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Detecting drivers' cognitive load from saccadic intrusion

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A B S T R A C T

In this paper, we have explored use of Saccadic Intrusion to detect drivers' cognitive load and instantaneous perception of developing road hazards. Saccadic Intrusion is a type of eye gaze movement which was earlier found to be related to change in cognitive load. We have developed an algorithm to detect saccadic intrusion from a commercially available low-cost eye gaze tracker and conducted four user studies involving a driving simulator and cognitive and hazard perception tests. Our results show that average velocities of saccadic intrusion increases with increase in cognitive load and recording saccadic intrusion and eye blinks for 6 s duration can predict drivers' instantaneous perception of developing road hazards.

1. Introduction

Detection of drivers' cognitive load is a well-investigated subject in Automotive Technology (Boril, Sadjadi, & Hansen, 2011; Healey & Picard, 2011; Lee & Boyle, 2007). Recent advancement of information technology added a plethora of infotainment system inside a car to help the driver (Sezgin & Robinson, 2007). However, proper and also improper uses of those systems often distract the driver from driving and lead to driving accidents. Besides the infotainment system, the change of mental states of driver due to road or traffic condition, duration of driving can also increase chances of accident.

Automatic detection of drivers' mental state and cognitive load can be used to take evasive action to prevent accident. Researchers already explored various options like facial expression (Afzal & Robinson, 2009; Sezgin & Robinson, 2007), acoustic features of voice (Boril et al., 2011), skin response (Healey & Picard, 2011), eye gaze movements (Tokuda, Obinata, Palmer, & Chaparo, 2011; Yoshida, Ohwada, Mizoguchi, & Iwasaki, 2014) and so on to detect drivers' mental state with varying range of success. The physiological metrics like heart rate or skin response (Healey & Picard, 2011) need intrusive devices limiting their practical application in everyday use. Use of facial expression is a well investigated prospective solution although detecting higher mental states except basic emotions in natural environment is still a research problem (Afzal & Robinson, 2009; Sezgin & Robinson, 2007). Change in acoustic features of drivers' voice (Boril et al., 2011) is also indicative of change in mental state but it will only be applicable when the driver is talking.

In this paper we have explored the use of a commercially available low-cost eye gaze tracker to detect drivers' cognitive load. Eye tracking is the process of measuring either the point of gaze (where one is looking) or the motion of an eye relative to the head. An eye tracker is a device for measuring eye positions and eye movement. Most commonly used non-invasive eye gaze trackers use pupil centre and corneal reflection technique (Duchowski, 2007). The eye gaze tracker has inbuilt Infrared LED (Light Emitting Diode) that illuminates the eye and infrared-sensitive video takes rapid pictures of eye. The LED

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reflects small amount of light off the cornea and through the pupil onto the retina. The bright pupil allows image processor to locate centre of pupil. The eye gaze tracker can then locate where the person is looking on the screen based on the relative positions of the pupil centre and corneal reflection within the video image of the eye. A simple calibration procedure that requires users to follow (means staring at) a shape around screen or a designated position in space tunes parameters for each individual user with respect to a two-dimensional screen or three dimensional space. However, there also exist eye gaze trackers that utilise cameras in visible spectrum like webcam or high speed video cameras although those systems are either less accurate (for webcam) or costlier (for high speed video cameras) than infrared trackers.

The complex eyes in human do not only support a complicated visual system but also work as an excellent medium to express affective states. Charles Darwin in his book *The Expression of the Emotions in Man and Animals* written in 1872, indicated a correlation between widening and narrowing of eyes with emotional states. In the first decade of 19th century, Redlich (1908) and Westphal (1907) related pupil dilation with physical task demand, or even thinking of physical task, while Hess (1975) reported change in pupil dilation with respect to viewing of photographs. In recent time, using sophisticated eye-gaze trackers, researchers found that an increase in cognitive load results in a sudden hike in pupil dilation which can be measured by a set of metrics calculated through Wavelet transform of the pupil signal considering driving simulator (Marshall, 2002), aviation (Marshall, 2007) or map reading (Klingner, 2010) tasks. Marshall (2002, 2007) investigated and patented use of pupil signal to detect cognitive load, but change of lighting condition also changes pupil dilation (at a slower pace than caused by a hike in workload) and so far there is not many study conducted on detecting cognitive load from pupil signal under varying ambient light condition.

Besides pupil dilation, researchers have also investigated change in fixation duration, blink count and variance in saccadic eye movements (Lee & Boyle, 2007; Liang & Lee, 2014; Palinko, Kun, Shyrokov, & Heeman, 2010; Yoshida et al., 2014) to detect drivers' cognitive load. There are mainly three types of eye gaze movement – saccades, smooth pursuit and vergance. Saccadic eye gaze movements are ballistic and works like a torchlight for moving attention from one location to other (Purves et al., 2001). In his 1991 report for *Navy Personnel Research and Development Centre*, Kramer (1990) presented a detailed review of endogenous blink and pupil dilation based techniques for mental workload detection. Although the relation between mental workload and rate of eye blinks is debatable but most study found a reliable correlation between average duration of blinks and mental workload in single and dual task situations. Yoshida et al. (2014) and Liang's (2014) work on change in fixation duration and variance in saccadic eye movement did not produce conclusive evidence for detecting cognitive workload from those features, while Toyota (Basir, Bhavnani, Karray, & Desrochers, 2004) has filed a patent for a device that can detect whether the driver is looking away from road from his eyelid movements although it does not consider eye gaze movements.

In aviation sector, van Dijk, van de Merwe, and Zon (2011), Merwe, Henk, and Rolf (2012) investigated eye gaze patterns to assess situational awareness during scenarios of instrument malfunctions. They measured eye gaze fixation rates, dwell time and visual scanning entropy and found that these measures add more insights into the situation than only subjective self-rating metrics. Ratwani, McCurry, and Trafton (2010) conducted a similar analysis on an UAV task and concluded that visual attention allocation and visual scanning are key components to operators' situational awareness.

In recent time, researchers concentrated on a particular type of micro-saccadic eye gaze movement termed as Saccadic Intrusion (SI) (Tokuda et al., 2011) in relation to detecting mental workload. Saccadic intrusions are conjugate, horizontal saccadic movements which tend to be three to four times larger than the physiological microsaccades and take the form of an initial fast eye movement away from the desired eye position, followed, after a variable duration, by either a return saccade or a drift (Abadia & Gowen, 2004). It is characterized by a type of eye gaze movement where

1. Eye gaze returned to same position between 60 and 870 ms interval.
2. Maximum deviation of eye gaze within the interval is more than 0.4° in X-axis.

Tokuda et al. (2011) already reported that the velocity of saccadic intrusion was higher in a complex task condition than the simpler one for most participants in an automotive environment. However Tokuda's study did not involve driving or operating a car simulator. In this paper, we have evaluated utility of saccadic intrusion in detecting cognitive load and its relation to instantaneous perception of developing road hazard.

Initially we have developed an algorithm to detect saccadic intrusion form the eye gaze fixation locations generated by an eye gaze tracker. We conducted four studies to investigate saccadic intrusion. The first study compared average velocities of saccadic intrusion in standard N-back cognitive tests. The second and third studies were conducted in a simulated automotive environment and compared average velocities of saccadic intrusion during single and dual task situations. The last study investigated temporal location of saccadic intrusion with respect to developing road hazard encountered by an automotive driver. We have described the studies in following sections. We hypothesized that

Parameters calculated from Saccadic Intrusion will be significantly different in conditions demanding different amount of cognitive load and distraction.

The independent variable is the condition which will have different levels based on the cognitive load while the dependent variable is parameters calculated from saccadic intrusion.