Towards the development of a deposition technology for an automated rail repair system

D. De Becker
Wolfson School
Loughborough University
Loughborough, Leicestershire
D.De-Becker@lboro.ac.uk

J. Dobrzanski
Wolfson School
Loughborough University
Loughborough, Leicestershire
J.Dobrzanski@lboro.ac.uk

Y. M. Goh
Wolfson School
Loughborough University
Loughborough, Leicestershire
Y.Goh@lboro.ac.uk

L. Justham
Wolfson School
Loughborough University
Loughborough, Leicestershire
L.Justham@lboro.ac.uk

***Abstract*—The work presented in this paper explored the use of a laser line scanner to generate robotic deposition paths for the repair portion of an automated rail repair system. Currently surface defects cost the UK around £4 million per annum [1] , with little traceability being available throughout the repair process. This paper proposes a robotic repair system primarily focussed on the development of the deposition system. The deposition system utilised two different deposition strategies, the first extracted the weld prep from the point cloud to generate the deposition paths for the robot and the second measured the height of the previously deposited material and adjusted the generated path. This paper focusses on the use of the two algorithms and the testing completed on a representative geometry, utilising a caulking gun as a reusable material replacement for the additive welding system.**

***Index Terms*—Path generation, Rail repair, Hybrid manufacturing, Robotic welding**

I. Introduction

The UK rail infrastructure requires constant repair and maintenance. A key contributor to the cost incurreded are maintenance costs in the form of rail defects. The work presented in this paper concentrated on the repair of surface defects found on the rail. One such defect is named a squat defect and the UK estimates the cost of squat repair on plain rail to be around £4 million per annum [1]. An example of a squat defect, taken at Great Central Railway line in Quorn station, Leicestershire, UK, can be seen in Fig 1.

Fig. 1. Squat defect taken at Quorn, Leicestershire, UK railway station

Considerable work has been done on automating the identification and registration of both surface and subsurface defects, however, little work has been done on automating the repair procedure once the defect has been found [2] [3] [4] [5]. In the UK this initial defect identification and detection is done by the New Measurement Train (NMT) run by Network Rail, coupled with its Plain Line Pattern Recognition (PLPR) system [6]. The current state of the art in the field of defect repair is the ARR (Automated Rail Repair) system developed during the Shift2Rail project [6]. This system uses a predetermined path and submerged arc welding to deposit material onto an already existing weld prep. This system, although requiring a much lower preheat, cannot achieve a full automated repair process in its current state. Therefore, the research presented in this paper has suggested a complete rail repair system using a industrial robotic arm, as shown in Fig 2.

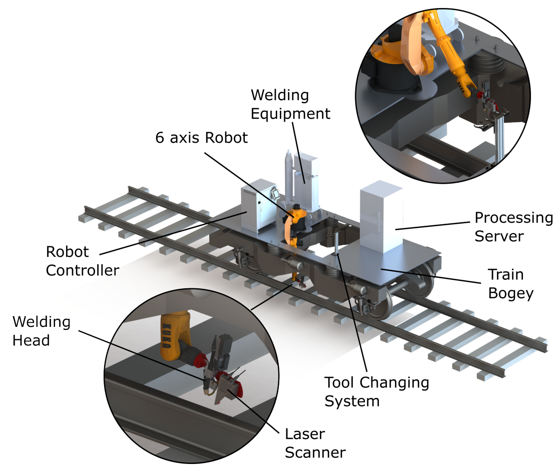

Fig. 2. Schematic of the proposed solution for the rail repair system

The 2019 report produced by Network rail for Welding process and technology developments states that weld failure in Wales is approximately 15%, with the key driver being the lack of automation and traceability within the welding process [9]. Therefore, the purpose of this paper is to show the development, testing and validation of an adaptive deposition system. The system can be used to add material onto an already existing weld prep. This weld prep would be generated by the subtractive subsystem within a fully automated rail repair system [10].

II. Adaptive welding algorithms generation

Fig 3 shows the weld prep, used for this work which was taken from the British Standard for Restoration of Rails by Electric Arc Welding [11]. The weld prep dimensions used for the trials were; *L =100mm, S=25mm and D=3mm*. The overall width was 70mm, which was equal to the width of the rail head used.

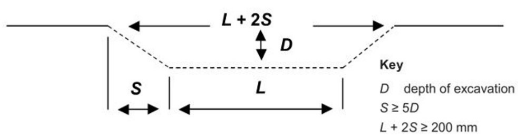

Fig. 3. Schematic of the weld prep used to generate the welding path taken from BS 15594:2009 [11]

During the adaptive welding process, there were two algorithms working together in order to create a robust additive welding process. The initial weld path generation algorithm was driven by the scan data generated by the laser line scanner as shown in Fig 4a. This algorithm identified the weld prep surface within the scan data as shown in Fig 4b, applying a translation technique for deposition optimisation. The technique used to extract this weld prep surface utilised the eigenvalue of the covariance matrix to identify local changes in the data. The covariance matrix is a statistical tool where the largest eigenvector indicates the direction of the data and the second largest eigenvector indicates the second largest data trend. The magnitude of these eigenvectors are defined as the eigenvalue. In this case, the covariance matrix was calculated over a 3mm neighbourhood and a ratio of the two largest eigenvalues of the covariance matrix was calculated. This ratio stayed consistent either side of the weld prep and a large change in this ratio was observed when the neighbourhood partially included data from the weld prep. Once the weld prep was extracted, it was possible to use the points adjacent to the weld prep to create a linear interpolation between the two sides. This yielded a surface which was used to recalculate the Z values for the points within the machined area. This ensured that the repair not only filled the area which had been extracted, but also accounted for any wear which would have occurred over time. The outcome of this linear interpolation and remapping of the points can be seen in Fig 4c, which shows how the final surface should appear once both the additive system, described in this paper, and final finishing operation was completed. Finally, the build plane was extracted and the fill strategy was implemented, an example of the first layer can be seen in Fig 4d. This fill algorithm was based on the user inputs, including the estimated bead width and height along with the step oversize. The fill algorithm worked by raising the build plane based on the estimated bead height and then intersecting the build plane with the point cloud. This generated a layering effect where the subsequent layer deposition height was adjusted by the second algorithm, to match the actual bead height deposited on the measured layer. Such a scan is seen in Fig 5. This allowed, for any

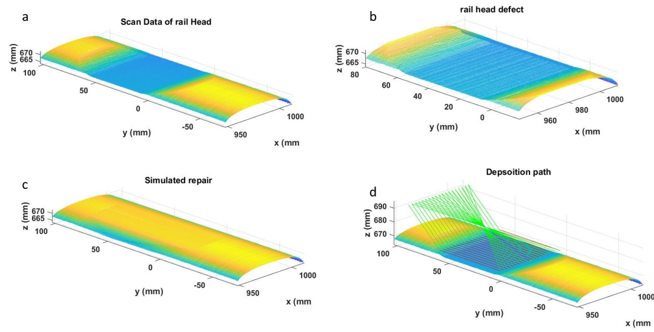

Fig. 4. Scans showing path generation sequence. (a)Original scan data. (b)The area of interest. (c)Repaired rail. (d)Deposition path for the first layer

difference between the bead height input by the user and the real-world bead height to be corrected for. This algorithm works on the highest 20% of Z values within the deposition area and fits a plane to those points. This plane was then used to adjust the next layer's Z values in order to adjust the weld path.

These adaptive welding algorithms undertook preliminary testing using a caulking gun, with caulk used as an additive test replacement to the metal of the welding process. This allows multiple attempts on the same piece without the need for part re-manufacturing. Both algorithms can be viewed functioning, with their outcomes in Fig 5, which shows the penulimate layer deposited. This Figure also shows the height adjustment algorithm working.

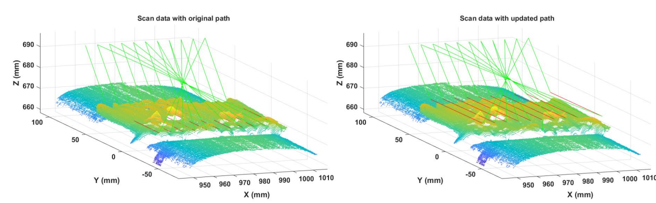

Fig. 5. Scan data showing the path being updated to avoid collisions

III. Conclusion

The initial testing proved that it was possible to extract the weld prep from a rail head using the covariance matrix. Moving forward this path generation will be tested on a representative flat plate in order to fine tune the welding parameters including the amperage, voltage and the pre-heat temperatures. Once these parameters have been tuned, the path generation will be tested on the representative geometry using the welding equipment. The final step will be to re-validate the testing carried out on the flat plate on a piece of real rail. This will, in turn, provide valuable information and validation of the deposition subsystem of this repair system.

ACKNOWLEDGMENT

The author would like to thank the Intelligent Automation Centre within the Wolfson School of MEME at Loughborough University and the Innovate UK funded CONFIGURE project for the use of the equipment and the continued support in generating this work.

REFERENCES

[1] Network Rail, "Challenge statement Rail head squats," tech. rep., Network Rail, London, 2015.

[2] C. Tastimur, O. Yaman, M. Karakose, and E. A. Õ, "A Real Time Interface for Vision Inspection of Rail Components and Surface in Railways," in *IDAP 2017 - International Artificial Intelligence and Data Processing Symposium*, 2017.

[3] M. Molodova, Z. Li, A. Núñez, and R. Dollevoet, "Automatic Detection of Squats in Railway Infrastructure," *IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS*, vol. 15, no. 5, pp. 1980–1990, 2014.

[4] X. Yin, X. Wei, and L. Jia, "Detection of Railway Track Squats by Using Bogie Acceleration Measurement," in *Proceedings of the 34th Chinese Control Conference*, pp. 6297–6302, 2015.

[5] J. Ye, E. Stewart, and C. Roberts, "Use of a 3D model to improve the performance of laser-based railway track inspection," *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit*, vol. 233, no. 3, pp. 337–355, 2019.

[6] E. Kallander, "In2Rail Deliverable D3.1 Investigation of Repair Methods and Welding Techniques," tech. rep., Horizon 2020, 2017.

[7] F. Javier De La Calle Herrero, D. F. Garcia, and R. Usamentiaga, "Inspection System for Rail Surfaces Using Differential Images," *IEEE Transactions on Industry Applications*, vol. 54, no. 5, pp. 4948–4957, 2018.

[8] Z. Xiong, Q. Li, Q. Mao, and Q. Zou, "A 3D laser profiling system for rail surface defect detection," *Sensors (Switzerland)*, vol. 17, no. 8, pp. 1–19, 2017.

[9] Network Rail, "Welding Process and Technology Development," tech. rep., Network Rail, 2019.

[10] D. De Becker, J. Dobranzski, J. Laura, and l. Y. M. Goh, "A laser scanner based approach for identifying rail surface squat defects (Under review)," *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit*, p. 107754631982824.

[11] BS EN 15594, "Railway applications - Track - Restoration of rails by electric arc welding," tech. rep., 2009.