

A Novel Thermal Measurement for Heart Rate

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Abstract—Heart rate is an important indicator for the mental and physical state, but it is usually measured through physical contact. In this paper, a novel non-contact method of heart rate measurement has been proposed from the infrared sequence images. First, a square region of interest (ROI) was manually selected to cover the temple on the first frame. Then a head movement detection algorithm based on the centroid coordinate change of the extracted skin area was applied to the infrared sequence images, and according to the movement result, the ROI location in subsequent frames could be identified. After that, the distance between the gravity center and the top-left corner in every ROI is computed to get a time-lapse signal. Finally, the discrete wavelet transform and an autoregressive model were used respectively to recognize the heart rate. Fourteen healthy subjects (24-29 years of age, 4 females and 10 males) participated in the experiment. Compared with the concomitant ECG, mean accuracy rate of 94.5% was acquired. The results show the potential of our method for non-contact heart rate measurement.

Index Terms—heart rate, infrared sequence images, wavelet transform, autoregressive model

I. INTRODUCTION

Heart rate monitoring is important in health care and affective computing. The conventional ways for heart rate measurement are electrocardiography (ECG) and photoplethysmography (PPG). Both methods need contact sensors, thus measurement itself may be a mental or physical stressor. Therefore, a mentally and physically low-restriction measurement for the heart rate is highly desirable.

Much effort has been made for the non-contact measurement of heart rate in recent years. Chen et al. measured the pulse rate in real-time through the pressure signal acquired from a pressure sensor placed under a pillow [1]. Chiihiro Takano et al. used the low-pass filter method to measure the heart rate through CCD sequence images [2]. Ming-Zher Poh et al. adopted the blind source separation to get the cardiac pulse signal through webcam images [3].

As infrared thermography could detect tiny changes in the skin temperature due to the pulsation, it has also been used in heart rate measurement. Pavlidis et al. [4]

harvested the cardiac pulse signal using a cooled infrared imaging system through the fast Fourier transform.

Compared with a cooled infrared imaging system, an uncooled infrared imaging system has lower temperature sensitivity, and there are no clear artery imprints in the infrared images. In this paper, we propose a novel method to obtain the cardiac pulse from the sequence images of an uncooled infrared imaging system.

The paper is organized as follows: In Section II, the experimental setup is introduced. In Section III, the proposed algorithm is presented in detail. The results are given in Section IV. Section V gives the discussion of the algorithm while Section VI concludes the paper.

II. EXPERIMENTAL SETUP

First, an uncooled infrared dynamic image acquisition system is constructed. It contains an uncooled infrared sensor (a long-wave FLIR Photon Camera, FLIR Systems Inc, Portland, USA), a digital analog converter system (DH-VT140, Daheng Group Inc, Beijing, China), and a workstation. Fig. 1 shows the system and the physiological record instrument (MP35, BIOPAC Systems Inc, Goleta, USA).



Figure 1. The infrared dynamic image acquisition system and the physiological recording instrument

The experiment was conducted in a quiet room with a temperature of nearly 25°C. The subjects stayed at the room for at least 20 minutes to get a thermal equilibrium with the ambient.

Then, each subject was told to keep a relaxed seating posture without rotating the head voluntarily. After that, we start to record the gray sequence images of all fourteen subjects one after another using the infrared dynamic image acquisition system. The temperature sensitivity of the infrared camera is 85mk and the video format is PAL at a rate of 25 frames per second. All images were saved in an 8-bit grayscale format, and the pixel intensity was linearly related to the temperature recorded by the thermal camera. At the same time, two BIOPACs were used in the experiment, one used respiratory belt transducer on the chest to record the respiratory wave, while the other used the three electrodes attached on the left and right wrist and the right ankle to record the ECG. The experiment lasted 20 seconds and 500 images were acquired in all. Fig. 2 is the first image of one subject's sequence images.

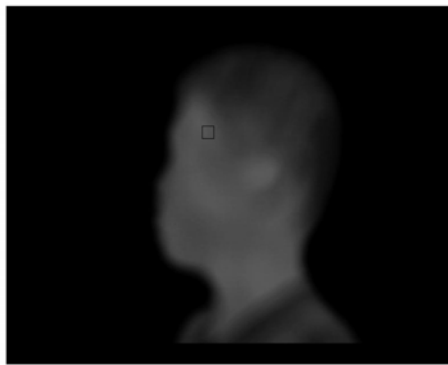


Figure 2. The first one of the sequence images. The large square near the temple area is the ROI of 20 pixels × 20 pixels.

It is hard to pinpoint the position of the superficial temporal artery in the images with our camera, but the temple area which covers the superficial temporal artery has a higher temperature than its surrounding tissue, so it is reasonable and feasible to select an area with a higher gray value near the temple as the ROI. We choose a large square ROI that covers the superficial temporal artery as much as possible around the temple. In our experiment, we choose the same ROI size 20 pixels × 20 pixels for every subject, and the square in Fig. 2 represents the ROI.

III. METHOD

A. Head Motion Detection

Obviously, the measurement is meaningful only when the ROI in every frame is on the same tissue area. Since the ROI is located in the temple area, it is liable to be disturbed by the subject's head rotation, and at worst conditions no ROI could be found in the images. Therefore, we require that the subjects limit their head rotation during the experiment and each experiment just lasts for 20 seconds to ease the inconvenience to the subject. In this case, the subjects' head movement is almost in their own up-down and front-back directions, and respiration is an important reason for the movement.

To obtain the information of artery pulsation, a novel motion detection algorithm based on the position change

of the centroid of the profile skin is proposed. First, in order to extract the centroid conveniently, the original images are changed to binary images using some threshold. The skin gray values exceed the threshold while the others are lower than the threshold.

Then the centroid of the binary image is calculated in every frame, and we compare every succeeding centroid with the first frame centroid, and the horizontal and vertical variations of the centroid's could denote the subject's front-back and up-down motions, respectively.

The calculated horizontal motion and the original respiratory signal are shown in Fig. 3 and Fig. 4, respectively. The result is in accords with our aforementioned assumption that respiration is an important reason for head motion. But this assumption is not fit for every subject. For example, some subjects hold their breath during the experiment or they involuntarily nod their heads during the experiment.

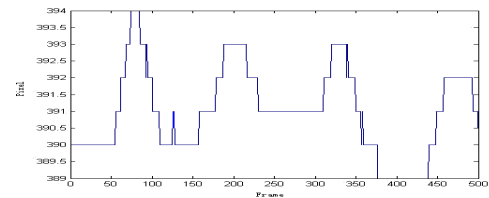


Figure 3. The variation due to horizontal head movement.

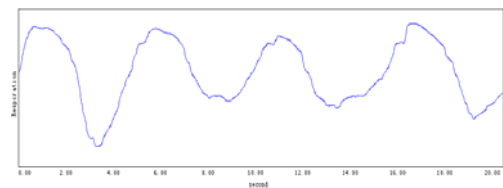


Figure 4. The respiratory wave measured by a BIOPAC

B. Gravity Centre Calculation

In this step, we introduce the gravity centre method to get the time-lapse signal. The method consists of two steps:

First step: define the gravity center of the image:

The $(p + q)$ order moment of a point with a coordinate (m, n) and a gray value $f(m, n)$ in the image is defined as

$$k_{pq} = \sum_m \sum_n m^p n^q f(m, n) \quad (1)$$

The gravity center coordinate $G (m_G, n_G)$ of the image is

$$m_G = \frac{k_{10}}{k_{00}}, n_G = \frac{k_{01}}{k_{00}} \quad (2)$$

Second step: according to the motion detection result above, the upper-left coordinate of the ROI in every frame should change correspondingly with the first frame. The distance between the gravity centre of the ROI and the top-left corner of the ROI in all sequence images – which represents the time-lapse signal – is calculated. Fig. 5 illustrates the time-lapse signal.

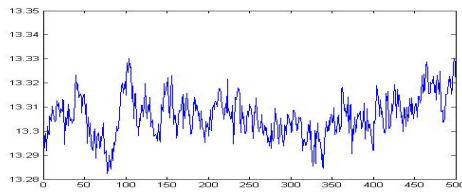


Figure 5. The time-lapse signal

C. Signal Processing

The discrete wavelet transform is used to decompose the signal.

Suppose there are $n = 2^N$ equally space values of a function $f(x)$, $f_1, f_2...f_n$. We shall use the superscript N to indicate the level of decomposition. At each new level, the spectrum is cut in half. The decomposition can be represented as

$$f^{(N)} = g^{(N-1)} + g^{(N-2)} \dots + g^{(N-M)} + f^{(N-M)} \tag{3}$$

Where $g^{(i)}$ is called the 'detail' signal, $f^{(i)}$ is called the approximate signal. M is so chosen that $f^{(N-M)}$ is sufficiently 'blurred'.

In our method, the wavelet basis 'sym8' is used, and after decomposition, the fourth level detail signal is selected for the detection of the heart rate and has a frequency range of 0.78~1.56Hz.

At last, the AR model is used to calculate the power spectral analysis. The AR method of order p is expressed as the following equation:

$$x(n) = -\sum_{k=1}^p a(k)x(n-k) + w(n) \tag{4}$$

where $a(k)$'s are AR coefficients and $w(n)$ is white noise of variance σ^2 . AR (p) model can be characterized by

AR parameters $\{a_1, a_2, \dots, a_p, \sigma^2\}$. The power spectral density (PSD) is

$$p_{AR}(f) = \frac{\sigma^2}{|A(f)|^2} \tag{5}$$

where $A(f) = 1 + a_1e^{-j2\pi f} + \dots + a_p e^{-j2\pi fp}$.

In our method, we use the Burg method, and the model order is set to 7 in this experiment.

All the results given in this paper are produced using MATLAB 7.6 for windows.

IV. RESULTS

Once the time-lapse signal is decomposed by the wavelet transform, we use the AR model to calculate the power spectral density of the fourth level detail signal; and a characteristic frequency can be obtained for the signal. Fig. 6 shows the frequency 1.12Hz corresponding to the peak value which is assumed to be the heart rate of a subject.

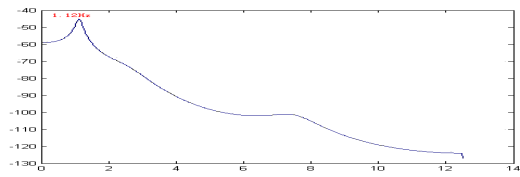


Figure 6. Power spectral analysis for the fourth level detail signal using AR model (order=7)

As the golden standard for heart rate measurement is ECG, we choose ECG as the ground truth. In order to verify the accuracy of the result of our method, we used one BIOPAC to measure all fourteen subjects' ECG when the sequence images were being acquired. The ECG result of the subject mentioned above shows that the heart rate is nearly 1.09Hz. Therefore, our method gives a precise result of heart rate for the selected subject.

The ground truth (GT) and our results (OR) of heart rate measurements for all fourteen subjects were compared. The comparison is based on the accuracy rate, which is defined as

$$\text{Accuracy rate} = 1 - \frac{|GT - OR|}{GT} \tag{6}$$

Table I shows the comparison of heart rates measured by our method and by BIOPAC, and the mean accuracy rate of all the measurements against the GT is 94.5%.

TABLE I
COMPARISON BETWEEN GT AND OUR METHOD FOR PULSE MEASUREMENT

Subject ID	GT (Hz)	OR (Hz)	AR (%)
1	1.25	1.27	98.4
2	1.22	1.25	97.5
3	1.33	1.27	95.5
4	1.33	1.29	97.0
5	1.22	1.27	95.9
6	1.32	1.34	98.5
7	1.12	1.22	91.1
8	1.17	1.29	89.7
9	1.09	1.12	97.2
10	1.18	1.25	94.1
11	1.43	1.27	88.8
12	1.20	1.17	97.5
13	1.18	1.22	96.6
14	1.55	1.32	85.2

GT: ground truth; OR: our result; AR: accuracy rate

V. DISCUSSION

In this study, we propose a novel method to measure heart rate using the infrared dynamic image acquisition system. With this method, a precise result of the heart rate can be obtained; it can be assumed that the position of the gravity center of the ROI varies due to the periodic heat effect of heart beat.

In general, the temperature variation due to heartbeat is less than 0.1 K [5], so it is not necessary to use a cooled infrared image system with sensitivity of 25mk as the sensor. Although our infrared camera has a lower sensitivity of 85mk, the accuracy rate is all the same acceptable for heart rate measurement.

Our method for motion detection yields good results for both the horizontal and vertical movements. Although our method could not obtain accurate movement information along the subject's right-left direction, it could cause a great change in the centroid coordinate if the subject turns around, therefore we can also be aware of the subject's motion in the left-right direction and repeat the experiment. In contrast, for other methods including condensation [4], coalitional tracking [6], none could track the ROI if the ROI is not in the image, which will interrupt the heart rate measurement.

In this experiment, we just record the infrared sequence images for 20 seconds, not for 5 minutes as in [4]. Several factors can affect the measurement result: 1) The heart beat is a non-stationary signal, short time measurement can reflect information about the momentary heart beat, and we could assume it to be a stationary signal in a short time experiment. 2) Subjects' psychological state is liable to change during the sequence images acquisition, and the change could also affect the heart beat signal. For example, subjects' psychological state may vary from calm to anxiety because of the discomfort caused by the BIOPAC as time goes by, and subjects' psychological changes can lead directly to irregular head movement. 3) The uncooled infrared camera will produce some additional thermal noise in a long run time. Therefore, we just choose a short time 20 s recording for the heart rate measurement.

Based on our experience, different ROI sizes may affect the heart rate measurement. First, if the ROI size is very small, limited by the low temperature sensitivity of our uncooled infrared dynamic image acquisition system, the ROI may not be selected exactly on the superficial temporal artery, and different ROI initial (upper-left point of the ROI) points may lead to different measurement results. In this regard, the measurement may be irreproducible across different ROI initial points. Second, if the ROI size is very large, then the ROI may contain too many areas that do not belong to the superficial temporal artery, and the measurement may be insensitive to the heart pulsation. In comparison, the ROI size 20 pixels \times 20 pixels is an optimal choice for all the subjects in the experiment, which could result in a relatively stable and sensitive heart rate measurement.

There are some negative factors that can affect the measurement, for example, perspiration on the ROI can remove the heat from the artery and other appliances (e.g. air-conditioner) may form convection near the ROI. So up to now, the measurement is effective only in the laboratory environment. Another impairing factor is that the subject's hair may shelter the ROI, which also causes inaccuracy in the result.

Our method demonstrates the feasibility of heart rate measurement through our infrared imaging system, in

practical applications, especially in an outdoor condition, however, there will be more sophisticated noises, and we need to develop a more effective method of noise reduction in future.

VI. CONCLUSION

In this study, for most healthy subjects in the rest state (heart rate in the range 50~90 beats per minute), the heart rate can be measured precisely by using AR spectral analysis on the time-lapse signal after the wavelet transform. Fourteen subjects participated in the test, with a mean accuracy rate of 94.5% being achieved for heart rate measurements.

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