ADVANCED THERMAL IMAGE PROCESSING FOR MEDICAL AND BIOLOGICAL APPLICATIONS

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Abstract- **In this paper, new image processing tools are presented for conversion thermal and visual images, mainly for application in medicine and biology. A novel method for area and distance evaluation based on statistical differencing is discussed. In order to increase the measurements accuracy, the interpolation and subpixel bitmap processing are chosen.**
Keywords – **Image processing, thermography, raster representation, segmentation**

I. INTRODUCTION

Defining regions of interest precisely is one of the important problem in thermal and visual image processing in medicine and biology. Once the boundaries of the investigated objects are calculated, thermal parameters, such as average temperature, standard deviation, histograms, etc. can be easily obtained.

Morphological algorithms for finding boundaries with sufficient accuracy of area estimation are one of the possible approach [1]. Many professional packages are using methods such as skeletoning, opening, dilatation and erosion, although in many practical cases, they are not successfully applied when the image is colorful with shadows.

Our approach assumes to use thermal and visual images captured almost simultaneously. Visual image is provides enough information to generate boundary mask that is applied to get the area of interest on thermal scene.

II. ADVANCED METHODS OF THERMAL IMAGE PROCESSING

A. Statistical differencing

One of the method for contrast enhancement and proper edge filtering is based on statistical differencing, where each pixel value is scaled by the standard deviation calculated in its neighborhood, as below [1,2]:

$$G(i,j) = \frac{F(i,j)}{S(i,j)} \tag{1}$$

where: *F(i,j,), S(i,j,)* denote the original pixel value and standard deviation, respectively.

The higher standard deviation, the lower pixel value. It means, that the part of the image with low color or luminance variation will be enhanced, and more image details are visible.

Standard deviation for *WxW* window of the image is calculated as:

$$S(i,j) = \frac{1}{W}\left[\sum_{i-w}^{i+w}\sum_{j-w}^{j+w}\left[F(m,n) - M(m,n)\right]^2\right]^{1/2} \tag{2}$$

where *M(m,n)* denotes the mean value of the part of the image in the window.

There is a question of the size of the window for calculating standard deviation. In practice, it can vary from 4x4 up to 32x32, but we are aware, that larger windows are statistically more significant. This method is very sensitive to the noise level, and preprocessing in the form of low pass filtering or averaging is recommended. Lately, Wallis introduced the modified operator for statistical differencing based on first and second order moments [1].

B. Interpolation and subpixel resampling

Due to the limited sampling frequency during the image acquisition by digital system, the thermal picture resolution is typically low, and not sufficient for more accurate calculation. It is especially required for medical applications, where often the temperature change is very low. Interpolation and resampling is one of the method to improve the accuracy of geometrical parameter estimation, such as areas, lengths, mean temperature in regions, etc. There are many interpolation functions that can be used for image processing. Sinc, square, triangle, bell, cubic, Gaussian functions are the most used. Obviously, the nonlinear interpolation gives better results as it involves more pixels in the processing.

Tradeoff between processing time and the order of interpolation function has to be considered. For thermal images, which are typically of lower resolution, the cubic interpolation can be easily implemented. Normalized cubic B-spline interpolation function takes a form [1,2]:

$$R(x) = \begin{cases} \frac{2}{3} + \frac{1}{2}|x|^3 - (x)^2 & for \quad 0 \le x \le 1 \\ \frac{1}{6}\left(2 - |x|\right)^3 & for \quad 1 \le x \le 2 \end{cases} \tag{3}$$

C. Adaptive histogram modification

Histogram modification is typically used for contrast enhancement. During image capturing, the signal from the camera is quantized, but often not in the full range. Additionally, using linear quantization, the scene is often dark, with plenty of non-visible details due to the nonlinear characteristic of human eye sensitivity. Among the known methods, the linear and nonlinear scaling of pixel luminance or color components are mostly used [1]. Histogram hyperbolization is applied to compensate eye characteristics, however it is computationally intensive and it is difficult to get contrast enhancement in real time. In order to choose the right transfer function for histogram modification, we need to know the probability density model of the image. In non-adaptive approach, uniform, exponential, Rayleigh, hyperbolic model are used [1].

Lately, the adaptive histogram modification has been introduced [1]. In such a method different transfer functions are involved for different pixels in an image. The new approach is based on moving window and the histogram is computed for any pixel neighborhood.

III. APPLICATION FOR INFLAMMATION

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Abstract

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Thermal, visual and radiological image processing in parallel brings many advantages. As shown in *Fig. 1*, there is a visible correlation between thermal and radiological images during pneumonia inflammation in children. The hot spots indicate the initial state of pneumonia [3]. The investigations seem to be very practical, while the thermography is much less invasive and stressed for human body in comparison to radiological tests.

Histograms modification is one the useful method of radiological images processing for contrast enhancement, as shown in *Fig.2*. One of the most helpful functions is on-line interactive histogram processing, together with image segmentation. (*Fig.3*). Enhanced image is then binarised by user-defined threshold level. One of the important problems is to define optimal threshold level. This level can be found by fixing the margins for the histogram and eliminating pixel below and above certain levels as shown in *Fig. 3*.

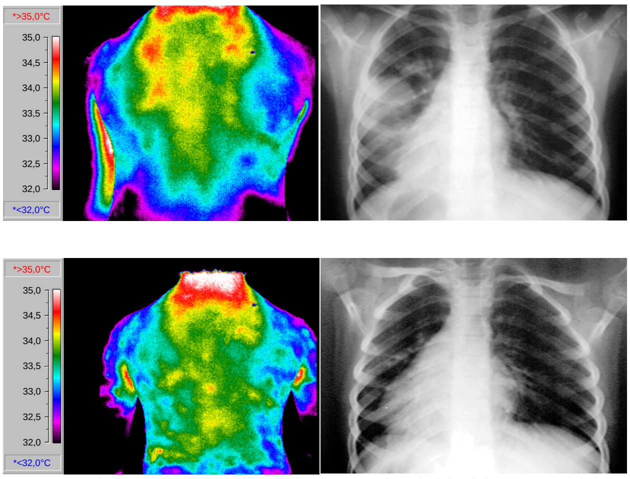

Fig. 1. Thermal and radiological images of a child with pneumonia inflammation, initial state of the disease, and after 14 days of treatment

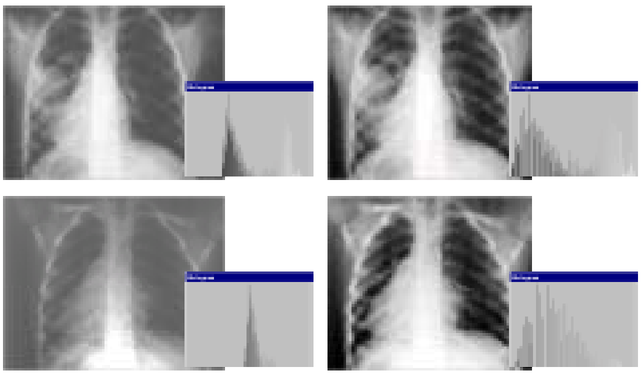

Fig. 2. Radiological image processing by histogram equalizing

The algorithm is fully interactive, and the user can adjust the margins for the histogram, as well as the threshold level for segmentation. The histogram equalizing together with binarisation makes possible to find a border of the inflamed area. The similar procedure can be performed for thermal images. It could hopefully replace radiological inspections by thermal ones in the future. Such investigations are the very preliminary, and should be confirmed by more cases, not only for pneumonia inflammation. The first trials are very promising. We believe that thermoregulation of the human body will not reduce significantly thermal effects on the skin caused by internal temperature increase.

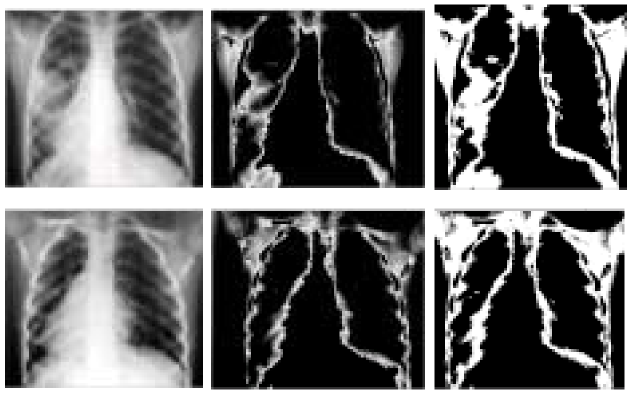

Fig. 3. Image segmentation by user defined threshold level

IV. AREA AND THERMAL SIGNATUREMEASUREMENT

Low temperature variation, and low thermal and visual contrast in many applications cause the demand of high accuracy in image processing, especially in biological and medical applications. As an application, we have chosen the analysis of leaves during plant's growth in different conditions – temperature, humidity, pressure, sun illumination, etc.

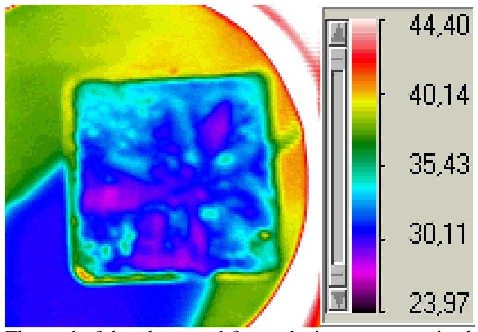

Fig. 4. Thermal of the plant used for analysis, non-recognized area of interest

Fig. 5. Original visual image of the plant used for analysis with shadows which make the processing difficult

The aim of the research was to calculate mean temperature and standard deviation in the region of interest very precisely defined on visual image captured together with thermal one. A few algorithms have been tested, and because of colorful visual images used, we proposed novel approaches based on separate processing of color components (R-red, G-green, B-blue) of the image. Although the leaves look green, the more precise analysis shows, that it is impossible to make the proper segmentation by differentiating using single color component. Additionally, the analysis is very sensitive to the shading and external illumination. In the general case, it may not be assumed that the light position is always the same, so the problem of e.g. sun light illumination has to be carefully considered.

The following procedure is proposed:

- Statistical differencing filtering with window *WxW*
- Segmentation with threshold *TH*
- Median filtering

Differencing filtering can work with different window's size, which can vary from *10x10* to *100x100* pixels. Having smaller window we can visualize more details, depending on their local statistical characteristics. On the other hand, larger window makes the edge of the area of interest smother, and some negligible details are automatically removed. It is clearly presented in *Fig. 8*.

Segmentation is performed globally using three R,G,B components of each pixel. Formula below describes how the segmentation is defined in the presented method.

$$S(i,j) = \begin{cases} 0 \quad \text{if} & G(i,j) > TH + B(i,j) \;\; \text{and} \\ & G(i,j) > TH + R(i,j) \\ 1 \quad \text{otherwise} & \end{cases} \tag{4}$$

where *S(i,j)* is the value of the pixel after segmentation, and *R,G,B* denote color components of the original image.

The threshold level *TH* for segmentation has to be chosen very carefully. Using too low *TH* value, we can artificially place many non expected details, especially on the border of the considered area, while the high *TH* value causes the unexpected thinning of the object. All these features of the method are presented in *Fig. 7-8.*

TABLE I
RELATIVE ERROR OF AREA MEASUREMENT BY THE PROPOSED ALGORITHM (IN %)

	31x31(*WxW*)	21x21(*WxW*)	11x11(*WxW*)
TH=30	0.41	6.5	21.6
TH=40	12.8	7.3	7.0
TH=50	23.5	18.4	5.9
TH=60	34.0	28.9	18.4

Fig. 6. Visual image after statistical differencing filter processing – histogram equalizing, contrast enhancement, more details visible (left), region of interest obtained manually (right)

Fig. 7. Influence of threshold level in the proposed method on the area if interest: *TH*=30, *WxW*=31x31 (left), *TH*=60, *WxW*=31x31(right)

Fig. 8. Influence of window size for statistical differencing on the area if interest: *TH*=40, *WxW*=31x31(left), *TH*=40, *WxW*=11x11 (right)

Nonlinear median filtering successfully removes the border non-continuity, pixels or their groups randomly placed next to the area of interest. Median filtering was included into the algorithm mainly because of shading existing in the image. Shadows can significantly change the results of area measurements, and as a consequence, the thermal index for the region can vary. In order to avoid shadows in the images, the median filter ends the algorithm.

Quantitative results confirm the influence of window's size and threshold level on accuracy of region measurement. In Table I, relative errors are presented. It shows the area of the region obtained by the proposed algorithm referring to the area measured manually (*Fig. 6*).

V. CONCLUSION

In this paper we present chosen image processing methods suitable for thermal and visual image processing. The main aim was to use visual image to compute thermal signatures for precisely defined areas of interest. The histogram modification gives many possibilities for contrast enhancement and details visualization. As in medicine and biology, the images are very non-homogenous, the processing using local statistical characteristics of the image is recommended.

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