Fourier based stabilisation of thermal images in dynamic thermography

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Abstract

In active dynamic thermography (ADT) sequences of consecutive temperature distributions are analysed. In biomedical applications of ADT some additional problems of movements of examined objects in front of thermal camera arise. Complete mechanical stabilisation of the patient is impossible due to natural voluntary and involuntary movements caused by pulse, breathing, etc. This paper presents a simple and efficient image sequence stabilisation method based on the two dimensional Fourier Transform.

1. Introduction

Image sequence stabilization and matching is a large topic of computer science used in many different areas of applications like: multimodal image matching [1], [2], aerial or satellite map forming [3], stereovision [4], photo art as e.g.: large multi image panorama creation [5] and much more different applications. In the process of image forming and matching different techniques are used such as correlation matching [4], feature detection [2] or phase correlation [6] and other. Every technique has its advantages and disadvantages. Correlation matching is rather slow depending on the measure of correlation, it requires identified image features like edges and corners. Phase correlation demands image frequency filtration and Fast Fourier Transform computation to be fast and efficient. In this paper a novel, simple and fast image sequence matching is presented. The method is based on assumptions, that images are relatively scaled, translated, rotated and the information is hidden in Fourier spectra of the images. This method performs best on images with smooth gradients and lack of distinctive features.

2. Problem statement

During our studies on biomedical applications of ADT problems of thermogram sequence stabilization arose. It is very hard to eliminate movements of examined body parts due to breathing, pulse and some other voluntary and involuntary reactions. This causes further image post processing procedures of parametric image computation and thermal tomography impossible or erroneous. Mentioned procedures demand image stillness to provide the best results, each pixel must correspond to the exactly the same point on the measured surface. This problem prevented researchers from performing advanced image analysis, although use of mechanical stabilization is sometimes available. By its nature it requires physical contact with examined structure and therefore may influence the results by distorting heat exchange processes.

Figures 1.a and 1.b present thermal images of a post surgery scar (after melanoma excision) taken with 0.2[s] time interval. Figure 1.c presents their difference image. Clearly movement between these two images is visible.

Movement artifacts are visible as large peaks or measured temperature trend distortions presented in figure 2. In this case temperature rise was observed by the camera after cooling down the skin by CO₂ gas. In order to provide reliable results of dynamic analysis we must either provide mechanical measurement set stabilization (not always possible, also can affect the results) or suppress movement further in the image sequence post processing. Presented method performs image post processing stabilization end eliminates movement artifacts.
3. Image frequency domain representation

The presented solution is based on the fact that the information about the geometrical relation between any two images of the sequence is easily extracted from their FFT spectrum. Each image can be represented in the frequency domain by its FFT (1):

$$F(u, v) = \frac{1}{MN} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} I(x, y) e^{-j2\pi (ux/M + vy/N)} ,$$  

(1)

where:

- $I(x, y)$ – image intensity,
- $F(u, v)$ – complex image spectrum
- $M, N$ – image width and height,
- $x, y$ – image coordinates,
- $u, v$ – spectrum coordinates; vertical and horizontal frequencies.

Each FFT can be presented by its amplitude and phase components (2). The amplitude contains the information about the intensity of the image in each frequency band. The phase on the other hand contains the information about spatial distribution of frequency components. Figure 3 illustrates an example of image phase and amplitude.

$$F(u, v) = |F(u, v)| e^{j \arg(F(u, v))} ,$$  

(2)

where:

- $|F(u, v)|$ - FFT spectrum phase,
- $\arg(F(u, v))$ – FFT phase argument.

These two spectral components, along with analysed images, undergo certain transformations which can be derived from Fourier Transform properties. This enables performing image matching at low computational cost and prepare an uncomplicated algorithm for matching thermogram sequences for further post processing ADT procedures.
Fig. 3. An example of image spectral representation

The following section explains the relations between image pair relative translation, rotation and scaling and its effects on the spectrum. Each operation is illustrated by a mathematical formula and the amplitude and phase two dimensional plot. In the following analysis square size of images is assumed (M=N).

3.1. Image translation

The effect of translation on the FFT spectrum can be written as (3):

\[
I(x - x_0, y - y_0) \Leftrightarrow F(u, v) e^{-j\frac{2\pi(x_0u + y_0v)}{N}},
\]

(3)

where:

- \(I(x,y)\) – image,
- \(x_0, y_0\) – translation vector,
- \(F(u,v)\) – FFT transform of \(I(x,y)\),
- \(N\) – image width and height.

Pure translation causes multiplication by the \(e^{-j\frac{2\pi(x_0u + y_0v)}{N}}\) factor which contains coordinates of the translation vector. This operation changes the phase of the image's FFT, while the amplitude spectrum remains unchanged. Figure 4 illustrates the graphic effect of this operation on the spectra.
3.2. Image scaling

The effect of scaling on the FFT spectrum can be written as (4):

\[ I(ax, by) \Leftrightarrow \frac{1}{|ab|} F\left(\frac{u}{a}, \frac{v}{b}\right), \]  

(4)

where:

- \( I(x, y) \) – image,
- \( a, b \) – scaling coefficients,
- \( F(u, v) \) – FFT transform of \( I(x, y) \).

An explanation of the scaling effect on image spectral representation is not so obvious as in the case of the rotation. But it can be seen that it affects only the amplitude component of the image FFT, which also undergoes scaling as well as power level change. This is illustrated on figure 5. The phase spectrum is omitted as it remains unchanged.
3.3. Image rotation

The rotation operation effect on the FFT spectrum can be written as the set of equations (5):

\[
\begin{align*}
I(x, y) & \Leftrightarrow F(u, v) \\
I(x', y') & \Leftrightarrow F(u', v') \\
\begin{bmatrix}
x' \\
y'
\end{bmatrix} &= \begin{bmatrix}
\cos \varphi & -\sin \varphi \\
\sin \varphi & \cos \varphi
\end{bmatrix} \begin{bmatrix}
x \\
y
\end{bmatrix} \\
\begin{bmatrix}
u' \\
v'
\end{bmatrix} &= \begin{bmatrix}
\cos \varphi & -\sin \varphi \\
\sin \varphi & \cos \varphi
\end{bmatrix} \begin{bmatrix}
u \\
v
\end{bmatrix}
\end{align*}
\]

where:

\( I(x, y) \) – image,
\( F(u, v) \) – FFT transform of \( I(x, y) \),
\( \varphi \) – image pair relative rotation angle,
\( x, y, u, v \) – spectral and image coordinate set before rotation
\( x', y', u', v' \) - spectral and image coordinate set after rotation

By rotating the image its amplitude spectrum is also rotated by the same angle. The phase remains unchanged. This property is very well illustrated on figure 6. The phase image is omitted due to its irrelevance in this analysis.

![Image](image.png)

**Fig. 6.** Graphic interpretation of rotation; image order is the same as in fig. 4; the amplitude component of the FFT becomes rotated by the same angle [7]

4. Stabilisation algorithm

The proposed algorithm takes advantage of discussed FFT properties just like Phase Correlation (PC), but the result is different: PC is capable of estimating affine transformation matrix between two transformed images. To match images additional reverse transform is required along with image interpolation afterwards. Discussed method is simpler. Instead of performing calculations a substitution of the phase spectrum is performed. This works well under certain assumptions: first, we assume that images of the sequence undergo translation in a small extent (up to several percent of image width and height). The region of interest should be in the centre of the image to reduce error after spatial windowing performed before FFT calculation. Also there should not be any step changes in the temperature pattern – like hot object in front of a cold background. This may produce high frequency distortions in the image after the inverse FFT calculation. A good quality, sharp
reference image from the sequence is required to perform the image matching (sharp image contains the most ‘complete’ phase spectrum of the examined object). Rotation and scaling transformations are not taken into account, because they influence the amplitude. The algorithm of two image matching is presented on figure 7.

![Image]

**Fig. 7. The Fourier based image matching algorithm**

5. **Results**

In this section some results of image matching algorithm are presented. Thermograms were recorded by the FLIR ThermaCam SC3000 thermal camera during evaluation of infrared imaging of breast cancer and skin melanoma, performed under support of Medical University of Gdańsk. The algorithm performance depends on certain ROI features. Best effects are achieved on images of large surfaces with smooth temperature gradients without any step changes in spatial temperature pattern. Windowing operation reduces the effect of frequency distortions caused by FFT spectrum leakage. Figure 8 presents the results of the algorithm applied to the image pair presented on figure 1. For this sequence the results of image stabilization are very good because it fulfills the assumptions mentioned in the section 4 of this paper. The movement artifact is eliminated from the temperature transient, but the rise trend is preserved (figure 9). The vignette visible in figure 8 is due to the spatial windowing. Figure 10 presents results of another matching case. Also the example of ineffective performance is shown in figure 11. Matching produced high frequency artifacts due to the presence of step change of temperature pattern (hot body - cold background). It suppressed temperature oscillations caused by respiration very well till the 80th frame, later the artifacts started to become visible.
Fig. 8a, b, Matched image pair; c. difference image illustrating differences between temperature values of two images.

Fig. 9. Temperature transient from the stabilized sequence; movement artifact has been eliminated.

Fig. 10. The results of stabilisation of another sequence – the scar after breast resection; mean temperature plot is taken from square area 100:120[pix], 100:120[pix] from the image; exponential temperature growth is preserved.
Fig. 11. Image of the breast; An example of ineffective performance; matched image reveals high frequency artefacts (apparent irregular grid on the image); temperature plot taken from square area of 100:120[pix], 100:120[pix]

Fig. 12. An example of advanced post processing procedure - breast parametric imaging; temperature return is matched to the two exponential model

6. Conclusions

The simplicity of this novel matching algorithm is its big advantage, however its performance should be assessed to fully understand the influence of different image features on the output and increase its performance in some cases. This will be the object of its further evaluation. The results of the algorithm enable us to apply more advanced image post processing procedures like parametric imaging, thermal tomography and other that require still images (an example of such a procedure is shown on figure 12). Such procedures could be useful in the development of new algorithms of infrared diagnostics in different fields of application like breast cancer detection, skin burns depth evaluation, skin diseases diagnostics and others.

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