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Using laser scanner and GPR data in geotechnical diagnostics of roads and railways

Utilisation des données du scanner laser et du géoradar dans les diagnostics géotechniques des routes et des chemins de fer

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ABSTRACT: Thanks to the fast development of data processor speeds and data storage capacity, the use of Non Destructive Testing (NDT) methods, such as Ground Penetrating Radar (GPR) and Laser Scanner (Lidar) technologies, are quickly becoming more and more popular tools among experts for geotechnical tasks in road and railway networks. The greatest benefit of the integrated analysis of laser scanner and GPR data is that, whilst laser scanning can provide an accurate surface model of roads and railways and their surroundings, GPR technology gives additional information about the substructures, subgrade soils and their properties such as moisture content (saturation degree) and moisture susceptibility. This allows engineers to not only detect the root cause of the problem but also to outline the problem area accurately. Finally, time series analysis using these techniques enables a move towards proactive maintenance policies where problems can be remedied as they arise before they turn into serious and expensive ones. This presentation provides an overview of GPR and laser scanner technologies and how they can be used in the different fields of geotechnical and other diagnostics of roads and railways.

RÉSUMÉ: Grâce au développement rapide des vitesses de traitement des données et des capacités de stockage, l'utilisation des méthodes de Contrôle Non-Destructif (CND), telles que les technologies de radar à pénétration de sol (GPR) et de scanner laser (Lidar), sont en passe de devenir des outils de plus en plus populaires pour les travaux géotechniques des réseaux routiers et ferroviaires. Le principal avantage de l'analyse jointe du scanner laser et des données géoradar est que d'une part le scanner laser fournit un relevé de surface précis des routes et des voies ferrées et de leur environnement, d'autre part, la technologie géoradar fournit des informations supplémentaires sur les infrastructures, la plate-forme support et leurs propriétés telles que le taux d'humidité. (Degré de saturation) et sensibilité à l'humidité. Cela permet aux ingénieurs de détecter non seulement la cause du problème, mais également de localiser avec précision la zone du problème. Enfin, l'analyse chronologique utilisant ces techniques permettent de passer à des politiques de maintenance proactive afin de résoudre les problèmes dès leurs apparitions et avant qu'ils ne se transforment en problèmes graves et coûteux. Cette présentation fournit une vue d'ensemble des technologies géoradar et des scanners laser et de la manière dont elles peuvent être utilisées dans les différents domaines de géotechnique et autres contrôle des routes et des voies ferrées.

Keywords: road, railway, laser scanner, GPR, diagnostics, structural condition

1 INTRODUCTION

Road and railway track condition is evolving under increasing axle loads, repeating dynamic effects, faster vehicles and seasonal changes. Many defects that affect the functional condition of the road or railway can be measured and located accurately using either a profilometer or track geometry inspection car, but the root-cause of the problems can be challenging to define without information about the structural condition and survey area environment. Integrated analysis of functional condition derived based on data from road profiling systems or track geometry cars together with ground penetrating radar and laser scanner can be used to provide important evidence of the possible causes of the problems. Typical reasons for the problems are inadequate structure, material quality problems, seasonal effects and frost action, insufficient drainage, discontinuities in the structures such as bridge transitions, culverts and crossings.

2 SURVEY TECHNIQUES

2.1 GPR

Ground Penetrating Radar transmits a short electromagnetic pulse in the medium using different types of antennas with a central frequency varying from 10 MHz up to 2.5GHz. These pulses travel through the structure at a speed limited by the materials' dielectric properties and when the pulse reaches an electric interface in the medium, some of the energy will be reflected back while the rest will proceed forwards. These reflected energy pulses are collected with GPR antenna and displayed as a waveform showing amplitudes and time elapsed between wave transmission and reflection. When these measurements are repeated at high frequencies (currently up to 1000 scans/second) and the antenna is moving, a continuous profile is obtained across the target (Saarenketo 2006). In road and railway surveys, pulse radars are the most popular GPR systems but, lately, stepped frequency systems have also entered the market. Figure 1 presents GPR systems.

Figure 1. Above: Road Doctor Survey Van (RDSV) with 2 GHz air coupled antenna and 400 MHz ground coupled antenna in front of the vehicle. Laser scanner with IMU and GPS is located on the roof behind the vehicle. Below: HyRail vehicle equipped with three 400 MHz ground coupled antennas.

In road and railway surveys, the GPR method has traditionally been used to measure the thickness of the pavement structure or railway structure. However, during the last 20 years GPR systems and knowledge of the electrical properties of materials and their relation to mechanical properties has dramatically improved. Thanks to that, using GPR it is currently possible to measure/monitor material properties such as ballast fouling (fines content), moisture content (saturation degree), susceptibility to permanent deformations, frost susceptibility and microcracking (Saarenketo 2006, Silvast et al. 2010; 2012). These improvements have led to GPR becoming a significantly a more popular tool in road and railway asset management (Saarenketo 2006, 2016).

2.2 Laser scanner

Laser scanner technique, also called Lidar, is a distance measurement technique that is based on the measurement of travel time of a laser beam from the laser scanner to the target and back. A laser scanner is composed of three parts: a laser canon, a scanner and a detector, a fourth essential part is an accurate positioning system. In addition, an inertial motion unit, IMU, is normally used with laser scanner to measure the exact position of the laser scanner during the survey. The laser canon produces the laser beam, the scanner circulates the beam and the detector measures the reflected signal and defines the distance to the target. When the laser beam angle is known, and beams are sent to a range of directions from a moving vehicle with a known position, it is possible to make a 3D surface image, or ‘point cloud’, of a road and its surroundings. The point cloud can have millions of points, with every point having x, y & z coordinates and additional reflection or emission characteristics (Saarenketo et al. 2012, Saarenketo 2016). Examples of different kinds of laser scanner point cloud presentation outputs are presented in Figure 2.

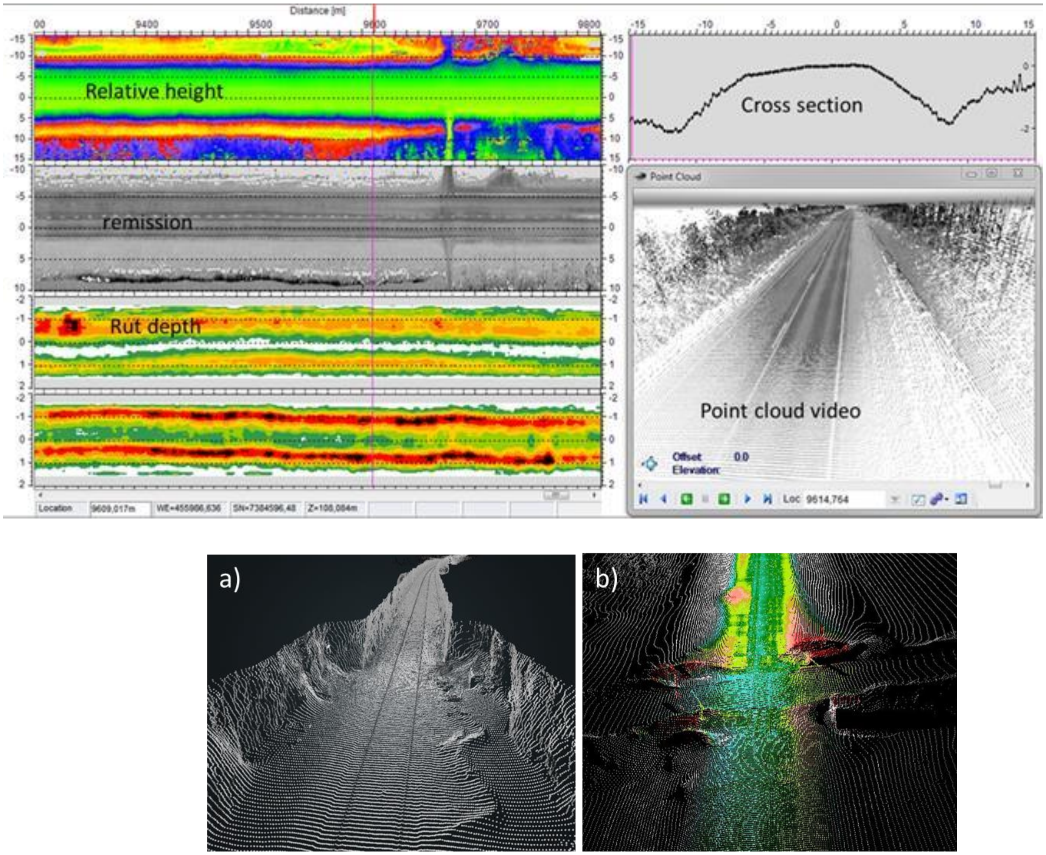

Figure 2. Top: different ways of presenting laser scanner data. Bottom: examples of lidar point-cloud data views from railways: a) transition from bedrock cut to tunnel and b) railway crossing with colour-coded snow height in point-cloud data.

2.3 GPR and Laser Data Analysis

Software is a critical part of integrated analysis of GPR and laser scanner data (Herronen et al. 2015). It must be able to process and analyse both data files with exact positioning and video data. In addition, software should be able to view and analyse all the other data collected from roads and railways that is needed for reliable problem diagnostics. To meet this requirement, over the last 20 years, Roadscanners has been developing different Road Doctor™, Rail Doctor ™ software packages customized for data collection, data linking, data processing and analysis, as well as maintenance and rehabilitation design and quality control. An example of this analysis is presented in Figure 3. This case is an excellent example showing that the root cause of the pavement damage is clogged or missing private access road culverts.

3 PROBLEM DIAGNOSTICS

3.1 Moisture and Frost

Poor internal and external drainage and thus water in the structure layers can cause several problems which weakens the road or track structures and their geometry (Arnold et al. 2017). According to Latvala et al. (2016), several studies have shown that water in railway structures may cause frost heave, thaw softening, attrition of ballast, and weakening of the load bearing capacity of a track's geometry. Frost action in soil refers to possible unfavourable phenomena due to freezing and thawing, frost heave and thaw softening which results in unevenness on the surface of the road or railway track. The primary cause of the frost action process in areas of seasonal frost is the formation of ice lenses in the freezing zone by water flowing from unfrozen soil to the frost-susceptible soil (Nurmikolu 2005).

The previously described subsoil conditions can be detected with laser scanner and GPR

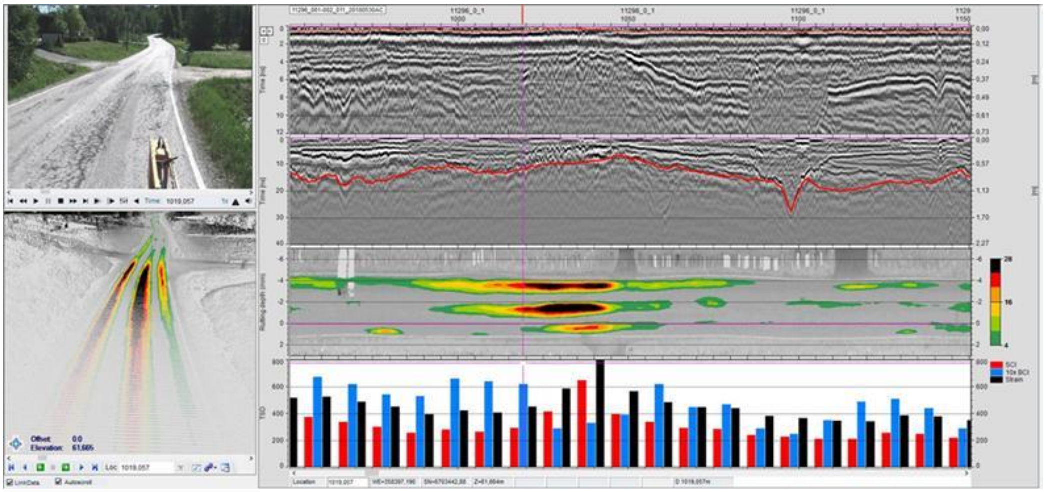

*Figure 3. Example of the benefits of the integrated analysis of different road survey technique. Smaller windows on the left present video (above) and point cloud video with rut depth information (below). The top field presents 2 GHz GPR data with pavement thickness interpretation and the second field presents 400 MHz GPR data with total pavement structure interpretation. Thickness scale is on the right. Third field presents laser scanner remission data with calculated rut depths. The bottom field presents bearing capacity parameters (SCI, 10*BCI and strain) calculated from the traffic speed deflectometer (TSD) data*

methods which can indicate the moisture condition in both the ditches and structures.

Drainage and ice lens formations under structures can be located by comparing the data from different seasons. Figure 4 shows an example of moisture profiles calculated from summer and winter GPR data sets. The upper moisture profile is calculated from a summer measurement and the lower profile from a winter survey. The summer moisture profile shows the moist areas as blue colours in the subballast – subgrade soil interface at a depth of 1-1.5 meters. The winter moisture profile shows a considerably stronger response in the same locations which indicates formation of an ice lens with unfrozen water. Longitudinal level standard deviation data from winter and summer measurement data also indicates frost heave problems in the inspected railway section.

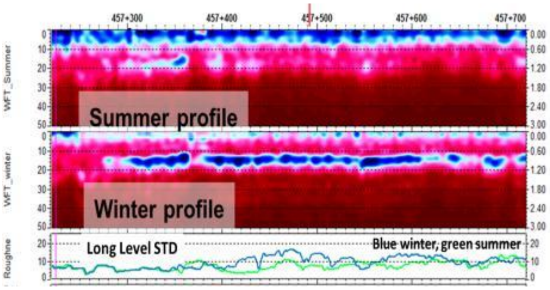

Figure 4. Time-series presentation of the standard deviation of the long wave length range (25-70 m) of track geomery longitudinal level from a settling embankment section.

Laser scanner can be used to detect the presence of water in ditches and the level of the drainage system. Figure 5 presents an example of the laser scanner plan view with color-coded water surface reflection representing the presence of water in the side ditch which is also visible in the track ditch video.

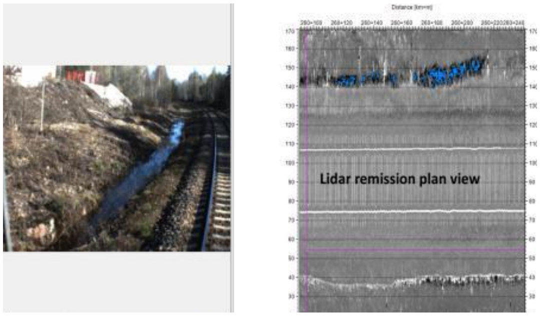

Figure 5. Analysis of external drainage using laser scanner remission data analysis. Presence of water is visible as blue colours in laser scanner remission plan view as well as in track video image

Season dependant problem analysis utilizing integrated laser scanner, GPR and track geometry data has been widely used on the Finnish rail network during the last 8 years to detect frost problem root-causes and prepare optimized maintenance plans for problematic track sections in Finnish Transport Agency´s (FTA) project for frost and soft soil problem detection (ROPE) (Silvast et al. 2017).

3.2 Settlements

On soft soils, road and railway structures will settle as an outcome of permanent deformation in the top structure and underlying layers. The settlement is caused by the embankment weight and repeated traffic loading. The severity of the settlement depends on the quality and performance of the structure layers and subgrade soils.

Settlements can be problematic for ride comfort and safety of the traffic. Developing settlements also requires constant maintenance. GPR in combination with laser scanners can be utilized to reveal potential problematic settlement locations. Figure 6 presents a settlement area from a section of railway in Northern Finland in which the height of the surrounding soil from laser scanner data is overlaid on top of the GPR data. This kind of data visualization enables the estimation of the depth of the settlement.

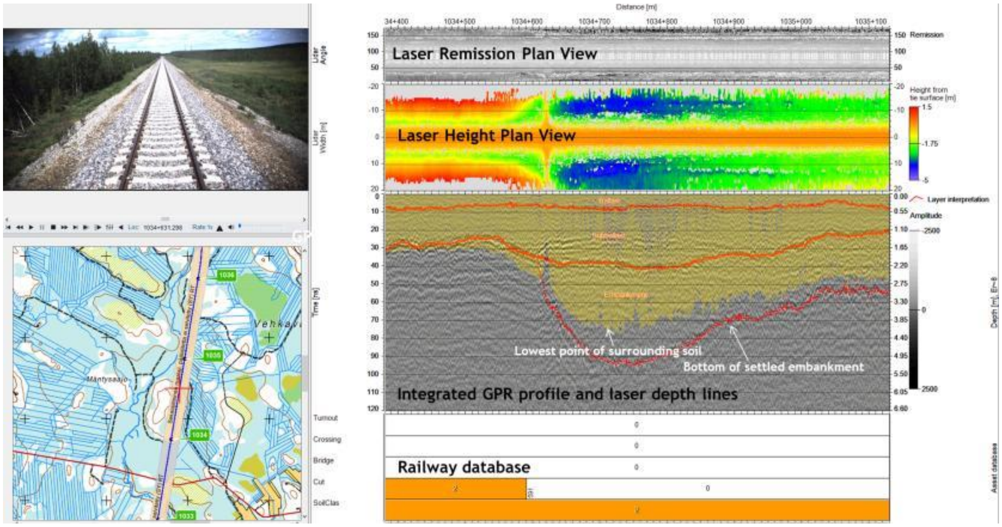

Figure 6. Example of the the settlement section in a railway embankment from a peat area. The settled section is visible in the GPR data (third field) where the bottom of the embankent is lower than the surrounding soil level.

3.3 Time-series

To analyse the progressive development of settlements, seasonal change dependant problems or any other time based deterioration the functional condition of the structures also must be evaluated as a time series (Silvast et al 2014). Figure 7 presents development of a settlement analysed from a track geometry longitudinal level time-series. It shows the behaviour of the track geometry over time as a colour-coded standard deviation of a longitudinal level long wavelength range between the years 2009-2015.

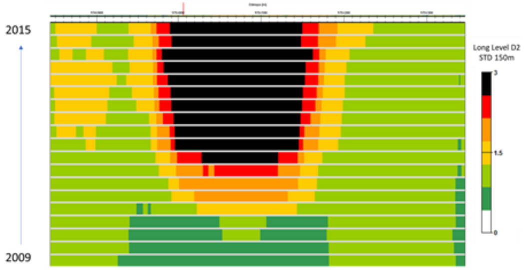

Figure 7. Time-series presentation of the standard deviation of the long wavelength range (25-70 m) of track geomery longitudinal level from settling embankment section.

4 GPR AND LIDAR IN ROAD ASSET MANAGEMENT

Since 2015, the integrated analysis of GPR and laser scanner has had an essential role in Finland in the PEHKO 2015-2025 project, that has been focusing on improving practices and policies in paved road asset management and thereby improve the condition of the paved road network, or at least keep it at the current level using less resources. GPR and laser scanner data has been used in all key asset management processes: 1) Improving daily maintenance, especially drainage. 2) Applying new NDT methods in the diagnostics of paved roads. These techniques allow engineers to focus rehabilitation measures exactly on the problem sections and address the root issues. 3) Changing maintenance policies from reactive to more proactive maintenance, allowing maintenance crews to fix the potential problem sections before serious pavement damage appears (Tapio et al. 2016).

A good example of the PEHKO diagnostics has been presented in earlier in Figure 3. This kind of diagnostics has been impossible to do with “traditional” methods because the problem’s root cause is outside of the road. GPR and Lidar data analysis together with TSD data have revealed soundly performing structures. Figure 8 presents how steel reinforcement installed in the unbound base has shown excellent performance against mode 2 rutting on a road built over peat. Pavement outside the steel grid section suffers from high shoulder deformation while hardly any deformation can be detected in the steel grid section.

In proactive maintenance, the key analysis result has been laser scanner maps that show annual or biannual rut increase. Figure 9 shows an example where high annual rut increase can clearly be related to the sandwich structure where old pavement has been left under the base course when the grade line of the road was raised. Building these “moisture traps” were a common solution in many countries in the 1980´s and 1990´s.

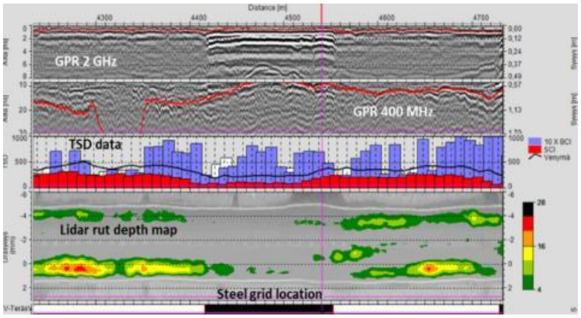

*Figure 8. Road Doctor software diagnostics from PEHKO area in central Finland showing soundly performing steel grid structure on a road built on peat. Top two fields: 2.0 GHz and 400 MHz GPR data, middle: Traffic speed deflectometer data where blue bars present 10*BCI values, red bars SCI value and black line pavement strain.*

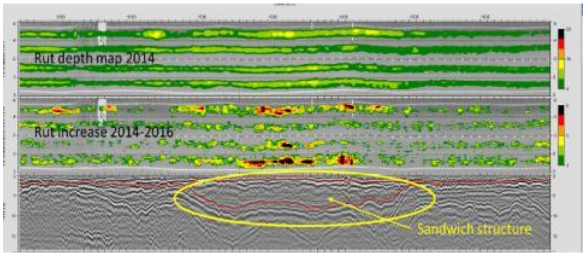

Figure 9. Top: laser scanner rut depth map from 2014, middle: map showing rut depth increase 2014-2016 where black colour shows >4 mm increase. Bottom 2 GHz GPR data showing location of sandwich structure.

5 CONCLUSIONS

The integrated analysis of GPR and laser scanner data has already proven to be an extremely efficient method in problem diagnostics of road and railway structures as well as proactive maintenance guidance. The greatest benefits of an integrated analysis is that it provides an easy way to adopt information from roads and railways and their surroundings combined with subsurface information. In addition, time series analysis also reveal how fast certain problems are growing and further enable proactive maintenance measures to be used before they develop into severe damages that are expensive to repair.

6 ACKNOWLEDGEMENTS

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