Detection of Fight or Flight Reaction on Facial Skin Thermogram using Spatio-Temporal Spectrum Differential Analysis

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Extended Summary

The present research is aimed at detecting the Fight or Flight Reaction (hereafter abbreviated as FFR) using facial skin thermograms measured using an infrared thermography unit. The experiment was conducted using an electromagnetic shielding room. The room temperature was $25.0 \pm 1.0$ degrees. Measurement of facial skin thermograms was done using an infrared thermography unit (NEC SANEI TH3102) positioned 1.0 m from the tip of the subject’s nose. Thermal images produced by the unit measured 255 x 239 pixels. The skin emissivity was $\varepsilon = 0.98$. One frame of thermal image data was captured per second. The display was positioned alongside the infrared thermography unit, in a position where it could be easily seen by the subject, and numbers from 1 to 9 were displayed. A ten-key pad used by the subject to input numeric values was positioned close to the subject’s right hand. Speakers that provided auditory stimulation were positioned on both sides of the head. After the subject had sat still for 35 seconds after the start of facial thermal imaging, he or she input numbers from one to nine in any order, without repeating any of the numbers, inputting one number every five seconds. When a certain number from among the numbers 1 to 9 was input, an auditory stimulus was applied in the form of a loud, explosive sound intended to provoke the FFR. The task was interrupted at the point when the auditory stimulus was applied, and the subject remained still for 35 seconds until the measurement was finished.

A new method titled Spatio-Temporal Spectrum Differential Analysis (hereafter abbreviated as STSDA) is proposed and used to detect spatio-temporal changes in the skin temperature on facial skin thermograms accompanying the occurrence of the FFR, and the detection accuracy is evaluated. With the STSDA method, the facial skin thermogram is divided into minute unit images, and in each unit image, differential analysis is conducted on time series image data in parallel, in order to identify reactions sites accompanying the spatio-temporal FFR. A two-dimensional discrete Fourier transform (2DDFT) was applied to the unit images, and the spatial frequency characteristic was characterized.

The central part of the face, including the eye socket area without the forehead and the left and right cheeks, was extracted as an image $I_e$ that includes the FFR reacted areas. Any micro-image included in $I_e$ is defined as a unit image $I_e[x, y; t], (0 \leq x_e < X, 0 \leq y_e < Y)$. In this paper, $X = 32$ pixels and $Y = 32$ pixels. A 2DDFT was carried out for the unit image $I_e$. The 2DDFT $F[k, l; t]$ of the $I_e[x, y; t]$ was defined as indicated by the following equation.

$$F[k, l; t] = \sum_{x_e=0}^{X-1} \sum_{y_e=0}^{Y-1} I_e[x, y; t]W_X^x W_Y^y f_{k,l}[x, y; t]$$

$x_e, k = 0, 1, \ldots, X - 1, \quad y_e, l = 0, 1, \ldots, Y - 1$

$W_X = e^{-j(2\pi/X)} \quad W_Y = e^{-j(2\pi/Y)}$

Here, the fluctuations in the spatial frequency characteristic of the time series unit image are determined from the difference between the Euclidean distance of the amplitude spectrum. When the amplitude spectrum for the coordinates $(k, l)$ at the beginning of the measurement is $F_{k, l; 0}$ and the amplitude spectrum for $t$ is $F_{k, l; t}$, this Euclidean distance $D(t)$ can be expressed by the following equation.

$$D(t) = \frac{1}{XY} \sum_{k=0}^{X-1} \sum_{l=0}^{Y-1} (F_{k, l; 0} - F_{k, l; t})^2$$

The average values $D_{ave1}(t)$ and $D_{ave2}(t)$ of $D(t)$ for the sections $[t - \Delta t, t]$ and $[t, t + \Delta t]$ for all of $t$ were determined using the following equation.

$$D_{ave1}(t) = \frac{1}{\Delta t} \sum_{i=t-\Delta t}^{t} D(i)$$

$$D_{ave2}(t) = \frac{1}{\Delta t} \sum_{i=t}^{t+\Delta t} D(i)$$

The evaluation values $E_D(t) = D_{ave2}(t)/D_{ave1}(t)$ relating to the fluctuation in the spatial frequency characteristic were determined. All of the unit images $I_e$ obtained in $I_e$ are extracted, and each of the evaluation values $E_D(t, n)$ is determined. $n$ denotes any unit image extracted from $I_e$. For each $E_D(t, n)$, the maximum value $E_{D_{max}}(n)$ of the $E_D(t, n)$ relating to $t$ is determined. Furthermore, the maximum value $E_{D_{max}}$ of $E_{D_{max}}(n)$ relating to $n$ is determined as the maximum evaluation value. In this paper, regions indicated by unit images that become $E_{D_{max}}$ are selected as reacted areas.

As a result of FFR arousal experiments, it was confirmed that the FFR in facial skin thermograms revealed reactive areas in which an abrupt increase in temperature is produced in the facial expression and other muscles. Also, as a result of using the STSDA method to detect sites at which the temperature rose, a detection rate of 76.5% was obtained, and thus the effectiveness of the proposed method is confirmed.
Detection of Fight or Flight Reaction on Facial Skin Thermogram using Spatio-Temporal Spectrum Differential Analysis

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It has been known that human being exhibits the Fight or Flight Reaction (FFR) when they feel anxiety, strain and threat. This paper describes experiments that were conducted to arouse the fight or flight reaction. Facial skin thermograms in which the temperature fluctuation in specific regions was identified were measured, and the characteristics of the temperature fluctuations in the relevant regions were quantitatively evaluated. The results showed that, for nine of the ten subjects, the FFR was confirmed in the form of reacted areas indicating acute increases in skin temperature, primarily in facial expression muscles such as the procerus muscle and cheek muscles. Additionally, the spatio-temporal spectrum differential analysis method for facial skin thermograms was proposed, and as a result of detecting spatio-temporal skin temperature fluctuations in the facial skin thermograms accompanying manifestation of the FFR, a detection rate of 76.5% was obtained. Thus, the effectiveness of the proposed technique was confirmed.

Keywords: facial skin thermogram, fight or flight reaction, 2DDFT, spatio-temporal spectrum differential analysis

1. Introduction

Autonomic nervous system reactions reflect dynamic reactions to external stimuli or inner stimuli caused by stress. The Fight or Flight Reaction (FFR) is a dynamic biological reaction by the autonomic nervous system that has been discovered in humans and in wild animals, and is thought to play an important role in self-protection when the person or animal encounters a life-threatening outside enemy. When faced with an imminent state that forces a decision of whether to fight or flee, the autonomic nervous system is activated and readies the body to handle threatening conditions such as a fight or a defense stance. Specifically, biological reactions occur in the form of an increased heart rate, rate of respiration, blood pressure and metabolism, dilated pupils, sweating hands and feet, contraction of the peripheral blood vessels, and dilation of the blood vessels in the skeletal muscles. In the modern-day society, it is believed that the FFR occurs during high-stress situations and in situations where people feel tension, anxiety and/or fear (1) (2).

Generally, before the occurrence of serious accidents, there are accidental occurrences, or “incidents,” that involve similar factors but stop short of being accidents. For instance, car accidents caused by violating the speed limit or inattentive driving can be considered “incidents.” Incidents, also called “close calls,” are situations in which a person experiences tension and fear. It is reasoned by analogy that the FFR occurs under circumstances such as these. Car accidents are closely related to a driver’s physio-psychological state, so ascertaining a driver’s physio-psychological state both objectively and quantitatively is an important step in accident prevention and other forms of preventive safety. Consequently, if the manifestation of the FFR in a driver can be determined using a biological measurement, it would be an extremely effective indicator for preventing car accidents. The advantage of this method is that measurement can be done objectively, quantitatively and in real time, without interfering with the driving. At the same time, however, physiological measurement of a driver needs to be done non-invasively, without contact, and without the driver being aware that the measurements are being taken (3)–(8).

The infrared thermography unit, which measures the intensity of infrared rays emitted from the surface of a person’s skin and displays the temperature differential as a two-dimensional image, is highly advantageous in that it enables measurement that is both non-invasive and non-contact. It was originally introduced to the medical field as a method for diagnostic imaging, but as advances were made to the unit, its performance in terms of temperature, time and spatial resolution improved dramatically. The infrared thermography unit has now moved beyond the boundaries of clinical diagnosis and expanded to applications in welfare, education and industry. Up to the present point, the advantages offered by the infrared thermography unit in terms of non-invasive, non-contact measurement and using the unit to evaluate physio-psychological states such as the

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pleasure/displeasure affect and to estimate the subject's degree of vigilance, based on facial skin thermography, have been discussed. Additional studies have been conducted in which mental workload and vigilance were evaluated using facial skin thermography when subjects were performing tasks during driving simulations (9)-(12).

Few reports have been issued on FFR measurement applications using infrared thermography units. Pavlidis et al. detected areas where the skin temperature rose in response to changes in the blood flow volume in the orbital region accompanying the occurrence of the FFR in facial thermal imaging. These findings are now being applied to fraud detection. They are using the blood flow volume estimated from differential thermal imaging as a detection indicator, but no detailed explanations concerning the specific thermal imaging processing have been offered. Thermography is a time series image signal, and real-time image signal processing algorithms, which are expected to be automated at some point, are indispensable not only for FFR measurements but in engineering applications of thermography as well. Although procedures have been observed pertaining to analysis methods of single images in research conducted up to this point, they comprise no more than fundamental investigations at the laboratory level, and it cannot be said that sufficient research has been conducted on realistic spatio-temporal image signal processing algorithms aimed at practical use.

The present research is aimed at detecting the FFR using facial skin thermograms measured using an infrared thermography unit. This paper reports on experiments conducted as a fundamental study of this objective. In this study, the FFR was aroused using a sudden explosive sound as a startle stimulus, and the characteristics of temperature changes in the face were quantitatively evaluated. Additionally, a new method titled Spatio-Temporal Spectrum Differential Analysis (hereafter abbreviated as STSDA) is proposed. The STSDA method is used to detect spatio-temporal changes in the skin temperature on facial skin thermograms accompanying the occurrence of the FFR, and the detection accuracy is evaluated. As a result, the effectiveness of the proposed method is confirmed. These results are reported in the following sections.

2. Arousal of the Fight or Flight Reaction

2.1 Experiment Figure 1 shows a schematic diagram of the unit used for testing. The experiment was conducted using an electromagnetic shielding room (3.4 m (W) × 3.7 m (D) × 2.3 m (H)). The room temperature was 25.0 ± 1.0 degrees and the illumination was approximately 200 lx. Measurement of facial skin thermograms was done using an infrared thermography unit (NEC SANEI TH3102) positioned 1.0 m from the tip of the subject's nose. Thermal images produced by the unit measured 255 x 239 pixels, and the temperature resolution was 0.08 degrees. The facial skin emissivity was ε = 0.98. One frame of thermal image data was captured per second. The display was positioned alongside the infrared thermography unit, in a position where it could be easily seen by the subject, and numbers from 1 to 9 were displayed. A ten-key pad used by the subject to input numeric values was positioned close to the subject's right hand. Speakers that provided auditory stimulation were positioned on both sides of the head. Figure 2 shows the procedure of the experiment. After the subject had sat still for 35 seconds after the start of facial thermal imaging, he or she input numbers from one to nine in any order, without repeating any of the numbers, inputting one number every five seconds. When a certain number from among the numbers 1 to 9 was input, an auditory stimulus was applied in the form of a loud, explosive sound intended to provoke the FFR. The task was interrupted at the point when the auditory stimulus was applied, and the subject remained still for 35 seconds until the measurement had finished. To make sure that the measurement would be carried out smoothly and correctly, elements such as an overview of the experiment and the measurement procedure were explained in detail to the subject ahead of time. At the same time, however, the number that would cause the auditory stimulus to be applied was chosen at random for each measurement, and the subject was not told the number. During the measurement, the subject sat still in a relaxed position. The subject pool contained ten healthy adult males ages 21 to 24. In order to make sure the subjects were accustomed to the room temperature, the experiments were not begun until the subjects had been in the room for at least 15 minutes.

2.2 Results Comparisons between the temperature data of the various pixels in the thermogram samples from before and after the point when the stimulus was presented were performed, and any regions in which temperature changes of any kind had taken place were identified. Figure 3 shows facial skin thermograms of Subject A taken just before the stimulus was presented and 12 seconds after the stimulus was presented. In the
Fig. 3. A rise of the temperature on the facial skin with FFR

Fig. 4. Change of average skin temperature in region A

Figure, the brighter shows the higher temperature. Being brighter in (b) After than (a) Before in region A indicates that temperature rise within region A. Hereafter, the region in which the temperature increase appeared in relation to before and after the stimulus being presented will be called the reacted area. Figure 4 shows the time series average temperature change in the reacted area of Subject A. The average temperature is arithmetic mean of all the pixels in the reacted area, which are $27 \times 35$ pixels. However, the time at which the stimulus was provided is set at $t = t_s$. A trend in which the average skin temperature began rising immediately after the stimulus occurred is present, and a peak was reached 12 seconds after the introduction of the stimulus. After this peak, the skin temperature gradually dropped. Of the ten subjects, the same trend was confirmed in the nine in who reacted areas were confirmed, and it is thought that the FFR is manifested as a rise in the facial skin temperature.

Here, the time series average skin temperature of the reacted area is set as $T(t)$. The time at which the stimulus was presented is set as $t = t_s$, and the maximum value of $|T(t) - T(t_s)|$ following the presentation of the stimulus is determined as the maximum temperature displacement absolute value $|\Delta T_{\text{max}}|$. Additionally, the time at which $|\Delta T_{\text{max}}|$ occurs is taken as the reaction time $\Delta t$. Figure 5 shows the relationship between $|\Delta T_{\text{max}}|$ and $\Delta t$ for the nine subjects in which reacted areas were confirmed. The same figure also shows, using asterisks (*), the relationship between $|\Delta T_{\text{max}}|$ and $\Delta t$ in relation to the time series average skin temperature at the tip of the nose measured through ongoing unpleasant sound stimulus experiments designed to provoke the displeasure affect, for comparison purposes. However, in the displeasure stimulus experiments, measurement was begun after the subject had remained quiet for 20 minutes, and after three minutes of continuous silence, a scratching noise was introduced for five minutes as the unpleasant sound stimulus.

The average values for $\Delta t$ and $|\Delta T_{\text{max}}|$ in relation to the fluctuations in skin temperature at the tip of the nose when the unpleasant sound was present were both high at 98.9 sec and 0.616 degrees, respectively, and both of these were strong and lasting reactions. In the FFR arousal experiments, however, the average $\Delta t$ was 6.44 sec and the average $|\Delta T_{\text{max}}|$ was 0.183 degrees. The fluctuation in skin temperature at the reacted areas accompanying the occurrence of the FFR was an acute reaction that occurred within a relatively short period, and the temperature displacement was small. The skin temperature fluctuations that occurred primarily in the nose area during the unpleasant sound stimulation experiment can be explained as being a principal factor in reducing the volume of blood flowing through the peripheral blood vessels, which is caused by the action of the anastomosis arteriovenosa that adjusts the blood flow volume to the capillaries that are concentrated in the subepithelial area around the nose. At the same time, however, sharp temperature fluctuations were seen accompanying the presentation of the stimulus in the experiment. These sites, identified as reacted areas, were different for each of the subjects. Using the results of the FFR manifestation, it is speculated that the peripheral blood vessels contract but the skeletal muscle blood vessels dilate. It is also surmised that, because there are approximately 20 types of skeletal muscles called facial expression muscles that exist in the surface layer of the face, the blood vessels in the facial expression muscles dilated with the manifestation of the FFR, resulting in an increase in skin temperature. For example, with respect
to the procerus muscle in the reacted area in Subject A, the increase in the skin temperature can be explained by an increase in the flow of blood to the muscle. In the other subjects as well, the reacted area was primarily near the procerus muscle or the muscles of the left and right cheeks.

3. FFR Detection Using Spatio-Temporal Spectrum Differential Analysis

It was explained in the previous section that the increase in the temperature of the facial skin caused by the FFR appears in the area near the facial expression muscles that are located throughout the central part of the face and under the skin, including the eye socket area except for the forehead and the left and right cheeks, and that the temperature increase is relatively small. This paper proposes the STSDA method as an algorithm for detecting the fluctuations in skin temperature that are unique to the manifestation of the FFR. With the STSDA method, the facial skin thermogram is divided into minute unit images, and in each unit image, differential analysis is conducted on time series image data in parallel, in order to identify reactions sites accompanying the spatio-temporal FFR. A two-dimensional discrete Fourier transform (2DDFT) was applied to the time series image data for detecting the fluctuations in skin temperature that increase in the temperature of the facial skin used by the FFR appears in the area near the facial expression muscles. However, thermal image samples for which the coordinates of the various pixels are (x,y) that include only the face section were determined using the following equation for the sections [t − Δt, t] and [t, t + Δt] in all of t. Δt is the observation time in relation to the skin temperature changes of FFR. In this paper, Δt = 10 sec based on the test results described in the previous section.

\[ T_{ave1}(t) = \frac{1}{\Delta t} \sum_{i=t-\Delta t}^{t} T(i) \]  

\[ T_{ave2}(t) = \frac{1}{\Delta t} \sum_{i=t}^{t+\Delta t} T(i) \]  

Next, the evaluation value \( E_T(t) = T_{ave2}(t) / T_{ave1}(t) \) relating to the temperature increase was calculated.

\[
\begin{align*}
E_T(t) &> 1 \\
Yes &
\end{align*}
\]

Calculate Euclidean distance \( D(t) \)

\[
\begin{align*}
D_{ave1}(t) &> \frac{1}{\Delta t} \sum_{i=t-\Delta t}^{t} D(i) \\
D_{ave2}(t) &> \frac{1}{\Delta t} \sum_{i=t}^{t+\Delta t} D(i) \\
Yes &
\end{align*}
\]

Fig. 6. The spatio-temporal spectrum differential analysis

Fig. 7. Extraction of the elemental image
Figure 8(b) shows an example of the evaluation value $E_T(t)$ in relation to the $T(t)$ shown in Fig.8(a). Here, with respect to the manifestation of the FFR, temperature increases caused by the increase in blood flow volume are occurring in the sections between $\Delta t$ sections, so it will be sufficient to find sections that satisfy $E_T(t) > 1$. Then, subsequently, as sections in which there is a possibility of FFR manifestation, sections comprising a sample group that satisfies $E_T(t) > 1$ were extracted as $\tau_l (l = 0, 1, \cdots, t, \cdots, n)$.

Next, a 2DDFT was carried out for the unit image $I_{c}[x, y; t]$. The 2DDFT $F[k, l; t]$ of the $I_{c}[x, y; t]$ was defined as indicated by the following equation.

$$F[k, l; t] = \sum_{x_c=0}^{X-1} \sum_{y_c=0}^{Y-1} I_{c}[x, y; t] W_{X}^{x_c k} W_{Y}^{y_c l} \cdots \cdots (3)$$

$$x_c, k = 0, 1, \cdots, X - 1 \quad y_c, l = 0, 1, \cdots, Y - 1$$

$$W_{X} = e^{-j(2\pi/X)} \quad W_{Y} = e^{-j(2\pi/Y)}$$

Information provided in the spatial area as a result of the 2DDFT serves as two-dimensional spectrum information provided by the $k$ and $l$ parameters. Also, $W_{X}$ and $W_{Y}$ from Eq. (1) are developed as follows, based on Euler’s formula.

$$W_{X}^{x_c k} W_{Y}^{y_c l} = e^{-j2\pi((x_c k/X)+(y_c l/Y))} = \cos \left( \frac{2\pi x_c k}{X} + \frac{2\pi y_c l}{Y} \right)$$

$$-j \sin \left( \frac{2\pi x_c k}{X} + \frac{2\pi y_c l}{Y} \right) \cdots \cdots (4)$$

Based on the data from the real part and the imaginary part, the amplitude spectrum of $F[k, l; t]$ is

$$|F[k, l; t]| = \sqrt{\text{Re}\{F[k, l; t]\}^2 + \text{Im}\{F[k, l; t]\}^2} \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots (5)$$

Here, the fluctuations in the spatial frequency characteristic of the time series unit image are determined from the difference between the Euclidean distance of the amplitude spectrum. Euclidean distance was proved to be effective to detect the difference of the spatial frequency characteristic of thermal images.(14). When the amplitude spectrum for the coordinates $(k, l)$ at the beginning of the measurement is $F_{k, l; 0}$ and the amplitude spectrum for $t$ is $F_{k, l; t}$, this Euclidean distance $D(t)$ can be expressed by the following equation.

$$D(t) = \frac{1}{XY} \sum_{k=0}^{X-1} \sum_{l=0}^{Y-1} (F_{k, l; 0} - F_{k, l; t})^2 \cdots \cdots \cdots \cdots (6)$$

Figure 9(a) shows the time series Euclidean distance for the unit image $I_{c}[x, y; t]$. Here, with the evaluation value $E_T(t)$ for $T(t)$, the average values $D_{ave1}(t)$ and $D_{ave2}(t)$ of $D(t)$ for the sections $[t - \Delta t, t]$ and $[t, t + \Delta t]$ for all of $t$ were determined using the following equation.

$$D_{ave1}(t) = \frac{1}{\Delta t} \sum_{i=t-\Delta t}^{t} D(i) \cdots \cdots \cdots \cdots (7)$$

$$D_{ave2}(t) = \frac{1}{\Delta t} \sum_{i=t}^{t+\Delta t} D(i) \cdots \cdots \cdots \cdots (8)$$
Similarly, the evaluation values \( E_D(t) = D_{ave2}(t)/D_{ave1}(t) \) relating to the fluctuation in the spatial frequency characteristic were determined. However, samples \( t \) that do not belong to the section \( \tau \) are considered to be unrelated to FFR manifestation, and for these, \( E_D(t) = 1, (t \notin \tau) \). Figure 9(b) shows an example of the evaluation value \( E_D(t) \).

When the origin of \( I_c \) in \( I_c \) is set to \((x_0, y_0), (x_l \leq x_0 \leq x_1 - X, y_l \leq y_0 \leq y_1 - Y) \), all of the unit images \( I_c \) obtained in \( I_c \) in the range of \( x_0 = x_1, x_l + 10, x_l + 20, \ldots, y_0 = y_1, y_1 + 10, y_l + 20, \ldots \) are extracted, and each of the evaluation values \( E_D(t, m) \) is determined. \( m \) denotes any unit image extracted from \( I_c \). For each \( E_D(t, m) \), the maximum value \( E_{Dmax} \) of the \( E_D(t, m) \) relating to \( t \) and \( m \) is determined. In this paper, regions indicated by unit images that become \( E_{Dmax} \) are selected as reacted area.

### 3.2 Studies Pertaining to the Detection of Reacted Areas

FFR arousal experiments similar to those described in Section 2 were carried out on 12 healthy adults between the ages of 21 and 24, and we attempted to detect reacted areas using the STSDA method from the facial skin thermograms that were measured. For five of the 12 subjects, a second measurement was carried out after the first measurement had ended and the subject had rested for 15 minutes, so the total number of subjects tested was 17. The results are shown in Table 1.

<table>
<thead>
<tr>
<th>Evaluation value</th>
<th>Detection rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>( E_{Dmax} )</td>
<td>76.9% (Visible) 76.0% (Total)</td>
</tr>
<tr>
<td>( E_{Tmax} )</td>
<td>53.8% 47.1%</td>
</tr>
</tbody>
</table>

At the beginning, increases in facial skin temperature accompanying the manifestation of the FFR were confirmed visually following presentation of the stimulus, and it was possible to confirm reacted areas in 13 cases. Here, for \( t \) comprising \( t_s - \Delta t \leq t \leq t_s + \Delta t, (\Delta t = 10 sec) \) in relation to the stimulus presentation time \( t_s \), \( E_D(t, m) \) becomes the maximum value \( E_{Dmax} \). Also, if success is defined as the visually identified reacted being consistent with the areas detected using this method, then the detection success rate was 76.9% (10 of 13 cases). Additionally, when reacted area detection was carried out using the STSDA method on the four cases in which reacted areas had not been confirmed visually, such areas were detected in three cases. When the possibility of visual confirmation was not taken into consideration, the detection success rate was 76.6% (13 of 17 cases). This technique picks up on the changes in skin temperature accompanying manifestation of the FFR, based on fluctuations in the spatial frequency characteristic, and detects reacted areas. However, this technique does not consider areas that do not accompany an increase in skin temperature. Consequently, increases in skin temperature have to be perceived in the reacted areas even in these three cases, but in time series facial thermograms, it is extremely difficult to confirm temperature increases in non-specific areas simply through visual observation. It must also be noted that temperature increases accompanying the manifestation of the FFR, in particular, are relatively small and thus the certainty of visual confirmation is low. The fact that reacted areas were detected that had not been identified through visual confirmation indicates the effectiveness of this technique. Additionally, for comparison purposes, detection was carried out on reacted areas based on the maximum evaluation value \( E_{Tmax} \) determined only from the evaluation value \( E_T(t, m) \) relating to an increase in skin temperature. The results showed that the detection success rate was 53.8% (7 of 13 cases) relative to reacted areas that were confirmed visually. When the possibility of visual confirmation was not taken into consideration, the detection success rate was 47.1% (8 of 17 cases). In either case, the detection success rate was low compared to the method using \( E_{Dmax} \). Erroneous detection occurred when a maximum evaluation value was obtained that was outside of sections \( t_s \pm \Delta t \) relating to the presentation of the stimulus. Cases in which erroneous detection was thought to result from the noise component being detected in situations not related to the FFR existed, such as positional offset when extracting facial areas, and in apparent skin temperature fluctuations that were caused by false measurements. Thus, if the noise component is larger than the skin temperature increase accompanying the manifestation of the FFR, it is not possible to separate FFR manifestation and the noise component from the facial skin thermograms simply by the degree to which the temperature rises when detecting reacted areas. However, the fact that the detection rate improved when fluctuations in the spatial frequency characteristic were observed suggests the robustness with respect to the image positional offset of the spatial frequency characteristic. It is also extremely interesting that changes occurred in the temperature distribution in the unit images of the reacted region following presentation of the stimulus, meaning that fluctuations occurred in the periodicity of the image signals. This is characteristically large with respect to
to fluctuations accompanying the manifestation of the FFR.

On the other hand, of the five test subjects who underwent measurement a second time, reacted areas caused by the FFR were detected both times in four of the subjects. Fig.10 shows the reacted areas in the facial images of the four pertinent subjects. Because the sizes of $I_f$ and $I_r$ vary from one subject to another, however, it is meaningless to compare the reacted areas shown. Also, the positions of the facial images displayed in the background should be taken only as a guide. It was expected that the subjects would become accustomed to the stimulus as the tests were repeated and it would become more difficult to detect the FFR, but it is thought that the repeated detection of reacted areas indicates the appropriateness of the test method used in this research, targeting the arousal of the FFR. Moreover, except for Subject C, the reacted areas detected in the second measurement were relatively close to each other, suggesting the possibility that an individuality of some sort relating to the sections in which the FFR was manifested in the facial skin temperature exists, but a more detailed investigation regarding this hypothesis is required.

4. Summary

This paper describes experiments that were conducted to arouse the fight or flight reaction. Facial skin thermograms in which the temperature fluctuation in specific regions was identified were measured, and the characteristics of the temperature fluctuations in the relevant regions were quantitatively evaluated. The results showed that, for nine of the ten subjects, the FFR was confirmed in the form of reacted areas indicating acute increases in skin temperature, primarily in facial expression muscles such as the procerus muscle and cheek muscles. Additionally, the spatio-temporal spectrum differential analysis method for facial skin thermograms was proposed, and as a result of detecting spatio-temporal skin temperature fluctuations in the facial skin thermograms accompanying manifestation of the FFR, a detection rate of 76.5% was obtained. Thus, the effectiveness of the proposed technique was confirmed.

(Manuscript received Aug. 18, 2005, revised Jan. 14, 2006)

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