A dual laser sensor scanning system for inspection of holistic weld geometry

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Abstract
Welding operations are widely regarded as one of the key fabrication technologies in manufacturing industries and are common in metal joining processes. It is a very complex process, and control of welding parameters is extremely crucial for achieving good weld quality. This is normally assessed by intermediate and post non-destructive inspection methodologies in accordance with applicable codes. Automatic real-time sensing, monitoring and inspection of welding process is desirable due to productivity advantages which reduce cost. In view of this, a stereo laser sensor assembly with two calibrated lasers is developed to efficiently process and inspect weld quality. A program is developed to combine the acquired groove profile form each sensor in 2D, and further to construct a 3D model of the groove revealing the weld bead surface quality. The work demonstrates the non-contact weld geometry inspection of a deep narrow groove weld to assess the exterior weld quality.

Keywords: laser triangulation; merging profiles, non-destructive; inspection; weld quality

1 Introduction
The choice of welding processes in joining industries is driven by the application type, productivity and weld quality requirements. The welded parts receive detailed quality assessments due to its increased failure possibility compared to the base material, which can affect the mechanical integrity of the join. Continuous developments in materials, welding process and inspection procedures are in high demand due to gradual push towards application limits. Meeting the required quality levels for the welded part is crucial for all industries, and requires close management of the welding process. Today, advanced mechanised and automated welding processes are available for maintaining repeatable weld quality [1]. Weld quality inspections are predominantly carried out separately using post-inspection methods [2]. Inspecting for quality only after

the process is complete can affect productivity since there is little option for correcting any defect in quality at that stage. Thus, monitoring and control of key welding process parameters (e.g. weld pool, bead geometry, joint set-up and alignment, weld groove distortions, interior and exterior weld defects) is vital in correcting weld quality as the weld is happening. In view of this, different online methods based on sensing technologies such as acoustic sensors, audible sound, thermal imaging, optical sensors, CCD (Charge-coupled Device) or laser based vision sensors and electromagnetic acoustic transducers have been developed to detect imperfections in welds [3-4]. As a part of this study, a laser profile sensor system is developed to efficiently process and inspect narrow groove geometry as well as external weld surface quality. Initial measurements with a single optical sensor revealed only part of the weld groove geometry due to line-of-sight issues and limited field view of the laser sensor. Thus an additional sensor is used at an inclined angle to compensate for the line of sight issues. A LabVIEW based profile processing algorithm is proposed in this study to obtain 2D and 3D profile of the weld for inspection of weld geometry features and weld surface defects.

2 System configuration

Two blue light laser sensors (Micro-epsilon, UK) with wavelength of 405 nm, giving 1280 points per profile were used to obtain data of the weld groove. Due to the shorter wavelength, those sensors do not penetrate the target surface, projecting a small light spot on the surface, which provided stable and precise results.

A 3D printed mock-up of Polysude welding head has been used to configure the best angle and working distance for the two laser sensors. Initial data of the model with 50 mm deep weld groove was obtained and examined. Groove dimensions and presentation of the Polysude head are presented below, Figure 1.

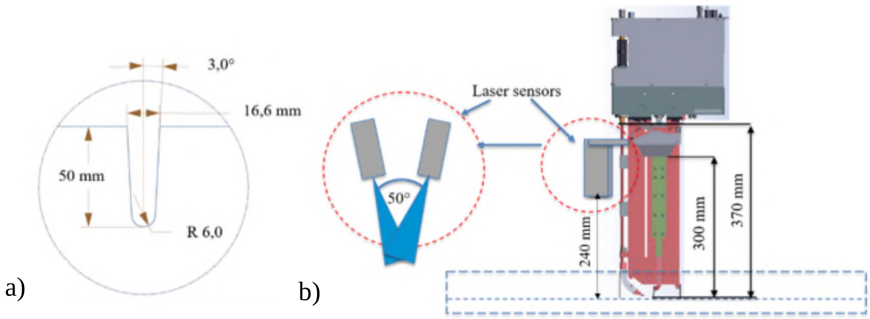


Figure 1: Investigated groove dimensions on the left (a) with the presentation of the setup on the right (b).

The best quality of data for post processing was obtained at the location and orientation for the sensor shown in Figure 1. (240 mm from the bottom of the groove to the sensor and 50° angle of inclination).

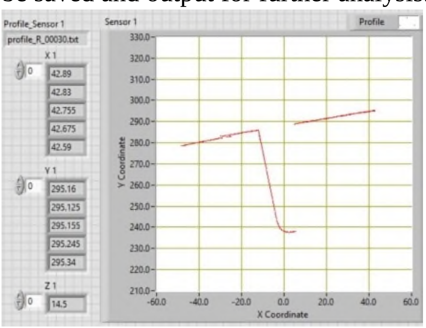
3 System calibration

The two laser sensors work in their own local coordinate systems. If the integrated system is to produce accurate results, these two coordinate system have to be unified a global system.

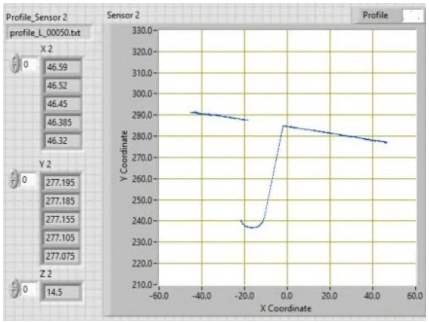
In this paper, a laser sensors calbration method has been developed based on Iterative closest point (ICP) algorithm. In this context, the proposed algorithm may be considered as a modification of the method introduced in [5]. It should be noted that the proposed method has been developed to deal with 2D points data, compared to the method in literature which is exploited to align 3D point cloud data.

4 Software development & system accuracy test

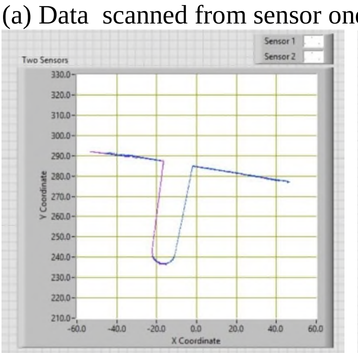
In order to visualize the scanning results and modify and change some of the parameters related to the data prcessing module, a human-machine interface has been designed using LabVIEW as shown in Figure 2. Figure 2 (a) and (b) shows the 2D points scanned from two laser sensors, respectively. Figure 2 (c) shows the 2D data points aligned and stiched together, which can dispaly the full profile of the weld bead. In Figure 2 (d), the 3D profile of the weld along with its position information, from which geometrical features can be obtained when the dual laser sensor scans across the weld bead surface. With this human-machine interface, the weld quality inspection can visualized and the scanned data of the weld can be saved and output for further analysis.



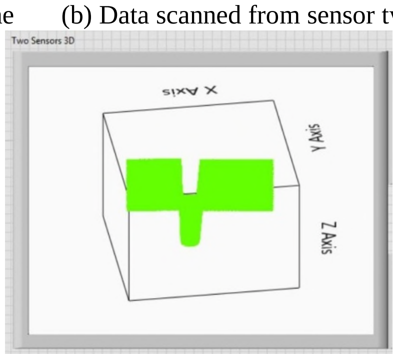
(a) Data scanned from sensor one



(b) Data scanned from sensor two



(3) Aligned 2D data



(4) 3D points cloud

Figure 2: Software interface of the dual laser sensors system

To verify the accuracy of the laser sensor system, three positions of the groove were selected and measured using both vernier callipers and laser sensors. The measurement results using the vernier callipers were selected as the benchmark measurement, then the values were compared with results using the laser sensor system. As the tolerance of the dimension of the groove is ±0.5 mm, vernier callipers are a sufficiently accurate solution (better than 0.025 mm). A standard deviation of laser sensors was calculated and its value is 0.27 mm. If the measurement uncertainty of vernier callipers is assumed as 0.025 mm and the observed maximum deviation from standard reference temperature (20 °C) is 2 °C, then the combined standard uncertainty is 0.27 mm and expanded standard uncertainty is 0.54 mm (95.45% measurement confidence, k=2) according to reference [6].

5 Conclusion & future work

In this paper, a dual laser sensors scanning system has been developed for the inspection of the weld geometries. By scanning the weld bead using the developed system, the 2D profile was obtained and the 3D profile generated as the laser scanning system travelled with the welding head. Compared to other developed 3D range sensors, our system can cover the full profile of the weld bead. With the dual sensors setup, the line-of-sight issues are solved, which is a common difficulty in welding inspection process. The increased spatial coverage capability can be easily extended to other applications e.g. the inspection of additive manufacturing process. Future work includes integrating the system into the welding head to realise real-time weld inspection.

References

1. X. R. Li, Z. Shao, Y. M. Zhang and L. Kvidahl, Monitoring and control of penetration in GTAW and pipe welding, Welding Research, 2013, 92, pp 190-196.
2. T. Stenberg, Z. Barsoum, E. Astrand, A. Ericson Oberg, C. Schneider and J. Hedegard, Quality control and assurance in fabrication of welded structures subjected to fatigue loading, Weld World, 2017, 61, pp 1003-1015
3. Wei Huang and Radovan Kovacevic, A laser-based vision system for weld quality inspection, Sensors 11,2011, pp 506-521
4. S. B. Chen and N. Lv, Research evolution on intelligentized technologies for arc welding process, Journal of Manufacturing Processes, 16, 2014, pp.109-122
5. Li, F., D. Stoddart, and C. Hitchens, Method to automatically register scattered point clouds based on principal pose estimation. Optical Engineering, 2017. 56(4): p. 044107-044107.
6. ISO, B. E. (2011). "BS EN ISO 14253-2:2011." Geometrical product specifications (GPS) - Inspection by measurement of workpieces and measuring equipment. Part 2: Guidance for the estimation of uncertainty in GPS measurement, in calibration of measuring equipment and in product verification.