Scientific Journals
Maritime University of Szczecin

Zeszyty Naukowe
Akademia Morska w Szczecinie

2013, 36(108) z. 1 pp. 116–120
ISSN 1733-8670

2013, 36(108) z. 1 s. 116–120

Application of eye-tracking techniques in human factor research in marine operations. Challenges and methodology

Bartosz Muczyński, Maciej Gucma

Maritime University of Szczecin
70-500 Szczecin, ul. Wały Chrobrego 1–2, e-mail: m.gucma@am.szczecin.pl

Key words: eye-tracking, technique methodology, maritime operations, human factor research, data analysis

Abstract
The following paper provides information about eye-tracking techniques and methodology. It is focused on introducing eye movement metrics in human factor research in maritime domain, explaining basic methodology and describing the types of data analysis, thus providing the background and guidelines for simple eye-tracking studies.

Introduction

In the recent years, the human factor has become increasingly important in many different areas, including shipping. Although there is a set of methods successfully used in this field, eye-trackers are rarely used to measure and evaluate bridge environment and officer's behaviour.

The following paper presents how the video-based eye-trackers can be used for improving the safety of navigation, and introduces the basics of eye-tracking methodology.

Eye-trackers

Eye-tracking, as the name suggests, focuses on tracking the position and movement of an eye. In general, we can distinguish two types of eye movement monitoring techniques: those that measure the position of the eye relative to the head; and those that measure the orientation of the eye in space (or *Point of Regard*, POR). For human factor studies, it is very important to understand the connection between eye movement and the visual scene, which allows to measure where, and for how long, the subject was focusing his/her attention, and how often certain areas in visual field were revisited, etc. Such an approach is widely used in usability studies, interface design, marketing, ergonomic evaluation of a workspace and in many other fields where subjects need to acquire information from specific areas in the visual field.

Video based eye-trackers

This type of eye-trackers uses video camera that constantly records the eye to provide information about the eye's position and movement. The most common method to estimate the point of regard (or point of gaze) is based on pupil and corneal reflection tracking.

Pupil is the most distinguishing feature of a human eye and it is relatively easy to extract from the recorded image information about its size and the location of its centre. The corneal reflections of the light source (typically infrared) are known as the Purkinje reflections, or images [1]. Four such images are formed on a human eye, each one on a different layer. Most of the modern eye-trackers determine the location of the first Purkinje image; the one that is formed directly on the outer surface of the cornea, relatively to the pupil centre. Technically, it is possible to use only the pupil-tracking but information about corneal reflection offers an additional reference point that allows for the compensation for the smaller head movements.

A crucial part of every eye-tracking system is the software used. It is directly responsible for the pupil and corneal reflection detection, for calculating the point of regard, and, most importantly, for the proper identification and classification of the recorded eye movement events. The quality of the gathered data highly depends on the type of algorithm used for raw data processing and it is advised to know the general characteristics and the limitations of the algorithm used for data analysis. More information about the most common algorithms can be found in [2, 3].

Stationary eye-trackers

This type of eye-tracker is perfect for working with a single monitor screen. Most often, it is a small piece of equipment with infrared light source and a camera that is attached below the screen. It is very easy to set up and does not require any additional equipment to be worn by the subject. Its calibration procedure is also fairly easy and reliable. Such eye-trackers are used in studies where stimuli are displayed directly on the screen, and it is very simple to map recorded events on the stimuli picture. From the point of view of the navigator, such an eye-tracker can only be used in a situation, where a subject remains stationary and works on a single screen. For this reason, it is highly difficult to introduce this type of equipment on the navigation bridge, or anywhere else, where the subject is moving. Still, it can be very useful in studies of a single interface, like, for example, a radar screen, ECDIS or for VTS operators.

Mobile eye-trackers

Modern mobile eye-trackers are pieces of head-mounted equipment with two cameras that record eye movements, and one additional camera that records the visual scene in front of the subject. In the most advanced solutions, such an eye-tracker has a form of lightweight glasses that are comfortable to wear and do not restrict head movements. It is widely used in studies where the subject is not stationary. It has already proven useful in studies on a navigation bridge simulator [4, 5]. Its main disadvantage is the time consuming and laborious analysis that requires mapping of every fixation from a video recording onto a static image of the stimulus.

Fig. 1. Example of mobile (left picture) and stationary (right picture) eye-trackers [6]

Eye movement events and their values in human factor researches

From several types of eye movement events (Table 1), two are the most common in human factor studies: the fixations and the saccades. The most recent studies suggest that also microsaccades can be used as a measure for mental workload [7] but to detect microsaccades, which have the duration of 10–20 milliseconds, an eye-tracker with very high sampling rate needs to be used. Most mobile eye-trackers, which are the only practical option to use on-board, have a sampling rate of not more than 30 Hz (with the exception of SMI eye-tracking glasses 2.0, which were presented in September 2013 and have the sampling rate of 60 Hz) and are simply not capable of detecting microsaccades.

Table 1. Types of eye movements and their characteristics

Type	Duration [ms]	Amplitude	Velocity
Fixation	200–300	–	–
Saccade	30–80	4–20°	30–500°/s
Glissade	10–40	0.5–2°	20–140°/s
Smooth pursuit	–	–	10–30°/s
Microsaccade	10–30	10–40'	15–50°/s
Tremor	–	< 1'	20'/s
Drift	200–1000	1–60'	6–25'

Fixations

A fixation is one of the most basic events related to movement of the eye and it occurs when the eye remains still over a period of time (it is fixating on a specific point in the visual field). During a fixation, three distinct types of eye movements occur: tremor, microsaccades and drifts [8] but those are mainly used in studies of human neurology and have not yet found any application in human factor research. Fixation itself, as an event during which visual information is acquired, is strongly connected to cognitive processing. Thus, the distribution of fixations in space: shows the main sources of navigation information for an officer; allows for identification of the main distractors, both on the bridge and in the manoeuvring area; helps to understand how the navigational and the hydro-meteorological situations influence the behaviour of an officer; and shows differences in the decision-making process between experienced and inexperienced crew [4].

The duration of fixations is directly related to mental workload. Subjects tend to fixate longer on the areas that are critical for a given task but also when the visual information is more complex or requires additional mental tasks (e.g. calculations). Also, experienced subjects show shorter fixations in the same task, compared to novices. Initial studies showed the same relation between captains, junior officers, and students [4].

Some researchers point out that shorter fixations can also indicate high mental workload, due to the stress level and the complexity of the task [2].

Saccades

A saccade is a rapid motion of an eye between one fixation and another one. It is the fastest movement that the body can produce and it is assumed that visual information is not acquired during this movement.

Since a saccade takes place between two fixations, the number and proportions of both events are strictly connected. Saccadic measures are widely used, mainly in the studies with a static stimuli. It is unclear, how exactly saccadic rate should be interpreted for a mixed stimuli (i.e. stimuli with both static and dynamic items, e.g. real world) [2].

A visualization of saccades and fixations on a stimuli picture creates the so called *scanpath*, which helps to identify information-seeking patterns and is very useful for the initial inspection of data. Observing a dynamic *scanpath* from a recording with a mobile eye-tracker, allows for quick evaluation of an officer and his performance, for example by showing when exactly and basing on which information, a risk of collision situation has been identified properly.

Pupil diameter

The changes in pupil diameter are a very popular measure for a variety of cognitive and emotional states. Increased pupil dilatation is positively correlated with difficulty level of a given task. Both complex calculations and tasks that require memorizing a large quantity of data result in significant increase of pupil diameter when compared to basic tasks. Additionally, pupil diameter is reported to decrease with increased drowsiness and fatigue.

At the same time, the pupil is highly sensitive to any changes in the luminance level. Even during studies in a closed simulator, with constant lightning conditions, radar, conning, and radar screens, introduced enough luminance changes to make pupil dilatation an unrealizable measure [4].

Blink rate and duration

Blink rate, defined as a number of blinks per second or minute, has proven to be a reliable measure of mental workload. Studies of drivers and air traffic controllers have shown an increased blink rate during more complex tasks [9, 10]. However, it is crucial to remember that there are many factors that can influence this measure as well, e.g. air pollutants, dry eye, time of day or age [2].

At the same time, the duration of a single blink is reported to be positively correlated with drowsiness and loss of vigilance [11, 12]. That can potentially help to identify moments during navigational watch when officer's level of concentration is the lowest.

Data analysis

When dealing with eye-tracking data, it is important to consider both, statistical analysis and visualisation of the data. It poses a problem when a dynamic scene is studied, if a mobile eye-tracker is used and the subject is not stationary.

Semantic gaze mapping

A function called *semantic gaze mapping*, offered by one of the manufacturers, allows mapping (transfer) every single fixation from a video recording acquired with mobile eye-tracker, onto a prepared static stimuli. Video stops automatically on every fixation and waits until a point is selected on static stimuli area and proceeds to next fixation (Fig. 2). It is reported that this piece of software can increase the efficiency of analysis by factor 10–50, compared to conventional frame-by-frame coding [13].

Having in mind that the average number of fixations for an 11 minutes-long simulator trial is around 1000 [4], it results in over 1000 mouse clicks for a single subject. Such approach would make an analysis of a full 4-hour navigational watch extremely time-consuming. This is one of the reasons why automated data analysis is so important for future eye-tracking studies.

Graphic visualizations

The two most commonly used methods for graphic representation of the eye-tracking data are focus maps and heat maps. A focus map alters transparency of the image basing on the amount of attention paid – the number and the time of fixations. It shows in the simplest way which areas have drawn the subject's attention and which were omitted. Heat maps use colour coding to add information about the number of fixations on the stimuli (Fig. 3). Both functions allow for a quick evaluation of the subject's performance, showing information that was missed; how the subject's attention was distracted; and what the preferred sources of information were.

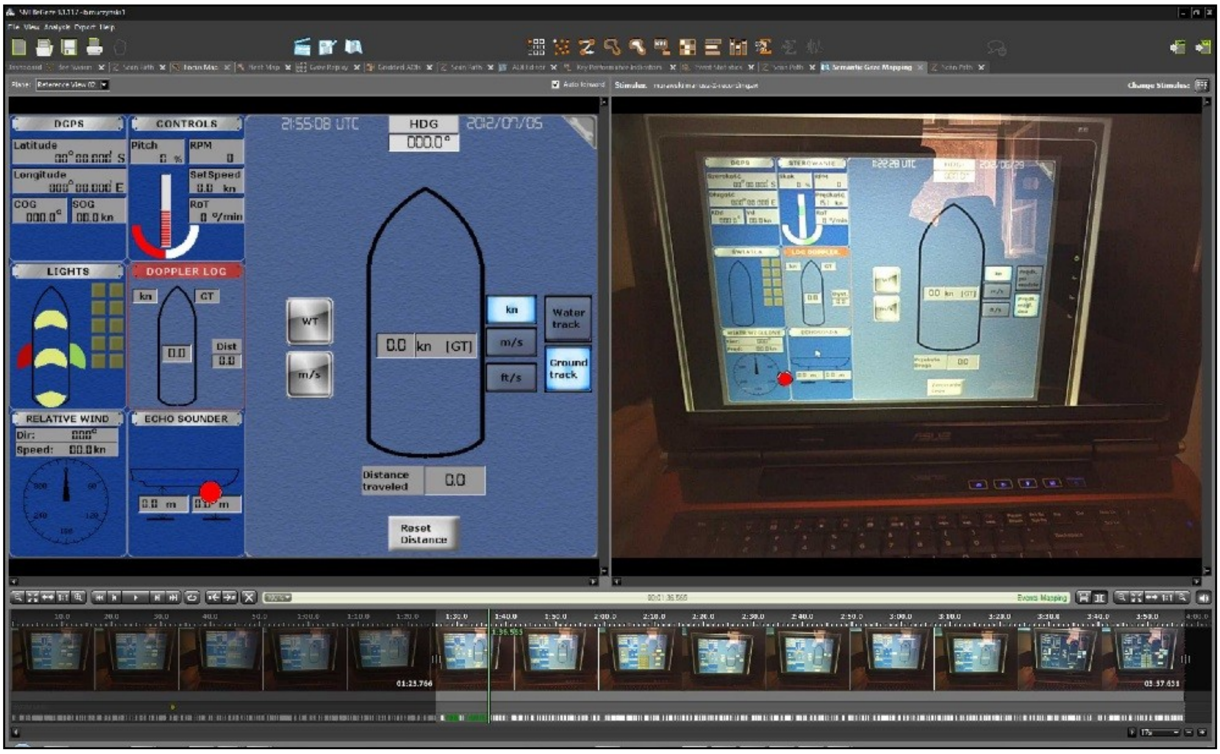

Fig. 2. Sematic Gaze Mapping function. The right side shows a recorded video stimulus; the left side shows static stimulus – image of tested interface. The red dot on both sides is the recorded fixation point

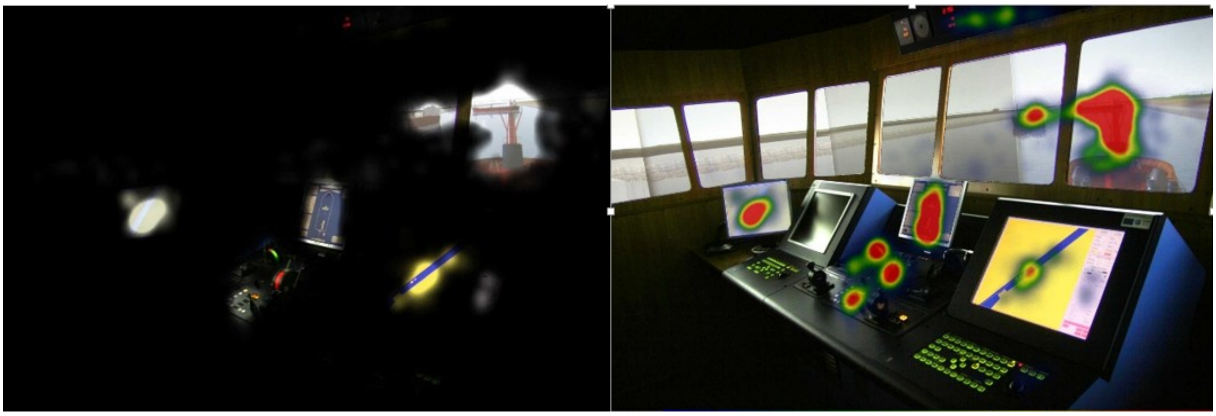

Fig. 3. Focus map (left) and heat map (right) created from eye-tracker data

Fig. 4. Defined (left image) and gridded (right image) Areas of Interests

Data distribution: Areas of Interests

Focus and heat maps give a very general overview of the subject's performance. Analysing the behaviour of an officer of the watch can show how long it took to acquire relevant information from navigational equipment; what the primary sources of information were; how often certain data was compared between different sources; how much the officers relayed on their own observations; how long it took to notice events relevant to safety of navigation, etc. To obtain such information, it is necessary to define those areas in the visual scene, for which additional analysis is made. In the eye-tracking studies they are generally called *Areas of Interests* – AOIs. On a navigational bridge we can, for example, define separate areas for ECDIS, radar, conning display, controls, GPS unit or specific ships in the visual field. For each one of such AOI, a set of eye-tracking metrics, like: the number of fixations; the dwell time; the per cent of all fixations; the average fixation time, is calculated separately. Additionally, gridded AOIs that divide whole stimuli evenly into small rectangle areas can be used (Fig. 4).

Conclusions

Eye-tracking techniques are widely used in many fields and have proven to be valuable in studies focused on usability, ergonomics and human factor [7, 14]. So far, very a few studies focused on measuring the eye movements of an officer of the watch. Additional research could help to improve both, the bridge design and the usability of ECDIS and radar interfaces contributing to safer navigation. Solving the problem of automated data analysis would provide a chance for a wide study of officers on different types of vessels and in different bridge layouts.

References

1. CRANE H.D.: The Purkinje Image Eyetracker, Image Stabilization, and Related Forms of Stimulus Manipulation. Visual Science and Engineering: Models and Applications, 1994, 13–89.
2. HOLMQVIST K., NYSTROM M., ANDERSSON R., DEWHURST R., JARODZKA H., VAN DE WEIJER J.: Eye Tracking. A Comprehensive Guide to Methods and Measures., Oxford University Press, New York 2011.
3. SALVUCCI D.D., GOLDBERG J.H.: Identifying fixations and saccades in eye-tracking protocols. Proceedings of the symposium on Eye tracking research & applications – ETRA'00, ACM Press, New York 2000, 71–78.
4. MUCZYŃSKI B., GUCMA M., BILEWSKI M., ZALEWSKI M.: Using eye tracking data for evaluation and improvement of training process on ship's navigational bridge simulator. Scientific Journals Maritime University of Szczecin 33(105), 2013, 75–78.
5. MUCZYŃSKI B., GUCMA M.: (2013) Method of gaze data analysis for marine ship's simulator researches. Evaluation of offcer's of the watch eye metrics. Book of Abstracts of the 17th European Conference on Eye Movements, Journal of Eye Movement Research 6(3), Sweden, Lund 2013, 271.
6. www.smivision.com; access 10.09.2013.
7. SIEGENTHALER E., COSTELA F.M., OTERO-MILLAN J., MCCAMY M.B., DI STASI L., MACKNIK S.L., MARTINEZ-CONDE S.: New Eye Movement Measures in Human Factors Research. Book of Abstracts of the 17th European Conference on Eye Movements, Journal of Eye Movement Research 6(3), Sweden, Lund 2013, 90.
8. MARTINEZ-CONDE S., MACKNIK S.L., HUBEL D.H.: (2004) The role of fixational eye movements in visual perception. Nature reviews. Neuroscience, Vol. 5, No. 3, 229–40.
9. TSAI Y.F., VIIRRE E., STRYCHACZ C., CHASE B., JUNG T.-P. Task Performance and Eye Activity Relating to Cognitive Workload. Aviation, Space, and Environmental Medicine, Vol. 78, No. 5, 2007.
10. BROOKINGS J.B., WILSON G.F., SWAIN C.R.: Psychophysiological responses to changes in workload during simulated air traffic control. Biological Psychology, Vol. 42, No. 3, 1996.
11. SCHLEICHERA R., GALLEYB N., BRIESTC S., GALLEYD L.: Blinks and saccades as indicators of fatigue in sleepiness warnings: looking tired? Ergonomics, Vol. 51, No. 7, 2008, 982–1010.
12. MORRIS T.C., MILLER J.: (1996) Electrooculographic and performance indices of fatigue during simulated flight. Biological Psychology, Vol. 42, 1996, 343–360.
13. SMI – Experiment Suite Software Package.
14. POOLE A., BALL L.J.: Eye Tracking in Human-Computer Interaction and Usability Research: Current Status and Future Prospects. Encyclopedia of Human-Computer Interaction, Idea Group, Inc., Pennsylvania 2005.