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DIAGNOSTIC VISION SYSTEM FOR WELDED JOINT AND WELDING PROCESS ASSESSMENT

Key words

Welding process diagnostics, vision system, image analysis.

Summary

The paper deals with a vision system applied for diagnosing the welding process and welded joints. The vision module of the system consists of three cameras (one IR and two CCD). The IR camera observes a welding arc and joint (in one image); whereas, two CCD cameras observe the arc and joint in two separate images. The system has been developed to operate during the welding process. Results of the operation of the system have been distinguished into groups related to process parameters and joint features. With the use of the system, it is possible to recognise some abnormalities and joint faults. They were enumerated and characterised. In the paper, the main modules of the system are described. Some examples of image processing and analysis are presented and discussed. At present, the system is being verified. Some observations related to the application of the system are described.

Introduction

The high quality of automatic welding processes is usually achieved through constant control of process parameters [1]. An alternative way is to employ visual and vision control [2, 3]. This approach can be based on observation in infrared and also in visible electromagnetic bands. Nowadays, the applications of vision systems for the assessment of welding processes is considered very promising [4, 5]. The most essential advantage of such systems is the possibility of rapid and accurate identification of abnormalities occurring during the process. It is especially important in the case of lot production where the same failures can occur repeatedly, which is often related to significant production losses. In the welding industry, methods based on image analysis have been used for seam tracking [6], weld pool size controlling [7], weld geometry controlling, and weld quality assessing [8], as well as for adaptive controlling welding processes [1].

This paper deals with a vision system consisting of three cameras. An IR camera observes a welding arc and pool and the joint that is getting cold, and two CCD cameras that record images representing the arc and joint. There are two goals of image analysis. Firstly, we assess the stability of the welding process, which is performed by means of the determination of geometrical parameters of the arc. Secondly, it is possible to detect some common defects of joints [9].

The automatic welding process can be performed with the use of different devices. The vision system developed within the framework of the research described in this paper has been assigned to MIG/MAG automated welding processes, where elements to be joined move and a device passing the filled wire is motionless. The general overview of the system was presented in [10]. The areas of observation are presented in Fig. 1.

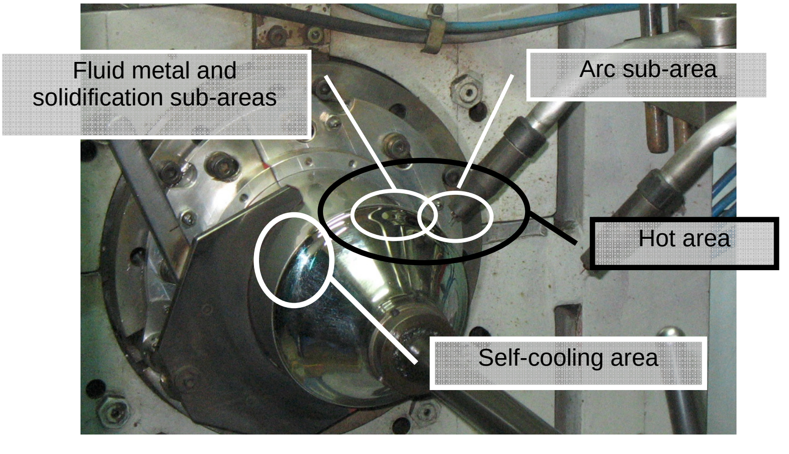


Fig. 1. Areas observed by the vision system

The system lets us record, archive, process, analyse, and recognise two types of images acquired by three cameras. They are the images of (Fig. 1):

– The hot area that includes sub-areas of arc, metal in fluid, and solidification phase; and,
– The self-cooling area containing weld and welded elements’ sub-areas.

In this paper, modules of the system and selected results obtained during its tests are presented. At present, the system is being under verification study. This paper deals with the discussion of the obtained results as well as some further directions of system development.

1. Vision module

The hardware part of the applied vision system consisted of three cameras and light sources mounted on a special support. One of the devices is an IR camera (*VarioCam* by Infratec) with resolution 320x240px, spectral range 8÷13 μm, temperature measurement range -40 to 1200°C, frame rate 50 f/s, and thermal resolution above 100 mK. The two remaining devices are CCD industrial cameras (*ImagingSource* DMK 31BF03, DFK 31BF03) with resolution 786x1024px and frame rate 30 f/s. The devices were equipped with replaceable lenses with focal lengths 25 and 50 mm. One of the CCD cameras, which observed arc and pool areas, was equipped with a blacken filter. IR devices had a polyethylene shield, protecting lens from hot spattering metal particles generated during the welding process. All cameras were connected via FireWire interfaces to the PC station where images were acquired and processed.

An extremely important factor influencing image quality was lightening. It was especially crucial in the observation of the joint. Appropriate ways of illuminating this area significantly simplified image analysis and let us decrease the number of pre-processing operations. It resulted in the increase of speed of the image analysis as well as the effectiveness of applied algorithms. One should stress that the way of illuminating was strictly related to welding parameters such as voltage, amperage, speed, material, and the thickness of welded elements. During the experiment, two halogen lamps that are arranged differently (300 W) were employed.

2. Image acquisition module

Synchronisation of measuring, recording and analysing data being gathered was performed by software that constituted the second part of the system. This part was developed with the use of *LabView*. In Fig. 2 there is shown one of the system windows. In three smaller windows, there were previews of the CCD cameras observing arc and pool areas (Fig. 2 upper left); and the CCD camera that following welded joint (Fig. 2 down) and IR camera observing arc and the self-cooling area (Fig. 2 upper right) are presented. The developed software made it possible to set acquisition parameters for each camera separately as well as to monitor and control image recording. Developed procedures let us record three images synchronously and to process them by applying thresholding, filtering, and ROI (region of interest) extracting.

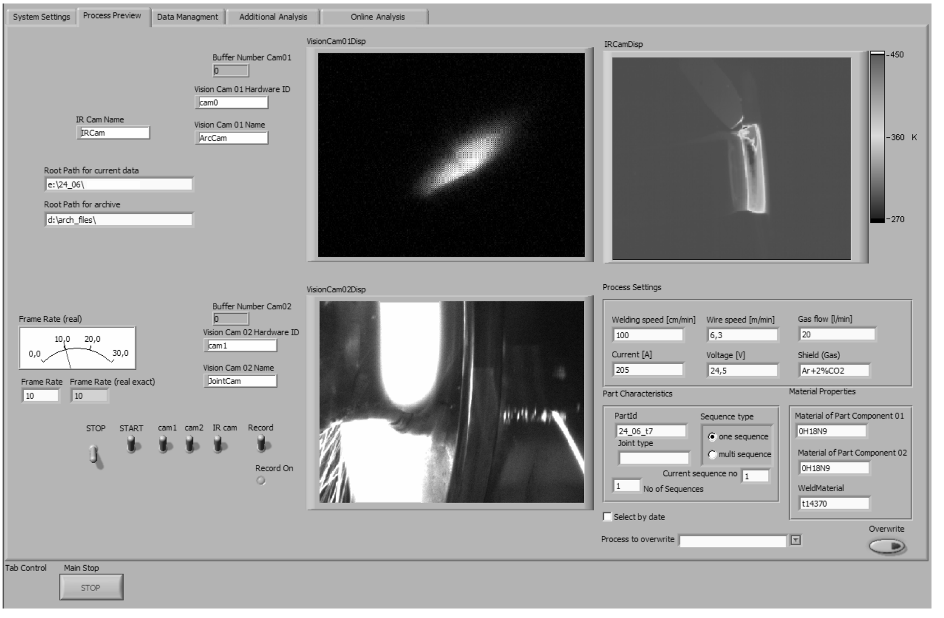


Fig. 2. User interface window of the system – module of image acquisition

The maximum value of frame rate (number of frames acquired per second – f/s) is equal to 30 f/s. This value is adjustable and common for all cameras.

3. Image management module

One of the most important modules of the software was the database, which let us gather and maintain huge sets of images as well as the results of their analysis. An integral part of the database was image patterns that represented different defects and abnormalities of joints as well as welding processes. A set of these patterns was built based on images recorded during numerous experiments performed under different conditions of welding processes and different states of welded elements and their areas. The database module was developed with the use of MySQL 5.0 Community server [11]. Data transfer between a client application integrated with main modules of the system and database was based on ODBC interface that is controlled from the *LabView* environment by means of procedures included in free-ware library sql_LV [12]. Recorded images were saved on a hard disc within separate, automatically labelled folders, containing consecutive observations. The main window of Database module is presented in Fig. 3. In order to prevent accidental loss of data, the database was supported by a procedure enabling the reconstruction of its contents. The structure and detailed description of the database are presented in [11].

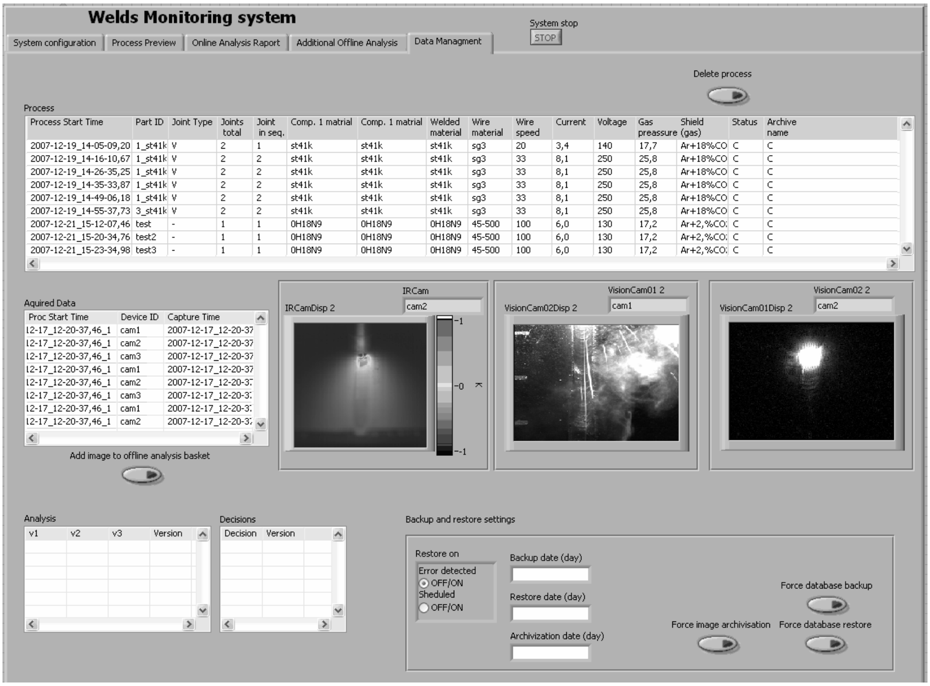


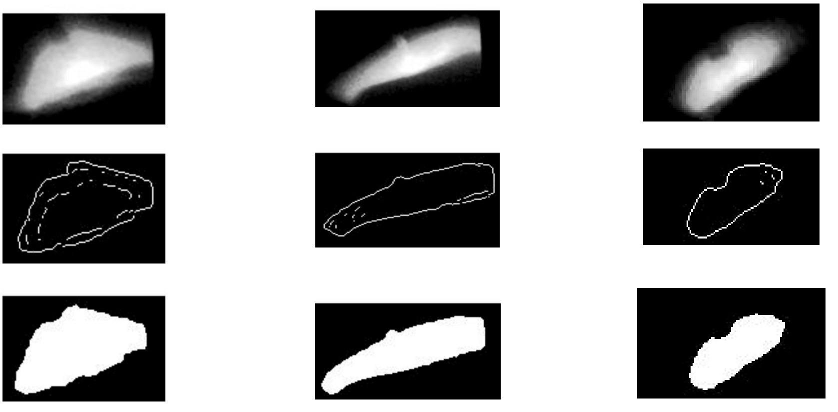
Fig. 3. User interface window of the system - database module

4. Image processing module

During the system verification, images of resolution 320x240 pixels (IR camera) and 786x1024 (two CCDs cameras) were analysed. In order to minimise processing time and focus the developed analysis procedures on specified objects regions of interest (ROI) in images were distinguished. With the present version of the system, it is necessary to indicate them in the first images recorded by each of the three enumerated cameras. Further work will be aimed at automatic selection of these areas.

ROIs represented the welding arc and joint (IR camera), welding arc (the first CCD camera) and joint (the second CCD camera). Observed areas are presented in Fig 1. Processing procedures, applied to the ROIs in the images recorded by CCD cameras as well as IR camera, were similar and consisted in converting monochromatic scale, filtration, and binarization. The main difference between these procedures was some parameters, especially values of the binarization threshold. These values were subjects of very detailed experiments.

At present, in the case of arc images, this value is determined for the whole series of images recorded by each camera. It was revealed that one common value for all images may cause a loss of some diagnostic information. The research related to automatic selection of the binarization threshold is still in progress. The approach to be applied is based on the analysis of local changes of pixel brightness, which are placed between the arc and background. In the next step, processed arc images are estimated by means of topologic features [13]. An example of processed ROIs for stable and unstable processes are presented in Fig. 4. Based on the extracted shapes, varieties of features are calculated. They are described in the following sections of the paper.



stable process Unstable process unstable process

Fig. 4. Example of processed ROIs of welding arc

Taking into consideration ROIs corresponding to images of welded joints, processing methods depended strongly on illumination of the observed area. Because of changes of illumination coming from the welding arc and light rays radiated by the self-cooling area of the welded joint, processing these ROIs was particularly difficult. Proper illumination made it possible to extract edges; thus, symmetry and rectilinearity were assessed [14].

The most crucial procedure employed in the case of thermographic images was segmentation that stood for distinguishing some regions and objects. These regions could be analysed by means of different methods. An operation carried out directly after segmentation was image binarization. The results of such operations are shown in [15]. In this case, determination of the proper threshold value was one of the biggest problems of thermogram processing [16]. The value was assumed based on experimental research. However, to estimate this value, it was necessary to analyse a series of images. Since the threshold strongly depended on welding conditions further work is aimed at its automatic selection. Distinguished ROIs after segmentation and binarization were analysed by means of different approaches presented in the following sections.

5. Image analysis module

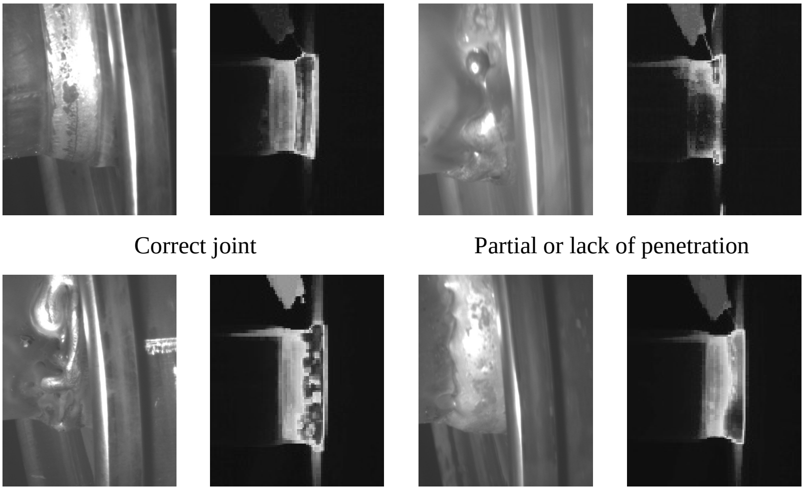
The core of the system was an image analysis module. Three types of recorded images required different approaches to the analysis. All procedures included in the module were limited to operations performed within distinguished ROIs, and the areas around ROIs were omitted. The goal of the analysis was to obtain a series of image features that could be the background for recognition abnormalities of the welding process and faults of the weld. It was assumed that a set of selected relevant features provided us with information enabling image classification into one of classes defined a priori. Every class represented different abnormalities of welding processes or weld faults. The classes were defined based on ROIs distinguished from images representing process abnormalities as well as selected welding faults.

Stability of the welding process was estimated based on images of the welding arc (Fig. 4). During initial experiments, numerous features were estimated, e.g. size of arc, centre of mass, compactness, elongation, arc symmetry, and circularity, Malinowska's coefficient and selected geometrical moments [17]. Based on correlation analysis, a set of relevant features was accepted. Observation of changes of these features let us estimate abnormalities of the process. Exemplary results of image analysis based on estimation of topological features (recorded for stable and unstable welding processes) are shown in [13, 14]. Among other factors, the stability of the welding arc is dependent on the quality of the elements being welded and an the welding parameters. In case of correctly prepared edges of welded elements, the process was stable, which entailed small deviations of arc and shape dimensions. In order to classify abnormalities of the process, pattern shapes of arc were determined.

Procedures that were developed for images representing welded joints were based on scanning operations. The goal was to look for outstanding areas or other special features. Scanning was conducted in two perpendicular directions. As a result, brightness profiles along distinguished straight lines were calculated. The approach enabled us to identify the width of the weld face and estimate the rectilinearity of its edges.

Examples of the application of scanning procedures are presented in [14]. Employment of these scanning methods also made it possible to identify welding faults like the following: concavity of the weld, metal spattering, and partial or lack of penetration. Examples of images of correct and faulty joints (in infrared and visible light) are presented in Fig. 5.

Analysis of the processed ROIs of thermograms could be carried out with the use of numerous methods. Within the framework of the research, several procedures were tested. The first approach was based on the estimation of the percentage values of binary image areas for pixels above a assumed threshold. These changes were calculated with reference to the whole area of the ROI selected during the segmentation. Then values in relation to time made it possible to identify process abnormalities. This approach could be applied to arc and solidification sub-areas.



Correct joint — Partial or lack of penetration

Lack of joint — Irregularities of edges

Fig. 5. Examples of images of correct and faulty joints

The second developed approach consisted in the estimation of horizontal and vertical temperature profiles. They were calculated along straight lines, which were perpendicular and parallel to the main axes of the weld. Results of this operation are described in [14]. Such profiles could be treated as specific functions and analysed with the use of statistics known from impulse and transient signal estimation [14, 15]. Additionally, ordering the profiles according to the time of the welding process let us acquire new images called *profilograms*. Such plots provided us with information on the instability of the welding process [15].

The third applied approach consisted in the estimation of frequency based features based on F-images obtained as results of the Fourier transform of considered images. Such spectral features, like Mean Longitudinal Fourier Power (MLPF), Mean Transversal Fourier Power (MTPF), or Mean Circular Fourier Power (MCFP), were proposed and estimated.

The first two features were values of the Fourier spectrum, calculated respectively for horizontal and vertical areas with reference to image axes (Fig. 6a). The widths of these areas were calculated as a percentage value. The MCFP parameter was estimated as a mean Fourier power calculated along a circle. The value was also determined as a percentage estimator. Examples of the diagnostic signals of estimated spectral features are presented in Fig. 6b.

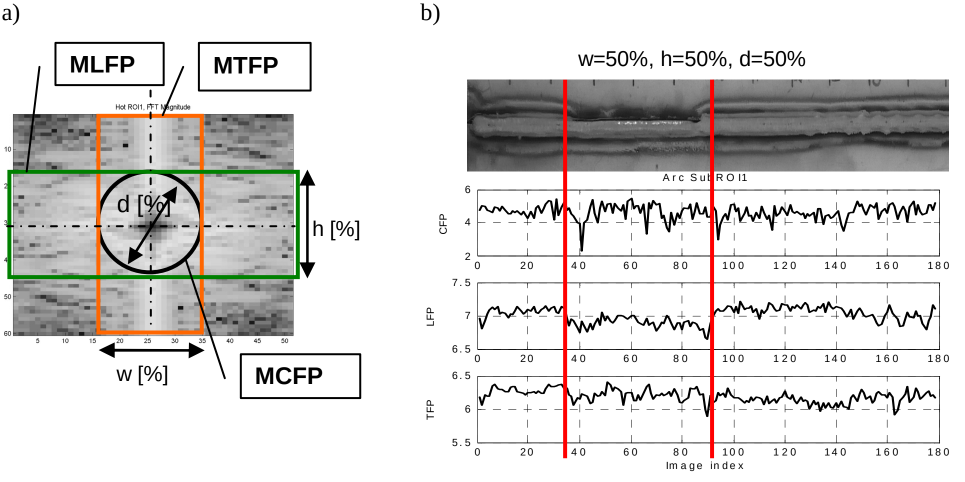


Fig.6 F-image estimated for arc area with marked spectral features a) and its diagnostic signals b)

6. Image recognition module

The main goal of the application of the system was to recognise the state of the process and some faults of welded joints enumerated above. Accordingly, it was necessary to identify two separate groups of patterns (Fig. 7).

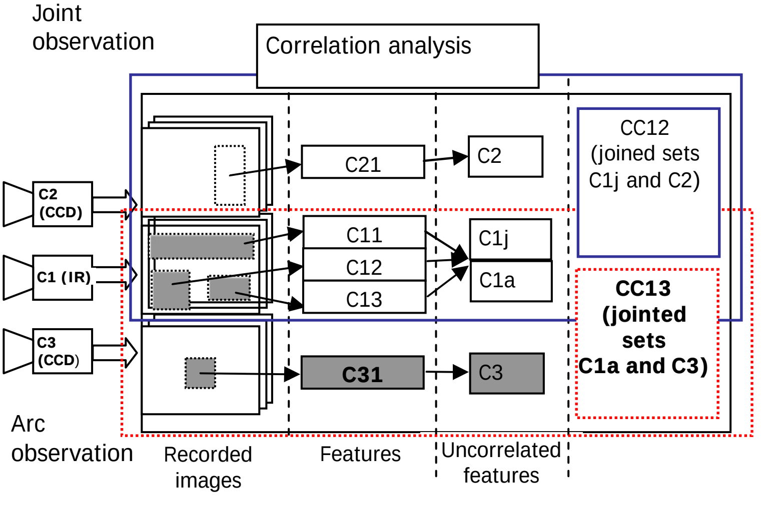


Fig. 7. Procedure of pattern identification

They corresponded, respectively, to the diagnostics of the process and the welded joints. Taking into account these two tasks, recognition algorithms were based on the analysis of features resulting from arc (assessment of the process; dotted red line) and welded joint (continuous blue line) observation. Features were estimated with the use of algorithms described within previous sections of this paper. Patterns represented process abnormalities as well as joint faults. In order to obtain appropriate reference images, a series of experiments were performed. To obtain outstanding examples of welds and processes, welding processes with improper parameters and prepared inappropriate welding elements (dirty and damaged surfaces) were observed. The results of image processing and analysis (from CCD and IR camera) in form of sets of selected relevant features were compiled. The resulting sets then underwent correlation analysis [13], which allowed us to distinguish unambiguous patterns of features. Extracted patterns were used for training two neural classifiers, which were prepared in order to assess the process and welded joint. It was important that patterns had to be identified for each process and welded elements individually, since they strongly depended on welding conditions.

At present, the system lets us identify selected kinds of joint faults and process abnormalities. The system is still under development. It is assumed that the application of the final version of the system will enable us to determine kinds of defects and their sizes and placement.

Conclusions

The diagnostic system presented in this paper is currently under verification study. Obtained results let us formulate some conclusions that can be distinguished according to system modules as follows:

– Parameters of the vision system are correct, and they let us recognise faults of 2 mm size; however, the arrangement of cameras has to be individually adjusted to the process.
– The number of image recorded per second should be set based on the duration time of single welding. Frame rate is limited by applied hardware (cams and PC). Experiments shows that (15 f/s) are sufficient for proper image recognition.
– The database and data management module meet the assumed requirements of the system, and some particular parts of this module will be improved within the framework of further work (labelling, parameter catalogue).
– The applied processing methods gave assumed results. The most important problems in the cases of all images are automatic binarization and ROI selection, and these problems are being currently investigated.
– Approaches applied within the analysis module let us distinguish separate patterns of process abnormalities and welded joint faults, and feature

selection and limitation play a crucial role (in case of thermograms, especially).

– The application of two separate neural classifiers made it possible to recognise phenomena that do not occur simultaneously; thus, they ensure process abnormalities and welded joint faults that are correlated. Obtained results depend strongly on the correctness of feature extraction, and structure of classifiers is still under verification.

A prototype version of the system will be tested during automatic welding car exhaust elements.

Scientific work financed by the Ministry of Science and Higher Education and carried out within the Multi-Year Programme "Development of innovativeness systems of manufacturing and maintenance 2004–2008".

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Recenzent:
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System diagnostyki połączeń spawanych i procesu spawania

Słowa kluczowe

Diagnostyka procesu spawania, system wizyjny, analiza obrazów.

Streszczenie

W pracy przedstawiono system wizyjny zastosowany do diagnostyki procesu spawania i połączeń spawanych. System składa się z trzech kamer (IR i dwóch CCD). Kamera IR obserwuje łuk spawalniczy i połączenie (prezentowane na jednym obrazie), podczas gdy dwie kamery CCD obserwują odpowiednio łuk i połączenie (prezentowane na dwóch oddzielnych obrazach). Sys-

tem został opracowany dla celów zastosowania w trakcie procesu spawania. Wyniki działania systemu zostały podzielone na grupę związaną z parametrami procesu i niezgodnościami połączeń. Zastosowanie systemu pozwala na rozpoznanie anomalii procesu oraz niepoprawnych połączeń. Zostały one wymienione i scharakteryzowane w pracy. Przedstawiono także przykłady i dyskusję wyników przetwarzania i analizy obrazów oraz opisano spostrzeżenia związane z zastosowaniem systemu. Obecnie, system jest w fazie weryfikacji.