Proceedings of the Sixth International Conference on
Railway Technology: Research, Development and Maintenance
Edited by: J. Pombo
Civil-Comp Conferences, Volume 7, Paper 6.6
Civil-Comp Press, Edinburgh, United Kingdom, 2024
ISSN: 2753-3239, doi: 10.4203/ccc.7.6.6

Processing Rail Crossing Geometries: From 3D Mesh to Cross-Section Profiles

S. Antia-Vallecillo[1], N. Gil-Negrete[1], B. Rodriguez-Arana[2,1], J. Nieto[2,1] and E. Fustes[2,1]

[1]Tecnun, Universidad de Navarra, Donostia / San Sebastián, Spain
[2]Ceit-Basque Research and Tecnology Alliance (BRTA), Ceit-Basque Research and Tecnology Alliance (BRTA)
Donostia / San Sebastián, Spain

Abstract

This work shows an example of a methodology which could be followed to process a crossing geometry with the objective of obtaining and evaluating planar sections. Primitive geometry is reached by profilometry techniques as point cloud geometry and then preprocessed with simple filtering in order to clean it from noise and outliers. Variable geometry on railway crossings requires methods to be then applied in different zones for checking if any local refinement is necessary. Lastly, sections are postprocessed, obtaining an intelligible contour curve to be afterwards visually inspected or as a profile source for multibody software.

Keywords: condition-based maintenance, railway turnouts, switch and crossings, geometric inspection, point cloud filtering, track models.

1 Introduction

A railway crossing is formed by variable rail profiles, which lets the vehicle travel to a diverted route in a turnout, as shown in Figure 1. This geometry, though, causes traditional crossing noses to be subject to big contact forces and even impacts on the passing of vehicles, keeping in mind this contact is not continuous, which remarks the importance of a proper periodical inspection of the component.

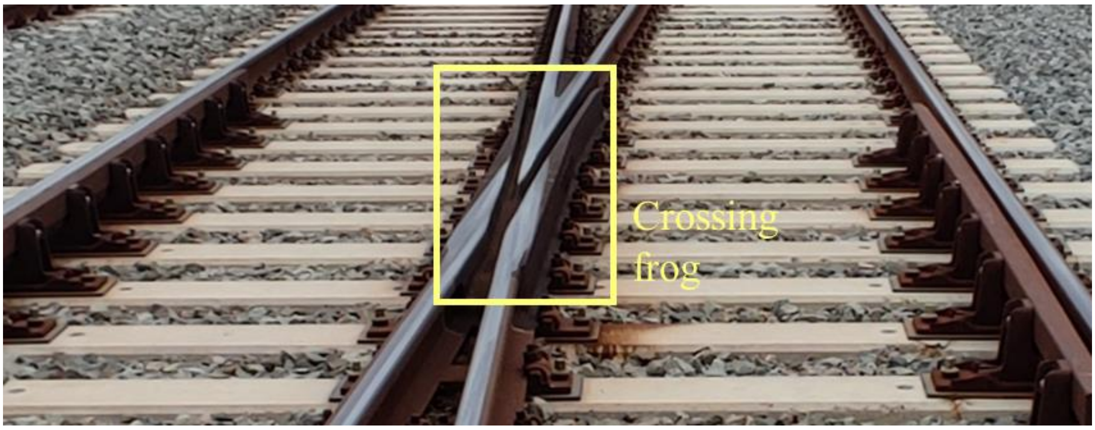

Figure 1. Rail turnout with the crossing indicated.

The research is motivated by the problem just described, and the objective is to be able to perform a geometrical inspection of any real crossing. Additionally, resulting profiles would also serve as a profile source for multibody software (MBS), however the study is limited to the extraction methodology and adjustment to the input formats will not be regarded.

Crossings can suffer from plastic deformation and, in consequence, misshapen nose, which is an observed defect on conventional crossings, like the one shown in Figure 2, which could occur due to a poor design of the crossing or assemble of elements or to impacts due to a bad guiding of the axle. Checked sources estimate it as a common defect on crossings, and with a moderate effect on service [1].

Figure 2. Misshapen nose (J. Wiedorn et al. [2]).

These geometries can be obtained by means of profilometry, that is, a technique based on measuring the topography using reflections of structured light, with the advantage that no contact with the object to be captured is required [3]. This needs to be processed in order to be able to extract proper results, making use of the following procedures.

State of the art of rails crossing geometry processing includes the following: Y. Bezin et al. [4] obtained profiles from geometries of switches and crossings; and H.

Ren et al. [5] carried out a profilometry geometry treatment by fringe pattern extraction from rails. Both works share common objectives with this essay.

Therefore, this writing is structured into the following parts: first, the study case crossing is described, as well as its format and main features; next, the methodology for its treatment in order to obtain useful data (profiles) is explained; after, results and discussion of relevant extractable information are presented; lastly, conclusions taken out and future research lines are mentioned.

2 Study case

The crossing chosen for this case is a real crossing located in a conventional line in Spain, affected by years of heavy rail runs (inter-city, regional services and freight services). It could be, therefore, a good example to show the degradation that can arise on a crossing. For the purpose of focusing on the methodology, as it is shown in Figure 3, only the side including the nose will be used for the study, i.e. the right track from the straight path.

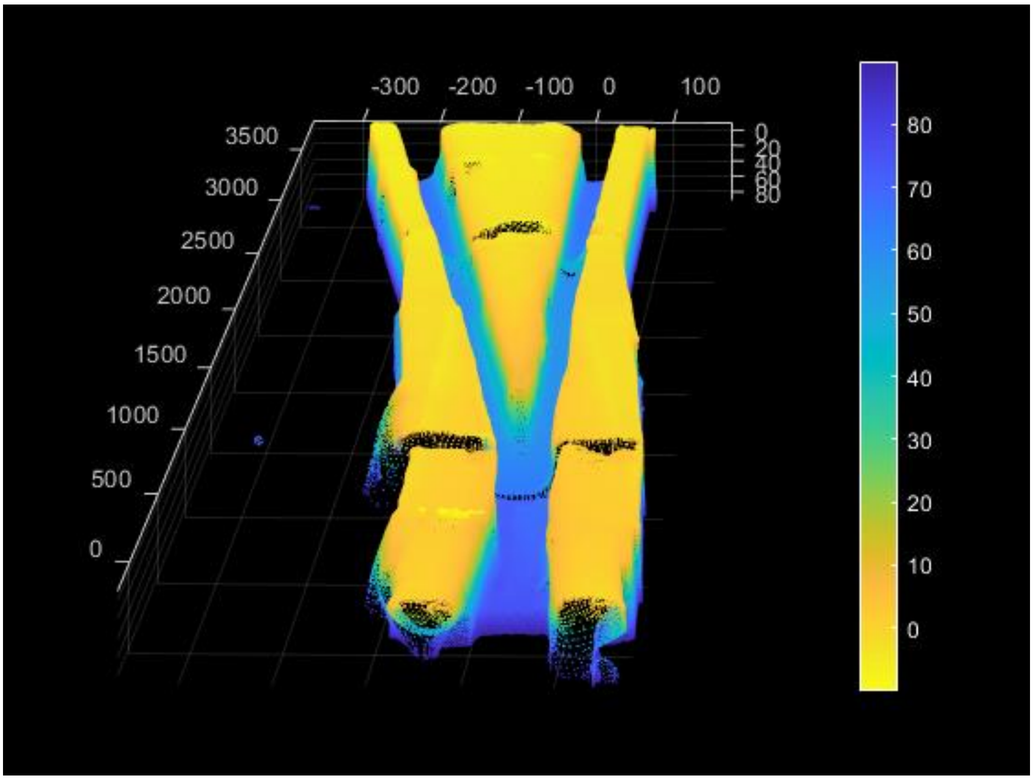

Figure 3. Crossing point cloud (x,y,z). Color scale for z axis.

The original crossing geometry was obtained by profilometry techniques by the Ceit Technology Centre and converted to point cloud data (PCD), and its format is a point cloud text archive with (x,y,z) coordinates of each point that composes the crossing. Position of the points is arbitrary on the (x,y) plane, opposite to techniques on which captures follow a pattern (e.g. linear LiDAR [6]).

This capture may require a previous global transformation because the taken reference system is the one on the sensor, which might not be useful to center the crossing on a horizontal plane. Reference for z=0 has been taken at the top of the running band, while the according to y=0 has been taken at the director plane, that is, at z =14 mm.

Geometrical information about the crossing includes the following:

- Crossing type: straight.
- Deviation angle tangent: 1/14.
- Length considered: 3.5 m.

In Figure 4 the geometric form of the crossing can be seen from above.

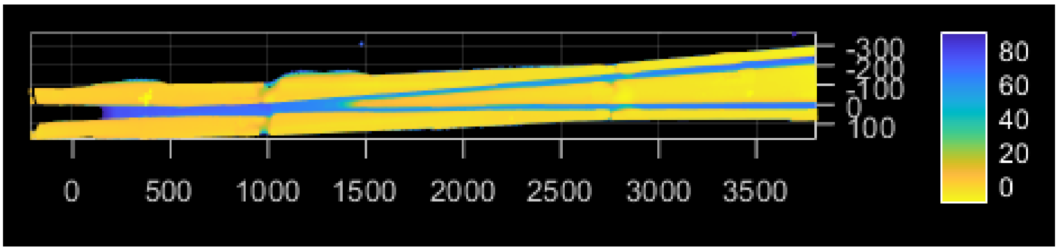

Figure 4. Crossing point cloud seen from above (x,y). Color scale for z axis.

Even if the nose presented a misshapen form, there are other possibilities to explain that result, like grease buildup or lack of accuracy when capturing or processing geometry. Captures should be repeated and reprocessed to confirm this hypothesis.

The final point cloud size is of about $7 \cdot 10^5$ profile points, some of which are considered outliers and others being too close to the edges. In both cases, these points are not considered as part of the geometry and so are deleted.

3 Methods

The proposed methodology for extracting profiles from a rail crossing is presented in this chapter. Input data will be a crossing geometry point cloud, as well as the crossing geometrical information (e.g. the crossing type) and the number of sections desired at the end (defined by the number of section planes). The output will be a series of files, each representing a different profile.

The flux diagram in Figure 5 sums up the whole methodology.

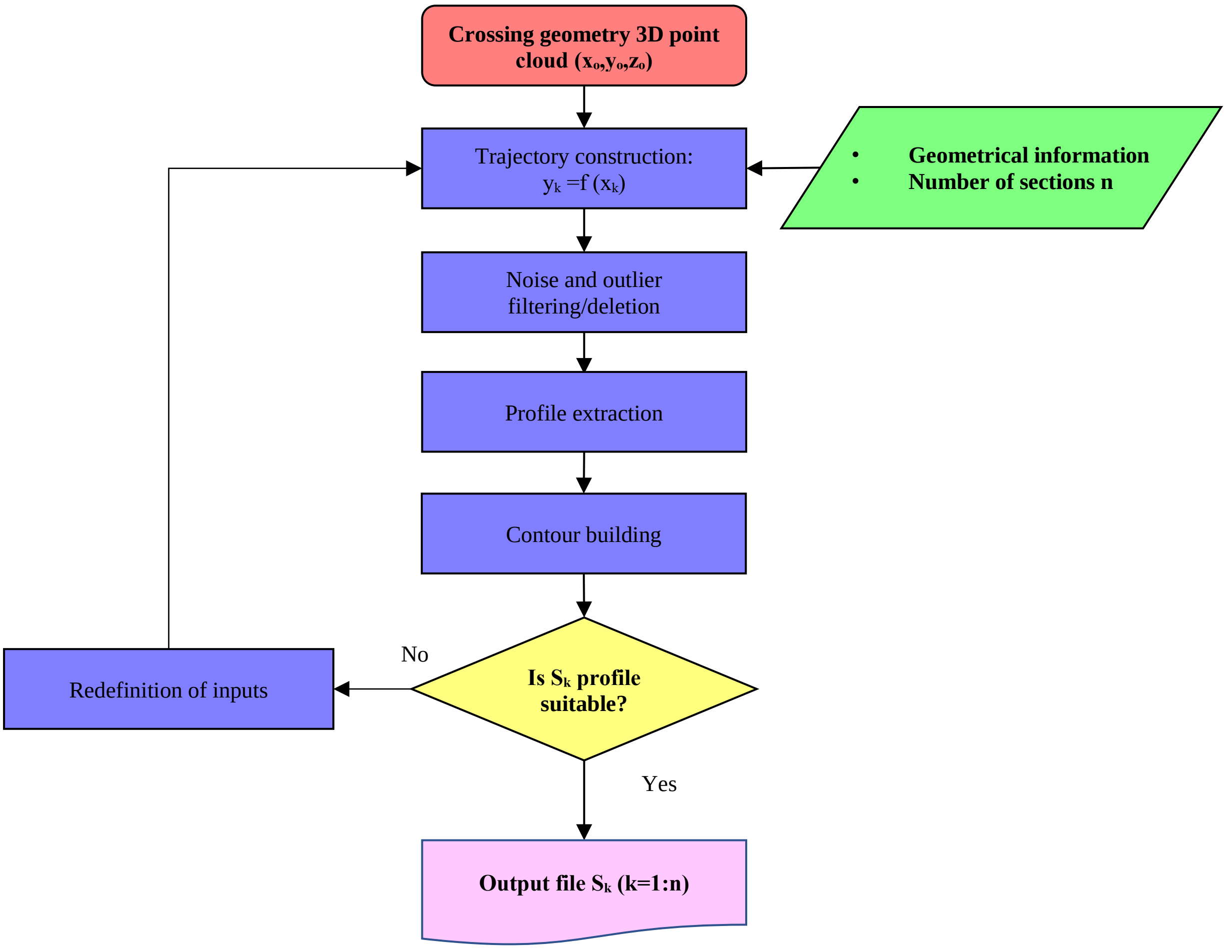

Figure 5. Methodology for processing the rail crossing.

The sectioning of a crossing geometry starts with a *trajectory construction* on the (x,y) plane. This is processed based on the *geometrical information* from the crossing given to the program. Another important aspect when preprocessing the geometry is specifying the *number of sections* desired (n), as it can be seen in Figure 6. This will determine the placement of the sections, which will be normal to the trajectory.

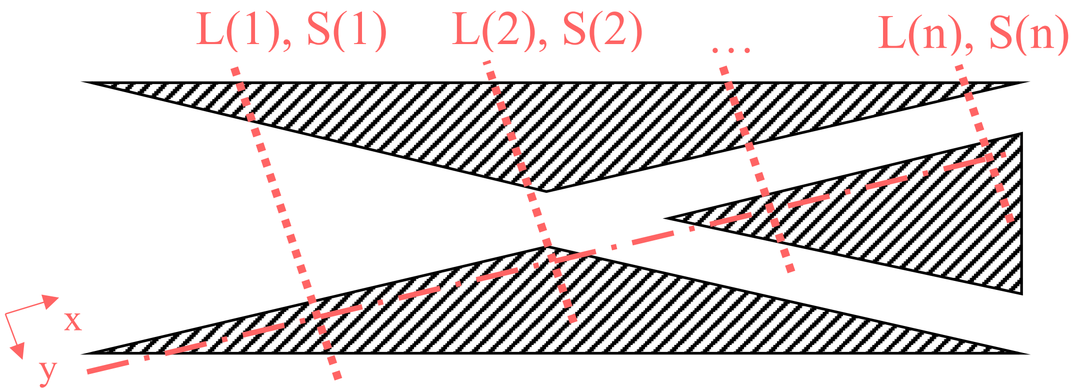

Figure 6. Plane positioning according to trajectory in a seen from above crossing.

Position of the profiles is in fact a relevant parameter because, in such a complex geometry like the crossing one, some zones will not require a big level of detail, whilst others (specially those near to the mathematical point) will need some more in order to guarantee precise results.

For this work four sections have been selected to show the capabilities of the proposed methodology, which are located at the next zones towards the nose according to the established reference system:

1. At the flangeway opening in the gap, following the throat (1.2 m from the considered entrance).
2. At the beginning of the nose, following the mathematical point (1.44 m).
3. Exiting the nose, midway between the point and the heel (1.68 m).
4. At the heel (1.92 m).

Noise and outlier (or ghost points) *filtering/deletion* is a challenging but vital task in order to guarantee that the obtained output is correct. A brief state of the art analysis has brought some algorithms for the deletion to be completed, including the radius outlier filter (ROL) or its local adaptative version statistical outlier removal (SOR) [7]. However, the methods presented are computationally expensive in case of big cloud data, so in the specific case of this study, a simple filtering methodology is enough.

Profile extraction has been analogous to the one used by Bezin et al. [4], i.e. mid--point tridimensional interpolation, considering in this case the closest three points.

Contour building (i.e. ordering points that form the extracted profile to follow a curve) can also be approached in several ways, e.g. by means of the "nearest neighbor" method, based on finding the closest points to the target [8]. This technique, however, fails if points in the contour points are too far from each other.

Output files will be composed of the final profiles, that will be contained in the corresponding local (y,z) plane and will have their longitudinal position through the trajectory. This profile outputs are saved as text files, and in case the profiles obtained are not adequate, which could happen because of several causes (e.g. curves are nor properly made into a contour or the trajectory does not follow the crossing one), *redefinition of inputs* shall be carried out.

4 Results

Profiles obtained with the explained procedures are presented below in Figure 7 and Figure 8.

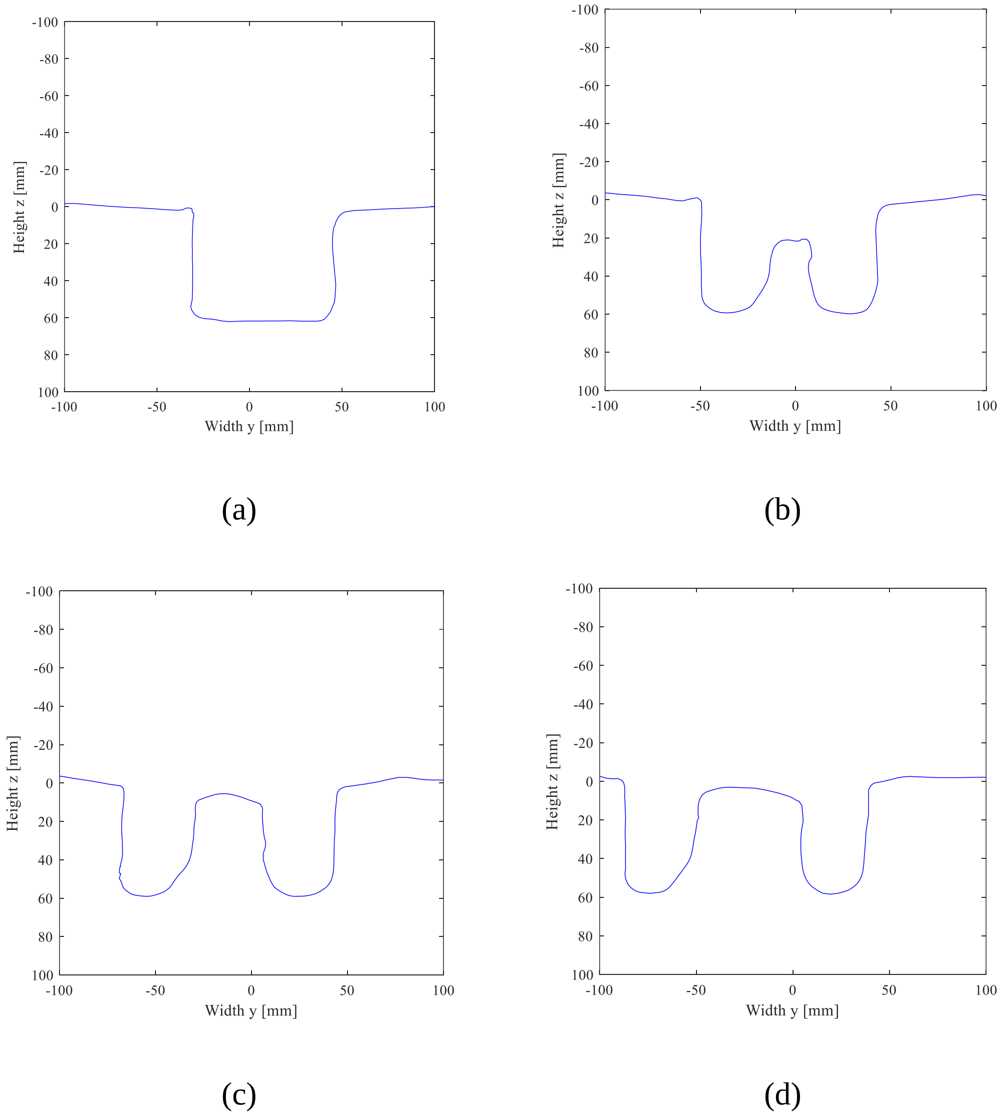

Figure 7. Profiles obtained at x=1.20 m (a), x=1.44 m (b), x=1.68 m (c) and x=1.92 m (d).

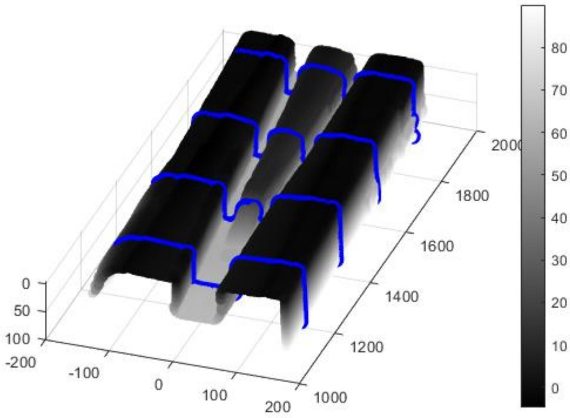

Figure 8. Profiles obtained compared to the starting crossing geometry. Gray scale for “z” axis.

Comparing the profile to the one from a new crossing, the nose tip has a large lateral deviation from the nominal one, even invading the flangeway, which if this was a case of misshapen nose it could put the safe circulation into risk. This deviation could also be observed as well on the wing rails.

Next, a refinement on the number of planes is carried out, showing at Figure 9 the depth profile at y = -20 mm (Y. Bezin et al. [4]) in the given trajectory for 10, 20 and 30 considered cutting points, giving an idea of how much should be necessary to properly represent the geometry.

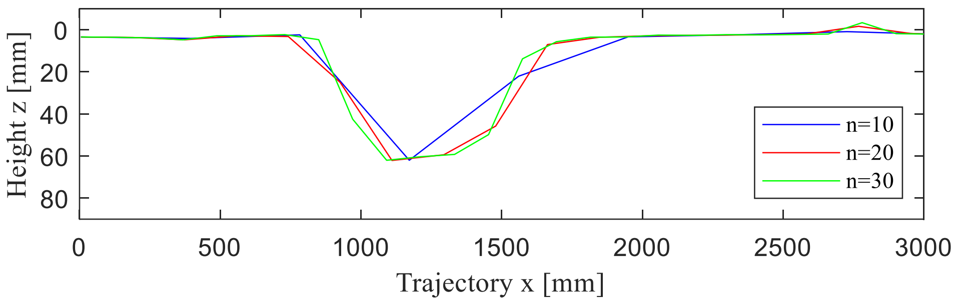

Figure 9. Depth profile at y=-20 mm.

If we observe the figure, it can be seen that each improvement in refinement on the extraction method will bring a better approach on the longitudinal profile of the crossing, showing a smoother curve with each improvement up to n=30, where it seems to give a precise enough result.

Refining too close to the nose tip, though, could bring up unexpected results if the flangeway has not been properly captured or processed, due to the abrupt appearance of new points forehead.

Another note from the figure is that the longitudinal profile of the crossing changes approaching the gap, descending as far as 60 mm, and at approximately x = 1.5 m will reach the initial height again. This sudden hollow explains impacts and thus the appearance of the mishappen nose [9]. A slight rise in the profile at about x=2.7 m is remarkable as well.

5 Conclusions & Contributions

With the present study, it has been possible to obtain simpler and more useful data (profiles) from raw geometries obtained by profilometry.

Conclusions

First of all, has to be noted that a point cloud geometry may have many points to clear due to noise and outliers, and to complete that task there are some methods which have not been analyzed in detail. As well as the point cloud cleaning, the profile contour construction has also been given attention, with different approaches depending on the case.

Secondly, profiles chosen for evaluation seem to enable making a geometric inspection of rail, and could be representative of misshapen nose due to plastic deformation. However, without more captures to check if this hypothesis is correct, it cannot be confirmed. In any case, the study shows that the methodology could be used in the condition-based maintenance field, with periodic inspections of the crossing.

Lastly, even if the presented profiles are enough for carrying out geometric inspection, they may not be enough for simulating the crossing, keeping in mind that having reached the crossing nose point, the sudden elevation that is produced needs to be represented as accurately as it is possible.

Future research

Importing profile data to MBS is to be done, keeping in mind that file reading and interpretation could vary from one program to the other. In addition, results from introducing the presented profiles have not been checked, so it could require some changes to match with the requirements, e.g. increasing refinement in the gap zone of the crossing.

Related to the previous, algorithm to construct contours has to be adapted to sudden changes of geometries, like the nose mathematical point, so that profiles represent the complete crossing.

Focusing on condition-based maintenance, results obtained could feed a deep learning tool which interprets changes in geometry and gives recommendations and warnings on the operation of the facility. Related to this, captures of the crossing geometry should be repeated and reprocessed.

Acknowledgements

This research has been accomplished with the backing, contributions and data from the Railway group and Intelligent Systems for Industry 4.0 group in Ceit-BRTA. It belongs to the Basque Government funded ELKARTEK TCRINI2 project for maintenance and inspection of critical infrastructure (Exp. No. KK-2023/00029).

References

[1] R. Meesit, P. Phornthepkasemsant, R. Rattanawan, and T. Ruamsab, "Risk Assessment of Railway Switch and Crossing Failures: Case Study of an Urban Rail Transit in Thailand," Civil Engineering and Architecture, vol. 10, no. 2, pp. 557–566, 2022, doi: 10.13189/cea.2022.100214.

[2] J. Wiedorn, W. Daves, U. Ossberger, H. Ossberger, and M. Pletz, "Investigation of deformation mechanisms in manganese steel crossings using FE models," *Tribol Int*, vol. 138, pp. 424–434, Oct. 2019, doi: 10.1016/j.triboint.2019.06.016.

[3] R. Ma, J. Li, K. He, T. Tang, Y. Zhang, and X. Gao, "Application of Moire Profilometry in Three-Dimensional Profile Reconstruction of Key Parts in Railway," Sensors 2022, Vol. 22, Page 2498, vol. 22, no. 7, p. 2498, Mar. 2022, doi: 10.3390/S22072498.

[4] Y. Bezin, B. Sambo, H. Magalhaes, W. Kik, G. Megna, and J. N. Costa, "Challenges and methodology for pre-processing measured and new rail profiles to efficiently simulate wheel-rail interaction in switches and crossings," *Vehicle System Dynamics*, vol. 61, no. 3, pp. 799–820, 2023, doi: 10.1080/00423114.2021.2014897.

[5] H. Ren, J. Li, and X. Gao, "3-D shape measurement of rail achieved by a novel phase measurement profilometry based on virtual reference fringe generated by image interpolation," *Optik (Stuttg)*, vol. 161, pp. 348–359, 2018, doi: 10.1016/j.ijleo.2018.02.027.

[6] M. Hasheminasab, T. Zhou, and A. Habib, "Linear Feature-based Image/LiDAR Integration for a Stockpile Monitoring and Reporting Technology," *IEEE J Sel Top Appl Earth Obs Remote Sens*, vol. 16, pp. 2605–2623, 2023, doi: 10.1109/JSTARS.2023.3250392.

[7] H. Benallal *et al.*, "A new approach for removing point cloud outliers using box plot 3-D watermarking," *Pattern Recognition and Tracking*, vol. XXXIII, 2023, doi: 10.1117/12.2618842ï.

[8] Ö. Faruk, E. Grul, M. Emin, and T. Gluk, "A novel version of k nearest neighbor: Dependent nearest neighbor," *Appl Soft Comput*, vol. 55, pp. 480–490, 2017, doi: 10.1016/j.asoc.2017.02.020.

[9] C. Andersson, T. Dahlberg, and C. Andersson', "Load Impacts at Railway Turnout Crossing," *Vehicle System Dynamics Supplement*, vol. 33, pp. 131–142, 1999, doi: 10.1080/00423114.1999.12063076.