Estimation Of Subjective Stress Via Finger Plethysmogram

Yusuke Kobashi, Genma Sano, Tsuyoshi Nakamura
Dept. of Computer Science and Engineering
Nagoya Institute of Technology
Nagoya, Japan
{kobashi, sano, tnaka}@ai.nitech.ac.jp

Masayoshi Kanoh
Dept. of Mechanics and Information Technology
Chukyo University
Toyota, Japan
mkanoh@sist.chukyo-u.ac.jp

***Abstract*—It could be very important and useful to enable human stress to be estimated on basis of quantitative values via objective analysis. There have been several approaches to estimate the stress so far. Most of them need a lot of time to measure or calculate it, and what is more, they might cause physical or mental burden for human subjects. The purpose of our study is to propose and develop a method to estimate subjective stress through a simple approach which doesn't cause much burden for users. In this paper we propose a method, which is called $\mathrm{TPA_f}$ (Turning Point Amplitude via finger plethysmogram). Original TPA is a kind of heart rate variability analysis and needs to attach sensors on his/her breast. Our experimental results indicated that it has a certain relationship between subjective stress and $\mathrm{TPA_f}$. A method based on $\mathrm{TPA_f}$ could be efficient to estimate subjective stress.**

Keywords-component; subjective stress; TPA; Face Scale (FS)

I. INTRODUCTION

Can you imagine a future society that humans and robots live together? They can talk and socialize with each other. Maybe humans and robots can understand each other through nonverbal communication. Robots can understand human feeling or emotion through his facial expression or biological signals. We consider that such a society isn't a dream or science fiction but a real society coming near future. Some studies of Human Agent Interaction(HAI) or Human Robot Interaction(HRI) focus on the communication between humans and robots. 'Palo' and 'ifbot', which are related to robot therapy, can behave based on nonverbal communication[8][9]. On the other hand, Palo and ifbot don't recognize and understand human feeling itself, of course, it is no problem from the standpoint of their design philosophy and concept. However, the near future society might require high-performance robots that have an ability to recognize human feelings or mental situation.

There have been many studies on measuring human feeling or emotions. Most of them employs subjective assessment measure, on the other hand there exist many approaches based on objective analysis. Some indexes of physiological evaluation are well known to measure human stress. For example, Immunoglobulin A type and cortisol in saliva are often used to measure the stress[1][2][3]. Stress indexes via heart rate variability (HRV) analysis is also often used [4]. The methods are very effective and useful, but there are some problems, assuming that the robots employ them to measure the stress. One problem is on sensing. In order to extract Ig. or cortisol from saliva, sensors need to be inserted in his/her mouth. HRV analysis needs to attach sensors on the breast. In daily life wearing the sensors is unnatural and it assigns a lot of burden to users. The another is on measurement time. In order to extract Ig. or cortisol from saliva, it takes only a few seconds. But HRV analysis generally takes several minutes to evaluate the electrocardiographic wave. In future daily life it would be better to employ an evaluation method based on near realtime analysis because the robots can quick respond and act according to the realtime mental situation of human.

In this study our goal is to develop a simple estimation of subjective stress which can measure the stress in near realtime. There are two kinds of subjective stress that are unconsicous and consious. People are not aware of unconsious stress existing, thus it might be important for people to care the unconsious stress in terms of medical reason. On the other hand, people could be aware of conscious stress. We consider that the conscious stress is suitable to decide and control robot behaviors for taking care of human people because users could be able to recognize the robot behaviors are due to the conscious stresses of users themselves. Unless users are aware of their stresses, they couldn't understand what the robot aims to do. The unconsicous stress to control autonomous robots would carriy a lot of risk in daily life. Our study therefore deals with consicous subjective stress. The contributions of this study to develop the estimation are as follows:

1) Proposal and development of $\mathrm{TPA_f}$ calculation via finger plethysmogram. Original TPA was developed by Yokoyama et al[5]. It could be calculated by the data of electrocardiographic wave measured for about several tens of seconds. The calculation formula of $\mathrm{TPA_f}$ is very simple, thus we could achieve near realtime processing. Furthermore, the finger plethysmogram is measured more easily than the electrocardiographic wave.
2) Investigation of a relationship between the subjective conscious stress and $\mathrm{TPA_f}$ via finger plethysmogram. $\mathrm{TPA_f}$ could have some relationship to human stress, but no experiments have been done on the relationship with conscious subjective stress so far. We employ Face Scale

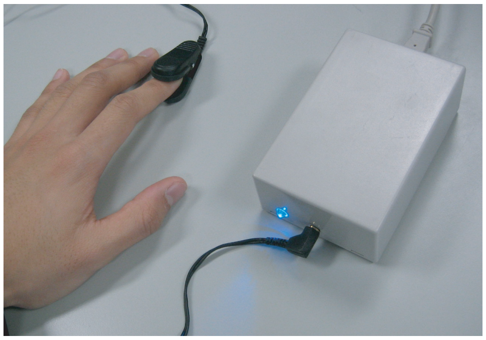

Fig. 1. Pulse sensor to measure finger plethysmogram

to measure conscious subjective stress.

II. EVALUATION INDEX OF STRESS

In this study we adopted heart rate variability (HRV) analysis via finger plethysmogram. The power spectra of heart rate variability contain the low frequency components (LF) from 0.04 to 0.15Hz and the high frequency components (HF) from 0.15 to 0.4Hz. HF is said to be mainly affected by components originated human breathing called 'Respiratory Sinus Arrhythmia (RSA)'. HF reflects the activity of the parasympathetic nerves. LF is said to be mainly affected by components originated blood pressure called 'Mayer Wave related Sinus Arrhythmia (MWSA)'. LF reflects the activity of the sympathetic nerves and parasympathetic nerves. The ratio of LF to HF reflects the activity of sympathetic nerves. It is said that the parasympathetic nerve activity becomes higher while feeling comfortable. Therefore HF is used as an index of relaxation or stress reduction. The power spectrum analysis, such as FFT, AR method and wavelet transform are generally used to calculate HF in HRV. Yokoyama et al. proposed a method which is able to estimate HF component of HRV based on local characteristics in time series[5]. Of course it has no need to use power spectrum analysis, and it is calculated by data at most of around 20-30 points. Thus the method is able to work in near real time because a calculating formula is simple. They verified that there was high correlation among the average values of HF detected with their proposed method, AR method and wavelet transform. In our study we adopted an method based on TPA (Turning Point Amplitude). TPA can be calculated in near real time, and it requires human subjects to attach sensors on their breast as mentioned in the previous section. Therefore we exploit a simple sensor to measure finger plethysmogram illustrated in Fig.1. The sensor is easier to handle than the sensors attached on the breast. In this paper $\mathrm{TPA_f}$(TPA via finger plethysmogram) is used to evaluate human stress from the objective view.

On the other hand Face Scale (FS) is a well-known index to measure human subjective feeling. FS, which is suggested by Lorish et al.[7], is a method to evaluate subjective feeling, FS is the illustrations of a person from a smile (scale 1) to a tearful face (scale 20) as shown in Fig.2. The subject has only to answer with the number of FS expressing his current feeling.

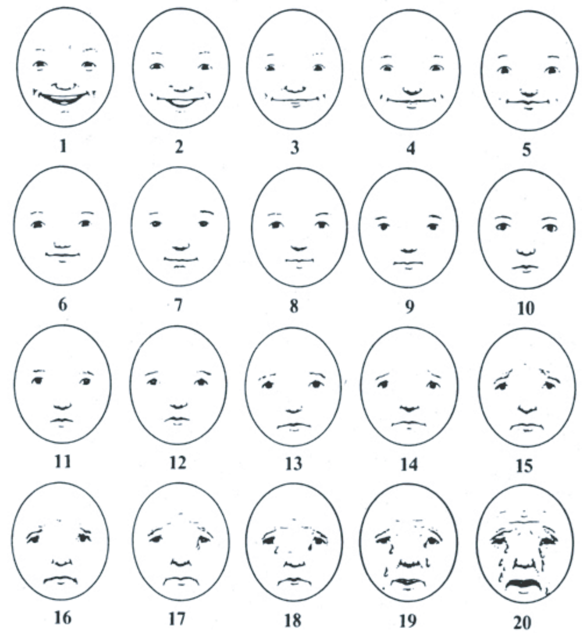

Fig. 2. Face Scale

There is a advantage to be able to perform the experiments in a short time. FS was also adopted as a method to evaluate a result of the treatment subjectively in the clinical medical field, and the effectiveness was reported[7]. This paper adopts FS to evaluate human subjective feeling, and attempts to find out a relationship between FS and $\mathrm{TPA_f}$.

III. EXPERIMENTS

We present our experimental method and the environment. We considered that it was important to measure FS and $\mathrm{TPA_f}$ at same time in order to investigate the relationship between them. Furthermore we considered that it was valid and proper to evaluate the human subjects who are in either normal mental state or stress state. Our experiment gave the subjects an artificial stressor such as mental arithmetic. The experiment evaluated the subjects in the three states that are pre-stress state, stress state and post-stress state.

A. Experimental Method

The experimental procedure is shown in Fig.3. Our experiment consists of three phases, the whole time was 15 min. In the first 5 min, human subjects closed their eyes. In the next 5 min, the subjects did mental arithmetics. While their constraining the mental arithmetic, they might have been directly under mental stress. Then they finished it and in the final 5 min, they closed their eyes or viewed the video. In the final 5 min they were not directly under mental stress, but its influences must have remained. Here we call the first 5 min, next 5 min and final 5 min 'pre-stress state', 'stress state' and 'post-stress state' respectively. After the end of each state, the human subjects chose FS number which was suitable to their own feeling at that time. In our experiment we prepared 'eyes closed' and 5 kinds of video image, each of which has

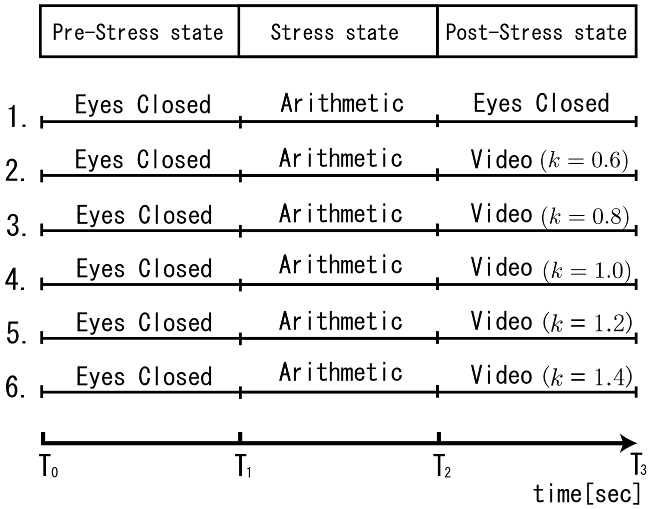

Fig. 3. Experimental Procedure

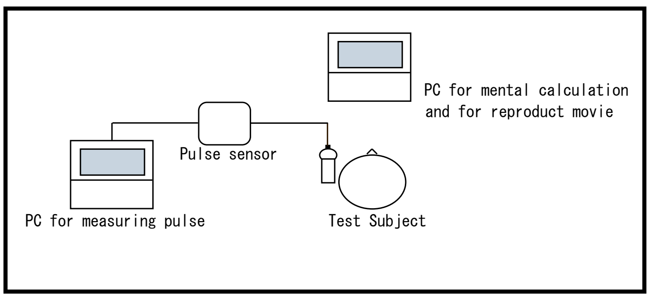

Fig. 4. Experimental Environment

different motion speed, for 'post-stress state' as shown in Fig. 3. The 'eyes closed' and the video were used for relaxation of the subjects [6]. The subjects performed all the experiments (1-6) in a different random order for each. Mental arithmetic was used as mental workload in the experiment. The details of mental arithmetic and the video images are mentioned later.

The experiment measured FS at T_1,T_2 and T_3. The time series of $TPA_f(t)$ were measured during all the time from T_0 to T_3. Here we define $TPA_f(t)$ which indicates a value of TPA_f at the time t.

The subjects were 9 males and 1 female in their 20s. Every subject didn't have the abnormal vision and were able to visually confirm the motions of the video. The experiment was conducted in the environment illustrated in Fig.4. The experiment environment was dark quiet room. The subjects kept sitting on the chair during the experiment. The computer displayed the questions of the mental arithmetic to enhance the subjects' mental workload, and the subjects answered them. The finger plethysmogram of the subjects were measured by the pulse sensor and the computer for measuring pulse wave.

B. Mental Workload

In the experiment, the mental arithmetic was used as mental workload [3]. The experiment required the subjects to repeat solving the mathematical questions: "Subtract 13 from a four-

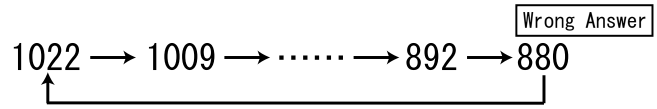

Fig. 5. Example of Mental Arithmetic the Human Subject Answered

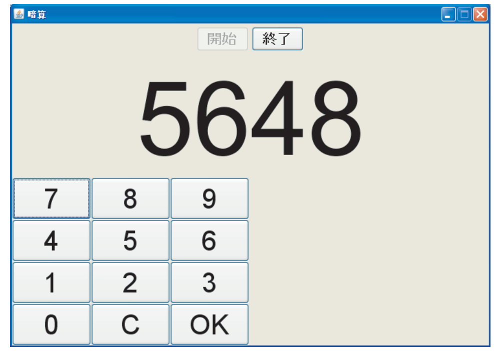

Fig. 6. Mental Arithmetic Application

Fig. 7. Capture Image of CG Video

digit figure X". The first figure X_0 is given at random and you answer $X_1 = X_0 - 13$. Next you answer $X_1 - 13$. Thus the i-th question will be $X_{i+1} - 13$. When the subjects made a mistake in the arithmetic, it restarted over from the beginning: $X_i = X_0$ illustrated in Fig.5. The subjects answered questions of the mental arithmetic on the computer monitor (Fig.6).

C. Video Image

We adopt 'ripples appearing on the water surface' as a video that the subjects view in the post-stress state for their relaxation [6]. The ripples, which we use a CG technique for generating, are displayed on the monitor. Ripples appear from the center of the image and disappear outside of the image. A capture image of the video is shown in Fig.7. In the experiment 5 kinds of the video with different motion speed parameter k $(= 0.6, 0.8, 1.0, 1.2, 1.4)$.

IV. EXPERIMENTAL RESULTS AND ANALYSIS

A. Relationship between TPA_f and FS

$TPA_f(t)$ is changeable and it isn't easy to find out the relationship between $TPA_f(t)$ itself and FS at the time t. It is

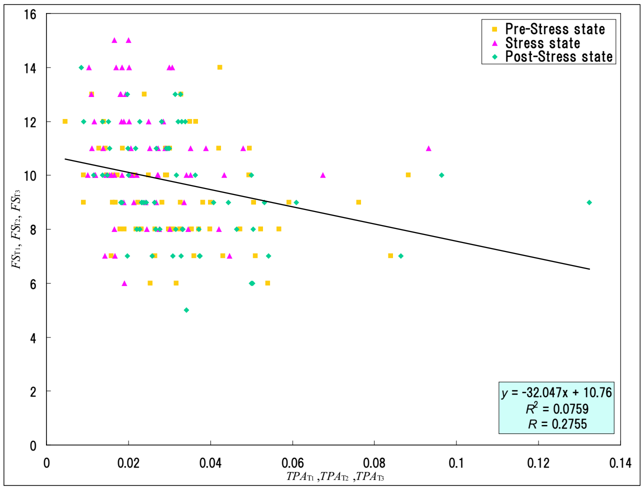

Fig. 8. Scatter plot of $\mathrm{TPA_f}$ and FS

said to be useful way to calculate the average value of 20-30 points of $TPA_f(t)$ [5].

Therefore we calculate $TPA_{\mathrm{T_i}}$ which is the average value of $TPA_f(t)$ for x seconds just before $\mathrm{T_i}$ as follows:

$$TPA_{\mathrm{T_1}} = \frac{1}{x}\int_{(\mathrm{T_1}-x)}^{\mathrm{T_1}} TPA_f(t)dt \quad (1)$$

$$TPA_{\mathrm{T_2}} = \frac{1}{x}\int_{(\mathrm{T_2}-x)}^{\mathrm{T_2}} TPA_f(t)dt \quad (2)$$

$$TPA_{\mathrm{T_3}} = \frac{1}{x}\int_{(\mathrm{T_3}-x)}^{\mathrm{T_3}} TPA_f(t)dt \quad (3)$$

In the each equation $\mathrm{T_0} = 0\mathrm{sec}$, $\mathrm{T_1} = 300\mathrm{sec}(5\mathrm{min})$, $\mathrm{T_2} = 600\mathrm{sec}(10\mathrm{min})$, and $\mathrm{T_3} = 900\mathrm{sec}(15\mathrm{min})$. x is 30 seconds in this experiment.

We use $TPA_{\mathrm{T_1}}$, $TPA_{\mathrm{T_2}}$ and $TPA_{\mathrm{T_3}}$ to evaluate pre-stress state, stress state and post-stress state respectively. As previous mentioned, each FS is also measured at $\mathrm{T_1}$, $\mathrm{T_2}$ and $\mathrm{T_3}$.

Fig.8 indicates the scatter plot of pre-stress state:($TPA_{\mathrm{T_1}}$, $FS_{\mathrm{T_1}}$), stress state: ($TPA_{\mathrm{T_2}}$, $FS_{\mathrm{T_2}}$) and post-stress state: ($TPA_{\mathrm{T_3}}$, $FS_{\mathrm{T_3}}$) of all the experiments to investigate the relationship between $\mathrm{TPA_f}$ and FS. The straight line represents the regression line in Fig.8. There is a small negative correlation (-0.2755) between $\mathrm{TPA_f}$ and FS, and Fig.8 indicates that it isn't easy to estimate the degree of FS with $\mathrm{TPA_f}$ itself.

We performed multiple comparison to confirm whether each state is different from each other or not. The multiple comparison that we apply is Kruskal Wallis test.

There is a significant difference at the 1% level between the pre-stress state and the stress state in Fig.9. What is more, there is also a significant difference at the 5% level between them in Fig.10. There are significant differences at the 5% level between the stress state and the post-stress state in Fig.9 and Fig.10. In addition, there are no significant differences between the pre-stress state and post-stress state in Fig.9 and Fig.10. In light of the results there is a possibility that $\mathrm{TPA_f}$ can distinguish between the state under the direct stress (stress state) and the stress-free state after the stress released (pre-stress state and post-stress state). There could be a certain relationship between $\mathrm{TPA_f}$ and FS.

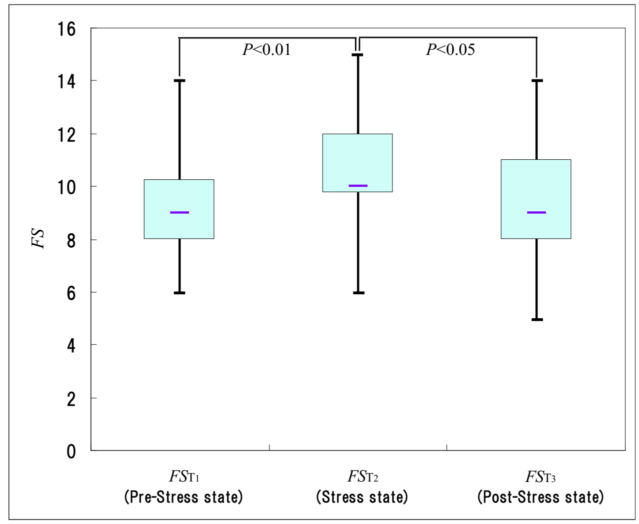

Fig. 9. Box plot of FS. Kruskal Wallis test is applied to the three states. There are significant differences at the 1% level among all of the states

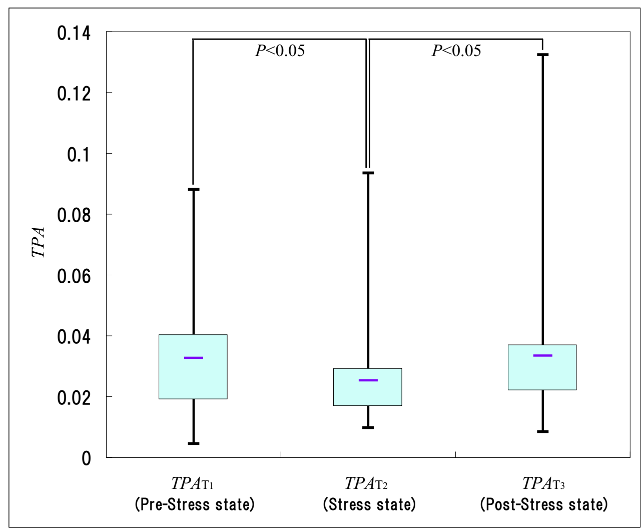

Fig. 10. Box plot of $\mathrm{TPA_f}$. Kruskal Wallis test is applied to the three states. There are significant differences at the 1% level among all of the states

B. Relationship between ΔTPA and ΔFS

We focus on the amount of change of $\mathrm{TPA_f}$ and FS to discuss the relationship between them. The pre-stress state is prepared to lead the subjects to be in neutral mental state. Nonetheless, you can see and confirm $FS_{\mathrm{T_1}}$ and $TPA_{\mathrm{T_1}}$ have a large variance in Fig.9 and Fig.10 respectively. Therefore we define and adopt the amount of change of both $\mathrm{TPA_f}$ and FS from the pre-stress state(from the time $\mathrm{T_1}$). We introduced $\Delta TPA_{\mathrm{T_2T_1}}$ and $\Delta TPA_{\mathrm{T_3T_1}}$, which are defined and calculated with Eq.4 and 5. $\Delta FS_{\mathrm{T_2T_1}}$ and $\Delta FS_{\mathrm{T_3T_1}}$ are

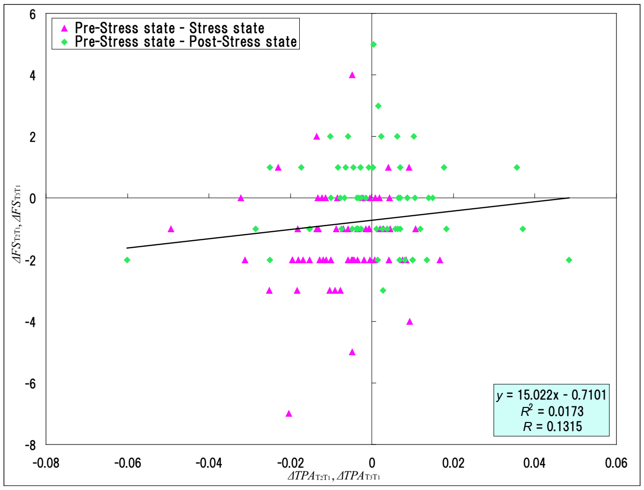

Fig. 11. Scatter plot of ($\Delta TPA_{\mathrm{T_2T_1}}$, $\Delta FS_{\mathrm{T_2T_1}}$) and ($\Delta TPA_{\mathrm{T_3T_1}}$, $\Delta FS_{\mathrm{T_3T_1}}$)

also defined as shown in Eq.6 and 7.

$$
\begin{aligned}
\Delta TPA_{\mathrm{T_2T_1}} &= TPA_{\mathrm{T_2}} - TPA_{\mathrm{T_1}} && (4)\\
\Delta TPA_{\mathrm{T_3T_1}} &= TPA_{\mathrm{T_3}} - TPA_{\mathrm{T_1}} && (5)
\end{aligned}
$$

$$
\begin{aligned}
\Delta FS_{\mathrm{T_2T_1}} &= FS_{\mathrm{T_1}} - FS_{\mathrm{T_2}} && (6)\\
\Delta FS_{\mathrm{T_3T_1}} &= FS_{\mathrm{T_1}} - FS_{\mathrm{T_3}} && (7)
\end{aligned}
$$

Note that Eq.4 and 5 are the subtraction from post-stress state, and Eq.6 and 7 are the subtraction from stress state.

Fig.11 shows the scatter plot of ($\Delta TPA_{\mathrm{T_2T_1}}$, $\Delta FS_{\mathrm{T_2T_1}}$) and ($\Delta TPA_{\mathrm{T_3T_1}}$, $\Delta FS_{\mathrm{T_3T_1}}$). The straight line represents the regression line in Fig.11. There might be little correlation between ΔTPA and ΔFS. Fig.11 also indicates that it is difficult to estimate the degree of FS with ΔTPA. We apply Wilcoxon test and paired t-test. Fig.12 and Fig.13 show more clearer significant differences (p&lt.; 0.01) than Fig.9 and Fig.10.

We adopt the other criteria to clarify the relationship between stress state and post-stress state. $\Delta TPA_{\mathrm{T_3T_2}}$ and $\Delta FS_{\mathrm{T_3T_2}}$ are defined and calculated with Eq.8 and 9.

$$
\begin{aligned}
\Delta TPA_{\mathrm{T_3T_2}} &= TPA_{\mathrm{T_3}} - TPA_{\mathrm{T_2}} && (8)\\
\Delta FS_{\mathrm{T_3T_2}} &= FS_{\mathrm{T_2}} - FS_{\mathrm{T_3}} && (9)
\end{aligned}
$$

The equations represent the difference from stress state to post-stress state. In order to compare them with the difference from pre-stress state to stress state as defined in Eq.4 and 6. Fig.14 shows the scatter plot of ($\Delta TPA_{\mathrm{T_2T_1}}$, $\Delta FS_{\mathrm{T_2T_1}}$) and ($\Delta TPA_{\mathrm{T_3T_2}}$, $\Delta FS_{\mathrm{T_3T_2}}$). It is confirmed that the most of ($\Delta TPA_{\mathrm{T_2T_1}}$, $\Delta FS_{\mathrm{T_2T_1}}$) are plotted on the left low quadrant and the most of ($\Delta TPA_{\mathrm{T_3T_2}}$, $\Delta FS_{\mathrm{T_3T_2}}$) are plotted on the right upper quadrant. $\Delta TPA_{\mathrm{T_2T_1}}$ tends to take minus(-) when $\Delta FS_{\mathrm{T_2T_1}}$ is minus(-). Otherwise $\Delta TPA_{\mathrm{T_3T_2}}$ tends to take (+) when $\Delta FS_{\mathrm{T_3T_2}}$ is plus(+). Thus the change of plus-minus sign of ΔTPA could correspond to the change of the sign of ΔFS. The result of Fig.14 indicates that it might be possible that the difference of $\mathrm{TPA_f}$, which is observed objectively and quantitatively, can estimate the increase and the decrease of subjective stress.

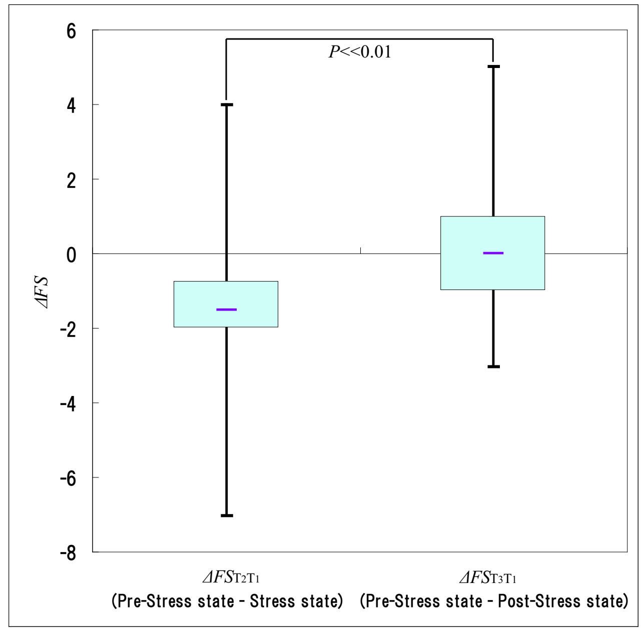

Fig. 12. Box plot of ΔFS. Wilcoxon test shows a significant differences at the 1% level between $\Delta FS_{\mathrm{T_2T_1}}$ and $\Delta FS_{\mathrm{T_3T_1}}$

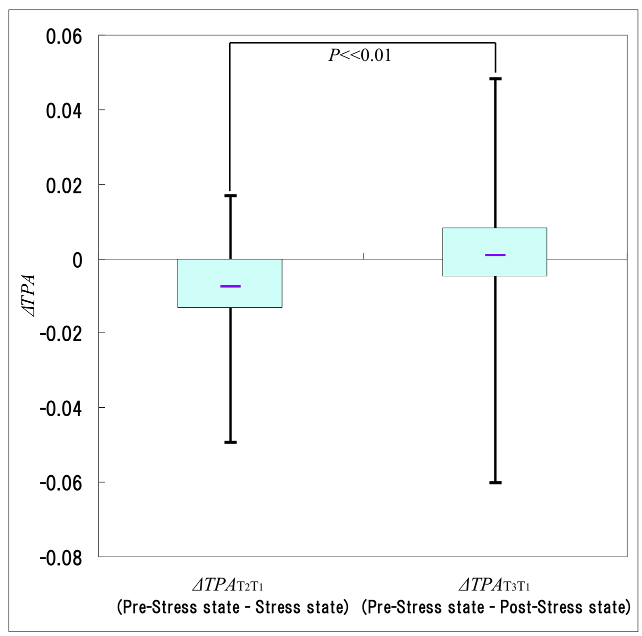

Fig. 13. Box plot of ΔTPA. Paired t-test shows a significant differences at the 1% level between $\Delta TPA_{\mathrm{T_2T_1}}$ and $\Delta TPA_{\mathrm{T_3T_1}}$

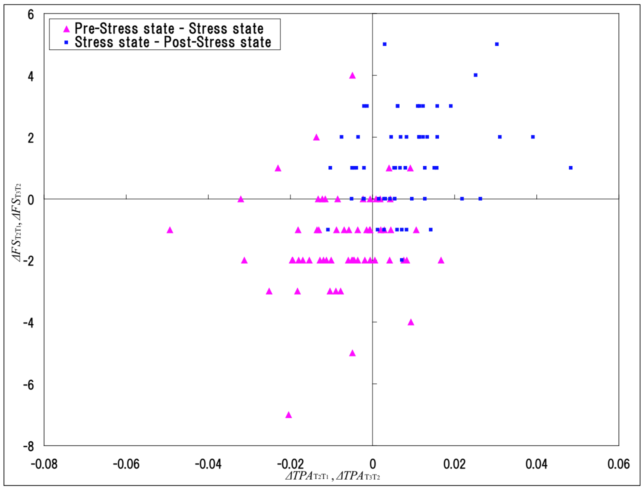

Fig. 14. Scatter plot of ($\Delta TPA_{\mathrm{T_2T_1}}$, $\Delta FS_{\mathrm{T_2T_1}}$) and ($\Delta TPA_{\mathrm{T_3T_2}}$, $\Delta FS_{\mathrm{T_3T_2}}$)

V. CONCLUSION

This study investigated the relationship between FS and $\mathrm{TPA_f}$ via finger plethysmogram. This paper shows that $\mathrm{TPA_f}$ could roughly estimate the change of human stress. We adopted a simple sensor and a simple method to measure and calculate $\mathrm{TPA_f}$. Furthermore $\mathrm{TPA_f}$ can be measured in near realtime. Therefore it couldn't be difficult to implement our method to robots. However we have some remaining problems to realize the robots that can estimate human stress or comfortableness. As first we must improve the accuracy to estimate human stress. Additon to that we might consider to combine $\mathrm{TPA_f}$ and other stress measures. The second is to conduct more experiments to collect the data from several environments and situations. The experiments woulld need to consider not only $\mathrm{TPA_f}$ but also other stress measures e.g. the amount of amylase in saliva and blood test. Addition to that, some researchers say that an effect of human stress is observed after a few seconds delay from finisning mental workload. In light of this we might consider to redesign the experiments The third is to develop a small sensor to measure finger plethysmogram like a wedding ring. We are planning to solve the problems in near future.

REFERENCES

[1] S. Tsujita and K. Morimoto, *Secretory IgA in saliva can be a useful stress marker*, Environmental Health and Preventive Medicine, Vol.4, pp.1-8, 1999.

[2] H.B. Valdimarsdottir and A.A. Stone, *Psychosocial factors and secretory immunoglobulin A*, Critical Reviews in Oral Biology and Medicine, Vol.8, No.4, pp.461-474, 1997.

[3] C. Kirschbaum and D.H. Hellhammer, *Salivary cortisol in psychoneuroendocrine research: Recemt developments and applications*, Psychoneuroendocrinology, Vol.19, No.4, pp.313-333, 1994.

[4] M. Pagani, F. Lombardi, S. Guzzetti, O. Rimoldi, R. Furlan, P. Pizzinelli, G. Sandrone, G. Malfatto, S. D. Orto, E. Piccaluga, M. Turiel, G. Basseli, S. Cerutti and A. Malliani, *Power spectral analysis of heart rate and arterial pressure variabilities as a marker of sympatho-vagal interaction in man and conscious dog*, Circulation Research, 59-2, pp.178-193, 1986.

[5] K. Yokoyama, N. Kamiya, *Simplified method for estimating high-frequency component of heart rate variability based on local characteristics in time series*, ERGONOMICS, Vol.40, No.6, pp.302-308, 2004.

[6] T. Sugiura, Y. Okudaira, Y. Kobashi, T. Nakamura, H. Itoh, *Relaxation effects of object speed in video images: Evaluation by heart rate variability analysis*, Kansei Engineering and Emotion Research, in CD-ROM, 2009.

[7] C.D. Lorish, R. Maisiak, *The face scale:a brief, nonverbal method for assessing patient mood*, Arthritis Rheum, Vol.29, pp.906-909, 1986.

[8] K. Wada, T. Shibata, *Living With Seal Robots. Its Sociopsychological and Physiological Influences on the Elderly at a Care House*, IEEE Transactions on Robotics, Vol.23, No.5, pp.972-980, 2007.

[9] T. Ando, M. Kanoh, *A Self-sufficiency Model Using Urge System*, IEEE World Congress on Computational Intelligence(WCCI 2010), pp.429-434, 2010.