Visual Analysis of Eye Movement Tracking Data

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Abstract

Eye-tracking movement studies are getting more important in world nowadays. Researchers often use different measures when publishing their results in eye-tracking movement studies. Even when the same metrics are used, they are given different names, causing difficulties in comparing studies. To support replications and facilitate advancing the state of the art, it is important that the metrics used by researchers be clearly and consistently defined in the literature. The goal of this paper is to illustrate a show of different research in this continued growth of remote eye-tracking movement, and consider what each can tell us about the overall effectiveness of different information visualizations and designs at this large data scale. Furthermore, the mechanisms have been discussed to visualize some properties of fixation behavior that eye-tracking movement metrics aim to capture

Index Terms

eye-tracking study, metrics, methodology , Fixation ,Gaze ,AOI, scan Path , Pupil dilation

1- Introduction

For over a century, eye tracking has helped experimenters to determine what an individual views, providing clues to what the subject could be cognitively engaged in. However, questions remain as to what metrics work best in determining subject state and, more specifically, subject workload [1].

Eye movements provide rich and informative window into a person's thought and intentions. Thus the study of eye movement may determine what people are thinking based on where they are looking. Eye tracking is the measurement of eye movement/activity and gaze (point of regard) tracking is the analysis of eye tracking data with respect to the head/visual scene Eye movements provide a rich and informative window into a person's thought and intentions. Eye tracking is the measurement of eye movement/activity and gaze (point of regard) tracking is the analysis of eye tracking data with respect to the head/visual scene[2] . Below some of related work on eye tracking movement

(Gwizdka , Zhang, 2015) Proposed the users' viewing of Web pages was characterized by eye-tracking measures, with a particular attention paid to changes in pupil size. The data was collected in a lab-based experiment, In particular, a larger pupil dilation on visits to relevant pages indicates, in part, a higher mental effort and attention paid to relevant pages, and particularly so on revisits or when a relevance judgment was finally made [3].

(Maskeliunas,2016) The manuscript presents an extension of our work on the development of gaze tracking based emotion recognition system, In other works we have taken a wearable eye tracking device as the main component of an emotion recognition system. Along with a practical task of tele-marketing we are now investigating if it was possible to recognize emotions using a system based on the remote gaze tracking device, Two additional emotional stimuli such as "sensory pleasure" and "shame" were introduced in the analysis framework. "Disgust" and "neutral" emotions were also measured for comparison purposes. The paper presents background analysis, implementation, and concludes with an experimental evaluation [4].

(Duong and etal. ,2016) proposed a VOG (video oculography)- based eye movement recording system that employs only a visual DSP(Digital Signal Processor) camera; head movement is free and no addi- tion devices need be worn An easy-setup eye movement recording system was developed for human- computer interaction. It uses robust pupil center and eye corner detection algorithms. A number of evaluation tests and a demonstration were undertaken by ten people; the results prove the accuracy and the applicability of the system [5].

(Drusch and etal , 2015)Proposed understanding the visual behaviors of people searching for information on Web pages, heat-maps and Areas Of

Interest (AOI)are generally used. These two techniques bring interesting information on how Web pages are scanned by several users, This research raises an important point in eye tracking studies, i.e., the analysis and interpretation of eye tracking data and many other questions. What have presented here to solve the problem of the analysis and visualization of scan-paths from many individuals is only one strategy and eye tracking tools should be used with caution as many questions regarding the analysis of the data are waiting for answers [4].

(Chennamma,Yuan,2013) With the introduction of different methods of eye tracking, this paper presented a review of non-contacting video based gaze tracking. The main intention of this paper is to give a review of latest growth in non-contacting video-based gaze tracking. Even though, the eye-gaze tracking has a history of 100 years of research, it has not been standardized. Future developments in eye tracking need to centre on standardizing what eye movement metrics are used, how they are referred to, and how they should be interpreted in the context of interface design [2]. therefore a need for a survey of eye tracking movement metrics to support the future object of standardizing eye tracking movement metrics .This paper search to bring realizing to the use of different metrics along with feasible suggestions of using them. It compares and contrasts various eye-tracking movement metrics

2- Background on eye tracking

Eye tracking movement is a sensor technology that enables a device to know exactly where your eyes are focused. It determines your turnout ,focus, interest , sleepiness ,awareness or other rational cases. This input information can be used design revolutionary new user interfaces across several devices or to gain deep insights into the behavior of consumer [4].

The eye tracking mean in the real world

- Understand human behavior Eye tracking interprets natural human behavior which helps us to gain deep insights into people’s attention and

actions. As a result we can also draw conclusions about the factors that drive certain behaviors.

- Enable hands-free interaction eye tracking facilitates interactions with computers and other devices when the user cannot or does not wish to use their hands as the input form.
- New user experiences and humanized user interfaces By combining eye tracking with other input modalities, for example keyboard, touchpad and voice, Tobii is paving the way for creating new user experiences and innovating interfaces for regular consumer devices.

3- Eye movement data analysis (Data visualization)

Eye movement studies has been used when studying language comprehension and production , scene perception reading or spatial reasoning. Eye movement analysis also has been introduced and inte- grated into usability studies. contend that performance and usability evaluations of spatial displays within information acquisition contexts, eye movement analysis has at least a 70 year long history [7] When dealing with traditional eye tracking data, several metrics are reported in usability studies, These metrics are used to analyze the visual search processes of users as well as to establish the location of their overt attention. For instance, such metrics can be helpful to find out which part of the map attracts most attention at first glance, or what is the order of user gaze points while observing the map or solving tasks with it. These metrics can be represented as density maps, gaze plots and graphs. Figure (1) shows an example of some common visualization methods used in representing eye movement data. a density map can be seen which shows the average fixation duration of multiple users (density maps can also represent fixation counts). These representations provide a simple and direct static view of eye movement data and as such, they are included in most common eye tracking and analysis software[7].

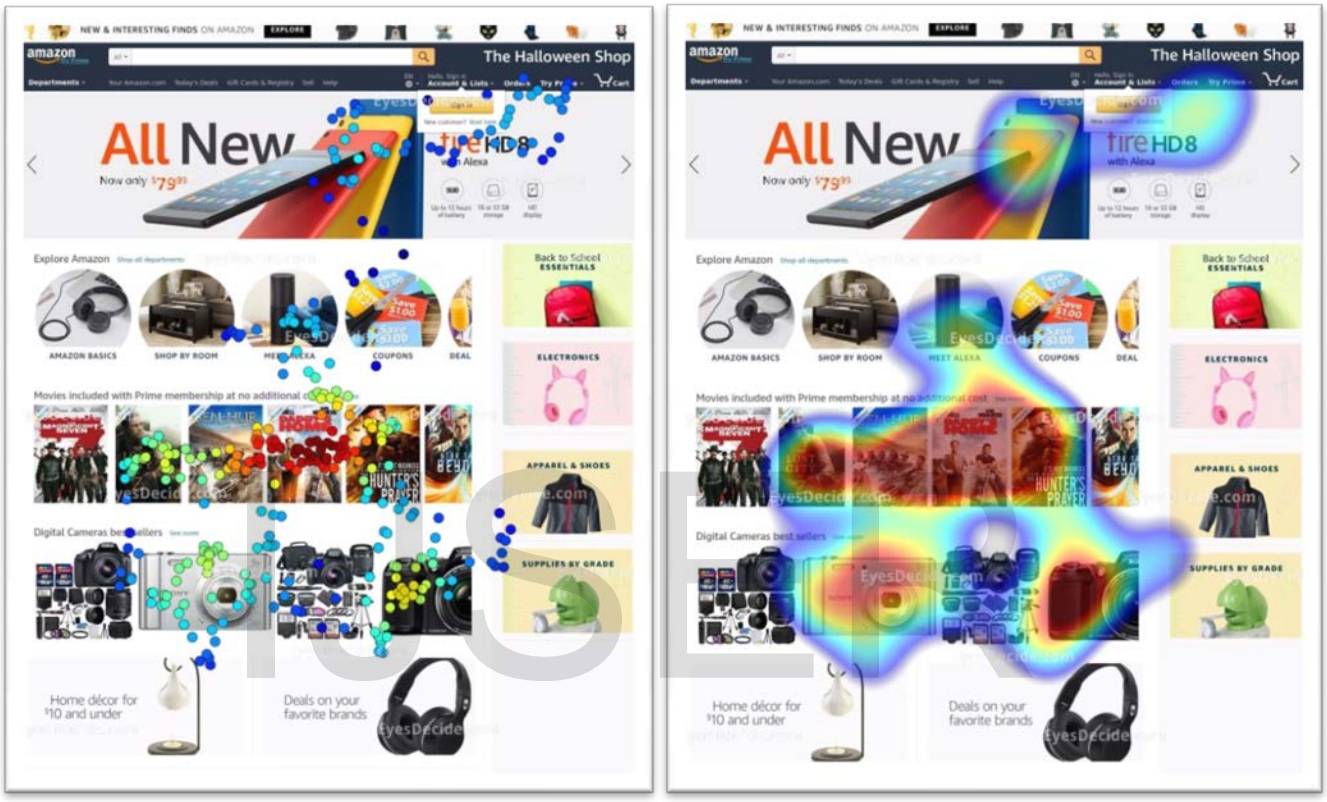

Figure 1: Two common visualization methods used in visualizing eye movement data Left image (a) shows a gaze plot, and the right image (b) shows heat-map

4- Visualization In Space – Time – Cube

The one of most data visualization methods are Space-Time –Cube (STC) Every session of eye-tracking recording delivers data consisting of: x and y

coordinates, time-stamps and fixation durations. These points can be described in a space-time cube (STC)[6] A common approach to support problem solving with visualization is based on a combination of user tasks, a data framework and a visualization frame- work. With these ‘constraints’ in mind the next section will first discuss how the eye movement data can be represented by the STC, followed by an argumentation on how these representations can con- tribute to the understanding of the data, and help overcome some of the problems mentioned in the previous sections[7] the fixation durations are transformed into points at the same spatial coordinates but at different times which generate straight lines parallel to the vertical lines as showing in Figure 2. Although the STC is a very effective model to describe eye-tracking data, bringing together all the individual scan-paths produce a quite unreadable representation [6]

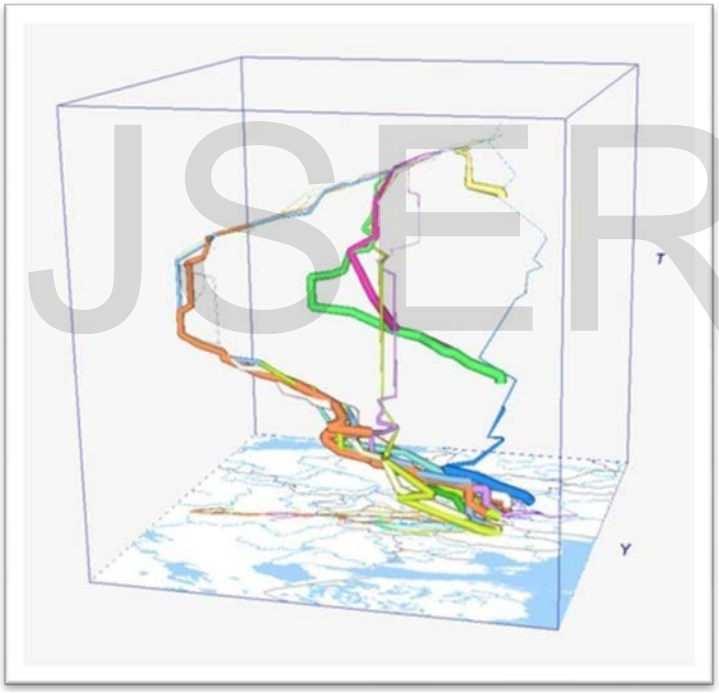

Figure 2: Figure 2. An example of the space-time cube [6]

5- Eye tracking Metrics Analysis:

In order to make the eye movement tracking possible , it is necessary to rely on metrics or determinants of eye movement to obtain a precise and rapid identification of the final sites reached by the eye move- ment and various gestures ,If you want to measure Eye points (where some one is looking at) as showing in Figure (3) or eye movements tracking , there is no alternative to eye tracking. It is hard to consciously control your eyes, which makes this measure a very attractive tool for quantitative research. It allows you to tap into subconscious processes and decisions of your audience and understand what elements of your products or services such as advertisements, websites, layouts and models etc. trigger the fun- damental brain circuits responsible for attention, cognition and emotion. Also, you gain insights into individual preferences and decision strategies of your target area of interest

the most common metrics and determination in eye tracking are presented AS

Fixation : The moment of eye comparatively stable, “encoding” or taking in information. the aver- age of Fixations are 218 milliseconds , with a domain between 66 to 416 milliseconds [8].

Saccade: The quick (and continuous) eye movements from one fixation to another. Saccadic eye- movements are extremely rapid (within 40-50 ms). Saccades are usually voluntary. Micro-saccades on the other hand are small jerky eye movements that are involuntary and occur during a long fixation to refresh the participant’s visual memory [8].

Gaze : commonly the total of all fixation period within a specific area. Also called “fixation cluster” ,“dwell”, or “fixation cycle" [9].

Figure 3: Figure (3) gaze plot and heat-map

Area Of interest(AOI) Or Point-of-regard: it is the Point of space where a person is looking (interested person) . Usually used in eye tracking research to detect where visual attentiveness is pointed[9]
Scan Path: spatial arrangement of a sequence of fixations[9]
Pupil dilation: The widening of the pupil, which allows more light to get into the eye in low light condi- tions. It also happens when a participant's mood or attitude changes or during complex cognitive tasks [8]
It is difficult to consciously control your eyes, which makes this measure a very appealing tool for quantitative research[10]

Fixation

Fixation is the stabilization of eyes on an object of interest for a certain period of time[11]. The stabilization of the eye on part of a stimulus for interval of time (200-300 ms). The connect between cognitive and

fixations processes depend on two supposition the immediacy supposition, which states that, as soon as a participant sees the word, she tries to clarify it, and the eye-mind supposition , which states that a participant fixates her awareness on the word until she understand it [5]

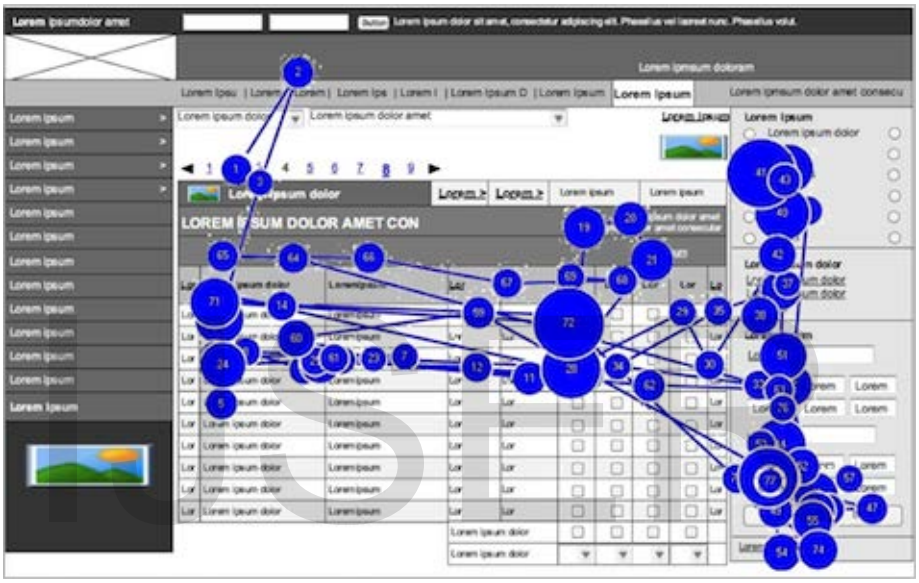

Figure 4: Fixations and gaze points

Saccade

are quick movements that move the eyes from one location to the next (i.e., refixates) [12]. Measures of saccadic movement are often times neglected in usability research initiatives because many of its close relation to fixations measures, which are easier to examine are used instead. There are several metrics available within the realm of saccadic eye movements that are unique and poten- tially useful in studies involving task oriented research. The length of the saccade, as well as the speed of which the saccade is made are both very easily calculated measures, simply calculating the distance from one fixation to the next in an ordered pair. The frequency of longer length saccadic movements could indicate a correlation of decreased efficiency, and

potentially an increase in perceived workload. The 14 frequency of specific length saccadic movements requires a limit be set to determine what a longer length saccadic movement is. This is dependent upon the specified areas of interest. Usability research has used the ratio of fixation to saccade times as a measure for analysis[12]

Gaze

Very similar to the fixation metric, gaze analyzes the grouping of fixations within a single region of interest. Much of Fitts' research focused on analysis of the gaze metric, including gaze rate (of gazes minute) on each area of interest, gaze duration mean and gaze percentage (proportion of time) in each area of interest for 40 pilots flying an aircraft landing approach. Gaze metrics focus more on the area of interest and what it represents, not only the measure of a fixation in any given region of space. The gaze metric places meaning behind the location of where a fixation occurs, with the region for which a gaze is calculated can be of any size depending on the area of interest. Measures within the gaze metric include the number of fixations within a single gaze, the total number of gazes, the frequency of gaze and the duration of gaze, including the mean and maximum statistics of this single measure [12]

Area of interest AOI

An area of interest, also referred to as AOI, is a tool to select subregions of the displayed stimuli, and to extract metrics specifically for these regions. For instance, if you show pictures of a person, it is possible to draw separate AOIs around the body and the face. You will then be able to display metrics for each region separately, e.g., how much time from stimulus onset passed until respondents looked into the region (time to first fixation = TTFF), how much time your respon- dents spent in the region, how many fixations were counted, how many people looked away and back (revisits). These metrics

come in handy when evaluating the performance of two or more areas in the same video, picture, website or program interface [4]

Scan Path

Scan path is a directed path formed by saccades between fixations Several research studies have been conducted that analyze scan-path as it relates to efficiency, workload, usability, effectiveness, effort, saliency, and other forms of human factors. Scan-path is often looked at as the measurable window that depicts how a subject uses their visual sensory perception to complete any task at hand, carrying with it also the distractions and other important artifacts that are included that add or detract to an individ- ual's intention of completing that task. Scan-path analysis measures the transitions between fixations, including measures of transitions between areas of interest (link-analysis) as a quantifiable measure [9]. It is particularly useful in bottom-up analysis approaches that seek to identify where someone is looking and why, in an attempt to understand the cognitive background to an individual's eye tracking behavior. Scan-path analysis proves to be critical in computational visual modeling, since hysteresis of scan-path can be observed to identify if a commonality between tasks exists. Scan-path direction was used to determine user behavior in selecting command buttons using varying strategies of selection [12] Other uses of scan-pattern include reviewing how individuals read over layouts of screen displays ,as well as sweep as an additional 15 scan-path metric indicating a progressive trend in scan-path direction From a top-down approach scan-path is seemingly less useful. Issues with real time analysis of scan- path as its own metric are that it is difficult to quantify since it is a combination of saccadic movements and fixations in a seemingly random sequence. A scan-path can be used to describe the behavior of an individual's gaze in several areas of interest over time, but only once the scan-path has been made, making it a post process analytical method. Attempts to quantify scan-path have been made by index- ing spatial randomness of scan-path behavior relative to what is expected for the given task [9] .

6- The comparative of visualization and data analysis for some researches of eye tracking movement are showing in the table below

no	Research title	Authors and Year	Metrics used	Performance
1	Eye Fixation Metrics for Large Scale Analysis of Information Visualizations	Zoya Bylinskii and Michelle A. Borkin 2015	Fixation	analyzing fixation coverage can help diagnose potential design issues, Fixations are discrete sample extracted from eye movement data. Afixation is recorded when the eyes are “still” according to prespecified parameters the investigation of other properties of eye movement behavior like scan paths and saccades are likely to provide additional insights. The results of eye movement analyses have the potential to make simultaneous contributions to the understanding of human cognitive and perceptual processes, visual content design principles, and general approaches to data communication [13]
2	Advanced Gaze Visualizations for Three-dimensional Virtual	Stellmach, Nacke , Dachselt 2011	Scan Path	Scan paths are generally useful for studying gaze sequences. In this context, depicting camera paths is regarded important as well. Thus, a

	Environments			combination of camera and scan paths is found useful by both groups. In contrast, cones were considered only moderately suitable for representing fixations. Instead, a simple combination of the spherical fixation representations with viewing directions and positions was preferred. While the motivation for individually depicting fixations and saccades was not evident to everybody, it was regarded useful in the overall rating[14]
3	EXPLORING EYE TRACKING MEASURES TO UNDERSTAND OPERATOR PERFORANCE	Dervon Chang,Sven Fuchs,Laura Milham, Meredlth Bell-Carroll,and Kay Stanney 2010	Area Of Interest AOI	AOI indicated high information importance of the display element, while long gaze duration reflected difficulties in information AOI and subsequent decision-making is impaired. Real-time recognition of attention lapses affecting situation awareness SA allows system designers an opportunity to provide operators with mitigation strategies to aid decision-making.[15]
4	Differences in eye-tracking measures between visits and re- visits to relevant and	Gwizdka , Zhang, 2015	pupil dilation	The data was collected in a lab-based experiment, In particular, a larger pupil dilation on visits to relevant pages indicates, in part, a higher mental effort and attention paid to relevant pages,

	irrelevant web pages			and particularly so on revisits or when a relevance judgment was finally made [3]
5	Analysing eye-tracking data: From scanpaths and heatmaps to the dynamic visualisation of areas of interest	Gautier Drusch,JC Bastien,and Stéphane Paris 2014	heat-maps and Areas Of Interest	These two techniques bring interesting information on how Web pages are scanned by several users, This research raises an important point in eye tracking studies [6].

Discussion

Through our review of the researches above we find that there are several ways to represent eye tracking data ,The aim of this paper is to review the recent growth in eye tracking, although eye movement tracking has begun more than 100 years of research it has not been considered As a general direction in the future we can conclude that eye tracking approaches will be a hot subject for researchers Special attention should be paid for performing experimental procedures in order to rectify the usability, reliability and accuracy of the eye tracking systems, The stability of the scan-paths or rather, the stability of the determinants of the scan-path will

also have to be addressed. When users find themselves in a group, will they find themselves in the same group if we change tasks or conditions? Are these characteristics stable over time? Given that groups of users can be identified, what are the implications for providing designers with ergonomic guidelines? All these points should remind us that despite their utility, and their ease of use, eye- tracking tools should be used with caution as many questions regarding the analysis of the data are waiting for answers ,another example of eye tracking movement visualization the Recording and analysis of eye movements offer interesting opportunities to support user-experience studies, including evaluation of geo-visualization systems. Current eye movement recording and analysis hardware and methods have come a long way since the first studies in 1960s . However, even with today's more comfortable procedures, analysis stages are still cumbersome. Qualitative analysis of data is typically performed by visually inspecting gaze plots and density maps. Such representations are of course useful depending on the purpose however, gaze plots typically suffer from massive over plotting , and density maps offer only aggregate visualizations. Since the eye movement recordings essentially produce multivariate spatio-temporal data, geo-visual analytics methods that handle multivariate spatio-temporal data can be used to also analyze eye movement recordings. The STC is a 3D visualization method, which provides a combined view of time and space

As a result of the analysis process, knowledge depending on the analysis task is extracted from the data. As discussed before, this knowledge could be insights that allow the researchers to refine a study design or conduct an entirely new experiment. In the cases where visualization has the main purpose to support statistical analysis, it often serves as dissemination of the finding in papers or presentations. In many eye-tracking studies, this is

typically the case when inferential statistics are performed on eye-tracking metrics and attention maps are displayed to help the reader better understand the statistical results.

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