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An algorithm for evaluating the thermogram heterogeneity based on its quadtree representation

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Abstract. An analysis of a thermal image (thermogram) of a human body surface shows the availability of correlation between the body state and the thermogram heterogeneity ("motley"). A new method for the quantitative analysis of the thermogram heterogeneity based on the thermogram representation by a quadtree of reduced images is proposed. In this method, we partition any image fragment into four parts when this fragment is heterogeneous. The image heterogeneity is evaluated as a value proportional to the number of leaves of the constructed quadtree. For amplification of the heterogeneity degree dependence upon an observed "motley" of real thermograms, a well known contrast expansion is applied.

1. Introduction

The results obtained in a human body thermal image (thermogram) analysis show that thermal pictures usually change as a consequence of the organ state changes and, in particular, in the beginning of a certain disease [1–4]. These changes are visually expressed as image heterogeneity variation. Determination of the heterogeneity degree and a possibility of the quantitative comparison of the heterogeneity levels can give a valuable information about physiological state of an organism with an evident enhancement of diagnostic possibilities of the medical imaging. It is possible to observe a heterogeneity variation in a thermograms series of a volunteer rotating pedals of an exercise bicycle (Figure 1). Here the abrupt heterogeneity growth is caused by intensification of perspiration.

In this paper, we propose a method for the quantitative analysis of the heterogeneity of images and, in particular, the heterogeneity of biomedical thermograms. The method is based on the thermogram representation by a quadtree of reduced images. This method is adequate to visual perception and gives a wider range of the heterogeneity degree variation than the earlier proposed methods [2–4].

2. Image heterogeneity evaluation based on its quadtree representation

Let an image be a square matrix A of degree 2. We propose the following algorithm to construct a quadtree $Q(A)$ [5] for the image A, where we

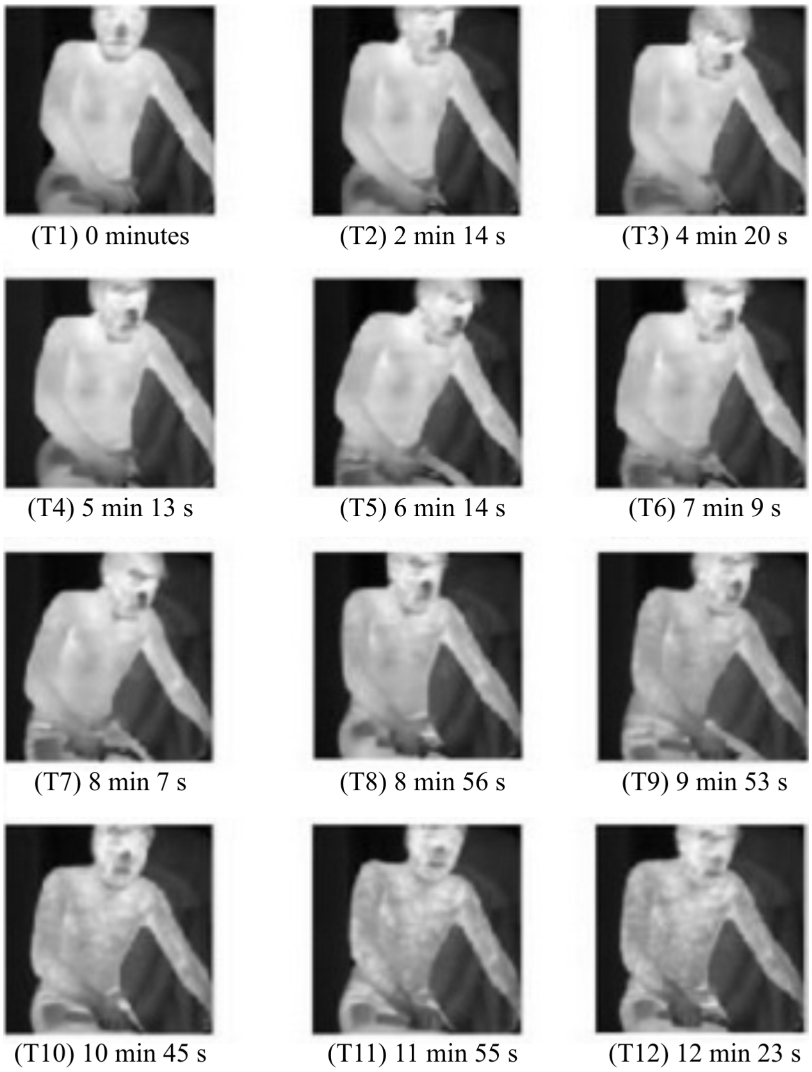


Figure 1. Thermograms of a volunteer on exercise bicycle

partition any image fragment into four parts only when the fragment is heterogeneous. Let $h(A)$ be a heterogeneity criterion of matrix A. If the matrix A is heterogeneous according to the criterion $h(A)$, then we partition it into four square matrices A_1, A_2, A_3, A_4 with the size equal to half size of the matrix A. The partitioning process is recursively repeated up to the size of one pixel. Note that any homogeneous image fragment corresponds to a leaf of the quadtree $Q(A)$. When a homogeneous fragment is detected, the number $L_{Q(A)}$ of the quadtree leaves is incremented.

A step of the recursive algorithm of the quadtree construction for some fragment B of the image A is the following:

1. Evaluate the average $m(B) = \frac{1}{|B|}\sum_{ij} b_{ij}$ of entries of the matrix B, $|B|$ is the number of entries of the matrix B.
2. Calculate the number n_B of entries b_{ij} with $|b_{ij} - m(B)| \leq T$ (a threshold T to be experimentally found).
3. If $n_B < k|B|$, where $k \in [0,1]$ is a coefficient to be found in the experiment, then consider the matrix B as a heterogeneous one and partition B into four fragments, else $L_{Q(A)} = L_{Q(A)} + 1$.

So, the above algorithm constructs a quadtree of images with leaves as homogeneous fragments. It is easy to see that the number of leaves in the quadtree depends upon heterogeneity ("motley") of the initial image A:

- if the image A is homogeneous, then the quadtree $Q(A)$ has only one leaf;
- a maximum number of leaves corresponds to a maximal heterogeneous image and equals the number of pixels of the image A.

Based on these considerations, it is natural to define heterogeneity $H(A)$ of the image A as ratio of the number of leaves $L_{Q(A)}$ in the quadtree $Q(A)$ to the number $|A|$ of pixels of the image A:

$$H(A) = \frac{L_{Q(A)}}{|A|}. \tag{1}$$

Obviously, $\frac{1}{|A|} \leq H(A) \leq 1$.

In Figure 2, the values of heterogeneity degree (1) are presented for the test images ("chessboards") with 256×256 pixels size.

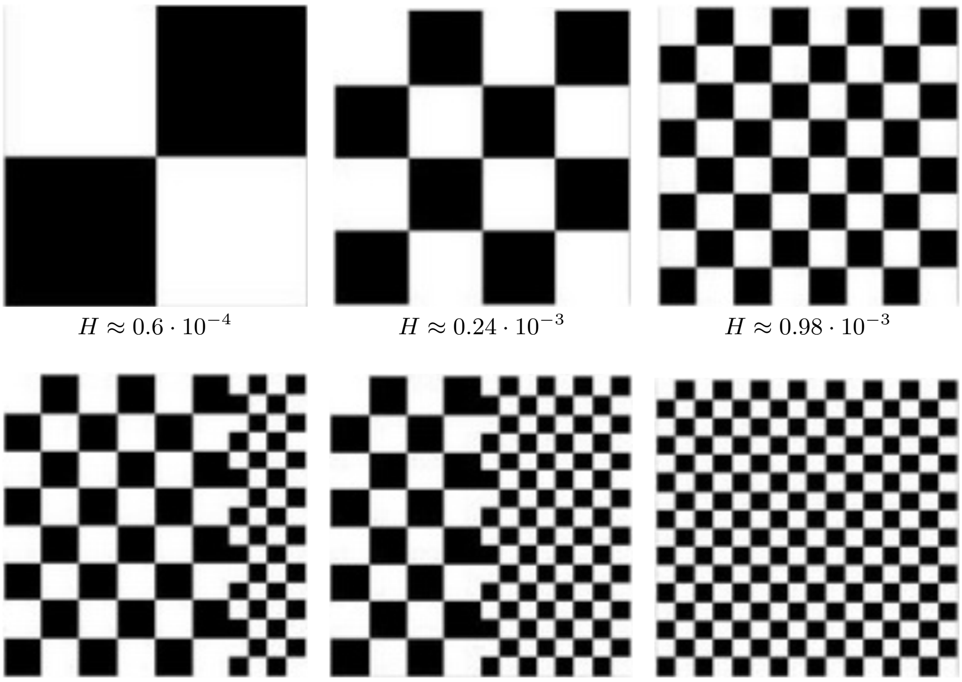
3. Evaluation of thermogram heterogeneity

For amplification of the heterogeneity degree dependence upon the observed "motley" of real thermograms, we apply the well-known contrast expansion [6]:

$$s = \frac{1}{1 + (c/r)^E},$$

where c is a contrasting threshold, r is an input image intensity, s is an output image intensity, and E is a slope of the expansion function. The contrast expansion allows us to remove the background details and to enhance the influence of details of interest (spots) on the heterogeneity degree evaluation (Figure 3).

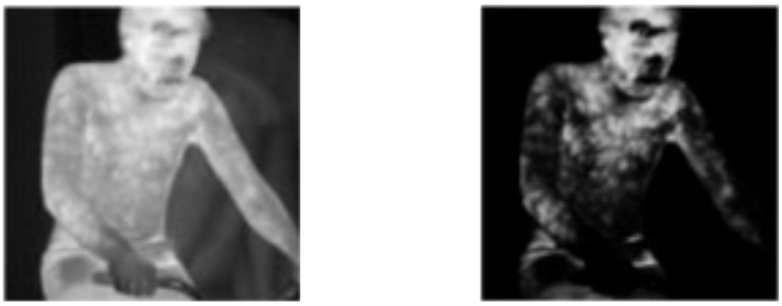
In experiments for the thermogram series of Figure 1 without contrast expansion we achieved $\frac{H_{\max}}{H_{\min}} \approx 1.4$, where $H_{\min}$ and $H_{\max}$ are, respectively, minimal and maximal heterogeneity degrees with the parameter values $T =$



$H \approx 0.6 \cdot 10^{-4}$ $H \approx 0.24 \cdot 10^{-3}$ $H \approx 0.98 \cdot 10^{-3}$

$H \approx 0.18 \cdot 10^{-2}$ $H \approx 0.24 \cdot 10^{-2}$ $H \approx 0.4 \cdot 10^{-2}$

Figure 2. “Chessboard” images and their heterogeneity degrees



T12 without contrast expansion T12 with $E = 10$ and $c = 200$

Figure 3. An example of the contrast expansion

6 and $k = 0.67$ (Figure 4). With the above contrast expansion, we have attained $\frac{H_{\max}}{H_{\min}} \approx 3.00$ with the parameter values $c = 190$, $E = 5$, $T = 14$, and $k = 0.67$ (see Figure 4).

In Figure 5, thermograms sorted out according to an the increase in the heterogeneity degree are presented. It follows from Figures 3 and 5 that the heterogeneity degree, evaluated by the method proposed here, is adequate to the visual perception of the thermogram heterogeneity.

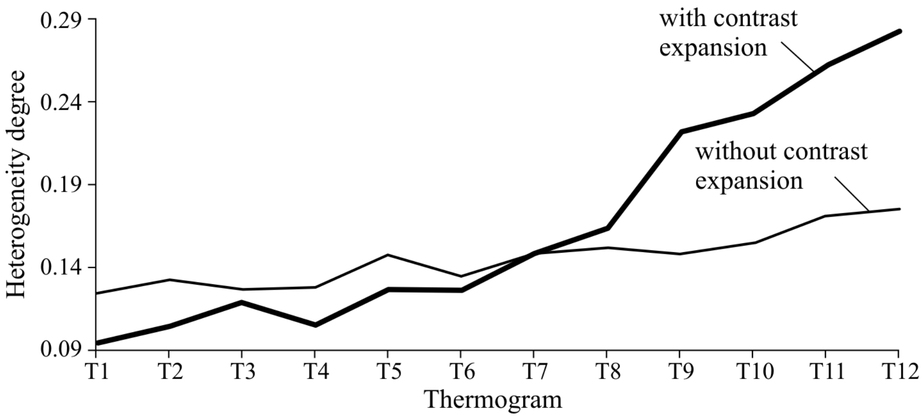
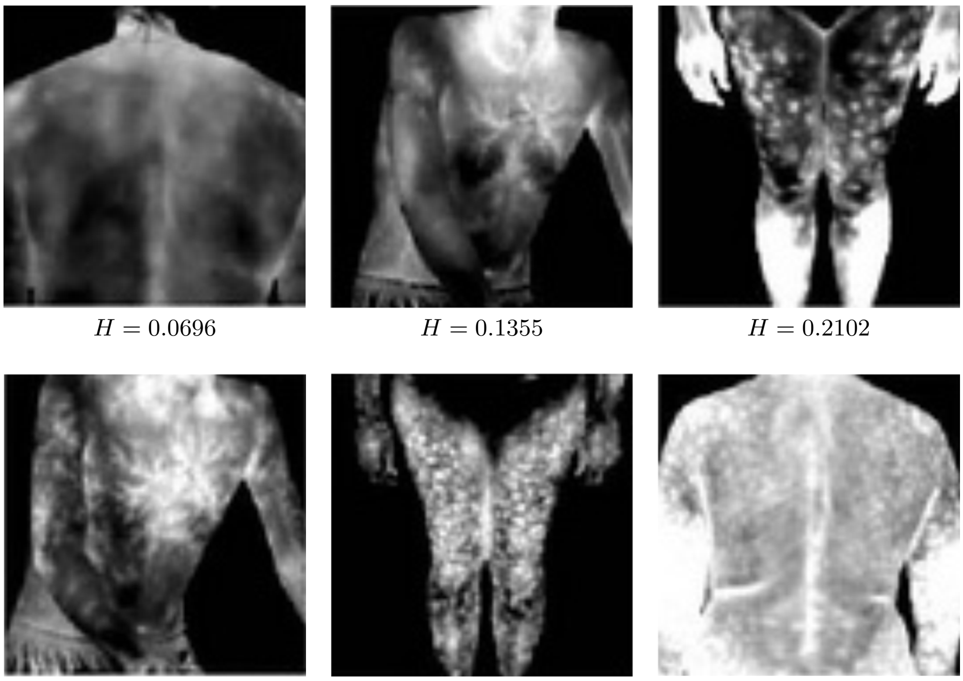


Figure 4. Heterogeneity degree evaluation for thermograms from Figure 1



$H = 0.0696$ $H = 0.1355$ $H = 0.2102$

$H = 0.2575$ $H = 0.2758$ $H = 0.5802$

Figure 5. Thermograms sorted out according to an increase in the heterogeneity degree

4. Conclusion

A method for the quantitative evaluation of the thermogram heterogeneity is proposed. This method is based on representation of a thermogram by a quadtree of reduced images with evaluation of their heterogeneities. In the experiments conducted, an adequacy of the attained evaluations of the heterogeneity degree to the visual perception is established. An additional expansion of the range of heterogeneity variations is achieved by the contrast expansion of thermograms for accentuation of fine details of a thermogram.

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