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Centimeter-accurate railway key objects detection using point clouds acquired by mobile LiDAR operating in the InfraRed[†]

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Abstract: The automatic detection and accurate geolocation of key railway objects plays a crucial role in the mapping, monitoring and management of railway infrastructure. This study presents a novel approach for the identification and geolocation of key railway elements through point cloud analysis. The methodology relies on high-density LiDAR point clouds acquired along railway lines using a Mobile Laser Scanning system operating in the Infrared (IR). This research contributes to the advancement of railway mapping and monitoring technologies by providing an innovative solution that can be integrated into railway infrastructure management software.

Keywords: Automatic Object Recognition, Mobile Laser Scanning system, Railway Mapping and Safety

1. Introduction

In European and international railway design, the need for interoperability between technological systems - such as ERTMS[1] - and the systems that make up the railway infrastructure requires the development of increasingly accurate and effective processes and procedures for the collection and digitalization of data. The project "NeMeSy-RAIL", funded by Regione Toscana in 2024, has been proposed with the aim to answer to this need, making the detection and digitalization of data for the design of ERTMS systems more accurate and effective, thanks to the adoption of a new Mobile Mapping System (MMS) equipped also with two mobile LiDAR working in the Infrared and the development of an automated image processing procedure for the identification and precise geolocation of key object in the railway system. LiDAR systems are renowned for precise mapping and extensive range [2]. LiDAR digital output is a 3D-point cloud. A point cloud contains very precise spatial information, but not ordered and not structured, thus recognizing the objects of interest can be challenging. This paper is focused on the development of an automatic point clouds processing procedure for the accurate key object detection of the railway infrastructure.

2. Materials and Methods

The MMS employed to acquire the dataset analyzed in this paper is the Leica TRK700 Evo [3]. Its main characteristics are reported in Table 1, while the system is depicted in

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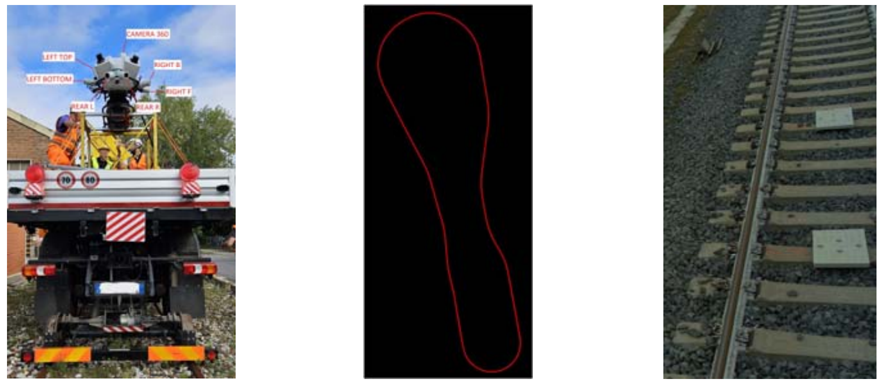


(**a**) (**b**) (**c**)

Figure 1. (a) Leica TRK700 Evo MMS mounted on a hybrid vehicle for the acquisition of the test dataset. (b) Track of the railway test circuit of San Donato (Bologna, Italy), (c) Image of two *balises.*

Figure 1 (a). In Figure 1 (b) is reported the track of the railway test circuit of San Donato where the dataset was acquired. The San Donato test circuit is 5.759 m long and was completely acquired with 73 raw point clouds in WCS (World Coordinate System) of approximately 1 GB each. Literature reports many techniques to process 3D-point clouds data, based on both classical data processing and machine learning approaches [4]; unfortunately, the lack of a common test dataset prevents from making comparisons between the different developed methods. For now, in the NeMeSy-RAIL project, we have decided to process the data with a classical approach, mostly because we have only a dataset with quite homogeneous characteristics. We have implemented an original procedure in MATLAB®, whose block diagram is depicted in Figure 2. It is mainly based on a statistical analysis approach. The key objects that were to be identified are the *balises* (Figure 1 (c)).

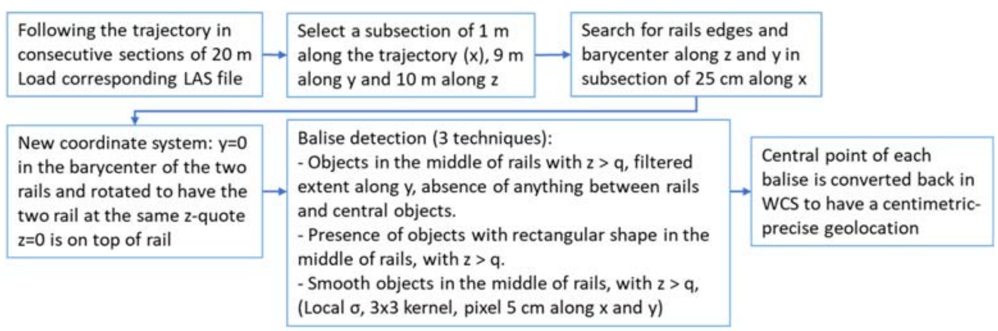


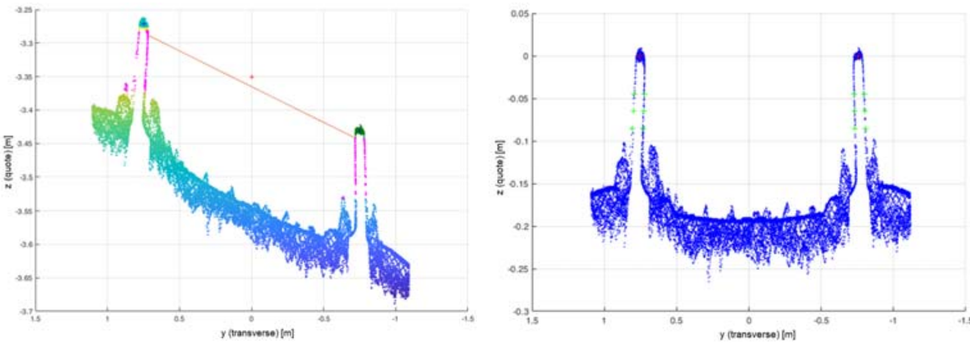
Figure 2. Block diagram of the proposed object identification procedure

Table 1. Main performance of the MMS.

Characteristics	Value
Absolute accuracy in [X,Y], [Z]	11 mm,11 mm (no GNSS outage), 14 mm,16 mm (60 s GNSS outage)
Maximum pulse rate	2 x 2.2 MHz
Maximum rotational speed	2 x 267 Hz
Precision	1 mm
Maximum range 50% reflectivity at 200kHz/500kHz	182 m
Maximum range 10% reflectivity at 200kHz/500kHz	182 m
Number of returns	1
Minimum range	0.3 m
Field-of-View	360° full circle
Data acquisition rate	Max. 2 x 1.094 million pixel/sec.

3. Results

The procedure described in Figure 2 has been applied to the entire dataset of 73 LAS file, along the full 5.797 m of the test circuit. In Figure 3 are reported two scatterplots for a 25 cm section located in one of the main curved regions of the circuit. In Figure 3 (a) is reported a section of the original point cloud, while in Figure 3 (b) is reported the same section after the change of coordinate system, correctly centered and rotated to compensate for the difference in height of the two rails, particularly evident in curves, that permits to have the top of rails at the z=0 quote. This operation, which is completely invertible, section by section, facilitates the identification of *balises*, allowing the entire route to be equalized in terms of orientation, inclination and roll.



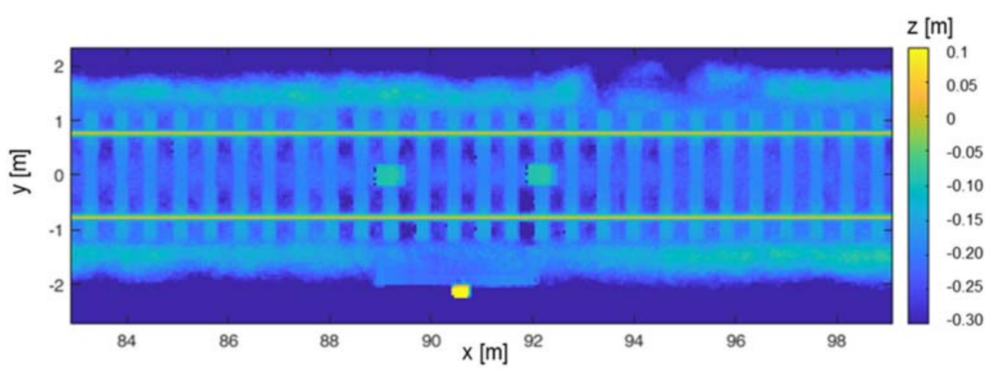
(**a**) (**b**)

Figure 3. (a) Original section of a 3D point cloud (mean intensity along x), (b) Same section in the new coordinate system (invertible transformation).

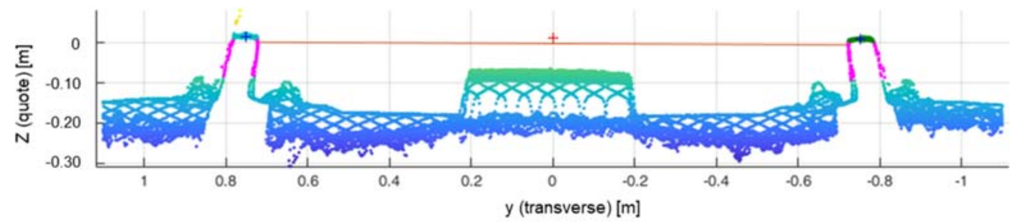
In Figure 4 (a) is showed, as an example, the quote of a section along the trajectory as it would be seen from above: two *balises* are clearly visible. In Figure 4 (b) is represented a scatterplot for a 25 cm transverse section containing a *balise*. In Table 2 are reported the scores of the procedure in terms of Accuracy, Precision and Recall [4] for the three detection strategies. All the three methods work well, but the Smoothness method gives the better results. In the S. Donato circuit are present 72 *balises*.

Table 2. Performance of the three methods developed.

Detection method	Accuracy	Precision	Recall
Section Profile	0.9	0.935	0.923
Rectangle	0.867	0.986	0.911
Smoothness	1	1	1



(a)



(b)

Figure 4. (a) Section of the trajectory 'seen from above' containing two *balises.* (b) Transversal section containing a *balise*.

4. Discussion

We have developed an original procedure capable of identifying all the *balises* in the circuit, by processing the 3D point cloud dataset acquired by means of a LIDAR working in the IR. Thanks to the excellent detection performances, the center of the *balises* are identified with centimetric precision (the same of the LIDAR itself). We have chosen to make use of classical data processing algorithm because the uniformity of the only available dataset could give overfitting problems if processed with machine learning algorithm. If other dataset will be available in future, some experiment with those methods will be carried out.

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Informed Consent Statement: Not applicable.

Data Availability Statement: The datasets presented in this article are not readily available because the data are part of an ongoing study. Requests to access the datasets should be directed to c.lastri@ifac.cnr.it.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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