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SEGMENTATION ALGORITHMS FOR INDUSTRIAL IMAGE QUANTITATIVE ANALYSIS SYSTEMS

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Abstract: In this paper computerized system for high temperature measurements of superficial properties has been presented. The process of superficial properties determination is based on digital image processing and analysis algorithms. Particular attention has been paid to adaptive thresholding algorithm with a local iterative threshold selection. Algorithm was elaborated to segment images obtained from the measurement process. Moreover, results of proposed algorithm have been presented. In the final stage of the paper difficulties appearing during high temperature measurements have been outlined. The authors have proposed methods of results correctness verification applying essential laws of the optics to a CCD camera lens.

Keywords: image segmentation, thresholding, image quantitative analysis system, surface properties, high temperature measurements.

1. INTRODUCTION

One of the biggest challenges for present-day automatics are computer vision systems, that terminally are to imitate the behavior of humans' sense of vision. Moreover, owing to usage of appropriate digital image processing algorithms, application of aforementioned systems, allows to gather information that is normally not distinguishable by humans' sense of vision. Because of those facts, computer vision systems are of great importance in almost every field of science, engineering and industry. The most significant applications are biomedical images analysis, controlling and superintendence of manufacturing processes, process tomography, computer thermography or biometry. However, it is necessary to remember, that visual representation of information contained in an image is characterized by high level of redundancy. Therefore, after converting the image into the digital representation, a stage of detailed image analysis is carried out, to separate information significant to user or process from entire information reaching to observer or detector.

The main issue of digital image analysis is image segmentation i.e. division of an image into fragments matching separate, visible on the image objects. Finding in analyzed image cohesive areas which are characterized by identical value of some attribute (for example lightness) or set of features (for example texture). The result of the segmentation should enable to define the geometric features of objects placed on a scene as accurate as possible with minimum computational complexity. That is why, in many applications the quality and the effectiveness of segmentation algorithm is the most important criterion to be considered during the image analysis and processing system design process.

In the field of digital image processing, problem of image segmentation is one of the most often deliberated. Nevertheless a wide variety of different segmentation techniques exists [1-3], there is no general theory of it. In the following part of this paper an effective segmentation algorithm based on thresholding strategy implemented in computerized system for high temperature measurements of surface properties of liquid and solid in contact (wetting angle, surface tension) has been presented.

2. THE EXPERIMENTAL SET UP

The "Thermo-Wet" system, where measurement have been performed (Fig.1) consists of high-temperature (up to 1800°C) electric furnace with a protective atmosphere (1), system for the precise temperature measurement and control (2), technological gases supply system (3), specimen insertion mechanism (4), vision unit (CCD camera, image analysis and processing algorithms, infrared filters with the algorithm of their automatic changes) (5). All stages of the measurement process are controlled by a computer (6). Block diagram of the system is shown on the figure 2.

Fig.1. The "Thermo-Wet" system

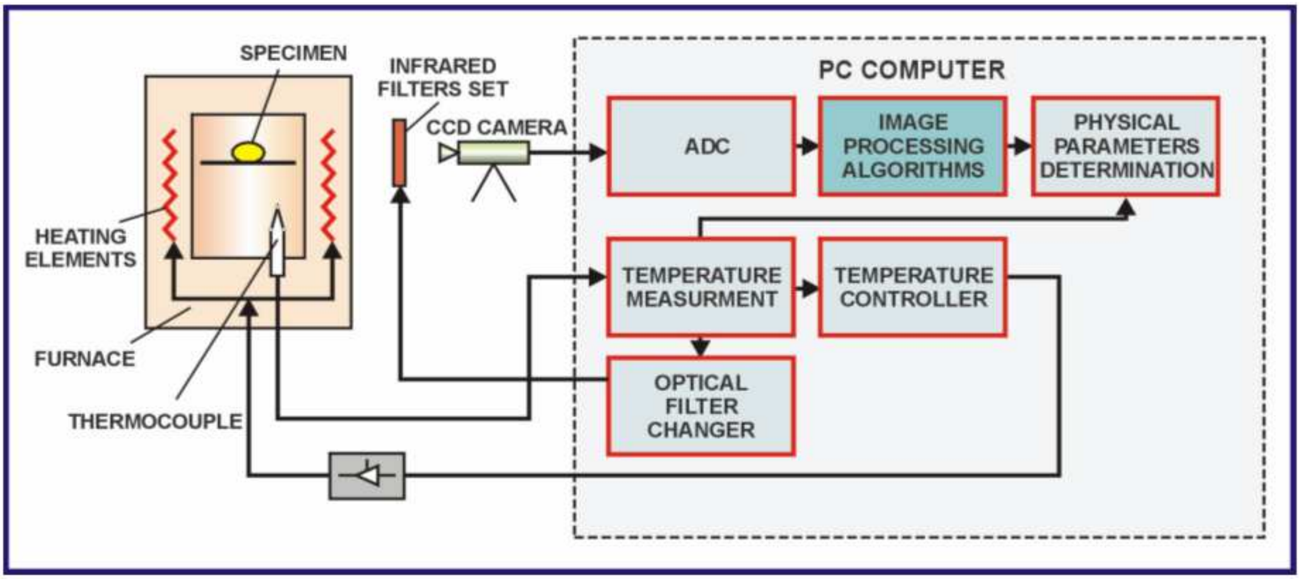

Fig.2. Block diagram of the measurement system

More detailed description of the measurement system structure can be found in [4] and [5].

After placing the specimen of the subject material inside the furnace, the specimen is heated to the temperature higher than the melting point. At this time, the research post's vision system (that consists of monochromatic miniature CCD camera with a constant focal lens, infrared filter changer and frame-grabber) acquires the image of the specimen and converts it to its digital representation. In the next experiment stage, the image is segmented. This step is the most important process as far as the subject matter of this paper is concerned.

3. THE SEGMENTATION ALGORITHM

3.1. Thresholding – basic information

Thresholding is the basic method of image segmentation [6][7]. It provides an easy and convenient way to perform segmentation on the basis of the different values of the certain attribute *Y(x,y)* (for example intensity) in the foreground and background regions of an image.

In simple implementations, the segmentation is determined by a parameter *T* known as a threshold which is a result of analysis of the attribute *Y(x,y)*. In the simplest algorithm implementation, each pixel of the image is compared with the threshold *T*. If the pixel's value of the attribute *Y(x,y)* is lower than the threshold, the pixel is qualified to the background otherwise, the pixel is marked as object's pixel.

The output of the segmentation is a binary image given by relation (1):

$$g(x,y)=\begin{cases}1 & for \quad Y(x,y)\geq T\\ 0 & for \quad Y(x,y)<T\end{cases} \qquad (1)$$

where object's elements are represented by 1 and background's elements by 0 (or *vice versa*).

The threshold can be used globally for all pixels, or can change dynamically over the image (adaptive thresholding).

3.2. Thresholding algorithm

Images obtained from the system described above contain objects (specimens) with homogeneous surfaces seen on a non uniform background (Fig.3.) However the segmentation of the specimen image is more challenging at high temperature and can't be done with a simple thresholding method. High temperature furnace and sample radiation cause glow formation around the specimen. This effect is often called "aura phenomena". Moreover, object reflection on the holder appears.

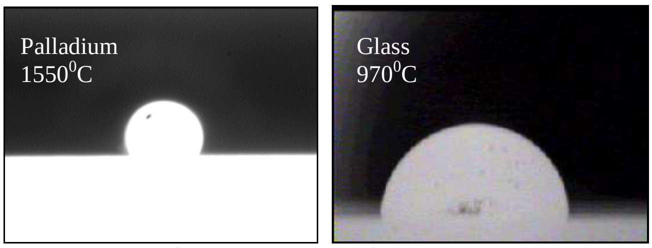

Fig.3. Images of specimens obtained from the acquisition system

Aforementioned effects preclude to a large extend determination of object's edges position. Upper edge of the base plate localization is also difficult. In consequence the proper threshold value selection is hindered. This problem is illustrated on the figure 4. The figure shows the original image and the effects of segmentation for three different threshold values. The global threshold selection usage effects with low accuracy of the segmentation results.

In order to solve this problem an adaptive thresholding algorithm described below was developed. Local threshold selection depending on the neighborhood's properties was used to enlarge the accuracy of the segmentation's results.

During carried out experiments, different modifications of the thresholding algorithm were checked. The best results were achieved using adaptive thresholding algorithm with a local (fixed) iterative threshold selection elaborated by the authors of this paper.

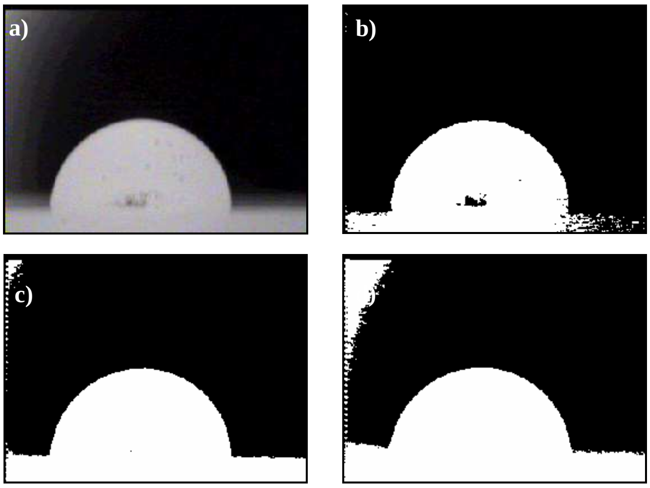

Fig.4. Original image of glass (970^{0}C) a) and results of segmentation for different threshold *T* values. b) *T* = 190, c) *T* =127, d) *T* = 75.

The iterative threshold selection process (consistent with the isodata algorithm [7]) is performed for each pixel of the analyzed image depending on the neighborhood's properties. A diagram of the algorithm has been presented on the figure 5. The methodology of the threshold value selection starts from segmenting the grayscale of the neighborhood into two parts using an initial threshold T_0 which is set to the neighborhood average lightness value L_N. Then the means of the gray values associated with the object's pixels L_O, and the background pixels L_B, are computed. The new threshold value T_1 is now set to the average of these two means as shown in the following equation:

$$T_1 = \frac{L_B + L_O}{2} \tag{2}$$

The process is repeated based upon a new threshold, until a threshold averages to a constant value. This situation corresponds to the following equation.

$$T_i = T_{i+1} \tag{3}$$

The size of the neighborhood is determined by a 3x3 size mask. The mask size has been chosen experimentally. The current pixel (for which the iterative threshold selection process is carried out) is placed in a central position of the mask. Mask passes through the whole image row-by-row (or column by column) in accordance with the image filtration mechanism. Basic information about image filtration have been presented in [6][7].

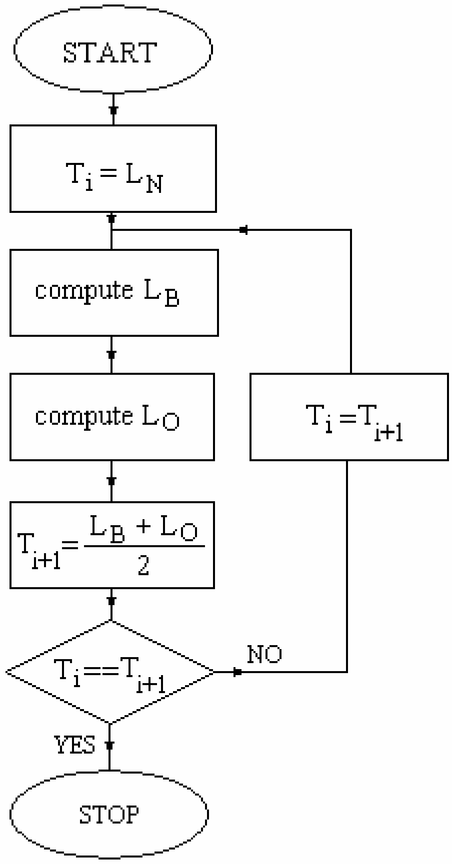

Fig.5. The flow diagram of iterative threshold selection algorithm. T_i -previous step threshold value, T_{i+1}- current step threshold value, L_N – average lightness of the actual pixel neighborhood, L_B – average lightness of background pixels, L_O – average lightness of object pixels.

In the last chapter methods of results' correctness verification worked out by the authors of this paper have been proposed.

4. RESULTS AND DISCUSSION

Figures 6 and 7 present results of elaborated thresholding algorithm. On two different samples at the different temperatures the results of the segmentation can be seen. Original image has been placed on the left side. On the right side, an effect of the segmentation can be seen. One can see that the non-uniform background, which is not satisfyingly segmented with a basic threshold, is well segmented with the presented iterative method. The contours of the samples are well presented. They are continuous without artifacts and present properly shape from the original images.

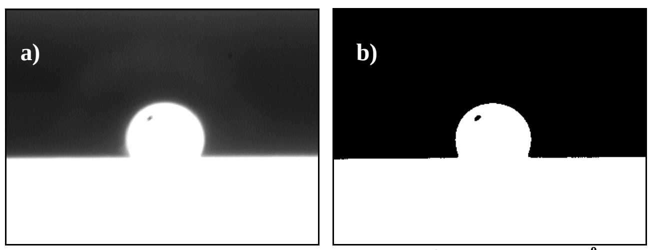

Fig.6. Original a) and segmented b) image of palladium (1550^{0}C)

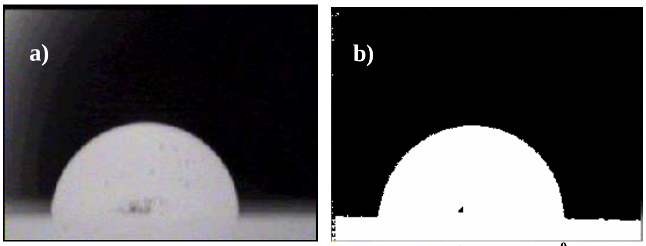

Fig.7. Original a) and segmented b) image of glass (970 ^{0}C)

5. VERIFICATION OF RESULTS CORECTNESS

In order to verify correctness of designed algorithms' results, imaging of the reference sample (object of known dimension) placed in the furnace was carried out. Images were taken at the room temperature, in order to eliminate the effects of borders illumination and specimen's shape change due to melting.

In the following step, applying essential laws of optics to the CCD camera lens (symbols as on Fig.8) equation of a lens (4) was written [8].

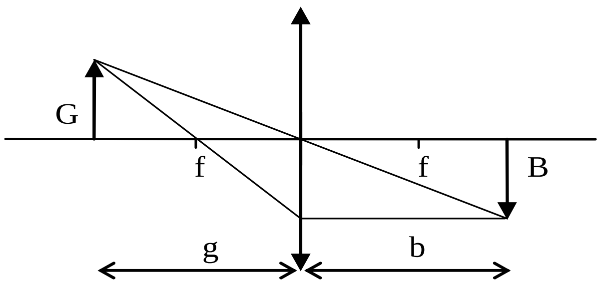

Fig.8. Optics of a thin lens

$$\frac{1}{g}+\frac{1}{b}=\frac{1}{f} \tag{4}$$

where:

- f - focal length of a lens,
- b - distance between object and lens,
- g - distance between image and lens.

Additionally, denoting height of the object as G, and height of the image on the CCD chip as B, magnification of the image s was expressed by equation (5).

$$s=\frac{B}{G}=\frac{b}{g} \tag{5}$$

and after deriving from (4) and (5) dependences (6) and (7) could be written.

$$s=\frac{f}{g-f}\,. \tag{6}$$

$$s=\frac{b-f}{f}\,. \tag{7}$$

Equations (6) and (7) indicate that measuring the focal length and distance between object and lens or between image and lens, the magnification of the image on the CCD chip can be determined easily.

Denoting as m and n CCD chip dimensions (in pixels), and respectively as M and N analyzed image dimensions (in pixels) magnification S of an object was described with equation:

$$S=s\frac{MN}{mn}\,. \tag{8}$$

In consequence the magnification of an object of interest by the computer vision system is given by:

$$S=s\frac{MP_xNP_y}{pp_xqp_y}t\,, \tag{9}$$

where:

- P_x - bitmap pixel's width ,
- P_y - bitmap pixel's height ,
- p_x - CCD chip pixel's width,
- p_y - CCD chip pixel's height,
- t - scale factor insuring proportionality of CCD chip and bitmap dimensions.

The size of the object after segmentation (determined by appropriate count of pixels qualified to the object) was compared with the size of reference sample multiplied by the magnification factor S. The corresponding ratio k is used to validate the segmentation method. For k values above 0.98 the method is acceptable.

Figure 9 shows an example of comparison between the original image of the cylindrical sample and two segmentation methods: local thresholding with iterative threshold selection (discussed in this paper) (Fig.9b) and global thresholding with threshold value T set to 127 (Fig.9c). It can be easily seen, that the first method gives good estimates of the real size of the sample.

The non-uniform background illumination that can be seen on the figure 9a is the result of internal lighting usage. Internal lighting is a set of spotlights composed in a ring. To make the object visible, it necessary to place it against the background of the spotlight glow.

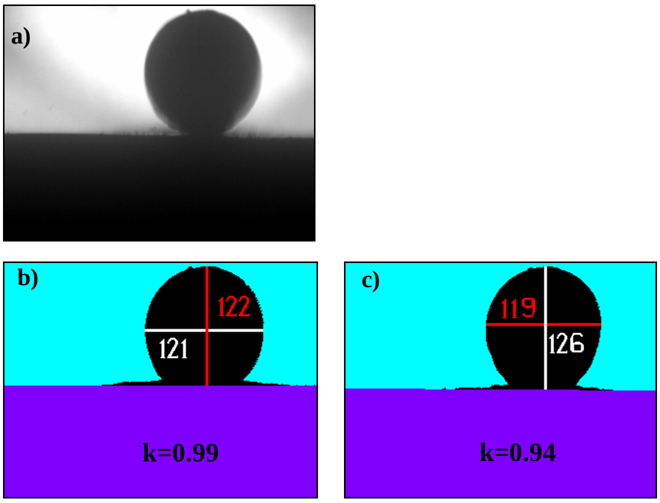

Fig.9. Original image a) and effect of correct b) and incorrect c) image segmentation.

6. CONCLUSION

In this paper application for digital image processing and analysis algorithms in industrial systems have been considered. Particular attention has been paid to computerized system for high-temperature measurements of surface properties of liquid and solid in contact (i.e. wetting angle and surface tension). The importance of the segmentation results quality has been explained. Author's method of image segmentation has been described. Results of applying proposed algorithm to images obtained from the measurement process has been presented. Methods of results correctness verification have been proposed. Suggested algorithm of segmentation as well as the method of its results verification is both universal and precise. Furthermore, all presented methods can be successfully used in wide spectrum of applications for industrial image quantitative analysis systems.

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