Lasers in Manufacturing Conference 2017

Joint tracking in zero gap laser butt welding using vision and spectroscopic sensing

Morgan Nilsen[a,*], Fredrik Sikström[a], Anna-Karin Christiansson[a], ,Antonio Ancona[a,b]

[a]*University West, Department of Engineering Sciences, 461 80 Trollhättan, Sweden*
[b]*IFN-CNR Institute for Photonics and Nanotechnologies, Physics Department, via Amendola 173, 70126 BARI, Italy*

Abstract

A critical issue in robotized laser beam welding of zero gap butt joints is to position the laser beam correctly in relation to the joint. An offset from the joint may cause a detrimental lack of sidewall fusion, a serious defect that is difficult to detect even when using non-destructive testing. In the case of machined parts, when the joint gap and misalignment are close to zero, available joint tracking systems will probable fail to detect the joint position. The proposed solution for this issue is a dual sensing approach using a vision and spectroscopic system. The vision system consists of a camera, LED illumination and matching optical filters integrated into the laser beam welding tool. Images of the area in front of the melt pool are obtained and by applying a vision and tracking algorithm the joint position can be tracked. In the spectroscopic system, a fast and high-resolution spectrometer captures the spectral emissions from the laser induced plasma via a fiber coupled collimator. The plasma electron temperature is calculated from the spectra acquired by the spectrometer and is then correlated to variations in the process. Welding experiments, using a 6 kW fiber laser have been conducted to evaluate the performance of the systems. Promising results are shown by combining the information from the vision and spectroscopic systems.

Keywords: Joining; Joint tracking; Optical spectroscopy; Vision sensor; Hybrid sensing

1. Introduction

In laser beam welding (LBW) the energy of the laser beam is focused to a small spot, enabling efficient energy transfer onto the material. This in turn enables narrow and deep welds with a small heat effected

* Corresponding author. Tel.: +46-520-223353 ; fax: +46-520-223099.
E-mail address: morgan.nilsen@hv.se.

zone (HAZ). However, the process is sensitive to how the focused laser beam is positioned in relation to the joint, especially during butt welding with technical zero joint gap width (<0.1 mm), and offsets from the joint can result in lack of sidewall fusion. This is a serious defect that is hard to detect even when using non-destructive testing methods such as ultrasonic testing. Tracking systems that control the laser beam position are used to avoid these issues, however when the fit between the parts to be welded is tight and there is no misalignment between the parts available systems tend to fail. Besides the problem of finding the joint position in the aforementioned situation, there is in general a problem when using camera systems for joint tracking with surface scratches that could be mistaken to be the joint and also the occurrence of tack welds that covers the joint in the camera image.

This paper proposes a dual sensor approach using a vison and spectroscopic system to track the joint position during welding of technical zero gap butt joints. Image and signal processing algorithms have been developed for the two sensors in order to extract the offset between the joint and the laser beam position. The limitations of each system are discussed and also how the information from both sensor systems can be used in order to enhance the tracking performance.

2. Experimental setup

The laser system, material and the monitoring systems used during welding experiments are described in this chapter.

2.1. Laser system and weld materials

Welding experiments have been conducted using an industrial robot, ABB IRB4400, and a 6kW, 1070 nm fibre laser from IPG (YLR-6000-S). The LBW tool is from Permanova Laser System AB and is equipped with a collimating lens with a 160 mm focal length and a focusing lens with a 300 mm focal length. The high power delivery fiber have a diameter of 600 µm giving a laser spot of 1.12 mm and a Rayleigh length of 13.7 mm. The laser was operated in pulsed mode with an average laser power of 2150 W and the laser beam was focused on the surface of the workpiece.

The samples used were 4 mm thick stainless steel (ss316) plates placed in a butt joint configuration with a technical zero gap. The parts were tack welded and clamped before welding to reduce process induced heat distortions. Argon was used for shielding and was supplied in a 10 mm tube with a diffusor using a flow rate of 32 l/min. The welding speed was 9.6 mm/s and welding was performed without filler material. The nominal path was a 280 mm straight line, and the robot was programmed to start welding in the joint and then it was moved out of 1.2 mm from the joint and back in. This step movement was repeated for four times during the weld.

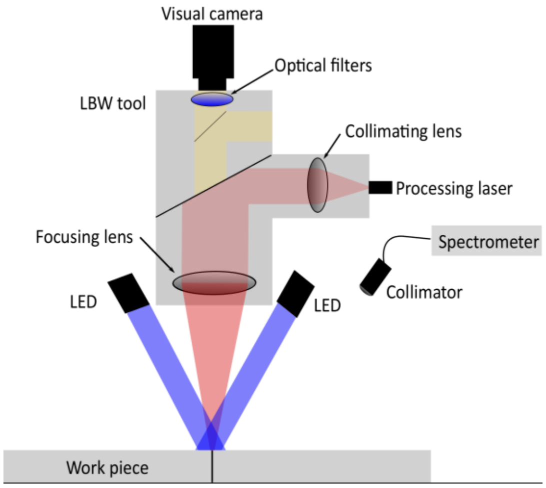

Fig. 1. Illustration of the LBW tool, sensors and illumination

2.2. Monitoring systems

The camera was integrated coaxially into the LBW tool, as shown in Fig. 1, and captured images of the welding area at a frame rate of 300 images per second. The pixel resolution of each image was 544 x 300 pixels, and the resolution on the work piece surface was 30 x 30 µm. The optical setup gave a field of view of the camera of approximately 16 x 9 mm. The LED illumination have a nominal wavelength of 450 nm and a matching bandpass filter was placed in front of the camera. At this wavelength the process disturbances are relatively low while there is still good sensitivity of the camera sensor allowing good image information even during harsh welding conditions (Sikström et al., 2014). The camera and the illumination were synchronously hardware triggered by a triggering module, and the LED was only active during the exposure time of the camera.

The spectrometer was connected to a collimator placed in an off-axis configuration as shown in Fig. 1. The spectral resolution of the spectrometer is 0.07 nm and the spectral range is 400-530 nm. The collimator was directed toward the interaction zone between the laser beam and the work piece, this is where the laser induced plasma is formed during welding.

3. Signal processing

The signal processing of the data obtained by the sensors are described in this chapter.

3.1. Camera system

An image processing and filtering algorithm has been developed in order to estimate the offset between the joint and laser beam position from images obtained by the camera. The images from the camera gives a clear view of the area in front of the melt pool where the joint is visible as shown in Fig. 2. The joint position was estimated by searching for lines in the image in front of the melt pool that could represent the joint. This was achieved by applying a Standard Hough Transform (Duda and Hart, 1972) on the binary image produced by an edge detection algorithm (Canny, 1986). A Kalman filter (Kalman, 1960) was then applied on the measurement in order to filter the noisy measurements and also to estimate the joint position when it was not possible to extract the joint from the images, e.g. when a tack weld covers the joint. In addition, to automatically detect when a tack weld is present in the image, the mean intensity of the image was calculated. This information could then be used in the Kalman filter. When a tack weld is present in the image and it was not possible to detect the joint, the measurements were not trusted and the joint was estimated purely based on the Kalman filter model predictions.

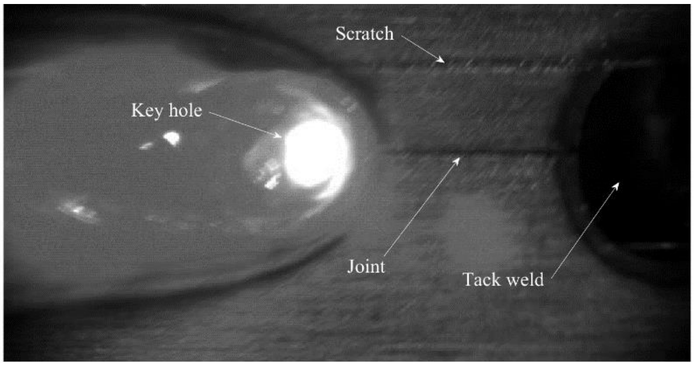

Fig. 2. Image from the camera showing the key hole, joint, a scratch and also a tack weld.

3.2. Spectrometer system

The assumption made when analyzing the spectrometer data was that the spectral emissions from the laser induced plasma formed during welding where expected to change when the process conditions changed i.e. welding out of the joint position. The spectral emission lines obtained by the spectrometer where analyzed and their intensity and wavelength where compared with the NIST atomic database (Suplee, 2009). The plasma electron temperature was then calculated from two selected spectral lines, belonging to the excited atomic specie Fe(I), using the method described in (Ancona et al., 2001).

4. Results and discussion

The data obtained during the welding experiments from both sensor systems have been analyzed offline and their tracking performance with regards to detect welding with an offset between the joint and laser beam position have been evaluated. Fig. 3 shows a welded plate from the physical experiments where the position of the tack welds are indicated by blue circles.

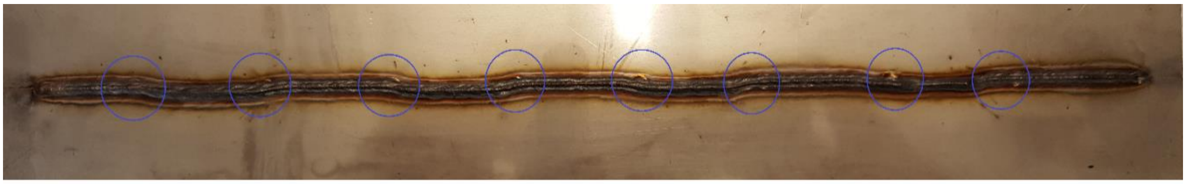

Fig. 3. Welded plate from experiment. Blue circles indicate the position of the tack welds.

Fig. 4 shows the result from the camera system for one welding experiment. Several identical welding experiments were conducted showing similar results. It can be seen from the figure that the estimated joint position has a good correlation with the robot path that was read out during welding and is used as a reference. However, it is also clear that when a tack weld is covering the joint, as indicated by the blue circles in the figure, the error in the estimate is increased. From this it is clear that a second sensor, insensitive to the occurrence of tack welds, would be beneficial.

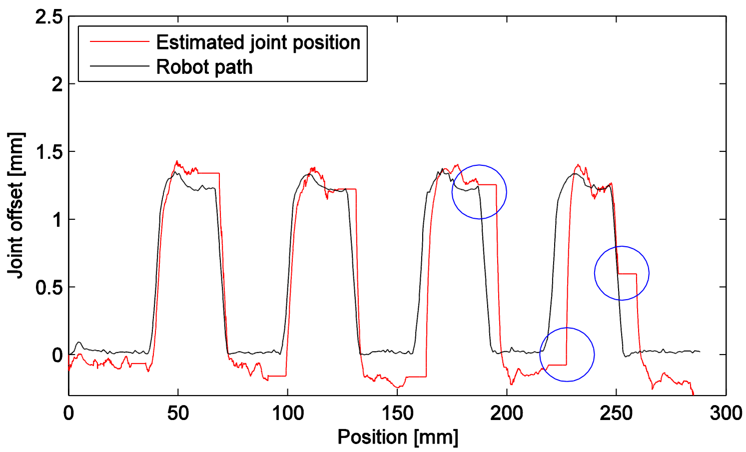

Fig. 4. Result from the camera system. Blue circles indicate the occurrence of tack welds influencing the position estimate.

Since the camera is unable to detect the joint position when a tack weld is covering the joint it is necessary to detect this situation. Fig. 5 shows the result from calculating the average intensity of each image during welding. When a tack weld is present in the image, the average intensity is significantly decreased. By setting a threshold value at 60, as indicated by the red line in the image, all images with a lower mean intensity value can be ignored, meaning the measurement from the camera cannot be trusted.

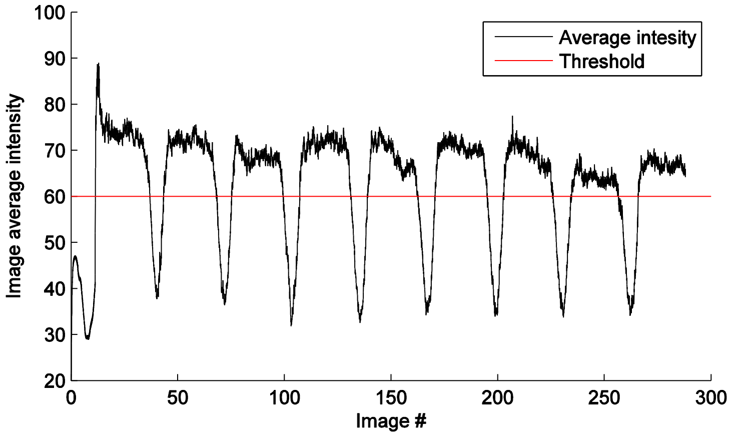

Fig. 5. Average intensity of each image during the complete welding.

Fig. 6 shows the result from calculating the plasma electron temperature during the welding experiment. There is a clear correlation between the plasma electron temperature and the robot position read out from the robot control system. When moving away from the joint, there is a clear drop in temperature that can detected by a tracking algorithm. Also, the calculated plasma electron temperature is not sensitive to the occurrence of tack welds. The plasma electron temperature signal can therefore be used as an indication of a deviation in the welding motion out from the joint, especially when the vision algorithm has captured a tack weld in the image and the camera measurement cannot be trusted. Hence a combination of the data from the camera and the spectrometer shows promising results for tracking the joint position, even when there are tack welds hiding the joint.

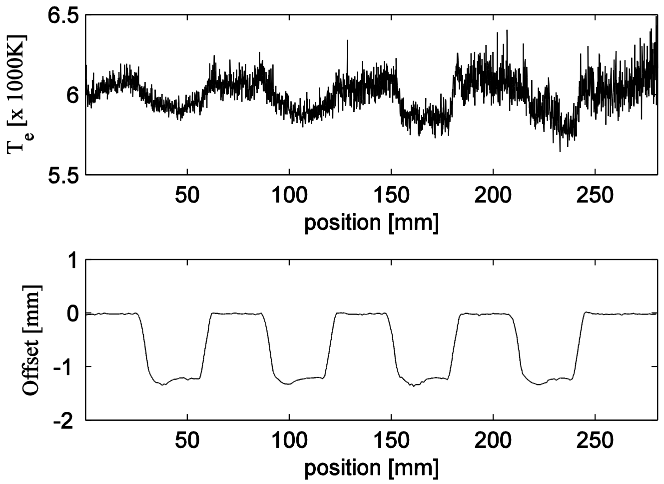

Fig. 6 Result from welding experiment showing the plasma electron temperature on the top figure and the robot position in the lower figure.

5. Conclusion

The performance of the camera and spectroscopic system to detect a welding motion with offsets away from the joint have been experimentally evaluated. By using a camera, LED illumination and matching optical filters it was possible to obtain high quality image information of the area in front of the melt pool where the joint is visible. An image processing algorithm was developed to extract the joint position from images. A strong correlations was found between the estimated joint position and the robot position read out from the robot control system. However, when a tack weld was covering the joint the camera system was not able to detect the joint position. By calculating the average image intensity of the images obtained by the camera it was possible to detect situations when a tack weld covers the joint. This information is useful when deciding if the data from the camera should be trusted or not. By analyzing the data from the spectrometer it was possible to calculate the plasma electron temperature from the spectral lines obtained during welding. A strong correlation was found between the plasma electron temperature and laser beam position with regards to the joint. Also, it was found that the signal from the spectrometer was not sensitive to tack welds that cover the joint. A promising method for tracking the joint position can therefore be achieved by combining the joint position estimate from the camera, the knowledge of when a tack weld is present and the information from the spectrometer.

Acknowledgements

This work was supported by the People Programme (Marie Curie Actions) of the European Union's Seventh Framework Programme (FP7/2007-2013) under REA grant agreement no 608473 (MoRE program project "Hy-Las" - Hybrid sensing for understanding of laser welding technology for process control). Funding from the VINNOVA project RobIn (2014-05227), G5-Demo (2013-04666), and the KK funded profile SUMAN (2010/0283) are also acknowledged.

References

Ancona, A., Spagnolo, V., Lugarà, P.M., Ferrara, M., 2001, Optical sensor for real-time monitoring of CO2 laser welding process, Appl. Opt. 40(33) 6019-6025

Canny, J., 1986. A Computational Approach to Edge Detection. IEEE Transactions on Pattern Analysis and Machine Intelligence PAMI-8 (6): 679–98. doi:10.1109/TPAMI.1986.4767851

Duda, R.O., Hart, P.E., 1972. Use of the Hough Transformation to Detect Lines and Curves in Pictures. Communication of the ACM 15 (1): 11–15. doi:10.1145/361237.361242.

Kalman, R. E., 1960. A New Approach to Linear Filtering and Prediction Problems. Journal of Basic Engineering 82 (1): 35–45.

Sikström, F., Nilsen, M, Eriksson, I., 2014. Optical Methods for In-Process Monitoring of Laser Beam Welding. In Proceedings of the 6th Swedish Production Symposium, Gothenburg, Sweden.

Suplee, C., 2009. Atomic Spectra Database. NIST. https://www.nist.gov/pml/atomic-spectra-database.