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DEVELOPMENT OF THE DRIVE DOZING PREVENTION TECHNIQIE USING A SENSOR INSTALLED IN THE SEAT FOR DETECTING DRIVER'S CONDITION

[1]Yuzo Hodoshima*, [1]Shigehiko Kaneko*
[1]The Department of Mechanical Engineering The University of Tokyo, Japan

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ABSTRACT-In this study, we have developed a system of sensor and a software program that could detect driver's dozing symptom before he actually starts sleeping. Car seat equipped with an air pressure sensor and a magnetic sensor monitors driver's vein pulse wave. Shape transformation of the measured vein pulse wave is evaluated by two parameters, Lyapunov exponent which is based on Chaos analysis and power which could be obtained by FFT. Anti phase motion of time derivatives of these two parameters indicates driver's dozing symptom.

1. INTRODUCTION

Although the number of fatal traffic accidents occurring is decreasing today, the number of traffic accidents itself is increasing. These accidents occur by several factors, most of which are carelessness of the driver. Among them, the driver's dozing is one of the most major and the most dangerous one. Recently, it has become a social problem that overwork drivers and night shift drivers are prone to fail to keep awake and fall asleep during driving. Therefore, developing a reliable system for detecting their sleepiness and alerting the drivers in order to prevent from dozing is an urgent task.

Until recently, much research have been done with people's sleep and doze. Research done by Fukuda et al [1] is one of them which has a close relation with our research. They suggested a method to estimate people's sleep stage by applying the chaos analysis to heart beat R-R interval, which could be obtained easily by non-invasive measurement. Significant results were obtained by applying this method to patients of sleep disorder and therefore it is expected to be applicable also for detecting and curing them.

In respect of the condition of driver's mind and body, Katayama et al [2] clarified the correlation between fluctuation of finger top plethysmogram and driver's mind and body condition and proposed a method to prevent dangerous driving which could lead to accidents. This method estimates the mind and body condition of a driver from the shape of returnmap of finger top plethysmogram wave. When the moment and the density of the returnmap is large and low respectively,it is estimated that the driver is dozing. If obtaining the shape of the returnmap in real time is possible, we could alarm the driver right after estimating his start of sleep.

However, these methods are focused on determining simply whether a driver is sleeping or not, and cannot make a prediction of a driver's sleep before he actually starts sleeping.

２.DEFINITION OF SLEEP PREDICTION SIGNAL

Human's sleep and uprise is closely related to one's bodily temperature control. It is considered that heat dissipation is an implementation of sleep while heat generation is an indicator of waking up. By monitoring a healthy man's temperature during one's sleep, we can find a rise in temperature of his skin right at the time when he starts sleeping. This phenomenon is considered to be a result of expansion of peripheral vessel due to recess of nervus sympathicus in advance of sleeping. Until now we have reported the possibility of detecting the phenomenon that occurs in advance of sleep, defined as sleep herald phenomenon [4,5].

In the following, we will show experimental data of human biological signals during sleep herald phenomenon. In the experiment, we have monitored three examinee's (A, B, C :age between 20 to 40, male) seven kinds of biological signals; pulse wave measured from their fingertip and back, brain wave, electrocardiogram, breath, temperature of their skin, surface blood flow measured by Laser Doppler Flow measurement (LDF) at their fingertip. The experiment was conducted under the temperature of 24~26 degrees Celsius with electric influence omitted. Examinees were seated on car seats, with their eyes shut and monitored for 30~50 minuets during their process to sleep.

In Figure 1, we can find the timing where the amplitude of time derivative of power (we name gradient of power in this paper) maximizes almost coincides with the start of increase in peripheral blood flow on the fingertip surface. This timing is defined as the starting point of sleep herald phenomenon, which continues until examinee starts sleeping.

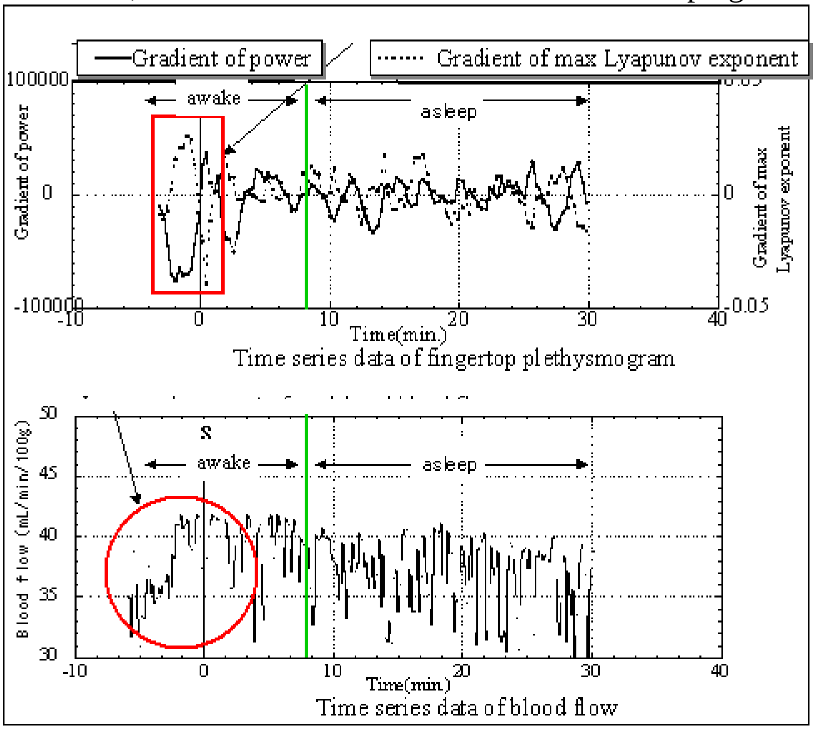

Figure1 :Time series data of fingertop plethysmo- gram and blood flow

３.WAVELET ANALYSIS OF HEART RATE FLUCTUATION

From the measurement data of electrical cardiograph, we detected their peaks and made a time-series data of heart beat intervals. The time series data was analysed by wavelet transformation and was examined whether sleep prediction signal was available or not.

First, we extracted high frequency noise in the electrical cardiograph data. From the result of heart rate fluctuation, we calculated smoothed derivative value by Savitsky-Golay smoothed derivative method. Obtained data is shown in Figure 2.

At the peak of electrical cardiograph, the smooth derivative value becomes zero and transforms from positive to negative. Therefore, we define peaks as the timing when smoothed derivative values change from positive to negative. In addition, in order to omit peaks of noise components, we counted out peaks which original electrical cardiograph value is under 0.3(V) as abnormal.

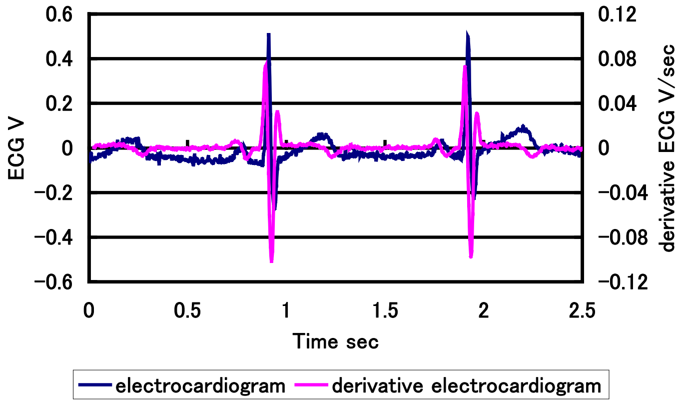

Figure2: Output of elecctrocardiogram and its time derivative

From the timing of peaks we obtained in such way, we calculated R-R interval, which is the interval between each peak and made a time series data of heart rates. The time series data of calculated heart beats of examinee B is shown in Figure 3, where abscissa and ordinate represent the number of heartbeat and heart rate, respectively.

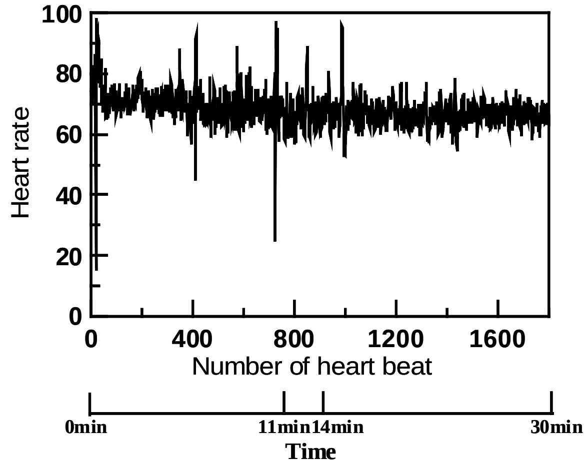

Figure 3 : Time series data of heartrates

From the output of Poly Smith, examinee B is assumed to start sleeping after 1000 times of heartbeats. The value of heart rates has generally decreased until 14 minutes later and stabilized afterwards. From this experimental result, a decrease in value of heart rates seems to indicate emergence of sleep herald phenomenon. However the rate of decrease is smaller than 10% ,which is too small to be detected.

In order to obtain a clearer indicator from this decrease in value of heart rates, this heart rate. fluctuation was analysed employing wavelet transform, which is widely used to signify low frequency components of signals. Molray base function was used in the wavelet transformation algorithm and heart rates under 50 is omitted from the original data as abnormal. Generally, while human is alert and excited, nervus sympathicus takes a dominant roll and amount of LF components (Low Frequency, 0.04Hz~0.15Hz) increases in one's biological signals. On the other hand, when human is relaxed or at rest, nervus sympathetics is replaced by parasympathetic nerve and amount of HF components (High Frequency, 0.15Hz~0.4Hz) increases. We included this medical outlook in our analysis and examined whether an increase in HF had taken place or not. The output of this analysis is shown in Figure 4.

The upper graph of Figure5 shows a time series data of transition of heart rates which is the same as shown in Figure 3.

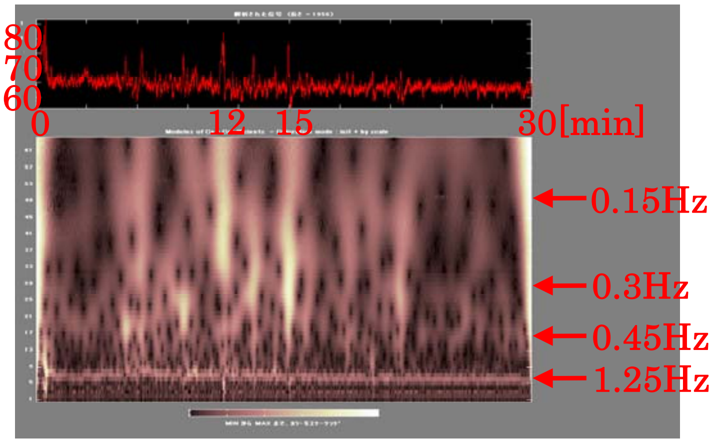

Figure4: Output from wavelet transform analysis of heart rates

The lower graph of Figure 4 shows the output of wavelet analysis of the heart rate fluctuation. Abscissa and ordinate represent time and frequency, respectively. The color of the figure shows the strength of signal, which becomes stronger as the color becomes whiter. The white zone we could find in both right and left edges are called edge effects which is the result of calculating non-existing data in both edges. Therefore, we will exclude the signals of the edge as meaningless.

From Figure 4, no increase in HF components could be detected until 12 minutes and similar shaped patterns of signals are repeated. Between 12 minuets and 15 minutes, characteristic increase in amount of HF componets are detected three times which could also be observed in the original heart rate data.

4. CHAOS ANALYSIS OF FINGERTOP PLETHYSMOGRAM

What we would like to mainly propose in this paper is the applicability of chaos analysis of pulse wave to detect sleep herald phenomenon. In this paper, we calculated the time derivative of max Lyapunov exponent and the time derivative of power from measured pulse wave data.

Amplitudes of human's biological signals vary with time and predicting their fluctuations are extremely difficult. Those fluctuations are considered to be derived from underlying physiological function. Chaos analysis is to model such physiological function and quantify its instability by approximating as a non-linear system. In what follows we will introduce the process how we could obtain Lyapunov exponent and power.

4.1 Fundamentals of Chaos analysis

Chaos analysis we used in our research could be devided into the following two parts, reconstitution of signal as an atractor and obtaining Lyapunov exponent.

4.1.1 Reconstitution of signal as an attractor

An atractor is an m-dimensional signal which visualizes the pathway of motion of a dynamical system sufficient time after it starts its motion with particular initial condition. In order to analyse unstable 1-dimensional signal such as pulse waves as a deterministic chaos, we first have to reconstitute the attractor of its underlying dynamical system. The most popular method for atractor reconstitution is transforming it into time-lag coordinate system from time-series cooridinate system.

In concrete terms, we should construct an m-dimensional vector defined mathematically in Equation [1] using a specific time-lag τ.

$$v(t) = (x(t), x(t+\tau), x(t+2\tau)......x(t+(m-1)\tau) \quad [1]$$

The dimension m of this vector v is called embedded dimension. An example of this m-dimensional vector (which is 3-dimensional in this case) is shown in Figure 5. In this way, the 1-dimensional pulse wave signal can be transferred to a m-dimensional signal and is ready for chaos analysis to be applied.

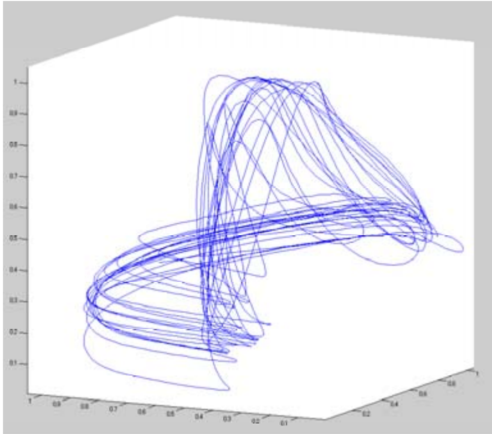

Figure5 3-dimensional attractor of pulse wave

4.1.2 Lyapunov exponent

Generally the motion of chaos dynamical system shows instability which could be explained as dependency on its initial condition. Therefore, a slight difference in its initial condition may lead to a massive difference of motion afterwards. This instability could be quantified by an indicator called Lyapunov exponent where its image is shown in Figure 7. When the difference in initial condition is ε_0, the difference will grow as $\varepsilon_0 e^{\lambda t}$, with t. In order to quantify this growth, we used Lyapunov exponent.

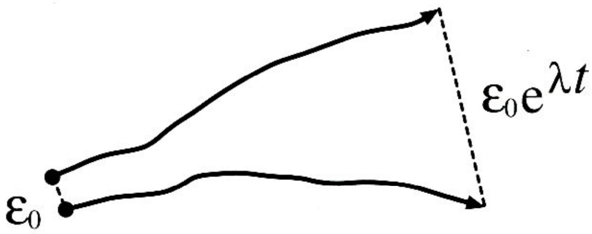

Figure 6 : Image of Lyapunov exponent

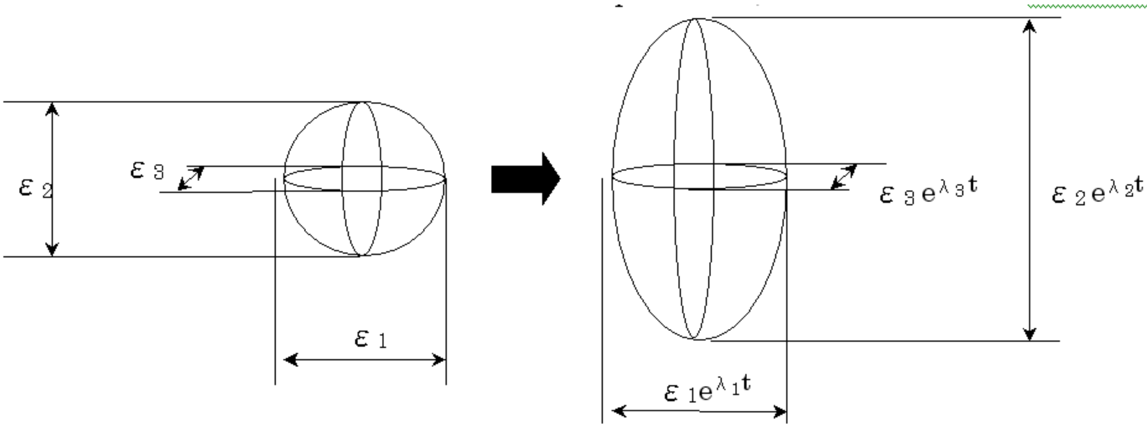

Figure7 3-dimensional image of Lyapuno exponent

Lyapunov exponents are represented as $\lambda_1, \lambda_2, ...\lambda_m$ which consist of the same number of exponents as the dimension of the signal. Then we could express these exponents as a vector $(\lambda_1, \lambda_2 ....\lambda_m)$,which is called a Lyapunov spectrum, and its largest component is called the max Lyapunov exponent. As an example, an image of 3-dimensional Lyapunov exponent is shown in Figure 7. The size of horizontal, lateral and vertical size of each sphear represents the value of the signal of the 1st ,2nd and the 3rd dimensions, respectively.

Sphere on the left side represents initial condition and the figure on the right side represents a state after a certain amount of time. The three sizes of the sphere change according to time, and their change rates are represented as Lyapunov exponents.

There are several methods to calculate Lyapunov exponents, and among them we used a method invented by Sano and Sawada [3].

4.2 Analysis of fingertop plethysmogram

In order to obtain a sleep prediction signal from the data of Lyapunov exponents obtained above, we calculated differential coefficients of them. At the same time, we calculated differential coefficients of power which will be explained below.

4.2.1 Time-series data of the time derivative of power

In the following, we will show the way we obtained time derivative of power. First we sectioned the original pulse wave data by 5 seconds and acquired local maximum value and local minimum value of the original data in every segment using the smoothing derivative method. Then, we calculated the average of maximum value and minimum value in every segment and multiplied by itself . This value is defined as power and a time-series data of power is obtained

Next, we calculated the time derivatives of power from the first 180 seconds time leg by least square method. Then, we shifted this time leg ahead by 18 seconds and similarly calculated the time derivative of power in the time leg between 18 seconds and 198 seconds. This process of shift and calculation was repeated and finally a time-series data of the time derivative of power was acquired.

4.2.2 Time series data of the time derivative of max Lyapunov exponents

From the first 30 seconds of the original time-series data of vein pulse wave, we created a three- dimensional attractor and calculated its max Lyapunov exponents using the Sano-Sawada method. Then, we shifted this 30 seconds time leg ahead by 1 second, so that the time leg becomes between 1 second and 31 seconds, and similarly calculated the max Lyapunov exponent in this time leg. In such a way we obtained a time-series data of max Lyapunov exponents.

Next, using the first 180 seconds of this Lyapunov exponents time-series data, we calculated the time derivative of max Lyapunov exponents inside this 180 seconds time leg by least square method. Then, we shifted this time leg ahead by 18 seconds and similarly calculated the time derivative of max Lyapunov exponent in the time leg between 18 seconds and 198 seconds. This process of shift and calculation is repeated and finally a time-series data of the time derivative of max Lyapunov exponents are acquired.

4.3 Comparison of two parameters and redefinition of sleep herald phenomenon

We compared the present two parameters, the time derivative of power and the time derivative of max Lyapunov exponents and found out a characteristic trend of the value of these two parameters. When the examinee is fully awake, these two parameters synchronise. When the examinee starts dozing, however, these two parameters behave 180 degrees out of phase. Experimental results from examinee B indicates this phenomenon and is shown in Figure 8. The above figure shows two time-series data, the time derivative of power and the time derivative of max Lyapunov exponent. We could find an anti phase in these parameters at around 10 minutes and 14 minutes. Considering that the examinee started sleeping at 14 minutes, we could define that the antiphase at 10 minutes indicates the examinee's sleepiness which could be called sleep prediction signal and the antiphase at 14 minutes indicates the start of sleep. An example of two parameters of a fully awake examinee is shown in Figure 9 where no antiphase could be detected.

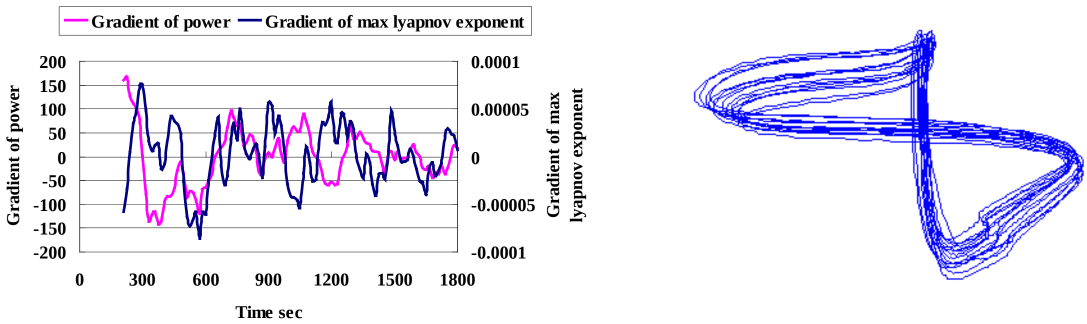

Figure 8 : Outputs of chaos analysis and shape of 3-dimensional attractor during sleep herald phenomenon

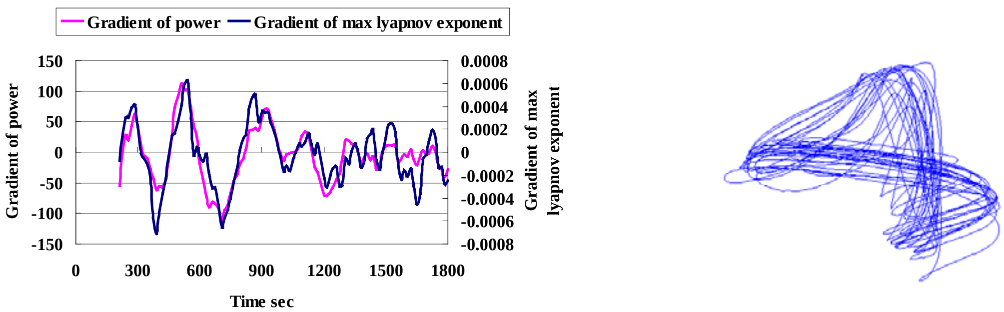

Figure9 : Outputs of Chaos analysis and shape of atractor while examinee is awake

5. MONITORING VEIN PULSE WAVES FROM SEATS

In order to apply the above method to drivers, we have to consider measuring biological signals without making drivers feel annoyed. What we have developed so far is a seat equipped with two kinds of sensors, magnetic circuit sensor, which speculates the driver's posture and pressure sensor which measures pulse waves from driver's back. Overall view of this seat is shown in Figure 10 (left part).

Magnetic sensor consists of torsion bars, convolved with coil windings and attached under a seat. This sensor could detect movement of center-of-gravity of a driver, his body weight, and speculate his posture. Analysis of collected data measured by this sensor could be useful for designing seats that could keep drivers from getting tired.

The second sensor, air pressure sensor, which is shown in Figure 10(right part) measures signals of pulse wave and breath by transforming them into electric signals. This sensor is called airpack sensor and attached to a seat back. Low frequency motion of driver's back by his breathing, subtle skin movement by his pulse waves conduct to the surface of the sensor and press out inside air. The amount of this pressed out air is transformed to an electric signal and is ready for analysis. In order to make it possible to measure driver's subtle skin movements even through thick clothes, the elasticity of the surface of the sensor is designed to match that of a human's skin.

By using this sensor, we have measured biological signals with almost the same frequency as the one taken from finger plethysmogram in an experiment.

Another problem we had to tackle in regards of the structure of the seat is the vibration conducted from roads. Biological signal measured with a sensor attached to an ordinary seat is mixed with vibration noise due to road asperity. These two kinds of signals are almost impossible to separate and therefore is a great obstacle to our analysis. This problem was alleviated by the development of suspension system with magnetic damper. Suspension set under the seat suppresses the conducted vibration and enabled a more precise measurement.

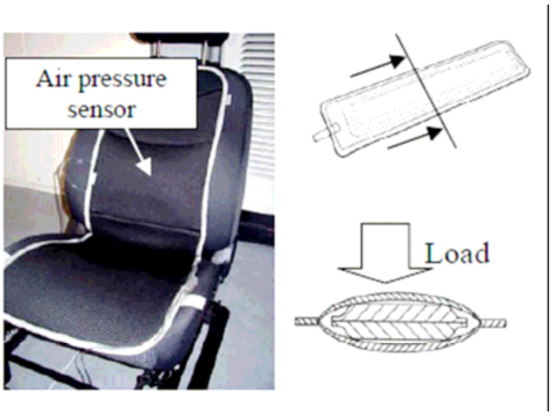

Figure10: Overall view of seat and air pressure sensor

6. CONCLUSION

In this paper, a data acquisition method for detecting the dozing symptom during wakeful state, sensors for extracting biological signals from the driver under the dynamic seated condition, a suspension to avoid cruel disturbance input from the floor and medical parameters for detecting fatigue level of the driver were developed and the following major results were obtained.

(1)Extracting biological signals can be possible with a detective sensor even if a driver under the dynamic seated condition exposed to cruel disturbance input by installing a suspension with a combination of a magnetic spring and a damper to the bottom of a seat.

(2) Sleep herald phenomenon can be defined as the starting point of antiphase of the following two parameters, the gradients of the largest Lyapunov exponent and the gradients of the power value.

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