

THERMAL RHYTHMOGRAPHY - TOPOGRAMS OF THE SPECTRAL ANALYSIS OF FLUCTUATIONS IN SKIN TEMPERATURE

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Abstract- It has been reported that skin blood flow and, consequently, skin temperature exhibit several periodic fluctuations. Although the mechanisms and physiological basis underlying these fluctuations are not yet well understood, it is thought that the fluctuations originate in the periodic rhythms of the autonomic nervous system.

In this study, a program for a far-infrared thermal imaging system was developed which is capable of displaying topograms of the power spectra of an arbitrary frequency range with respect to changes in skin temperature (i.e. thermal rhythm).

Thermographic images were taken using a high-speed far-infrared thermal camera. The change in the skin temperature with respect to time at every pixel was obtained from the time series of the thermograms, and the power spectrum was calculated by the FFT method using the personal computer. The amplitude of the power spectrum at an arbitrary frequency range was changed into pseudo-colors at each pixel, and a 2-dimensional or 3-dimensional color image of the amplitude mapping of the power spectrum at each frequency range was obtained.

We are now analyzing differences between healthy subjects and patients with Raynaud's syndrome in the distribution of the rhythms of skin temperature using this system.

Keywords - Thermal rhythm, spectral analysis, autonomic nervous function

I. INTRODUCTION

It has been reported that skin blood flow and skin temperature exhibit several periodic fluctuations[1-3]. As skin temperature is mainly affected by the skin blood flow, the fluctuations of the skin temperature with respect to time are also influenced by fluctuations of the skin blood flow; in addition, the blood flow into the skin is further regulated by the activity of the autonomic nervous system. For these reasons, although the mechanisms and physiological basis underlying these fluctuations are still not yet well understood, it is thought that the fluctuations originate in the periodic rhythms of the autonomic nervous system [4].

If so, it is thought that the properties of these fluctuations of the skin blood flow or skin temperature could become good indices for evaluating abnormalities (e.g. Raynaud's syndrome) or the activation of the autonomic nervous system (e.g. mental stress)[5] it is also thought that the locations of the abnormality or activation could be determined by obtaining the topograms of these thermal rhythm spectra.

In 1987, the authors developed a system which is capable of displaying topograms of the FFT power spectrum with

respect to changes in skin temperature[6], and tried to analyze the differences in the distribution of the rhythms of skin temperature between healthy subjects and patients with Raynaud's syndrome using this system. However, at that time, the performances of both far-infrared cameras and personal computers were inadequate (the sampling rate of the thermographic images was 1.92 sec, and only 256 time series thermograms were used for the FFT processing); this meant that conclusive results could not be obtained then.

More than 10 years have passed since then, and the substantial recent developments and improvements of infrared thermal detectors now allow dynamic thermal images to be processed at the same rate as videos with a high degree of thermal and spatial resolution; in addition, the surprising progress in the performance of personal computers (especially their processing speed and memory capacity), has made it possible to now perform various types of image processing for dynamic thermographic images, including thermal rhythm spectroscopy.

In this study, the authors developed a new image-processing system for a far-infrared thermal imaging system which is capable of displaying topograms of the FFT power spectra of an arbitrary frequency range with respect to changes in skin temperature.

II. METHOD AND SUBJECTS

A. Experimental Arrangement

Figure1 shows the experimental arrangement that was used in this study.

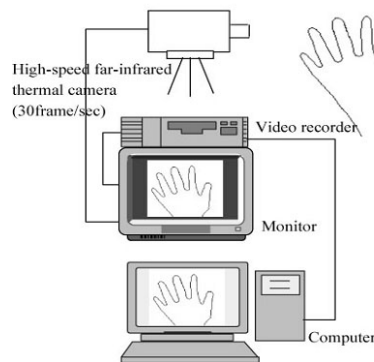


Fig. 1. Experimental arrangement.

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In this system, thermographic images were taken using a high speed far-infrared thermal camera (Laird 3ME system, Nikon, Japan; scanning speed: 30 frames/sec) and recorded by a digital video recorder (Video cassette recorder WV-DR7, Sony, Japan). The thermal data (720x480 pixels x 8 bits) were then transferred to a personal computer system (Desktop PC, Hewlett Packard Co., Ltd.; CPU: 450MHz, main memory: 320MB) and stored in the hard disk memory (disk array memory: 50GB). The same computer was used for FFT batch processing of the thermal data, and the results (topograms of the power spectra of an arbitrary frequency range with respect to changes in skin temperature) were displayed on a liquid crystal display.

B. Data Analysis

Figure 2 shows the procedure for processing topograms (images of the distribution) of the FFT power spectrum at an arbitrary frequency range with regard to changes in skin temperature.

The change in the skin temperature with respect to time at every pixel was obtained from the recorded time series of thermograms, and the power spectrum of the temperature fluctuation was calculated by the FFT method using the same computer. In this process, changes in the temperature were recorded for every three images (thus giving a sampling rate of 10 Hz.), and a total of 8192 images were processed (the time for observation was therefore 819.1 seconds).

Prior to FFT processing, in order to decrease the effect of motion artifacts and at the same time to reduce the processing time, a block mean processing was adopted; 4x4 pixels were integrated together in a single tile block, and the temperature value of the block was determined and taken to be the mean value of these 16 pixels.

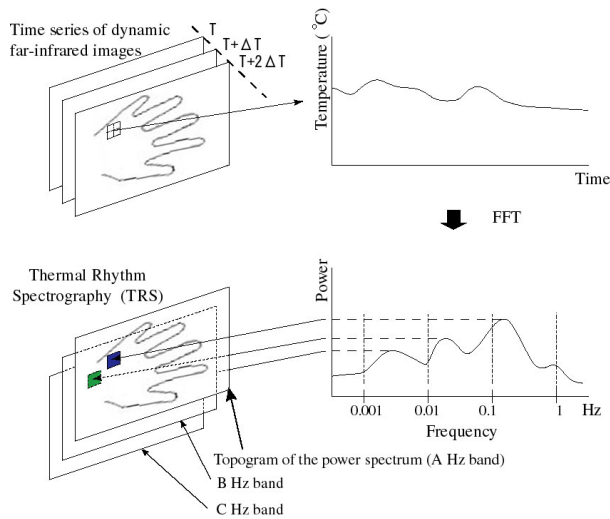


Fig. 2. Processing procedure used for topograms (images of the distribution) of FFT power spectra with regard to changes in skin temperature.

After this preliminary processing, a time series of the changes in the skin temperature was profiled and recorded at every tile. The power spectrum of this thermal fluctuation was then calculated using a hamming window and the FFT method. The results (i.e. the mapping of the amplitude of the power spectrum at an arbitrary frequency range) were displayed either 2-dimensionally or 3-dimensionally. In the former case, the amplitude of the power spectrum at each tile was expressed by pseudo-colors and in the latter case, it was expressed by the height of the bar chart.

III. RESULTS AND DISCUSSION

The subjects were 4 healthy volunteers (3 males aged 49, 34 and 29, and 1 female aged 23). The arms of the subjects were exposed from the shoulder down, and the subjects were acclimatized in a climate-controlled room until their body surface temperature stabilized at the ambient temperature. The room temperature was maintained at 25 °C and the humidity at 50%.

The specific periodicity of the thermal rhythm in healthy control subjects was not prominent (Fig. 3).

In the case of the FFT power spectra, several peaks were generally observed, especially at the fingers. In many cases no prominent peak was observed at the back of the hand (Fig. 4).

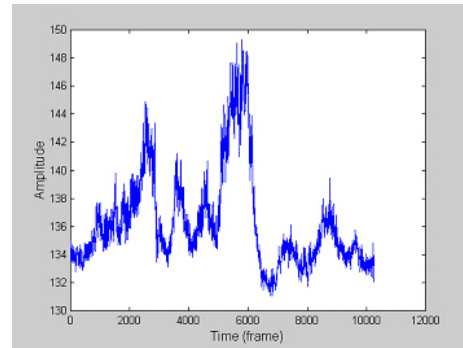


Fig. 3. Changes with respect to time in the skin temperature at specific areas of the hand in a healthy control subject.

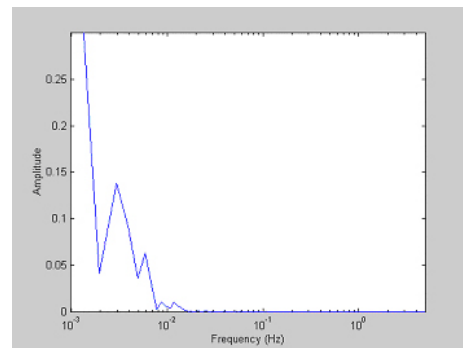


Fig. 4. FFT power spectrum of the changes with respect to time in the skin temperature at specific areas of the hand in a healthy control subject.

Topograms of the power spectra of an arbitrary frequency range with respect to changes in skin temperature were obtained using the above-mentioned image-processing system.

Figure 5 shows the topogram of the FFT power spectra of a frequency range between 0.004 and 0.005 Hz with respect to changes in skin temperature. In many cases, as can be seen in this topogram, areas with a comparatively high amplitude were observed only at the fingers; no high amplitude area was observed at the back of the hand.

It is well known that physiological phenomena or activities of the living body exhibit periodic fluctuations with various periods. For example, electroencephalograms show a frequency between 0.5 and 25 Hz, and the concentrations of certain hormonal factors in the blood exhibit periodicities of one day (the circadian rhythm), one month (the sexual periodicity of females), and one year.

It is therefore thought that an analysis of these periodicities may provide a useful index for the physiological basis underlying the periodic rhythms.

At the same time, the topogram – i.e. the distribution – of the amplitude of the periodicity is thought to be very important because it provides information about where the periodicity originated, or may indicate the physiological basis of where an abnormality underlying the periodic rhythms exists.

In actual fact, this method has already been applied to the analysis of electroencephalograms in order to detect areas which exhibit abnormal function or to detect specific areas which are activated when the brain is in some specific state, or when it is activated by some external stimuli.

The skin temperature also has been reported to exhibit several periodic fluctuations. Although details about the mechanisms of the fluctuations still remain unclear and the physiological basis underlying the periodic rhythms of the skin temperature are not well understood, the factor believed most likely to cause this periodicity is a change in the blood flow and the activity of the autonomic nervous system; this is because skin temperature is determined mainly by the volume of the blood flow into the skin, and the blood flow into the skin is further regulated by the activity of the autonomic nervous system.

This suggests the possibility of using these fluctuations as indices for diagnosing activation or dysfunctions of the autonomic nervous system or for evaluating the individual's psychological state, such as degree of stress or comfort [5].

The authors tried to conduct a similar method of processing more than 10 years ago. However, at that time, the performances of both far-infrared cameras and personal computers were inadequate. For example, the sampling rate of the thermographic images was only 1.92 sec, and only 256 (time series) thermograms could be used for FFT processing; consequently, conclusive results could not be obtained at that time.

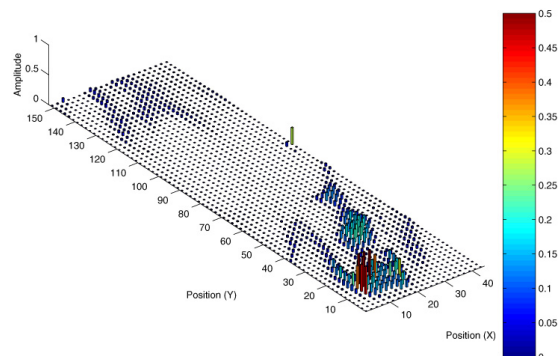


Fig. 5. Topograms of the FFT power spectra of a frequency range between 0.004 and 0.005 Hz with respect to changes in skin temperature, in the same healthy control subject.

The results at that time showed that[6]:

- 1) In all healthy subjects (N = 5, ages 29 to 38), only one peak was observed at the frequency range of 150 – 170 seconds in the FFT power spectrum; this was prominent in the hand, especially the fingers.
- 2) In all cases with Raynaud's syndrome (N = 22, ages 28 to 67), the peak was observed in the same range as in the control subjects.
- 3) In 13 of the 22 Raynaud's patients, a noticeably higher and clearly demarcated amplitude of the peak was observed at the fingers.
- 4) In many cases, this high amplitude was observed at all the fingers; however, in 3 cases it was observed at specific fingers.
- 5) With respect to the relationship between this high amplitude and the clinical signs and symptoms, the amplitude measured at the finger did not always show a significant correlation with the severity of the Raynaud's phenomenon.
- 6) The remaining 9 Raynaud's syndrome cases did not show a high peak amplitude at the fingers even though they suffered from Raynaud's phenomenon; in addition, no significant differences between these two groups of Raynaud's syndrome cases were observed concerning clinical signs and symptoms.

In the present study, dynamic thermal images are processed at the same rate as videos with a high degree of thermal and spatial resolution, and we are now comparing the topograms of the spectra of the skin temperature fluctuations of healthy subjects with those for patients suffering from autonomic nervous dysfunction, such as Raynaud's syndrome. However, the number of both patients and healthy subjects is currently too small to allow definite conclusions to be drawn, and further experiments need to be performed.

IV. CONCLUSION

This study showed that the periodic fluctuations of skin temperature and their spatial distribution may provide useful information about autonomic conditions, and thus that topograms of the spectra of fluctuations of skin temperature could become a useful tool for the evaluation of autonomic function (and dysfunctions such as mental stress).

In order to evaluate the feasibility of this method of analysis, we are now analyzing differences between healthy subjects and patients with Raynaud's syndrome in the distribution of the rhythms of skin temperature using this system.

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