IMPLEMENTATION OF AUGMENTED REALITY IN WELDING PROCESSES

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Abstract
Welding processes are special processes and special attention should be put on them when we are talking about the quality assurance problems. Standard quality management systems based on ISO standards indicate areas on which this special attention should be put, in order to obtain results which will meet the requirements. Thus, it is necessary to ensure the adequate employees’ preparation, adequate control of equipment used in a welding process, adequate work methods and systems supporting a welder in the error-free welding process realization. In this paper, applying augmented reality in order to support a spot welding process is described. The solution presented is simple and makes use of low cost devices. At the same time, a welder training time can be shortened through the use of the proposed solution. The tests of work performed with the use of the proposed solution gave good results allowing an operator to avoid mistakes during a welding process performing. Simultaneously, shortening of the process realization time is obtained.

Keywords
mistake proofing, quality assurance, special processes, Augmented Reality

Introduction
Nowadays, manufacturing systems face many problems which are a consequence of a market situation. If a company wants to be competitive it must ensure a short lead time, a good price and a good quality of a product or service.

It is particularly important to ensure adequate control of the special processes such as welding processes, which depend on many different factors and require suitable preparation as well as proper control during their execution. In order to ensure the above, a company has to:
• Plan special processes properly, in particular when they are complex [1],
• Place emphasis on the adequate suppliers selection, to be able to depend on them not only in the matter of quality but also of deliveries punctuality [2],
• Monitor processes in order to manufacture a product in a good way from the first time, not to correct them, since it takes time and consumes money [3],
• Optimize costs by the process and welders work’s quality improvement [4],
• Implement and maintain an efficient quality management system [5].

In this work, the augmented reality implementation in a quality development of a welding process realization is described. The presented method supports the welding process realized by a welder to decrease the possibility of making mistakes during the process and to make the process more efficient.

Quality assurance in a welding process
Welding processes are special processes and a special procedure is needed in order to ensure their quality. These processes are characterized by difficulties with assessing a result of the process during the process. The standard ISO 9001:2008 tells that when the results of the process can’t be verified by monitoring or measurement and, in consequence, mistakes cannot be disclosed before the utilization, the validation of the process should be performed. The validation of the processes should reveal their ability to obtain planned results.

An organization should determine settlements concerning these processes. When the settlements are concerned, they should include: criteria regarding a process review and approval, equipment approval, personnel selection, using specified methods, development and employment of procedures, indicating records necessary to be kept, as well as the information on the necessity of next validation.

The criteria concerning the process review and approval should be connected to the product of the process assessment which are performed in the validated process and its characteristics.

The equipment, which is going to be assigned to the process, should ensure the good quality and repeatability of the obtained results. That means to ensure stable work. The equipment should be controlled in a proper way, for example in TPM (Total Productive Maintenance) system. The level of control and the necessary maintenance activities can be determined with the use of a method of a machine categorization proposed in work [6].

Personnel selection is connected with choosing adequately qualified people to perform the special process. The selection should be made on the basis of an operator’s education, experience, trainings and skills.

Using specified methods means, first of all, developing them adequately to the process, as well as the accepted process results, equipment used in the process and an operator’s competence. The methods used may
also concern tools, devices, measuring instruments used in the process, environmental conditions which should be maintained during the process, and activities which should be performed during the process.

Developing and using procedures is also indispensable to ensure the repeatability of the process. The procedures should contain answers for the following questions: Who can perform the process? What exactly should be done? In what order activities should be performed? What kind of equipment should be used? What kind of activities should be done before the process starts? What is most important during the process realization? What kind of activities should be done after finishing the process? What kind of the detailed instructions should be used in the process and in the treating of the product? What is the way for process documenting and what kind of data are important from the evaluation of correctness of the process realization point of view? What kind of a signal can show the lack of correctness of the realized process? What kind of activities an operator should undertake in case of noticing symptoms showing the lack of correctness of the realized process or in case of failures?

The most important element of a welding process is the human operator [7], under the condition that other elements of the process are controlled in a proper way. Among the main causes of that, we can enumerate: the lack of possibility of achieving a hundred percent of concentration during the whole working day, tiredness of a worker, a low level of motivation to work, not sufficient understanding of procedures and lack of information, what leads to the welder’s mistakes.

That is why a created quality system and the techniques used should support the worker in the welding processes realization.

In order to ensure the quality of welding processes, ISO 3834 standards [8]–[11] are recommended. They can be used separately or together with ISO 9001. In these standards, the requirements concerning areas such as the review of requirements and a technical review, subcontractors, welders, personnel for measurements and control, non-destructive testing, welding equipment, welding techniques, storage and maintenance of additional materials, heat treatment after welding, measurements and control, nonconformities and corrective actions, calibration and measurement equipment validation, identification and traceability and quality records are included.

In order to ensure the quality of welding processes the following activities can be performed:

- Control of the input material or/and evaluation of supplier quality management systems,
- Periodical control of welding equipment technical condition,
- Monitoring the conditions of a welding process (temperature, humidity, noise, vibration, etc.) which can influence both the process and the welder,
- Assessment of the welders’ work organization (scope of work, working time, breaks, etc.),
- Evaluation of the welders’ work preparation (trainings, experience, known methods, increasing competence),
- Work methods used and their standardization (work instructions, standard devices, holders, etc.),
- Systems supporting the welding process (welding path monitoring, augmented reality, control of the process parameters).

In the further part of the paper, a way for supporting a welder in production tasks realization is described. The presented method allows to minimize a number of mistakes made by an operator and it can be one of important elements of the quality assurance in a welding process.

Case study: Augmented Reality to improve the execution of spot welding

Resistance spot welding is commonly applied in the automotive sector to join the parts of the car body since it is a flexible, consistent and above all a cost-effective process. It is applied both to manual and to automatic assembly.

The quality assurance is achieved by a careful choice of the electric parameters operated by welding quality control systems, as described in [12]–[15]. Unfortunately these monitoring systems are useful only for automatic Spot Welding, as they rely on the possibility of interacting in real time with the welder and on the exact knowledge of where will be the next welded point. A solution to improve the manual welding should pass through the empowerment of the human operator. We should transfer him/her the same information that would be available to a robot in a fully automatic cell. Our research aims at exploit Augmented Reality (AR) by:

- directing the operator to the exact point where the welding has to be performed;
- preventing selection errors of the welding program by controlling the welding parameters with the same control unit used by the robot (possible only if the position of the welded spot is known);
- allowing, to customize the parameters of every single point to optimize the spot quality;
- ensuring, through the use of the Welding Quality System (WQS), the respect of joint requirements in terms of mechanical resistance and metallurgical properties;
- notifying the operator and the supervision system of bad spots;
- preventing welding until the clamp is not on the correct position and alignment.
State of the art and known issues of manual welding

Spot welding in automatic and manual assembly stations

The spot welding process consists of forcing the passage of high current (6 – 15 kA) between two metal sheets pressed by two electrodes made of a copper alloy CuCrZr. The shape of the electrodes determines position and size of the joint.

The welding system makes use of a current transformer fed at mains frequency (typically 380 – 500 V 50/60 Hz) whose secondary, thanks to the reduced number of coils is capable to deliver the high currents necessary for welding. In the case of medium-frequency welding, the power of the transformer is instead obtained by using a Medium Frequency Inverter that transforms a three-phase mains voltage (380 V – 690 V 50/60 Hz) into a voltage at 1000 Hz – 1800 Hz frequency, with significant advantages both from the point of view of energy efficiency and of current control.

The proposed solution

In order to state what kind and level of assistance is required by welding operator, an extensive set of observations and interviews were performed at GF-Welding, a tool maker.

The workflow of the activities performed during the welding process is described here. The operator holds the electrodes in a reference point outside the operation theatre, then move the tool to the first point with a right pose. The electrodes are opened in the wider position to facilitate insertion on the sheet. They are closed to the working configuration (minimum opening). When the tool is positioned correctly and centered exactly on the welding spot, the operator selects the welding program (intensity of current, welding time and pressure over the electrodes). Then the welding starts. The tool reopens and, if there is room on the sheet, the operator repeats a new point. Eventually, the operator moves back the tool to the initial reference position.

The desired actions are: simplify the operator’s work, increase productivity, improve the repeatability of the welding points, and improve welding quality. The mere introduction of AR in the process addresses some of the objectives. The quality can be improved only by activation of WQS also in the manual welding. The system can work only if the exact position of the welded spot is known, because every point has different execution parameters. The position can be found as a side effect of the use of AR. In order to superimpose virtual objects to the real world, it is necessary to locate with fairly good accuracy the position of both the tool and of the display. This datum could be passed to WQS that therefore receives indirectly the knowledge of position where the next point is going to be joined.

Once stated the scope of the application, it is time to define exactly the set of messages that will be displayed to assist the welding operator. Due to the peculiar nature of the AR, the format we use to display the message is as much important as the datum itself. A typical defect of most AR systems is the overflow of information. The interface provides the operator too much facts and figures, distracting him from the task. The welding operator has a few seconds before moving to the next point, therefore the messages should be few, of immediate understanding, possibly graphical or symbolic. After interviews with technicians, the list of messages in Table 1 was selected, after carefully discarding everything deemed unnecessary.

Definition of the dataflow for the AR assisted solution

The rationale behind the proposed solution is described by the scheme of Fig. 1. The welding gun position is obtained by means of optical tracking of markers placed in the corners of the working area.

Table 1. List of the messages provided to the welder

<table>
<thead>
<tr>
<th>Stage of operation</th>
<th>Information</th>
<th>Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overview to prepare assembly</td>
<td>Position of all the spots</td>
<td>CAD rendering</td>
</tr>
<tr>
<td>Welding gun positioning</td>
<td>Position of the target point</td>
<td>CAD render highlighted</td>
</tr>
<tr>
<td></td>
<td>Suggested movement</td>
<td>Symbol (arrow)</td>
</tr>
<tr>
<td></td>
<td>Gun position and orientation</td>
<td>Dynamic symbol</td>
</tr>
<tr>
<td>Welding execution</td>
<td>Selected program</td>
<td>Symbol (blink)</td>
</tr>
<tr>
<td>Spot quality analysis</td>
<td>Spot quality</td>
<td>Symbol (color)</td>
</tr>
</tbody>
</table>
It is also the possible to integrate the observation with data from encoders mounted on the welding gun. Not all the degrees of freedom can be measured through encoder and therefore, presently we have not tested this solution. An external camera observes the welding zone and the AR engine augments the image by adding the welding instructions. The embedded camera of the tablet can be used instead of the dedicated external camera. We used this option to avoid placing an additional camera in the working area.

**Camera calibration**

To provide a credible combination of real and virtual objects it is crucial to perform a camera calibration both of the internal camera geometric and optical characteristics (intrinsic parameters) and of the position and orientation of the camera frame (extrinsic parameters) with respect to a reference system [16].

The intrinsic parameters take into account the camera distortion, too. They can be considered with good approximation as constants. Extrinsic parameters are variable as the camera is mounted on the welding tool that is movable. There is therefore the necessity for an initial calibration to be performed at the beginning of the work and of a real time calibration to update in real time the camera position. The two procedure are performed using different methods.

Initial calibration makes use of OpenCV standard routines [17], while iterative refinement of the control points [18] is under testing. We used as initial calibration tool either a black and white chessboard or a symmetrical circle pattern. In Fig. 2, the last version of the calibration object is presented, with superposed in the four corners the fiducial square markers that are used to determine position and orientation of the camera.

![Fig. 2. The calibration circle grid that constitute the canonical image with easy to localize control points and the square fiducial markers](image)

The calibration object (circle grid or chessboard) is observed by many different angles. On the object it is possible to individuate a set of points \( P_i \). The transformation between the object coordinates \( (X_i, Y_i, Z_i) \) and the image coordinates \( (u_i, v_i) \) is obtained through a projection matrix \( [P] \) in the homogeneous coordinate system.

\[
[P] = [K][R][t] \tag{1}
\]

Where \([K]\) and \([t]\) are the rotation and translation matrices and are extrinsic parameters, \([K]\) is the calibration matrix and is composed by intrinsic camera parameters.

\[
[K] = \begin{bmatrix} f_x & s & p_x \\ 0 & f_y & p_y \\ 0 & 0 & 1 \end{bmatrix} \tag{2}
\]

The image coordinates \((u_i, v_i)\) must be corrected for the lens distortion that is assumed to be radial and tangential. Neglecting nonlinear effects, the distortion parameters are presented as a distortion matrix \([D]\).

\[
[D] = \begin{bmatrix} k_1 & k_2 & p_1 & p_2 & k_3 \end{bmatrix} \tag{3}
\]

The meaning of the distortion parameters can be found in [17]. The matrices are identified simultaneously by comparing several (around 10) different snapshots of the same object. This is the first step in the camera calibration and is used to assign the intrinsic parameters of the camera. The second step is to determine again the extrinsic parameters of the camera, position and orientation, exactly for every frame. As the camera has a frame rate of 30 images per second it is important to adopt fast algorithms in order to keep up with the visualization rate. In this second step the parameters to be identified are the coefficients of the matrices \([R]\) and \([t]\) and can be obtained by using only four fiducial markers in the corners of the image.

The application was tested in the factory GF-Welding. A professional welder tried to execute the welding points and, after a short training time, was able to repeat the operation without errors.

**Conclusions**

In the presented solution, its specific advantages need to be underlined. Thanks to the simplicity of using the solution, it is possible to train a welder fast and there is no necessity of incurring high costs of the solution. Simultaneously, we can achieve considerable improvement of the process quality. It is also worth underlining that decreasing the costs concerning saving the time of a welding process and the elimination of mistakes, can also eliminate necessity of products repair.

**REFERENCES**

ZASTOSOWANIE RZECZYWISTOŚCI ROZSZERZONEJ W PROCESACH SPAWANIA

Streszczenie


Słowa kluczowe
zapobieganie błędom, zapewnienie jakości, procesy specjalne, rzeczywistość rozszerzona