Effect of External Stimuli on Eye Movement for Eye Gaze Applications

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Abstract

Disturbances in external environment tend to affect eye movement behavior. Detection, tracking of eye movements and gaze estimation is pivotal for understanding the effects of visual or non visual stimuli. Effect of various stimuli on eye movements has been analyzed by various researchers using different approaches. In this paper a general overview of different methods of eye detection, movement tracking and gaze estimation is presented. A summary of approaches used for analyzing external stimuli effect on eye movements based on different factors i.e. different types of stimuli, environment etc has been presented.

Keywords: Gaze, stimulus, saccades, fixations, gaze bias, smooth pursuits.

I. INTRODUCTION

Stimulus is the disturbance present in the environment or within the system/ organism. Stimuli external or internal tend to elicit response from a system. Stimuli can be artificially induced into the environment to check and analyze their effect on an organism or a system. Different parts of human body will react differently to different stimuli, eyes being one of them. Eye movement is the continuous shifting/drifting of eyes while as gaze is the fixture of eyes at a point for a certain period of time. Tracking of eyes may involve estimating line of sight or following the course of eye movements across various frames.

Eyes tend to get affected by the external stimuli e.g. visual, sound etc and exhibit certain behavior under the influence. Tracking eye movements can reveal the effect of external stimuli on eyes. By manipulating stimulus exposure, different eye movements and gaze direction can be analyzed. Humans tend to exhibit six types of eye movements: saccadic, fixations, smooth pursuits (SPs), optokinetic reflex, vestibule-ocular reflex and vergence [1].

Researches pertaining to eyes find its application across various domains. Techniques based on eyes are being employed in various disciplines i.e. medical, cognitive science, psycholinguistics, human computer interactions, language/ reading research, advertising and marketing. Eye movement can be used in all major application: surveillance, control and analysis [2].

Different methods have been employed for eye movement detection, tracking and gaze estimation. Methods based on shape, features of eyes, based on interpolation of data, neural networks etc are being used. Analysis of external factors i.e. stimuli effect on eyes have been carried out through different methods. Different experiments under different environments have been set up to investigate the effect and different results are inferred. Relationship between driver’s gaze and peripheral vehicles, sound effect, eye movement variability during various scenes etc are some of the examples of the work carried out in this field. In this paper an overview of different methods and techniques used for eye gaze estimation, movement tracking is presented. The main focus is to discuss effect of external stimuli on eye movements and gaze as put forth by different researchers.

II. EYE DETECTION AND MOVEMENT TRACKING

Eye detection in an image or video is the first step for eye gaze estimation or eye movement tracking. Eye detection methods have been classified under different categories depending on the approaches used. Broadly eye detection methods are classified as shape based [3], feature based [4], appearance based [5] and hybrid [6]. Apart from these categories there are other many ubiquitous techniques like blink, symmetry, corneal reflection etc for better eye detection or tracking [7]. Eye tracking is the process of eye movement detection in successive frames once the eye is localized in initial frames. It can also be defined as a process of gaze direction determination. Generally eye tracking can be classified as sensor based and computer vision based. Sensor based methods tend to analyze eye movements based on electric potentials measured with electrodes placed around eye region. Computer vision based use cameras to trace and detect eye movement. Computer vision may involve pattern recognition, corneal reflection, neural network etc techniques [8][9][10].

Figure 1. Glimpse of eye detection based on iris recognition (DARPA IRIS recognition System ).

There are many commercial eye trackers available in the market like EAGLEEYES, BLINK, SMI, EYELINK and TOBII [11]. The eye tracker captures eye data ranging from 50 Hz to above 100 Hz, thus providing reliable data about movement of eyes.
III. GAZE ESTIMATION

Eye gaze interaction can provide a convenient and natural addition to user computer dialogues [12]. Eyes possess distinct characteristics; this makes gaze estimation and tracking convenient for many applications like diagnostic, analytic and behavioral. Eye gaze can be estimated through various approaches. Most of the recent work on eye gaze estimation can be classified into two categories: feature based and appearance based [13]. 2D methods based on regression, interpolation and 3D models are used for gaze estimation [14] [15].

Fig. 2 demonstrates eye gaze estimation without auxiliary light source. The process of gaze estimation requires accurate determination of region of interest (ROI) from eye region frames. Gaze estimation can also include IR illumination. The use of infra red illumination leads to formation of glint via corneal reflection. Glint vector, relative position and different eye features e.g. pupil, together estimate direction of gaze.

IV. STIMULI AND EYES

Although substantive work is carried out on investigating effect of different stimuli on eyes, the research carried out is quite diversified. This research domain has branched into domain of psychology, reading research, medical domain, music, marketing to name a few. Besides different types of stimuli e.g. sound, visual, color, static or dynamic under different environments have been investigated regarding their effect on eye movement. The following discussion is in the light of work carried out by different researchers of varied domains. This segment will provide an insight into the expansion of work correlating stimuli and eye movement/gaze feature.

Eileen Kowler [17] has discussed about different eye movements i.e. saccadic, micro saccades, smooth pursuits etc. D.Purves et al. [18] define saccades as rapid, ballistic eye movements, smooth pursuits as much slower tracking movement following stimulus and are under voluntary control. The alternating slow and fast eye movement is being termed as optokinetic. Vestibule-ocular movements stabilize the eyes compensating for head movements. Vergence movements are disconjugate unlike other movements and may involve convergence or divergence depending on equation between line of sight and distance of object. T.Alvarez [19] have segregated vergence eye movements as convergence and divergence eye movements and experimentally tried to establish relation between these eye movements and stimulus. V.Komogortsev et al. [20] have tried ternary eye movement classification which separates fixations, saccades and smooth pursuits. The authors have focused on developing new and modifying existing eye tracking algorithm for the classification. L.Larsson et al. [21] have classified stimuli as static and dynamic. Static stimuli involve text and images. Mostly eye movements studied or captured during application of static stimuli are saccades and fixatures. Fixature is the resting position of eyes. Dynamic stimuli involve videos when video clips are used as external stimuli. Smooth pursuits or vergence eye movements are captured during dynamic stimuli. S.V.Wass et al. [22] have presented new algorithms designed to identify and eliminate fixations that may be anti-factual. They have discussed ways of relating attention and learning in naturalistic setting through studying fixation duration. C.Clifton et al. [23] have reviewed work correlating eye movements and reading, information processing. Majorly referring to keith rayner’s pioneer work, the review asserts that reading procedure, pattern and bias can be understood through the investigation of eye movements. Rayner along with his colleagues have developed a computational sequential attention shift model of eye movement control during reading known as E-Z Reader. J.S.Ashby [24] have used eye tracking methodologies to investigate attention in subjective monetary valuations of consumer goods. The findings indicate individual’s attention to rating is related to their frequencies, attention towards positive negative information etc. K.P.Mital et al. [25] investigated the contribution of low to mid level visual features to gaze location during free viewing of a large dataset of videos ranging in content and length. Also during dynamic scene viewing gaze clustering is predicted by motion. D.G. Bird et al. [26] aimed at finding that eye movements can have causal influence on formation of preferences. The investigation was based on finding relation between decision making and eye movements. The failure to detect appearance of unexpected visual object /inattentional blindness, detection of unexpected stimulus and the effect when similar as attended object has been studied by M.Koivisto et al. [27]. J.Theeuwes et al. [28] have reviewed the recent findings relating interrelating attention, eye movements and working memory. M.Dysli [29] investigated the physiological oculomotor response of vergence, saccadic eye movements in healthy individuals after shifting gaze from a viewing position and inferred various results. R.S.A Khan et al. [30] examined the gaze of surgeons performing a task in the operating room and later watching the operative video in a lab in two phases. Junior residents also were asked to watch the videos (other-watching) and their eye gaze was recorded. Dual eye-gaze similarity in self-watching was computed by the level of gaze overlay and compared with other-watching. The findings showed that there is a significant difference in gaze patterns between novice and expert surgeons while watching surgical videos. T.Schafer et al. [31] observed preference and absorption are significantly higher for the preferred music than for unknown one. Participant showed longer fixations, fewer saccades and more blinks while listening to music than sitting in silence. Results of T.J.Smith et al. [32] suggest that the viewing task can have a significant influence on gaze during a dynamic scene. The gaze behavior is more predictable during free viewing of dynamic than static scenes. A series of experiments with imagery of geometric forms and figures of animals as stimuli has been performed by B.Laeng et al. [33]. The experiments are based on hypothesis that eye region should focus on regions containing more local features that are relevant for object recognition. S.Hamel et al. [34]
investigated influence of color on eye movements when viewing video stimuli in two condition: color and grayscale. The mean amplitude of saccades, mean duration of fixation has also been compared. A.Coutrot et al. [35] have tried to assess effect of salient auditory events in sound tracks on eye movements while video exploration. The analysis suggested that sound can have impact on visual exploration not only after salient events but in a more global way.

Table I summarizes some of the experiments carried out by different researchers using various techniques and varied stimulus to analyze effect of external stimuli on movement of eyes. A description of experimental and environmental set up is also put forth. The results generated by performing various experiments are also presented in the table.

<table>
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<tr>
<th>Technique and Nature of Stimuli</th>
<th>Experiment Description</th>
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<tr>
<td>Dynamic / video based, acoustic stimuli, simulated, eye tracker, dispersion, Kullback-Leibler divergence [36].</td>
<td>Participants were seated 57 cm away from 21 inch CRT monitor with head phones. Head stabilization and eye movement recorded using eye tracker (EyeLink 1000, SR research). Eye position recorded every millisecond in binocular “pupil-corneal reflect” tracking mode. Early on participants focused eye gaze on 9 separate targets on a 3×3 grid. 50 video sequences with sound track. Each video sequence seen in visual (V) condition by 20 participant and audio-visual (AV) by 20 other.</td>
<td>Eye movements of 40 participants watching assorted videos with and without their related sound track were recorded. Findings show that sound impacts on eye position, fixation duration and saccade amplitude. Shorter saccade amplitude and fixation duration in V than in AV condition.</td>
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<td>Dynamic/ video based, visual stimuli, natural scenes normalized scanpath saliency (NSS), Kullback-Leibler divergence [37].</td>
<td>Hdtv video camera used to record high resolution movies of variety of real world scenes. Each movie cut to 20s duration. Pupil corneal reflection to estimate gaze at 250Hz. Recording made with SR Research EyeLink II eye tracker. Subject seated 45 cm away from screen.</td>
<td>54 subjects on 18 high resolution videos of outdoor scenes. NSS to assess inter subject variability. On natural movies, saccadic amplitude follows a skewed distribution with a mean of 7.2 deg and median of 5.5 deg. Stronger bias for center of screen. Variability increases with repetitive viewing of same stimuli.</td>
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<td>Real time, visual stimuli, natural setup, Bayesian framework, kalman filter [38].</td>
<td>During a particular phase of driving participants performed a secondary hands free task of playing songs. With in around 30s of successfully retrieving each song, participant had to retrieve another one. Experiment performed on two or three lane highway. Peripheral vehicles are the visual stimuli.</td>
<td>Total of 30 participants with driver’s license for a mean period of 18.6 years. Advanced ‘NUDrive Vehicle’ for data collection. The timing of gaze towards stimulus under distracted state is later than under neutral state. To analyze temporal gaze distribution Naive Bayesian framework used. For tracking peripheral vehicles in blind area, kalman filter applied.</td>
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<td>Static/ image based, simulated, visual stimuli, remote eye tracking (RED) device, ANOVA, post-hoc/ t tests [39].</td>
<td>Participants seated in front of monitor at a distance of 73cm. Fixation point set prior to introduction of stimuli. Participants asked to distinguish between male and female faces by pressing one of two labeled keys. Stimulus remained on screen until participant made response.</td>
<td>Total of 49 naive students. Stimuli consisted of 96 color photos of 24 unfamiliar faces. Participant’s sex categorizations were on average 98.75% correct. Central area of face that was specific to each view was the preferentially attended target. Eye region was highly attended regardless of view. Males anchored gaze lower and more centrally than females.</td>
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<tr>
<td>Natural environment, visual stimuli, video based, ANOVA [40].</td>
<td>Participants were recruited in the supermarket. 25 performed decision task and 15 performed search task. Participants were fitted with wireless SMI iViewX HED video based pupil and corneal reflex system. Two cameras used one for eye movement and other for scene recording.</td>
<td>40 participants chose from 90 options. Consumers only attend to a small subset of the options available in the shelf (25.7% in decision task and 27.5% in search task). Time in front of shelf is quite long compared to decision times.</td>
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<tr>
<td>Dynamic, visual stimuli, video based eye tracking (ISCAN RK-464), PCA, luminance contrast model, saliency model [41].</td>
<td>Naive subjects watched video clips totaling approx. 27 minutes in duration. Viewing distance for humans was 97.8cm and for monkeys 60cm. Each video presentation was preceded by a fixation point. Standard velocity measurements along with PCA differentiated saccades, smooth transits, fixations etc.</td>
<td>10 participants (5 humans, 5 monkeys). Human and monkey gaze behavior contrasted by 115 natural and artificial video clips. Monkeys exhibited broader range of saccadic end points and amplitude and showed differences in fixation and inter saccadic intervals. Monkeys were less center-biased.</td>
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The discussion above is a corroboration of work on causal effect between external stimuli and eye movement. Relating different facets of stimuli and eye movements, a framework can be setup suggesting the steps needed to investigate correlation between stimuli and eyes. Fig. 3 briefly summarizes stages for analyzing external stimuli effect on eye movements.

![Diagram](image.png)

**FIGURE 3. Proposed Framework For Analysis Of Stimuli Effect On Eye Movement.**

Stimuli effect dynamic or static on eye movements can be studied in natural environment or the investigation can be carried out in artificial setup. The stimulus effect on the eyes of a subject under investigation needs to be captured through a video capturing device. The captured data is transferred to an acquisition system. The data is preprocessed and segmented for detection of eye centers. Based on eye detection and movement analysis, gaze is estimated and effect of different factors on eye movements is analyzed.

V. CONCLUSION

In this paper we have put forth major techniques for eye detection, eye movement tracking and gaze estimation. We have reviewed different approaches regarding investigation of stimuli effect on eye movements. The investigations are carried out in varied environments with different types of stimuli.

In the past few years there has been an upsurge in the eye tracking data visualization approaches. There has been growing number of research publications, articles relating eye movements and different factors/ phenomena that could be artificially induced or naturally available, in a effect- causal relationship. The investigation concerning external stimuli effect on eye movements has been instrumental in understanding reading pattern, gaze bias, preferential looking, detection of abnormal blink rate, attention span and behavioral patterns, driver’s drowsiness, gaze deviation, eye movement trajectory etc.

Besides effective eye gaze systems have been developed. Analysis of eye movements in the light of external factors may further enhance the better detection of the gaze coordinates, improvement of refresh rates of video screens and better understanding of different expressions, behavior of the subject etc. External stimuli effect may be used in gaming, virtual reality to increase complexity levels for users, in advertising and marketing to obtain attention of user’s eyes to a particular item etc.

REFERENCES


