WELD JOINT TRACKING SYSTEM IN AN AUTOMATIC INSPECTION CELL BY USING EMISSIVITY VARIATION

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Abstract: Thermography has proven to be a suitable nondestructive testing method for automatic crack inspection of welds. However automatic weld inspection raises challenges. E.g. the position of the weld might not be exactly as the predefined weld seam, and a weld joint tracking system is needed. To reduce the number of equipment used, a solution is presented in this papers. The infrared camera in the thermography system is a carrier of information of the weld path. This is used for the weld joint tracking system. It is shown that the weld joint tracker is fast enough for an on-line automatic inspection.

Keywords: Weld joint tracking, Emissivity variation, IR camera, Automatic nondestructive testing.

1 INTRODUCTION

In recent years the interest in automation of nondestructive testing (NDT) methods has increased and it is clear that automatic testing of the quality of each product is competitive. Automatic inspection of production has many advantages when it comes to time and cost efficiency (Runnemalm *et al.* 2012; Runnemalm *et al.* 2014), as well as operator independency (Carvalho *et al.* 2008). Several NDT methods are available for weld inspection, all with pros and cons (Raj *et al.* 2000). When it comes to automatic inspection of weld joints, a full field and non-contact system is preferable. Thermography is both a full field and non-contact system and has been proven to be a suitable method for automatic weld inspection (Broberg *et al.* 2014).

In an automatic NDT-cell for weld inspection, the scanning needs to follow the weld bead. There are different solutions for seam tracking available, mainly for following the weld seam before or during the welding process. Typical systems are among others through-arc seam tracking (TAST), arc-voltage control (AVC), torch sensing, electromagnetic sensing and vision based sensing (Xu *et al.* 2008). Traditionally this type of sensors are used in an operation performed before or during the welding operation i.e. it is a gap between the two sheets to be joint which the seam tracking sensor can detect. The main problem, especially for vision based seam tracking during welding, is the disturbances (e.g. heat, intense light arc and splatter). Wherefore vision based seam tracker normally consist of a thin, straight laser line positioned perpendicular to the weld seam. An optical sensor measure and analyses the variation in the line due to the gap in the weld seam. Signal or image processing are performed on the output signal from the sensor to determine the position of the weld seam (Fang *et al.* 2010). Several off-the-shelves external sensor system, commonly used in arc welding, exists today, such as systems from Servorobot, Arc products and Scansonic. In laser welding the seam tracker is today integrated in the laser optics (Lekander *et al.* 2011). Systems for tracking welded joints are though not common, due to not integrated automatic NDT application. During the weld operation, unwanted stresses and distortion are introduced to the component due to the local heat input. The distortion is changing the location of the joint compared to the predefined weld seam, and an adaptive weld joint tracker is needed in the automatic inspection cell. In addition, an automatic NDT-cell with the possibiliy to access narrow spaces is an advantage. Therefore, a weld joint tracking system with reduced number of equipments is prefarable.

In this paper, a solution for weld joint tracking based on an infrared (IR) camera is presented. By using an IR camera, the same system can be used both for weld joint tracking and inspection by thermography. This is an advantage in a fully automated inspection cell, especially for inspection of hard to reach areas where space is to be considered. The system presented in this paper uses edge detection methods on the images captured by an IR camera to find the position of the weld joint. In order to identify the weld path direction, the IR images are analyzed in at least two positions over the inspected area.

In the suggested setup of an automatic inspection cell with a weld joint tracer, the thermography system is mounted on the arm of an industrial six-axis robot. The robot arm is programed to follow a nominal path along a weld. Images from the thermography system are continuosly processed using image analyses where the weld joint is identified. An updated robot path is sent to the robot system which moves the robot arm along the updated path.

In the following the definition of automatic NDT and the theory of thermography and IR camera is briefly descruibed in chapter 2 together with the theory for image processing related to the set-up used in this study. In chapter 3 the description of the demonstrator build in this study is presented, together with the description of the weld joint tracking system build. Finaly the conclusions from the study is drawn in chapter 4.

2 THEORY

An automatic NDT-cell can schematically be divided into two parts; mechanisation of the scanning and analyse of the acquired data (Broberg 2011). The mechanisation consists of the NDT system as well as the scanning equipment. To achieve a full automatic inspection both the mechanisation and the analyse need to be automatic, as well as the interaction between them.

2.1. Theromgraphy and IR camera

A thermography system captures temperature distribution on a surface. In active thermography, as is used in this study, the temperature distribution during a time sequence due to a heat input, i.e. an excitation source, is recorded (Maldague and Moore 2001). The measurement sensor is an IR detector in an IR camera. The signal received by the detector depends on the thermal and surface properties of the studied test sample. The spectral radiance, L_λ, emitted at a wavelength, λ, of the studied surface is;

$$L_\lambda = \varepsilon_\lambda L_{b,\lambda} \qquad (1)$$

where $L_{b,\lambda}$ is the blackbody radiance at the given wavelength and ε_λ is the emissivity of the test surface. The emissivity is wavelength dependent, and also temperature dependant for high temperature variations. In addition the emissivity depends on viewing angle and surface conditions. For an inspected weld seam the temperature and viewing angle is relatively constant over the viewed area during the measurement, but the emissivity varies due do variation in surface conditions. Since the weld joint has a different surface topology compared to the vicinity, a variation in emissivity will be detected by the IR camera corresponding to the weld joint.

2.2. Image processing

A machine vision system is often referred to as an industrial system utilizing visual sensors for sensory data acquisition (Graves and Batchelor 2003; Steger *et al.* 2008). It is a key technology in manufacturing industry due to its diverse ability to e.g. supervise, document and trace changes in the production flow. A machine vision system is often connected to a mechanical device such as a robot, which can pick, remove and manipulate products in the production flow. Such a system typically consists of the following parts (Steger *et al.* 2008):

- Camera, optics and illumination.
- Vision computer for image analysis
- Communication hardware between the camera and the vision computer, such as IEEE 1394 and USB2.
- Mechanical device(s), such as an industrial robot.
- Communication between vision computer and mechanical device(s), such as RS232, Profibus Ethernet.

Images of the desired scene are captured by the camera, which can be mounted either on a mechanical device or fixed in space in the work cell. The captured images are sent to the vision computer for analyses. The result from the vision system is then sent to the mechanical device control system for further processing, e.g. move the mechanical device to a defined position in space. For camera system with lenses it can be important to take into account several properties, such as lens distortion and image noise. Lens distortion is due to irregularities in the lens system and can follow many patterns, the most common of all distortions is the radial distortion. There are many types of image noise: Gaussian, salt and pepper (saturated impulsive noise), photographic grain etc., and according to Bovik (Bovik 2005) the most common is the Gaussian. Another important issue is the relation between the image coordinates (u, v) and an object point in the camera frame coordinates (x, y, z). This can in general be expressed by the following functions, where additional camera parameters are included in the parameter vector θ:

$$\begin{aligned} u &= f_u(x, y, z, c_x, c_y, f, \theta) \\ v &= f_v(x, y, z, c_x, c_y, f, \theta) \end{aligned} \qquad (2)$$

Using the camera calibration method, the parameter vector for an unknown camera with lenses can be determined. In the procedure the camera parameters are calculated for a camera model i.e. the intrisic camera parameters θ and the camera position for each image, also called extrinsic camera parameters which also includes the relation between the mechanical devices work coordinate system and the camera coordinate system. The camera calibration calculation procedure is described in more detail in (Ryberg *et al.* 2008).

Several commercial software exists for image processing, among other Halcon and Cognex. In more research and development of demonstrations applications such as Matlab and OpenCV are commonly used.

3. DEMONSTRATOR

A demonstration cell consisting of a thermography system mounted on the an industrial six axis robot (an ABB robot, IRB 2400) has been defined at Production Technology Center (PTC) in Trollhättan, see Fig. 1. The thermography system used consist of an IR camera and a continous light source as excitation. The IR camera was a FLIR SC 5650 with a band width of 2.5 – 5.1 µm and a 27 mm optical lens. The camera had an InSb detector with a resolution of 640x512 pixels and the frame rate during the recording was 100 images/s. The exciation source used was a LUMATEX Superlite SUV-DC giving contonous ultraviolet ligth in the band pass range between 320 and 500 nm.

3.1. Implemented vision system

The vision system used in this study was custom made using Matlab from Mathworks and its Image Processing Toolbox (MathWorks Inc). The image processing toolbox comes with a large amount of machine vision algorithms and functions which can be easily implemented. Images were captured from the IR camera through a Profibus system. The images were analyzed in the vision system and the weld seam were determine. Several preprocessing operations are done to ensure good and equal images. First a cropping algorithm is applied on the original image (Fig. 2a) to remove effects from the lamp.

Fig. 1. Image of demonstrator for inspection of surface cracks. The emissivity varitiation detected by the IR camera is fed to the robot for positioning during inspection.

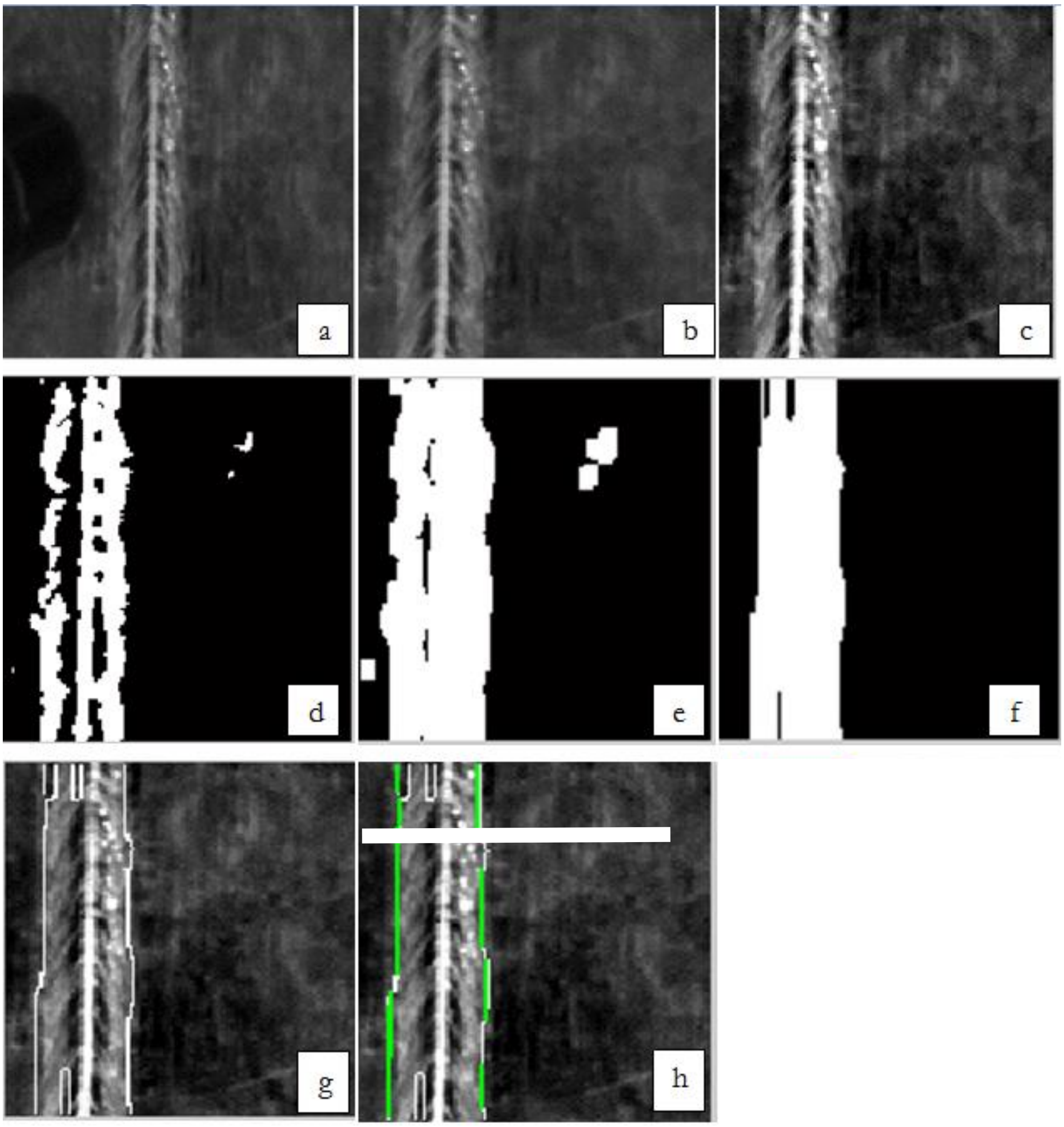

Fig. 2. Image processing's first phase. a) Original; b) Cropped; c) Contrast Enhancement; d) Binarization e) Dilatation; f) Hole filling and erosion; g) Edge detection; h) Line extraction using Hough Transform.

A median filter is however used to diminish even the smallest amount of disturbance in the image. This operation is followed by a contrast enhancement filter with the purpose to increasing the dynamic range of the original image, and the images is then converted to a black-and-white image using the threshold method Otsu's algorithm (Otsu 1979) and last a dilatation and erosion is applied to remove unwanted holes in the image, see Fig. 2(b-f). The preprocessing operation follows of analyze face with the aim to find the weld seam and then the next robot coordinate. Here two operations is used, the first is a Canny edge detection filter (Canny 1986) used followed by a Hough transformation function (Steger *et al.* 2008) to connect the edges, see Fig. 2(g-h). The position for the next measuring postionen is detected along the horizontal line in Fig. 2(h) where the searched point is the change between the plate and the weld seam where the edge is. The search box is moved downward in figure Fig. 2(h) if the left edges is not found i.e. a curved weld. The left edge is used as a reference edge. The correct position on the right edge is then calculated perpendicular from point and direction on the left edge, see Fig. 3. Finally the next measuring position includning rotation are converted from image coordinates to robot coordinates using the camera model θ, and sent to the robot.

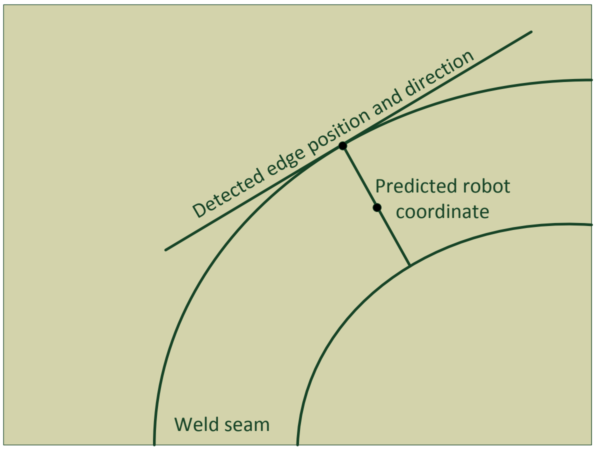

Fig. 3. Predicted robot coordinate on curved weld seam.

3.2. Robot motion planing

A rapid program in the robot is handling the coordinates received from machine vision system. The coordinate information, the points location and orientation in space (*x*, *y*, *z*, *rx*, *ry*, *rz*), is used to do coordinate transformation and rotation of the next point for the robot to move. After the coordinate manipulation, a liner motion is done to reach the new location. When reaching the new location, a new image is captured in the vision system, see Fig. 4. This will generate a discrete motion of the robot arm which follows the weld seam. This type of motion is accepted in this application due to the NDT analyze of the image parallel to the motion to the next location to capture a new image.

3.3. Localization of detected defect

The thermography system provides an image of the measured surface with the detected defect. As an example a surface defect in the vicinity of a weld is presented in Fig. 5. By analysis algorithms the defect is positioned in the captured image (Broberg *et al.* 2014; Runnemalm *et al.* 2012; Runnemalm *et al.* 2014). Due to the knowledge of the postion of the camera in relation to the scanned test sample, the location of the defect is known.

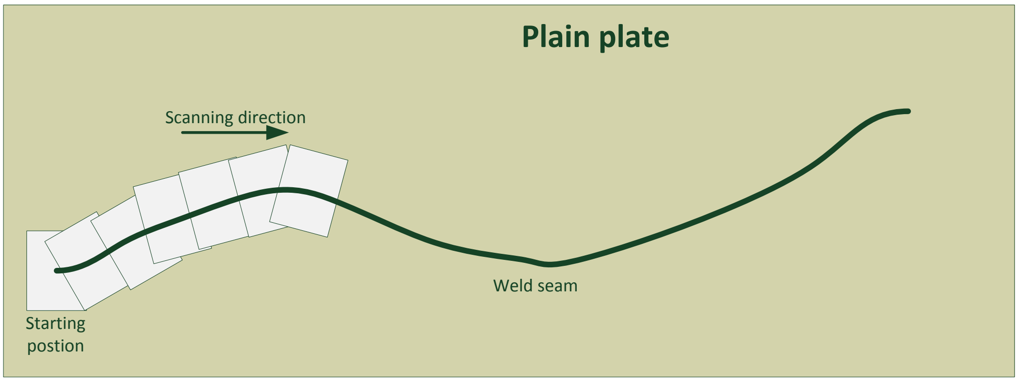

Fig. 4. Plain plate with weld seam showing the captured images used for seam tracking.

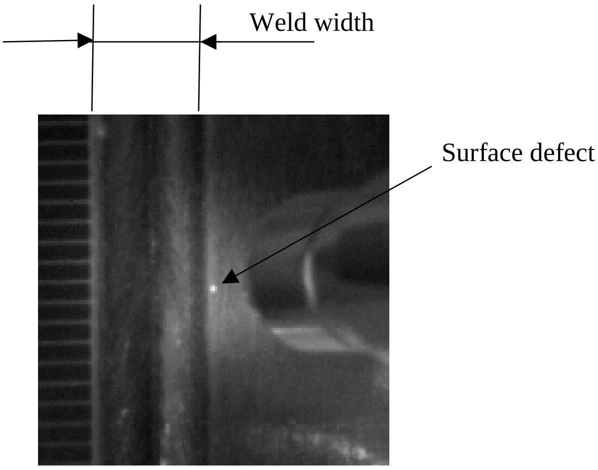

Fig. 5. Example of image from thermography system. The bright spot is the detected defect, a surface notch with the width 140 µm and 260 µm. To the left of the weld joint, a ruler is visible.

4. CONCLUSION

Several experiments have been performed to validate the system using a plane plate with an unknown curved weld joint. The plates has been welded using a beam on plate method i.e. single plate without a joint between two plates. The location of the experimental plate were randomized (both position and rotation) with the constrained that the weld joint were always detectable in the first image and the robot moved to the same starting position. Tests with different types of weld joints have been performed, both laser and Gas tungsten arc welding (GTAW) plates. The main difference between the different welding methods are that the weld seam is wider on a GTAW-welded plates. Another difference is the width of the Heat affected zone (HAZ), which is larger on the GTAW plates. The HAZ are changing the emissivity, compared to the base material, due to the oxidation on the surface. Experiments were utilized at PTC in an industrial like environment with different lightning conditions. Due to the added light from the excitation source the image processing work well independent on the surrounding light in the robot cell. The results show that the variation of emissivity is easily detected by the IR camera. It is shown that the variation in emissivity can be used as input for a weld joint tracking system. The weld joint tracking system developed in this study is shown to be able to be used in a full automatic inspection cell based on thermography with IR cameras. The system is capable to detect different types of weld joints independent of the welding method. The demonstrator shows that the weld joint tracker is fast enough for an on-line automatic inspection.

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