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A Novel Driver-friendly Ecg Monitoring System Based on Capacitive-coupled Electrode

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Abstract: Studies have shown that a variety of indexes of electrocardiograph (ECG) signal is related to the fatigue degree of the body, which implies that fatigue driving can be prevented effectively by evaluating the fatigue degree of the driver through monitoring ECG signal. In this paper, we designed a novel system for monitoring driver's ECG, which utilized a direct-contact electrode and a capacitive-coupled electrode. The direct-contact electrode was placed on the steering wheel, which directly contacted one hand of the driver, while the capacitive-coupled electrode on which an operational amplifier was mounted was set on the driver's seat. ECG signals from the two electrodes was acquired and amplified by an instrument amplifier and then sent to the post-processing circuits. A simulation experiment was conducted in our laboratory and ECG signals in resting state, steering manipulation and pedaling motion were measured in this experiment, respectively. Results have shown that ECG signal, especially the R peak, of the subject can be detected by this system except some motion artifacts caused by pedaling.

Key words: ECG monitoring, capacitive-coupled electrode, contactless ECG, fatigue detection

INTRODUCTION

With the increasing number of vehicles in China, the traffic accidents also increase rapidly. There are hundreds of reasons that cause traffic accidents, among which fatigue driving is one of the most important reason. Reaserches have shown that some indexes of ECG signal are closely related to the fatigue degree of the body (Wilson and O'Donnell, 1988), such as the heart rate, heart rate variability and T-wave amplitude, etc. Therefore, through monitoring ECG signal in real time, we can effectively prevent fatigue driving by evaluating the fatigue degree of the driver through monitoring his ECG signal.

Currently there are two types of ECG detection method: direct-contact detection and indirect-contact detection. Direct-contact detection is widely utilized in hospitals and clinics, which is able to obtain ECG signal by fixing the electrolyte gel coated Ag-AgCl electrodes on specific positions of the body surface with a pad, which has a adhesive layer on the surface (Page and Bevilacqua, 1978). Although it has many advantages such as high-quality signal and mature technology, there are also many disadvantages, such as inconvenient operation, irritation to skin and solidification of electrolyte gel and so on. While in the case of indirect-contact detection with capacitive-coupled electrodes, ECG signal of the subject can be detected without contacting the bare skin directly (Kim *et al*., 2007). Contactless ECG detection was firstly described by (Richardson, 1967). However, owning to the relatively low level of chip fabrication at that time, it was difficult to manufacture high-performance capacitive electrodes, thus this method could not be developed fully. As more and more operational amplifiers with high input impedance and low noise have become available over the past years, it is easy to integrate amplifiers to electrodes to get high-performance capacitive electrodes. As a result, the method of contactless ECG monitoring has attracted more and more attention (Lim *et al*., 2004, 2006; Kim *et al*., 2004; Eilebrecht *et al*., 2010). Wartzek, Leonhardt and others allocated capacitive-coupled electrodes on the back of driver's seat as the signal electrodes and ECG signal of the car driver was obtained successfully (Wartzek *et al*., 2011a; Leonhardt and Aleksandrowicz, 2008). However, during the driving process, there will be relative movement between the upper body of the driver and the signal electrodes caused by the actions, such as turning the steering wheel and stepping on the pedal, which will result in severe interference. By allocating the signal electrodes on the driver's seat, the relative movement between the human body and signal electrodes can be reduced effectively, thus the interference can be reduced.

On the basis of indirect-contact ECG detection method, we designed a system for monitoring ECG signal of the driver with a direct-contact electrode and a capacitive-coupled electrode. The direct-contact electrode was placed on the steering wheel, which directly

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contacted one hand of the driver, while the capacitive-coupled electrode was located on the driver's seat that was under driver's buttocks. ECG signal of the driver was acquired through the two electrodes while the driver wore regular clothing.

SYSTEM DESIGN

Capacitive-coupled electrode: The capacitive-coupled electrode designed in this paper took PCB as the substrate, including the sensor layer, shield layer and operational amplifier. The size of the electrode was 100×150 mm, about 5 mm in thickness. Figure 1 shows the two-dimensional vertical section of the capacitive-coupled electrode and the coupling between the electrode and the human body. The bottom sensor layer on the PCB was a layer of copper which was coated with solder mask for sensing the potential change of the body surface. The sensor layer, solder mask, clothing, as well as the skin of the person whose ECG signal was to be measured constitute a plate capacitor, through which ECG signal of the person was coupled to the input of the amplifier on the top of the PCB. The middle layer, which was also a layer of copper, was the shield layer, used to protect the sensor layer from the external interferences. The operational amplifier was mounted on the top of PCB for buffering ECG signal sensed by the sensor layer. The sensor layer and shield layer were connected to the operational amplifier by vias.

Since the impedance between the body and the sensor layer is very high, the operational amplifier must have extremely high input impedance. In this paper, the LMP7702 was adopted as the operational amplifier in the capacitive electrode, w hich was a rail-to-rail input and output precision amplifier with low noise and high input impedance and was ideal for sensor interface. Each LMP7702 chip consists of two operational amplifier units. The circuit model of the capacitive-coupled electrode is shown in Fig. 2. LMP7702A was configured as an unit-gain voltage buffer. C1 and R1 were used to protect the input of the operational amplifier and separate the output of the operational amplifier from the shield layer, respectively. C2 and R2 formed a high pass f ilter, eliminating the DC component and low frequency noise in the output signals of LMP7702A. The filtered signals were added to an appropriate DC voltage by Vref and then sent to the noninverting input of LMP7702B, which was a unit-gain voltage buffer for buffering the high-passed signals and send to the measurement circuit for further processing.

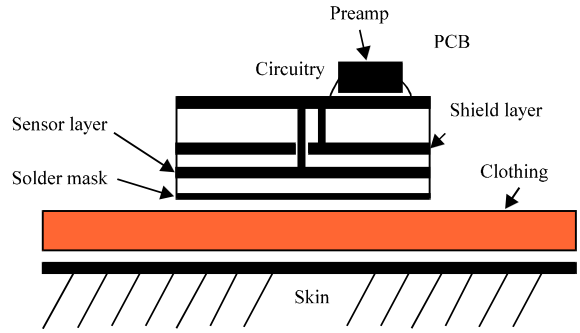

Fig. 1: Two-dimensional vertical section of the electrode

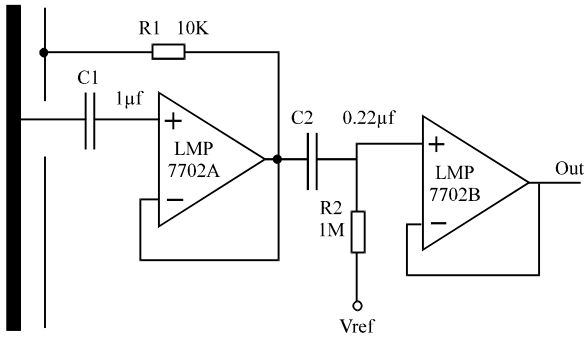

Fig. 2: Circuit model of capacitive-coupled electrode

Measurement circuit: The measurement circuit consisted of analog circuit and digital circuit. The function of the analog circuit was to accomplish signal processing, including first-level amplifying circuit, filter unit and second-level amplifying circuit. While the function of the digital circuit was to accomplish signal sampling and transmission, including analog to digital converter, microcontroller and Bluetooth module. The diagram of the measurement circuit is shown in Fig. 3.

The first-level amplifying circuit was composed of instrument amplifier, employing INA116 chip, which obtained ECG signal of the driver from the direct-contact electrode and the capacitive-coupled electrode and amplified the ECG signal for 50 times. After that, the amplified ECG signal went through the 50Hz notch filter and high pass filter with the cut-off frequency 0.78Hz, as well as the low pass filter with the cut-off frequency 67.5Hz in the filter unit and then entered the second-level amplifying circuit. The signals were amplified by 20 times in the second-level amplifying circuit by LT6010. After the processing of analog circuit, the original ECG signal was amplified by 1000 times in total. In the digital circuit, the 12-bit A/D-converter MAX164 was controlled by the microcontroller MSP430 to sample the output signals of the second-level amplifying circuit with a sampling rate of 1000Hz and the sampled data were transmitted through a

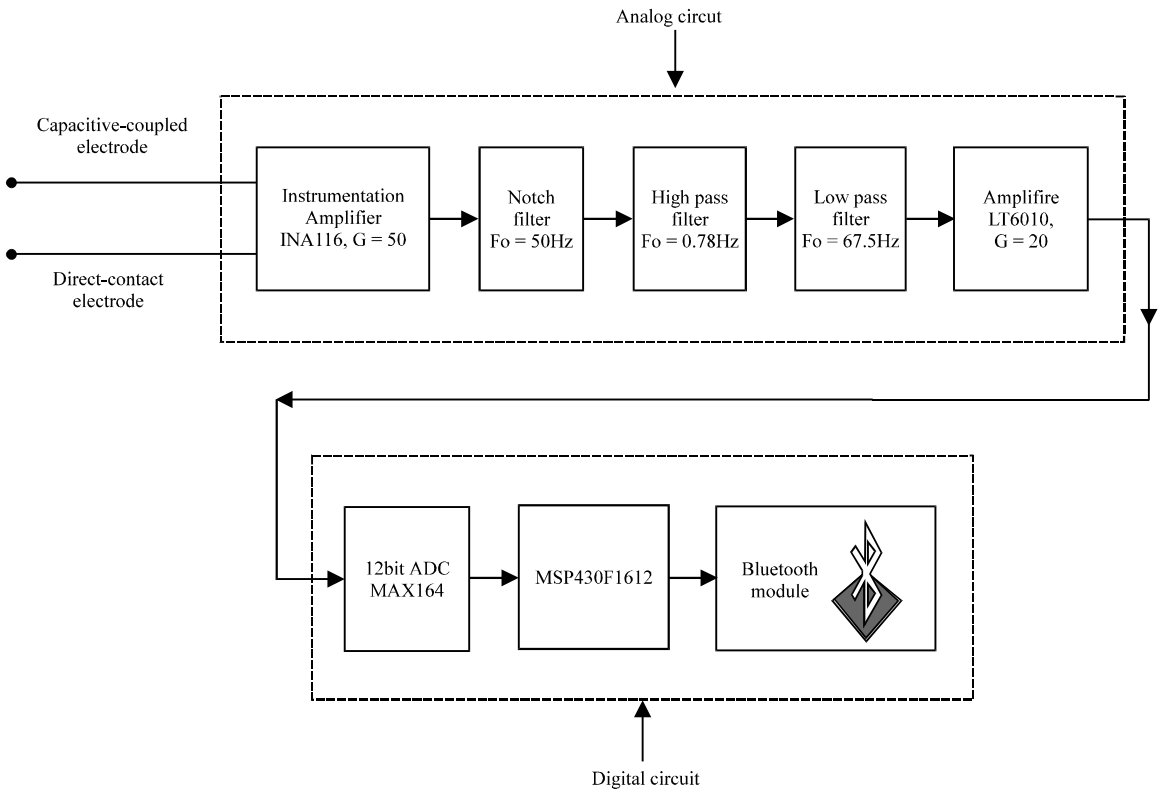

Fig. 3: Diagram of measurement circuit

Bluetooth module. Along the signal path, the sampled data were received by a Bluetooth stick that was connected to a computer via USB interface. In this computer, there was a LabVIEW-based application program that used for storing and displaying data.

EXPERIMENTS AND RESULT ANALYSIS

Simulation experiment: ECG monitoring system for a car driver, which utilized a direct-contact electrode on the steering wheel and a capacitive-coupled electrode on the driver's seat, was evaluated in the laboratory. The experimental configuration is shown in Fig. 4. The driver's seat, steering wheel and pedal used in this experiment were adapted from driving game controller to simulate the situation in driving cab. In order to reduce the electromagnetic interference produced by the AC power line, the experiment platform was allocated on a block of polystyrene foam board, whose size was 1500×1000 mm, about 100 mm in thickness.

The direct-contact electrode, which was made from thin copper sheet, was allocated on the periphery of left semicircle of the steering wheel, contacting the left hand of the subject. The electrode size was 30×150 mm and its

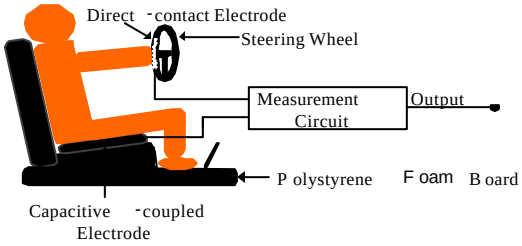

Fig. 4: Configuration of simulation experiment

thickness was 0.25mm. The capacitive-coupled electrode was fixed on the driver's seat, which directly contacted the pants of the subject. Therefore, ECG signal between the left hand and the buttocks of the subject was obtained through the two electrodes, which is called "Lead III" in ECG analysis. In the simulation experiment, the subject wore a regular pant with 99% cotton and 1% polyester and the thickness was about 0.5 mm. In order to simulate the real driving operation, ECG signal in resting state, steering manipulation and pedaling motion were measured respectively. In resting state, the subject put his hands on the steering wheel and feet on the polystyrene foam board and kept the body still, Fig. 5(a). In steering manipulation, the subject kept his left hand contacting with the direct-contact electrode and turned the steering wheel

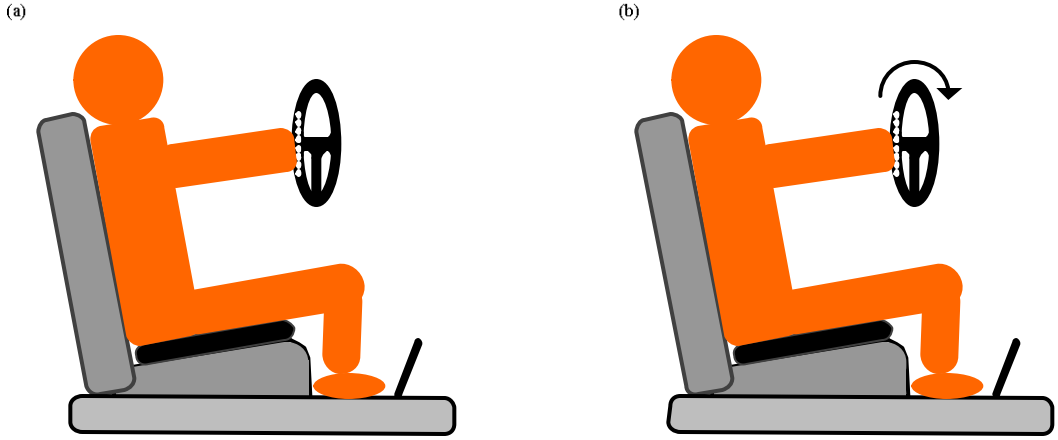

Fig. 5(a-b): Illustration of resting state and steering manipulation (a) resting state (b) steering manipulation

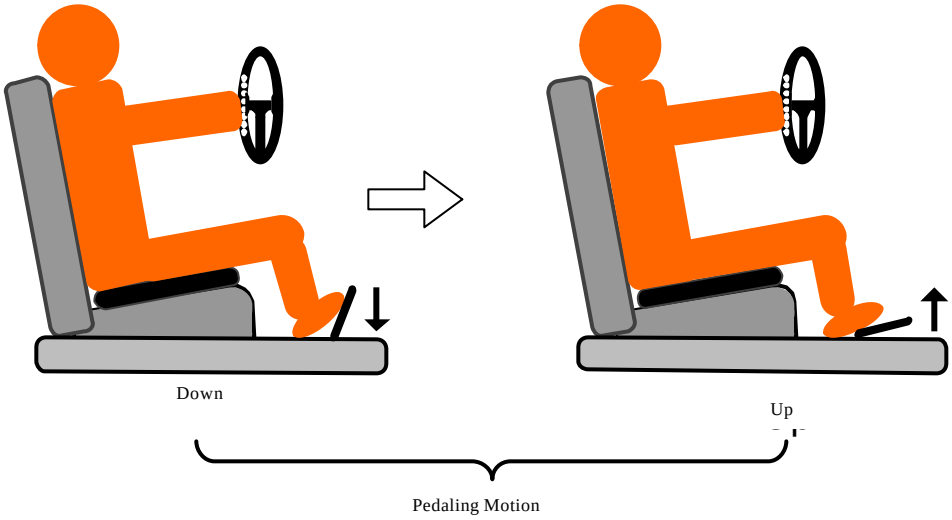

Fig. 6: Illustration of pedaling motion

90°C clockwisely, Fig. 5 (b). In pedaling motion, the subject kept the heel on the polystyrene foam board and the forefoot stepped on the pedal, as shown in Fig. 6. The pedal motion was used for simulating the motions of stepping on the clutch, brake pedal and accelerator in the driving process.

Experimental results and analysis: ECG signal obtained in resting state, steering manipulation and pedaling motion are shown in Fig. 7 and 7(a) shows ECG signal in resting state, from which it can be seen that the ECG monitoring system designed in this study can detect ECG signal of the subject successfully. The sharp pulses that appear approximately every second is the R waves. It benefited from allocating the capacitive-coupled e lectrode on the driver's seat that steering manipulation, Fig. 7(b). However, in Fig. 7 (c), pedaling motion resulted in the motion artifact (baseline fluctuation). When the motion was relatively large, R wave would disappear. In references (Ottenbacher and Heuer, 2009; Wartzek *et al*., 2011b), the motion artifact in the contactless ECG detection system was analyzed. In our experiment, when the subject stepped on the pedal, the distance between the sensor layer of the capacitive-coupled electrode and skin of the buttocks of the subject changed and leaded to the variations in capacitance. If there was common-mode voltage between the subject and the common of the measurement circuit, the changes in capacitance would result in the fluctuations of output voltage.

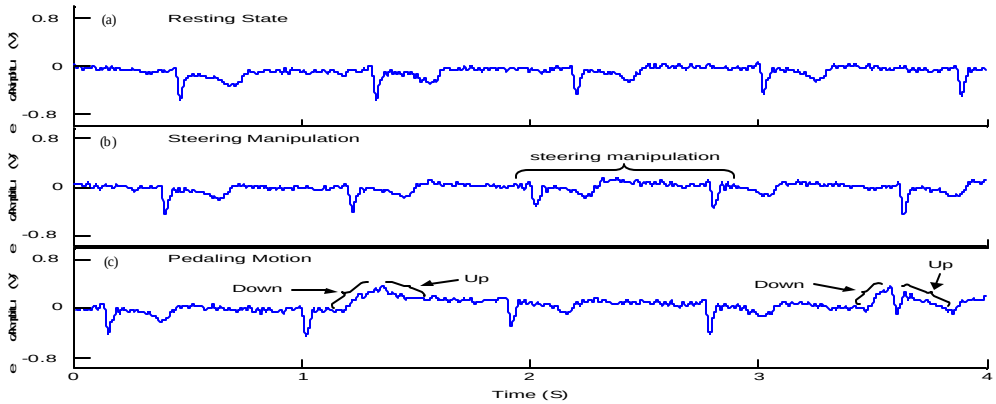

Fig. 7(a-c): ECG signals acquired in resting state (a), steering manipulation (b) and pedaling motion (c)

CONCLUSION

In this study, a system for detecting ECG signal of the driver was designed. According to the results of simulation experiment in the laboratory, ECG signal of the subject can be detected effectively. Gentle steering manipulation do not introduce significant interference, but large motion artifacts caused by pedaling motion is a problem to be solved. In the next step, the way to reduce the baseline fluctuation caused by pedaling action will be studied and the current design will be optimized by conducting experimental study on vehicles.

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