SEGMENTATION OF WELDING ARC IMAGES FOR PURPOSES OF WELDING DIAGNOSTICS

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Summary

The paper concerns the research on diagnostics of a welding process. The estimation of the process state is being performed by means of the analysis of infrared images and images recorded within visible range of electromagnetic radiation. To carry out the image analysis it is necessary to cut out the area called region of interests (ROI). In case of welding which is the dynamical process this operation appeared complicated. The most important point of the operation is image segmentation. The author proposed and tested an algorithm of the definition of the ROI as well as verified numerous image segmentation methods.

Keywords: process diagnostics, welding monitoring, infrared, image fusion, image processing.

SEGMENTACJA OBRAZÓW ŁUKU SPAWALNICZEGO
DLA POTRZEB DIAGNOSTYKI SPAWANIA

Streszczenie

W artykule przedstawiono badanie nakierowane na diagnozowanie procesu spawania. Estymacja stanu procesu była przeprowadzana poprzez zastosowanie metod analizy obrazów termowizyjnych, jak również obrazów zarejestrowanych w widzialnym paśmie promieniowania elektromagnetycznego. Przeprowadzenie analizy obrazów wymagało wyboru i wycięcia obszaru, zwanego regionem zainteresowania (ang. region of interests, ROI). W przypadku spawanie będącego procesem bardzo dynamicznym operacja ta jest dość skomplikowana, a jej najważniejszym etapem jest segmentacja obrazu. Autorzy zaproponowali i zweryfikowali algorytm definiowania ROI, przy zastosowaniu kilku różnych metod segmentacji obrazów.

Słowa kluczowe: diagnostyka procesów, monitorowanie spawania, fuzja obrazów, przetwarzanie obrazów

1. INTRODUCTION

Monitoring and diagnosing of a welding process with use of vision systems is nowadays an object of interest of many research institutes and industrial companies [1, 2, 3, 4]. In the Department of Fundamentals of Machinery Design (Silesian University of Technology), research concerning welding process diagnostics with use of multisensor data fusion, has been carried out for several years [5, 6]. One of tasks being realized has been an application of image fusion of welding arc infrared and regular images. The goal is to diagnose the welding process [7, 8].

An evaluation of the welding process state is performer on the background of image series recorded during the process. Every image of the series is processed and analysed. As the result one or some relevant features are being obtained. Values of these features arranged in time order are considered as diagnostic signals. They are fundamental to basic diagnostic stages such as defect detection, localization and identification.

The process of estimation of feature values is usually conducted for a selected image area which is known as a region of interests (ROI). There are some advantages of examination of the ROI instead of the whole image. Examples are a decrease of processed image sizes as well as image analysis time. These factors are particularly important in case of on-line diagnostic systems.

An issue of the ROI selection seems to be a simple in case of single images. A specific area of determined size and shape can be indicated manually. In case of image series which are on-line recorded, processed and analysed the ROI selection may turn out more complicated task. The main problem is an image content very often difficult to be predicted. It may change dynamically during the process or object observation. An example is mentioned above the welding process. A welding arc visible in images recorded within visible range of electromagnetic radiation as well as a weld pool present in infrared images may change their shapes and sizes. In this case defined ROIs require particular attention and initial research.

2. IDEA OF A DYNAMIC ROI SELECTION

The main task of the application of vision systems to process diagnostics is quick detection of process abnormalities. Processed images present scenes which consist of several objects. Among them some are crucial to process evaluation, whereas others are unnecessary. The scene is a result of a camera placement and optical set application and is often difficult to be changed. To evaluate the process quickly and effectively the ROI is necessary to be selected. This specific area should be focused on proper scene objects. Apart from removing insignificant object, the approach let us also decrease the image size and the same limit analysis time. The simplest solution is to define the shape, size and localization of the ROI. These parameters can be used for every image of the series. Such approach is correct in case one assure invariability of the process. It means that localization of the observed objects as well as changes of their shapes and sizes can be passed over. The ROI selection appears to be more complicated in case of observation and evaluation of a dynamic process. In the course of such processes the objects visible in the image which carry information on the process state may change their parameters dynamically. Additionally the intensity of these changes is often related to process abnormalities. Extra factors making the ROI selection more difficult are deviations of an observed phenomenon source and camera localization. A typical example is discussed the welding process. In Fig. 1 two images of the welding arc are presented. The images have been recorded within range of visible electromagnetic radiation. Two different courses of the process were observed. The evaluation of the process was achieved on the basis of features estimated for the welding arc area. The size, shape and localization within the ROI (Fig. 1a) were calculated for a single image sequence. It is clearly noticeable that the ROI properly defined for one sequence (Fig. 1a) turned out to be improper for other images (Fig. 1b). In the second case the welding torch was accidentally moved during welded elements assembly. Additionally, significant changes of the arc shape caused by oil on welded surface were observed.

a) b)

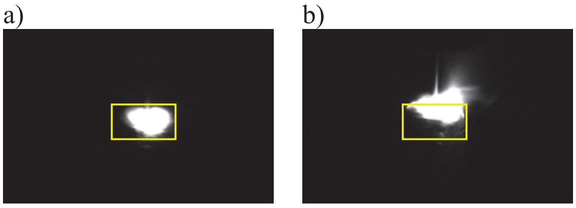

Fig. 1. Examples of properly a) and improperly b) ROI selection

The analysis of the ROI corresponding to Fig. 1b led to incorrect results of the algorithms, thus wrong conclusions on the process abnormalities. In such case a method of the ROI selection is necessary to be especially elaborated. As it was mentioned above, one assumed that basic parameters of the ROI are its shape, size and localization. One can assume any shape of the ROI. It can results from the shape of the observed object. However, the most often its shape is rectangular since it can be represented as a numeric array and easily processed by computer systems. Regardless of the shape, the ROI size is usually defined be means of two parameters such as width and high of the rectangle within the shape is inscribed. The ROI localization is defined through coordinates of the rectangle mass centre. It appears that to describe the ROI the size and localization of the rectangle mass centre are only necessary to be defined. Taking into account the process dynamics the ROI shape, size and localization change and may be different for each image from the sequence. It is not favourable since the parameters should be recalculated for each image. Moreover, the size of the matrix corresponding to the ROI also changes. The changes of the ROI localization and size may also influence values of the diagnostic signals. Additional interference and step changes may be interpreted by an inference algorithm as state changes. In order to avoid such problems two-stage method of ROI selection was proposed and elaborated. Firstly, so-called working ROI is estimated. It is characterized by the constant size and localization. In the second stage the appropriate shape of the observed object is searched within the working ROI. The search is dynamically conducted. Next, the object is analysed and some additional estimators are calculated.

Fig.2. Working and appropriate ROIs

To perform the first stage a sequence of training images is necessary to be prepared and processed. The sequence should include representative cases corresponding to different states that may occur during the welding process. In the second stage the appropriate ROI is estimated for a currently recorded image. It is important that both stages require the application of proper segmentation methods.

The proposed algorithm of ROI definition consists of the following steps:

- Prepare a training sequences of the image.
- Define the shape of the estimated objects for every image of every training sequences; a proper segmentation method should be applied.
- Estimate the height ho and width w_o of the object.
- Find coordinates x_o,y_o of the object centroid.
- Record the size parameters of the object (h_o w_o) and coordinates of its centroid x_o,y_o.

- Estimate mean values x_{om},y_{om} on the basis of a set of centroid coordinates defined for all images of all sequence.
- Find maximal values h_{omax}, w_{omax} on the basis of a set of size parameters estimated for all images of all sequence.
- Define the rectangular working area of the high h_{omax} and width w_{omax} with the centre localized in xom,yom for every image.
- Define the appropriate ROI within the working ROI; a proper segmentation methods should be applied.

The essential point of the algorithm is to detect correctly the observed object. In case of the majority of images analysed during the welding process, the observed object is the welding arc. Object detection can be perform automatically with the application of one of the image segmentation methods. In the further parts of the paper selected methods of segmentation have been characterized. To estimate the possibility of their application as a part of the elaborated algorithm of ROI selection, some tests have been carried out. Properties of these methods have been also examined to check their application to definition the appropriate ROI.

3. IMAGE SEGMENTATION METHODS

Image segmentation methods have been developed since the beginning of research on image processing and analysis. In the literature numerous of methods of segmentation are described. The image segmentation is called subdivision of an image into its constituent regions (e.g. objects) [10]. Results of the application of different segmentation methods strongly depend on a type of the scene that is represented in the image. For very complex images where the difference between the background and interested object is small, it is very hard to find an appropriate method of image segmentation and in many cases the segmentation is almost impossible or gives results that are far from the one expected [11]. In case of the images with difference between the objects and background is distinct (e.g. bright objects on the dark background) this operation in easier and less complicated. The segmentation is very important in numerous applications (such as monitoring, visual inspection), especially in the cases where further analysis of the extracted object is performed in order to define dimensions, shape or localization of the real object represented in the image.

The algorithms of segmentation of monochromatic images are based usually on two types of features. They are distribution of intensity values in the image: similarity and discontinuity. Therefore one can distinguish a group of methods that divide images into regions which are similar according to some conditions (region-based methods) and a group of methods based on searching an abrupt change in intensity (edge-based methods). Another group of the segmentation methods is represented by histogram. There are method based on thresholding or multi-thresholding where thresholding could be performed globally (one threshold value for whole image) or as adaptive thresholding (the image is divided into subregions and in each subregion new threshold value is being set).

In this article the authors made an attempt to compare chosen segmentation methods, applied to welding arc images. Procedures have been tested on the series of images of two types: infrared and vision images. Some examples of the application of chosen methods for the vision images of welding arc have been presented below.

3.1. Region-based methods

This group gathers methods based on the analysis of the intensity values of neighbouring pixels. Depending on the algorithm, pixels with the value of intensity that fulfils some conditions - could be included or excluded or split into regions [10]. Differences between methods have been described below.

Region growing - in this approach to segmentation it is obligatory to define initial "seed points" and the algorithm examines neighbouring pixels and determines whether the pixel neighbours should be added to the region. The result of the method is a final region which grows from the seed pixel. Some methods of region growing enable directional growing where pixels with the highest intensity value of a pixel are added to a region firstly [12].

Region merging - an idea of region merging is to verify the value of the features of neighbouring small regions, if the constrains are fulfilled - these regions are merged.

Region splitting - the basic idea of region splitting is to break the image into sets of disjoint regions which are coherent within themselves. The algorithm starts from the assumption that whole image is an area of interests. After verification of assumed similarity constraint, region image is split into sub-areas

Split and merge - split-and-merge segmentation is based on a partition of an image. It is sometimes called quadtree segmentation. This method starts at the root of the tree that represents the whole image. If the region is not sufficiently coherent, region is split into four quadrants and these steps are recursively applied to each new region (the splitting process). If the entire region is coherent (i.e., if all pixels in the region have sufficient similarity), the region is left unmodified. Those regions could be merged as several connected components (the merging process). This process continues recursively until no further splits or merges are possible. Since this algorithm starts with regions larger than single pixels, this method is more efficient in comparison to the merging method [13]. A modification of this method is an application of split and merge algorithm to analyse histogram of the image instead of the image itself [14].

3.2. Edge-based methods

This kind of segmentation is based on searching lines or curves (edges) that represents region boundaries, since there is often abrupt change of intensity at the region boundaries. In order to find edges located horizontally, vertically or skew different masks such as Sobel, Canny, Prewitt, Roberts are usually used [10].

3.3. Clustering method

In this group the most popular algorithm of segmentation is the K-means algorithm. It is an iterative technique that is used to divide an image into K clusters. The K-Means algorithm is called an unsupervised clustering that classifies the input data points into multiple classes based on an inherent distance from each other. The chosen criterion takes a measure of the similarity between data elements of a group and the dissimilarity between different groups for segmenting the images [15]. The difference is typically based on a pixel colour, intensity, texture, and location, or a weighted combination of these factors. K can be selected manually, randomly, or by an heuristic.

3.4. Watershed segmentation

The watershed transformation is applied for the images considered as the gradient magnitude of an analysed image as a topographic surface. The highest gradient magnitude intensities (GMIs) of pixels correspond to watershed lines. These lines represent the region boundaries. Water placed on any pixel enclosed by a common watershed line flows downhill to a common local intensity minimum (LIM) Pixels belonging to this local minimum compose the segment. Let suppose that the grey level range of an image is [0,255]. Algorithm starts from the pixels of intensity values equal to 0. They form the basis for new watersheds. If the pixels with intensity equal to 1 are next to existing watersheds (0-intensity pixels), they are added to these regions. If not, a new region is started for each pixel that is not close to an existing region. This process repeats for each intensity k up to the maximum (255 in presented case) [13].

3.5. Active contours method

This method of segmentation differs from the ones shortly described above. In this method searching of the object in the image is dynamic and based on the model of active contours to detect objects in the image [16]. Assumptions of the method are based on techniques of curve evolution. An algorithm starts from defining "starting region" anywhere in the image and then the algorithm finds the inner contour of the object. Finally it becomes a boundary of the region found. In Fig. 3 some results has been presented. The active method of segmentation can be very useful in situations, where shape and size of the welding arc is changing very fast. This was the first attempt to apply the active methods to image segmentation and became very promising.

a) b)

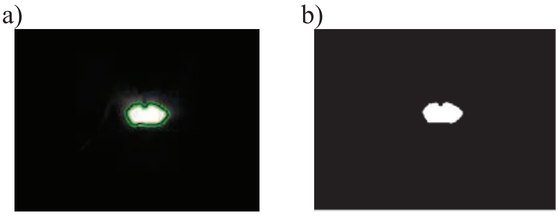

Fig. 3. Example of application of active contour method to vision image of welding arc a) original image with indicated object boundary, b) final effect of segmentation

4. CHARACTERIZATION OF CONSIDERED IMAGES

During the research considered infrared and vision images taken during welding of plates made of steel S235JR (EN 10027-1) with dimensions 300x150x5 mm on the mechanised welding stand for rectilinear MIG/MAG welding equipped in microprocessor controlled welding machine Castolin TotalArc 5000. The edges of the joined plates were bevelled at an angle of α=60° and the offset between them was b=1,0 mm. For welding purposes a solid electrode wire with a diameter of 0,2 mm (Castolin CastoMag 45255) and a shield gas M21 (82%Ar+18%CO2) were used. Nominal welding parameters are presented in Tab. 1.

Infrared and vision images were synchronically acquired with rate 50 fps by use of uncooled infrared camera Infratec VarioCam Head with resolution 640x480px equipped in lens f=50mm and visible light CCD camera ImagingSource DMK21AF04 with resolution 640x480px and lens with focal length f=25mm. Camera's lenses were equipped in a suitable filters suppressing the excess of the electromagnetic radiation and protecting it against splatters generated during welding. Cameras connected to the computers and images acquisition process was controlled by software developed in LabView environment. Series of experiments simulating different faults of welding process were carried out. It permitted to record the collection of sequences of infrared and vision images for 12 different states of welding.

Table 1. Optimal MAG welding parameters

Welding current [A]	Welding voltage [V]	Welding speed [cm/min]	Wire feeding rate [m/min]	Shield gas flow [l/min]	Electrode outlet [mm]
240	25	32	7,4	15	15

Process classified in the following way:

- correct welding process.
- welding with decay of the shielding gas flow.
- welding of the plates with distinct outbreaks of atmospheric corrosion on the welded surfaces.
- welding with use of corroded wire.
- welding of plates with irregularities of the plate edges from side of the weld root.
- welding of plates with oil contamination.
- welding with deviation of current.
- welding of plates with different offset intervals.
- welding with deviation of voltage.
- welding of the plates with improper welding groove geometry.
- welding with deviation of speed.
- welding with use of worn rollers of wire feeder.

Because of the huge number of images acquired during the experiment, results of application of the segmentation methods have been shown only for couple of chosen images.

5. Comparison of usefulness of segmentation methods to sequences of images recorded during welding

To verify the elaborated algorithm of the working and appropriate ROI definition the sequence of the infrared images has been selected. It should be stated that these images are more complicated in comparison to the images recorded within visible range of electromagnetic radiation. The use of these images let us more effectively check different segmentation methods. The image sequence used in the verification stage was recorded during the welding process when decay of the shielding gas was observed. The images presented in the further parts of the paper were recorded during different stages of the process. The images show also process diversity and dynamics. In Fig. 4 selected infrared images have been presented. In Fig. 5 - 10 there are corresponding to them images resulting from the application of the following segmentation methods: Region Growing, Region Merge, Region Split and Merge, K-means Clustering, Otsu Thresholding, Watershed Transformation. The results differ depending on the segmentation method. Considering the further analysis the most important objects of the images are the weld pool and heat affected zone. These objects are fundamental to diagnostic signals estimation. The majority of the tested method let us detect these areas properly in case of the images characterized by significant contrast between searched objects and other areas visible in the images. In case of images distinctly showing the cooling joint some methods presented only one area.

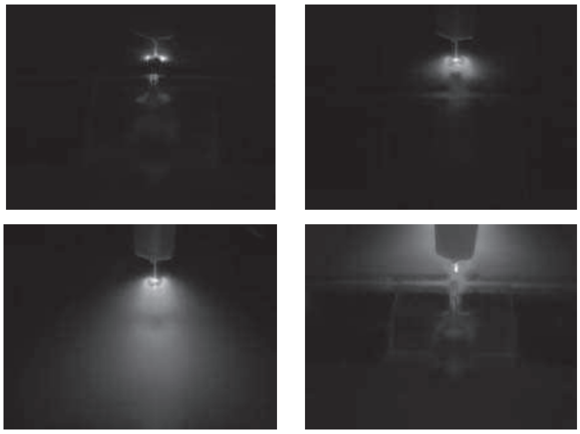

Fig. 4. Selected images of acquired infrared images sequence during welding with decay of the shielding gas flow

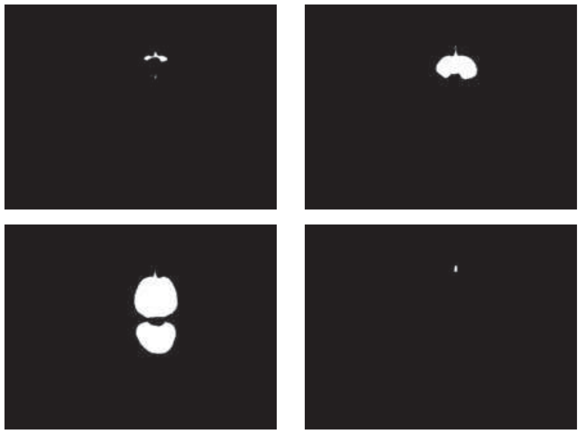

Fig. 5. Results of segmentation of infrared images presented in Fig. 4 by use of Region Growing method

Fig. 6. Results of segmentation of infrared images presented in Fig. 4 by use of Region Merge method

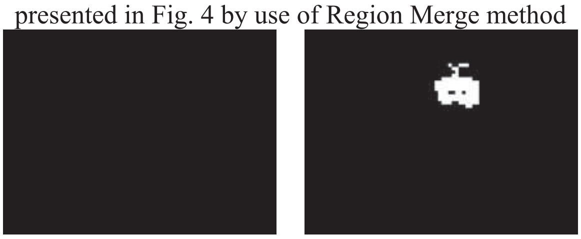

Fig. 7. Results of segmentation of infrared images presented in Fig. 4 by use of Region Split and Merge method

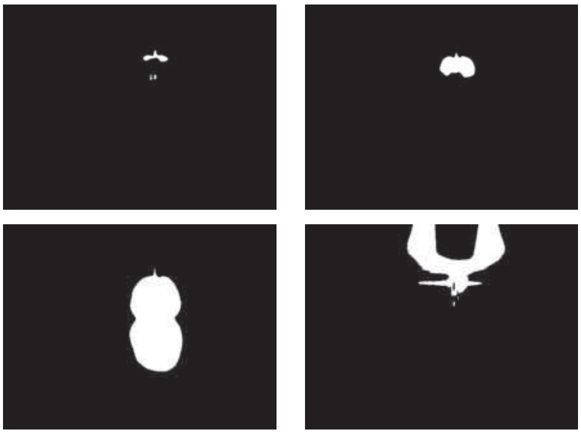

Fig. 8. Results of segmentation of infrared images presented in Fig. 4 by use of K-means Clustering method

The weld pool and heat affected zone were shown together (Fig. 8 and Fig. 9). Results of other methods showed areas of infrared radiation different for the weld pool and arc. Examples are images recorded during decay of the shielding gas were observed (Fig. 6, Fig. 8 and Fig. 9).

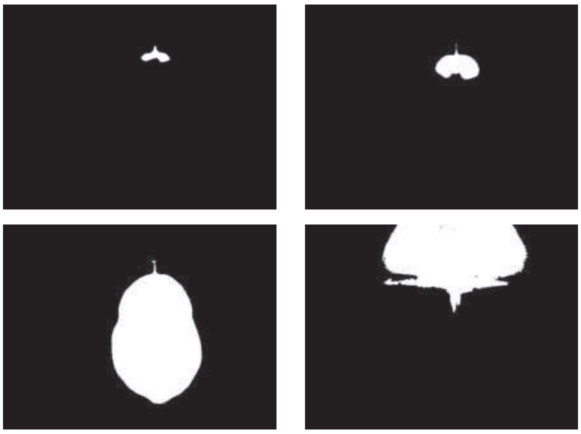

Fig. 9. Results of segmentation of infrared images presented in Fig. 4 by use of Otsu Thresholding method

According to the proposed algorithm the mean values of centroid coordinates and maximal values of width and height of the object resulting from the segmentation have been estimated. These values can be background to the inference on changes of the process state. Mentioned parameters have been presented in Tab. 2. Exemplary infrared image with the drawn ROIs on the basis of the parameters collected in Tab. 2 were presented in Fig. 11.

Fig. 10. Results of segmentation of infrared images presented in Fig. 4 by use of Watershed transformation method

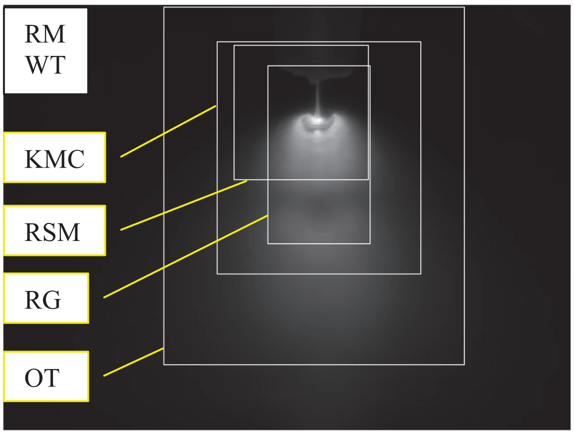

Fig. 11. Exemplary infrared images with drown ROIs which parameters estimated on the basis of presented algorithm applied different segmentation methods

In Fig. 12 exemplary comparison between the coordinate y_o and high h_o of the objects resulting from the segmentation based on Region Growing and Watershed transformation was presented. In case of the Region Growing values of the parameters (object high and width) increase as an effect of gradually heat up of the welded elements. The course of changes of the object parameters let us also identify the moment when instability of the welding process occurred. In the presented example the instability was triggered off by instability of the shielding gas. In case of the method based on the Watershed transformation there is a significant difference between estimated parameters. It indicates a high sensitivity of the methods.

Table 2. Comparison of working ROI parameters calculated on the basis of infrared image sequence

	Mean X Centroid x_o^m	Mean Y Centroid y_o^m	Max Width w_o^{max}	Max Height h_o^{max}
Region Growing (RG)	357	170	116	201
Region Merge (RM)	357	157	640	480
Region Split and Merge (RSM)	337	123	152	152
K-means Clustering (KMC)	357	174	230	262
Otsu Thresholding (OT)	351	205	339	403
Watershed transformation (WT)	187	122	640	480

The approach is especially sensitive to temperature changes dynamics what is reflected in pixel values in infrared images. Considering the Watershed method and resulting images it is clearly visible that the moment of the instability occurrence is also difficult to identify. On the basis of analysis of mean values of coordinates of the mass centre (Tab. 2) one can conclude that except of the Watershed transformation all the methods tested let us identify horizontal localization x_o^m of the working ROI. The localization was within the range corresponding to the centre of the image. In case of the vertical coordinate y_o^m better results were achieved with use of the Region Split and Merge as well as Watershed transformation. These results allowed us to localize the centre of the working ROI close to centre coordinates of the weld pool. The rest of the methods gave resulting objects larger then one expected. It was an effect of joining several hot areas visible in the image.

a) b)

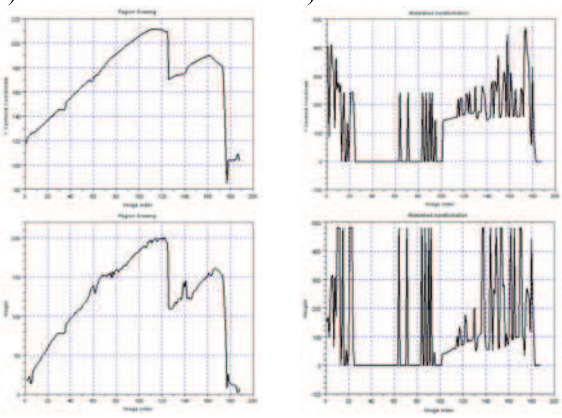

Fig. 12. Comparison of values of Y Centroid coordinate and height of objects being result of segmentation using Region Growing method a) and Watershead transformation b)

The verification of the segmentation methods was also performed to determine their usefulness as elements of diagnostic procedures. In this case the methods can be used to estimate the appropriate ROIs. The estimated objects resulting from the application of different segmentation methods were characterized among others parameters by an area. Fig. 13 presents the comparison of changes of values of the object area. The objects were detected with use of the segmentation based on Region Growing and Otsu thresholding. The segmentation based on the Otsu thresholding made it impossible to exactly detect the moment of the process abnormality (decay of the shielding gas). It was detected be means of the method based on the Region Growing.

a) b)

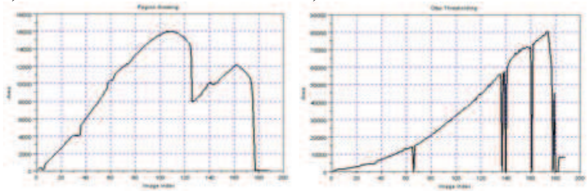

Fig. 13. Comparison of diagnostic signal of area values of objects being result of segmentation using Region Growing method a) and Otsu thresholding method b)

6. SUMMARY

The results shown in the paper let us conclude that in case of estimation of the infrared image sequence during the welding process each of the tested segmentation methods gave different results. It should be stated that some of these results were very unfavourable taking into account the algorithm of the appropriate ROI definition. The conclusion based on a subjective estimation of the obtained result seems to be that the most beneficial approach is the Region growing. The method is only slightly sensitive to rapid changes of the image contents. The next conclusion of the verification research is the most promising solution is to apply not only one but several methods of segmentation. It will let us optimally select the parameters of the working ROI. A very important factor of the proposed algorithm is that effective detection of the objects in the analyzed images corresponds to a proper choice of the segmentation method. The choice can be performed by means of optimization. It is the further step of the research conducted by the authors.

However it is necessary to stress that the images selected to verification were very complex. Despite of the variety of the obtained results and in some cases poor results it is worth to underline that one was able to verify the proposed algorithm and simultaneously estimate usefulness segmentation methods. Considering the part of the verification with use of images of the welding arc recorded within range of visible radiation which was not shown in the paper it is necessary to remark that the contrast between the objects in images was more distinct. In this case the majority of the tested

segmentation methods gave correct and acceptable results. An exception was the Watershed approach. Generally, all the achieved results were better then in case of infrared images.
Summarizing, one can state that to define the appropriate ROI the segmentation methods based on the active searching for the object contour seems to be the best solution. At present, the application of these approaches to analysis of images recoded in visible range of electromagnetic radiation is examined by the authors.

REFERENCES

[1] Rockinger, O.: *Image Sequence Fusion Using a Shift Invariant Wavelet Transform*. Proceedings of the International Conference on Image Processing, vol.3, pp. 288-291, 1997.
[2] Sadjadi F.: *Comparative Image Fusion Analysis*, Proc. of the 2005 IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'05) - Workshops, Vol. 03, p.8, 2005.
[3] Information on http://www.ishotimaging.com/weldi-home.html, Weld-i Series, Weld Monitoring Inspection Systems.
[4] Camilleri D., Gray T., and Comlekci T.: *Use of Thermography to Calibrate Fusion Welding Procedures in Virtual Fabrication Applications*. Proc. of Information 2004 Conference, vol. 5 pp. 121 -131, 2004.
[5] Bzymek A., Fidali M., Jamrozik W., Timofiejczuk A.: *Diagnostic vision system for welded joint and welding process assessment*. Maintenance Problems, 4/2008, pp. 39-52.
[6] Jamrozik W.: *Method of diagnosis of industrial processes with use of data fusion*, PhD Thesis, Gliwice, 2012.
[7] Fidali M., Jamrozik W.: *The processing of fused infrared and vision images of a welding arc for fault detection*, Proceedings of 11th Quantitative InfraRed Thermography, 11-14 June 2012, Naples, Italy.
[8] [8] Bzymek A., Timofiejczuk A.: *Estimation of welding process stability based on image analysis and recognition*, Diagnostyka 4(52) / 2009, pp 41-44.
[9] Zhang, Y. M, Kovacevic, R., Ruan, S.: *Sensing and Control of Weld Pool Geometry for Automated GTA Welding*, Transactions of the ASME, 1995, vol. 117, pp.210-222.
[10] Gonzales R. C., Woods R. E., Eddins S. L.: *Digital image processing using Matlab*, Pearson, Prentice Hall, London,2004.
[11] Zuva T., Olugbara O. O, Ojo S. O. and Ngwira S. M.: *Image Segmentation, Available Techniques, Developments and Open Issues*, Canadian Journal on Image Processing and Computer Vision Vol. 2, No. 3, March 2011.
[12] Hojjatoleslami, S. A., Kittler, J.: *Region growing: a new approach*, *Image Processing, IEEE Transactions on* , vol.7, no.7, pp.1079-1084, Jul 1998 doi: 10.1109/83.701170.
[13] Information on http://homepages.inf.ed.ac.uk/rbf/CVonline/LOCAL_COPIES/MORSE/region.pdf.
[14] Reyad Y. A., El-Zaart A., Mathkour H., Al-Zuair M.: *Image Thresholding Using Split and Merge Techniques with Log-Normal Distribution*, Canadian Journal on Image Processing and Computer Vision, Vol. 1, No. 3, July 2010.
[15] Tatiraju S., Mehta A.: *Image Segmentation using k-means clustering*, EM and Normalized Cuts, doi=10.1.1.187.6371.
[16] Chan, T. F., Vese L. A.: *Active contours without edges*, *IEEE Transactions on Image Processing* vol.10, no.2, pp.266-277, Feb 2001, doi: 10.1109/83.902291.

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