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An Improved Method for IR Image Filtering from Living Beings

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Abstract— **A new method to enhancing the quality of the images acquired with infrared camera is presented. Usually, thermal image filtering process relies on heat conductive component that propagates through tissue. An improved method for nonlinear filtering is presented in this article. A new component of the heat, the convection is associated heat that propagates through the tissues of living beings. From the physical point of view, this component is the result of blood flow through the tissue. The proposed algorithm uses both parts of the heat components and iteratively minimizes the noise that is added to the signal. During the iterative filtering process, the noise is more quickly minimized than other methods can do. Thermal contour shape is an important indicator for oncologists to diagnose superficial cancers such as breast, thyroid and skin. The proposed method has been tested on more patients and an example of an IR image filtering taken from a patient suffering from papillary carcinoma is shown at different iterations. The algorithm convergence speed and the contour shape are compared with the results obtained by using anisotropic filtering.**

I. INTRODUCTION

Analyzes undertaken by several international associations that monitor the health of the population showed that the second cause leading to death in many countries of the world was the cancer. More than, unfortunately, oncologists estimate that the number of these deaths will increase in the near future by about 45% [1]. A lot of researches have been done into oncological field in order to improve the results of curative therapy. It is widely accepted that for the best results of treatment, an early diagnose has to be done. Early detection, as the key factor, involves not only the need to highlight a tumor tissue as small as possible, but the differentiation between a malignant and benign tissue as well. Current medical devices analyze the morphological aspect of tumor, and detect the tumor existence when the diameter is larger than about five mm, or could appreciate a malignant tumor when its diameter exceeds 20 mm [2]. Cellular metabolism relies on physical and chemical processes generated by bioheat. Bioheat is uniform and symmetrically distributed inside the healthy human being. Local cellular metabolism changes generated by infectious process, uncontrolled cell multiplications or angiogenesis will disturb the spatial bioheat distribution. Bioheat transfer to skin occurs through several means. In this paper, only two means were simulated: conduction and convection. The heat changes could be measured on skin surface when the infectious processes are not deeper than about four cm [3, 4]. In this way, a thermal image could inform the physician about a local infectious process, including cancer.

An early detection is based on the possibility to evaluate a very small temperature variation, the contour shape, and the outbreaks of infection inside the thermal signature. Unfortunately, the thermal images are noisy, and important data are lost. One of the most widely used denoising techniques with well preserving edge features in medical imaging is anisotropic diffusion filtering. A lot of explicit schemes were proposed [5-8]. They are based on the iterative solving of the diffusion equation that takes into account only the heat propagation by conduction. This is the real physical phenomenon that occurs when heat travels through all objects. The perfusion blood represents an important way to transfer the bioheat in living beings, and therefore a new equation that models the physical phenomenon could be used. The new filter using Pennes equation [9, 10] for bioheat has tested, and its performances have been evaluated in terms of denoising with edge preservation, the possibility to assess the structure of the region of interest, ROI, and computer time. The last parameter is presented in comparison with the performances of three well-known anisotropic diffusion filters.

As a part of an ongoing project to develop new techniques for early cancer detection, the current study is aimed at developing a numerical scheme which significantly reduces the computer time for thermal image denoising with edge preservation, a critical factor in making efficient the clinical diagnosis. The new technique is demonstrated on an image taken with a Flir infrared camera that shows the thermal signature on the neck skin of some anatomo-pathological modifications inside the thyroid right lobe, papillary carcinoma.

II. MATERIAL AND METHODS

In the body of living beings, the main source of heat is the result of metabolic activity at the cellular level. Heat spreads to neighboring cells by conduction and convection. In the latter case, the heat is carried by the blood flow. In pathological cases, cellular activities can be heavily modified, accelerated (such as cancer or infectious processes) or slow. As a result, between the temperatures measured on the skin

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there will be some mathematical relationships that can be modeled as mathematical solutions of nonlinear equations. Pennes [9,10] proposed the following equation:

$$\rho c \frac{\partial T}{\partial t} = k\nabla^2 T + \omega_b c_b \rho_b (T_a - T) + h_m \quad (1)$$

where c is the specific heat of tissue, ρ is the density of tissue, k is the tissue thermal conductivity in the absence of blood flow, ρ_b is the density of blood, ω_b is the perfusion rate per unit volume of tissue, c_b is the specific heat of blood, T is the local tissue temperature, T_a is the temperature of arterial blood, and h_m is the rate of metabolic heat production evaluated per unit volume of tissue. The last parameter is for the bioheat source.

The partial differential equation (1) can be solved iteratively by using the numerical method developed by J. Crank and P. Nicolson [11, 12] in 2D space. The bi-dimensional space derivative term is replaced with the central difference approximation, and the mono-dimensional time derivative is replaced with forward difference approximation. Equation (1) is applied for the temperatures of the internal nodes. The temperature is iteratively updated for each (*i, j*) spatial coordinate of the current pixel, so at the *n+1* iteration, it takes the form [13]:

$$T_{i,j}^{n+1} = k_1\left(T_{i-1,j}^{n} + T_{i+1,j}^{n}\right) + k_2\left(Ti,_{j-1}^{n} + T_{i,j+1}^{n}\right) - \left(2k_1 + 2k_2 + k_3\right)T_{i,j}^{n} + k_4 \quad (2)$$

The equation coefficients are as follows:

$$k_1 = \frac{\Delta t\, k_x}{\rho c \Delta x^2}, \qquad k_2 = \frac{\Delta t\, k_y}{\rho c \Delta y^2},$$

$$k_3 = \frac{\omega_b \rho_b c_b \Delta t}{\rho c} - 1, \quad k_4 = \frac{\omega_b \rho_b c_b T_a + h_m}{\rho c}\Delta t .$$

The convergence and stability of the explicit difference schemes are provided by the Courant–Friedrichs–Lewy condition, CFL [14]. In our example, the time step size should be $\Delta t < 1/(2d)$, with d is the dimension number of the data, for 2D thermal image d=2.

The coefficients k_1 and k_2, which represent diffusivities on the orthogonal axes X and Y, are evaluated at each iteration using the relations given in [14, 15]. They have different values in the case of an anisotropic filter. The coefficients k_3 and k_4 can be defined only for thermal images. The coefficient k_3, which depends only on the blood perfusion rate, was approximated in this paper with the normalized value of temperature gradient around the central node:

$$k_3 = k_0 \frac{T_{i+1,j}^n + T_{i,j+1}^n - T_{i-1,j}^n - T_{i,j-1}^n}{T_{i+1,j}^n + T_{i,j+1}^n + T_{i-1,j}^n + T_{i,j-1}^n} \quad (3)$$

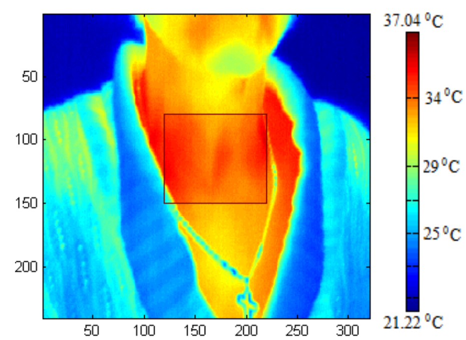
The last term, k_4, is updated as follows:

$$k_3 = k_0 + k_3 \quad (4)$$

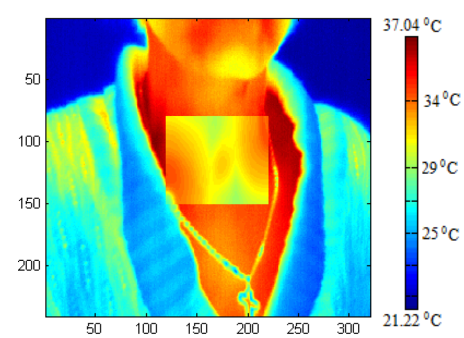
were k_0 is a constant between 0.2 and 0.8, depending on the number of bioheat sources in ROI. The solving of bioheat equation represents an iterative process. A new image is obtained after each iteration by gradually reducing of noise and details from the original image. The final temperatures converge to constant values. Therefore, the stopping of diffusion process is very important for obtaining a good image reconstruction. Several authors attempted to devise optimal stopping criteria, such as: Weickert - the variance of the filtered image relative to the variance of the original image [14], Mrázek – minimizing the covariance of the image to the noise [15], Dolcetta and Ferretti - minimization of the performance index [16], Bazan – maximum of the second derivative of correlation between initial and current images [17, 18]. We compared the temporal evolution of the thermal image filtering when the bioheat has only the conductive component, such as the algorithms proposed by Malik and Perona, Weickert, and Gonzales, with the proposed algorithm using two bioheat components: conductive and convective. We have found that Bazan's criterion agrees well with the behavior of these filters.

III. EXPERIMENTAL RESULTS

Thyroid area can be detected from thermal images only if it doesn't work normally only. As an example for this filtering method, a thermal image [18, 19] showing the temperature distribution on the neck area of a person suffering from papillary carcinoma is shown in Fig. 1a.



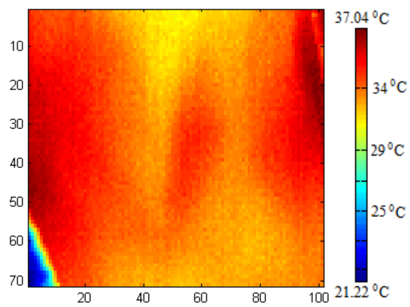
a)



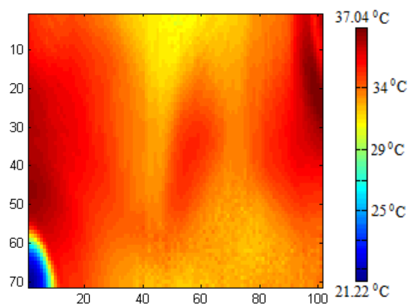
(b)

Fig. 1 Thermal images with ROIs before, (a) and after (b) filtering process.

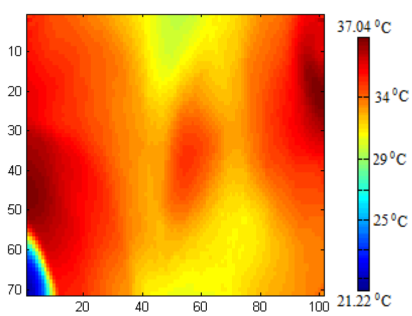
The ROI was manually selected, cut, and displayed as it is shown in Fig. 2a. The space step, Δx, is set to 1, and time step to 0.1. These values were imposed by the CFL condition. The iterative process begins by calculating the diffusion coefficients using the algorithm described by Gonzalez in [13, 18] and the coefficient k_3 from (3). The temperature of each pixel is obtained from (2). After first iteration, ROI is shown in Fig. 2b. The ROIs after the sixth and the ninth iteration are depicted in Fig. 2c and Fig. 2d, respectively. The color bar shows the correspondence between temperature and the associated color.



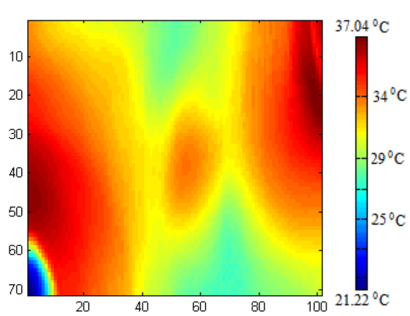
(a)



(b)



(c)



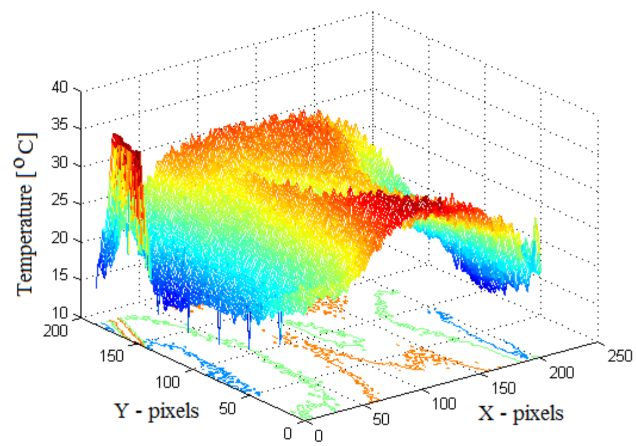
d)

Fig. 2 ROIs for initial state - (a), after the first- (b), sixth –(c), and ninth (d) iteration.

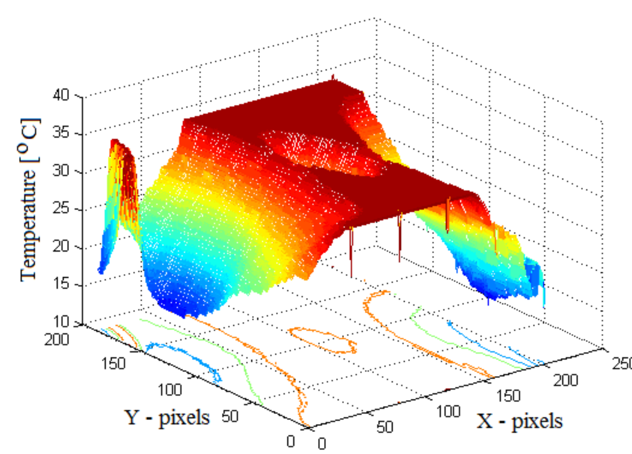
The filtered ROI is inserted in the initial thermal image, Fig. 1b. The noise removing could be better seen using 3D representation of ROI, before and after filtering, Fig. 3a and Fig.3b, respectively. Moreover, several heights can be noticed in Fig. 3b that correspond to some possible outbreaks of infections.

It is easy to follow the spatial evolution of temperature or the shape of a certain contour for a given temperature. There are significant changes in contour shape during these nine iterations. At the end of the iterative process, a smoother contour became due to reducing noise from initial thermal image, as it is shown in Fig. 3b

Beginning with the tenth iterations, the second derivative of correlation between initial and current images decreases, so the iterations process is stopped because the Bazan's stopping condition is accomplished. The second derivative evolution of this correlation coefficient is presented in Fig. 4, for four filtering methods. Three of them are based on diffusion filtering using only conductive heat component (Malik-Perona, Weickert, and Gonzales algorithms), and the last one uses simultaneously conductive and convective biobioheat components (the proposed method). The convergence of the proposed filtering method was achieved after nine iterations, and it was faster than the other three methods.



(a)



(b)

Fig. 3 The 3D representation of temperature in ROI, initial state (a), and final state (b).

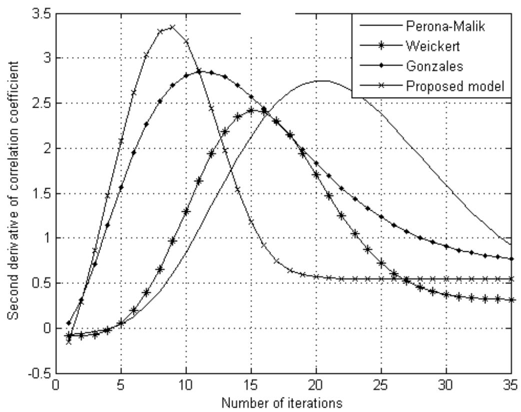


Fig. 4 The second derivative of correlation coefficient versus number of iterations.

IV. Conclusion

A new method of image filtering is presented. It is based on physical phenomenon of metabolic heat propagation, and uses the bioheat equation, and is applied only for removing noise from thermal images of living beings. This filter allows the physicians to assess, faster than using other anisotropic diffusion filters, the contour shape, to locate the outbreaks in ROIs, and to give information concerning benignancy or malignancy.

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