Partial Automated Multi-Pass-Welding for Thick Sheet Metal Connections

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Abstract

The production of tubular-node-connections, which are required for the construction of offshore wind energy plants or converter platforms, is subject to high manufacturing standards. The welding process is currently carried out manually and requires a great deal of experience on the part of the welder. In this process, one or more branch member pipes are welded to a base pipe, which vary in their diameters and alignment to each other. This results in a small batch size for which no standard automation solution can be considered. The approach of a pre-defined offline path-planning is not expedient, since the weld metal forms differently with the multiple curved geometries and the desired target result cannot be achieved with an integrated compensation. The approach for automation combines the experience of a skilled welder with the accuracy of an industrial-robot. For implementation, the robot system moves along the welding contour with a 2D-profile sensor. The joint profile is recorded at defined measurement

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points. Parallel to the seam cross-section, the current gradient of the geometry in relation to the horizontal plane is stored. After all the information has been generated, it is visualized for the operator in a graphical user interface. The operator can use his experience in the field of welding technology and can carry out the positioning of the weld seam in every single scan generated. The decisions on positioning are stored in the system and serve as a base for a future implementation of an automatic system for positioning welding beads on multi-curved contours.

Keywords
Multi-pass-welding · Sensor-based programming · Lightweight robots · Robot arc welding

1 Introduction

In order to reduce the manual work the developed process steps for the semi-automated welding of tubular-node connections already start with the consideration of the tolerance-afflicted pipe production. Here, production deviations of 1% in the pipe-diameter can occur. The variance in the wall thickness can be around 17.5% [1]. In order to take these inaccuracies into account and to achieve an optimal result for welding, both pipes are measured for the cutting process. The branch member pipe is cut by robot on the base of the real geometry [2, 3].

For the welding process it is first of all assumed that a constant welding parameter set is used over the entire three dimensional welding contour. This has already been determined by experimental tests. Since this way the identical weld volume is produced at any time, the cut and the seam preparation is designed with regard to this boundary condition. The main geometry is based on the AWS D1.1 [4].

If the branch member pipe has been cut, it is placed on the position to be welded. The root layer is weld by hand and then grounded. This preparation serves as a base for semi-automatic welding, which will be done by the orbital welding system (Fig. 1).

The orbital welding machine is clamped in the branch member pipe with a clamping mechanism. By means of an additional linear unit and an endless rotation axis, the working area of the robot is extended so that the tubular node connection can be processed continuously [5].

2 Description of the Developed Process

The developed process serves as a base for the automatic welding of tubular node connections. Here, a 2D-profile sensor is used to record the geometric data of weld seams, which are manually evaluated by an experienced welder and serve to plan the path of the

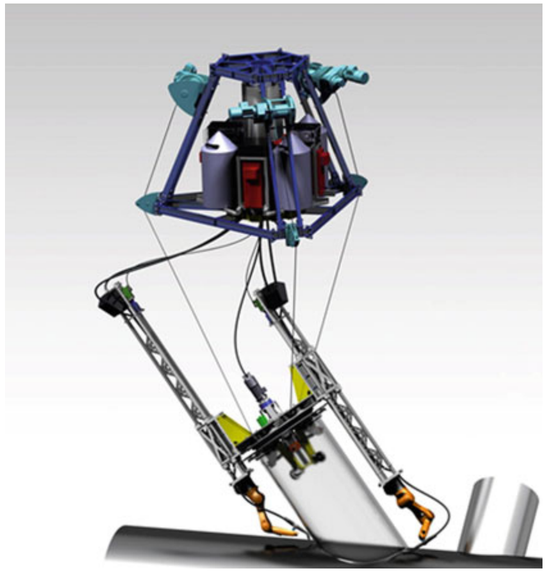

Fig. 1 Orbital welding system for partial automated welding [5]

welding process. For the evaluation of the geometric data a software was designed, which serves the welder for visualization. Based on this, the evaluated data are linked to the raw data. These links are to be used for the training of a neural network.

2.1 Solution Approach

As much data as possible must be generated to implement the solution approach. First, measurement points are determined on the intersection contour of the two pipes to be welded. Based on these points, a robot measuring program is generated, which is run with the orbital welding machine. As the number of measurement points increases, the data generation as well as the accuracy of the welding path and geometry generation increases.

At each of these points a scan of the seam geometry is generated during the measuring run. In the next process step these are transformed in a self-developed software in combination with the measuring program of the robot with regard to the horizontal plane. This is necessary to consider the influence of the earth's gravity on the formation of the weld bead.

Based on the transformed scan data, an experienced welder determines the position of the bead to be welded. Depending on the slope and seam opening angle, the welder also adjusts the torch orientation.

Depending on the selected positions and orientations, a robot welding program is generated. Parallel to this, this data is stored in the transformed scan data and saved. These data serve as a base for teaching the neural network. After the welding process, the measurement process is repeated. Now the comparison between welded and unwelded geometry can be performed and the choice of welding position and orientation can be evaluated.

2.2 Test Setup

A lightweight robot with a load capacity of 10 kg is used to carry out the measurement data generation and welding. It has a 2D-profile sensor and a welding torch attached to the hand axis. The robot controller and the profile sensor are accessed and the communication is coordinated via a higher-level control system with the self-developed software. The programs for the measuring and welding program are generated on the control system and transferred to the robot control system. The robot stops at defined measurement points and triggers the sensor to start a scan. This scan data is then transferred to the higher-level control system, where it is transformed and visualized on the software for the operator (Fig. 2).

2.3 Software/GUI

The developed software with user interface serves the operator to visualize the scanned weld seam profiles and for spatial orientation. Here, he is given a multitude of setting options, which he can also influence during manual welding. Depending on the welding

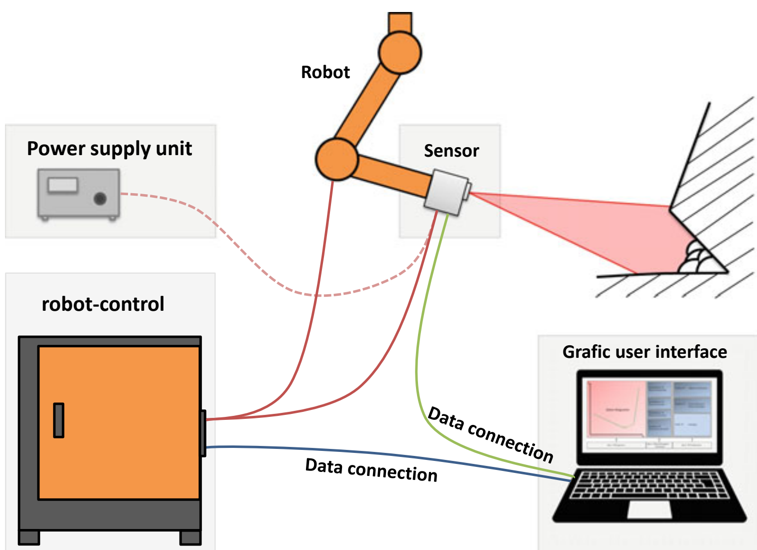

Fig. 2 Test setup for measurement process

position, the orientation of the torch can be adjusted or the respective type of movement can be changed. When these settings are adjusted, the orientation of the torch changes in relation to the scan data. Thus the visualization of the scan data in combination with the welding torch geometry is helpful as a preliminary stage of a collision control.

The following describes the areas shown in Fig. 3 and shows which changes can be made manually:

1. Load Profiles or new data
2. Slider for scans
3. Definition welding torch geometry
4. Definition torch orientation
5. Positioning weld
6. Coordinates for the robot-program
7. Visualization welding torch and Scan.

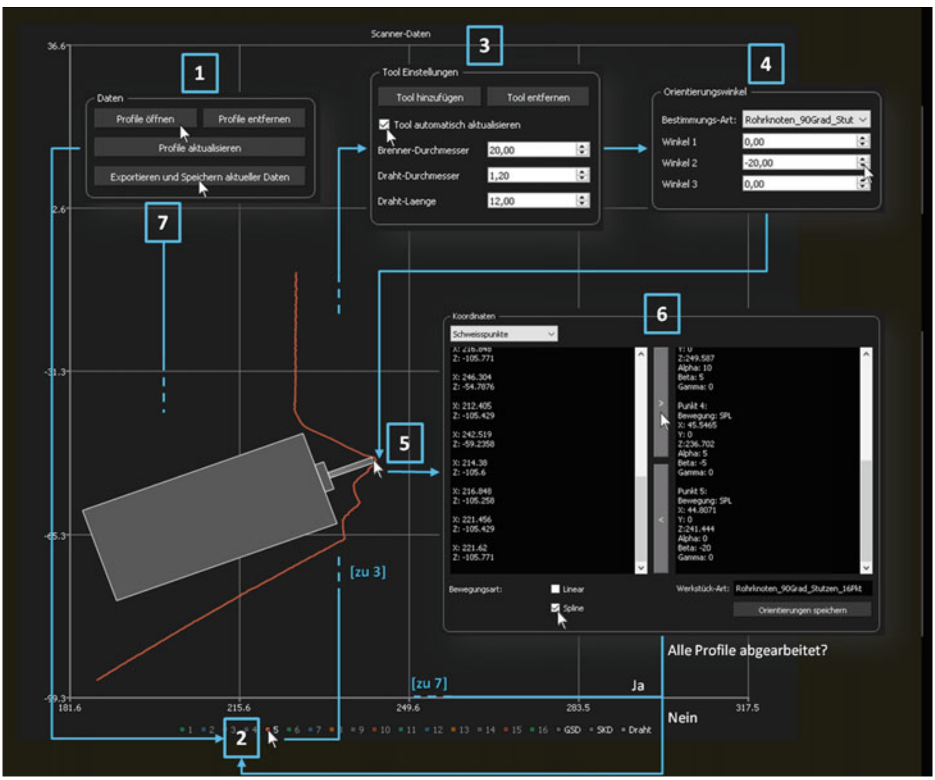

Fig. 3 Graphic user interface for positioning the weld

3 Implementation

To implement the solution, the first step is to create a gradient diagram of the intersection contour. This diagram is used to define interpolation points at which scan data of the seam geometry are generated in the subsequent process. Using this scan data, an experienced welder determines at which position and with which orientation the next weld bead is to be welded. At the same time, the system stores the welder's decisions and stores them with the generated scan data.

3.1 Planning the Welding Path

Depending on the geometry of the tubular pipe connection and the resulting intersection contour, measurement points must be defined to generate the measuring path (Fig. 4). Based on a 90° tubular node connection, the intersection contour is shown in Fig. 5. Based on the gradient, characteristic points, such as a change in gradient, minima or maxima are selected, which represent the contour as accurately as possible by means of a spline interpolation. At the defined points (red crosses in Fig. 4), measurements are made for the welding process, at which welding positions and alignments are determined by means of a graphical user interface.

By increasing the number of measurement points, both the accuracy of the trajectory and the amount of data required for training are improved.

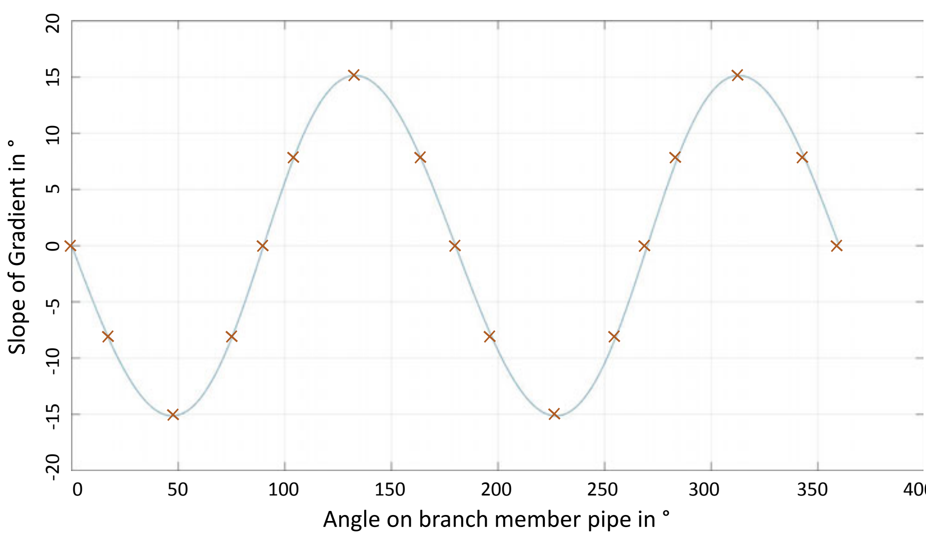

Fig. 4 Slope of gradient for a welding path at a 90° tubular connection with measuring points

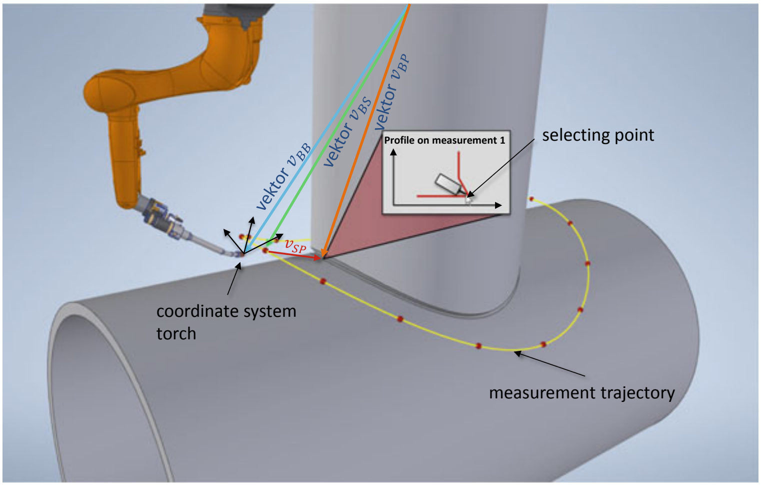

Fig. 5 Measuring run including vectors

3.2 Scan of the Welding Path

A measuring program is generated based on the generated interpolation points. The weld seam is scanned at the measurement points with a defined safety distance. For the subsequent transformation into the welding torch coordinate system, the scan data are generated in the RobRoot coordinate system, which is located in the center of the orbital welding system. After the measuring run is completed, the scan data are transferred to the software.

3.3 Human–Machine Collaboration

For the visualization, the scan data are first transformed according to their real orientation to the earth's gravitational force in order to take the influence of this force into account when positioning the next weld seam. Figure 6 shows a transformed scan with a welding torch. The red contour corresponds to the recorded scan data where 2 welding beads have already been welded. For the positioning of the third welding bead the welding position is selected in the first step. With the torch geometry stored in the software, the torch orientation is defined in the second step. Here the accessibility is already checked. By changing the wire length, minor adjustments can also be made.

Since the welds are performed in out of position and not in continuous flat position like in [6] or [7], the torch orientation along the welding contour must be adjusted in the third step as shown in Fig. 7. Welding is done in a falling position, whereas welding must be done in a dragging orientation and in a rising position in stabbing orientation.

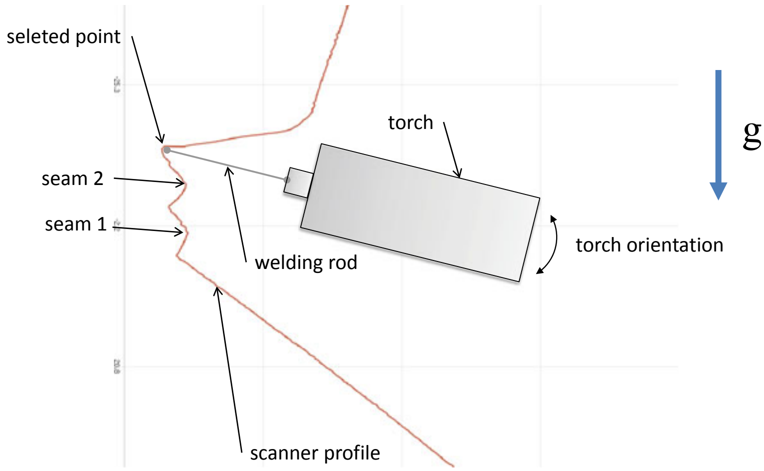

Fig. 6 Measured scanner profile for positioning next seam

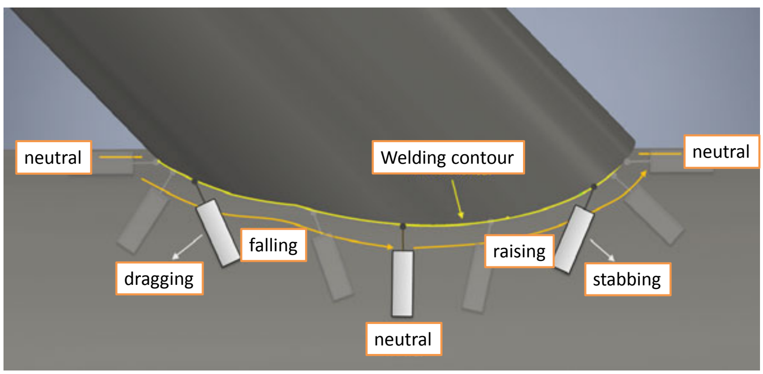

Fig. 7 Torch orientation depending on the slope of gradient

After confirming the welding position with orientation in each scan, a post-processor generates a robot welding program which is transferred to the robot controller. In the post-processor, additional welding commands, inputs and outputs and motion profiles are added.

After the performed welding, the measuring program is started again and the process is repeated with the selection of the welding positions.

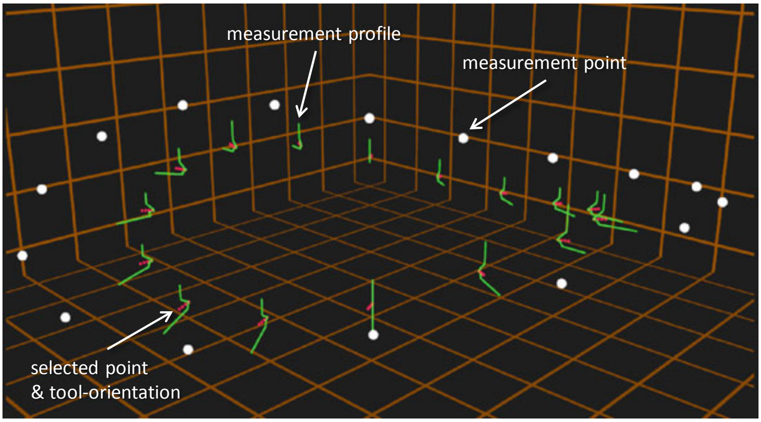

Fig. 8 Three-dimensional representation of the selected welding data sets

4 Generating Data

For control and traceability, the individual scans, the points of the measurement run and the selected welding points and their orientation are transformed into the RobRoot coordinate system in a final step and presented to the user in three dimensions as shown in Fig. 8.

Thus, with every weld bead created, new data is generated that can be used for artificial intelligence. Depending on the tubular node connection geometry, the material thickness or the welding bead to be positioned, new boundary conditions arise again and again, which the experienced welder covers in the first steps. In order to be able to access the data in the subsequent steps, they are stored systematically as shown in Fig. 9.

5 Using AI

Current research activities focus on the development of methods to determine the optimal weld seam positions automatically.

Due to constantly changing joint geometries and boundary conditions, an exclusively analytical approach is most likely not effective. The reason for this is that, as a rule, assumptions have to be made to establish the mathematical relationships and that there is insufficient generalization ability.

To solve this problem, a grey-box model is used [8, 9]. On the one hand, it contains an analytical sub-model based on a priori knowledge (white-box approach). This is used to suggest an optimal position first. On the other hand, there is a data-based sub-model from the field of machine learning (black-box approach) which serves to compensate for possible errors in the analytical part (see Fig. 10).

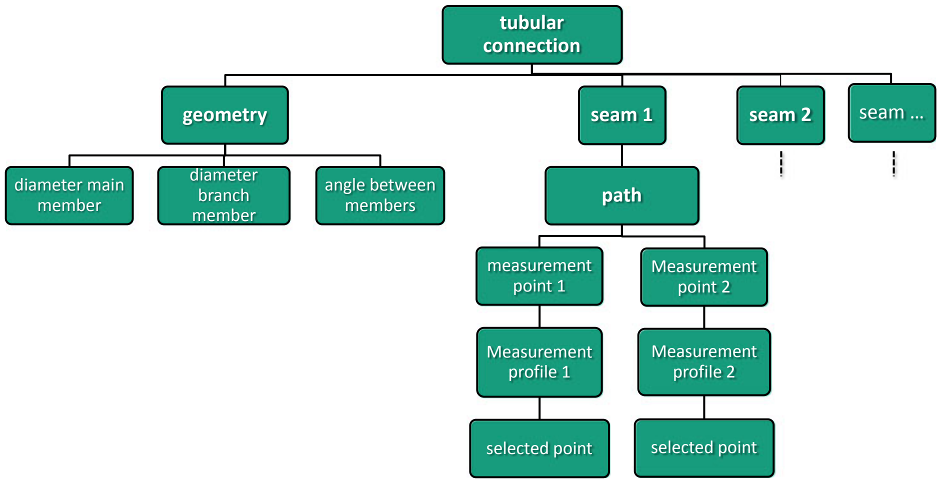

Fig. 9 Data to be stored and its hierarchy

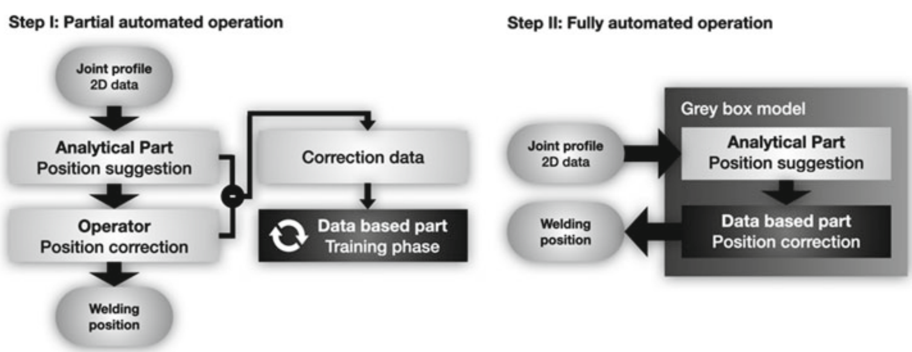

Fig. 10 Workflow to train and use the grey box model

In the analytical model part, a simplified seam geometry is assumed, the proportions or area of which depend on the selected welding parameters (wire feed, welding speed, voltage, current etc.). An algorithm fits the geometry into the point cloud of the joint scan afterwards. The supporting effect of the flanks is also taken into account here. After determining the initial position for the nth seam, the following positions are limited to a certain area around this point.

In a partially automated phase, seam positions for each scan are suggested by the analytical model part first and are corrected manually by the user if necessary. The correction data is collected in order to train the machine learning model part. Input–output data pairs are required for the training. The joint scan, the gravitational vector, the calculated cross-sectional area of the seam and the result of the analytical seam position determination represent the input data. The seam position corrected by the user, however, represents the output data. An artificial neural net is used as a model.

The duration of the partially automated phase depends on the amount of data collected. By using a new tubular node connection with a defined pipe geometry, as many new scan and positioning data as possible are generated. For example, if the branch member pipe is divided into 1° steps and about 25 single weld beads are necessary, 9000 data sets are generated. The machine learning model is trained at regular intervals and the performance of the entire grey box model is recorded as part of evaluation welds. The mean absolute deviation between the predetermined seam positions of the model and the selected positions of an experienced welder could serve as a metric for evaluating the model performance. If the deviation is in the range of 1–2 mm, it is probably possible to switch from the partially automated phase to the test phase for fully automated operation.

6 Conclusion and Outlook

The first milestone for the automation of tubular node connection production was laid with the development of a software with an user interface. This involves determining defined measurement points on the joint to be welded at which scans are generated. Based on these scans, an experienced welder generates a robot welding program. Thus, the welder is not exposed to the direct welding process but can contribute his experience to the process. Compared to the manual teaching of such a welded joint connection, the programming time is reduced from about 30 min to only 5 min. For complete automation, the decisions of the welder are stored in a database in order to build up a generally valid neural network for the most diverse tubular node connection geometries.

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