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Evaluation of U- shaped weld prep identification and tracking.

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***Abstract*—An autonomous welding system must be able to identify and extract the relevant features of the weld seam to generate an accurate weld path. Furthermore, the system must be able to adapt the weld torch position in real time during the weld. This has led to a two-stage approach, with the first stage identifying the weld path from a roughly scanned weld seam and the second stage adjusting the weld torch position in real time. In order to track weld seams, it has become popular to utilize a laser line scanner due to its versatility in measuring a wide range of materials and the non-contact nature.**

Three methods were explored in extracting the shoulders of a U-shaped weld prep. This included a clustering method utilizing a density based spatial clustering approach, a line of best fit approach and an image processing approach utilizing Hough line transforms. Both the clustering and line of best fit approach use a spline fit to find the bottom of the weld prep. While the image processing approach uses a circular Hough transform to find the same position. Further testing, with real world data, showed that the clustering approach struggled when the weld prep was not perpendicular to the scanning axis. This issue was not observed in either the line of best fit method or the image processing method, however the image processing method often found multiple lines on the same shoulder of the weld prep. This led to more testing being carried out with the line of best fit method which tended to be the most robust method. The main drawback of this method was the higher computational requirement. However, during the real-time seam track testing it was found that the robot position could be updated at 30Hz without the use of buffers.

I. INTRODUCTION

When two parts are joined by a weld, the interfacing area is known as the weld seam. In order to create a more homogeneous joint a weld prep is normally used. This is achieved by the machining both interfacing faces. When the two faces are joined the machined faces typically conform to patterns derived from either a U or V shape as these are easy to machine and conform to the British standards [1]. An image taken from the British standard showing various weld preps can be seen in Figure 2.

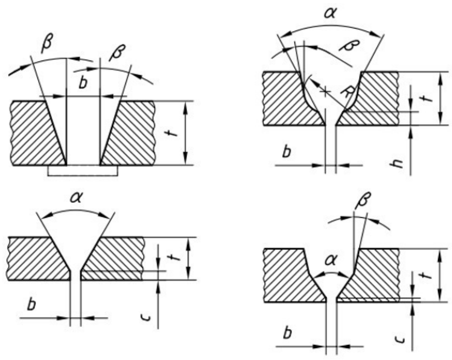

Figure 2. Weld prep examples taken from British standards BS EN ISO 9692-1:2013(E) [1].

The weld seam is a crucial component in obtaining good quality welds leading to weld seam tracking becoming more prevalent in the automation of welding processes. This can be seen in the increased interest in a large number of sectors including the automotive, ship building and nuclear repair industries [2] [3]. This is most likely due to the increased use of complex geometries, harsh working environment for welders as well as the increased need for better quality control [4][5]. With this greater need in weld seam tracking, many researchers have tended towards the use of laser line scanners due to their decrease in cost over the years as well as their ability to work with a wide variety of materials [4]. As stated by Pires et al. the trend for seam tracking techniques has been to move from a two pass approach obtaining the geometry and then following the tracked seam in the second pass to tracking the seam in real time while obtaining information about the weld seam [6].

II. METHODOLOGY

The purpose of this work is to identify a U-shaped weld prep using a laser line scanner with the intention of generating a robot weld path from the extracted features. This allowed for any errors in the machining or the work piece fitting process to be accounted for and the robot path to be adjust to these errors [7]. Once the scan path has been generated the robot

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could use the same seam tracking algorithm to weld the bespoke seam and adjust the path in real-time as the part warps and distorts due to the welding process. The equipment used during this evaluation included a Micro Epsilon 2900-100/BL laser line scanner, a KUKA KR16-2 controlled by a KRC-2 controller utilizing both KR-XML and Robot Sensor Interface (RSI). An image of the laser scanner calibration routine designed for this experiment can be seen in Figure 3.

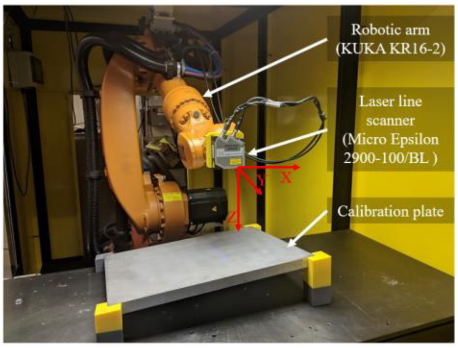

Figure 3. Setup used for generating the laser scan data.

During the testing the Laser scanners co-ordinate system was used. A depiction of this co-ordinate system can be seen in Figure 4. When the robot moves linearly over a weld prep, such as the image shown in Figure 5A, the laser scanner was able to capture the profile of the weld prep which can be seen in Figure 5B, this figure along with the other figures in this report use the laser scanners reference frame as described in Figure 4.

Figure 4. Image showing the laser scanner co-ordinate system.

The full profile of the weld seam was initially scanned with feature extraction used to generate a robot weld path. Once the weld path was generated the same feature extraction algorithm could be used to adjust the robot position in real time as the component warps and distorts under the welding conditions. Therefore, the feature extraction must be able to work in a deterministic and timely manner.

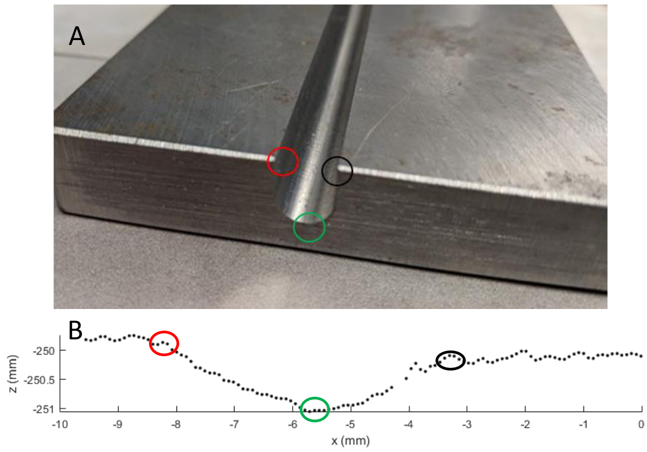

Figure 5. Example of a U-shaped weld prep (A) and a graph showing the laser scanner data of a U-shaped weld prep.

III. WELD PREP IDENTIFICATION

To identify the weld prep, raw data was taken from the laser scanner, an example of which can be seen in Figure 5B. The key features that needed to be extracted can be seen in Figure 6. These include the left shoulder labelled as A which is in red, the bottom of the U which is labelled B and C found in green and purple respectively, and finally the right shoulder D which can be seen in black. If the weld prep doesn't have a gap, then position B and C are coincident.

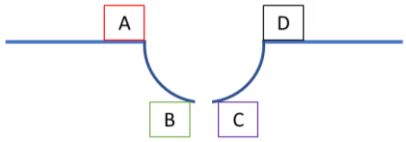

Figure 6. Diagram of a labelled U-shaped weld prep.

These features are paramount for a successful weld to be created as it stops the filler wire either touching down or contacting the wall of the weld seam. As well as identifying where to deposit the filler wire.

It was identified that finding feature A and D, as described in Figure 6, was the most prevalent as this would generate the region of interest to find feature B and C. In order to extract these features, three methods were explored:

- a clustering method
- a line of best fit method
- an image processing approach

Once the edges of the shoulders were identified for both the clustering and line of best fit approach, the data points between the two shoulders were extracted and a spline was fitted between them, an example of this can be seen in Figure 7. The data point closest to the bottom of the spline was assumed to be the bottom of the weld prep and thus position C or D in Figure 6 could be found. If there was data missing at the bottom of the weld prep it would be assumed that there was a gap between the two mating faces. Therefore, instead of C and D being coincident they would be identified as two separate points at either edge of the gap as described in Figure 6.

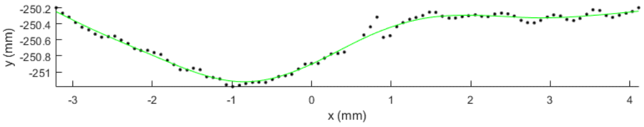

Figure 7. Identifying bottom of the U weld prep using a spline fit.

A. *Clustering approach*

The first approach used a simple clustering algorithm to find the shoulders. This method utilizes a Density-based spatial clustering [8] to group points based on their Z values, the group with the largest number of data points would be identified as the shoulders with the edge of the shoulders being identified as largest gap between neighboring points in the data. Alternatively, the edge of the shoulders could be found by clustering the shoulder values based on X values, as this would create two distinct groups for the left and right shoulders as shown in Figure 8.

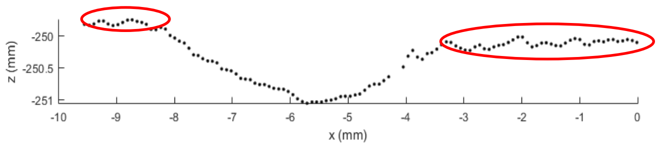

Figure 8. Approach 1(Clustering) showing the single cluster making up the two shoulders of the U weld prep.

The main drawback of this method was its susceptible nature to noise, particularly when gaps occurred in the data or if the data was not levelled. An example of the data not being levelled can be seen in Figure 9, this leads to the shoulders being misidentified, as the largest group no longer occurs at the shoulders.

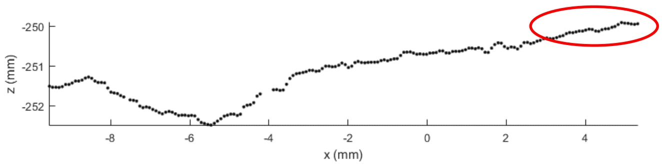

Figure 9. Misidentification of shoulders due to an off-axis scan.

B. *Line of best fit approach*

The second approach uses a line of best fit to identify the two shoulders as shown in Figure 10. The line of best fit was generated for both the left shoulder and right shoulder independently as shown by the red and blue lines respectively. The line of best fit was created by taking the first 1.5mm of the shoulders. This was approximately a third of the full shoulder length, thus having a good compromise between representing the shoulder accurately, while maintaining the capability of handling off center scans, such as the scan shown in Figure 9. Once the line of best fit was generated an upper and lower limit could be set for the edges of the shoulders. Once the points deviate outside the lower limit, this was identified as the edge of the shoulder. The lines of best fit also allowed for more information to be categorized such as the height and angle difference between the two shoulders. This could be used in an adaptive welding process to change the relevant robot or welding torch orientation in real-time.

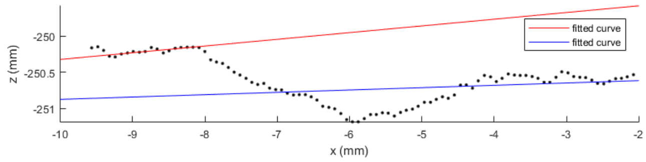

Figure 10. Approach 2 (Line of best fit) to find the shoulders of the weld prep.

This implementation can also be used to level the data, thus dismissing the problems identified in the clustering method. However, it does require some initial conditions; this includes the maximum gap size at the bottom of the weld prep, the minimum shoulder length to generate the lines of best fit, as well as the minimum and maximum size of the prep itself. These values make the overall finding of the two shoulders much more robust compared to the clustering process. This method can also be used to identify other types of weld preps including V preps and U/V hybrid preps as it only requires a straight shoulder leading into the weld prep.

C. *Image processing approach*

The third and final approach uses an image processing method known as Hough line transform [9] to find the shoulders of the weld seam. Unlike the other approaches it uses a circular Hough transform to find the bottom of the U prep as shown in Figure 11. The Hough transform uses a binary image of the laser scan data to identify the prominent lines within the image. This is based on information given by the user, including the minimum length of the line as well as the minimum distance between two-line segments. A processed image with lines and circles identified can be seen in Figure 11.

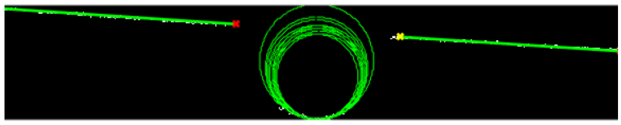

Figure 11. Approach 3 (Hough Transform) to find the shoulders and the bottom of the weld prep.

The main drawback of this method is in the conversion between an image which is measured in pixels and the data given by the laser scanner which is in mm. This conversion must be equal to the resolution of the laser scanner camera. If the image was set to a smaller resolution, then detail of the scan would be lost, while if the image was larger than the resolution of the laser scanner then the extra pixels would be redundant and increase the computing power required. This would lead to a very large image size which may be impossible to process on conventional hardware in real time. In testing it became apparent that 10μm resolution was the limit before the file size became too large to compute quickly, however this was finer than the resolution of the laser scanner used. Further testing also showed, that dependent on the input parameters selected, often multiple lines would be detected on the same shoulder, as shown in Figure 12. This would lead to further decisions needing to be made, most likely based on a maximum and minimum U prep size to decide which line was correct. The final drawback is that, due to the nature of the circular Hough transform, the image processing method can only be used on rounded weld preps, such as the U weld prep described in this paper.

Figure 12. Errors in the Hough line approach with multiple lines identified when only a single shoulder is present.

IV. EVALUATION AND CONCLUSION

Although the clustering approach is simple to implement, due to its inability of handling off axis scans, it is difficult to use in a real-time seam tracking application. Although, further work could be done on leveling the data before the clustering is completed. In contrast to this, the image processing approach using Hough transforms, allows for off axis measurements as well as being considerably quicker than the other methods. However, when testing on real world data it became apparent that this approach was very susceptible to the user inputs with multiple Hough lines generated when there is only a single line present. Due to the similar amount of user input required, it was decided to take the line of best fit approach further as this is the only approach that would be suitable for other weld prep shapes including V and hybrid U/V preps. This would increase the versatility of the system over the clustering approach or the image processing approach. However, it should be noted that this method does require higher amounts of computational power over the image processing approach.

As stated, the line of best fit approach was taken forward and implemented into the real-time robot control system. This system used the bottom of the U prep to track where the weld torch should be in real time. Initially a full scan of a seam was completed and a path generated the results of which can be seen in Figure 13, with the same colour convention used as in Figure 6. The figure shows a successful extraction of features with a smooth spline following both shoulders and the bottom of the prep without being distorted by the large amount of the reflection. Once the path was generated the U prep was moved a few mm from this generated path to simulate the seam moving under welding conditions. The robot scanned the weld prep at a constant frequency while moving at a constant speed of 5mm/s. The system was able to find all four features well as identifying the center of the weld prep, the robot was then told to adjust its position to move the center of the weld prep into the center of the laser scanners field of view. It was observed that the robot adjusted its position at 30Hz with a maximum offset of 0.5mm from the current position. This testing showed the successful implementation of a closed loop seam tracking algorithm which could be used in a real time welding application.

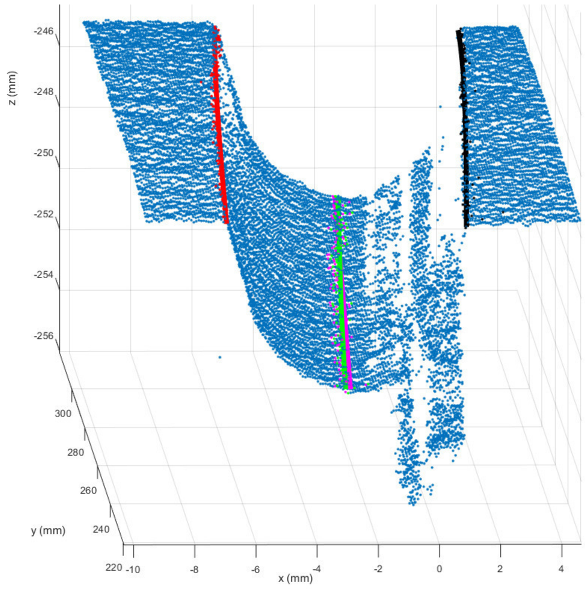

Figure 13. Image of feature extraction using the line of best fit method.

To further develop this seam tracking system, further work should test the versatility of the system by testing various weld prep shapes, as well as focusing on further refining the algorithm to remove outliers and including some more advanced adaptive welding techniques based on the orientation of the shoulders. Finally, some further testing could be done on the performance of this system during a real-world welding application.

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REFERENCES

[1] British Standard, "BSI Standards Publication Welding and allied processes — Types of joint preparation shielded metal arc welding , gas welding ," BS EN ISO 9692-1:2013(E), 2013.

[2] J. N. Pires, A. Loureiro, T. Godinho, P. Ferreira, B. Fernando, and J. Morgado, "Welding robots," *IEEE Robot. Autom. Mag.*, vol. 10, no. 2, 2003.

[3] M. Wilson, "The role of seam tracking in robotic welding and bonding," *Ind. Rob.*, vol. 29, no. 2, 2002.

[4] A. Rout, B. B. V. L. Deepak, and B. B. Biswal, "Advances in weld seam tracking techniques for robotic welding: A review," *Robot. Comput. Integr. Manuf.*, vol. 56, 2019.

[5] Y. Zou, L. Jinchao, X. Chen, and R. Lan, "Learning Siamese networks for laser vision seam tracking," *J. Opt. Soc. Am.*, vol. 35, no. 11, 2018.

[6] J. N. Pires, A. Loureiro, and G. Bolmsjö, *Welding robots : technology, system issues and applications*. Springer, 2006.

[7] S. B. Chen, "Research evolution on intelligentized technologies for arc welding process," *J. Manuf. Process.*, vol. 16, no. 1, 2014.

[8] M. Ester, K. Hans-Peter, S. Jorg, and X. Xiaowei, "Density-Based Clustering Algorithms for Discovering Clusters in Large Spatial Databses with Noise," in *Association for the Advancement of Artificial Intelligence*, 1996, no. 96.

[9] P. V. Hough and A. A. Mich, "Method and means for recognizing complex patterns," US Patent 3069654, 1962.