Development of Real-Time Driver's Health Detection System by Using Smart Handle

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ABSTRACT

The number of vehicle accidents due to driver's drowsiness continues to increase. Therefore, prompt and effective detection for driver's health during driving is crucial to improvement of traffic safety. A set of real-time health detection system built-in a smart handle for driver is proposed in the research. By monitoring driver’s biological signals, including respiration, hand gripping force, photoplethysmogram (PPG), and electrocardiogram (ECG), driver's health condition (drowsiness) is able to be detected via the developed algorithm. Meanwhile the driver's state of arrhythmia can be diagnosed too. The test results indicate that the developed real-time driver’s health detection system can effectively monitor not only the state of vigilance but also the state of arrhythmia of a driver.

1. INTRODUCTION

Traffic Accident Analysis Center (2012) reported that the number of traffic accidents caused by driver’s carelessness gradually increases. Drowsiness and fatigue have become one of the major reasons of serious traffic accidents. Bergasa, Nuevo, Sotelo, Barea, and Lopez (2006) found that , according to the U.S. National Highway Traffic Safety Administration (NHTSA), drowsiness during driving is responsible for at least 100000 vehicle crashes annually, resulting in annual averages of roughly 40000 nonfatal injuries and 1550 fatalities. Rosekind (2006) shown that the National Sleep Foundation has also reported that 60% of adult drivers have driven while feeling drowsy, and 37% have even actually fallen asleep at the wheel. Moreover, driver’s serious disease, such as heart attack, of would lead to fatal traffic accidents. Thus traffic accidents due to driver’s carelessness have become a serious social problem. As a result, prompt and effective detection for driver's health while driving is crucial to improvement of traffic safety. Researchers have developed lots of methods to monitor driver’s state of vigilance. Once the driver is considered to be falling asleep equipment is able to wake up the driver by giving warning signals via strong seat vibration or high pitch sound so as to prevent vehicle accidents. Eskandarian and Mortazavi (2007) monitored the driver’s state of vigilance on the basis of driving performance to estimate the driver’s fatigue. Other methods based on monitoring eye activity by means of video cameras have been developed to indicate the driver’s state of vigilance too.

The most reliable monitoring method is to use physiological signals, such as brain waves, heart rate, pulse rate, and respiration rate signals. Considering convenience of monitoring driver as driving, respiration, hand gripping force, and electrocardiogram (ECG) signal are utilized in the research to detect wake or sleep stages of the driver by analyzing heart rate (HR) and heart rate variability (HRV). How to construct the monitoring system will be given in the section 2, while the detection algorithm of driver’s state of vigilance and arrhythmia will be proposed in the section 3.

2. REAL-TIME DRIVER'S HEALTH DETECTION SYSTEM

The proposed real-time health detection system applied onto the smart handle is composed of three biological sensors, an interface circuit, a data acquisition (DAQ) board, and a personal computer (PC), which can monitor driver’s biological signals, including respiration, the gripping force, a photoplethysmogram (PPG), and electrocardiogram (ECG). The layout the entire smart handle system is shown in Figure 1.

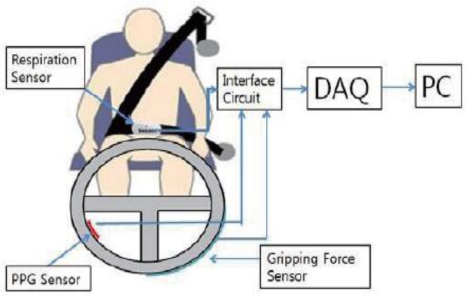

Figure 1. Layout of real-time driver's health detection system: smart handle.

2.1. Sensors for Monitoring Driver's Health

Three biological sensors are adopted in the smart handle: pressure sensors, a PPG Sensor, and ECG detection probes. The respiration signal and gripping force are obtained from pressure sensors attached to the seat belt and the steering wheel, respectively. The PPG signal is acquired from a PPG sensor that consists of a light-emitting diode (LED) and a phototransistor (PT) attached on the steering wheel. And the ECG signal is obtained by two the probes attached on the steering wheel and a probe on backrest.

The pressure sensor is bonded to the abdomen part of the safety belt to measure driver’s respiration, as illustrated in Figure 2. The respiration signal is an important and easy-to-measure signal. A correlation has recently been found between respiration and drowsiness. The respiration signal can be acquired by means of the resistance variation of the pressure sensor attached on the safety belt as the driver inhales and exhales.

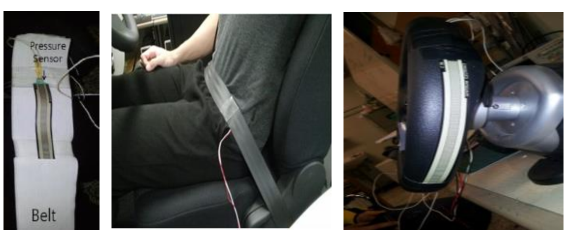

Figure 2. Pressure sensor attached onto the safety belt and the smart handle.

Figure 3 shows a PPG sensor, including a light-emitting diode (LED) and a phototransistor (PT) attached on the steering wheel. As driver hand catches hold of the smart hand, light generated by the LED is shone onto the skin, and then the amount of light reflected to the PT can be measured. The amount of reflected light depends on the volume change of the blood vessels induced by the pressure pulse of the cardiac cycle. By using information obtained from the PPG sensor, driver’s heart rate (HR) and heart rate variability (HRV) can be obtained.

Figure 3. PPG sensor including LED and PT

Two conductive fiber, as electrodes, are attached on the smart handle (refer to Figure 4) so as to detect the tiny electrical changes on the skin that arise from the heart muscle's electrophysiologic pattern of depolarizing and repolarizing during each heartbeat. In order to ensure to obtain reliable ECG signal, an additional probe is installed on the driver seat backrest.

Figure 4. ECG detection probes by using conductive fiber

2.2. Interface Circuit and Data Acquisition Board

Interface circuit is necessary to convert signals from sensors to proper analogue signals for reading of data acquisition board. Another function of interface circuit is to filter and amplify signals. For example, Waveforms with frequencies between 0.15~4Hz are main components in human ECG signal. Therefore a high-pass filter with cutoff frequency 0.15Hz, a low-pass filter with cutoff frequency 4Hz, and a notch filter for taking out 50Hz noise are designed for conditioning of ECG signal. And then the filtered ECG signal is amplified by about 20 times. The interface circuit of ECG signal is shown in Figure 5.

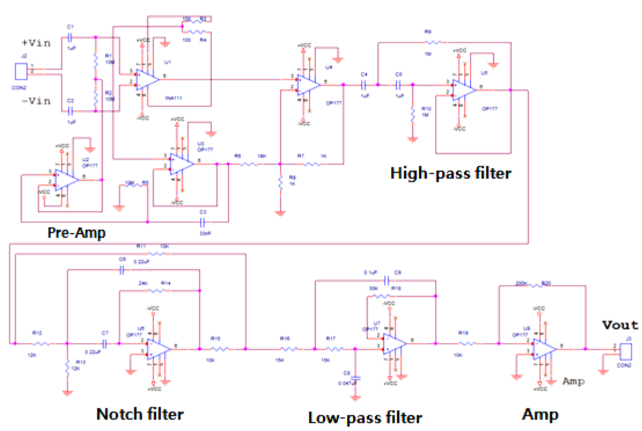

Figure 5. Interface circuit of ECG signal conditioning

A 10-bit data acquisition board as well as a PC is constructed for hardware part and the monitoring graphic user interface is developed on LabVIEW platform. Figure 6 presents signals acquired by various sensors in GUI.

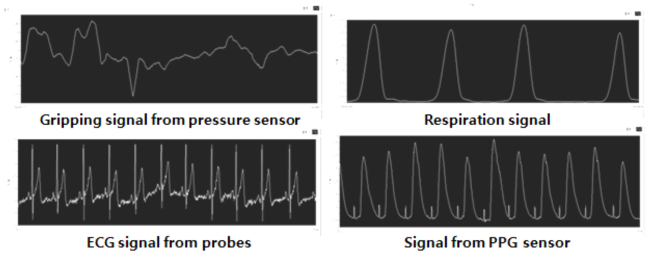

Figure 6. Signal representation in LabVIEW platform

3. DEVELOPMENT OF DETECTION ALGORITHM

Based on the previous hardware construction of real-time driver's health detection system, the next work is to develop detection algorithm of driver's drowsiness (vigilance) and arrhythmia.

3.1. Detection Drowsiness

As stated previously, driver's respiration signal is utilized to detect drowsiness. The peak value and moment of the acquired respiration signal are firstly determined and then respiration rate can be calculated from continuous respiration signal. The peak values and respiration rates in wake state and sleep state are different, therefore the reference values can be used to judge if the driver gets into drowsiness state or not. The number of drowsiness is counted and if it arrives three time the driver's drowsiness is judged. The entire detection process based on respiration signal is given in Figure 7.

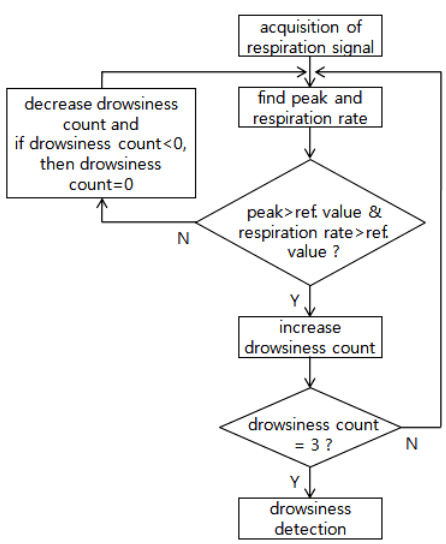

Figure 7. Drowsiness detection algorithm based on respiration signal

As far as the PPG signal is concerned, its peak (shown in Figure 6) can be also found and some statistical analysis is performed, such as average and dispersion of peak-peak interval. Similarly, these two statistical quantities are compared with the reference values so driver's drowsiness can be detected. The algorithm flow chart is shown in Figure 8. The heart rate is thus calculated from peak-peak interval.

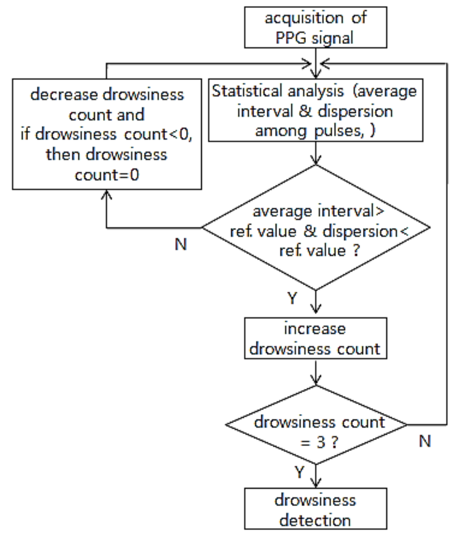

Figure 8. Drowsiness detection algorithm based on PPG signal

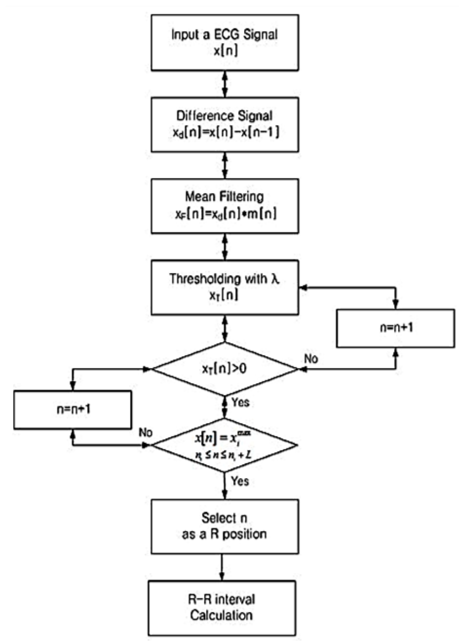

Figure 9. Heart rate detection algorithm based on ECG signal

The driver's ECG signal is a reliable one to obtain information of heart, like heart rate and heart rate variability. To find QRS wave peak is most important for analysis of

ECG signal. And then the interval between peaks of two neighboring QRS waves, i.e. R-R interval, can be easily calculated. This process is illustrated in Figure 9. Figure 10 shows how to find the R wave peak, start point, and end point of QRS wave and then to determine R-R interval and R wave duration.

Combining the above three detection algorithms, the entire flow chart of drowsiness detection algorithm is given in Figure 11. The PPG signal and ECG signal depend on where the driver put his/her hands on the smart handle, so both signals are utilized to ensure successful drowsiness detection. Of course the respiration signal is always variable. Once driver's drowsiness is finally detected the warning system for driver will take function.

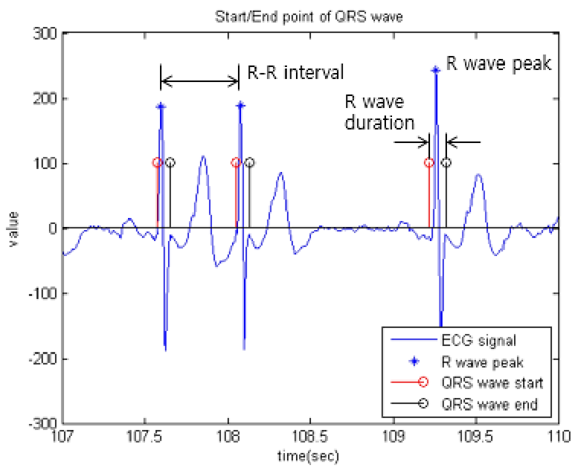

Figure 10. Determination of R-R interval and R wave duration of ECG signal

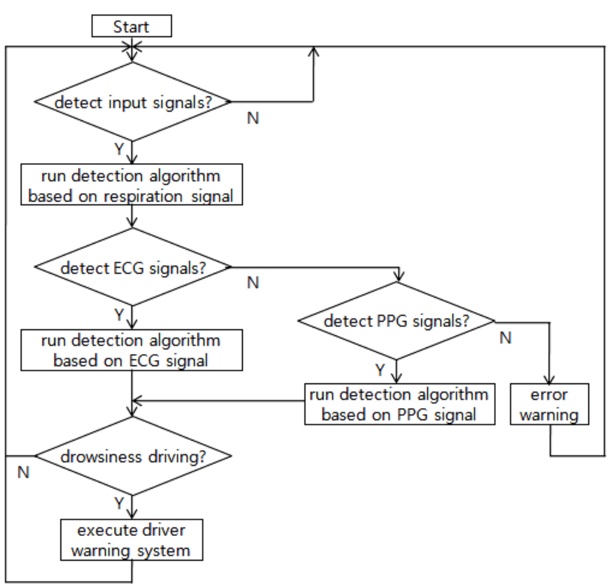

Figure 11. Flow chart of drowsiness detection algorithm

3.2. Detection Arrhythmia

The driver's state of arrhythmia can also be detected by analyzing ECG signal. Values of R-R interval and R wave duration of ECG signal for normal persons follow in a certain range. Therefore if the driver's R-R interval and R wave duration of ECG signal locate outside of the normal range, it means that the driver is probably subject to threat of heart attack, for example, the most common case, arrhythmia. Figure 12 illustrates an analysis result of arrhythmia by using R-R interval and R wave duration of ECG signal. The R-R interval and R wave duration can be found in the upper figure by as like shown in Figure 10. And then it is found that there are two abnormal R-R interval at about 4537 sec and 4547 sec, which show fast heart rate than normal persons (in middle figure). The corresponding R wave duration at these two moments are compared with the normal value and finally it is determined that arrhythmia happened two times in this period as shown in the below figure.

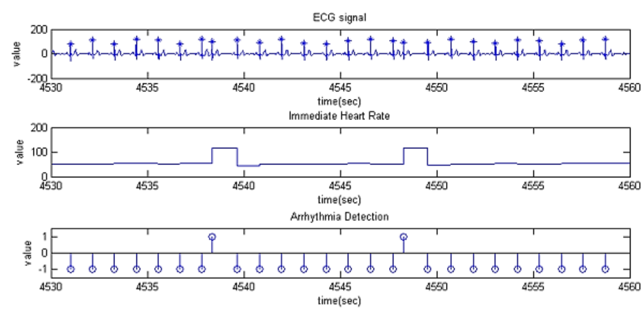

Figure 12. Diagnosis of arrhythmia from ECG signal

4. CONCLUSION

A set of real-time health detection system applied on a smart handle for drivers is proposed in the research. The proposed detection system of the smart handle is composed of three biological sensors, an interface circuit, a data acquisition (DAQ) board, and a personal computer (PC). By monitoring driver's biological signals, driver's healthy condition is able to be detected via the developed algorithm, which includes driver's drowsiness (or vigilance) and driver's state of arrhythmia. The test results indicate that the developed real-time driver's health detection system can effectively monitor not only the state of vigilance but also the state of arrhythmia of a driver. The accuracy and reliability of the developed system, especially detection algorithm, are being validated based on more really measured data. It is expected that the results could be advanced to the automotive driver's prognostic health management in near future.

ACKNOWLEDGEMENT

This work was supported by the Ministry of Knowledge Economy (MKE) and Korea Institute for Advancement of

Technology (KIAT) through the Center for Automotive Mechatronics Parts (CAMP) at Keimyung University.

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