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Real Time Drowsiness Detection by a WSN based Wearable ECG Measurement System

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Abstract

Whether a person is feeling sleepy or reasonably awake is important safety information in many areas, such as humans operating in traffic or in heavy industry. The changes of body signals have been mostly researched by looking at electroencephalogram(EEG) signals but more and more other medical signals are being examined. In our study, an electrocardiogram(ECG) signal is measured at a sampling rate of 100 Hz and used to try to distinguish the possible differences in signal between the two states: awake and drowsy. Practical tests are conducted using a wireless sensor node connected to a wearable ECG sensor, and an ECG signal is transmitted wirelessly to a base station connected to a server PC. Through the QRS complex in the ECG analysis it is possible to obtain much information that is helpful for diagnosing different types of cardiovascular disease. A program is made with MATLAB for digital signal filtering and graphing as well as recognizing the parts of the QRS complex within the signal. Drowsiness detection is performed by evaluating the R peaks, R-R interval, interval between R and S peaks and the duration of the QRS complex..

Keywords : Wearable ECG Measurement System, Wireless Sensor Network, QRS Complex, Drowsiness Detection, R-R Interval, Interval between R and S Peaks

1. INTRODUCTION

Sleepiness or drowsiness, a state of near-sleep with a strong desire to sleep, has been recognized as a serious cause of accidents or near-accidents in traffic as well as in industry[1,2]. For this reason, a lot of research has been done to find indications of the need to sleep. If recognition of the first symptoms of drowsiness was possible by the use of small body area sensors, it would enable the development of a warning system that would alert a driver or worker of the need to take a break for the safety of themselves and everyone around.

In this study, ECG data is used to try and find some diagnostic differences between the data collected from a drowsy person and a person who is wide awake. An ECG is an electrical recording of the heart. It can be used for multiple purposes when investigating the health or sickness of a heart and for that reason; it has been widely studied since it was first discovered by Eithoven in 1893[3]. Traditionally ECG was measured with a twelve lead system where electrodes are attached to skin and then to a machine. However, these existing methods for measuring physiological signals are inconvenient and complicated because the wired electrodes ought to be directly connected on the body. To improve these inconvenient factors, researches into the relation between drowsiness and fatigue have been studied by using wearable sensors[4]. A lot of effort has been focused on how to get physiological signals in a convenient and noninvasive measurement environment. In addition, development of drowsiness detection systems for drivers has been reported in the literature. These drowsiness detection methods can be categorized into two major approaches. Traditionally, video recognition techniques using camera images have been used widely. This approach analyzes the images captured by cameras to detect physical changes in drivers, such as eyelid movement, eye gaze, yawning, and head nodding[5]. This vision-based method is not very accurate because it is severely affected by environmental background, driving conditions, and driver activities[6]. Among the many technologies used to check the body's condition, one of the best techniques is to measure

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biomedical signals such as brain waves, heart rate, and pulse rate in real time. In addition, high reliability and accuracy of detection of various driver conditions such as stress, fatigue, chronic disease, and health status can be achieved by measuring biomedical signals via nonintrusive methods.

In recent years developments in technology has allowed us to diminish the number of leads needed for a diagnostically eligible signal and now, since the development of body sensor networks(BSN), it is one of the most researched biological signals to be recorded and transferred through wireless sensor network[7]. The body sensor network is a network of sensors spread around a body. The sensors are generally attached directly to the body or attached to clothes someone is wearing. The basic organization of a BSN consists of attached sensors and a control unit to which send their data. Remote servers or gateways then perform further data processing, aggregation or storage functions. In this paper, a wearable ECG measurement system is proposed to measure an ECG signal with the two conductive electrodes on the chest for evaluation of health. The system allows ECG signals to be transmitted through a wireless sensor network from the wearable ECG sensor to a base station connected to server PC via IEEE 802.15.4 standard. A MATLAB program is written with which the recorded and transferred data is filtered to achieve comparable results in order to recognize the drowsiness of a person while, for example, driving a car.

2. SYSTEM DESIGN

Fig. 1 shows the design of the proposed ECG measurement system. A wearable sensor is connected to a wireless sensor node placed on a patient's body to collect ECG signals and transmit them to the server for analysis.

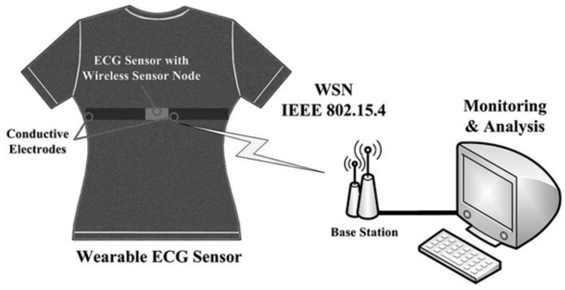

Fig. 1. Architecture of the ECG measurement system.

To make the monitoring as comfortable as possible, the ECG sensor is placed in a shirt with conductive fabric electrodes. Two 8 cm conductive fabric electrodes are placed on the inner chest part of shirt in contact with the patient's skin. The ECG signals are measured by both chest electrodes and by an analog signal conditioning circuit that consists of two amplifiers, two low pass filters(LPF), and a high pass filter(HPF). Then, they are transmitted by wireless communication to a gateway-connected PC. The raw ECG signal is taken from the ECG interface and processed through an analog signal conditioning circuit designed to eliminate analog noise signals. The final cut-off frequency is from 0.5 Hz to 34 Hz and the total gain is 500(27 dB) as shown in Fig. 2.

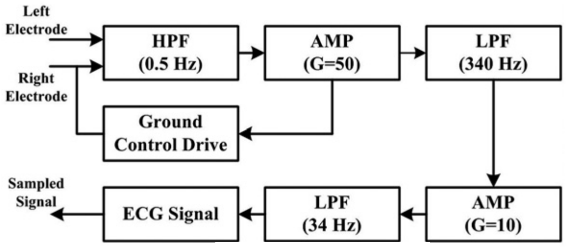

Fig. 2. Configuration of the analog signal conditioning circuit.

The ECG signals are sampled at 100 Hz from the wearable ECG sensor and saved in buffers with a 20-byte packet size for wireless communication. The ECG sensor interface is connected to the wireless sensor node via the IEEE 802.15.4 standard. Both the ECG sensor and the wireless sensor node are operated at 3.3 V and support several low power operating modes, consuming as little as μA while in sleep mode and 18 mA in active mode. Fig. 3 and Table 1 show the hardware for the wearable ECG sensor and the specifications of the ECG sensor interface connected to the wireless sensor node. The wireless sensor node uses TinyOS, which is an open source operating system for wireless embedded sensor networks[8].

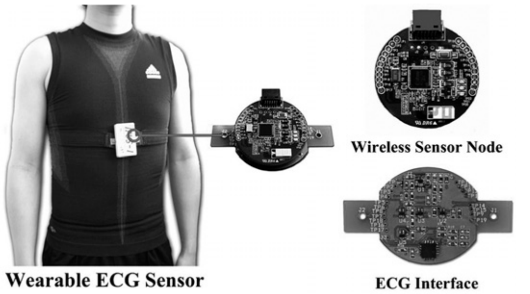

Fig. 3. Hardware devices for wearable ECG sensor.

Table 1. Specification of the wearable ECG sensor

Sensors	Items	Specifications
ECG Sensor	Electrodes	Strap (Polar)
	Gain	500 (27 dB)
	Cutoff Frequency	0.5 Hz ~ 34 Hz
	Power	3.3 V
Sensor Node	MCU	MSP430F1611
	RF Interface	IEEE 802.15.4
	RF Transceiver	TI CC2420
	Data Rate	250 kbps

3. METHODS

An ECG signal of the cardiac cycle consists of a P wave, a QRS complex, and a T wave as shown in Fig. 4. The baseline voltage of the ECG signal is measured as the portion of the signal following the T wave and preceding the next P wave. The duration of the P wave reflects the time taken for the wave of depolarization to spread over the atria. The QRS complex records potentials at the body surface generated when the wave of depolarization passes through the ventricles. The amplitude of the QRS complex is greater than that of the P wave because the ventricular mass is greater than that of the atria. Table 2 provides approximate values for the durations of various waves and intervals in a normal adult ECG. Many are age or gender dependent and can vary with heart rate[9].

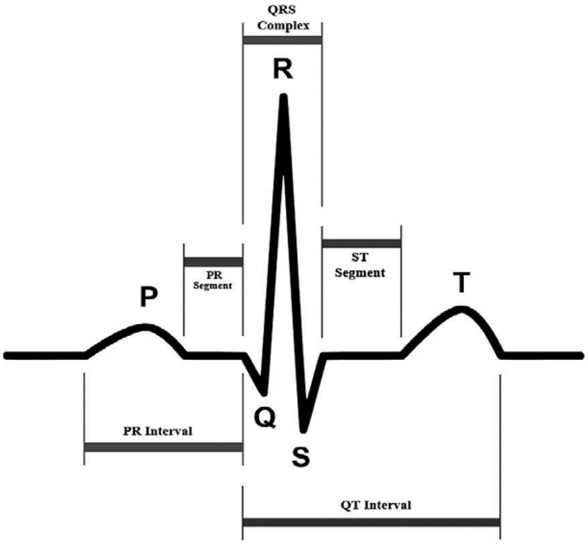

Fig. 4. Typical ECG tracing of the cardiac cycle.

Table 2. Durations of waves and intervals in a normal adult

Parameters	Duration (ms)
P-R Interval	120 - 200
Q-T Interval	300 - 400
P wave	80 - 100
QRS Complex	60 - 100

Real-time QRS detection is based on analysis of slope, amplitude, and width of the QRS complexes. It includes a series of filters and methods that perform low pass, high pass, derivative, squaring and integration procedures. Filtering reduces false detection caused by the various types of interference present in the ECG signal. This filtering permits the use of low thresholds and thereby increases the detection sensitivity. After differentiation, the ECG samples are squared. This makes all data points positive and nonlinear amplification of the output of the derivative emphasizes the higher frequencies. The moving window integration extracts more information from the signal to detect the QRS complex by averaging a certain number of samples per window[10, 11]. Once these preliminaries are complete, signal processing of the QRS complex is performed in order to analyze the measured ECG signal using MATLAB R2007a. After trying a few other methods and reading some articles, we decided to filter our signal with a simple fourth order Butterworth filter. The order is chosen by trial and error as well as using some reference materials where the fourth order is recommended for ECG filtering. The low pass filtering is very important for the reduction of the noise gathered during the measurement and the high pass filtering is used to straighten the signal baseline. Detection of the QRS complex is then processed as shown in Fig. 5 and an attempt to distinguish some features that could be considered different from the proposed parameters is made. These differences could indicate when people change from one state to another [12].

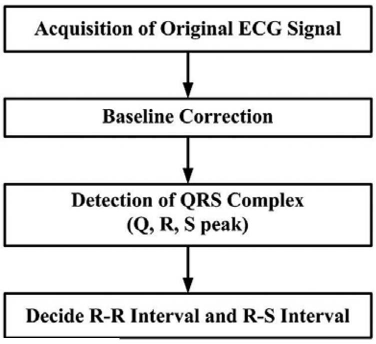

Fig. 5. ECG analysis flowchart.

4. EXPERIMENTAL RESULTS

Practical experiments are carried out so that healthy subjects participated in three normal and drowsy state experiments. Each experiment took three minutes over 3 days using the ECG sensors in real time. The original data on its own can be seen in Fig. 6.

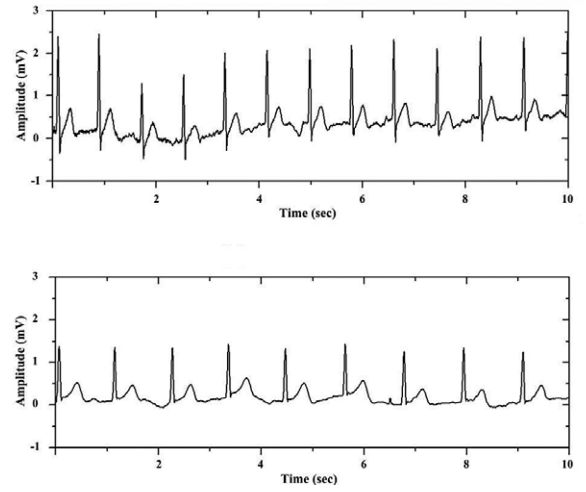

Fig. 6. The measured original ECG signals.

In signal processing, the one minute average of the samples is counted to clear the signal and simplify the handling of the data. The ECG signal is first saved to a server PC to make the handling and reading of it easier. Then, the raw ECG signal is filtered and amplified through analog signal conditioning circuits. For ECG analysis, a variant of the Pan-Tompkins algorithm is used[9]. This algorithm was adjusted according to our analysis requirements and the programming was done in the MATLAB program. The Pan-Tompkins algorithm uses real-time QRS detection based on the analysis of slope, amplitude, and width of QRS complex. It includes a series of filters and methods that perform low pass, high pass, derivative, squaring and integration procedures. Filtering reduces false detection caused by the various types of interference present in the ECG signal. This filtering permits the use of low thresholds and thereby increases the detection sensitivity. The algorithm adjusts the thresholds automatically and the parameters periodically to adapt to changes in the QRS morphology. Here we use 100 samples per sec and an 80 ms moving average, the moving window integration process produces a signal wherein the peaks of the signal have been emphasized. The threshold value in the moving window is 12 % of the R peak.

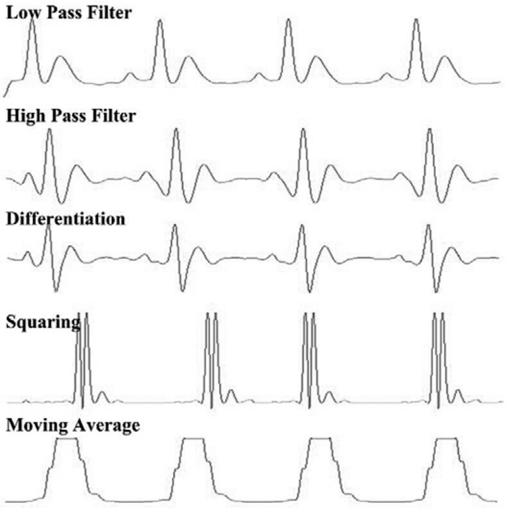

Fig. 7. Step results of the QRS complex processing.

Fig. 7 shows the sequential results from measurements where data passes through the QRS complex processing procedure by using a MATLAB program in the server. By following these steps, we can calculate R peaks, R-R intervals, width of the QRS complex and the interval between the R and S peaks properly. According to our results, some difference can be seen between the groups studied in the R-R interval value as shown in Fig. 8. It is also easy to see that the R-R interval spreads rapidly, and is wider and shorter for a subject awake in comparison to one who is drowsy. This means that the heart beat for an awake person beats properly and the sympathetic nervous system and parasympathetic nervous system of the autonomic nervous system are also appropriately active. These results are also supported by previous research that stated that during sleep your heart rate drops to lower levels than when you are awake[13].

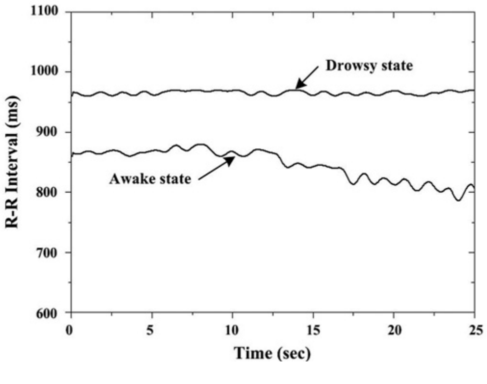

Fig. 8. Comparison of R-R interval between awake and drowsy states.

Even though the drowsy person is not considered to be asleep, their situation can be compared to a sleeping person's state due to the level of tiredness they have. The R peak of a drowsy person is lower across the whole data range and the interval between the R and S peaks is seen to be longer in both groups studied, as shown in Fig. 9. Due to these results, the time distance can be left out from further studies as a meaningful attribute for drowsiness detection. With regard to the R-R interval, it should be noted that aside from the distance between R and S peaks, there is likely to be another shorter time period with a meaningful difference.

Table 3. Comparison of parameters between awake and drowsy states

Parameters	Awake	Drowsy
R peak (mV)	2.3 (± 0.37)	1.4 (± 0.13)
R-R Interval (ms)	821 (± 22.1)	966 (± 9.3)
R-S Interval (ms)	35 (± 3.7)	43 (± 1.8)
QRS Complex (ms)	83 (± 6.9)	108 (± 4.2)

From these results, we decided to concentrate on the comparison between awake and drowsy state by examining the amplitude of the R peaks, the length of the R-R interval, the interval between the R and S peaks and the QRS complex, as shown in Table 3. These parameters are used to evaluate the different state conditions. The signals where the threshold value of the width of the passing moving window is more than 130 ms, the R-R interval is over 950 ms, and the QRS complex is over 100 ms determine a drowsy state.

5. CONCLUSIONS

The QRS complex in an ECG signal is analyzed to solve whether some differences in the R peaks, the R-R interval, the interval between R and S peaks, or the QRS complex can help distinguish between a person properly awake and a person feeling drowsy. The signal is measured with a wearable ECG measurement system that uses WSN to transfer the data to a server. After using MATLAB for signal processing, it was seen that both signal features are different between the compared groups. The R-R interval and the interval between R and S peaks of the drowsy group are seen to be longer and the R peak amplitude lower than in the group that is wide awake. Our research results can be used to offer a convenient ECG measurement method and provide helpful information on the user's state. Thus, the developed algorithm makes correct state evaluations even under situations where the patient is unconscious or unaware and provides a capability for real time analysis of the ECG signal at the server.

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