior, assistive technology, and scientific research
LooxidVR	headset foam pads, Mask, dry EEG electrodes, and built-in eye-tracking cameras	Unity	Researchers focusing on acquisitioning of synchronized eye and brain data for Healthcare, Education/Training, Marketing and Brain-Computer Interface research,
FOVE	headset foam pads and Mask	Unity, Unreal, Xenko	It is the first VR headset to have embedded eye-tracking, Gaming, education, healthcare and medical, movies, social communication, and development.
Varjo	headset foam pads and Mask	Unrea, OpenXR, and Unity	Design, training, simulation, and research.
Eyegaze Edge	Screen with Infrared camera and sensors	NA	Locked-in users to communicate with the world via robust, accurate eye tracking devices, and software
TM5 mini	Screen with Infrared camera and sensors	NA	ALS, Cerebral Palsy, Muscular Dystrophy, Spinal Cord Injury, Traumatic Brain Injury, Stroke, Spinal Muscular Atrophy
Ergoneers	Goggles	NA	Market research, Ergonomics, Vehicle research, Airplane research, Usability, Behavioral research, Perception research, Design clinics, Sports and biomechanics research, Medical research, Realtime gaze control, Behavioral studies in virtual reality, Games testing (Maria, et al., 2019), Evaluation of virtual design concepts, Pre-Test of new product ideas, Test of early interface designs, Eye tracking integration in helmets, Design of individual head mounted eye tracker.
Blickshift	headset foam pads and mask	NA	Scientists, cognition scientists (MK, B, AT, & SA, 2017) (Bueno, Sato, & Hornberger, 2019), automotive engineers, AI developers, usability experts and market researchers.

A list of abbreviations used in this manuscript is shown in Table X.

Table X. List of abbreviations used in this manuscript

AIoT	Artificial Intelligence of Things
ALS	Amyotrophic Lateral Sclerosis
ADHD	Attention Deficit Hyperactivity Disorder
AR	augmented reality
AR	augmented reality
ASD	Autism Spectrum Disorder
CCD	Charged Coupled Device
DA	discriminant analysis
ECAS	Edinburgh Cognitive and Behavioral ALS Screen
EOG	Electrooculography
EOG	Electrooculography
ElSe	Ellipse Selector
EUD	End-User Development
ExCuSe	Exclusive Curve Selector
FREDA	Fast and robust ellipse detection algorithm
HMD	Head-Mounted Displays
Helmholtz	Hermann Ludwig Ferdinand von Helmholtz
HMM	Hidden Markov Models
HCI	Human Computer Interaction
HCI	Human Computer Interface
HRI	Human–Robot-Interaction
IR	Infrared Light
IOG	Infrared Oculography
IoT	Internet of Things
LSS	Lensless Smart Sensors
LSS	Lensless Smart Sensors
ML	Machine Learning
NBC	Naive Bayes Classification
PCCR	Pupil Center Corneal Reflection
RANSAC	Random Sample Consensus
ROIs	Region of Interests
SSC	Scleral search coil
SMI	SensoMotoric Instruments
SVM	Support Vector Machine
VOG	Video Oculography
VR	Virtual Reality
ZM	Zernike Movement

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Highlight 1:

Eye Tracking Algorithms, Techniques, Tools, and Applications

Highlight 2:

Scleral search coil, Infrared Oculography, Electro-Oculography, Video Oculography

Highlight 3:
Eye Tracking using Machine Learning Approach

Highlight 4:
Eye Tracking using Internet of Things and Cloud Computing

Highlight 5:
Eye Tracking Techniques and Applications limitations and Future directions