Detecting Driver Drowsiness using Wireless Wearables

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***Abstract*—The National Highway Traffic Safety Administration data show that drowsy driving causes more than $100,000$ crashes a year. In order to prevent these devastating accidents, it is necessary to build a reliable driver drowsiness detection system which could alert the driver before a mishap happens. In the literature, the drowsiness of a driver can be measured by vehicle-based, behavior-based, and physiology-based approaches. Comparing with the vehicle-based and behavior-based measurements, the physiological measurement of drowsiness is more accurate. With the latest release of wireless wearable devices such as biosensors that can measure people's physiological data, we aim to explore the possibility of designing a user-friendly and accurate driver drowsiness detection system using wireless wearables. In this paper, we use a wearable biosensor called BioHarness 3 produced by Zephyr Technology to measure a driver's physiological data. We present our overall design idea of the driver drowsiness detection system and the preliminary experimental results using the biosensor. The detection system will be designed in two phases: The main task of the first phase is to collect a driver's physiological data by the biosensor and analyze the measured data to find the key parameters related to the drowsiness. In the second phase, we will design a drowsiness detection algorithm and develop a mobile app to alert drowsy drivers. The results from this project can lead to the development of real products which can save many lives and avoid many accidents on the road. Furthermore, our results can be widely applied to any situation where people should not fall asleep: from the applications in mission-critical fields to the applications in everyday life.**

***Index Terms*—biosensor, data analysis, drowsiness detection, mobile app, wearable**

I. Introduction

According to National Highway Traffic Safety Administration, drowsy driving causes more than $100,000$ crashes a year, resulting in $40,000$ injuries and $1,550$ deaths. In order to prevent these devastating accidents, it is necessary to build a reliable driver drowsiness detection system which could alert the driver before a mishap happens.

There are detection systems that are designed based on the measurement of a driver's drowsiness, which can be monitored by three widely used measures: vehicle-based measures [4], behavior-based measures [9], and physiology-based measures [5]. The vehicle-based method detects drowsiness by measuring a driver's degree of deviation from lane position, movement of the steering wheel, pressure on the acceleration pedal, etc. It has a drawback of not catching drowsiness early enough to prevent the accident sometimes. The behavior-based method detects drowsiness using image processing on a driver's facial movements captured by cameras. It depends on the availability of lighting and the speed of image processing on videos can be a bottleneck. The physiology-based method detects drowsiness by measuring a driver's physiological signals. Though the reliability and accuracy of this method are very high, it is not comfortable for a driver to wear these cumbersome measuring devices all the time.

With the latest release of wireless wearable devices such as biosensors, it is possible to explore new ways to design a reliable and non-intrusive driver drowsiness detection system. In this paper, we present the overall design idea of a driver drowsiness detection system using a wireless wearable sensor called BioHarness 3 [1]. A driver can comfortably wear the sensor close to his chest while he is driving. The physiological data measured by the sensor will be sent to a mobile app wirelessly. If the analysis result of the data is above a certain threshold, the driver will be alerted. This project will be completed in two stages. In the first stage, we collect the physiological data from the biosensor and conduct data analysis to find out the parameters that are related to a driver's drowsiness. In the second stage, we design a drowsiness detection algorithm and a mobile app based on the detection algorithm to wake the driver up if he is drowsy. Two REU students, one male and one female, are recruited to do this project. At the current stage, they have conducted some experiments to collect the physiological data measured by BioHarness 3. In our preliminary results, we find that a person's breathing rate and heart rate are related to the drowsiness. More specifically, before a person falls asleep, there is an obvious increase in his/her heart rate and an obvious decrease in his/her breathing rate.

To the best of our knowledge, we have not seen a driver drowsiness detection system built using wireless wearables so far. The smartphone app car safety [2] under development by Dartmouth College etc. uses a behavior-based approach and is subject to blind spot and computing power limit problems. Another smartphone app Somnoalert [3] which is being developed by researchers in Europe uses the vehicle-based approach. If our research results are promising, they can lead to the development of real products which can save many lives and avoid many accidents on the road. Furthermore, our results can be widely applied to any situation where people should not fall asleep: from the applications in mission-critical fields such as battlefields, machine operation, mining, and to the applications in everyday life such as meetings.

The rest of the paper is organized as follows: Section II references the related works; Section III introduces our methodology; and the conclusion is in Section IV.

II. Related works

In the literature, a driver drowsiness detection system is designed based on the measurement of driver's drowsiness, which can be monitored by three widely used measures: vehicle-based measures [4], behavior measures [9], and physiological measures [5].

The vehicle-based method measures deviations from lane position, movement of the steering wheel, pressure on the acceleration pedal, etc. Any change in these that crosses a specified threshold indicates a significant increased probability that the driver is drowsy. However, studies found that vehicle-based measures are poor predictors for drowsiness because the change in the metrics can be caused by other factors such as alcohol or drugs [8]. In addition, if the driver starts to deviate from the lane, maybe it is too late to prevent an accident.

The behavior measures capture drivers' facial movements, including blinking, nodding or swinging their heads, and frequent yawning by cameras and detect drowsiness by image processing. The main limitation of this vision-based approach is lighting because normal cameras do not perform well at night. Another limitation is that the speed of image processing on videos is a bottleneck.

The physiological measures use physiological signals such as electrocardiogram (ECG), electromyogram (EMG), electroencephalogram (EEG), and delectro-oculogram (EoG) to detect drowsiness. The physiological signals start to change in earlier stages of drowsiness. Comparing with other methods, the reliability and accuracy of this method are very high [8]. However, this method has an intrusive nature: Electrodes need to be placed on the driver's body or scalp. Researchers overcome this drawback by placing electrodes on the steering wheel or driver's seat. Signals are sent wirelessly to a smartphone for processing and the drowsy driver is alerted [6]. However, the accuracy of this non-intrusive system is relatively low due to movement and improper electrode contact.

The latest release of wireless wearable devices such as biosensors [1] makes it possible to explore new ways to design a reliable and user-friendly driver drowsiness detection system. These wearables are non-intrusive: People can wear them $24/7$ without being distracted from their normal lives. They can measure people's heart rate, heart beat-to-beat interval (RR interval), breathing rate, posture, activity level, peak acceleration, respiration rate etc. The measured data are then sent to a smartphone wirelessly for processing and display. Studies show that heart rate varies significantly between the different stages of drowsiness [7]. Therefore, heart rate can be used to detect drowsiness. The RR interval change in the heart rate can also detect drowsiness where the low (LF) and high (HF) frequencies fall in the range of $0.04 - 0.15$ Hz and $0.14 - 0.4$ Hz, respectively [5]. The ratio of LF to HF decreases progressively as the driver progresses from an awake state to a drowsy state. Inspired by these new gadgets, our goal in this project is to explore the possibility of designing a user-friendly and accurate driver detection system using wireless wearables.

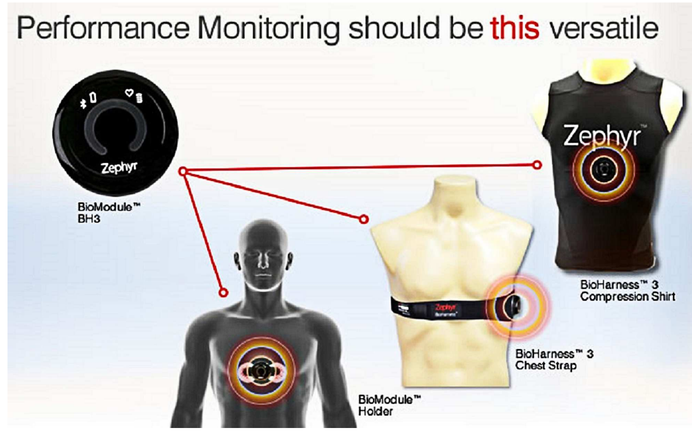


Fig. 1. A BioHarness 3 sensor can be worn by a driver in different ways. This diagram is taken from the BioHarness 3 website [1].

III. Our Methodology

A. Wearable Device

The wearable device we use is the BioHarness 3 sensor produced by Zephyr Technology [1]. It is a premiere compact physiological monitoring module that enables the capture and transmission of comprehensive physiological data on the wearer via mobile and fixed data networks - enabling genuine remote monitoring of human performance and condition in the real world. It outputs an individual's X, Y, Z accelerometers, activity, ECG, heart rate, posture, breathing rate, RR interval, etc.

B. Overall Picture of the Detection System

The overall idea of the driver drowsiness detection system is as follows: As shown in the diagram in Figure 1 provided by the BioHarness 3 website [1], a person can place the biosensor close to his chest by wearing a shirt, a strap, or a holder when he is driving. The sensor monitors his physiological parameters and transmits them wirelessly to his smartphone. The measured data will be processed by the drowsiness detection app on his smartphone. The main ingredient of the app is a drowsiness detection algorithm based on the detected parameters. If the processing result is above a threshold, a warning sound will be played to wake the driver up. We plan to carry out this project in two phases: The main task of the first phase is to collect a driver's physiological data by the biosensor and analyze the measured sensor data to find the key parameters related to drowsiness. In the second phase, we will design a drowsiness detection algorithm to predict driver drowsiness and develop a drowsiness detection mobile app that incorporates the algorithm to alert drowsy drivers. Finally, we will test the system extensively using false positive and false negative metrics on a diverse group of people with different gender, age, occupation, etc.

C. Preliminary Experimental Results

Some preliminary experiments have been completed by two REU students (one male and one female) in order to identify which data points reported by BioHarness 3 provide an indication that an individual has fallen asleep. In the preliminary experimental procedure, we simply attached the BioHarness 3 to a subject and then the subject would lie down and go to sleep. If possible, the subjects would note the approximate time that they fell asleep to allow for later confirmation of the results. We conducted 10 experiments on the female and 5 on the male. We make sure that the subject is in a calm state before he/she goes to sleep.

We determined that there were a few key readings provided by the BioHarness 3 that indicate that a subject has fallen asleep. These readings are breathing rate and heart rate. We are able to isolate 361 seconds of data centering on the 'fall asleep' point.

Figure 2(a) shows that when a subject falls asleep, his/her breathing rate drops quickly. The average decrease for all experiments was nearly 4 breaths per minute and the total duration of the decrease was 39 seconds. Figure 2(b) shows that just before falling asleep a subject's heart rate begins steadily increasing. For all the experiments performed, the increase began approximately 27 seconds prior to falling asleep and peaked approximately 15 seconds after falling asleep. There was an increase of 15 beats per minute during the 42 seconds that the change occurred.

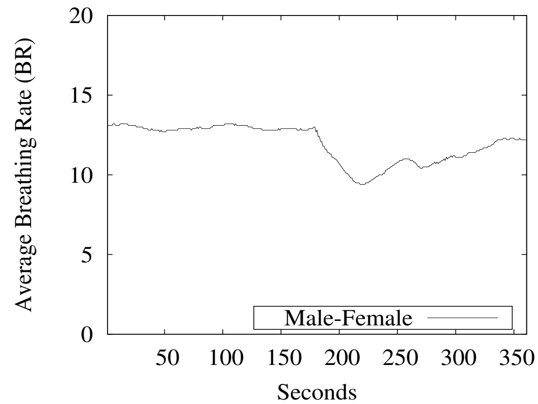
There is a noticeable difference in breathing rate for male and female that can be seen in Figures 3(a) and (b). The decrease in breathing rate when the subject falls asleep seems similar: The male breathing rate decreased by 3.8 breaths per minute in 46 seconds and the female breathing rate decreased by 3.7 breaths per minute in 33 seconds.

Figures 4 (a) and (b) show that the heart rate in male and female exhibits similar activity at the point that the subjects fell asleep. The male heart rate began to increase 16 seconds prior to the subject falling asleep and peaked 13 seconds after falling asleep. For the male, the total climb lasted 29 seconds and the heart rate increased a total of 15.9 beats per minute. The female heart rate began to increase 12 seconds prior to the subject falling asleep and peaked 15 seconds after falling asleep. For the female, the total climb lasted 27 seconds and the heart rate increased a total of 16.6 beats per minute.

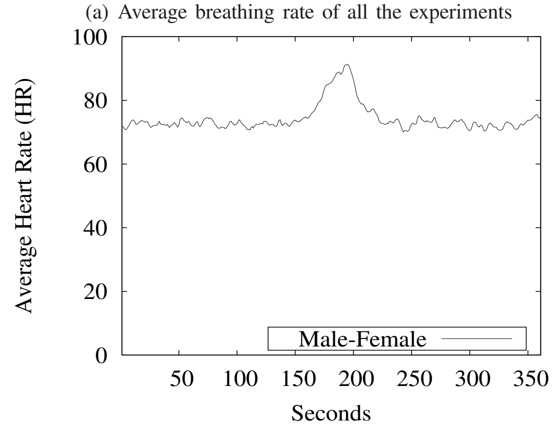
Based on the research in the literature [5], Heart Rate Variability (HRV) should be a good indicator, however BioHarness 3 does not report it. Some additional indicators were Posture, ECG Amplitude, and ECG Noise. But they seem to be inconsistent over multiple experiments so their applicability is questionable.

D. Data Analysis and Prediction

After we get the data from the sensor, we will pre-process the data by using a filter algorithm to attenuate the noise recorded due to muscle movements and interference. We will remove data that are too low or too high. Then we will use Fast Fourier Transform (FFT) to convert the pre-processed heart rate and breathing rate time series data to their frequency domain. To reduce aliasing (different signals become indistinguishable when sampled), we will apply Hanning window on the FFT data. Then a power spectral density (PSD) graph showing how heart rate/breathing rate variance (power) distributes as a function of frequency can be generated. We will then convert the PSD graph into vectored inputs to a Neural Network, which is inspired by the interactions among neurons within human brain. The basic computation element in a neural network is a node. It receives inputs $\{x_1, x_2, \cdots, x_n\}$ with their respective weights $\{w_1, w_2, \cdots, w_n\}$ from some other nodes or external sources and computes a weighted sum. The weighted sum is then fed into an activation function to generate output to serve as input to other nodes. The basic framework of a neural network can be designed by selecting architecture (feed-forward or feedback), activation functions (e.g. threshold logic unit, logistic function, bipolar logistic function etc.) and learning rules (e.g. delta learning rule and widrow-hoff learning rule to train the neural network). We will first train the neural network using data sets representing 'drowsy' and 'awake' states, then validate the weights generated from the neural network by another set of data, and finally use the neural network to predict drowsiness and test its accuracy. Further accuracy improvement can be made through designing a neural network with multiple layers and

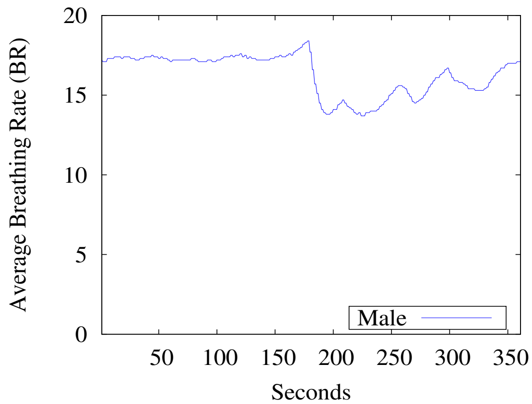


(a) Average breathing rate of all the experiments

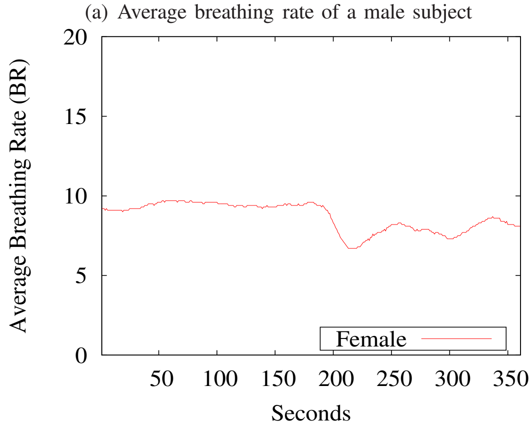


(b) Average heart rate of all the experiments

Fig. 2. The breathing rate goes down and the heart rate goes up when a person falls asleep

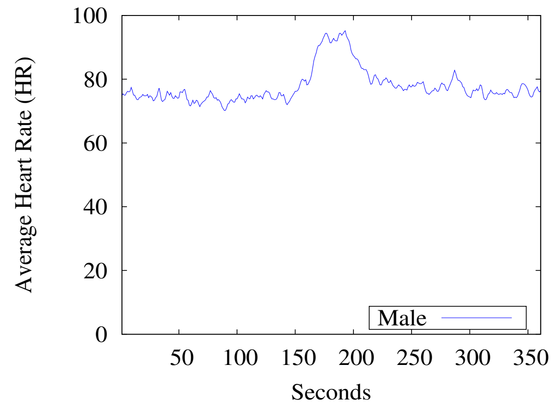


(a) Average breathing rate of a male subject

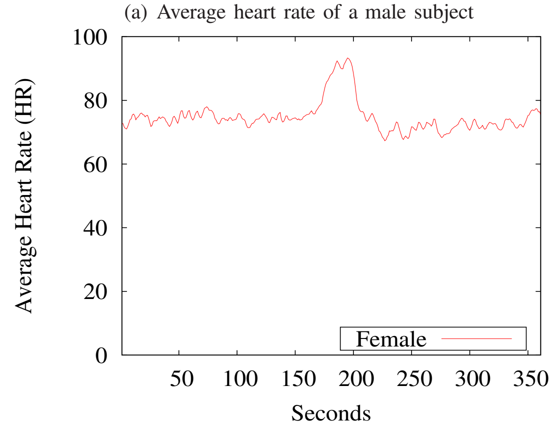


(b) Average breathing rate of a female subject

Fig. 3. The difference in breathing rate for male and female



(a) Average heart rate of a male subject



(b) Average heart rate of a female subject

Fig. 4. The difference in heart rate for male and female

with more participating users. We will do more experiments with the biosensor to find out the best parameters to use for our detection algorithm. Adding more physiological data may also help. But we hope to attain the detection accuracy using minimum required data category to less disturb a user's normal life.

E. Mobile App and Testing

After the parameters related to the drowsiness are determined, we will design a drowsiness detection algorithm to predict a driver's drowsiness. We will write a mobile app to catch an individual's state change from 'awake' to 'drowsy' based on the threshold in the drowsiness detection algorithm and activate a sound alarm if the driver becomes drowsy. We will test the effectiveness of our system extensively by calculating the false positive and false negative rates and then further improve our system. We will carry out the testing on a diverse group of people with different gender, age, and walk of life.

IV. Conclusion

In this paper, we presented the overall idea to build a driver drowsiness detection system using wireless wearable sensors. We conducted preliminary experiments and the results showed that a driver's heart rate and breathing rate are good indicators of drowsiness. In the next phase, we will do more experiments in a driving environment, collect more data for statistical analysis, design good detection algorithms, and write a mobile app to warn a driver if drowsiness is detected.

Acknowledgments

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