The Design and Development of Drowsiness Detection System for Road Safety Improvement

Nantakrit Yodpijit, Pathompong Kaewnin, Teppakorn Sittiwanchai

Abstract— **Drowsy driving leads to road traffic accidents, causing fatalities, injuries, and property damages. Over the years, several methods were proposed to detect and predict drowsiness. Eye behavior such as blinking can be used to estimate drowsiness level. The purpose of this research was to design and build a low cost blinking detection system by measuring the resting potential of the retina or electrooculography (EOG) signal. A new design of blinking detection system was tested with participants in laboratory settings. Findings indicated that the blinking detection system worked under controlled conditions. Implications, limitations and future work of the eye blinking detection system were also discussed.**

Index Terms— **Drowsiness, Eye Blinking Detection System, Electrooculography (EOG)**

I. INTRODUCTION

DROWSINESS is a major cause for traffic accidents due to a significant decline in driver's perception of risk and vehicle-handling ability [1]-[4]. The National Sleep Foundation (NSF) reported in "Sleep America Poll 2005" that 60% (around 168 million people) of adult drivers had driven while felling drowsy and more than one-third (37% or around 103 million people) had actually fallen asleep at the wheel [5]. For this reason, it would be beneficial to find ways to detect drowsiness and warn the driver in time before it occurs. Previous research suggested that changes in blinking behavior, such as blinking rate, can be used to detect drowsiness [6], [7]. In addition, in-vehicle warnings with drowsiness detection system can be done to prevent accidents caused by drowsy driving.

EOG is a measure of resting potential of the retina in the human eye. The signal obtained from the measurement is called the electrooculogram. The major applications of EOG are in the areas of ophthalmological diagnosis and analysis of eye movements including blinking detection [8].

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The EOG signal can be measured using electrodes which are placed near the eye. In measuring one pair of eyes, the signal is possible to show measuring results from each eye. It is because the signal is generated by independent measurements from each eye. In healthy people, eye movement is coupled in a vertical direction. Thus, it is adequate to measure vertical motion with a single eye [9]. The amplitude of EOG signal is found between 0.001 to 0.3 mV with a frequency range of 0.1 – 10 Hz [10]. Most often, the EOG signal comes with noises and has non-stationary features even when all possible variables are in control. This is implied that the stability and variability of the EOG signal depend on several factors, which are difficult to determine [9], [11].

For this research project, we have developed and proposed a low-cost EOG wireless system for eye blinking detection. In this system, the EOG signals are sent out to a personal computer for motoring and processing the signals. In the future, we need to make further development on methods for detecting and interpreting eye blinks.

II. A SYSTEM DESIGN

In this study, a new design for the EOG detection system is presented in Fig. 1. First, the EOG signal is measured using electrodes that have been placed around the eye of the subject. The positions for placing electrodes on the face are shown in Fig. 2. Second, the EOG signal is pre-processed by the amplifier circuit and sent out to microcontroller for the second-processed. Finally, the processed signal is transmitted to a personal computer for motoring and doing data analysis via a wireless transmission unit.

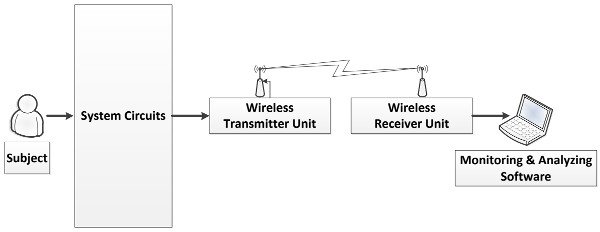

Fig. 1 A connection of a new design for EOG detection system.

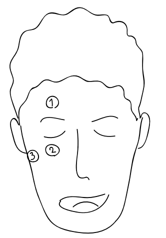

Fig. 2 An electrode placement guide.

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The design and development of this eye blinking detection system is based upon four stages (A-D) as given details below:

A. The EOG hardware

Regarding the design of the EOG hardware, we focused on concepts of making and maintaining the system with low costs, and achieving high-quality signal. The dimension of EOG hardware excluded battery is about 5 cm x 8 cm x 3 cm, as shown in Fig. 3. The EOG system operates at 175.164 mW with 3.7-V DC power supply. This module can operate for over 11 hours with a 2000 mAh Li-ion battery. The hardware consists of three different modules: an amplifier circuit, a microcontroller and a wireless transmitter unit, as given the detail below.

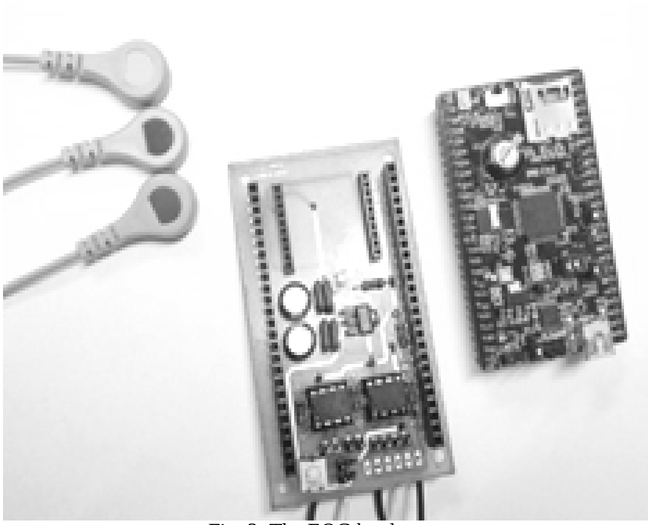

Fig. 3 The EOG hardware.

First, the amplifier circuit has a Low Power Instrumentation Amplifier (INA118 from Texas Instrument [12]), as shown in Fig. 4, and a low-pass filter. The gain of the amplifier circuit is set at 500 times.

Fig. 4 INA118 Instrumentation Amplifier.

Second, microcontroller (Fio-Std from Aimagin [13]), as shown in Fig. 5, receives the amplified signal of 12 bit analog-to-digital converter (ADC) with a sampling rate of 200 Hz. This microcontroller has a great advantage of taking low power consumption due to ARM 32-bits CortexTM – M3 Processor (STM32F103RET6), the built-in RapidSTM 32 native-support boot loader, 496 Kbytes available flash memory, high capacitance (0.33F) capacitor as RTC backup battery and C code support generation of a custom user program for STM32 from a MATLAB Simulink model, to process the amplified signal and send EOG signal to wireless transmitter unit.

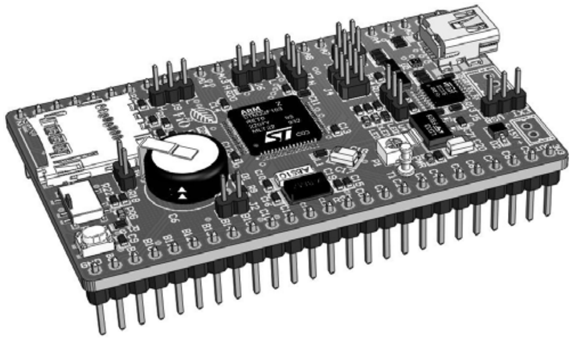

Fig. 5 Fio-Std microcontroller.

Third, the wireless transmitter module (XBee from Digi [14]), as shown in Fig. 6, is used as a wireless transmitting/receiving unit. Since the wireless unit operates at Ultra-High Frequency band (2.4 GHz) to transmit data wirelessly, it can work just fine by using an internal printed-circuit board (PCB) antenna with the data transmission rates of up to 200 kbps.

Fig. 6 XBee Module.

B. EOG Signal Processing Process

Since the amplified signal has been passed to the microcontroller via ADC, the next step is the digital signal processing. With the advantages of using a built-in RapidSTM32 native-support boot loader in Fio-Std microcontroller, it can support C code generation of a custom user program for STM32 from a MATLAB Simulink [15] model.

One of the most challenging roles for the EOG signal processing is to understand characteristics of the EOG signals. We designed the EOG signal processing process with the understanding that the EOG signals always present recorded results and unwanted noises, and the EOG signal does not have a constant feature in nature. Therefore, the EOG signal processing process has to deal with noises and reduces them as they occur. The signal processing process for this EOG system contains only one low-pass FIR filter, using an Equripple method with 80 orders - pass frequency of 3 Hz and cut-off frequency of 4 Hz. Fig. 7 shows a graph of magnitude response obtained from this filter. Fig. 8 shows an example of processed EOG signal from the system. The embedded processor uses a universal asynchronous receiver/transmitter (UART) [16] as an interface to communicate with the wireless transmission unit (XBee) for transmitting signals to a personal computer.

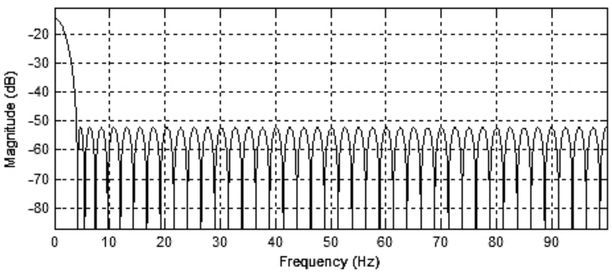

Fig. 7 A graph of magnitude response of the filter.

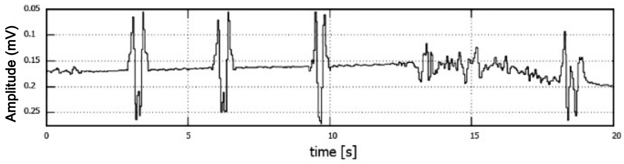

Fig. 8 The processed EOG signal.

C. Blinking Detection Algorithm

At the end of the signal processing process, the processed signal is sent to the personal computer via wireless transmission unit (XBee) to detect eye blinks. This blinking detection system works under the analysis of mathematical functions of time domain. The detection method uses the first derived amplitude of the EOG signal in vertical interval as a decision parameter, which a decision needs to be made by the experimenters or users. An example of the peak detection to be used as decision parameter is presented in Fig. 9.

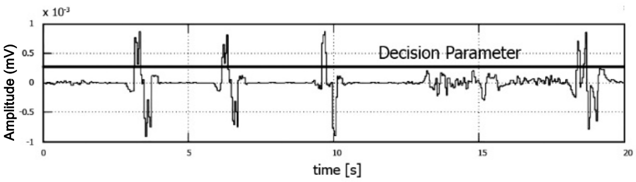

Fig. 9 The EOG signal as a decision parameter.

Adjustable parameters are assigned to help differentiating blinks signal peaks from noises and saccadic eye movements that appear in a detection function. The algorithm pseudo code to determine eye blinks is given below:

```
IF Signal[i] > Decision Parameter THEN
 WHILE Signal[i] > Decision Parameter
    i=i+1
 ENDWHILE
 Blinkcount = Blinkcount +1
ENDIF
```

Given: *Signal* is a vector variable which denotes the first derived signal detecting in a function waveform; *Blinkcount* is a variable in counting the number of blinks; and *Decision Parameter* is an adjustable parameters.

D. Experiments

All experiments conducted in this research project were run in a laboratory setting, as shown in Fig. 10. Decision parameters are manipulated by the experimenters. In these preliminary experiments, a total of 5 participants (3 males and 2 females) were tested. The main purpose of the experiments was to investigate the ability of the system whether it can detect eye blinking or not. Each experiment was run for 10 minutes on each participant. Fig. 11 shows the monitoring screen of the blinking detection system.

Fig. 10 The experimental settings.

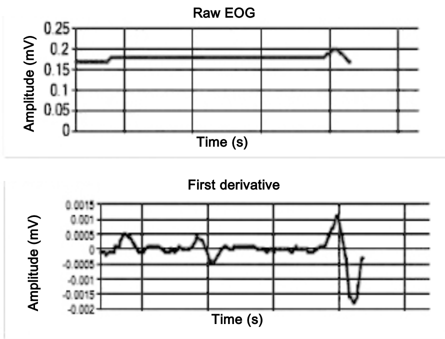

Fig. 11 The monitoring screen.

III. RESULTS

Results from the current study suggest that the blinking detection system using EOG signal can detect eye blinks at the time when eye blinking occurs. The blinking detection system works well when the parameter from EOG signal is higher than decision parameter. Fig. 12 shows the blinking indicator. The system can interpret the blinking logic timeline as shown in Fig. 13 and count eye blinks correctly in a real time manner. Fig. 14 shows blinking rate (blinks counted per minute). This may be concluded that the EOG detection system can work just fine under a controlled condition. However, several issues have been found during the experiments and need to mention as suggestions and limitations for this study. Examples include (1) shaving and cleaning up facial skin before placing electrodes, otherwise the proper EOG signals would be difficult to receive, (2) smaller size and lighter weight of system is needed for the use in a real world situation.

Fig. 12 The blinking indicator.

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Fig. 13 The blinking logic timeline.

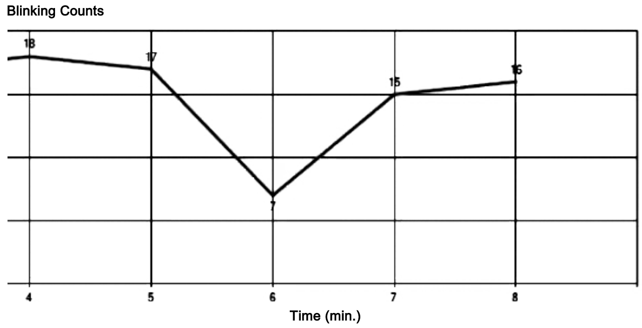

Fig. 14 The blinking counts rates measured from the detection system.

IV. Conclusions and Discussions

A low-cost blinking detection system is built with simple modules and acceptable performance by measuring the EOG signal from one low-pass filter. Results from the preliminary experiments suggest that the blinking detection system can work just fine under controlled conditions such as in a laboratory. However, this blinking detection system has some technical issues that need to be resolved (ie, an automatic blinking detection system, the instability of the signal, the use of electrodes, etc). There are several limitations on using this blinking detection system. Examples are (1) decision parameter needs to be adjusted by the users, (2) the electrode wires are no longer needed for the further development of blinking detection system, etc. For the future research on road safety improvement, the new design on blinking detection system should be developed for the ease of use, installation in a driving simulator and/or a real vehicle, and testing as an in-vehicle warning system to protect drowsy drivers.

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