Basic Study of an Evaluation that Uses the Center of Gravity of a Facial Thermal Image for the Estimation of Autonomic Nervous Activity

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***Abstract*—In this paper, we propose using the temperature-centroid of a facial thermal image as a new index to evaluate the Mental Work Load (MWL). The existing evaluation methods using thermal images are non-contact mental-stress–evaluation methods that measure a change in the temperature of the regions around the nose, which is caused by MWL. However, automatic evaluation of mental load is difficult because identifying a part of the nose automatically from the thermograph is difficult. In this paper, we have focused on developing a solution to this problem that combines temperature with the coordinates of the thermal image.**

Keywords-facial thermal image; nasal skin temperature; mental work load.

I. INTRODUCTION

Mental load or mental burden associated with work is called mental work load (MWL) [1]. Moderate mental load results in a positive effect on the workers; however, excessive mental load can cause negative effects such as fatigue, decreased attention span, and monotony [2][3]. Thus, if possible, MWL that leads to human errors and reduction in work efficiency should be evaluated.

In previous studies, a variety of indicators were used for the evaluation of MWL [4]-[7]; for example, behavioral assessments that use work performance, psychology evaluations using questionnaires, and physiological evaluations using electrical physiological signal indicators. In particular, the evaluation using a physiological index is an attractive option in quantitative real-time applications. The physiological indicators that are generally used are the heartbeat, respiration rate, blood pressure, electromyography (EMG), and electroencephalography (EEG). However, to measure these metrics electrically, the concerned electrodes must be attached to the skin; this calls for the development of a measurement environment such as a laboratory, for the physiological measurement of MWL. To solve this problem, we developed a technique for assessing the mental state of humans using facial thermal images. These images are obtained using non-contact infrared thermography [8]-[10]. Facial thermal images can be used to study human physiological psychology, because they vary depending on the changes in the blood-flow rate associated with human autonomic nervous activity. In addition, changes in skin temperature due to MWL are significantly different at different regions of the face. For example, the concentration of the arteriovenous anastomoses (AVA) vessels that adjust the blood flow in capillaries is higher in the periphery of the nose compared to the other sites. Furthermore, the blood-flow changes due to autonomic nervous activity and inhibition are directly reflected as skin-temperature changes because the blood vessels run through low-fat regions between the skin and the nasal bone. Thus, it is possible to quantitatively evaluate the MWL using sympathetic-activity MWL (mental arithmetic tasks) by measuring a temperature drop in the nose region for a short period. Physiological psychology assessments using facial thermal images do not use physical restraints, and hence, they are non-contact compared to assessments using other bioelectric-signal indexes. Thus, this assessment is believed to be suitable for the physiological evaluation of MWL in real work situations.

We focused on the evaluation of MWL using facial thermal images. Furthermore, we aimed for a more established, robust, and stronger measurement and evaluation system that is capable of withstanding disturbances such as changes in the subject's position, changes caused by wind, and so on. So far, we have evaluated MWL using the temperature difference between the skin at the forehead and at the nose [11]-[13]. The MWL evaluation method using thermal images has a measurement accuracy and reliability that is of the same order as those of the evaluation methods using other physiological indicators or questionnaires. However, the results of the temperature comparison between the forehead and nose regions may become less accurate because it does not use information on the position or area of the thermal images. Therefore, we consider the use of the temperature–center-of-gravity as a parameter by adding temperature information as a depth to the coordinate information. If it is possible to divide the facial thermal image into a number of regions, and evaluate the change in temperature distribution in each region, the realization of a strong physiological psychology state-estimation, in spite of disturbances such as effects of movement or shooting angle of face, can be made possible.

The method proposed in this paper was verified through experiments to determine how the temperature–center-of-gravity was affected by the number of area divisions at the time of capturing the facial thermal image. In Section II, we explain the relationship between the characteristics of the facial thermal image and MWL. This enables us to measure

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the change in MWL using the temperature-center-of-gravity as a first step. In Section III, we report and discuss the results of an estimation experiment. In addition, we verify the amount of change in the temperature displacement of the center-of-gravity by dividing the facial thermal image into a number of regions and examining its effectiveness.

II. Characteristics of the Facial Thermal Image

Nasal skin temperature (NST), which refers to the difference between the forehead temperature and the nasal temperature, has been used for evaluating the MWL from the thermal image of the face. The temperature image obtained using infrared thermography captures the face; however, it is necessary to extract the forehead and nose regions from this image because the NST is the difference between the temperatures at these two locations on the face. The automatic extraction of the nose portion was previously performed using image processing [9], utilizing the local binary pattern (LBP) feature values and AdaBoost. However, to use a machine-learning algorithm such as AdaBoost, it is necessary to prepare in advance a large amount of training data to improve the identification accuracy. In addition, the efficiency of the general image-processing techniques with different detection rates tends to decrease with changes in the thermal images caused by factors such as changes in temperature, skin-temperature changes due to wind, and changes in the image caused by tilting the head. To solve these problems, we focused on the temperature differences between several regions of the image. We tried to identify areas of significant temperature changes by dividing the thermal image into multiple regions. Figure 1 shows an example of a thermal image. The temperature–center-of-gravity (*G*), which is considered as an evaluation index for the new MWL, is defined by the average of the coordinates obtained from the x and y-axes and the temperature of the thermograph obtained by adding high or low temperatures to the position information of the thermal image. This is because when the number of pixels in the image region is *n*, *G* is expressed as

$$G = \frac{1}{n}\sum_{i=1}^{n} \vec{x}_i \vec{y}_i \vec{T}_i. \qquad (1)$$

where, *x* is the horizontal axis of the image, *y* is the vertical axis, and *T* denotes the temperature. Figure 2 shows an example for calculating the temperature-centroid of a complete thermal image. We hope to evaluate the effect of MWL by evaluating the temperature-centroid changes in each image region after division. Furthermore, the thermal image of the face of a person is at a higher temperature than the thermal images of the other parts of the body. Therefore, it may be possible to extract the face region easily using a temperature-centroid of the entire thermal image. This is one of the future challenges. If qualitative MWL evaluation using thermal images can be realized, it can become one of the indexes for evaluating usability in the field of human-computer interaction (HCI) such as in input user interfaces.

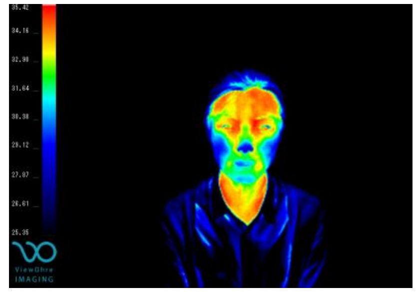

Figure 1. Example of a thermal image.

III. Experiment

We conducted an experiment to study the changes in the temperature–center-of-gravity of the facial thermal image during MWL work, using four subjects. We considered 10 divisions of 10^2 pixels each in the thermal image, for acquiring the characteristic amount of the temperature-centroid (G) by evaluating the scalar values of the center-of-gravity changes in this experiment.

A. Experimental Procedure

Figure 3 shows the outline of the experiment environment. In the experiment, an infrared thermographic camera (View Ohre IMAGING XA0350) was installed at a horizontal distance of 1 m from the nose of the subject. Specifications of the photographic image obtained from the apparatus are as follows: 320-pixel horizontal and 240-pixel vertical. The sampling frequency was 1 Hz. Figure 4 shows the measurement process. The subjects repeatedly performed simple mental arithmetic tasks with a rest time of 3 min after every 10 min. In addition, the evaluation was performed continuously, allowing the participants the resting time of 3 min even after the completion of the task. The mental arithmetic tasks involved addition of two integers between 10 and 99. The subjects were asked to enter the answers of problems displayed on the computer, using a numeric keypad. The problem was presented for 3 s. Regardless of the correctness of the input, when the problem presentation time was over, the next question was presented. Here, the importance is on the input; the correctness of the answer or feedback does not matter.

B. Experimental Result

Table 1 shows the changes in the temperature-center-of-gravity resulting from the longitudinal MWL challenges. Here, the average of the splits within the region of changes in the temperature–center-of-gravity summarizes the respective differences. Again, it shows a typical example of the change in the characteristic amount of the sum due to the region division number (scalar value) as shown in Figure 5.

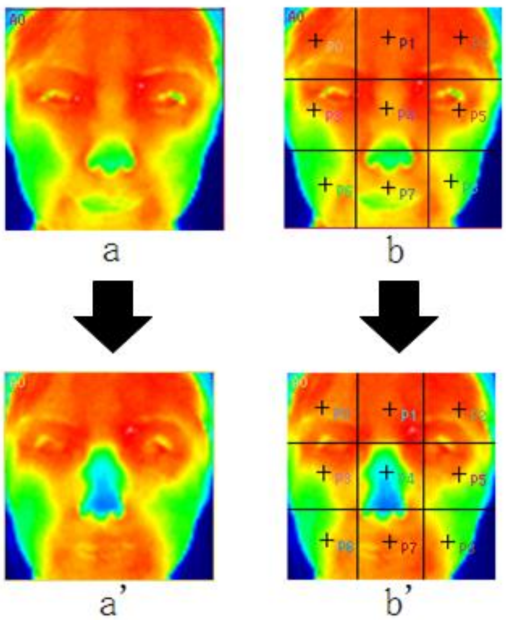

Figure 2. (a) Thermal images before and after mental arithmetic tasks. (b) Divided regions and each temperature-centroid (e.g., 3 × 3)

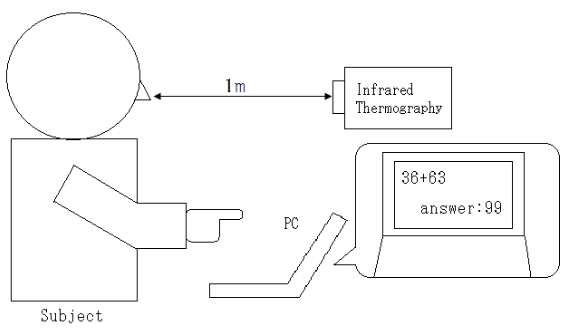

Figure 3. Experiment environment.

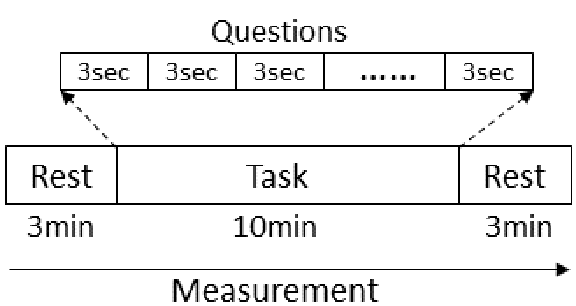

Figure 4. Experiment protocol.

TABLE I. SUM OF CHANGES IN THE TEMPERATURE-CENTROID FOR EACH NUMBER OF DIVISION [$*10^2$ PIXEL]

Division numbers	Subject A	Subject B	Subject C	Subject D
1	0	0	0	0
2	0.549	0.233	0.347	1.689
3	0.586	0.240	0.327	1.637
4	0.564	0.236	0.341	1.583
5	0.557	0.228	0.316	1.532
6	0.538	0.214	0.307	1.485
7	0.510	0210	0.295	1.437
8	0.507	0.205	0.288	1.381
9	0.483	0.201	0.283	1.327
10	0.458	0.207	0.270	1.269

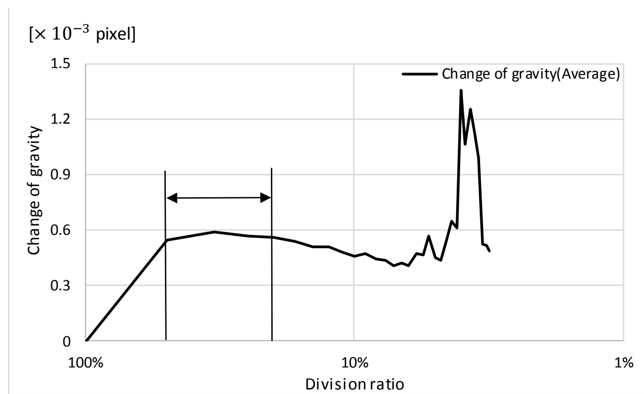

Figure 5. The sum of change in the temperature-centroid value for each division number (logarithmic graph).

C. Discussion

Figure 5 indicates that the feature amount increases monotonously, in this experiment, as the number of divided regions increases to a certain value. However, a tendency of one side of the divided area to become unstable was observed for a sum of feature values from a periphery of 1/10 or less divisions of the total number of image pixels. This is because of the availability of less amount of temperature information from the divided areas because of the influence of increased relative noise. Furthermore, the feature quantity of the sum is found to be insufficient for capturing the changes in temperature to be used for the evaluation of less mental activity in the case of reducing the number of divisions, in reverse. Therefore, it is considered that a splitting ratio of about 30%, which approaches the maximum value before the unstable evaluation sum of feature values to do the mental activity based on the temperature-centroid is suitable. In the current experiment, the most residual, even if you increase the number of divisions when using the maximum value when considering a change in temperature-centroid, was small. Therefore, it is considered stable when compared to the other two feature evaluations. In the future, we plan to estimate the autonomic nervous activity by evaluating the vector value of the temperature change using the split system that was verified in this paper.

IV. CONCLUSION

We studied analysis methods to take advantage of the temperature–center-of-gravity of the thermal image, using thermography as a non-contact and robust autonomic nervous-activity measuring method. Autonomic evaluation of the temperature changes in the facial area caused by nervous activity during MWL was carried out. We believe that it might be possible to quantitatively assess the distribution of temperature caused by the autonomic nervous activity, using the temperature-centroid (including coordinate information of the temperature change in the face area) as an index. In the first stage of the experiment in this study, the number of divisions that can be best measured was confirmed based on the changes in the temperature–center-of-gravity before and after the MWL challenges.

In future, we want to develop a more accurate verification technique by increasing the amount of data collected from the subjects. In addition, we want to establish an evaluation system for autonomic nervous activity by evaluating the change in temperature as a center-of-gravity vector. By performing these tasks, we are planning to apply and establish a usability evaluation method for user interfaces.

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