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IMAGE PROCESSING IN PHYSICAL PARAMETERS MEASUREMENT

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Abstract: In this paper, there are presented some preliminary image processing methods. They are applied in the vision system for the automatic measurement of the surface tension and wetting angle in solid-liquid systems over a wide range of temperatures. The properly-selected image processing algorithms yielded the results of accuracy and repeatability not yet obtained in any classical methods.
Keywords: image processing, high temperature measurement, interfacial phenomena

1 INTRODUCTION

At the Technical University of Lodz we have built a device which allows one to measure such properties of solid-liquid systems as surface tension (surface energy) and the density of liquid, as well as the wetting angle over a wide temperature range: 700-1800^{o}C. The theory of interfacial phenomena can be found in the fundamental work [1].

A block diagram of the computerised measurement system is shown in Fig. 1.

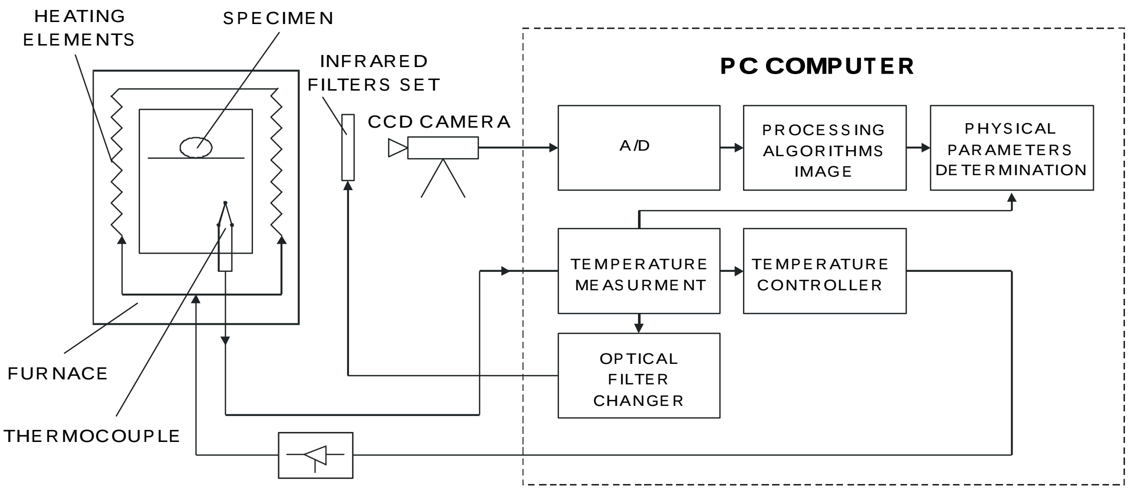

Figure 1. Block diagram of computerised system with CCD camera for measurement of surface properties.

Both the surface tension and wettability of solids by liquid at an elevated temperature are essential in many industrial branches, in the metallurgy, foundry, surface engineering, welding, glass-making industry, etc.

The vision unit of the automatic system for the measurement of the wetting angle and surface tension performs the following operations:

- acquisition and conversion of an image into a digital form;
- preliminary processing of the image (its filtration and sharpening as well as thresholding);
- image analysis (localisation of the specimen under investigation in the image and measurement of its geometrical features);
- determination of thermo-physical properties of the specimen on the basis of the geometrical parameters measured.

The image analysis and determination of thermo-physical properties of the material under investigation are discussed in [2]. The aim of this paper is to present the question of image acquisition, its conversion into digital form and then its preliminary processing.

2 REPRESENTATION OF IMAGE INFORMATION

Definition: The domain □ of an image is a two-dimensional set □ $\in R^2(R \times R)$; where: R^2 is an Euclidean plane, so □ $\in \{(x,y) \in R^2; a \le x \le b \wedge c \le y \le d \wedge a,b,c,d \in R\}$.

The monochromatic image refers to the non-negative brightness function *f(x,y)* describing brightness distribution in the spatial coordinates belonging to the picture domain $(x,y) \in R^2$. The value of the function *f* at any point of the image $(x,y) \in$ □ is proportional to the brightness (the degree of the image grey at this point).

The image *f (x, y)* is a perspective projection of the source image onto the converter plane.

The function *f (x, y)* describes the distribution of the lighting intensity of the converter plane placed in the coordinates (*x, y*). As this function is a certain form of energy, it must be non-zero and finite: $0 < f(x,y) < \infty$.

The value of the function *f* results from two phenomena observed on the object surface:

- the luminance *i(x,y);*
- the reflection of part of the light striking the object surface, described by the reflection coefficient *r(x,y)*.

$$f(x,y) = i(x,y) \circ r(x,y); \text{ where: } 0 < i(x,y) < \infty; \; 0 < r(x,y) < \infty. \tag{1}$$

The value of the function *f (x, y)* is determined by the grey level *l* for a given point *(x,y)*:

$$0 < L_{\min} < l < L_{\max} < \infty \; . \tag{2}$$

The interval $\langle L_{min} , L_{max} \rangle$ is called a Gray Scale.

3 IMAGE ACQUISITION AND CONVERSION INTO DIGITAL FORM

The authors decided to use a CCD camera as an input device in the vision channel of the measuring system under construction, since such a camera appears to satisfy the following conditions: high resolution, stability, and precision of reproduction of the spatial geometry of the image.

It is important to select appropriate optical accessories for the camera. A constant focal-length lens was applied, since the distance between the specimen and the camera is always the same. A system sequence of infrared filters has to be used in the optical unit in the case of high-temperature measurements.

The digital image **-** the image whose spatial coordinates (x, y) were digitized and the values f (x, y) were subjected to quantization. It can be interpreted as a table in which the line and the column number identify its element, i.e. the point of the image. The point of the digital image is a *pixel*.

In the systems of digital image processing a vision signal corresponding to the analogue image being recorded is subjected to sampling and quantization.

As a result of sampling of *f(x,y)* a two-dimensional discrete function is obtain:

$$f_S(x,y) = \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} f(i\,\Delta x, j\,\Delta y)\, d\,(x - i\,\Delta x\,, y - j\,\Delta y)\,; \tag{3}$$

where:
d - is two-dimensional Dirac function.

For simplicity, let: $\Delta x = \Delta y = 1$;

$$f_S(x,y) = \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} f(i,j)\, d\,(x - i, y - j)\; . \tag{4}$$

During quantization process $f(x,y) \in [f_{\min}, f_{\max}]$ range is divided into *L* intervals of the width Δf:

$$L\,\Delta f = f_{\max} - f_{\min}\,. \tag{5}$$

To all the vision signal values within the *k*-th interval:

$$f \in (f_{\min} + k\,\Delta f\,,\, f_{\min} + (k+1)\,\Delta f)\,; \tag{6}$$

an integer belonging to the range $k \in \{0,1,\ldots,L-1\}$ is assigned. This integer is called the brightness of a digital image:

$$[f_{\min}, f_{\max}] \rightarrow [0,1,\ldots,L-1]. \tag{7}$$

Sampling and digitisation are performed by an A/D converter (as a part of a programmable frame-grabber card). The sampling is carried out on a rectangular grid with sampling intervals T_1, T_2. The image size is $N\,´M$ pixels. In this application, image size is 640×480 pixels.

The A/D converter performs quantization of the sampled image as well. In this application, the *grayscale* images are quantized at 256 levels and require 1 byte (8 bits) for the representation of each pixel [3,4].

The aim of the initial processing of the image is to improve its quality. Filtration and selective reduction of the amount of information are basic. It is essential when such a course of preliminary conversion is selected that no important data are lost under any permissible conditions of measurement. In industrial conditions, such parameters as work area lighting, ambient temperature, air clarity and dirt on optical elements are variables, and this variability must be taken into consideration [3,4].

4 PRELIMINARY IMAGE PROCESSING

Preliminary data processing procedures were adopted for the analysis of two types of images, shown in Fig. 2 and Fig. 3. These images show two cases of wetting: weak (Fig. 2) and strong wetting (Fig. 3).

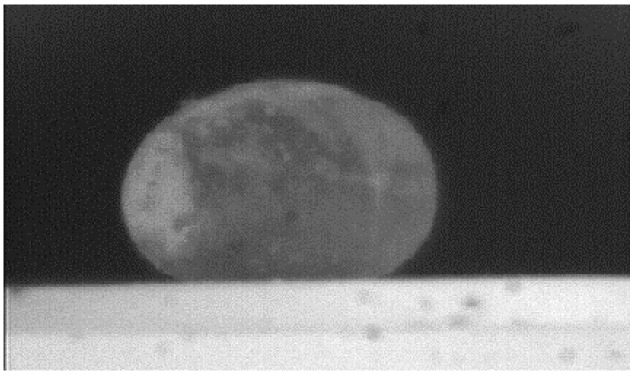

Figure 2. A tin drop on the ceramic base in an atmosphere of air at a temperature of 900°C.

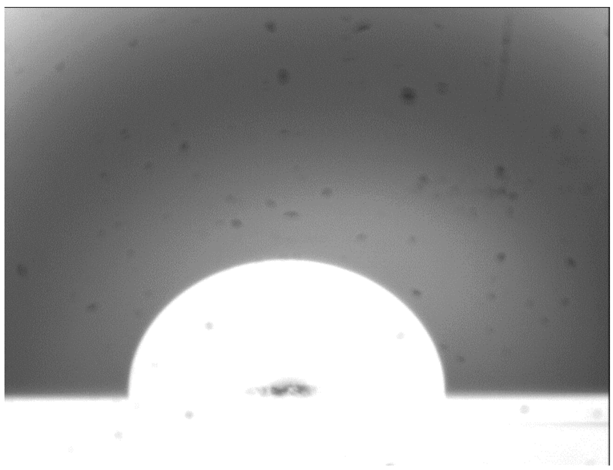

Figure 3. A glass drop on the ceramic base in an atmosphere of air at a temperature of 1000°C.

The degrees of grey of an image can be treated as random variables from the range $l \in (o, L)$. Assuming that they are continuous quantities, their distribution can be treated as a certain function of probability density $p(l)$, that is to say the histogram of the image.

The function of probability density should be possibly uniform, which will give the maximum of information contained and the entropy will be the greatest.

The entropy of an image:

$$H = -\sum_{k=1}^{L} p_k \log_2 p_k \quad . \tag{8}$$

Entropy is a global measure of the information contained in an image.

$$p_{k=} = \frac{l_k}{N}; \tag{9}$$

where:
p_k - is the probability of occurrence of the level of grey of the value k.
N - is the number of points in the image.

If:

$$p_k = \frac{1}{L}, \qquad k = 1, \ldots, L; \tag{10}$$

then the histogram obtained is an ideally uniform histogram, while the entropy H assumes the maximum value:

$$\max H = -\sum_{k=1}^{L} \frac{1}{L} \log_2 \frac{1}{L} = \log_2 L \tag{11}$$

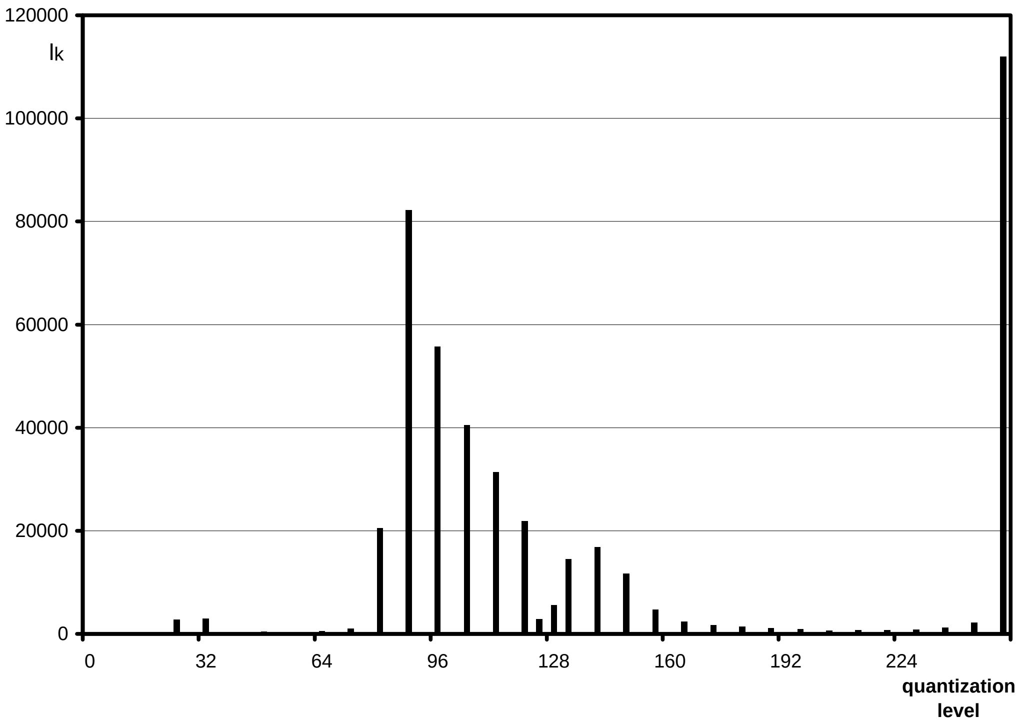

Figure 4. Histogram of the specimen image from Fig. 3.

The first stage of the preliminary image processing is thresholding [3,4], during which a white colour (255) or a black colour is assigned to each pixel, depending on the initial grey level (1):

$$a[i] = \begin{cases} 0 \\ 255 \end{cases}; \quad \text{for} \quad \begin{matrix} a[i] < \text{threshold} \\ a[i] > \text{threshold} \end{matrix}. \tag{12}$$

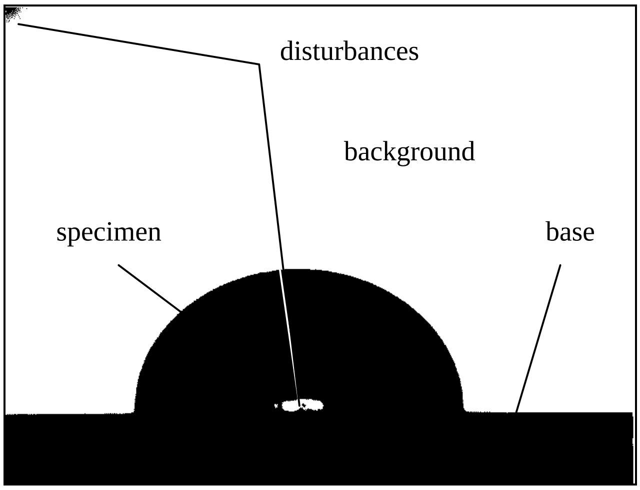

Figure 5. Image of a melted tin sample after thresholding.

The threshold value can be easily determined basing on the image histogram (Fig. 4).

With correct lighting, it allows the background from the remaining elements of the drawing to be separated, and reduces the amount of information contained in the image. A example image subjected to thresholding is shown in Fig. 5.

It contains a distinct boundary between the background and the base. The fidelity of reproduction of the boundary between the background and the sample depends significantly on the threshold used and the lighting of the sample. The image subjected to thresholding contains noise as well. Digital image noise usually appears in high frequencies of the image spectrum. Therefore, a low-pass digital filter may be used for noise removal. However, linear low-pass filters tend to smear image details (e.g lines, corners), whose power lies in high frequencies as well. Thus, a non-linear low-pass filter based on *data ordering*, such as a median filter, should be used to remove noise effectively and preserve image edges and details [3,4]. However, these single pixels inside objects, coloured white or single black pixels in the background are not essential. For measurement purposes, noise occurring on the edges of objects, visible under greater magnification, is the most important. To remove this noise an operation of the convloution is carried out (2,3) [6]. Considering the properties of the image and the properties of the convolution operation itself, this transformation corresponds to the two-dimensional median filtering [3,4].

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \xrightarrow{filtration} \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_p & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}; \tag{13}$$

$$a_p = \begin{Bmatrix} 0 & dla & \sum_i \sum_j a_{ij} < 4 \\ 1 & dla & \sum_i \sum_j a_{ij} >= 4 \end{Bmatrix}. \tag{14}$$

This filter levels the edges of the areas and removes from the image objects of an area of 1 to 3 pixels. The image formed after filtering is shown in Fig. 6.

As can be seen, the image is not completely noise free. Within the object and the background there are irregularly-shaped spots of dimensions of several to several thousand pixels. Their presence can lead to errors during basic conversion; therefore, they must be removed.

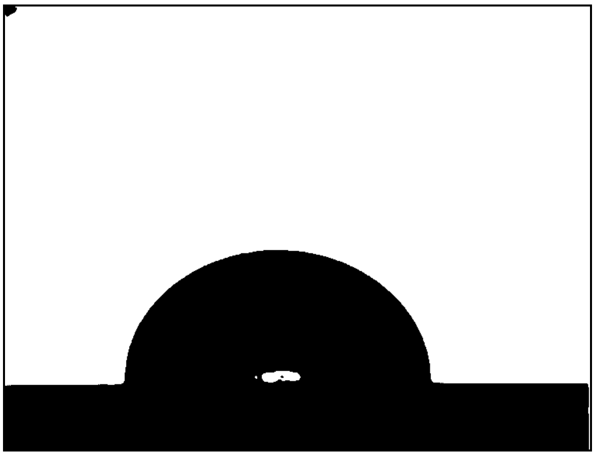

Figure 6. Image of a tin drop after filtering.

5 IMAGE ANALYSIS

Specimens being investigated at high temperatures emit visible radiation, which leads to the formation of a specific 'aura' around them. The brightness and size of this 'aura' depend on the temperature and physical-chemical properties of the material. On the other hand, it is often the case that the specimen is displaced during the experiment. These phenomena were considered when solving the problems of specimen localisation in the image and the measurement of its geometrical features. In this step, edge-following algorithms, which allow finding boundaries of the object and its geometrical features, are used [2].

Measured in this step geometrical parameters the specimen allow us to determine thermo-physical properties of the specimen under investigation [2].

6 CONCLUSIONS

Preliminary image processing algorithms described in this paper allow us to obtain as their result image, which is ready for analysis. High quality of this images allows us to determine thermo-pchysical properties of specimen under investigation with much more accuracy then results obtain in traditional methods, as was shown in [2].

The relative errors reported in the calculation of the surface tension and wetting angle of liquid metals in three most common and accurate traditional methods are as follows [2]:

- Maximum bubble pressure method - about 5.5%.
- Levitated droplet method - at least 2%.
- Sessile droplet method - 3-5%.

Basing on our own preliminary results, the accuracy of the surface tension and wetting angle measured in our device is estimated to be within 0.2-0.5%, which is the result of high accuracy image processing algorithms, which do not depend on the operator's subjective analysis of the specimen.

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