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Noninvasive biological sensor system for detection of drunk driving

Shigeyuki Kojima, Shinitirou Maeda, Yumi Ogura, Etsunori Fujita, Kohji Murata, Tsutomu Kamei, Toshio Tsuji, *Senior Member*, *IEEE*, Shigehiko Kaneko, and Masao Yoshizumi

Abstract— **Systems capable of monitoring the biological condition of a driver and issuing warnings during instances of drowsiness have recently been studied. Moreover, many researchers have reported that biosignals, such as brain waves, pulsation waves, and heart beat are different between people who have and have not consumed alcohol. Currently, we are developing a noninvasive system to detect individuals driving under the influence of alcohol by measuring biosignals. In this paper, a new algorithm to distinguish between the normal and intoxicated state of a person is proposed as the basic theory of the sensing system.**

Index Terms—*Driver Behavior, Drunk Driving, Preventive Safety Biosignal, Safety*

I. Introduction

THE most common factors in traffic accidents caused by human error are driving under the influence of alcohol, drowsiness and inattention, also known as the “Big Three”. In order to eliminate these factors, a wide variety of research has been conducted on systems for monitoring drivers’ biological signals such as EEG (sleepiness in driving) [1] [2] [3], motor behavior, divided attention and/or mental workload under the influence of alcohol [4]. But, few reports have addressed non-invasive methods for monitoring the condition of a driver.

We have constructed a seat incorporating an air-pack sensor that can be retrofitted into an existing automobile seat and reported the capabilities of this seat for non-invasive detection of impairment of a driver who has consumed alcohol [5] [6] [7]. The sensor system in the seat has since been improved. Biological signals, such as body-trunk plethysmogram and respiration, were detected from the back of the driver using the air-pack sensor, a noninvasive and non-confining method. Then, the air-pack sensor signals were filtered using a frequency analysis to separate the signal of the body-trunk plethysmogram [8]. The extracted body-trunk plethysmogram signal was defined as an air-pack pulse wave (AP-PW). An algorithm for the quick detection of alcohol-impaired driving was generated from investigations of the AP-PW.

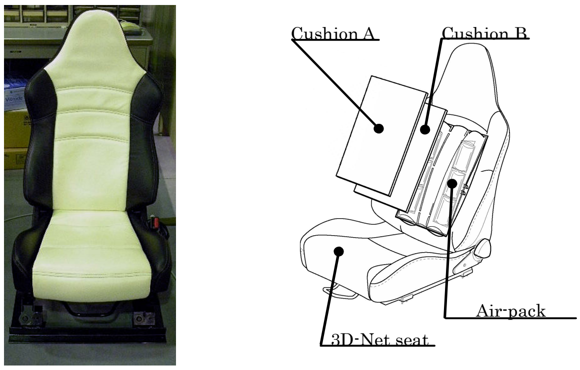

Fig. 1 Experimental apparatus

II. Experimental Method

A. Experimental apparatus

A seat containing the air-pack sensor used to monitor the AP-PW of a subject is shown in Fig. 1. The digital pulse volume, using a finger clip photoplethysmograph (SR-5C, Amco K.K.) and the breath-alcohol concentration (ALC-mini, Tokai Denshi K.K.) were measured with the AP-PW, simultaneously.

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S. Kojima is with Deltatooling Co., Ltd., 3-1 Taguchi-kenkyu-danchi, Higashi-hiroshima-shi, 739-0038 Hiroshima, Japan (phone: 082-420-2262; fax: 082-420-2264; e-mail: skojima@deltatooling.co.jp).

S. Maeda is with Deltatooling Co., Ltd., 3-1 Taguchi-kenkyu-danchi, Higashi-hiroshima-shi, 739-0038 Hiroshima, Japan (e-mail: mag.maeda@deltatooling.co.jp).

Y. Ogura is with Deltatooling Co., Ltd., 3-1 Taguchi-kenkyu-danchi, Higashi-hiroshima-shi, 739-0038 Hiroshima, Japan (e-mail: ogu@deltatooling.co.jp).

E. Fujita is with Deltatooling Co., Ltd., 3-1 Taguchi-kenkyu-danchi, Higashi-hiroshima-shi, 739-0038 Hiroshima, Japan (e-mail: gonzo@deltatooling.co.jp).

K. Murata is with Shimane Institute of Health Science, 223-7 Enya-cho, Izumo-shi, 693-0021 Shimane, Japan and Kanazawa University Graduate School of Medical Science, 13-1 Takaramachi, Kanazawa-shi, 920-0934 Ishikawa, Japan (e-mail: murata6600@go9.enjoy.ne.jp).

T. Kamei is with European University Viadrina Frankfurt (Oder), 15230 Frankfurt (Oder), Germany, Shimane Institute of Health Science, 223-7 Enya-cho, Izumo-shi, 693-0021 Shimane, Japan and Kanazawa University Graduate School of Medical Science, 13-1 Takaramachi, Kanazawa-shi, 920-0934 Ishikawa, Japan (e-mail: ttm@fork.ocn.ne.jp).

T. Tsuji is with Hiroshima University, Faculty of Engineering, 1-4-1 Kagamiyama, Higashi-hiroshima-shi, 739-8527 Hiroshima, Japan (e-mail: tsuji@bsys.hiroshima-u.ac.jp).

S. Kaneko is with The University of Tokyo, School of Engineering, 7-3-1 Hongo, Bunkyo-Ku, 113-8656 Tokyo, Japan (e-mail: kaneko@mech.t.u-tokyo.ac.jp).

M. Yoshizumi is with Hiroshima University Graduate School of Biomedical Sciences, Kasumi 1-2-3 Minami-ku, Hiroshima-shi, 734-8551 Hiroshima, Japan (e-mail: yos1956oktbh@hiroshima-u.ac.jp).

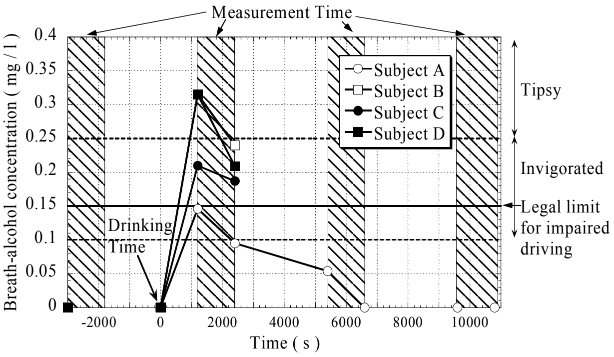


Fig. 2 The breath-alcohol concentration

B. Experimental method

Four subjects participated in the present study. The subjects were healthy males between the ages of 20 and 50 years (mean age: 35.5 years). All subjects underwent an ethanol patch test on the day prior to the experiment involving alcohol, and were verified to be of phenotype NN. Biosignals were taken from the subjects for 20 min prior to consuming alcohol, for subsequent comparison to signals from the non-invasive sensors in the air-pack. Subjects then consumed alcohol (beer, 500 ml), and the first measurements were taken during a 20-min period 20–40 min after consumption of the beer, when the blood alcohol is believed to reach the highest levels. To observe the changes over time in Subject A, measurements were also recorded at 90–110 min and 160–180 min, for a total of 4 measurements. Subjects had not eaten for at least 3 hours prior to consuming the alcohol, but were provided a typical volume of snacks along with the beer, to reproduce usual conditions under which alcohol is consumed. Otherwise, subjects consumed only water, no other food or drinks. The breath-alcohol concentration was measured before and after measuring all biosignals, and results are shown in Fig. 2.

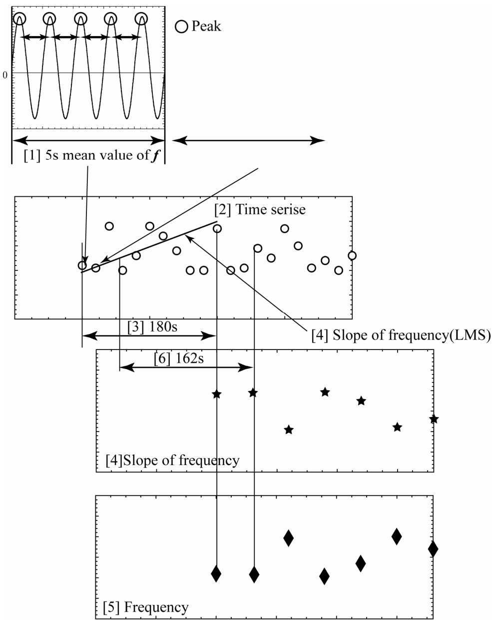
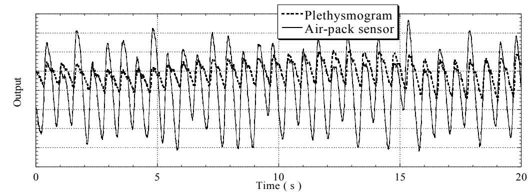


Fig. 3 Time series computation of frequency gradient and mean frequency

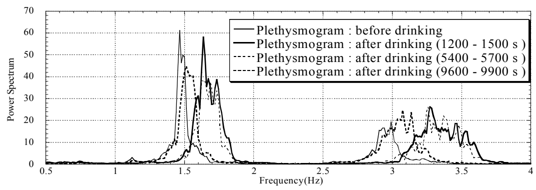
C. Analytical Method

The analysis of the time series for slopes of the AP-PW curves is shown in Fig. 3. Numbers (1)–(6), in Fig. 3, indicate methods used in the calculation. The Savitzky and Golay smoothing filter was used to find the maximum value in the time series of the AP-PW data [9]. (1) The maximum value in each 5-s period of data was determined, the reciprocal of the time between peaks was evaluated to find the frequency (f) and the mean frequency (F) was calculated. (2) F was plotted at 5-s intervals to create a time series of frequency. In order to identify long-term variations in the waveform of the time series, (3) a 180-s time window was defined and (4) the slope of the frequency was found using the least-squares method. (5) The mean frequency was calculated and the frequency fluctuations were identified. (6) The same calculations were carried out for the next 180-s interval, which overlapped the previous interval by 162 s, and the results were plotted. This process was repeated to create time series of frequency fluctuations and frequency slopes.

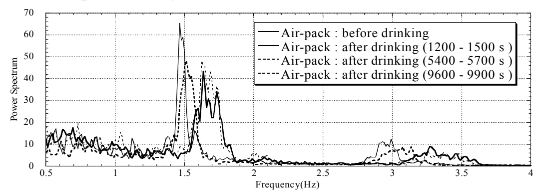
Then, the largest Lyapunov exponent, which is one index that quantifies the chaotic phenomenon of AP-PW frequency, is calculated. The Lyapunov exponent is the averaged ratio of expansion and contraction of the attractor’s orbit as it moves farther away, then draws closer again. In this study, the Lyapunov exponent was computed using the Sano-Sawada method [10].



(a) Comparison of pulse waves (before consuming alcohol)



(b) Photoplethysmogram



(c) Air-pack sensor

Fig. 4 Results of spectral analysis (Subject A)

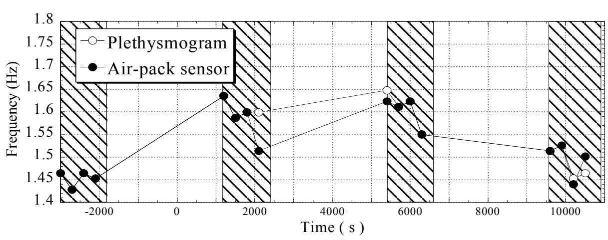
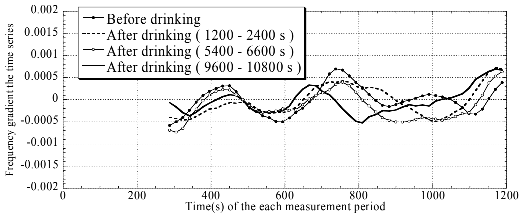
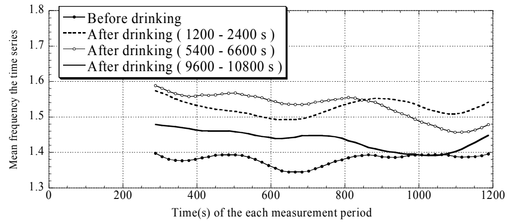


Fig. 5 Results of spectral analysis (Subject A)



(a) Time series of frequency gradient



(b) Time series of mean frequency

Fig. 6 The time series of frequency gradient and mean frequency

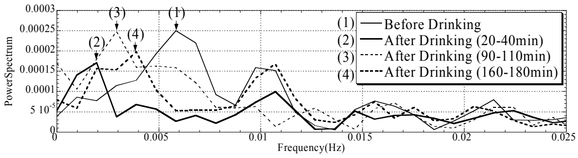
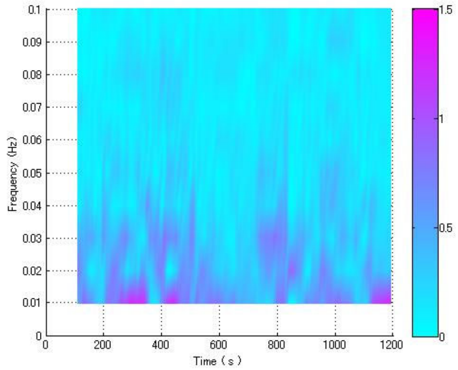
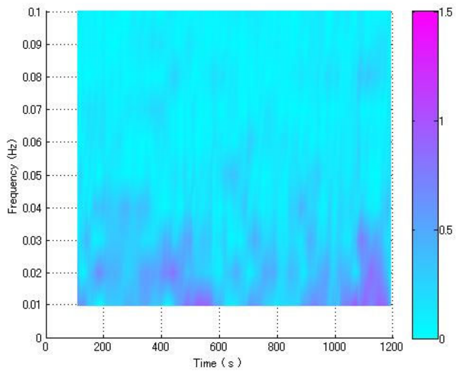


Fig. 7 Frequency analysis of frequency gradient time series



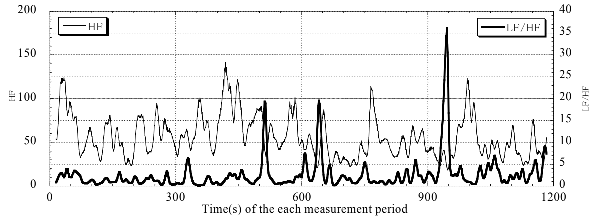
(a) Before consuming alcohol



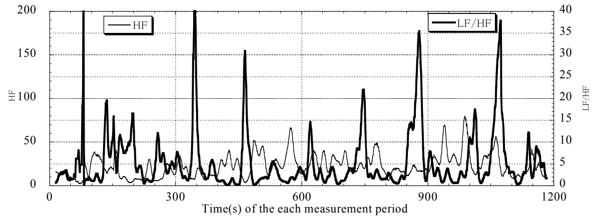
(b) After consuming alcohol (1200–2400 s)

Fig. 8 Frequency analysis of the Lyapunov exponent time series

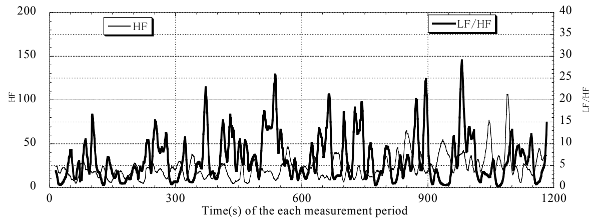
Finally, the results of a wavelet analysis of pulse fluctuations obtained by digital pulse volume in the subjects are used to investigate the relationship between the consumption of alcohol and the nervous system.



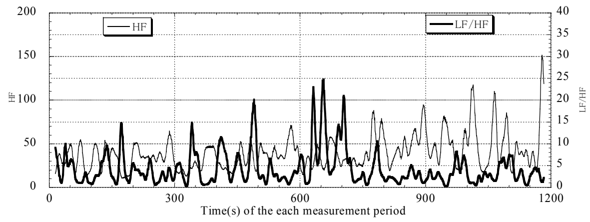
(a) Before consuming alcohol



(b) After consuming alcohol (1200–2400 s)



(c) After consuming alcohol (5400–6600 s)



(d) After consuming alcohol (9600–10800 s)

Fig. 9 Wavelet analysis of heart rate variability

III. Results and Discussion

The original waveforms and 5-min frequency analysis results from data strings of the digital pulse volume and the AP-PW from the first 5 min of measurements in Subject A are shown in Fig. 4.

The transitions of the dominant frequencies of the respective pulse waves in Subject A are shown in Fig. 5. The peak times of the dominant frequencies of the digital pulse volume and of the AP-PW are nearly identical, indicating the presence of pulse waves with similar frequency characteristics.

These transitions of the fluctuations of pulse wave frequencies show a correspondence between the fluctuations in AP-PW frequency and the rise in breath-alcohol concentration after consuming alcohol, and allow an observer to detect rises in pulse rate due to the consumption of alcohol. In time, this concentration decreases and the pulse rate approaches the rate observed prior to consuming alcohol. These results indicate that the pulse wave measured using either the digital pulse volume or the AP-PW show fluctuations in pulse or heartbeat frequency and provide sufficient information to judge whether a subject has been drinking alcohol.

Time series of frequency fluctuations and their slope in Subject A according to the AP-PW are shown in Fig. 6. As was seen in the frequency analysis, the frequency fluctuations were influenced by the consumption of alcohol, showing a shift to higher frequencies.

Frequency analysis of the time series waveform of the slopes of the frequency fluctuations (Fig. 6) is shown in Fig. 7. The peak of the dominant frequency shifted to lower values with an increase in breath-alcohol concentration. Subsequently, it returned to higher frequencies as the breath-alcohol concentration decreased. The chaotic phenomenon of AP-PW frequency was decreased by the consumption of alcohol.

The power spectrum of the AP-PW when the time window and overlap were changed to 100 s and 90 s, respectively, using Lyapunov exponents, is shown in Fig. 8. The intensity of fluctuations in the Lyapunov exponents of the AP-PW due to the consumption of alcohol is expressed by the degree of strength of the power spectrum. Moreover, shift of this power spectrum to lower frequencies indicates that an increase in breath-alcohol concentration due to the consumption of alcohol suppressed fluctuations in the AP-PW frequency.

The results of a wavelet analysis of pulse fluctuations obtained by digital pulse volume in Subject A are shown in Fig. 9. Consuming alcohol increases the fraction of LF/HF burst waveforms indicating involvement of the sympathetic nervous system, and reduces the baseline level of HF components. This seems to indicate elevation of sympathetic nervous system activity. On the basis of chaos analysis, it has been reported that the pulse waveform is simplified and becomes less chaotic when the sympathetic nervous system is in a state of tension [11] or during intra-aortic balloon pumping that mechanically induces a pulse wave [12]. These findings suggest that, in the present study, the suppressed fluctuation of the frequency of digital pulse volume and of the AP-PW were associated with the excitation of the sympathetic nervous system and the accompanying simplification of the pulse waveform. Also, in the present investigation, elevation of sympathetic nervous system activity following the decrease in breath-alcohol concentration decreased over time was actually suppressed; however, in comparison to the situation prior to the consumption of alcohol, the subject was under tension, not having fully returned to a state of relaxation. The other three subjects showed similar results.

Compared to previous studies monitoring the condition of the driver, our approach using the AP-PW has the advantage to capture the drivers' biological signals by non-invasive methods without any electrical devices on the body during driving. And its techniques for filtering noise or artifact signals are not complicated compared to those of an EEG [1] [2] [3]. It is not necessary to add other signals such as eye-movement or eye-blinks to increase the reliability of our algorithm with AP-PW to distinguish between a normal or intoxicated state [2] [3]. Also, it is not necessary for the drivers to do any task to measure performance [4]. Further research in real-environment conditions is still needed to enhance this system for detecting drunk driving.

IV. Conclusions

An air-pack sensor installed in an automobile seat was found to record the same pulse wave, dominant pulse frequency and second dominant frequency peak as the signal provided by a digital pulse volume probe. Measurements of the air-pack pulse wave (AP-PW) over 5 min also revealed differences due to the consumption of alcohol, suggesting that the AP-PW contain potential information to distinguish sobriety from intoxication. The algorithm for the time series of the slope of pulse wave frequency generated in the present study has this potential, as well. Wavelet analysis of digital pulse volume indicated excitation of the autonomic nervous system by the consumption of alcohol. It may be possible to combine this analysis with the slope of frequency fluctuations waveform to improve the accuracy in the detection of driving while under the influence of alcohol.

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