GLL
Geomatics, Landmanagement and Landscape No. 4 • 2025, 111–123

ISSN 2300-1496 https://doi.org/10.15576/GLL/213749

Research paper

Received: 20.10.2025
Accepted: 29.10.2025
Published: 29.12.2025

LIDAR data processing for the inventory of the railway infrastructure

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Summary

Classic methods of geodetic and diagnostic measurements performed on railway infrastructure are characterised by the time-consuming nature of data acquisition. For highly complex structures, such as railway stations, it is not easy to collect comprehensive information about the inventoried structure. Hence, there has been a considerable increase in the demand for and use of modern measurement techniques, such as mobile and aerial laser scanning, where a compromise between the quality and speed of information acquisition is required and achievable.
The paper demonstrates the possibility of using aerial laser scanning technology for the inventory and modelling of railway infrastructure. The following presentation outlines the stages of processing point clouds obtained in different coordinate systems in the TerraSolid program environment. The transformation of point clouds between the '1992' and '2000' systems followed the acquisition of data from a 2130 m long section of railway line in Bochnia, in the Małopolska Voivodeship. The density of the source point clouds was 11 and 17 points/m^2, respectively. The transformation of the clouds into a single coordinate system enabled the creation of a point cloud with an average density of 28 points/m^2. This dense point cloud, created by transforming the '2000' system, formed the basis for inventorying the railway infrastructure and creating a 3D model of the studied object, using MicroStation and TerraSolid software.

Keywords

Inventory • LIDAR • railway infrastructure

1. Introduction

The construction of buildings and engineering structures increasingly involves the use of modern measuring and design tools that offer broad support to contractors involved in design and investment works. In today's technical world, creating, processing and analysing all data in the development of a conceptual project is linked to information and computer technology support for design.

Photogrammetric technology, which is based on modern measuring devices and computer software, is rapidly penetrating fields related to engineering in the broad sense, finding applications in these areas. The functionality of technical solutions in the field of photogrammetry turns them into a key pillar in the process of creating the final product. The use of photogrammetry in large-scale investment and modernisation projects, such as road and rail infrastructure, improves the quality and comfort of the performed work.

As part of a wide range of surveying works at many stages of the investment process, implementation measurements are carried out in the case of servicing the construction of new railway sections and their modernisation. It is also very important to run ongoing checks on the technical condition of the infrastructure. Measurements of track geometry and technical and operational equipment provide the necessary data for diagnostic tests. The measurements include, among other things, track width, rail height and unevenness of their course in the vertical and horizontal planes. These measurements refer to track axis control indicators. These issues have been described in studies by [Strach 2009, Mikrut et al. 2012, Strach 2013]. Technical and operational equipment includes turnouts and crossings, which are the most critical and vulnerable to damage and wear elements of railway tracks. All structures located within the railway track, and in particular the distances between them and the tracks, are also measured. This applies to station buildings, warehouses, but also to electric traction support structures, semaphores, platforms, bridge structures, tunnels and others. The data obtained on the location of these structures makes it possible to analyse the structure gauge. A study by Kamczyk [2013] confirms this. Detailed guidelines on the elements that must be measured are included in the technical specifications.

Classic methods of geodetic and diagnostic measurements performed for railway are characterised by the time-consuming nature of data acquisition. In the case of very complex structures, such as railway stations, it is not easy to gather comprehensive information about the inventoried structure. We see here a solution based on modern measurement technology, namely laser scanning, supported by precise positioning systems [Kwoczyńska et al. 2016].

Classic methods guarantee the precision and accuracy of measurements demanded by the manual and the client, while staff equipped with high-quality instruments and many years of experience ensure the creation of top-quality cartographic products and data sets. The D-19 manual specifies the elements that must be measured, the measurement methods, the technology and the accuracy requirements. Published in 2000, it focuses mainly on the use of electronic tachymeters and levellers, but also takes technological progress into account. It contains the following statement: '(...) Measurements using other methods and technologies are permitted, provided that the required measurement accuracy is maintained (...)' [D-19 2000]. This statement leaves open the possibility of testing and implementing new measurement solutions.

A significant problem with the use of tachymetric methods or geometric levelling is the high time consumption of the measurement. Technological developments allow the use of modern measurement methods that significantly increase work efficiency.

Measurements using an aerial laser scanner have created a prospect for a fast and, as technology develops, increasingly accurate method of collecting spatial data. The application of this method to the measurement of railway routes and adjacent areas largely results in a significant survey area being covered in a short time, with the quality of the obtained data increasing.

Research on the use of laser scanning for recording and inventorying railway infrastructure has been ongoing for many years around the world, as illustrated by the works of [Głowienka et al. 2015, Kremer and Grimm 2012, Pyka et al. 2010, Soni et al. 2014, Rodríguez-Cuenca 2015, Lou 2018 and Sadeghi 2019].

Some concern the classification of point clouds containing railway lines [Che et al. 2019, Ma 2018, Yang 2013, Arastounia 2012, Beger et al. 2011, Neubert et al. 2012, Zhu et al. 2014], others to algorithms used for the detection of rails and cables [Arastounia 2017, Sánchez-Rodríguez 2018, Luo 2014, Elberink 2015, Stein 2016], and still others create 3D models of railway tracks for infrastructure monitoring [Yang 2014, Hackel 2015].

The use of terrestrial, mobile and aerial laser scanning in numerous scientific and research projects has made it possible to identify the advantages and disadvantages of each of these techniques [Bęcek et al. 2015, Marmol and Mikrut 2017, Borowiec 2014, Tarek 2002, Soilán 2019, Yu 2015, Chen 2016, Falamarzi 2019]. The data acquired in this way and its accuracy enables performing a series of diagnostic analyses presented, among others, in the following studies [Głowienka et al. 2015, Mikrut et al. 2012, Muhamad 2013, Strach 2013].

Working with LIDAR data obtained in various coordinate systems and processing and converting it in CAD software requires their preparation by the users.

The main aim of the paper was to present the method of transforming point clouds between the two coordinate systems used in Poland, '1992' and '2000', and to use them to create an inventory and visualisation of railway infrastructure in Bentley's MicroStation programme. Point clouds were processed in the TerraSolid software environment.

The data intended for transformation originated from aerial laser scanning measurements of the railway line in Bochnia. For the study, a test area approximately 2 km long was selected on the Kraków-Tarnów railway line. Two aerial laser scanner recordings were used – from a height of 300 m and 500 m, generating two point clouds with a density of 17 and 11 points/m^2, recorded in different coordinate systems. The presented procedure and the result of converting data from the original '1992' system to the secondary '2000' system were based on purely mathematical calculation relationships.

Thanks to the diversity of the railway infrastructure that constitutes the study object, it was possible to identify not only the strengths of automated laser data processing, but also, in particular, areas where the operator's intervention, knowledge and experience are essential for the correct analysis of the research material.

2. Coordinate systems and their transformations

Each measurement of the environment or the object from which the measurement points are derived can be entered into a coordinate system, giving it a mathematical location in space. Coordinates not only describe the position of a point relative to the origin of the system, but also provide important information about the arrangement of points relative to each other, and by forming segments from them, also information about angles. Basic knowledge of the structure of national coordinate systems facilitates the solving of certain problems that arise when processing spatial data.

In Poland, there are two commonly used coordinate systems: '1992' and '2000' (Table 1).

Table 1. The parameters of the '1992' and '2000' systems

	'1992' system	'2000' system
Type of cartographic representation	Gauss-Krüger conformal projection	Gauss-Krüger conformal projection
Reference ellipsoid	GRS-80	GRS-80
Mapping zones	One mapping zone	One mapping zone
Longitude of the axial meridian	19°	15°, 18°, 21°, 24°
Coordinates of the main point	$X = -5\ 300\ 000$ m, $Y = 500\ 000$ m	$X = 0$ m $Y_{15°} = 5\ 500\ 000$ m $Y_{18°} = 6\ 500\ 000$ m $Y_{21°} = 7\ 500\ 000$ m $Y_{24°} = 8\ 500\ 000$ m
Similarity scale on the central meridian	0.9993	0.999923
Linear distortions	−70 cm/km ÷ +90 cm/km	−7.7 cm/km ÷ +7 cm/km
Application	Medium-scale and small-scale maps	Large-scale maps, base map

Source: Author's own study

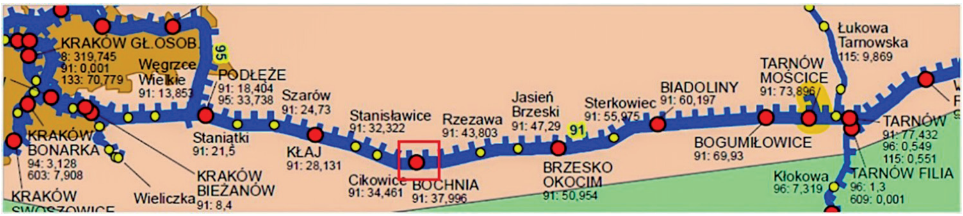
The author's work focused on converting plane coordinates from the '1992' system to the '2000' system for existing point clouds, using MicroStation with a TerraSolid add-on that allows for the transformation and further processing of point clouds.

Transformations of systems that have the same ellipsoid do not require additional information from the users about the ellipsoidal heights of points for a correct transition between systems. The situation is different when converting systems with different ellipsoids (e.g. the '1965' system to the '2000' system), where information about ellipsoidal heights is necessary and corrections must be applied to obtain correct coordinates [Kadaj 2002]. The '1992' and '2000' systems are based on the GRS-80 ellipsoid, therefore the transformation of point clouds only concerned the flat X and Y coordinates.

Most works involving transformation are based on vector data (e.g. polygon networks) or the calibration of rasters to a given geodetic system. This publication applies the concept of transformation to photogrammetric work, specifically demonstrating the procedure for converting LIDAR data from the '1992' system to the '2000' system. The decision to address the issue of point cloud transformation was prompted by the fact that there are few studies and comprehensive solutions that can help in converting large amounts of data. However, the discussed subject of transferring coordinates from one coordinate system to another point cloud coordinate system still demands a number of analyses, but at this stage, according to the author, it can already be applicable to less rigorous projects in terms of accuracy.

3. Features of the study object

The point clouds used in this study were obtained by MGGP Aero Sp. z o.o. from Tarnów using a Riegl LMS-Q680i scanning device mounted on board a Cessna T206H NAV III aircraft, covering a section of the railway line on the E30/ C-E-30 railway route in Bochnia, as part of the III Pan-European Transport Corridor railway line. This route begins in Dresden (Germany) and ends in Lviv and Kyiv (Ukraine). Figure 1 shows a section of the railway map specifying the location of Bochnia in relation to two cities in the Małopolska Voivodeship, Krakow and Tarnów, with the location of the study object marked.



Source: www.plk-sa.pl

Fig. 1. Section of a railway map with the location of the study object marked

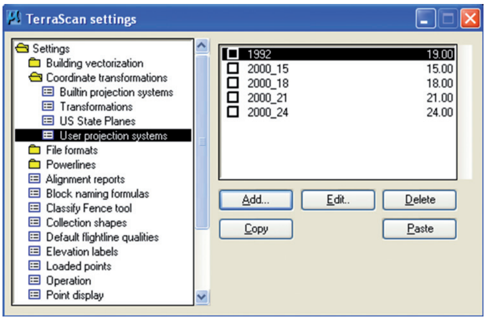
The study area covered a 2,130 m test section, for which two aerial laser scanner recordings were made – from heights of 300 m and 500 m, resulting in two point clouds (ALS 300) with a density of 17 points/m^2 and (ALS 500) with a density of 11 points/m^2, recorded in different coordinate systems ('1992' and '2000'). The densified point cloud created through the transformation to the '2000' system was the basis for performing an inventory of the railway infrastructure and a 3D model of the studied object using TerraSolid software.

4. Results of the study

4.1. Technology of data processing

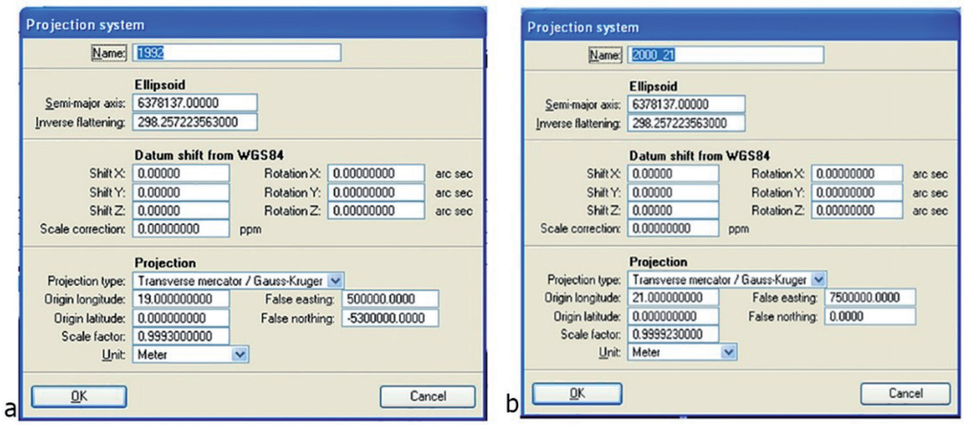
The transformation of the point cloud was carried out using the point transformation module in TerraSolid. The transformed point cloud with a density of 11 points/m² (ALS500) allowed for the densification of the second point cloud with a density of 17 points/m² (ALS300). Transforming the clouds into a single coordinate system created a point cloud with an average density of 28 points/m². This increased the detail of the linear objects recorded on both clouds, which in turn considerably facilitated the vectorisation of the railway infrastructure.

In TerraSolid, point cloud transformation is not complicated, as the programme has a module that enables the user to define custom coordinate systems in the *User Projection System* tab (Fig. 2) by entering their parameters (Fig. 3).



Source: Author's own study

Fig. 2. Defining custom coordinate systems in TerraSolid



Source: Author's own study

Fig. 3. Examples of definitions of PUWG systems: a. '1992' and b. '2000' in the TerraSolid programme

In this case, the transformation of point clouds does not require complicated transitions between different programmes and data formats, as everything is done in *.las format. The coordinates of control points calculated according to the formulas [Kadaj 2002] and TerraSolid software were compiled for control purposes (Table 2).

Table 2. List of control point coordinates.

No.		Coordinates of control points	
		'2000' system (software)	**'2000' system (calculations)**
1	X	5 538 075.28**48**	5 538 075.28**49**
	Y	7 459 470.7297	7 459 470.7297
2	X	5 538 045.6226	5 538 045.6226
	Y	7 458 594.3603	7 458 594.3603
3	X	5 538 035.20**90**	5 538 035.20**89**
	Y	7 457 755.5656	7 457 755.5656

Source: Author's own study

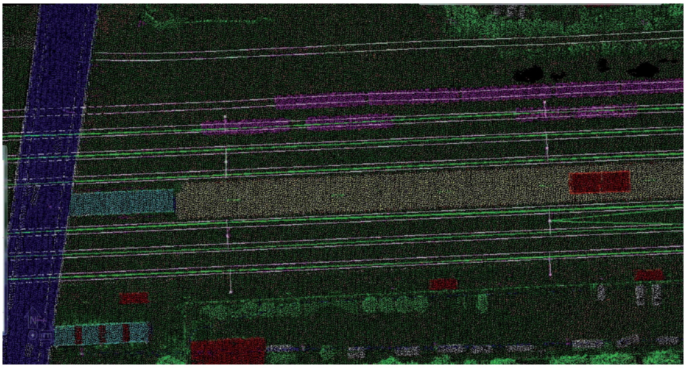
4.2. Inventory of railway infrastructure in the TerraSolid software

To develop the transformed point clouds, the author used TerraScan add-on solutions dedicated to working with railway data. These tools enable automatic detection of rails and overhead lines with the possibility of correcting the obtained results, as well as determining the type of rail that should be recognised in the cloud.

Data processing using most TerraScan add-on tools is possible after selecting the classes of selected elements. Classification can be carried out automatically or manually. In practice, both solutions are usually used, as the automatic process requires control and correction of errors [Kwoczyńska et al. 2016]. Due to the fact that the dense point cloud after transformation averaged 28 points/m^2, the detection process (Fig. 4) and subsequent extraction of railway infrastructure elements proceeded very smoothly (Fig. 5).

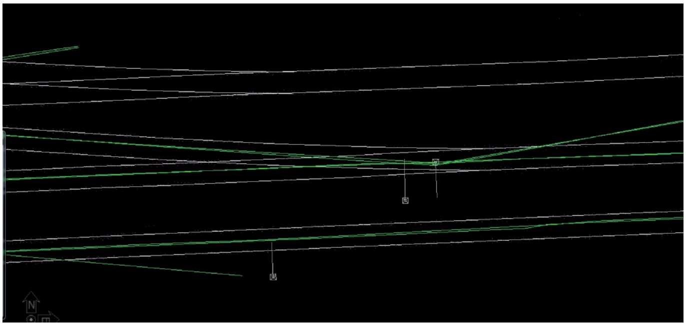
The TerraScan module contains tools for selecting points that represent support lines and contact wires, as well as for routing them. These functions can be applied to both railway and tram networks. All points classified on the selected layer or those located along the indicated axis can be detected. The programme reclassifies conductor points into a separate layer and creates corresponding linear elements (Fig. 6).

Automatic vectorisation of the traction network using TerraScan add-on tools is very simple and efficient. Drawing the course of the suspension lines and reinforcement cables manually would be difficult and time-consuming, as it would require frequent snapping (attaching the drawn line) to the point cloud. These are hanging elements



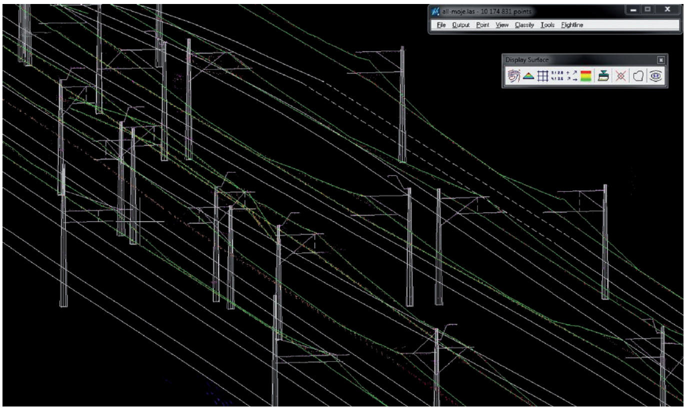
Source: Author's own study

Fig. 4. Point cloud after classification



Source: Author's own study

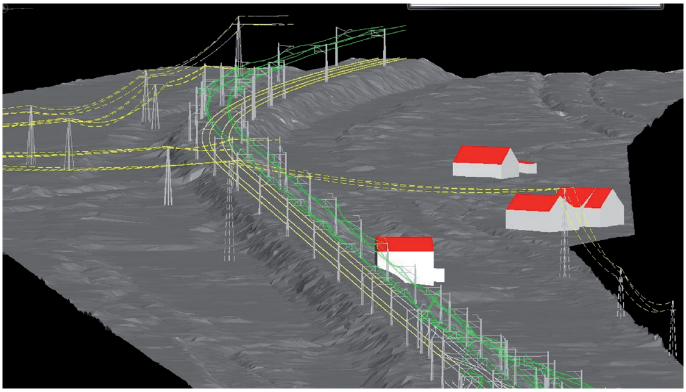
Fig. 5. Automatic rail detection



Source: Author's own study

Fig. 6. Traction network detection in TerraSolid

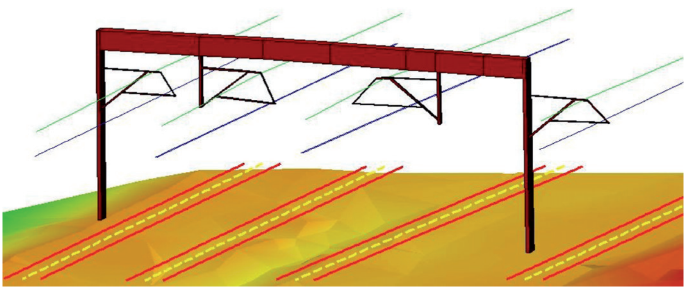
that form arcs. Therefore, the author considers the detection algorithm to be effective and the application to be suitable for inventorying all cables located in railway areas, including cables supplying power to nearby buildings (low voltage) or passing over high-voltage tracks. Given the presence of a power line in the vicinity of the inventoried railway line, it was also vectorised using TerraScan tools adapted for this purpose. The result can be seen in Figure 7.



Source: Author's own study

Fig. 7. Vectorised power line in the studied area

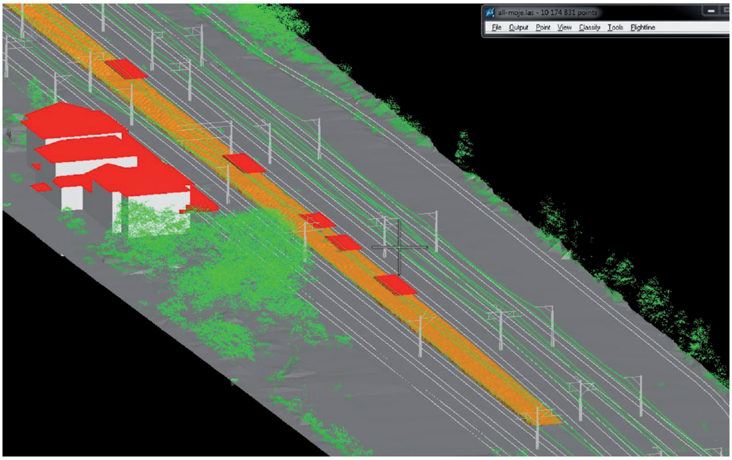
The tools included in the TerraScan package dedicated to working with point clouds that represent railway infrastructure do not yet provide solutions for the automatic or semi-automatic creation of support structure models. These are complex, irregular structures, and the use of a triangle mesh to present them leads to a large number of erroneous vectors. Due to the fact that the manual modelling process is very time-consuming, it is possible to use the function of rewriting cloud points to vectors, which makes the work substantially easier. The result of modelling the support structure is shown in Figure 8. The accuracy and detail of such a model is determined by the purpose for which it is created.



Source: Author's own study

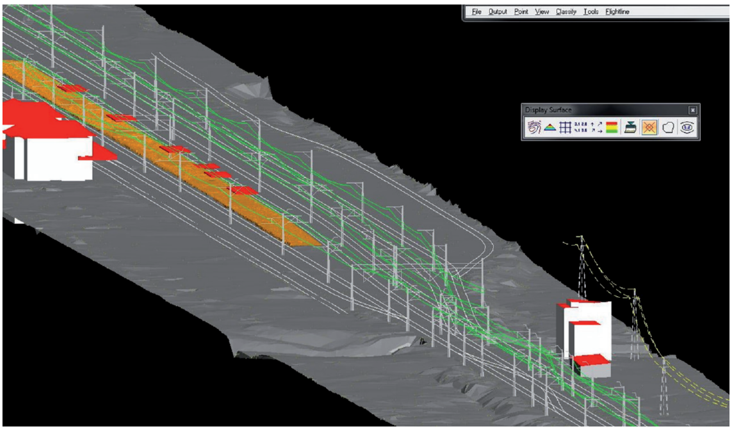
Fig. 8. Model of gate support structure

Modelling buildings located in the vicinity of the railway line under study in the TerraSolid software is facilitated by tools for automatic and semi-automatic vectorisation of these objects. Whereas, creating a model of the entire object requires the generation of a digital terrain model of the area directly under the track and the remaining area. The tools included in the TerraModeler add-on were used for this purpose. Platform models were developed for the examined section of the railway line. The combined effect of the work related to modelling the traction network, rails, buildings, platforms and surfaces, supplemented with other infrastructure elements and greenery, is presented in Figures 9 and 10.



Source: Author's own study

Fig. 9. Extract from the terrain model with railway infrastructure elements



Source: Author's own study

Fig. 10. Extract from the terrain model with railway infrastructure elements

5. Summary and conclusions

The measurement of railway structures involves a wide range of tasks, methods and solutions. Despite providing a high level of accuracy, traditional measurement methods are time-consuming and labour-intensive. Hence, there has been a clear increase in demand and use of mobile and aerial laser scanning where a compromise between quality and speed of information acquisition is required and achievable.

LIDAR data processing can be carried out in various software environments, depending on the available financial resources. Some automate office work, while others rely on manual work of the operator. Inspired by the possibilities of laser scanning technology, scientific studies from Polish and foreign research centres dealing with the use of this technique in railway infrastructure measurements were analysed, including [Bitenc et al. 2001, Kremer and Grimm 2012, Mikrut et al. 2012, Pyka et al. 2010, Soni et al. 2014]. The market for software supporting point cloud processing and analysis was also reviewed. The solutions proposed by TerraSolid were also presented. The testing ground was a section of the railway line in Bochnia, which was characterised by the complexity and diversity of its technical infrastructure elements. The experience gained during the successive stages of work with data from aerial laser scanning allowed the following conclusions to be drawn:

1. The density of point clouds obtained from aerial laser scanning is the parameter that decides whether they can be used for railway infrastructure inventory. A density of 11 and 17 points/m² does not guarantee satisfactory results for automatic railway track classification, hence the need to increase their density.
2. The transformation of point clouds between different coordinate systems, stemming from the nature of the data, can be a complex process that requires knowledge of various external computer programmes if, for example, Leica's Cyclon programme is used as the working environment.
3. Carrying out point cloud transformation is easy and quick if the working environment is TerraSolid software. The possibility of applying point cloud transformation helped to adapt the measurement materials to the current '2000' system without the need to repeat or order LIDAR flights, which reduces costs.
4. Vectorisation and modelling of railway infrastructure in TerraSolid ensures substantial automation of work, and thus less time-consuming data processing.

The use of LIDAR data for the development of railway infrastructure allows for the creation of a reliable spatial model of the object, which can serve as a basis for further analyses and measurements. The possibilities offered by the development and use of data obtained using laser scanning make this method a popular choice for large investors for whom it is important to create a spatial and clear model of the object.

References

Arastounia M. 2012. Automatic Classification of LIDAR Point Clouds in A Railway Environment. Univ. Twente, Netherlands.

Arastounia M. 2017. An Enhanced Algorithm for Concurrent Recognition of Rail Tracks and Power Cables from Terrestrial and Airborne LIDAR Point Clouds. Infrastructures, 2, 8.

Beger R., Gedrange C., Hecht R., Neubert M. 2011. Data fusion of extremely high resolution aerial imagery and LIDAR data for automated railroad centre line reconstruction. ISPRS J. Photogramm. Remote Sens., 66, S40–S51.

Bęcek K., Gawronek P., Klapa P., Kwoczyńska B., Matuła P., Michałowska K., Mikrut S., Mitka B., Piech I., Makuch M. 2015. Modelowanie i wizualizacja danych 3D na podstawie pomiarów fotogrametrycznych i skaningu laserowego. WSIE, Rzeszów.

Bitenc M., Lindenbergh R., Khoshelham K., van Waarden A.P. 2011. Evaluation of a LiDAR Land-based Mobile Mapping System for Monitoring Sandy Coasts. Remote Sensing, 3, 7, 1472-1491.

Borowiec N. 2014. Ekstrakcja elementów liniowych infrastruktury kolejowej na podstawie danych z lotniczego skaningu laserowego. Logistyka, 6, 2211-2218.

Che E., Jung J., Olsen M.J. 2019. Object recognition, segmentation, and classification of mobile laser scanning point clouds: A state of the art review. Sensors (Switzerland), 19.

Chen X., Li J., Cloud P., Crack P., Detection A., Road U., Canada I. 2016. A feasibility study on use of generic mobile laser scanning system. Proc. Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci., XLI, 545–549.

D-19. 2000. Instrukcja o organizacji wykonywaniu pomiarów w geodezji kolejowej, załącznik do Zarządzenia Nr 144 Zarządu PKP z dnia 23 października 2000 r.

Elberink S., Khoshelham K. 2015. Automatic Extraction of Railroad Centerlines from Mobile Laser Scanning Data. Remote Sens., 7, 5565–5583.

Falamarzi A., Moridpour M., Nazem A. 2019. Review on Existing Sensors and Devices for Inspecting Railway Infrastructure. J. Kejuruter., 31, 1–10.

Głowienka E., Jankowicz B., Kwoczyńska B., Kuras P., Michałowska K., Mikrut S., Moskal A., Piech I., Strach M., Sroka J. 2015. Photogrammetry and the laser scanning in the 3D modeling (Fotogrametria i skaning laserowy w modelowaniu 3D), WSIE, Rzeszów.

Hackel T., Stein D., Maindorfer I., Lauer M., Reiterer A. 2015. Track detection in 3D laser scanning data of railway infrastructure. Proceedings of the 2015 IEEE International Instrumentation and Measurement Technology Conference (I2MTC), IEEE, 693–698.

Kadaj R. 2002. Polskie układy współrzędnych. Formuły transformacyjne, algorytmy i programy. Rzeszów.

Kamczyk A. 2013. Prace geodezyjne i kartograficzne na terenach zamkniętych Narodowej Sieci Kolejowej w Polsce. Cz. I. Przegląd Geodezyjny, 85, 2.

Kremer J., Grimm A. 2012. The railmapper - a dedicated mobile lidar mapping system for railway networks. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XXXIX-B5, 477-482.

Kwoczyńska B., Sagan W., Dziura K. 2016. Elaboration and Modeling of the Railway Infrastructure Using Data from Airborne and Mobile Laser Scanning. IEEE Xplore, 106–115, https://doi.org/10.1109/BGC.Geomatics. 28

Lou Y., Zhang T., Tang J., Song W., Zhang Y., Chen L. 2018. A Fast Algorithm for Rail Extraction Using Mobile Laser Scanning Data. Remote Sens., 10, 1998.

Luo C., Jwa Y., Sohn G. 2014. Context based multiple railway object recognition from mobile laser scanning data. Int. Geosci. Remote Sens. Symp., 3602–3605.

Ma L., Li Y., Li J., Wang C., Wang R., Chapman M.A. 2018. Mobile laser scanned point-clouds for road object detection and extraction: A review. Remote Sens., 10, 1–33.

Marmol U., Mikrut S. 2017. Attempts at automatic detection of railway head edges from images and laser data. Image Processing & Communication, 17, 4, 151‑160. https://doi.org/10.2478/v10248-012-0041-z

Mikrut S., Pyka K., Tokarczyk R. 2012. Systemy do pomiaru skrajni kolejowej – przegląd i tendencje rozwojowe. Archiwum Fotogrametrii, Kartografii i Teledetekcji, 23, 291–301.

Muhamad M., Kusevic K., Mrstik P., Greenspan M. 2013. Automatic Rail Extraction in Terrestrial and Airborne LIDAR Data. IEEE Xplore. https://doi.org/10.1109/3DV.2013.47

Neubert M., Hecht R., Gedrange C., Trommler M., Herold H., Kruger T., Brimmer F. 2012. Extraction of Railroad Objects From Very High Resolution Helicopter-Borne Lidar and Ortho-Image Data. Comm. VI, WG VI/4.

Pyka K., Borowiec N., Poręba M., Słota M. 2010. Airborne Laser Scanning Data For Railway Lines Survey. PAK, 56, 01, 2‑5.

Rodríguez-Cuenca B., García-Cortés S., Ordóñez C., Alonso M.C. 2015. Automatic detection and classification of pole-like objects in urban point cloud data using an anomaly detection algorithm. Remote Sens., 7, 12680–12703.

Sadeghi J., Motieyan Najar M.E., Zakeri J.A., Kuttelwascher C. 2019. Development of railway ballast geometry index using automated measurement system. Measurement, 138, 132–142.

Sánchez-Rodríguez A., Riveiro B., Soilán M., González-deSantos L.M. 2018. Automated detection and 899 decomposition of railway tunnels from Mobile Laser Scanning Datasets. Autom. Constr., 96, 171–179.

Soilán M., Sánchez-Rodríguez A., del Río-Barral P., Perez-Collazo C., Arias P., Riveiro B. 2019. Review of Laser Scanning Technologies and Their Applications for Road and Railway Infrastructure Monitoring. Infrastructures, 4, 58. https://doi.org/10.3390/infrastructures4040058

Soni A., Robson S., Gleeson B. 2014. Extracting rail track geometry from static terrestrial laser scans for monitoring purposes. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XL-5, 553‑557.

Stein D., Spindler M., Lauer M. 2016. Model-based rail detection in mobile laser scanning data. IEEE Intell. Veh. Symp. Proc., August, 654–661.

Strach M. 2009. Pomiary dróg kolejowych i obiektów z nimi związanych oraz opracowanie wyników na potrzeby modernizacji kolei konwencjonalnych. Archiwum Fotogrametrii, Kartografii i Teledetekcji, 19.

Strach M. 2013. Nowoczesne techniki pomiarowe w procesie modernizacji i diagnostyce geometrii torów kolejowych. Rozprawa habilitacyjna. AGH, Kraków.

Tarek Z. 2002. Skanowanie terenu laserem lotniczym. Geodeta, 12. Warszawa.

Yang B., Fang L., Li J. 2013. Semi-automated extraction and delineation of 3D roads of street scene from mobile laser scanning point clouds. ISPRS J. Photogramm. Remote Sens., 79, 80–93.

Yang B., Fang L. 2014. Automated extraction of 3-D railway tracks from mobile laser scanning point clouds. IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens., 7, 4750–4761.

Yu Y., Li J., Guan H., Wang C., Yu J. 2015. Semiautomated Extraction of Street Light Poles From Mobile LIDAR Point-Clouds. IEEE Trans. Geosci. Remote Sens., 53, 1374–1386.

Zhu L., Hyyppa J. 2014. The Use of Airborne and Mobile Laser Scanning for Modeling Railway Environments in 3D. Remote Sens., 6, 3075–3100.