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“Here´s looking at you, kid.” Does he see pupil size changes?

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In human-human interaction, looking into one’s eyes is an important characteristics. Assuming that pupil-based information is of importance in such social interactions, its integration might also be conductive for smooth human-computer-interaction. We review respective hitherto existing approaches with the aim to identify promising perspectives for future applications. Stimulus-driven pupil-based selection (e.g., Mathot et al., 2013) makes use of the fact that brightness changes produce large and reliable changes of the pupil size. Nevertheless, this methods is slowed down by the requirement of a binary decision process. Another attempt utilizes actively controlled pupil size changes which can be achieved via biofeedback (e.g., Ehlers et al., 2015, 2016). This produces reliable signals without the need to use binary decisions. The results obtained with active pupil size changes suggest that selection times of about 1s are achievable. Using automatic pupil size changes for input (e.g., Strauch et al., 2017), the signal amplitude is smaller but, pupil size changes can be observed much faster. Although comparative evaluations of all approaches are still missing, the observations so far suggest that pupil-based input provides promising information for target selection..

Keywords: pupil-assisted input, eye movement, pupillometry, human-machine-interaction, gaze input

Introduction

During human-human interaction, gaze behavior reveals quite a lot of information about the persons involved: Fixated objects provide reliable nonverbal clues on a person’s attentional focus, and eye movements are supposed to communicate even complex intentions (e.g., Foulsham, 2015).

Similar to human-human interaction, modern interfaces have taken advantage of the possibilities of human gaze behavior. Recently, also pupil-based information has gained more interest. Pupil diameter constitutes a significant source of implicit information as it features autonomic activity changes that arise from various cognitive and/or affective processes. Analogous to eye movements, dynamics are suggested to play a crucial role also in social interaction. For example, Harrison et al. (2006) report sad facial expressions to be moderated by pupil diameter, assuming constricted pupils to correlate with high attributions of valence and arousal. Kret and coworkers (2015) demonstrate that pupil dilation may be of special importance in group interactions, in that dilating and constricting pupils of our opponents significantly alters our willingness to cooperate and is mimicked by ourselves during social interaction. As such, we may have developed the ability to infer information on the internal states of human opposites from their pupil size changes. To improve data exchange between user and computer, the same type of information is attempted to be assessed on the basis of pupil diameter and processed by modern interaction concepts. During the last years, the perspective on pupil size changes has been extended considerably. Pupil diameter had often been regarded as passive

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information channel that may be employed to assess mental workload or a user's emotional state online (e.g., Partala & Surraka, 2003). However, as of recently, pupil diameter changes are employed as a means for active computer input, that is, a certain change in the pupil is used as input command for target selection.

In the following, we will review the respective ac-counts developed so far with the aim to clarify underly-ing mechanisms and evaluate them for future applica-tions. Actually, three kinds of approaches can be distin-guished, depending on the functional mechanisms they make use of. Although the accounts differ in their ap-plicability, they all have certain strengths and might even be used complementary.

Approaches in pupil-based HCI

Stimulus-driven pupil-based selection

One suggestion for pupil-assisted target selection is based on the finding that pupil adapts to the change in brightness of a displayed stimuli when attending towards it, even when not fixating (S. Mathôt, L. van der Linden, J. Grainger, and F. Vitu, 2013; M. Naber, G. A. Alvarez, and K. Nakayama, 2013). Mathot et al. (2016) present a possibility which allows to infer attended objects that change in brightness via pupil size. Two objects are dis-played that either turn dark from a bright state or vice versa repeatedly. The live monitoring of pupil diameter allows to infer the attended object. Hereby, it had been shown that also selections from a set of up to eight ob-jects can be performed by firstly displaying the eight objects. The four attended stimuli can be identified and further split to two objects and so forth, using the same mechanism. Although the input rate is scarcely better than for common brain computer interfaces, this ap-proach is remote and thus, easier and cheaper applicable than EEG systems – merely relying on real-time analyz-ing of stimulus driven changes in pupil diameter.

Active control on implicit events

Recent studies indicate that pupil size changes do not simply label sympathetic activity; at least to a certain degree, the associated dynamics are subject to cognitive control, albeit with individual varying success and over differing durations (Ekman et al., 2008; Laeng & Sulut-vedt, 2013; Ehlers et al., 2015). Given that valid and continuous feedback is provided, participants deliberate-ly expand diameter up to one millimeter beyond baseline mean (Ehlers et al., 2016). Pupil enlargements that arise from the ability to resize diameter occur slowly with strong effects and maximum values usually about three to five seconds after feedback onset (Ekman et al., 2008; Ehlers et al., 2016). This supports the assumption that changes in pupil diameter may certainly be considered as an active input mechanism for HCI. Stoll et al. (2013) applied pupil dilations due to arithmetic processing to establish communication with locked-in patients; howev-er, in a rather non-applicable form. Recently, Ehlers et al. (in press) utilized self-induced dilations as selection crite-rion in a simple search-and-select task and report promis-ing results with regard to comparatively fast selections and high accuracy rates at low cognitive requirements. Actively controlled pupil size changes may be usable for complex application scenarios that are associated with high user demands and difficult or uncertain selection decisions.

Automatic pupil size changes

Pupil diameter changes are connected with Locus Co-eruleus activity (Einhäuser et al., xx). This correlation appears to be almost temporarily synchronous and thus offers information about the attentional state of a user with high temporal resolution (Gilzenrat et al, 2010). For example, pupils dilate when a relevant object is spotted during visual search (Klingner, 2010), and during a deci-sion for “yes” in comparison to a decision for “no” (de Gee et al., 2014). Given the similarity to the process of selection in human computer interaction (search and select if correct), these findings suggest that mouse clicks can be predicted on the basis of pupil diameter (Jadue et al., 2015). Strauch et al. (2017) present an eyes-only interface using automatic pupil size changes as input signal. Here, users select from a set of objects, employing a selection criteria that was activated when the pupil dilated beyond a certain threshold. Performance was superior to the aforementioned interfaces but, worse than for dwell. Pupil dynamics showed inter-individually con-sistent signal shapes for the moment of fixation on af-terwards selected objects. Therefore, one might assume that pupil variations can enhance fixation-based target selection. This finding had already been replicated em-ploying an on-screen key-board operated by automatic pupil size changes, while the screen was even placed next to a window (Strauch et al., submitted).

Evaluation of pupil-based HCI

An empirical comparison between the approaches is still missing. Regarding stimulus-driven selections, we can conclude that the certainly work reliably although slowly. Active control results in similar performances but, it can easily be applied for more than only binary decisions. Automatic pupil size changes are characterized by rapid but small dilations. Taken together, all pupil-based approaches offer promising ways to remotely access users´ states and use them for improving target selection.

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