Autonomic Nervous Activity Estimation Algorithm with Facial Skin Thermal Image

Tota Mizuno, Shunsuke Kawazura,
Kota Akehi, Shogo Matsuno,
Kazuyuki Mito and Naoaki Itakura
Department of Informatics Graduate
School of Informatics and Engineering
The University of Electro-Communications
Chofugaoka, Chofu, Tokyo 182-8585
Email: mizuno@uec.ac.jp, k1430023@edu.cc.uec.ac.jp,
a1540001@edu.cc.uec.ac.jp, m1440004@edu.cc.uec.ac.jp,
mito@se.uec.ac.jp and ita@se.uec.ac.jp

Hirotoshi Asano
Department of Electronics and Information
Engineering, Faculty of Engineering,
Kagawa University
Hayashi-cho 2217-20, Takamatsu,
Kagawa 761-0396, JAPAN
Email:asano@eng.kagawa-u.ac.jp

***Abstract*—The aim of this study was to achieve the absolute evaluation of mental workload (MWL) by proposing a novel algorithm for the evaluation and estimation of autonomic nervous activity with facial thermal imaging. Innovation in Information and Communication Technology(ICT) has resulted in workers experiencing an increasing mental workload, which is caused by using the computer. In our research group we have studied a method to evaluate and estimate autonomic nervous activity using facial thermal imaging as measured by infrared thermography. Previous methods extracted the forehead and nose as a method for performing the evaluation and estimation using the temperature difference. However, this approach does not consider the area. The proposed method enables parts or areas of temperature change other than the nose to be captured. This presents the possibility of accurate evaluation and estimation at levels that are more sensitive than the conventional method. In addition, there is the possibility of absolute evaluation by using one thermal image of the face. We also examined whether further high-precision evaluation and estimation would be possible. Our results showed the proposed method to be a highly accurate nasal skin temperature (NST) evaluation method compared to results obtained in previous studies.**

***Index Terms*—Facial thermal image; Nasal skin temperature; Mental work-Load.**

I. INTRODUCTION

Innovation in the area of ICT has resulted in workers experiencing a higher mental workload (MWL) [1] caused by using the computer. Although an appropriate MWL has health benefits for human beings, long-term excessive MWL can cause fatigue and lead to a drop in concentration, thereby leading to human errors and creating a health hazard. It is therefore very important for workers to evaluate their MWL, in terms of preventing and reducing human errors and the associated health hazard.

A previous study used estimation methods based on psychological, behavioral, and physiological evaluations to assess the MWL [2]–[12]. Psychological evaluations are based on the use of questionnaires or similar methods. Behavioral evaluations involve the assessment of work results and performance, for example, whereas the methods used for physiological evaluations use electrophysiological signal indices or methods such as these. In particular, the use of physiological indices for evaluation purposes enable researchers to perform assessments objectively and quantitatively and in real time. In addition, physiological indicators have excellent features that can be detected by way of the involuntary reaction of the unconscious. In general, physiological indices are often used as an indication of autonomic nerve activity derived from indicators such as the heart rate, respiration, blood pressure, myoelectric properties, and electroencephalogram (EEG) measurements.

These physiological indicators are used to evaluate autonomic nervous activity, which provides an estimation of MWL. However, when recording these bioelectric signals it is necessary to use mounted electrodes, for example, and this may cause difficulties when applied in the actual workplace.

Prompted by the need to overcome these difficulties, our research group has been studying a method based on the use of facial thermal imaging as measured by infrared thermography [12]–[24]. This method extracts the forehead and the nose from the facial thermal image to determine the temperature difference by using the nasal skin temperature (NST) to evaluate and estimate the autonomic nervous activity.

The advantage of using NST is that, unlike the measurement of electrophysiological indicators, the method obviates the need to attach sensors; hence, it is possible to measure the MWL by using low-bound and non-contact methods. However, this method uses time series data and is a relative evaluation based on the comparison of resting and task loading; thus, providing feedback of the results of the analysis is time consuming.

Therefore, we have investigated the evaluation of the physiological mental state to determine the MWL by using a heat image of the skin temperature of the whole face, as measured by infrared thermography. This method enables temperature changes of areas other than the nose to be captured. Therefore, it is possible to perform the evaluation and estimation more

 ISBN: 978-1-61208-468-8

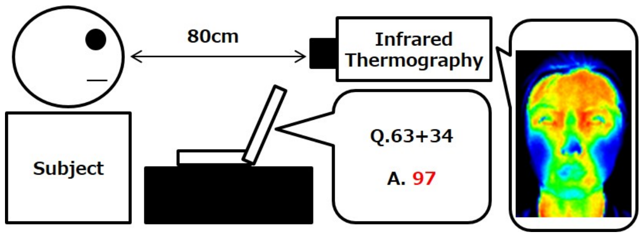

Fig. 1. Experimental system.

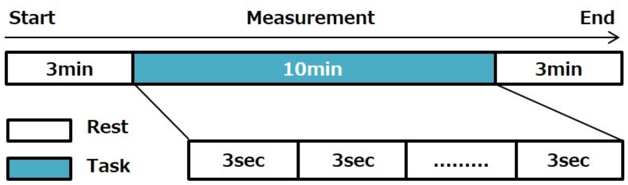

Fig. 2. Experimental protocol.

accurately and more sensitively than with the past technique. In addition, the possibility of absolute evaluation by a single thermal image of the face exists.

Previous studies of ours led to the development of a high-precision method based on the histogram of the skin temperature of the entire face. However, the MWL evaluations were not necessarily accurate, because different shooting angles could cause a reduction in the accuracy of temperature measurements. Thus, we suggest the use of a large end portion of the face by using an appropriate thermographic and photographic angle. Evaluation results that include the end portion of the face have been shown to be less accurate [25]–[27].

The objective of this study was to perform an absolute evaluation of MWL, by considering an algorithm for the evaluation and estimation of the autonomic nervous activity. Therefore, we examined the possibility of further high-precision evaluation and estimation.

II. Experiments

Experiments were carried out to acquire facial thermal images (FTIs) of the different MWL states. We required subjects to carry out a consuming MWL task.

A. Experimental protocol

Fig.1 shows the experimental system. Thermal images were taken when a subject solved the mental arithmetic calculation. An infrared thermography device (ViewOhreIMAGING XA0350) was placed at a distance of 1 m horizontally from the nose of the subject. The thermal image size was 320 $\times$ 240 pixels, and the sampling period was 1 s. A PC display and numeric keypad were placed upon the desk. Fig.2 shows the experimental protocol.

Subjects rested for 3 min, in a sitting position. After this initial rest period, subjects began the mental arithmetic calculation task and continued this task for 10 min as MWL.

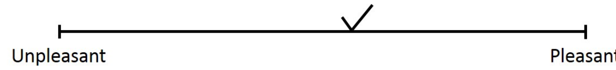

Fig. 3. Example of Visual Analogue Scale.

After completion of the task, subjects again rested for 3 min, thereby completing the experiment. The calculation involved the addition of two integers, each of which was between 10 and 99. The subject inputs the answer of the calculation displayed on the PC by using the numeric keypad. The calculation is displayed for 3 s. After 3 s, the following calculation will display on the PC, regardless of whether the subject answers the calculation within 3 s. Seven facial thermal images as physiological indices at 0, 2, 4, 6, 8, and 10 min after resting are taken during the experiment. Visual Analogue Scale (VAS) was used as psychological indices. Fig.3 shows an example of VAS. Subjective senses and feelings can be measured by marking a position on 10cm long scale characterized by a pair of opposite words or phrases at the both ends. This method is featured with little individual differences in the understanding of the description, and shorter time to perform the measurements. In this study, four pairs of words for VASs were employed. There were “Unpleasant-Pleasant”, “Distracted-Concentrate”, “Pleasant-Unpleasant” and “Fatigue-Vigor”.

The subjects were four healthy adults from 22 to 27 years old who were well rested the night before the experiment.

B. Results and Discussion

First, we examined the estimated possible face area of the autonomic nervous activity. It shows the thermal image before and after mental arithmetic calculation task load in Fig.4.

The task takes into account that the temperature in the vicinity of the nose and lips changes significantly. In addition, according to previous studies [3], those parts of the face that require the camera to use a large shooting angle do not provide accurate temperature measurements. Therefore, as shown in 4, regions of the face that exclude the end portion of large faces and which have a suitable camera imaging angle ((a) whole face excluding the hair, (b) the eyes and the area between the eyes and downwards, only, and (c) the nose and mouth) can be used for the analysis.

Next, an analysis region is extracted from seven different thermal images of the state of the acquired MWL, and were investigated with the average of the regions (a) and (b) to determine the change. Fig.6 shows the average value and the standard deviation of the time series data of the average temperature of each subject.

Although there are differences in the average temperature of each subject, the standard deviation is within 1[Celsius]. Large variations were observed in the average temperature of the whole area due to the influence of the MWL load. As the blood flow is expected to flow to the nose and in the vicinity of the lips depending on the MWL, we considered the blood flowing to the entire face to remain unchanged. As a result, the average change in temperature was considered to be less.

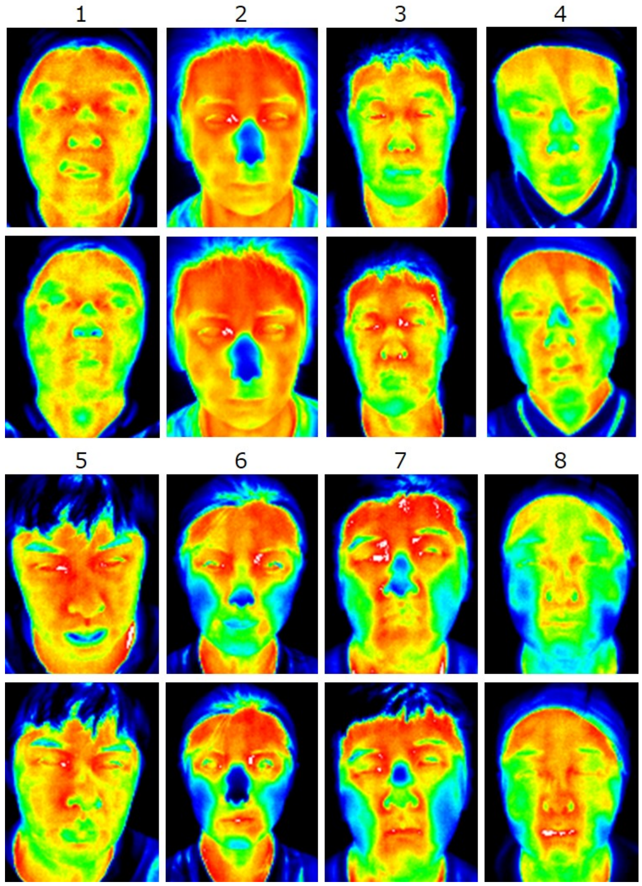

Fig. 4. Thermal image before and after mental arithmetic calculation task load.

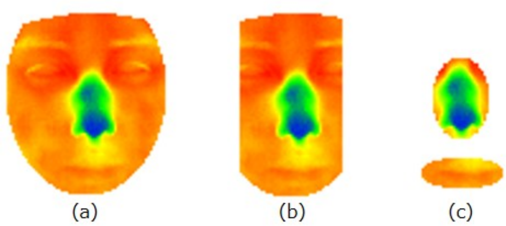

Fig. 5. Analysis region (a) whole face which does not include the hair, (b) the inside of the eyes, only (c) nose and mouth) and the analysis region.

III. Proposed Autonomic Nervous Activity Estimation Algorithm

We are aiming for absolute MWL evaluation by obtaining a single face thermal image. This study proposes an algorithm to reproduce autonomic nervous activity, with the aim of absolute MWL evaluation by using a single thermal image of the face. As our study is based on the average temperature of the entire region that undergoes little change due to the MWL, we propose an algorithm to estimate the autonomic nervous activity.

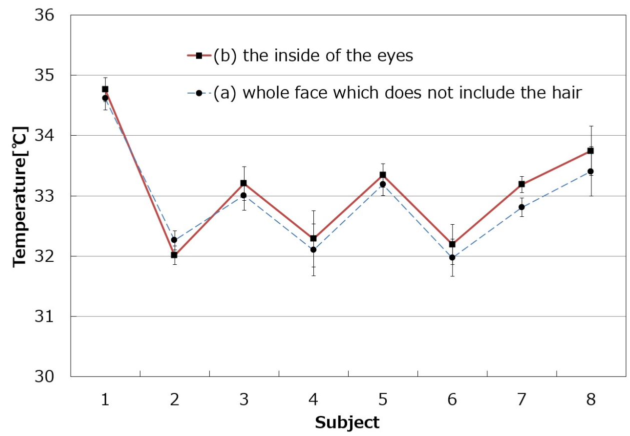

Fig. 6. The average value and the standard deviation of the time series data of the average temperature of each subject.

A. Method of calculating the estimated value

The average of the entire area was calculated by plotting the temperatures in the region, after which the sum of the difference in the region was calculated. This temperature change due to changes in the autonomic nervous activity was examined to determine whether it is a possible measurement. The calculation formula of the average temperature and the temperature difference in each area are obtained using the following equation:

$$F(x, y) = \sum_{i=0}^{n} (T - X_i)^2 \tag{1}$$

where T is the average temperature, Xi is a temperature value for each pixel in the region, and n is the number of pixels in the area. By squaring the reference and the difference of the temperature, the effect of the sign is taken into account. We evaluated the MWL using the estimates obtained for each of the three regions shown in Fig.5.

B. Evaluation method

1) General correlation between mental state and physiological indices (Evaluation method 1): We investigated the general relationship between the mental state and each proposed physiological index by comparing the psychological indicators and physiological indices that underwent change as a result of the imposed calculation problem tasks to determne the MWL. The correlations between VAS and each of the physiological indices were determined by Pearson's correlation coefficient using the mean values of all subjects.

2) (Evaluation method 2): In this case, we investigated the relationship between the mental state and each proposed physiological index within the subject by using multiple regression to determine the variations between the psychological indicators and physiological indices. We used VAS as the outcome variable, and each physiological index and the subjects as predictor variables. Subjects were treated as categorical factors using a dummy variable with eight degrees of freedom. The value from the t test for the regression slope of VAS was used

 ISBN: 978-1-61208-468-8

TABLE I
RESULTS OF THE ANALYSIS.

VAS	Indexes	Analysis Method 1		Analysis Method 2	
		Coefficient of Correlation	P Value	Coefficient of Correlation	P Value
Pleasure - Unpleasure	NST	0.88	0.004 **	0.41	0.008 **
	a	0.82	0.013 *	-0.38	0.014 *
	b	0.88	0.004 **	-0.47	0.002 **
	c	0.86	0.006 **	-0.47	0.002 **
Distracted - Concentrate	NST	0.35	0.400	0.03	0.876
	a	0.20	0.639	-0.05	0.733
	b	0.19	0.004	-0.12	0.447
	c	0.32	0.434	-0.13	0.425
Pleasant - Unpleasant	NST	0.75	0.031 *	0.27	0.093
	a	0.64	0.085	-0.23	0.156
	b	0.66	0.077	-0.22	0.167
	c	0.71	0.048 *	-0.40	0.010 **
Fatigue - Vigor	NST	0.75	0.030 *	0.10	0.528
	a	0.63	0.097	-0.17	0.283
	b	0.64	0.091	-0.15	0.351
	c	0.68	0.065	-0.38	0.013 *

to determine the probability of the analysis. The magnitude of correlation coefficient between VAS and each physiological index within subjects was calculated as the square root of (sum of squares for VAS)/(sum of squares for VAS + residual sum of squares). The sign of the correlation coefficient was given by that of the regression coefficient for VAS.

C. *Results and Discussion*

Table 1 lists the results of the analysis. Evaluation method 1 found significant correlation between some VAS and each physiological index. In particular, the correlation of Pleasure-Unpleasure was observed. These results show that the NST obtained by the proposed method, is high hedonicof the general relationship of psychology. Next, evaluation method 2, in particular, also showed a significant correlation of Pleasure-Unpleasure. Other statistically significant differences, including the Pleasant-Unpleasant correlation of VAS items was also observed. This showed that the value is lower than the NST. Thus, within subjects, the correlation that was statistically determined using the proposed method was higher than that obtained with the evaluation method using the NST of previous studies.

IV. CONCLUSION

The aim of our work was to perform the absolute MWL evaluation by using a single thermal image of the face. Thus, we proposed a novel algorithm to estimate the autonomic nervous activity. The results showed our proposed method to be highly accurate compared to the NST evaluation method proposed in previous studies.

REFERENCES

[1] S. Haga, "Theory and measurement of Mental Work-load," Japan Pabulication Service, 2001.

[2] A. Murata ,"Measurement of mental workload by heart rate variability indexes," Japan Ergonomics Society,28(2), pp.91-99, 1992.

[3] K. HIRAYANAGI, K. IWASAKI, S. KANDA and K. YAJIMA, "An experimental study on the measurement and assessment of mental workload(MWL)," Japan Ergonomics Society, pp.251-259, 1996.

[4] T. MIYAKAWA, T. YOSHIDA, R. KUBOTA, H. IKEDA," Development of the mental workload evaluation method," Human interface : proceedings of the Human Interface Symposium , Human interface : proceedings of the Human Interface Symposium

[5] R. Tokunaga, T. Hagiwara , S. Kagaya and Y. Onodera , "Effects of Talking through Cellular Telephone on Driving Behavior," Japan Society of Civil Engineers No.17 pp995-1000, 2000.

[6] H. MATSUNAGA and H.NAKAZAWA, "Relation between Mental Workload and Satisfaction Measures Evaluated from EEG," The Japan Society of Mechanical Engineers 66(648), 2884-2890, 2000.

[7] M. KARASHIMA, T. YAMAZAKI, "A study on the relationship between the time pressure by time constraints and the time estimations," Japan Ergonomics Society 39(1), 30-37, 2003.

[8] H. Zenju , A. Nozawa, H. Tanaka and H. Ide ,"The Estimation of Unpleasant and Pleasant States by Nasal Thermogram," The transactions of the Institute of Electrical Engineers of Japan. C, A publication of Electronics, Information and System Society 124(1), 213-214, 2004-01-01.

[9] H. Kaname, I. Kenichi, K. Shougo, Y. Kazuyoshi ,"An experimental study on the measurement and assessment of mental workload(MWL)," Japan Ergonomics Society, 32(5),pp.251-259, 1996.

[10] I. Hiroo Quantitative evaluation of mental work by thermography. The Society of Instrument and Control Engineers Vol.24, No.2, pp107-111, 1988.

[11] K. Mitsuhiko, Y. Tomoyuki ,"A study on the relationship between the time pressure by time constraints and the time estimations," Japan Ergonomics Society, Vol.39, No.1, pp30-37, 2003.

[12] K. Hioki, A. Nozawa, T. Mizuno and H. Ide , Physiological Evaluation of Mental Workload in Time Pressure. The transactions of the Institute of Electrical Engineers of Japan. C, A publication of Electronics, Information and System Society 127(7), 1000-1006, 2007-07-01.

[13] A. Nozawa, T. Mizuno, H. Ide, H. Asano and S. Nomura, "Evaluation of the Effect of Intermittent Mental Work-Load by Nasal Skin Temperature," The transactions of the Institute of Electrical Engineers of Japan. D, A publication of Electronics, Information and System Society Vol.J93-D, No.4, pp.535-543, 2010.

[14] A. Nozawa, S. Tomono, T. Mizuno and H.Ide ,"Detection of Fight or Flight Reaction on Facial Skin Thermogram using Spatio-Temporal Spectrum Differential Analysis," T.IEEJ Trans.FM, 126(6), pp.470-477, 2006.

[15] R. Sakamoto, A. Nozawa, H. Tanaka, T. Mizuno and H. Ide," Evaluation of the Driver's Temporary Arousal Level by Facial Skin Thermogram," Effect of Surrounding Temperature and Wind on the Thermogram. The transactions of the Institute of Electrical Engineers of Japan. C, A publication of Electronics, Information and System Society 126(7), 804-809, 2006-07-01.

[16] K. Hioki, A. Nozawa, T. Mizuno and H. Ide, "Physiological Evaluation of Mental Workload in Time Pressure," The transactions of the Institute of Electrical Engineers of Japan. C, A publication of Electronics, Information and System Society 127(7), 1000-1006, 2007-07-01.

[17] T. Mizuno, S. Nomura, A. Nozawa, H. Asano and H. Ide, "Evaluation of the Effect of Intermittent Mental Work-Load by Nasal Skin Temperature," IE-ICE, J93-D(4), pp.535-543, 2010.

[18] Advanced Industrial Science and Technology - Institute for Human Science and Biomedical Engineering," Handbook of Human measurement, Asa-kura publisher, 2003.

[19] T. Mizuno, N. Nakategawa, Y. Kume, "Color influences on human beings evaluated by nasal skin temperature," IArtificial Life and Robotics, Vol.16, Issue 4, pp 519-522, 2012.

[20] Bashar A. Rajoub, and Reyer Zwiggelaar, "Thermal Facial Analysis for Deception Detection," IEEE Transactions on Information Forensics and Security, Vol. 9, No. 6, pp.1015-1023, June 2014.

[21] Sarun Sumriddetchkajorn, Armote Somboonkaew, Tawee Sodsong, Itthipol Promduang, Niti Sumriddetchkajorn, and Thawatchai Prada-in, " Simultaneous Analysis of Far Infrared Signals From Periorbital and Nostril Areas for Nonintrusive Lie Detection: Performance From Real Case Study," Journal of Lightwave Technology, Vol. 33, No. 16, pp.3406-3412, August 2015.

[22] Dvijesh Shastri, Manos Papadakis, Panagiotis Tsiamyrtzis,Barbara Bass, and Ioannis Pavlidis, " Perinasal Imaging of Physiological Stress and Its

 ISBN: 978-1-61208-468-8

Affective Potential," IEEE Transactions on Affective Computing, Vol. 3, No. 3, pp.336-378, 2012.
[23] Sophie Jarlier, Didier Grandjean, Sylvain Delplanque, Karim N'Diaye, Isabelle Cayeux,Maria Ine´ s Velazco, David Sander, Patrik Vuilleumier, and Klaus R. Scherer, " Thermal Analysis of Facial Muscles Contractions," IEEE Transactions on Affective Computing, Vol. 2, No. 1, pp.2-9, 2011.
[24] Brian R. Nhan and Tom Chau, " Classifying Affective States Using Thermal Infrared Imaging of the Human Face," IEEE Transactions on Biomedical Engineering, Vol. 57, No. 4, pp.979-987, April 2010.
[25] S. Kawazura, H. Asano, A. Nozawa, M. Uchida, N. Itakura, K. Mito and T. Mizuno, "Estimation of the autonomic nerve activity with facial thermogram," 2014 11th international Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology, CD-ROM Advanced Techniques in Applications, DSP and Hardware Design, No.1320, May 14-17, 2014, Thailand.
[26] T. Mizuno, S. Kawazura, H. Asano, K. Mito, Y. Kume and N. Itakura, "Evaluation of the autonomic nerve activity using facial thermal image," The Twentienth International Symposium on Artificial Life and Robotics 2015 (AROB 20th '15),PID3158279, 2015, Japan.
[27] T. Mizuno, T. Sakai, S. Kawazura, H. Asano, K. Akehi, S. Matsuno, K. Mito, Y. Kume and N. Itakura, "Facial Skin Temperature Fluctuation by Mental Work-Load with Thermography," The International Conference on Electronics and Software Science (ICESS2015) Proceedings pp. 212-215, 2015, Japan.