IMPROVING QUALITY OF MEDICAL INFRARED IMAGES BY SEQUENCES OF FRAMES FILTERING

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Abstract: *In this paper we propose an improved method for image filtering with slow time variation obtained from some successive frames of a thermovision camera investigating the heat radiated by human beings. In the first step, a single image is obtained as a result of the mean value evaluation from median filtering of all temporal frames. The standard deviation of each pixel is computed as well. The second stage consisted of a spatial filtering of the image from the first step by using the anisotropic diffusion filtering. New relations for the weighted coefficients of the diffusion matrix were proposed from the local statistic estimators. This method was tested on infrared images of different patients. Both subjective and objective evaluations of a patient image suffering from papillary thyroid cancer showed good performances for improving the signal to noise ratio and location of tumor.*

1. INTRODUCTION

Cancer is the second cause for mortality in many world countries. There are several medical devices using different kinds of energies allowing detection of impalpable tumors. We investigated the heat radiated from human body. At the level skin, the heat is the result of local metabolic process. Therefore, it is very useful for physicians to localize the infection center. It can give information about tissue health at local state, about the existence of a malignant tissue, for example. Thermal image is corrupted by noise and blur, so this task is not easy one.

The inherently noisy nature of digital images, low contrast of suspicious areas, and ill-defined mass borders make mass segmentation a challenging problem [1], [2]. The design of an appropriate preprocessing filter is essential for segmentation algorithms to delineate masses with high accuracy. Given the low spatial infrared image resolution, which greatly decreases the observable details, this paper describes a new method to enhance the original image. It presents a spatiotemporal analysis of the digital image obtained from an infrared camera.

Linear processing techniques are used extensively in digital signal/image processing and offer satisfactory performances for many applications, but many digital image processing problems cannot be efficiently solved by using linear techniques.

The human visual perception mechanism has been shown to have nonlinear characteristics. Also, human vision is sensitive to high frequency information. Image edges and image details have high frequency content and carry very important information for visual perception. So, a digital image processing filter requires having the good edge and image detail preservation properties. Most of the classical linear digital image filters have low pass characteristics, tending to blur edges and to destroy lines, edges, and other fine image details [3].

In this study, the input data are obtained from 32 infrared consecutive frames. Two steps were used for the infrared image processing: the processing of temporal signals, when the pixel behavior with the same spatial coordinates is analyzed in time, and then the processing of spatial signals. The temporal signal processing consists in a filtering based on order statistics. One of the most important applications of order statistics is robust estimation of parameters [4]. The median is a prominent example of robust estimators, and other estimators are expected and dispersion values.

The enhancement and representation image are important parts of biological and machine early vision systems. In the last decade, nonlinear diffusion filters have become a powerful and well-founded tool in image analysis [5]. These models lead to an image simplification, which simultaneously preserves or even enhances semantically important information such as edges, lines. The spatial signal processing, the second step in the presented filtering, is based on anisotropic diffusion [6], [7].

The displayed image, representing thermal signature of a patent, is modeled by a partial differential equation, PDE, equation of heat propagation. New relations are proposed in this paper for the diffusion matrix coefficients. They take into account of the variability of each pixel during the 32 frames.

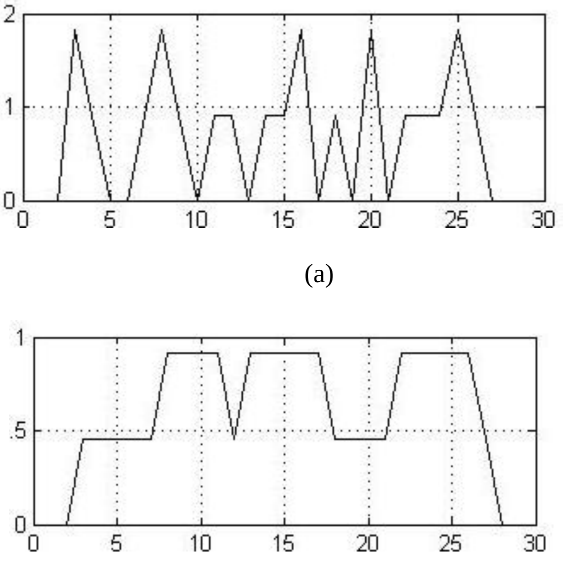
2. MATERIALS AND METHODS

2.1 Estimation of Local Statistics

Let I_1, I_2,……………,.I_P, be P consecutive temporal frames. Each frame consists of MxN pixels as random variables, $S_{i,j,k}$, where i=1÷M, j=1÷N and k=1÷P. At the beginning, we assume that these variables have a Laplacian distribution with median as robust estimator.

If the frames are arranged in ascending order of pixels for each position (i,j): $I_{(1)}$, $I_{(2)}$,………..$I_{(P)}$; where $I_{(r)}$, is called the r-th order statistic; the output of the median filter of size s is defined by applying the following relation for each pixel:

$$\left(S_{i,j,r}\right)=\begin{cases} S_{i,j,r+1} & if\ \ s=2q+1 \\ \dfrac{S_{i,j,r}+S_{i,j,r+1}}{2} & if\ \ s=2q \end{cases} \tag{1}$$



(a)

(b)

Fig. 1 The input (a) and output (b) of the monodimensional median filter, length s=4

For a particular signal, $S_{a,b,k}$ having the values between 0 and 2, with mean and standard deviation values: μ=0.7857 and σ=0.7382, that is shown in Fig. 1, the output signal at a median filter of length s=4 has μ=0.6964 and σ=0.3426, about the same average value but a half spread.

Other possible distribution of the variables is Gaussian distribution. In the case of median filtered signals, the arithmetic mean (expected value) is the maximum likelihood estimate:

$$\mathrm{S_{i,j}}=\frac{1}{P}\sum_{k=1}^{P}\left(S_{i,j,k}\right),\quad i=1\div M,\ j=1\div N \tag{2}$$

These signals will be used to generate a single image, U, from the 32 frames. The standard deviation $\sigma_{i,j}$ will be evaluated for pixel values $\left(S_{i,j,k}\right)$.

2.2 Anisotropic diffusion filtering

The spatial image is given by heat radiated from body surface. The heat diffusion equation is modeled by the following PDE:

$$\frac{\partial U}{\partial t}=div\,(D\nabla U) \tag{3}$$

where, *U* is concentration, *div* is the divergence operator, ∇ is the gradient operator, *D* is diffusion tensor and *t* is time.

Diffusion tensor has constant components for all pixels from the given image, in the case of isotropic diffusion. The diffusion tensor components could be variable in the case of anisotropic diffusion.

The choice of the diffusivity *D(x,y,t)* strongly influences the results. The anisotropic filter uses for the *D(x,y,t)* a nonincreasing function of the image gradient ∇U :

$$D(x,y,t) = g(\nabla U) = \exp\left(-\frac{\nabla U^2}{k^2}\right) \tag{4}$$

with *k* as gradient threshold. Diffusion filter can remove noise near the edges, and the diffusion tensor which controls the diffusion process should be not a scalar but a matrix. Weickert proposed the following structure:

$$D = \begin{pmatrix} d_{11} & d_{12} \\ d_{21} & d_{22} \end{pmatrix} \tag{5}$$

with values in the interval [0, 1], due to the fact that during diffusion processes mass is not created or destroyed. Whether *D* matrix has eigenvalues λ_1 and λ_2 ($\lambda_1 > \lambda_2$) and $\bar{e}_1$, $\bar{e}_2$ are eigenvectors, than $\bar{e}_1$, and $\bar{e}_2$ give the minimum and maximum variation directions.

Weickert proposed choosing $\widehat{\lambda}_1 = 1 - \exp(-3.315/\lambda_1^4)$ as approach to reduce diffusion across edges (along maximum variation direction given by $\bar{e}_1$, for edge enhancing filter: A measure of coherence is $(\lambda_1 - \lambda_2)^2$ and the maximum coherence direction is given by $\bar{e}_2$, the minimum variation direction.

The coherence enhancing filter enhances flow like structures, closes interrupted lines. The strategy is to diffuse along the coherence direction with a diffusion coefficient increasing with the coherence, for instance: $\widehat{\lambda}_2 = \alpha + (1-\alpha)\exp\left(-3.3(\lambda_1 - \lambda_2)^{-2}\right)$, where $\alpha \in (0,1)$.

In our method, we used the following relations for evaluation the anisotropic diffusion filtering:

$$d_{11} = \frac{\dfrac{S_{i-1,j}}{\sigma_{i-1,j}} - \dfrac{S_{i+1,j}}{\sigma_{i+1,j}}}{\dfrac{S_{i-1,j}}{\sigma_{i-1,j}} + \dfrac{S_{i+1,j}}{\sigma_{i+1,j}}}, \qquad d_{12} = \frac{\dfrac{S_{i-1,j-1}}{\sigma_{i-1,j-1}} - \dfrac{S_{i+1,j+1}}{\sigma_{i+1,j+1}}}{\dfrac{S_{i-1,j-1}}{\sigma_{i-1,j-1}} - \dfrac{S_{i+1,j+1}}{\sigma_{i+1,j+1}}},$$

$$d_{21} = \frac{\dfrac{S_{i-1,j+1}}{\sigma_{i-1,j+1}} - \dfrac{S_{i+1,j-1}}{\sigma_{i+1,j-1}}}{\dfrac{S_{i-1,j+1}}{\sigma_{i-1,j+1}} \dfrac{S_{i+1,j-1}}{\sigma_{i+1,j-1}}}, \qquad d_{22} = \frac{\dfrac{S_{i,j-1}}{\sigma_{i_{i,j-1}}} - \dfrac{S_{i,j+1}}{\sigma_{i,j+1}}}{\dfrac{S_{i,j-1}}{\sigma_{i_{i,j-1}}} + \dfrac{S_{i,j+1}}{\sigma_{i,j+1}}}. \tag{6}$$

where points (*i*, *j*) are shown in Fig. 2, $S_{i,j}$ is for the pixel value and $\sigma_{i,j}$ is for the standard deviation value.

The assessment of perceptual quality of the filtered image by human observers is subjective, cumbersome and expensive [8], and many criteria can be met in the literature [9]-[12]. In this paper, the image quality was evaluated by using two traditional error metrics: mean square error, MSE, and peak signal-to-noise ratio, PSNR, [13]-[16] for the two images, initial image - $I^0(x,y)$ and filtered image - $I^1(x,y)$:

$$MSE = \frac{1}{MxN}\sum_{y=1}^{M}\sum_{x=1}^{N}\left[I^0(x,y) - I^1(x,y)\right]^2 \tag{7a}$$

$$PSNR = 10\log_{10}\left(\frac{255^2}{MSE}\right) \tag{7b}$$

The MSE is the cumulative squared error between the filtered and the original image, whereas PSNR is a measure of the peak error.

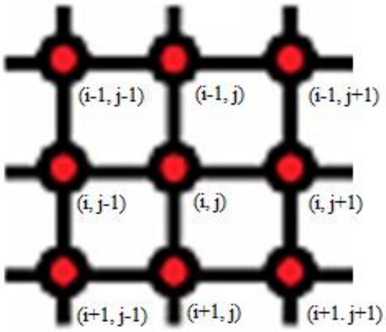


Fig. 2 Spatial position for diffusion coefficient evaluation

3. RESULTS

A number of 32 consecutive images were taken from a thermovision camera. Each image has 240 rows and 320 columns, 240x320 pixels. The first image from the 32 frames is shown in Fig. 3.

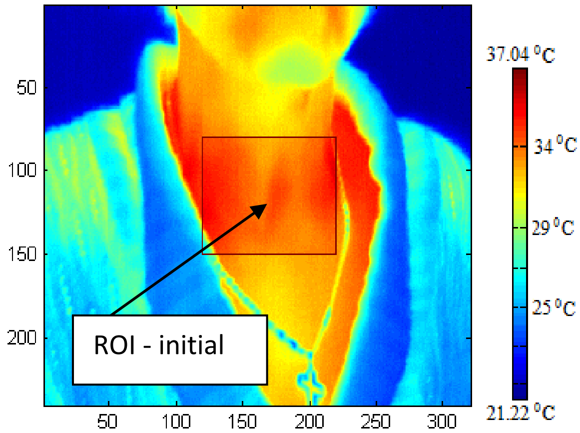


Fig. 3. The first image from the 32 consecutive images

A smaller image, 72x102 pixels, representing region of interest, ROI, is extracted manually from each of the 32 frames. After spatiotemporal filtering process, the final ROI is put back in the initial image, Fig. 4. A better localization of cancer nodule can be noticed.

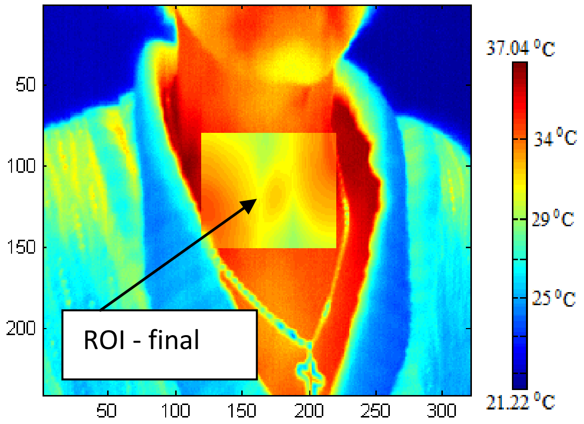


Fig. 4 The result of the spatiotemporal filtering

The spatiotemporal filtering process can be analyzed by watching the images from Fig. 5.

The initial ROI, from the first frame is shown in Fig. 5 (a). The pixels, having the same spatial positions in the 32 frames are median filtered and the mean, $S_{i,j}$, and standard deviation, $\sigma_{i,j}$, are evaluated.

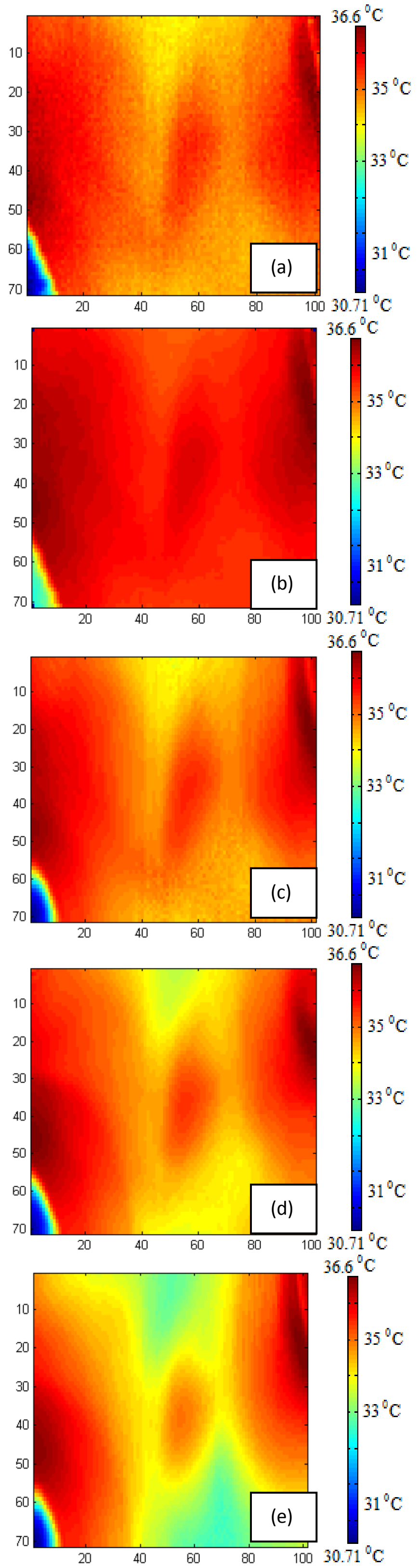


Fig. 5 The ROI initial - (a), after median filtering – (b), after 8 - (c), 40 – (d), and 96 - (e) iterations during anisotropic diffusion filtering

The ROI image from Fig. 5(b) depicts the mean values obtained from the 32 frames. The process of anisotropic diffusion is applied by successive iterations, using the coefficients evaluated from (6). The intermediate results of diffusion process are shown in Fig. 5(c) to Fig. 5(e) and represent the ROI images after 8, 40 and 96 iterations.

After 96 iterations no improvements can be observed. In order to determine a superior limit of the number of iterations for the quantitative evaluation of the image quality, the peak signal-to-noise ratio, PSNR, was computed for intermediate iterations by using (7a) and (7b). PSNR depends approximately exponentially on the number of iterations. Thus, for a small number of iterations, for example, after 8 iterations, the PSNR is 14.28 dB, after 40 iterations it amounted to 23.24 dB, and reaches to 56.82 dB when the number of iterations is 96, showing that the image obtained is quite close to the original, and the noise is very small. As the number of iterations is higher as image quality is better, the noise will be reduced providing better performance for physician.

For a better understanding of the two steps filtering process, we select the middle row, number 36 from ROI, and we displayed in Fig. 6.

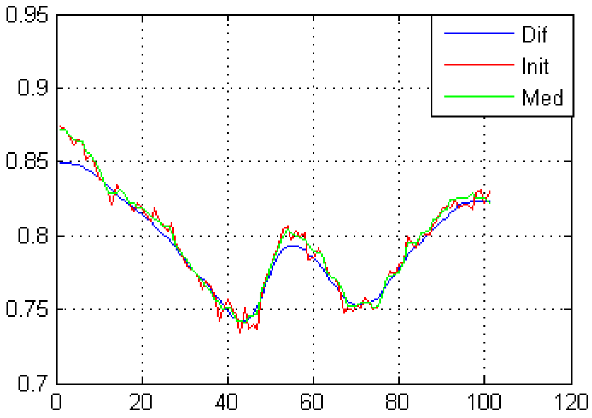


Fig. 6. The output data from the 36th row of ROI, initial - red, after median – green and diffusion filtering - blue

The initial state is depicted by red color. On this image a lot of high frequency components can be seen. A part of them were removed by median filtering, green line. The signal after 96 iterations is presented by blue line. The improvement of signal filtering quality can be seen.

4. CONCLUSIONS

The infrared images were processed in two steps: temporal, by median filter, and spatial, by anisotropic diffusion filtering. In the first step, the robust estimators such as median, mean and variance were evaluated from 32 frames, and a single image is obtained. The image is not so smoothly. After less than 96 iterations, in the second step, an improved image quality was obtained and the physicians have the opportunity to do a better localization of the infection centre or tumor.

5. ACKNOWLEDGMENT

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