

Features in eye-tracking data for classification: A systematic literature review

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Abstract : Eye-tracking is a technology to measure and determine an individual's eye movements and eye positions. The eye data can be collected and recorded using an eye-tracker. Eye-tracking data offers unprecedented insights into human actions and environments, digitizing how people communicate with computers, and providing contributions in computer science such as the research on classification. The objective of this paper was to review what features can be obtained from eye-tracking data for classification. We performed a systematic literature review (SLR) covering the eye-tracking studies in classification published from 2016 to the present. In the search process, we used 3 independent electronic databases such as IEEE Xplore, ACM, and ScienceDirect digital libraries. We concluded that there are many researchers who used features from eye-tracking data for classification tasks. The features contained information that can be utilized to classify the difference. There are several features found from eyetracking such as pupil size, saccade, fixations, velocity, blink, pupil position, EOG, and gaze point. Fixation is the most commonly used feature among the studies found.

(Keywords : Classification · eye-tracking · fixation · machine learning pupil size)

Introduction

The research in computer science is in an increasing trend since new technology grows rapidly especially artificial intelligence (AI) and human-computer interaction (HCI). Scientific researchers put their efforts into the work of interaction between humans and the machines. The studies on classification using machine learning become more popular such as emotion classification and image classification since its ability to learn automatically and perform specific

tasks with different algorithms. Therefore, there are studies on classification using different approaches such as emotion classification using brainwave signals¹ and image classification using neural networks². While a representative study on learning machines, the work from Nilsson concerned more with machine learning for pattern classification³. The studies on eye-tracking also increased in recent years. Many researchers conduct their experiments with the question of how eye-tracking data can be utilized in their research. Hence, the usage of eye-tracking technology in classification research springs up with the doubt of what eye features can be obtained from eye-tracking data for classification. Eye-tracking technology refers to the process of tracking and measuring the eye movements and the focus point of the user's eyes. Eye-tracking is widely used in many domains such as psychology, marketing, medical, computer gaming, and cognitive science. Therefore, eye-tracking is increasingly used in computer science fields and utilizes eye features to study information processing tasks⁴.

Eyetracking data can be measured and obtained by using an eyetracking sensor or a camera. The data provides several features and it can be used for several classification tasks. Eye-tracking technology is very helpful and it can be widely adopted and implemented in the future, as it only requires a simple camera to collect the data needed. In this paper, we present a systematic literature review and collect all studies and papers relevant to the usage of features that can be obtained from eyetracking data for classification within 5 years, that is from 2016 to present. The

first section presents the introduction of this paper. In Section 2, we provide a background on eye-tracking technology and eye-tracker types including desktop eye-tracking, mobile eye-tracking, and eye-tracking in Virtual Reality (VR). A methodology of research is described in Section 3 including research question, selection criteria, search process, and selection process. Section 4 presents the results and the related studies are summarized in the table. The next section is discussion and the final section concludes this paper.

2 Background

2.1 Eye-tracking technology

Eye-tracking technology is an emerging technology used to monitor a user's eye movements or the focus point of an individual. It is a process of measuring the point of gaze or the position of eyes and collecting the eye features from an individual and it is recorded in the form of data, which is comprehensive statistics such as fixation counts, first fixation, and fixation duration. These recorded data can be analyzed by using visual analytic approaches to study and extract the eye features. Applying a visual analytic technique is to improve visualization of common visual problem solving strategies⁵.

Eye data also can be explored and analyzed graphically using data visualization software, such as heatmaps and saliency maps. Eye-tracking data can be categorized on the basis of the essential ocular activity indicators, which are fixations, saccades, and scan path. Fixations are eye motions stabilizing the retina above a stationary object of interest with a duration of 100ms to 400ms. The fixations are fairly centered and the eye travels at low velocity. They are characterized by ocular drifts, ocular microtremor, and microsaccades⁶. Saccades are quick movements of both eyes used to reposition the fovea, the middle part of the retina, into a new location in the visual environment. Saccadic movements are typically in duration from 10ms to 100ms and they are reflexive and voluntary⁷.

There are 4 types of saccade classifications, which are predictive saccades, antisaccade, memory-guided saccade, and visually guided saccade⁸. Scan path of the eye movement is defined as the direction taken by the eyes of the viewer when reading a text or observing a scene. The scan path data is the information of the trajectories of the eyes as the visual field is scanned and some kind of visual information is interpreted and analyzed. A scan path is the resulting series of saccades and fixations.

2.2 Eye-tracker

An eye-tracker is a device to detect eye movements and eye positions. It is built to measure the visual attention of a subject by gathering data on eye movement when the subject observes a stimulus while operating on a task. There are three types of eyetracker, which are eye-attached tracking, optical tracking, and measurement of electric potentials with electrodes. Eye-attached tracking is a measurement by using an eye attachment, for example, a special contact lens. The attachment's movement is calculated on the basis that it does not shift dramatically as the eye rotates. This method allows for measuring the movement of the eyes in horizontal, vertical, and torsional directions⁹.

Optical tracking determines an object's position in real-time by monitoring the positions that are attached to the object. The location of the reflex point is determined by means of a camera device. The optical method tracks eye movement without contact to the eye directly. This method is commonly used for gaze-tracking, especially those based on video capture, and is preferred for being affordable and non-invasive. The third type of eyetracker is the measurement of electric potentials with electrodes. The eyes are the source of a permanent electrical field that can be observed in complete darkness even when the eyes are closed.

The example of this tracking method is the electrooculogram (EOG). It is a technique used

to measure the corneoretinal standing potential that occurs between the human eye's forehead and back. It is a very lightweight solution that needs only very low computing power. It also performs under various lighting conditions and it can also be implemented as an integrated, self-contained wearable device¹⁰.

3 Methodology

3.1 Research question

What features can be obtained from eye-tracking data for classification.

3.2 Selection criteria

The selection included the studies on classification using eye-tracking technology, which focuses on what features are used from the eye-tracking data for the classification tasks.

3.3 Search process

In the search process, we used independent electronic databases such as IEEE Xplore¹, ACM², and Science Direct³ digital libraries separately. We ensure that the search query is the same for every digital library. We search the studies including the research articles, journals, and conferences within 5 years (2016-2020) with a unique search query. According to the research question, the searching query is "eyetracking for classification". Since our objective is to investigate what eye features can be obtained from eye-tracking data in classification, eye-tracking and classification are used as our keywords in the searching query. Therefore, we presented the 2 sets of keywords with a quotation mark, which is between a "". We collected all the papers and a reference management software, called Mendeley⁴ is used to save and manage the papers.

3.4 Selection process

We select the appropriate related papers from the 3 digital libraries and ensure that there is no duplicated paper in the selection process. The selection is executed with PRISMA guidelines and the papers are managed in Mendeley. In

Mendeley, we applied the tools to checked for duplicates to remove the same papers. We remove all unrelated papers by searching the keywords in papers including the title, abstract, and contents. Full-text articles are retrieved for final inclusion. Since our research is related to eye-tracking, hence the keywords are "eye-tracking", "eyetracker", "eye", "gaze", and "pupil". Those papers that have no results from these searching keywords are removed in the eligibility process. The papers that have less than 20 from the searching keywords are checked by reading the methodology of the paper to ensure that eye-tracking is used in the investigation. In the last process, we choose the studies in qualitative synthesis to ensure that the paper is matched to our research question. Those papers that use eye-tracking but not for classification tasks are also removed.

4 Results and Discussion

Initial results returned a total number of 431, which are 33 from ScienceDirect digital library, 92 from IEEE Xplore digital library, and 306 from Association for Computing Machinery (ACM) digital library. Through the screening process, there is a number of 420 after applied duplicate removal in Mendeley. It turned to 31 studies included in qualitative synthesis after 48 full-text articles assessed for eligibility. There are 12 articles have no results relating eye-tracking studies and 5 articles have no results relating classification. Studies were divided into 2 categories, which are the 20 studies that use eye features solely from eye-tracking data for classification, and 11 studies that use eye features with a combination of other signals for classification.

4.1 Pupil size

Cao *et al.*¹¹ proposed an approach for the intention recognition system with an endoscopic manipulator using pupil size and velocity of eye rotation. The study showed that pupil variation has a significant impact on an endoscope's control. In¹², the authors constructed an experiment to determine someone is lying or

not using the changes of pupil diameter and the movement of the eyeball, which is left or right. Determination of lies is classified using decision tree algorithm. Eye-tracking technology is also widely used in security. In the work of Bozkir *et al.*¹³, a gaze-driven cognitive load recognition scheme for drivers in safetycritical circumstances is proposed based on pupil diameter in VR. In¹⁴, the authors conducted an experiment to recognize the understanding of vocabulary and language of a user in augmented reality (AR) and VR interfaces.

4.2 Saccade

In¹⁷, the investigators studied biometric identification and verification using saccadic eye movement signals. The performances are good with the highest identification rate of 90¹⁸, the authors investigated the eye movement parameters such as saccade amplitude, number of saccades, and the ratio of total fixation duration to total saccade duration (RFDSD) to classify the genders. In the study of¹⁹, an image classification investigation is proposed to predict the valence of the scene using multiple features of eye movements such as saccade count and saccade frequency, along with machine learning.

4.3 Fixation

Eye movement data is also widely used in medical and clinical analysis. From the study of²⁰, the authors performed a fetal ultrasound image classification for obtaining the standardized abdominal, head, and femoral image frames using extracted eye fixations. The findings showed that producing a bag of models of words using fixations is a promising method for identifying fetal US images. Zhou *et al.*²¹ presented an investigation on image classification using a method of two-stage feature selection. The feature is based on the region of interest (ROI), which is identified from the extracted fixation data. Qi *et al.*²² utilized fixation points and gaze paths for material recognition and improve the performance by

generating saliency maps. The study of²³ analyzes the reading patterns using fixations and saccades with multiple classifiers to determine which is the best for the evaluation. In another study²⁴, a gaze-based approach is proposed for the intention detection using fixation duration and radius of fixation. In the work of²⁵, the authors classified autism spectrum disorder (ASD) based on scan path and saliency features. There is a study²⁶ conducted two separate emotional experiments in the investigation based on EEG and eye-tracking data solely with a content-based ensemble method (CBEM) as a classifier. Fixations capture the visual attention of an individual when focusing on an interesting thing. Vidyapu *et al.*²⁷ proposed an attention prediction on webpage images using multi-label classification. In²⁸, the authors developed a method for the cognitive process to identify ambiguous images.

5 Conclusions

We presented a systematic literature review to investigate what features can be extracted or used from eye-tracking data for classification tasks. In this paper we used 3 independent electronic databases, which are ScienceDirect, IEEE Xplore, and ACM digital libraries to search the related papers within 5 years (2016-present). Out of 431 publications found, there are 31 papers relevant to our research. There are several features found from eye-tracking such as pupil size, saccade, fixations, velocity, blink, pupil position, EOG, and gaze point. Fixation is the most commonly used feature among the studies found. Most of the studies used multiple features from eye-tracking data instead of a single feature. Furthermore, there are also studies that used the combination of other signals for the classification. However, EEG is the most commonly used by the researchers among the studies found in this work. In future work, we plan to perform a review on the usage of features from eye-tracking data in more widely domain instead of classification only.

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