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Ventilation and Heart Rate Monitoring in Drivers using a Contactless Electrical Bioimpedance System

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Abstract. Nowadays, the road safety is one of the most important priorities in the automotive industry. Many times, this safety is jeopardized because of driving under inappropriate states, e.g. drowsiness, drugs and/or alcohol. Therefore several systems for monitoring the behavior of subjects during driving are researched. In this paper, a device based on a contactless electrical bioimpedance system is shown. Using the four-wire technique, this system is capable of obtaining the heart rate and the ventilation of the driver through multiple textile electrodes. These textile electrodes are placed on the car seat and the steering wheel. Moreover, it is also reported several measurements done in a controlled environment, i.e. a test room where there are no artifacts due to the car vibrations or the road state. In the mentioned measurements, the system response can be observed depending on several parameters such as the placement of the electrodes or the number of clothing layers worn by the driver.

1. Introduction

According to [1], crash statistics suggest that about 10-20% of all crashes might be sleep or fatigue related. For that reason, detecting drowsiness or fatigue states has received increasing attention recently. Research efforts on that field can be classified into three main branches. First one is based on driving performances i.e. unintended lane departures, steerings and brakes. The second one is related to camera systems that allow detect the percentage of eye closure (PERCLOS), head movements and blinks [2]. Finally, the last one is based on monitoring biomedical signals, e.g. EEG, ECG or heart rate variability (HRV) [3].

Therefore, in this paper a set of measurements realized using a system based on the last group is shown. This system, through measuring the bioimpedance using the 4-wire technique, is capable of monitoring the ventilation, and also heart rate, of a driver. It is worth mentioning that the measurements were done in a laboratory environment where there are no interferences caused by the state of the road or the car engine vibrations.

2. System

The bioimpedance system designed for monitoring the ventilation consists of several textile electrodes and two main blocks: an analog front-end (AFE) and a generator-demodulator block, see figure 1. It is worth mentioning that all the system is controlled by LabView and, the generator-demodulator block consists of the PXI System by National Instruments. Briefly, a sinusoidal signal with a frequency of 62.5 kHz is generated using one of the PXI modules, NI

PXI-5422. Later, this generated signal is injected to the AFE block. In the injection stage of the AFE, the voltage signal coming from the PXI is converted to a current signal by a second generation current conveyor (CCII) [4]. By this way, the injected signal to the driver by the textile electrodes connected to HC and LC in figure 1 is a current driving instead of a voltage driving. In the voltage sensing stage, a differential to single ended voltage conversion is done by a wideband differential amplifier. However, before this conversion, the voltage difference between the pair of sensing electrodes, HP and LP in figure 1 is measured by a pair of high-impedance buffers. Finally, the output signal of the AFE is acquired using other PXI module, NI PXI-5122, and an In Phase-Quadrature (IQ) demodulation is done by LabView. It is worth mentioning that there is also a Common-Mode Feed-Back (CMFB) stage in the AFE which is useful to reduce the effect of high electrode mismatch.

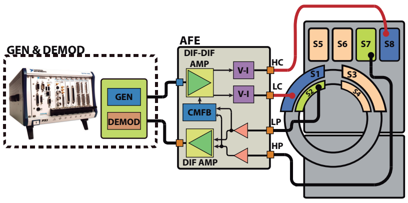
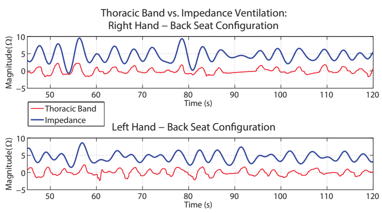


Figure 1. A block diagram of the system. It consists of a PXI system, an AFE and several textile electrodes attached to the steering wheel and the car seat.

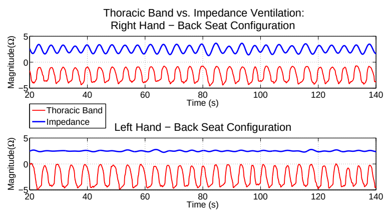
3. Measurements

3.1. Comparison to a Reference Signal

To check the proper work of the system, several volunteers are monitored not only by the designed system but also by a commercial one made by BIOPAC Systems. This commercial device acquires the ventilation signal using a piezoresistive thoracic band. Therefore, the designed system works properly if the measured signal fits to the signal related to the thoracic band, i.e. for the same period of time, the exhalation-inhalation ratio is the same in both signals.



(a) Volunteer 1



(b) Volunteer 2

Figure 2. Comparison between the Thoracic Band and the Bioimpedance Device for two volunteers. (Top) Configuration where both pairs of driving-sensing electrodes are in the right side of the body. (Bottom) Configuration where a pair of electrodes is in the left hand and the other pair is in the right side of the back. In both plots, the upper line is related to the bioimpedance device and the bottom one comes from the thoracic band.

As observed in figure 2, for each volunteer two different configurations are tested. On one hand, in the upper graphs, all four electrodes are placed at the right side, i.e. whereas S1 and S5 in figure 1 are the driving electrodes, S2 and S6 are the sensing electrodes. On the other hand, in the bottom graphs whereas the electrodes on the back seat remain at the same point (S5 and S6), both electrodes on the steering wheel are moved to the left side (S3 and S4 in figure 1).

Note that for all cases except for the bottom graph of the second volunteer, both signals, from the bioimpedance device and from the thoracic band, match up and show a normal respiration

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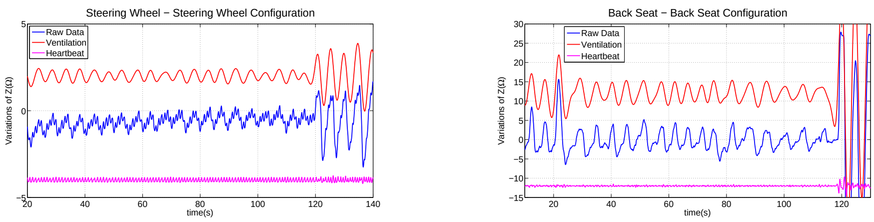
rate, i.e. between 11 and 20 breaths per minute in adults and in normal conditions. The special case can be due to the lack of contact between any textrode and the volunteer. Due to this fact, it is important to check the system according others parameters such as the placement of electrodes or the dependencies on clothing.

3.2. Configuration of Electrodes
In this second group of measurements, to check the system whereas the placement of the electrodes is changed, the same test is done. That test consists of a two-minute monitoring and, around the last 30 seconds, five deep breathing are taken. Therefore changing the place of driving and sensing electrodes, three configurations are tested: Steering Wheel-Steering Wheel Configuration (SW-SW), Steering Wheel-Back Seat Configuration (SW-BS) and Back Seat-Back Seat Configuration (BS-BS).

Briefly, in SW-SW configuration, whereas in figure 1 S1 and S3 are the driving electrodes, S2 and S4 are the sensing ones. In SW-BS configuration, S3 and S5 are the driving electrodes and S4 and S6 are the sensing ones. Finally, in BS-BS configuration, whereas S5 and S8 are the pair of driving electrodes, S6 and S7 are the pair of sensing.

In figures 3(a), 3(b) and 4(a), three signals are plotted. The middle one is the raw signal measured by the bioimpedance device and without processing. This signal is based on two components: a low-frequency component, between 0.1 Hz and 0.3 Hz, and a high-frequency component, over 1 Hz, that are related to the ventilation and the cardiac rhythm, respectively. To show better the component related to the heartbeat, figure 4(b) corresponds to the zoomed-in signal of the figure 4(a) in a one-minute period. Note that whereas in figures 3(a) and 4(b) the heartbeat component can be observed, in figure 3(b) that is not possible. Therefore, to measure the signal related to heartbeat, to be in contact directly to a hand seems required.



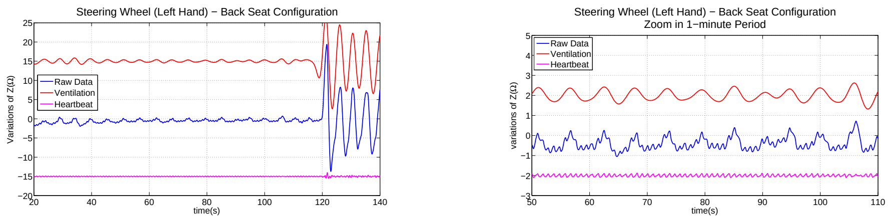
(a) SW - SW Configuration

(b) BS - BS Configuration

Figure 3. Two configurations of electrodes: (a) Steering Wheel - Steering Wheel Configuration. (b) Back Seat - Back Seat Configuration. In both cases, (Middle) The raw data. (Top) The ventilation signal. (Bottom) The signal related to the cardiac rhythm.

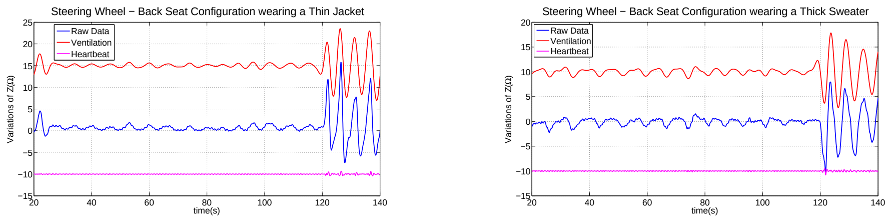
3.3. Influence of the Thickness of Clothing
In the last group of measurements, dependencies on clothing are checked. Applying the same test explained above and the SW-BS configuration, a subject is monitored wearing several clothing. So, whereas in figure 4(a) the volunteer wears a thin 100% cotton T-shirt, in figures 5(a) and 5(b), the volunteer wears, over the same T-shirt as before, a thin 100% polyester jacket and a thick sweater, respectively.

Note that the respiration rate is different in the three figures. Meanwhile in figures 5(a) and 5(b), the respiration rate is around 8 breaths per minute, in figure 4(a) a normal rate of 11 breaths per minute can be observed. Therefore, there seems to be a correlation between clothing and the measured signal. Depending on the clothing, the system could not work properly because of some inhalations or exhalations cannot be monitored.



(a) SW - BS Configuration (b) Zoom in a one-minute period

Figure 4. Steering Wheel - Back Seat configuration of electrodes. (b) is a zoom in a one-minute period to the signal shown in (a). In both cases, (Middle) The raw data. (Top) The ventilation signal. (Bottom) The signal related to the cardiac rhythm.



(a) Wearing a thin Jacket (b) Wearing a thick sweater

Figure 5. Measurements wearing several clothes in a SW-BS configuration. In (a), the subject is wearing a thin jacket made of polyester (100%) over a thin T-shirt made of cotton (100%). In (b), the subject is wearing a thick sweater made of woolen (33%), polyester (27%), acrylic (27%) and polyurethane (13%) over a thin T-shirt made of cotton (100%).

4. Conclusions

Basically, in this paper is shown that monitoring the ventilation, and heart rate, using a bioimpedance system with textile electrodes placed over the clothes is possible. To check this, the designed system and a commercial device are compared and, as shown in this paper, both signals match up. However, it is worth mentioning that the system has been only tested in a simulation environment. It is to be expected that in a real environment, the lack of contact with the textile electrodes will appear because of the vibrations and the state of the road. Furthermore, the system could not work properly at an injected frequency of 62.5 kHz due to the high capacitive behaviour of the interface between clothing and textile electrodes. Thus, although testing the system in a real environment or with a higher injected frequency is required, the results obtained in a controlled environment are encouraging.

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