

EXTRACTION OF RAILROAD OBJECTS FROM VERY HIGH RESOLUTION HELICOPTER-BORNE LIDAR AND ORTHO-IMAGE DATA

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ABSTRACT:

LiDAR (Light Detection and Ranging) sensors and digital aerial camera systems using a slow and low flying aircraft provide a new quality of data for a variety of promising large-scale applications. The main of this study objective is the development of methods for the automated object extraction of railway infrastructure from combined helicopter-based extremely dense laser scanner measurement points and very high resolution digital ortho-imagery. Thus, different existing methods from digital image processing, image segmentation and object recognition have been compared regarding their performance, output quality and level of automation. It turned out that all existing methods are not suitable to meet the requirements (geometrical accuracy of the result, amount of data to be processed etc.).

Since original LiDAR point data provides a higher accuracy than derived DTM raster data or ortho-imagery new suited methods for the object extraction from point clouds have been developed. For the extraction of linear features, such as rails and catenaries, two new methods were implemented. The first method sets up on pre-classified laser points as input data. Therefore the RANSAC algorithm was implemented successfully to extract linear objects within the environment of MATLAB and ArcGIS. Second, a knowledge-based classification method was designed to compare a reference profile with the situation along the track using IDL.

The results show new prospects to automatically extract railroad objects with a high geometrical accuracy from extremely dense LiDAR data without using aerial imagery. The decision not to use image data was especially caused by the enormous data amount to be processed as well as radiometric differences of the imagery. The introduced methods are suitable to provide up-to-date information about the railroad infrastructure in order to transfer them to a infrastructure database.

1. INTRODUCTION

High-precision sensors such as airborne laser scanner (ALS) and digital aerial cameras featured with a differential global positioning system (DGPS) and an inertial measurement unit (IMU) offer new data sources for a variety of promising large-scale applications. In the beginning the ALS technique was mainly used for the generation of digital terrain models (DTM). With the improvement of the sensor technique it became possible not only to monitor the surface of the earth but also to identify small objects like rails or cables. ALS became in this way an economic alternative to terrestrial surveying for the documentation and control of rails or power lines.

In our study this kind of data were analyzed in order to extract railway infrastructure equipment and its surrounding objects. The main focus is on studies for a fully automated processing in consideration of profitability aspects compared to traditional surveying methods. A further objective is the development of methods for the object extraction of railway infrastructure from combined helicopter-based extremely dense laser scanner measurements and very high resolution digital ortho-imagery. The developed methods are aimed at the generation of high-

precision input data to create and extend a railroad infrastructure database. The required density of laser points can only be achieved with high quality equipment and a slowly flying aircraft. For being able to detect small and thin elements such as rail tracks the relative (and absolute) accuracy of the laser points must be at centimeter level. To meet this goal the positioning of the aircraft (and the subsequent geo-referencing) has to be at the same accuracy level.

The study area is a 36 km railroad section between Korneuburg and Hollabrunn, north of Vienna, Austria. The corridor contains single- and double-track sections as well as some small railroad station areas and is property of the Austrian Federal Railway (ÖBB-Infrastruktur Bau AG), who is also the initiator of this study.

2. INPUT DATA AND DATA PROCESSING

The capturing and pre-processing of the data was performed by the company BEWAG Geoservice GmbH. The company uses a helicopter-based platform for the simultaneous acquisition of laser measurement points and image data. The helicopter was

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equipped with a Riegl LMS-Q560 laser scanner and a Rollei AIC modular-LS (H25) camera in combination with a high precision IMU (IMAR INAV_FJR-001).

Due to the low speed and the low altitude (approx. 170 m above ground), laser measurements with an extreme point density from 20 to 30 m⁻² and very high resolution digital RGB ortho-imagery (5 cm ground resolution) can be acquired.

The DGPS/IMU data was processed with Novatel's Waypoint software. The resulting trajectory provides a sub-decimeter accuracy. The analysis of the raw full-waveform laser data and the following transformation from the laser coordinate system to the earth-fixed-frame was carried out by software tools of the laser scanner manufacturer. The raw point cloud was further processed using TerraSolid's TerraScan software where the classification of the points by object types was carried out (see figure 1). TerraPhoto was used to process the ortho-photo mosaic by means of the single images and the terrain model based on the ALS points.

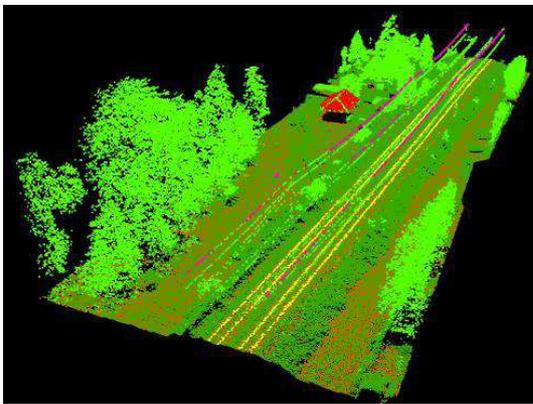


Figure 1. ALS data example of a railroad section showing the classified laser point cloud in a 3D-view (different colors represent different object classes, e.g. rails)

3. METHODS FOR OBJECT EXTRACTION FROM ORTHO-IMAGERY

Various image processing methods have been tested to extract railway features from the ortho-imagery. Due to the image resolution (5 cm) and perspective distortions the imagery is suitable for extracting the rail track only. The methods tested are:

- Combined Fourier and Hough transformation (Erda Imagine 9.1);
- Edge detection (HALCON 8.0);
- Object recognition (FeatureAnalyst 4.1);
- Image Segmentation (Definiens Developer 7).

Combined Fourier and Hough transformation: Using this combined approach we tried to produce a binary image for the extraction of straight rail track sections by Hough transformation. Thus, a Periodic Noise Reduction based on a Fourier transformation was followed by a high pass filtering. The resulting, intensely emphasized rail tracks and sleepers were binarized by thresholding (see figure 2).

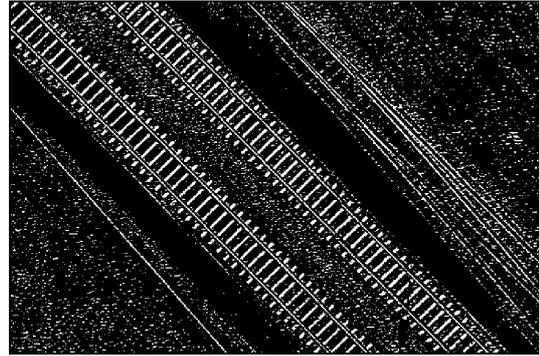


Figure 2. Resulting binary image calculated by a Fourier transformation followed by a high pass filtering

This approach causes a high computational effort and is not able to be automated (manual parameter settings due to different radiometric characteristics of the aerial images). Furthermore, radiometric differences of frequented and non-frequented rail tracks as well as different materials occur. The result is only suitable for a limited extent since there is still too much information in the binary image. Anyway, Hough transformation itself is applicable for straight sections only and causes a high computational effort as well.

Edge detection: In order to extract the rail tracks from the imagery a combined edge detecting and dynamic thresholding algorithm has been developed using the HALCON library. This library provides efficient implementations of various image processing methods (MVTec 2007). As its main field of application is industrial object recognition, it lacks reasonable handling of large multispectral image data sets and their geographical projections. To solve this problem significant pre- and post-processing is necessary. Despite of extensive tests with varying parameter settings the algorithm failed due to the complexity of imagery, interfering objects and radiometric differences (e.g. shadows). A further optimization using Hough lines did not produce satisfying results either.

Object recognition: Feature Analyst is an object recognition software with implemented learning algorithms for an extensive automated analysis. First, training areas (highly influencing the result) and a learning algorithm have to be selected and adjusted. Applying some post-processing the result can be optimized and the centerline of the detected polygons can be extracted (see figure 3). Due to the radiometric differences of the rail tracks multiple elongated neighboring polygons are formed which need a laborious manual merging. A use of extensive datasets or a batch processing respectively is not possible and the training areas have to be re-selected interactively for each image.

Image Segmentation: Methods of image segmentation or object-based image processing are common in the field of high resolution remote sensing image analysis. For our tests we applied the widely used Definiens software. The same problems as reported for the object recognition with Feature Analyst occur (multiple elongated neighboring polygons, gaps in the extracted rail tracks, additional redundant outlines at cut edges of the image mosaic and uncertain delineation in shadowed areas). Since the image tiles are not balanced radiometrically there is a negative impact on the segmentation and classification result. Thus, an extensive manual adjustment of parameters for each tile would be necessary.



Figure 2. The result of the edge detection algorithm developed with HALCON shows disconnected rail tracks and interfering objects



Figure 3. Rail track extraction result using Feature Analyst

In summary, various existing methods from digital image processing, image segmentation and object recognition have been tested for extracting objects from the ortho-imagery. All were compared regarding their performance, output quality and level of automation. It turned out that all applied methods are not suitable to meet the requirements especially in terms of the completeness of extraction, the resulting geometrical accuracy as well as the amount of data to be processed. Problems were caused also by shadows, perspective distortions or along cut edges of the ortho-image mosaic.

4. METHODS FOR OBJECT EXTRACTION FROM LIDAR DATA

Since original LiDAR point data provides a higher accuracy than a derived DTM or ortho-imagery new suited methods for the object extraction from point clouds have been developed and implemented to extract features such as rails, catenaries, cantilevers and railway poles. Basically, there were two different promising approaches which have been worthwhile to research into: Firstly, the extraction of straights and arcs using an adapted RANSAC algorithm, and secondly, a knowledge-based method for rail track extraction using 2D cuts.

4.1 Rail track extraction using an adapted RANSAC method

RANSAC principles: The method for rail track extraction sets up on pre-classified laser points (e.g. from TerraSolid software) as input data which are afflicted with outliers. Therefore the

RANSAC (RANDOM Sample Consensus) algorithm developed by Fischler and Bolles (1981) was implemented to extract objects within the environment of MATLAB and ArcGIS successfully. RANSAC is an iterative method and is widely used in the field of statistics to fit parameter-dependant model curves into series of measurements. This algorithm can also be transferred to geometrical point clouds to fit into parameter-dependant geometric objects.

Filtering classified ALS points: Before running the RANSAC algorithm one out of two different developed filtering methods need to be applied in advance to reduce outliers from the pre-classified ALS points. Firstly, the software TerraScan allows re-classifying points using the option 'classify by height from ground' since rails are planar for example. This results in optimized data for the extraction process containing much less outliers. Another method for filtering classified ALS points was developed using ArcGIS. In this case the filtering is realized by analyzing the height of neighboring points. The principle is to calculate the difference between the heights of the classified rail points against the mean value of the ground points within the immediate neighborhood. Only those ALS points "hovering" above the ground within a certain interval will remain in the dataset. Depending on the used search size and a valid height-difference interval the method is able to reduce the amount of points classified as railway to a portion of about 10-50 %. Therefore the point density of the resulting dataset along the rail varies between 0.3 m^{-1} and 2.1 m^{-1} . The remaining points of different reduction cycles have been estimated for their usability to describe the railroad geometries (see figure 4). It could be shown that in straight railroad sections the highly reduced point number of only less than 10 % would not lead to wrong results if the railway geometry is considered as a regression line between the x- and y-coordinates of the points.

Adaption of the RANSAC algorithm: The aim of using RANSAC is to iteratively generate simple geometrical objects through a point cloud. Thus, functions for straight lines or circular arcs are fitted into the filtered 2D point cloud which can still contain misclassified points and outliers (cf. McGlone et al., 2004; Gonzalez et al., 2004). First, a tiling of the dataset is performed along the trajectory which is coarsely related with the rail direction. It is possible to adjust the size of the data tiles (e.g. length, width and overlap distance) according to the curvature (see figure 5).



Figure 4. Portion of classified railroad points: original pre-classified points (above); remaining railroad points after post-processing (below)

Next, the RANSAC algorithm is started for each tile respectively. In its classical form the method results in just one solution – the one with the highest degree of fitting. For our purpose the algorithm has been adapted to detect multiple lines or curves (at least two parallel rails with a certain distance, see figure 5). Further, based on the detected lines and the corresponding points the best fitting regression lines were calculated. Therefore the identified inliers (points that are within a certain distance to the extracted function) were used to calculate a curve-fitting function based on the Least Squares Method (LSM). This improves the geometrical accuracy of the lines through minimizing the RMS errors.

To ensure the criteria of parallelism the track gauge was used. The following adaption of the RANSAC-Algorithm was implemented:

- Automatic decision to fit a line or circular arc;
- Detection of parallel lines or circle arcs;
- Detection of multiple results;
- Computation of a curve-fitting function (adjustment) based on LSM;
- Termination conditions (e.g. amount of points or point density).

Based on the extracted rail elements the dual lines were collapsed into a track centre line (see figure 6). The final step merges the line or circular arc segments of the overlapping tiles automatically.

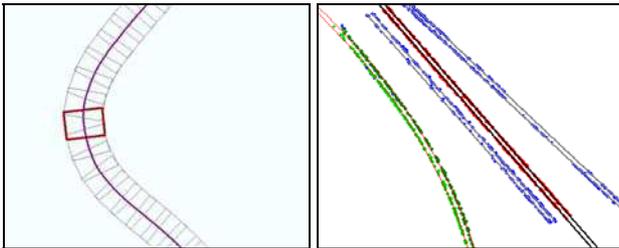


Figure 5. Overlapping tiles along the direction of the flightline (left) and fitted line and circular arc functions for a tile using the adapted RANSAC algorithm (right)



Figure 6. Ortho-image overlaid with the extracted rail tracks: rail (solid), rail centre line (dashed) and filtered rail points (white) (right)

4.2 Rail track extraction using 2D cuts

A knowledge-based classification method was designed to compare a reference track profile with the situation along the railway using IDL (Interactive Data Language). The trajectory represents the approximated railway. Therefore the non-classified laser measurement points were analyzed step by step along this trajectory. In a 2 m interval the ALS data was selected in a small stripe perpendicular to the local trajectory (2D cut, see figure 7).

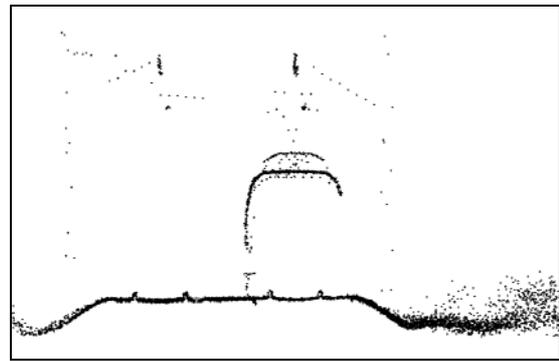


Figure 7. Visualization of a 2D cut across the railway wherein the rails are clearly identifiable above the nearly flat track bed even if a vehicle shadow interrupts one of both scanning missions

A collection of conditions defines the following hierarchic calculations in order to find the track axis. In particular the following conditions were derived from the knowledge about the typical geometry of the track bed and its surrounding area:

- The rail bed around the track is nearly horizontal and flat (condition 1 in figure 8).
- It is assumed that the railway loading gauge is free of objects (thus free of valid laser measurement points, condition 2 in figure 8).
- The mean track profile is known and two tracks with a fix distance (track gauge) define the railway (see figure 9).

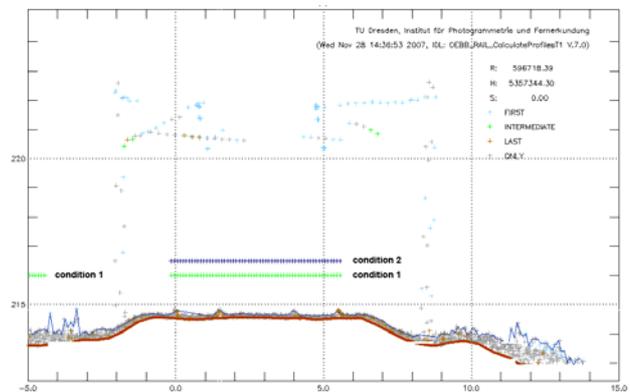


Figure 8. The laser measurement points (color coded by echo type), the temporary terrain model along the 2D-cut (brown), and the results of hierarchic analysis of the 2D cut: condition 1: horizontal rail bed, condition 2: free railway loading gauge

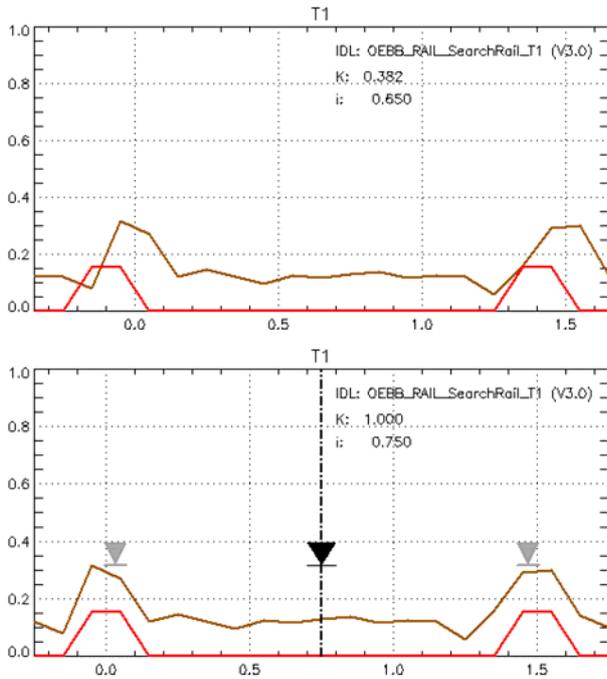


Figure 9. Comparison of the local terrain model (brown profile) with the reference profile (red profile) with a low correlation coefficient i (above) and when the track axis is found (below)

In the last step of the fully automated hierarchic analysis the local terrain model is compared with the reference profile (see figure 9). The correlation coefficient i between both profile lines and the coordinates are stored when the track axis is found. This comparison is performed for all areas if the condition 2 is fulfilled. The result is a collection of points which represents the track axis (see figure 10).



Figure 10. Resulting track axis points (black) along the trajectory (blue), outliers are coded in red

4.3 Extraction of further rail road infrastructure objects

Based on the extracted track axis other important railway infrastructure objects can be detected easily using geometrical railway construction standards (e.g. distance or height). The following objects can be detected with spatial and attributive knowledge-based queries in a GIS.

Catenary: The catenary consists of the mounting wire and the contact wire. We assume that catenary points can only be a first echo because of the small dimension of the cable (approx. 1 cm) in combination with a laser footprint size of 8.5 to 10.0 cm. Further the points should be higher than 5.0 m above the DTM and can only be located within a 0.4 m buffer tolerance regarding the extracted track axis. All the laser points with a height from 5.0 to 6.1 m are contact wire points. The rest are points of mounting wire or other mounting components (see figure 11). In a further step these selected points can be converted to lines using the RANSAC method described above.

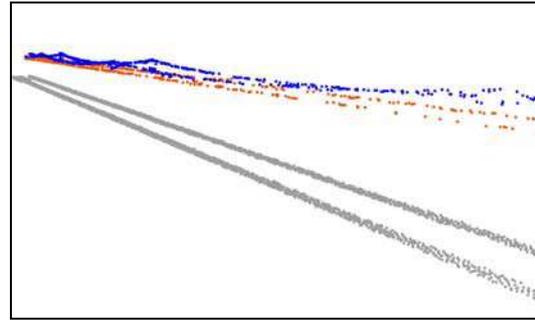


Figure 11. 3D view of extracted contact wire (red) and mounting wire (blue) laser points above the rail points (grey)

Cantilevers and railway poles: The points belonging to cantilevers and railway poles can be extracted with spatial queries as well. Therefore we assume that cantilever points have at least a distance of 0.8 - 1.6 m to the extracted rail track axis. Because of the sufficient dimension of the objects in comparison to the small footprint size, the measurements can be 'first pulse' or 'only pulse' points with a normalized height of 5.0 m above the ground. After converting the points to a binary raster to identify regions the clump-and-sieve function can be used to separate the interfering points from the wires for tensioning. Based on these cantilever points the railway poles are determined searching for the local maxima orthogonally to the track direction. In future it is supposable to reconstruct the exact catenary from one railway pole to another.

Vegetation and buildings: High vegetation close to the rail track can be a safety risk e.g. in case of storms. Thus, the spatial location of vegetation is interesting for railway operators. The extraction of vegetation based on LiDAR points is possible using the local relative point density and the normalized height of non-ground points (Hecht et al., 2006). The detected vegetation patches can further be converted into polygon geometry with an item containing the mean height values of the vegetation. Buildings next to the rail track are safety-relevant information too. They can be derived successfully using the algorithms of the TerraScan software (Soininen, 2005).

5. RESULTS

We found out that it is possible to extract railroad objects automatically from extremely dense LiDAR data without using any information from aerial imagery. Of course these are useful for orientation, visualization and checking, but their capability for automatic feature extraction is limited due to perspective distortions for some objects (especially non-ground objects like

catenary, cantilevers) and insufficient spatial resolution (e.g. wires).

The methods developed are particularly suited for long sections with single- or multiple rail tracks. Further investigations are needed to estimate the degree of correctness, but visual checks of the extracted features promise a reliability above 90 %. Even if there are still a few gaps for areas in and around railroad stations (with complex rail geometries and a lot of switchblades) the advantage is the high degree of automation. Since the railway system is mainly characterized by long track sections the applied methods can be used very efficiently.

Table 1 summarizes both developed methods to extract the railway tracks from laser point data.

Method	Adapted RANSAC method	Profile method
Data base	Classified laser points	Non-classified laser points
Strengths	Fully automated	Fully automated
Weaknesses	Limited results in areas with complex rail geometries (rail switches)	Limited results in areas with complex rail geometries (railroad stations, rail switches)
Classification accuracy	Height: aprox. ± 10 cm Position: aprox. ± 10 cm (depends on the classification result)	Height: ± 10 cm Position: ± 10 cm

Table 1. Overview on the methods of rail extraction from laser measurement points

6. CONCLUSION AND OUTLOOK

For the future planning and maintaining of railroads using geographic information technology the traditional used methods of positioning (railway, track and kilometeric position) have to be substituted by absolute geodetic coordinates. This was also the outcome of the International Union of Railways (UIC) GEORAIL project which highlighted the "overall needs and requirements for a coordinate-based description of the rail system". The methods presented here can contribute to reach this goal.

During construction, maintenance and operation processes of a railway infrastructure company spatial data of the rail network and the railway infrastructure are collected, applied and modified. At the same time all these spatial information are embedded in spatial base data of the surrounding world (e.g. within railroad information systems or infrastructure data bases). LiDAR-based captured data can meet the requirements and thus can become a relevant data collection source for railroad GI-systems due to its high level of automation during data recording and analysis.

LiDAR data of railway networks and associated infrastructure can be advantageously acquired area-wide, fast, with high precision, and without interfering the ongoing rail traffic. The value of these data is utilizable only by means of an IT-based and considerable automated processing.

The results show that it is possible to extract railroad infrastructure objects automatically with a high geometrical accuracy from extremely dense LiDAR data without using aerial imagery. The accuracy of the results using both introduced methods is comparable. The procedure demonstrates a profitable way to acquire relevant railway infrastructure data automatically and therefore can help to save costs. Thus, the methods are suitable to provide up-to-date information about the railroad infrastructure as a basis for an infrastructure database.

Further work will focus on the advanced implementation of the methods especially to handle areas with complex rail geometries and to extend them concerning the extraction of additional objects as well as performance optimization. Since railway geometries and construction standards are similar worldwide the methods are transferable to a large extend.

Beside the demonstrated possibilities of object extraction other beneficial applications of these data arise for railway operators: Detailed digital terrain and surface models, 3D simulations for the emergency management and planning bases for all technical departments.

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