Drowsy Driving Detection Based on Human Pulse Wave by Photoplethysmography Signal Processing

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ABSTRACT

Drowsiness of driver while driving is one major factor of traffic accident. Therefore, there are many researches to prevent and detect drowsy driving. Recent researches have focused on motion detection using cameras to determine drowsy driving. However, we have focused on non-invasive and inexpensive drowsiness detection system. In our previous research, we suggested a system based on the driver's head movement using infrared sensors. In this paper, we suggest another non-invasive and inexpensive system based on the driver's pulse wave by photoplethysmography (PPG) signal processing. Firstly, the system collects a pulse wave from a PPG sensor on a steering wheel and then it processes the signal to analyze driver's state. In order to evaluate the effectiveness of a human pulse wave for drowsiness detection, we integrated two systems. The experimental result using new integration system showed 83 percent drowsy driving detection rate in the state of real driving.

Categories and Subject Descriptors

H.1.2 [**Information Systems**]: User/Machine Systems – *Human information processing;* I.5.4 [**PATTERN RECOGNITION**]: Applications – *Waveform analysis.*

General Terms

Human Factors

Keywords

drowsiness detection, human pulse wave, photoplethysmography (PPG), driving, sensing, signal processing.

1. INTRODUCTION

From day to day, traffic accidents caused by drowsiness are increasing. According to research report[1] from Virginia Tech Transportation Institute and National Highway Traffic Safety Administration of the United States, drowsiness while driving can raise the risk of accident 4 to 6 times. In practice, 22 to 24 percent of traffic accident factors are about drowsiness. For these reasons, many researchers have studied about drowsiness detection and alarm for drowsiness. In our previous research, we provided the drowsy driving detection system[2] based on the driver's head movement analysis using four infrared sensors and showed 78 percent of success rate to detect driver's drowsiness while practical driving. Like the previous research, the aim of the present paper is also detection of the drowsy driving. In this paper, we suggest a system to detect drowsy driving based on human pulse wave analysis by PPG signal processing. We found the drowsy driving on the hypothesis that the human pulse wave is liable to variation in different activities, especially sleep. The driver's pulse wave was collected by a 990nm wavelength infrared light emitting diode (Ir LED) and proximity sensor, which are mounted with the steering wheel of a car. From the collected data, the suggested system takes the feature point of drowsiness.

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2. RELATED WORK

Recently, there has been growing interest in detection of drowsiness while driving. We already provided a system[2] to detect drowsy driving based on driver's head movement. Although, it showed good drowsy driving detection rate, yet it is lacking in detail. Therefore, we needed an optional system to complement it. Many researches about detection drowsiness while driving use biosignal. Lee et al.[3] suggested the safety driving system using e-health and telematics technology. It used the body temperature and skin impedance level (SIL) to detect drowsiness. Lin et al.[4] suggested the electroencephalogram (EEG) based drowsiness estimation system with virtual reality (VR) based dynamic driving simulator. However, they both are not practical because they need expensive equipments and provide invasive approaches. Because of these reasons, our research was focused on the non-invasive and inexpensive drowsy driving detection system.

3. MATERIALS AND METHOD

Figure 1 shows the conceptual design of suggested system. It consists of two main parts: Sensing part and Analyzing part. The sensing part senses the human pulse wave which is the variation of a infrared signal reflecting from the driver's finger. The analyzing part gets the digital data from the sensing part, then analyzes and detects the drowsiness points.

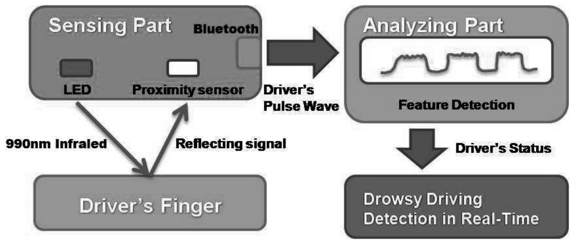

Figure 1. Conceptual Design of the System

3.1 Sensing Part

3.1.1 Photoplethysmography Sensor

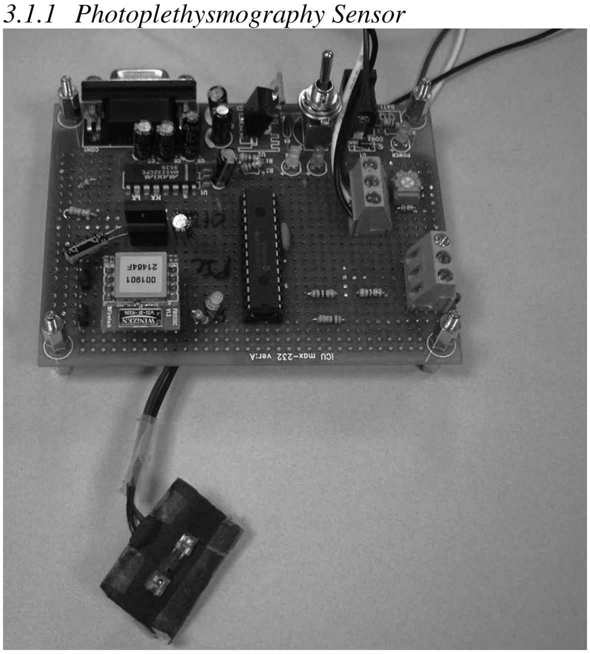

Figure 2. Implementation of PPG Sensor

The PPG sensor is a common method to measure the human pulse wave. Figure 2 shows the implemented PPG sensor using a PIC chip, Bluetooth module, 990nm wavelength infrared LED and proximity sensor. At first, we used a 660nm red light LED. However, it was so weak against external light sources. Therefore we replaced a 660nm wavelength red light LED by a 990nm wavelength infrared LED. In addition, we wrapped up infrared LED and proximity sensor part of PPG sensor with small black board to make the sensor stronger against external noise. Finally, PPG sensor can collect the driver's pulse wave from the reflection of driver's finger while driving.

3.1.2 Installation of PPG Sensor in a driver's seat

To collect driver's pulse wave while driving, we installed the LED and proximity sensor part of PPG sensor on the steering wheel. Pilt et al.[5] suggested that the PPG probe must locate second finger for efficient measurement. Therefore, we mounted the PPG sensor with the common location for second finger of left hand on the steering wheel. In addition, we located main circuit board of PPG sensor on the dashboard in front of the car. Our first prototype of PPG sensor contained RS232 cable for data transmission and 12V adapter for electric power supply. However, these cables were the cause that driver was uncomfortable. On that score, we decided to use Bluetooth module for wireless data transmission and 9V battery for electric power supply.

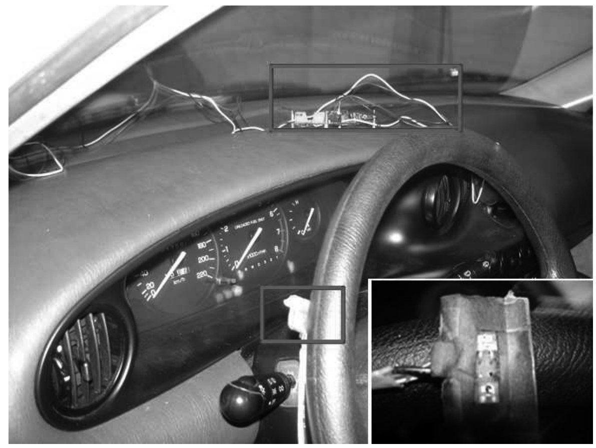

Figure 3. Installment of PPG Sensor in a Driver's Seat

Lastly, we installed a laptop computer with a rack in a passenger seat to receive and analyze driver's pulse wave. From this, we finished building an experiment environment.

3.1.3 Software for Getting Sensing Values

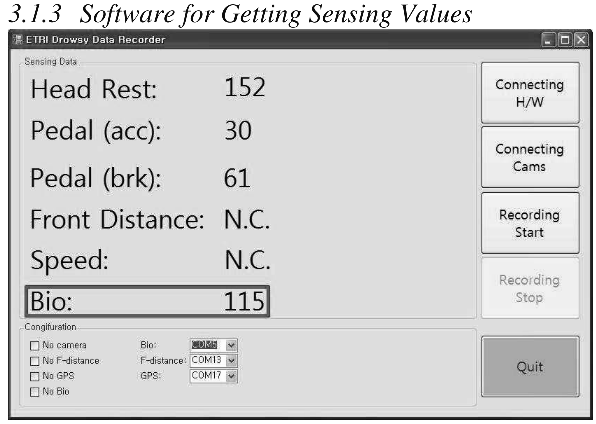

Figure 4. Human Pulse Wave Recording Program

We made simple software to receive sensing values from infrared sensor of headrest, pressure sensor of pedal and PPG sensor. Among others, the Bluetooth module of PPG sensor main circuit sends driver's pulse values to the recording program with 80 samples per second. In addition, the range of each value is 0 to 255.

Eventually, we could get the driver's pulse rate in stable environment.

3.2 Analyzing Part

The analyzing part processes the digital signals from the sensing part in real-time. Figure 5 shows the driver's pulse wave from the PPG sensor. The analyzing part calculates the driver's pulse wave then, gets the feature point using these signals to determine driver's status. In order to extract the feature point, we extract attributes of the wave using smoothing technologies and we analyze the variation of peaks and wavelength according to driver's status. Also, we need the pre-defined user's preference parameters.

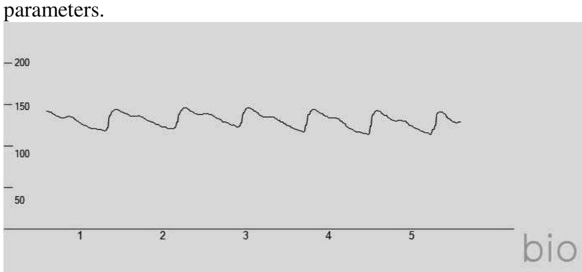

Figure 5. Human Pulse Wave

3.2.1 Analysis Method for Driver's Pulse Wave

We had a hypothesis to analyze driver's status using pulse wave. Possibly, the driver's pulse wave in drowsiness status would be more monotonous than in normal status. To prove our hypothesis we made another software, which finds pulse wave except for noises and computes width and height value of the pulse wave within each period.

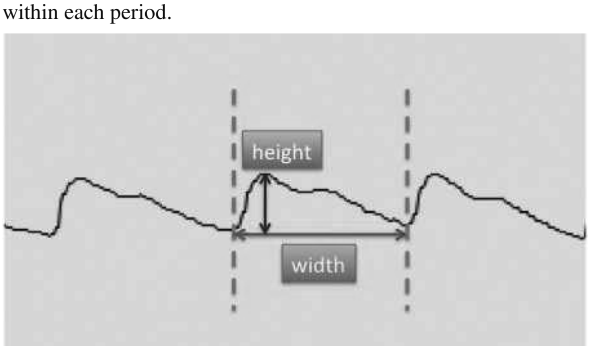

Figure 6. Human Pulse Wave Analysis Method

3.2.2 Classification of Driver's Status

To classify the driver's status, we made a classification rule based on a threshold value. At first, we made an experiment on driver's status. Subjects of the experiment are five people. The Subjects participated in the experiment for five days. Each subject performed the experiment about driver's status in simulated driving situation at least an hour, everyday. Eventually, we could get enough reference data, and make a threshold value based on the experiment result of five people.

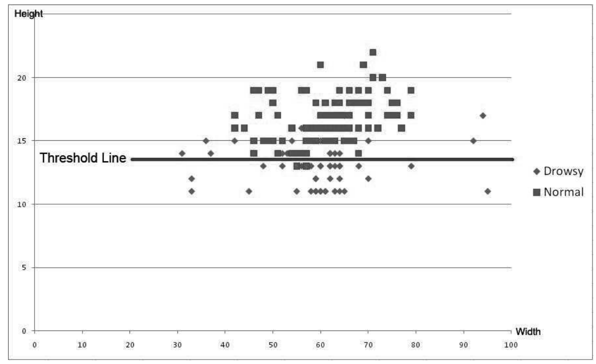

Figure 7. Result of Sample Data Analysis

Figure 7 shows a result of sample data analysis. It is a result just about 300 to 400 data samples. In substance, we used over a million samples to get the threshold value. We referred our hypothesis to analyze driver's status. As a result of the experiment, we could confirm a point of difference between normal status and drowsy status. The width value of each pulse wave doesn't have enough of a difference. However, the height value has a difference to distinguish drowsy status from normal status. In general, the height value of drowsy status samples is lower than height value of normal status samples. We got a more specific threshold value from reference data, and applied it to non real-time and real-time drowsy driving detection system.

3.2.3 Non Real-time Drowsy Detection System

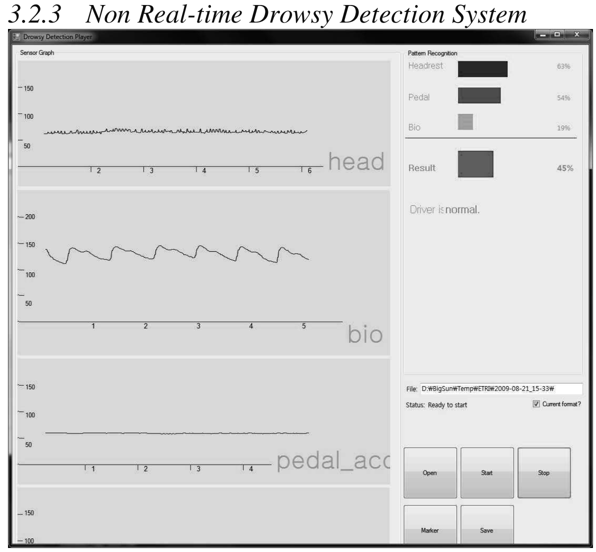

Figure 8. Non Real-time Drowsy Detection System

In previous research, we made a drowsy driving detection system based on the driver's headrest movement using infrared sensors. In this paper, we suggest a drowsy driving detection system based on the driver's pulse wave using PPG sensor. We integrated these two systems. Each system computes a drowsy rate, individually. The drowsy rate is expressed by percentage. Beside, integrated system computes a final drowsy rate using two drowsy rates with SVM (Support Vector Machine). The final drowsy rate, which is bigger than 50% decides system to recognize drowsy driving.

3.2.4 Real-time Drowsy Detection System

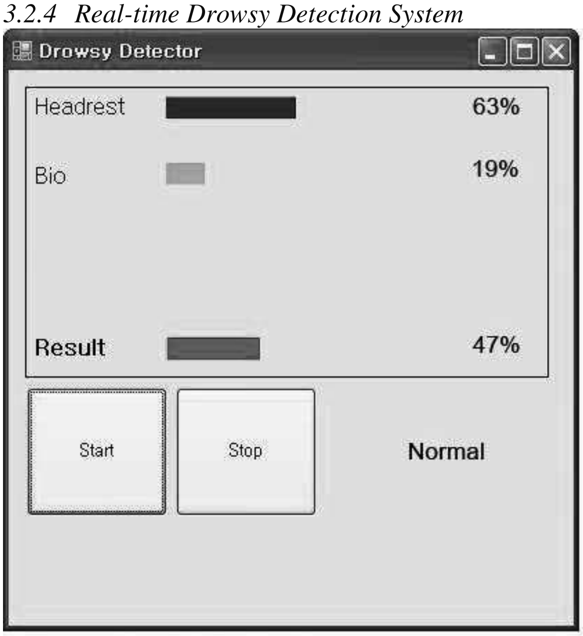

Figure 9. Real-time Drowsy Detection System

We gathered data using non real-time drowsy driving detection system. Beside, we added learning module to the system. We could build a real-time drowsy driving detection system through the non real-time drowsy driving detection system and added learning module. Finally, we can classify driver's status in the state of real driving.

4. RESULTS

We integrated two systems: the system based on the driver's head movement using infrared sensors and the system based on human pulse wave by photoplethysmography signal processing. We did experiments using integration system for five subjects in the state of real driving. The experiments made it a condition that driving is performed on a secluded and straight road. The drowsy driving detection system showed 83 percent drowsiness detection rate. In our previous research, the system based on driver's head movement showed 78 percent of success rate to detect driver's drowsiness while practical driving. In contrast to previous research, the detection rate was raised slightly.

Subject	Age/Sex	Detection / Drowsy Driving
A	24 / MALE	2 / 3
B	25 / MALE	2 / 2
C	26 / MALE	1 / 2
D	26 / MALE	3 / 3
E	28 / MALE	2 / 2
Total		10/12
Detection Rate		83%

Table 1. Result of Experiment in Real Driving Situation

5. CONCLUSION AND DISCUSSION

In this paper, we suggested drowsiness detection system based on the driver's pulse wave. The implemented PPG sensor collects the driver's pulse wave. In addition, we built the system, which can detect drowsy driving in non real-time and real-time situation. The suggested system showed 83 percent drowsiness detection rate in the state of real driving. In the near future, we will apply adaptive threshold value and add learning module to the system, which is based on human pulse wave using PPG sensor. We expect that the detection rate will be better than now.

6. REFERENCES

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