A Novel Method to Monitor Driver's Distractions

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Abstract
Many attempts were made in the past to monitor a driver's visual and cognitive distractions. Yet, most of the techniques did not become a practical application due to their contact-based nature of monitoring. In this paper, we describe research that aims to monitor the driver's distractions from a distance. The proposed method is based on the thermal signature of the face. The method measures human physiology in a contact-free manner and therefore, is suitable for continuous monitoring. We conducted two experiments to analyze the validity of our method. Experiment-1 focused on driver's cognitive distraction by allowing cell phone talking while driving. Experiment-2 focused on driver's visual distraction by allowing texting while driving. The experimental results from 11 participants illustrate that the facial physiology alters in a measurable amount in both kinds of distraction. The proposed method quantifies this physiological change and detects periods of distractions. Ultimately, this information can be utilized to alert the drivers in real time. Participants' performance analysis confirms validity of the proposed method.

Keywords
Driver's distraction, Multitasking, Handheld devices, Thermal imaging

ACM Classification Keywords
H5.2. Information interfaces and presentation: User Interfaces – Interaction styles, Theory and methods; K.4.1 [Computers and Society] Public Policy Issues: Human safety; H.1.2 [Models and Principles] User/Machine Systems: Human factors.

General Terms
Experimentation, Human factors, Measurement

Introduction
Driver distraction has been a topic of discussion since the last century. The hypnotic effect of windshield wipers on driving performance was debated in 1905. Around the 1930s, the focus was on the impact of the radio programs on the primary driving task. In the current era, the debate has gained attention for cell phone usage in the vehicle. There are several studies devoted to designing a monitoring system for vehicle drivers' distraction. Yamaguchi et al. proposed monitoring driver's stress using biomarkers [7]. Healey et al. used four types of physiological sensors, electrocardiogram (EKG), electromyogram (EMG), skin conductivity (EDA, GSR) and respiration (through chest cavity expansion) for monitoring driving stress [1]. Yamakoshi and his group used differential skin temperature as a driving stress index [6]. Previous work has primarily relied on on-body sensors for use in cars. On body-sensors may not be practical for continuous monitoring. In addition, they restrict users' motion and increase their awareness of being monitored. Therefore, it is not an effective way of continuous monitoring. We explore a method of monitoring facial physiology using a thermal camera. It is passive and contact free and thus, suitable for continuous monitoring.

We use supraorbital skin temperature as a physiological parameter. Because of higher measurement sensitivity and ease of measurement, the skin temperature based stress monitoring has been a popular approach [2][3][5][7]. Our previous work has demonstrated that the supraorbital skin temperature reflects machine operators' mental overloading [3][4]. This physiological parameter has been successfully utilized in user-centric game designing [8]. However, there has been no previous effort made to exploit the facial physiology for monitoring cognitive and visual distractions.

Visual distraction occurs when the driver looks away from the road in order to perform a secondary task (e.g., press buttons on a cell phone). Cognitive distraction occurs when the driver is mentally engaged in an activity which is not directly related to the driving task (e.g., talking on a cell phone).

We have conducted a feasibility study of contact-free physiological monitoring for the abovementioned distractions. Specifically, we first examined cell phone talking while driving instance to analyze the cognitive distraction (Experiment-1). Next, we examined texting while driving instance to analyze the visual distraction (Experiment-2). The physiological variable acquired during the experiments is compared against the participants' simulated driving performance to validate the applicability of the proposed method.

Experimental Design
Thermal Imaging System
We used a high quality Thermal Imaging (TI) system for data collection. The TI system uses a ThermoVision SC6000 Mid-Wave Infrared (MWIR) camera. It records electromagnetic energy between 3-5μm wavelengths

with temperature accuracy of hundredth of a degree centigrade.

Experiment Setup

Figure 1 shows the experimental setup. We used an XBOX-360 game console and the *Test Drive: Unlimited* game to simulate driving. For the cell phone activities (talking and texting), we used an iPhone. A total of 11 participants (4 males and 7 females) volunteered. The mean age of the participants was 27.5 years.

We recorded thermal signature of the participants' face as they were: playing the driving simulation game (Single tasking), talking on the cell phone while playing the game (cognitive distraction), and texting while playing the game (visual distraction). The thermal data was later used to extract the supraorbital signal which reflects the participants' physiological responses. We also recorded participants' game play performance via a Logitech webcam. The visual clips were later used to quantify the performance variables such as driving speed and out of lane time.

Exploring the Experimental Setup

The participants were given an opportunity to explore the driving simulation setup for 10 minutes. This test drive allowed them to acquaint themselves with the experimental setup, and hence helped to reduce anxiety of performing a new task. The participants were asked to follow all traffic signs, and not race during the experiment. They were instructed to maintain a driving speed of approximately 25-30 miles/hr. They were also given an opportunity to get familiar with the iPhone usage including handling phone calls, and texting.

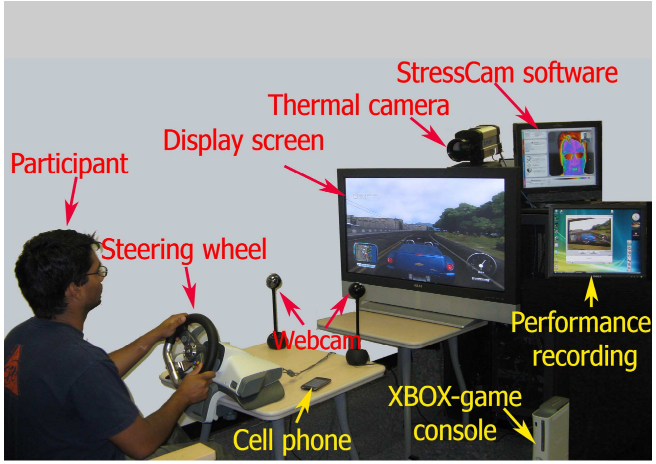

figure 1. Experimental setup; participant, imaging equipments, gaming equipments.

Single Tasking

Next, the participants were asked to play the driving simulation game for 5 minutes. The participants' physiological and performance data collected in this phase was later used for a comparative analysis.

After this period, the participants were asked to relax for 3 minutes. We let them listen to soft/calm music. This helps to isolate effects of other psychological factors that the participants may have carried from the past events. This relaxation period was introduced at the end of each experimental phase.

Experiment 1: Cognitive distraction

The participants were asked to play the driving simulation game while attending to a cell phone call. This phase of the experiment lasted about 5 minutes. After around 1 minute of the primary driving task, the participant received a cell phone call that played a set of prerecorded questions. The question-set was a combination of basic, logical, simple math, and ambiguous questions. The order of the questions was designed to build-up pressure on the participants. Additional pressure was achieved by repeating one more time every question that was incorrectly answered. At the end of the phone conversation, participants put the phone down and continued driving until the end of the phase.

Experiment 2: Visual distraction

Next, the participants were asked to execute texting task simultaneously with the driving activity. This phase of the experiment lasted about 5 minutes. The participants initiated the texting conversation at the end of the first minute by send a text message, "I am running late for the party". Once they received a reply message which was "How much time would you take?" they replied back by texting a message, "I will be there in 10 min". The length of the conversation depended on the participants' texting skill. However, all participants completed the task before the end of the 4th minute of the experiment.

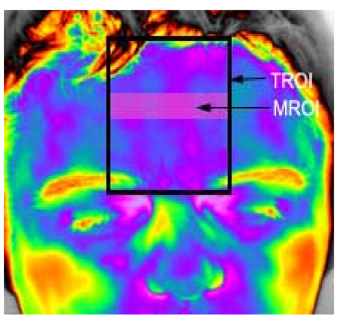

figure 2. The supraorbital signal was extracted from the mean thermal footprint of the pink colored region (MROI).

Methodology

We observed considerable skin temperature increase in the supraorbital region of all 11 participants during the cognitive and visual distractions. This temperature change is an outcome of altered blood supply to the supraorbital, which is an indirect measurement of mental activities [3].

On the initial frame of every thermal clip, we manually selected a Tracking Region of Interest (TROI) such that it encompasses the supraorbital region as shown in figure 2. The TROI is then tracked over time via the smoothie tracker [9], which is specifically designed for the facial tissue tracking. This tracker can handle various head poses, partial occlusions, and inter-tissue region temperature variations. We computed the mean temperature of the Measurement Region of Interest (MROI) for every frame in the thermal clip. Thus, a 1D supraorbital temperature signal is extracted from the 2D thermal data. However, due to imperfections in tissue tracking and systemic noise, the measurements from this area carry substantial noise. We suppressed the noise to a large degree by utilizing the Fast Fourier Transformation (FFT) based noise reduction technique [5]. Next, we modeled the noise-cleaned signal by fitting a linear polynomial to every 20-second signal segment. Although the parameter value 20 was determined heuristically and experimentally, the rationale behind the selection is that the linear fitting on a shorter period segment is affected by the signal noise while the fitting on a larger period segment may overlook the local physiological changes. The linear fitting generates a slope value which represents rate of temperature change for every 20-second segment. Finally, we computed the mean of the slope values over every a one minute period which represents the participants' mental loading [4].

We used two driving variables in the performance analysis: *driving speed* and *out of lane time*. The variables are computed manually from the visual clips. The driving speed is sampled every 2 seconds and averaged over every one minute period. The *out of lane time* variable illustrates an amount of time the participant was driving off the designated lane. It was computed for every one minute period as well.

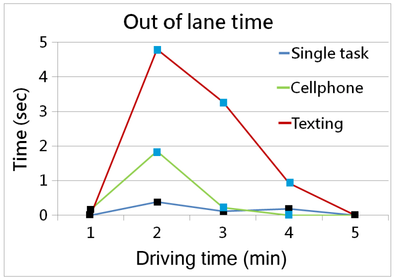

figure 4. The graph illustrates driving performance (*out of lane time*) of the mean participant for the single and dual tasks. The black colored data-points represent single tasking. The blue colored data-points represent dual tasking.

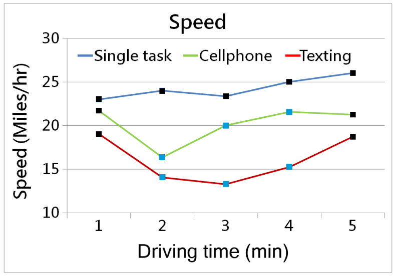

figure 5. The graph illustrates driving performance (*driving speed*) of the mean participant for the single and dual tasks. The black colored data-points represent single tasking. The blue colored data-points represent dual tasking.

Experimental Results

Single tasking

Figure 3 illustrates the mean values of the mental loading of the various segments of the entire dataset (statistically constructed mean participant). An eye-catching observation one could make from the figure is about the minimal mental loading during the single tasking. With the absence of other secondary tasks, the participants give full attention to the primary driving task. Therefore, their mental loading is consistently lowest throughout the experimental period. This observation is in par with driving performance results. The mean participant consistently drove in the designated lane during the single tasking (see figure 4). The driving speed was also maintained close to the desired speed (25-30 miles/hr) during this period (see figure 5).

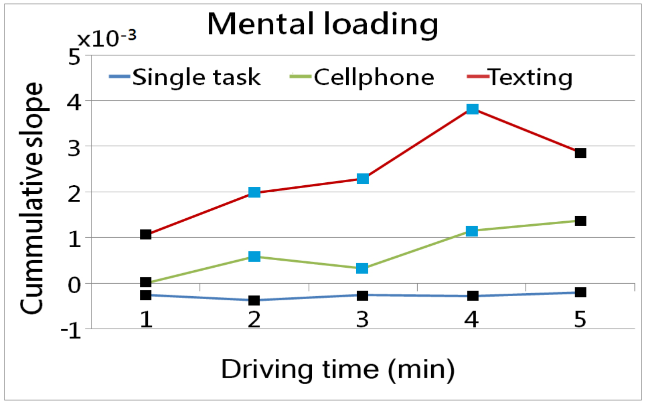

figure 3. The graph illustrates the mental loading of the mean participant for the various segments. The black colored data-points represent single tasking. The blue colored data-points represent dual tasking.

Cognitive distraction

Furthermore, figure 3 illustrates that cognitive distraction increases the drivers' mental stress. The increase in mental loading results from the simultaneous engagement in two mentally challenging activities: talking and driving. The driver's divided attention due to two demanding cognitive tasks overload the brain with information receiving and processing tasks. As a consequence, the brain drains more energy, which in turns increases the blood flow to the supraorbital region. A change in the blood flow alters heat dissipation from the supraorbital region. Thus, tracking the region over time in the thermal domain provides an indirect measurement of the users' mental loading and psychological state [8].

The mental loading consistently increases during the experiment as the cognitive distraction is sustained. The performance analysis demonstrates relatively poor driving performance, especially the driving speed, of the mean participant during the period (see figure 4 and 5). Thus, it confirms the physiological results.

Visual distraction

Figure 3 illustrates the impact of texting while driving on the mental loading. The mental loading is consistently higher during the visual distraction. This mounting mental loading proves that the texting while driving is indeed a very stressful dual tasking. In the extreme case, the accumulation of the mental load was almost 4 times higher than that of the single tasking and 2 times higher than that of the talking activity (see results at the 4th minute in figure 3). The performance results show that the driving performance significantly degrades during the texting period (see figure 4 and figure 5). In general, this finding raises serious concerns about the drivers' safety issues. Therefore, texting while driving should be strictly avoided.

In conclusion, the observations we derived from the results suggest that the proposed method successfully utilizes the facial physiological information to identify the drivers' cognitive and visual distractions. Whenever the mental loading is beyond a certain limit, the method should provide audio-visual feedbacks to limit their secondary activities. Thus, the method can be extended to alert the drivers in real time.

Conclusions

This research work demonstrates the feasibility of the contact-free facial physiological monitoring system for the detection of driver's distraction. The experimental results illustrate that the quantified mental loading is significantly different between single tasking and dual tasking. The mental loading during the cognitive and visual distractions (dual tasking) is considerably higher than that of the single tasking. Thus, we can safely claim that the proposed system is capable of detecting the driver's distractions. This work opens a new area of research that leads to a non-contact monitoring of drivers' psychological states.

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