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Quantification of fatigue degree from pulse wave

Hidenori Shigi† and Hiroyuki Kitajima‡

†Faculty of Engineering, Kagawa University
2217-20 Hayashi Takamatsu, Kagawa 761-0396, Japan
Phone: +81-87-2226, FAX: +81-87-2262
†Email: s07g460@stmail.eng.kagawa-u.ac.jp
‡Email: kitaji@eng.kagawa-u.ac.jp

Abstract—Fatigue causes mistakes, accidents and disorder. However, it is very difficult to know our own fatigue degree. If we can know it accurately, we can avoid serious accidents triggered by fatigue. In this study, we try quantification of fatigue from fingertip plethysmogram by nonlinear and statistical time series analysis. As a result, we find the indexes, such as the Lyapunov exponent, the local variation and the coefficient of variation of pulse-peak intervals, for quantifying fatigue.

1. Introduction

Recently, intensifying international competition makes companies to seek further efficiency and rationalization. There are many companies operating on 24-hour schedules and undergoing major restructuring. And the introduction of computers makes people handle immense volumes of information. In such circumstances, many workers have fatigue problems without self-awareness and that would cause serious accidents.

Fatigue is a physiologic phenomenon between arousal and rest. Our ability is decreased in quality and quantity by fatigue. We feel fatigue, when we work hard. However, there is a big difference between real fatigue and feeling fatigue. Because feeling fatigue is greatly affected by motivation and sense of accomplishment. If we can know our own fatigue degree accurately, we can avoid hazards. There are methods for measuring fatigue using a brain wave and integral electromyogram [1]-[4]. However, these methods are not adequate to estimate our fatigue degree in a daily life. Because they demand complex measurement equipment and a long time to measure. If we can estimate fatigue from a pulse wave, we can downsize the measurement device and shorten a measurement time. Moreover, it is considered that pulse waves contain several pieces of biological information [5].

In this study, we try to quantify the fatigue degree from the pulse wave by nonlinear and statistical time series analysis. As a result, we find the indexes, such as the Lyapunov exponent, the local variation and the coefficient of variation of pulse-peak intervals, for quantifying the fatigue degree.

2. Method of Analysis

2.1. Lyapunov spectral analysis

We embed the pulse wave into a state space using Taken's theorem. We use the dimension of the space and the time-delay as 4 and 50[ms], respectively [6]. In the state space, we can calculate the Lyapunov exponent(LE) using Sato-Sano-Sawada's method [7][8].

2.2. Statistics analysis for peak intervals of pulse wave

We detect peaks shown as closed circles in Fig.1 from the pulse wave. From the time of the peaks, we calculate peak intervals. We use the following statistical indexes for the peak intervals.

$$\text{Coefficient of variation(CV)} = \frac{\sqrt{\sum_{i=1}^{n}(T_i - \overline{T})^2}}{\overline{T}}$$

$$\text{Coefficient of skewness(SK)} = \sum_{i=1}^{n} \frac{(T_i - \overline{T})^3}{\sqrt{(T_i - \overline{T})^2}^3}$$

$$\text{Local variation(LV)} = \left|\frac{1}{n-1}\sum_{i=1}^{n-1}\frac{3(T_i - T_{i+1})}{T_i + T_{i+1}}\right|$$

T_i = i-th peak interval
$\overline{T}$ = Average of peak intervals
N = Total number of peak intervals

CV is a measure of the interval variation, SK is a measure of an asymmetry in the interval distribution and LV is a measure of a local variation of the peak sequences [9].

3. Results

3.1. Experiment

We obtain pulse waves from 26 male students for 25 seconds before and after a two-hour desk work(mainly their programming). We use the equipment(CHAOS21) shown in Fig.2 made by CCI Corporation and the sampling frequency is 200[Hz].

3.2. Indexes

We show the results in Fig.3,4,5 and 6. In each figure, the vertical axis is the rate of change for each index before and after the desk work. In Fig.3 the Lyapunov exponent is increased after the work except for one person(subject 25), however for several persons a rate of increase is very little. In Fig.4 and 6, the coefficient of variation and local variance are increased after the work for 88% subjects, however they have the same problem as that of the Lyapunov exponent. In Fig.5 there is no regularity, thus the coefficient of skewness is not a suitable index for quantification of the fatigue degree.

3.3. Correlation of index

In the previous subsection, we find that LE, CV and LV are increased after the desk work. Here we study the linear correlation between them. Figures 7, 8 and 9 show the cross correlation of LE and CV, LE and LV, and LV and CV, respectively. The cross correlation of LE and CV is 0.364, that of LE and LV is 0.0230 and that of LV and CV is 0.2283, thus there is no linear correlation between them. Finding non-linear correlation is one of our open problems.

3.4. Experiment on automobile seat

We obtain another experimental results from Y. Hashimoto of Doi Laboratory in our faculty. They set an automobile seat on a vibrator and a subject sits on the seat(Fig.10). The vibrator reproduces the vibration of driving on an American express highway. They record pulse waves for one hour. Figure 11 shows a time series of the pulse wave. At the time marked (a), the subject dozes off and at the time marked (b), he falls into a deep sleep. From this data, we calculate the coefficient of variation of the peak intervals using 60-second data for every 30 seconds. We show a time series of the coefficient of variation in Fig.12. We can see that at the time (c), the coefficient of variation begins to decrease slowly. From the time (d), CV is decreased dramatically; this means that CV has possibility as an index for detecting deep sleepiness.

4. Conclusion

We investigate the possibility of quantifying the fatigue degree for the Lyapunov exponent, the local variation and the coefficient of variation of peak intervals from pulse waves. We carry out the simple experiment and show that LE, CV and LV are increased after the two-hour desk work. However, for some persons they are decreased or little increased. Finding a good combination of these indexes is one of our open problems.

We also find that CV of pulse-peak intervals is a good indicator for falling a deep sleep. We are now studying its universality.

Acknowledgments

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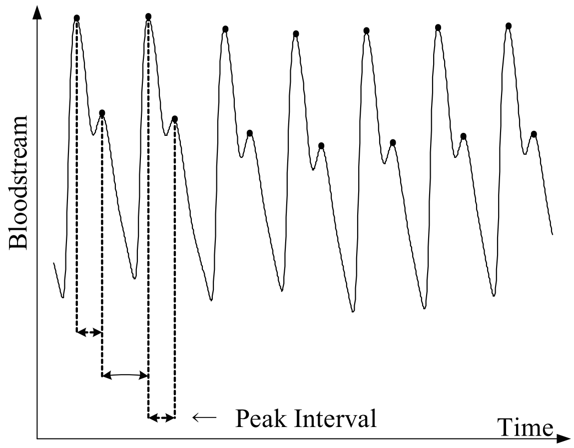

Figure 1: Waveform of pulse wave.

Figure 2: Measurement equipment.

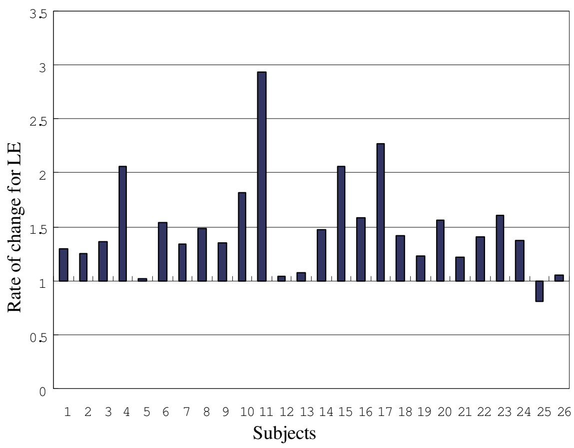

Figure 3: Result of Lyapunov analysis.

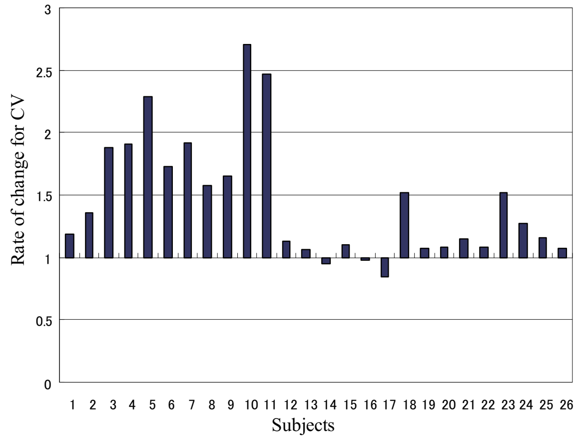

Figure 4: Result of statistical analysis (CV).

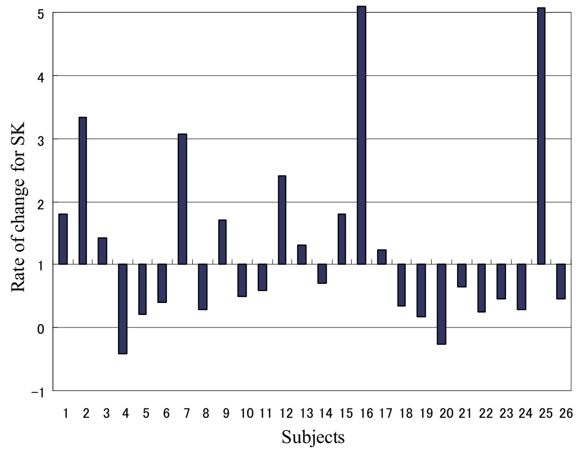

Figure 5: Result of statistical analysis (SK).

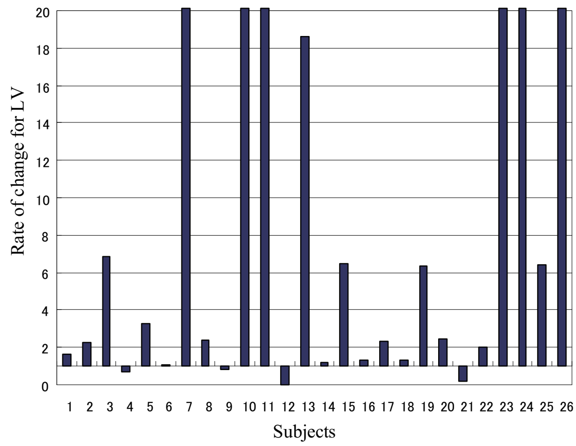

Figure 6: Result of statistical analysis (LV).

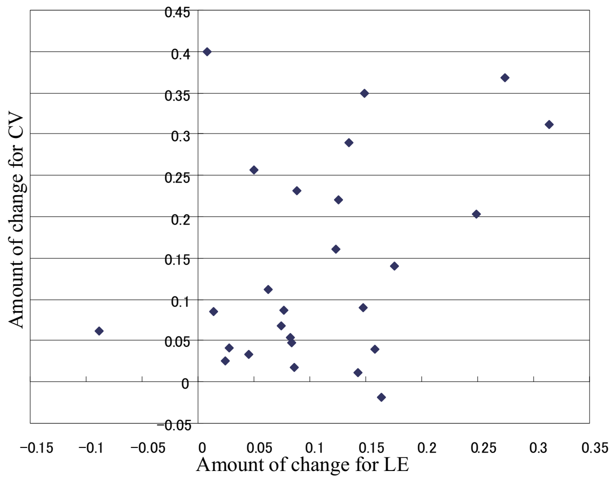

Figure 7: Cross correlation of LE and CV.

Figure 10: Automobile seat on vibrator.

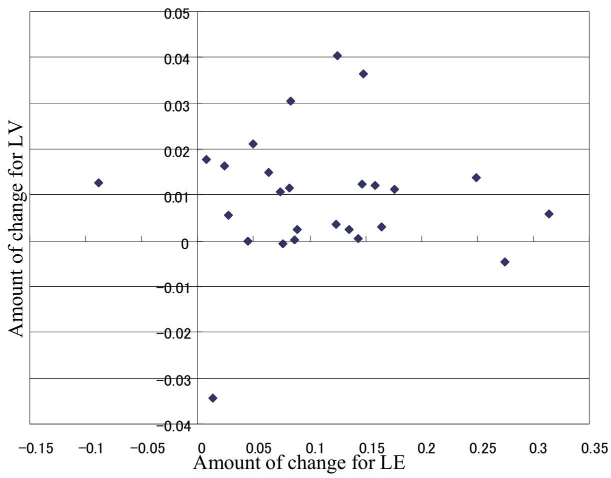

Figure 8: Cross correlation of LE and LV.

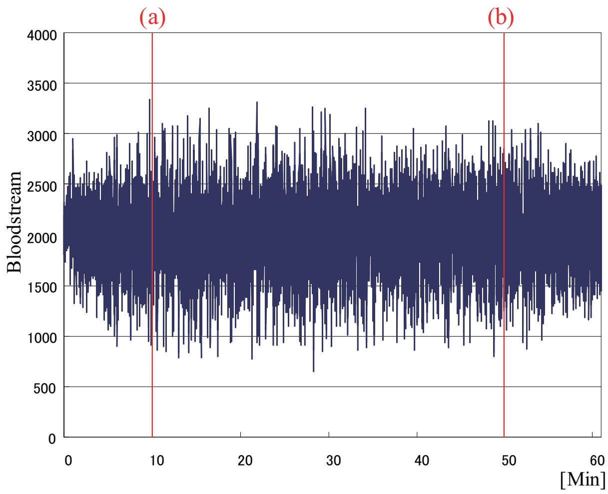

Figure 11: Time series of pulse wave for one hour.

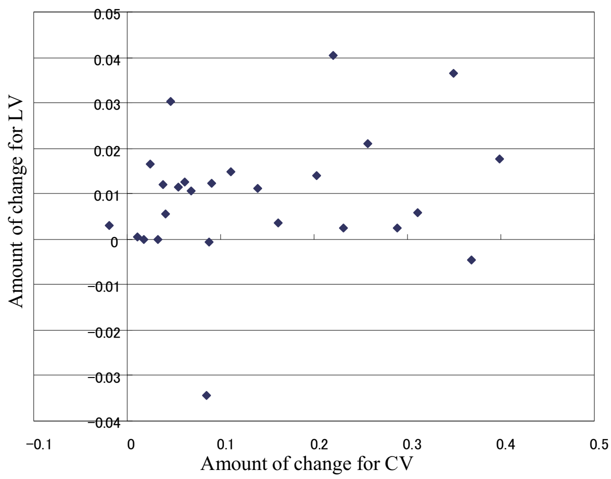

Figure 9: Cross correlation of CV and LV.

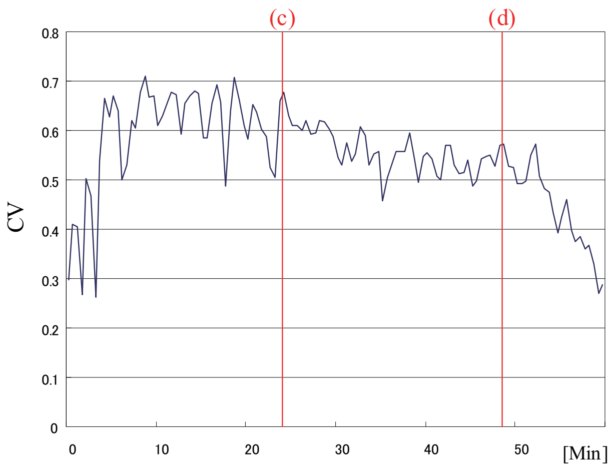

Figure 12: Time series of CV from Fig.11.