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IMAGE PROCESSING ALGORITHMS IN ASSESSMENT OF QUALITY OF SOLDERS

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Abstract – in this paper a new segmentation algorithm based on the k –nearest neighbours statistical decision rule is presented. This algorithm was designed for use in systems of quantity image analysis, especially in industrial measurement systems. This algorithm was implemented in a system measuring surface tension and wetting angle parameters, knowledge of which is extremely important for the assessment of quality of solders, for example.

Keywords: image segmentation, physical properties measurements, solderability tests.

1. INTRODUCTION

Soldering and brazing are one of the most widespread methods of joining materials, without which most branches of modern technology could not exist. Depending on the soldering process temperature, which is mainly - but not only - related to the melting point of the filler metal, and indirectly to the strength of the joints resulting from its use, the joining can be divided into:

– soldering (up to 450°C);
– brazing (from approx. 450 to approx. 1000°C);
– high-temperature brazing (above 1000°C).

Soft soldering is mostly used for the assembly of electronic elements. Brazing is used in machine-building, tool, electrical and power industries; i.e. in the branches, where obtaining joints of increased strength is necessary. High-temperature brazing has a limited use - due to the alternative of welding - and is used for obtaining joints operating at high temperatures or liable to mechanical damage.

A property, or rather a set of properties, determining the usability of a given material for soldering can be called ‘solderability’. However, it is not only related to the material itself but also depends on a number of factors resulting from the use of a given soldering technique, additional materials (solders, solder fluxes), soldering parameters, and finally from the requirements of the joint.

A complicated set of phenomena on the interface of the solid, metallic liquids and gas underlies the soldering process. The basic measurable quantities characterizing interfacial interactions include: the surface energy (surface tension) of a liquid phase and the extreme wettability of the base. These constitute the basis for calculating the remaining quantities important for a given system, responsible for making a joint: adhesion energy, interfacial tension and possibly adsorption. Measurements and calculations are performed for the conditions of a thermodynamic equilibrium.

Soldered joints are characterized by a relatively small soldering fissure in the order of tenths of a millimetre. Thus, during the soldering process these are filled as a result of the action of capillary forces. The height of elevation h of a liquid in a vertically positioned capillary pipe of radius r is defined by a formula known from the physical chemistry of surfaces [1]:

$$h = \frac{2\sigma_{LV}\cos\Theta}{r\rho g}\,; \tag{1}$$

where σ_{LV} is the surface tension of a liquid, ρ is its density, while Θ is the extreme angle of wetting of the capillary material. It is obvious that for a liquid to flow into the capillary ($h > 0$) there is the condition that $\Theta < 90^o$. If the capillary is tilted from the vertical by an angle α, the length of its filling l is given by the formula:

$$l = \frac{h}{\cos\alpha}\,; \tag{2}$$

hence:

$$l = \frac{2\sigma_{LV}\cos\Theta}{r\rho g\cos\alpha}\,. \tag{3}$$

In a technological practice, calculations based on the given formula are insufficient due to the factors mentioned. Therefore, an empirical approach must be used.

For the surface characteristics of a ‘solid – liquid – gas’ system two quantities must be determined: the wettability angle Θ and the surface tension σ_{LV} of the liquid.

So far, an optical method, such as the sessile droplet method [2], has generally been used for the measurement of the surface tension and wetting angle. This method is based on the continuous observation of a specimen shape and manual or photographic recording of changes of its shape as a function of temperature. The recorded profiles are then analysed by a specialist, who measures the basic specimen parameters by means of graphical methods and calculates the values of the desired surface quantities. This optical method has a long history, and many references in the literature, but it has a number of drawbacks, such as an extremely labour-consuming measurement cycle and a poor accuracy and repeatability of results, to name just a few.

Within the framework of the research the authors built a computerised device for the automated measurement of a surface phenomena occurring during the contact of liquid and solid phases [3-6]. The device is capable to measure such properties of solid-liquid systems as surface tension (surface energy) and the density of liquids, as well as the wetting angle over a wide range of temperatures: 700-1800 °C

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

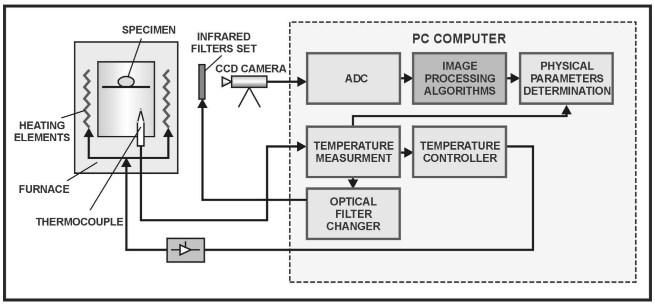

Fig. 1. Block diagram of computerised system with CCD camera for measurement of surface properties

The vision unit used in the measuring system is responsible for the following operations:

- acquisition and conversion of an image into a digital form;
- preliminary image processing including its segmentation;
- image analysis: localisation of the specimen, evaluation of its geometrical attributes;
- determination of the thermo-physical properties of the specimen under investigation.

2. IMAGE SEGMENTATION PRELIMINARIES

One of the most difficult problems in image processing is segmentation - the process of dividing an image into meaningful regions [7-8]. Typically, the regions fulfil certain criteria of homogeneity. Nevertheless a wide variety of different segmentation techniques exist [7-9], however there is no general theory. The goal of this part of image processing is to produce a segmented image, where segments correspond to visually coherent, slightly differing surfaces of the same texture. The segmentation process described above can also be defined as finding the partitioning of the data into equivalence classes, where the equivalence relationship is the homogeneity measure together with the constraints given by the external parameters.

The task of segmentation of an image can be presented as forming - out of the digital image $L_S(x,y)$ - images of s objects $H_1(x,y), H_2(x,y), \dots, H_s(x,y)$ and an image of the background $H_\varphi(x,y)$, for which the relationship is satisfied:

$$L_S(x,y) = H_1(x,y) + H_2(x,y) + \dots + H_s(x,y) + H_\varphi(x,y). \quad (4)$$

Beside:

$$\left.\begin{array}{l} H_K(x,y) = 0 \quad \text{for} \quad (x,y) \notin D_K \\ H_\varphi(x,y) = 0 \quad \text{for} \quad (x,y) \notin D_\varphi \end{array}\right\}; \quad (5)$$

where:

$H_k(x,y)$ - image of k object $(k = 1,2,\dots s)$;

$D_k \subset D$ - area of k object;

$D_\varphi \subset D$ - area of k background;

D - area of the analysed scene.

Additionally for areas of objects D_k and for area of background D_φ, relationships given by (6) and (7) are fulfilled.

$$D_1 \cup \dots \cup D_s \cup D_\varphi = D; \quad (6)$$

$$D_i \cap D_j = 0 \quad \text{for} \quad i \neq j. \quad (7)$$

To present an input image in the form (4) it is sufficient to define the transformation:

$$\pi : D \to \{0,1,\dots,s\}. \quad (8)$$

Transformation (5) should fulfil:

$$\pi(x,y) = \begin{cases} l & \text{dla} \quad (x,y) \in D_l \\ 0 & \text{dla} \quad (x,y) \in D_\varphi \end{cases}, \quad \text{where} \quad l \in \{1,2,\dots,s\}. \quad (9)$$

Representation (8) can be understood as a rule in which a unique label $\pi(x,y)$ is assigned to each point of an image $(x,y) \in D$. Additionally, different values of the labels assigned to points of an image correspond to areas of various objects or to the area of the background.

3. k-NN BASED SEGMENTATION ALGORITHM

The new segmentation algorithm, developed especially for industrial measurement systems, is based on the k – nearest neighbours decision rule [10-11].

For this algorithm, the transformation (8) can be presented in the form of two independent stages described by formulae (10) and (11):

$$\pi_I : D \to R; \quad (10)$$

$$\pi_{II} : R \to \{0,1,\dots,s\}; \quad (11)$$

The first step of this algorithm is to build a reference set for k-NN classifier (10). It can be done by taking every pixel with its neighbourhood from the image and calculating its features describing the surface to which pixel under investigation belongs. The choice of feature selection and the size of neighbourhood depend on the nature of the image and task of segmentation. For example, it can simply be the average grey level of the pixel and its neighbourhood or a more compressive result of Fourier transform values. A good selection of features, coherent to the nature of the image, gives better segmentation results.

A set of points in the feature space is obtained as the result of the first step of the algorithm. Every point from this set describes one pixel of the image.

In the second step every point from this reference set is taken and classified with k-NN rule to one of the classes, which represent objects in the image (11). The point is classified to the existing class only when distances between this and the nearest points of known classes are smaller than the defined threshold, in other cases a new class is created.

The above classification process allows to disjoint reference set to subsets corresponding to objects in the original image.

4. IMAGE SEGMENTATION IN INDUSTRIAL MEASUREMENT SYSTEM

The presented segmentation algorithm has been implemented in a surface tension and wetting angle measurement system. The goal of segmentation in this application is to disjoint the specimen under investigation (and the base-plate on which specimen is placed) from background to measure its geometrical properties and next, on the basis of these, the wetting angle and surface tension.

In order to test the efficiency of the implemented segmentation algorithm, a number of experiments were performed for four different materials: glass, silver, gold and palladium, in wide range of temperatures.

All experiments were performed for different values of segmentation algorithm parameters:

1. the size of pixel neighbourhood investigated during calculation of pixel features;
2. threshold value of distance between objects in feature space.

The nature of images obtained from the system described allows the simplest set of features to be used for describing pixels in a reference set: average grey level of pixel and its neighbours and variance of grey level value in the neighbourhood.

Original images taken during experiments and results of their segmentation are presented on Fig. 2-5.

Figs. 2 and 3 present the influence of the first parameter on segmentation results. It can be seen (Fig. 2) that its increase leads to smothering of the object boundaries. It is especially visible on the upper edge of the base-plate (A) and for a fragment of the internal foundry wall (B). Additionally, optimum selection of this parameter obtains good segmentation results for the specimen area with a non-homogenous texture (C).

Fig. 3 shows the effect of increasing this parameter in removing object (A).

Analysis of images from Fig. 2 and 3 enables the formulation of the conclusion that an increase of neighbourhood size leads to removing small disturbances from images (smaller then neighbourhood size). In this way estimated boundaries are smooth and free of artefacts, and provide good estimates of contours of objects in original image.

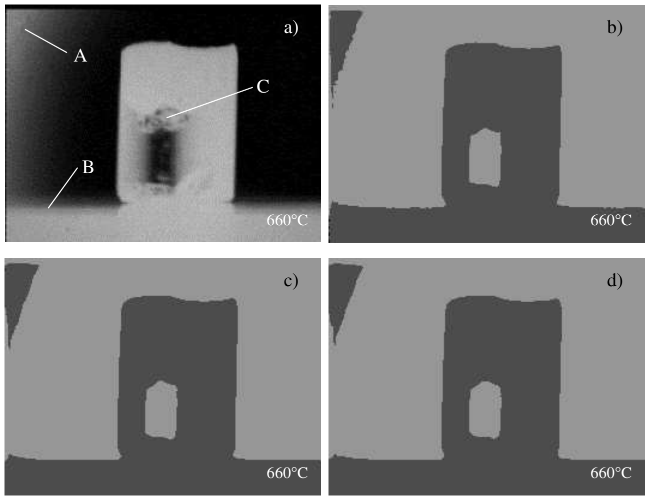

Fig. 2 Original image of specimen of glass (a) and results of its segmentation (b, c, d).
(A – upper edge of the base-plate; B – fragment of internal foundry wall; C – object area with non-homogenous texture)

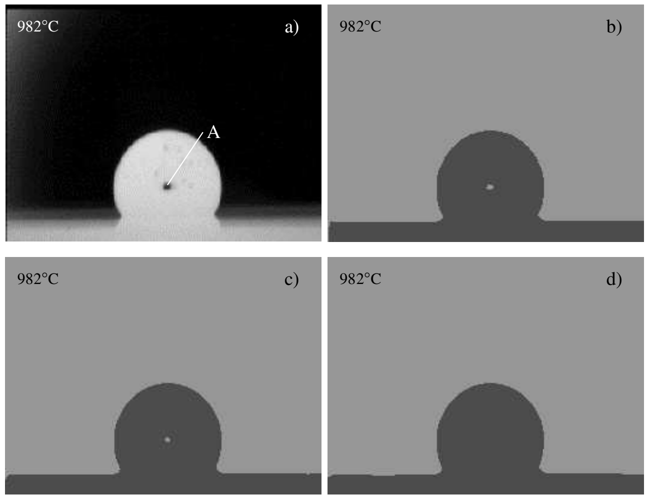

Fig. 3 Original image of specimen of silver (a) and results of its segmentation (b, c, d).
(A – object removed in segmentation process)

Figs. 4 and 5 illustrate influence of second algorithm parameter on segmentation results. Proper selection of its value allows good localisation of blurred edges like upper edge of base-plate (A) in Fig. 4.

Specimen heated to a high temperature emits light in a visible part of the spectrum. This light forms “aura” surrounding the specimen and blurring its edges. The properties of light emitted are a function of temperature rather than a function of the specimen material properties. This phenomenon makes image processing and analysis especially difficult.

Fig. 5 shows images of specimen of palladium in the temperature of 1564°C where phenomenon of “aura” occurs. The correct selection of the value of threshold distance of the object in feature space enables the correct localisation of specimen edges despite of the “aura” (A) phenomenon.

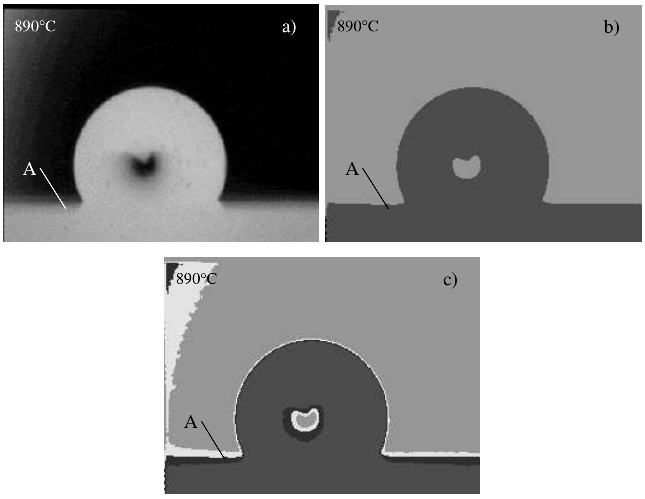

Fig. 4 Original image of specimen of glass (a) and results of its segmentation (b, c).
(A – upper edge of the base-plate)

Analysis of segmentation results presented in Figs. 4 and 5 leads to the conclusion that implemented segmentation algorithm gives the possibility of proper detection of objects with blurred edges.

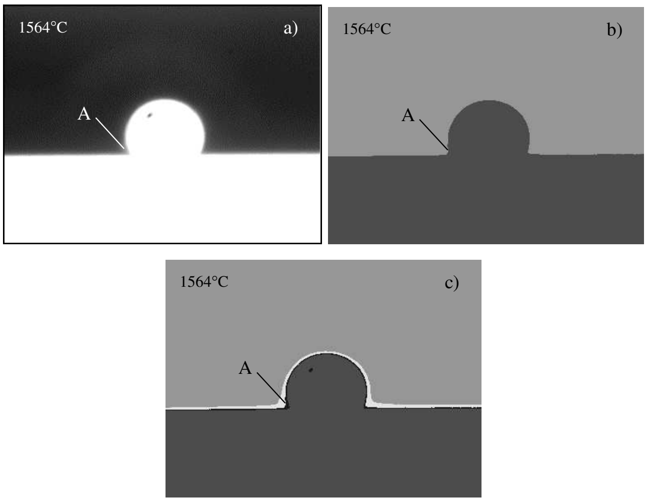

Fig. 5 Original image of specimen of palladium (a) and results of its segmentation (b, c).
(A – “aura” phenomenon)

5. CONCLUSIONS

The new segmentation algorithm, designed especially for the high temperature measurement application mentioned above, allows objects of various shapes to be extracted from the image and works very well with images taken in different lighting conditions. All obtained final images are free of artefacts and have smooth boundaries. They provide good estimations of contours of objects in the original image. Thus the images obtained can be successfully used for the quantity image analysis algorithms.

The results obtained with the device described in this paper are far more accurate than those currently obtained by means of non-automatic methods based on the operator’s subjective evaluation. This is due to the highly accurate image processing algorithms, which do not depend on the operator’s subjective analysis of the specimen.

The image segmentation method presented in this paper can be successfully applied to a wide range of quantity image analysis systems, especially in measurement systems.

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