3D CALIBRATION OF GPR (GROUND PENETRATING RADAR) FOR BRIDGE MEASUREMENTS - CASE KAJAANI VARIKKO BRIDGE

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Abstract

3D calibration was performed for a GPR measurement system for concrete bridge decks. An old bridge having been repaired approximately two years prior with a new bridge deck part was considered in the test results. The deck, including then visible subsurface features, was measured earlier during the construction phase using a 3D laser scanning system, then after construction by two different GPR measurement systems and antennas. Several subsurface structural layers as well as the deck reinforcement were measured by the GPR systems. These 3D point clouds were compared with the mid-construction laser scanned point clouds. The results showed high accuracy in measurements of reinforcement, but less accuracy in measurement of concrete surface under road layers. Future development possibilities are also discussed.

KEYWORDS: GPR, ground penetrating radar, bridges, bridge health measurements, non-destructive evaluation

1 INTRODUCTION

GPR (Ground Penetrating Radar) is a non-destructive evaluation (NDE) or measurement method which uses discrete pulses of radar energy with a central frequency varying typically from 10 MHz up to 2.5 GHz. The aim of GPR is to resolve the locations and dimensions of electrically distinctive layers and objects in materials. Pulse radar systems transmit short electromagnetic pulses into a medium; when the pulse reaches an electric interface in the medium, some of the energy will be reflected back while the rest will propagate forward. The reflected energy is collected and displayed as a wave showing amplitude (reflected power) and time elapsed between wave transmission and reflection. By repeating measurements (currently up to 1000 scans/second) with the antenna moving, a continuous 3D profile is obtained across the target (Saarenketo 2006).

The GPR technique was first used in bridge deck surveys in the early 1980s (Saarenketo 2006). Later research and development was ever more focused on developing automated or semi-automated GPR data analysis, along with multi-channel GPR systems for mapping bridge deck structural health. Recently the focus has been on collecting reflection amplitude data from bridge decks and preparing maps that present damaged areas in the bridge structures. It has been found that using GPR the following features can be measured from the bridges: pavement thickness, thickness of single pavement layer, pavement damage, concrete cover of top layer reinforcement, spacing between reinforcement bars, position of tendons or tendon ducts, concrete damage and different concrete and pavement properties.

According to Rutgers University (2009) researchers, non-destructive methods support imaging inside a structure, where most deterioration starts. Good examples of 3D information models measured by impact echo as well as 3D GPR have been provided by Rutgers University (Fig. 1). However, no other published work or research reports were found about the use of 3D GPR method related to bridges. In order to utilize GPR measurement results in the emerging process of 3D bridge engineering, 3D measuring methods as well as analysis and modeling processes must be developed. In principle, the aim of the GPR measurement technique should be to detect the presence, location and extent of possible damage in 3D for bridge structures.

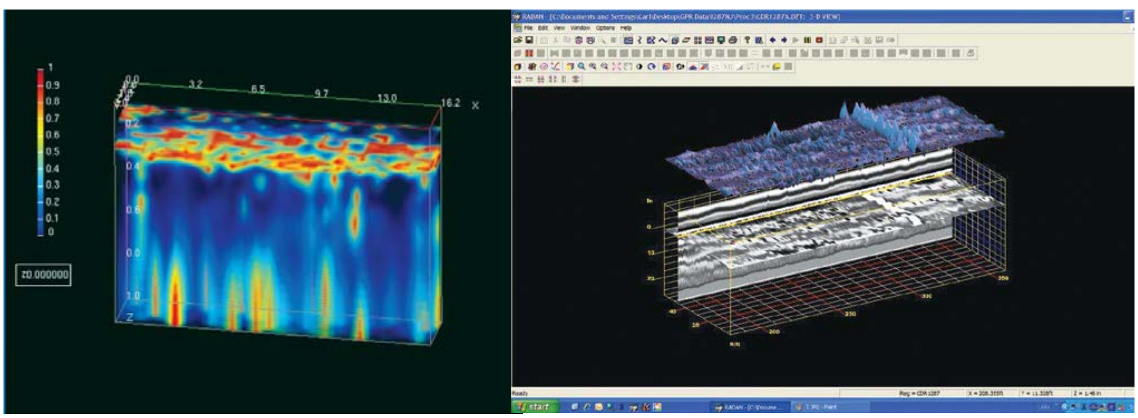

Fig. 1. Examples of 3D NDE measurement by impact echo method (left) and 3D GPR result (right), indicating the severity of damage to the structure (source: Rutgers University 2009).

According to Saarenketo (2006), GPR alone cannot provide sufficient information on the damage in the deck. Instead, it can be an excellent tool for the initial mapping and specifying of locations where other NDE methods and limited ground-truth (core sampling) testing can be used to verify the problems. In Finland, Roadscanners Oy has performed experiments analyzing and producing some GPR results in 3D (Fig. 2). No accuracy analysis was provided with these results.

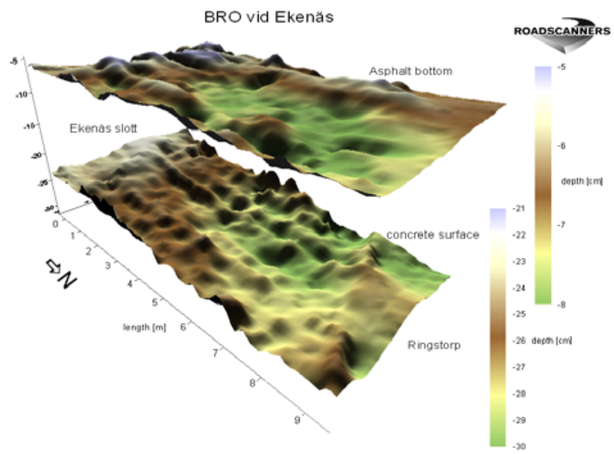

Fig. 2. BRO vid Ekenäs bridge measured in Sweden (2008). Based on 3D GPR measurements, the derivative quantities of the surfaces of asphalt bottom and upper concrete layers were determined (source: Roadscanners Oy).

This research was a part of the Finnish 5D BRIDGE2 consortium and aims to develop measurements, product modelling, and the information chains of work processes and construction automation. In earlier research "Construction Automation – Case Kajaani Varikko Bridge", several laser scans were executed during the construction phases of this bridge in a high-accuracy 3D coordinate system (Heikkilä *et al.* 2007). Measurements included the surfaces of completed road and bridge structures, and more importantly later invisible concrete structures and reinforcements. These measurements created a very accurate 3D reference or baseline for all later measurements (Figs. 3-5).

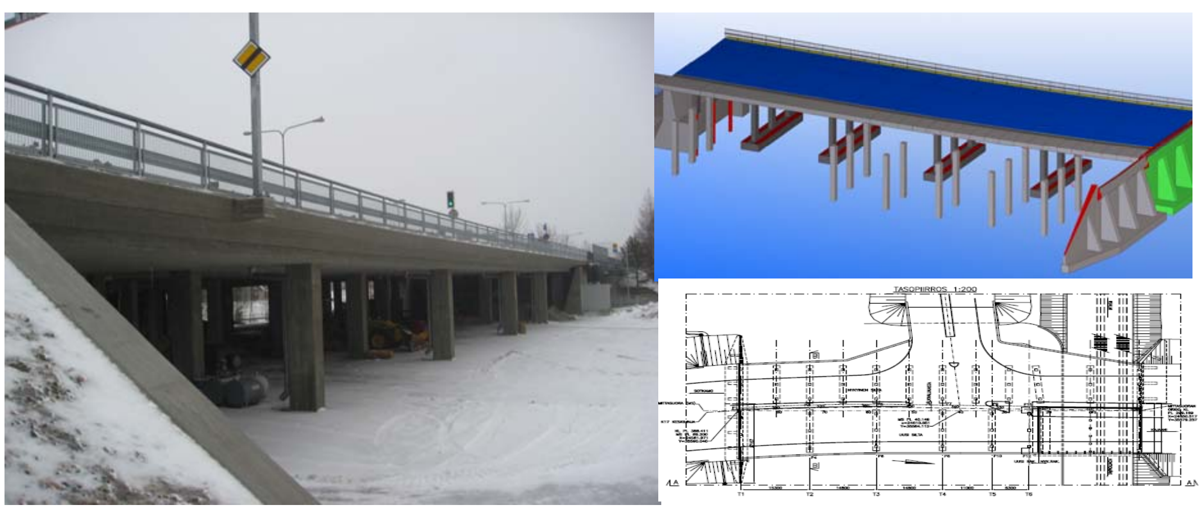

Fig. 3. The Varikko Bridge: completed bridge (2008) after construction phase (left), 3D product model (upper right), 2D drawing (bottom right).

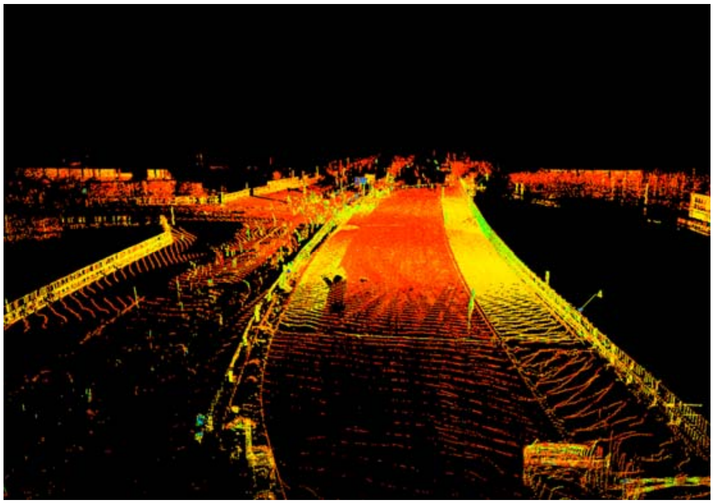

Fig. 4. Laser scan point cloud of the paved road on the Varikko Bridge (2007).

When measuring bridge structures by the GPR technique while simultaneously using accurate 3D positioning from the GPR (Ground Penetrating Radar) device, GPR results can be compared with the earlier laser scan results; this enables 3D calibration for the 3D GPR method. This calibration also enables and supports any adjustments and final evaluations of the accuracy of measurement of the 3D GPR technique.

The aim of the research was to perform 3D calibration for the GPR technique used, comparing the observations to the references measured by 3D laser scanning. The aim was also to develop the measurement and modeling processes of the GPR technique and evaluate the accuracy of measurement and the usability of the measurement results. An additional aim was to study the possibility to create a 3D point cloud including different features in addition to the 3D geometric information (so-called voxel model).

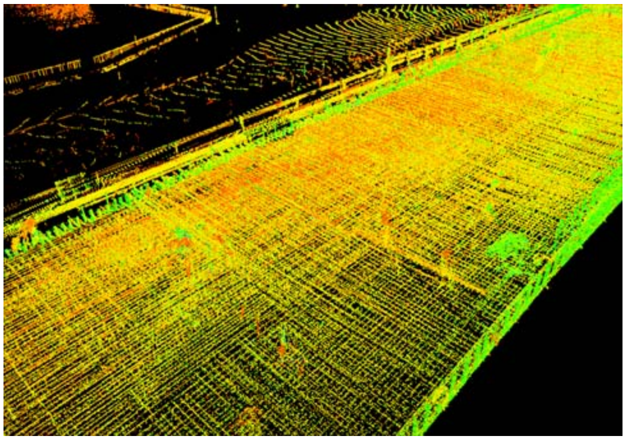

Fig. 5. Laser scan point cloud of the reinforcement of the Varikko Bridge (2007).

2 METHOD

2.1 Execution of laser scans

The outer geometry of the bridge was first measured by the Zoller+Fröhlich Imager 5006 laser scan system (Fig. 6) of Mitta Oy (measurement frequency 500,000 points/sec, maximum range 79 m, single point accuracy of about ± 2 to ± 7.5 mm depending on measurement distance and color / reflectivity of the object surface). In total, 19 scans were performed from above or below the bridge deck. These scans were transformed (registered) into the bridge coordinate system by measuring the control target points located in the measurement range (Fig. 7-8). The registration was made using Zoller+Fröhlich LaserControl software. The 2009 results were compared with the earlier results of the laser scans of 2007.

Fig. 6. The laser scans were executed using the Zoller+Fröhlich Imager 5006 system.

Fig. 7. The coordinate transformation to the bridge site coordinate system was determined by measuring three control reference points using a Leica TCRP 1200 total station. The same reference points were also measured by the Trimble R8 GNSS device to determine the same transformation for the GPR system.

Fig. 8. The measurement below the bridge deck (left), and a target used in the laser scan registration process (right).

2.2 3D GPR measurement

The measurement target was a renovated deck part of the Varikko Bridge. The GPR system used was from Roadscanners Oy, and included antennas of 1.5 GHz and 2.6 GHz made by Geophysical Systems Inc. The GPR device was accurately positioned by the RTK-GNSS method using the Trimble R8 system of the University of Oulu. The length of the measured bridge deck was 66.8 m, width 14.3 m and total area 955 square meters. Measurement lines with 25 cm intervals were used for the whole width of the deck. The measurement frequency was 100 measurements/m. The measurement results were transformed using the Helmert (7-parameter) transformation to the same coordinate system used in the earlier laser scans. Final analysis and interpretation of the GPR measurements were executed by Roadscanners Oy.

Fig 9. GPR measurement on the deck.

2.3 Combining GPR data with the laser scan results

The point clouds and surface models measured by both the GPR method and the laser scan system were combined to one digital 3D model. The 2009 laser scan point cloud was compared with earlier measurement results made in 2007 during the construction phase of the bridge. The surfaces modeled from the GPR data were compared with the surfaces modeled from the laser scan point cloud.

3 RESULTS

3.1 Results of the laserscannings

Based on the laser scan results, the lower deck surface has fallen down about 2-4 mm in two years when comparing 2009 results with 2007 results. Some tracks caused by traffic as well as a small compaction can be detected from the point clouds on the upper asphalt surface.

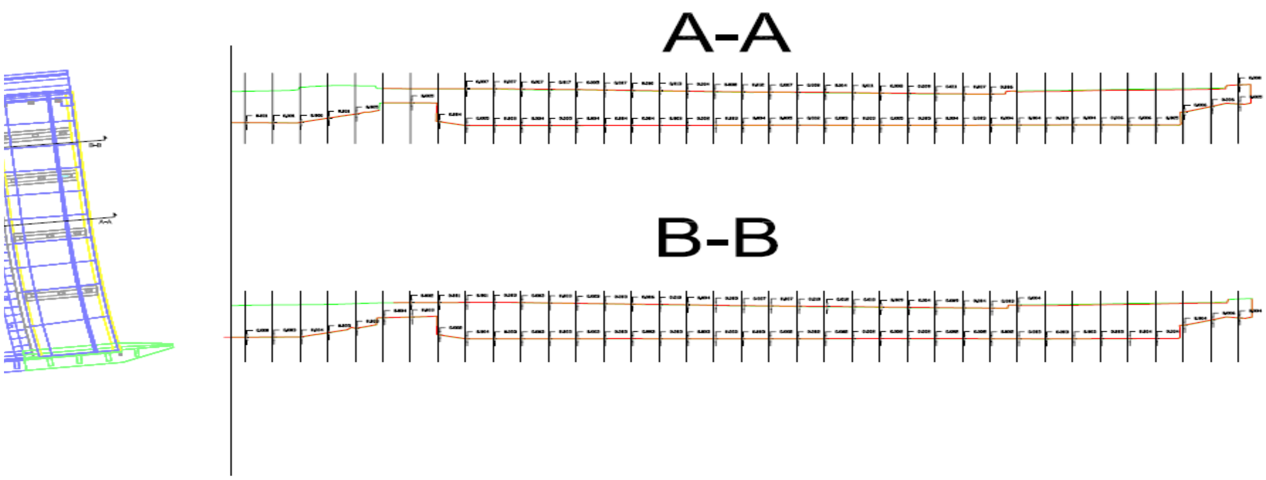

Fig. 10. Comparison of the 2007 and 2009 laser scanned point clouds.

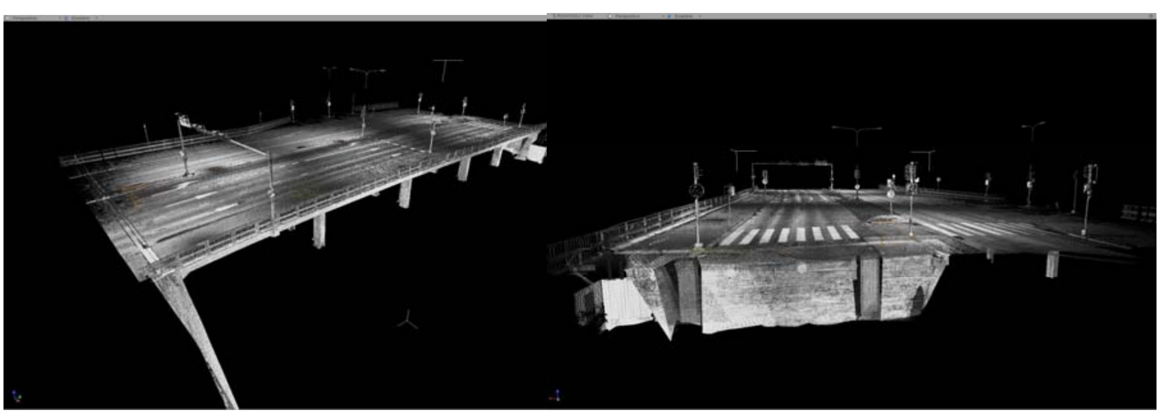

Fig. 11. The laser scan point cloud of the bridge.

3.2 Combining the laser scan and GPR results

Examples of the combined point clouds measured by laser scan as well as GPR are presented and compared in this section. Based on 3D visual inspection, the point clouds quite accurately equal each other.

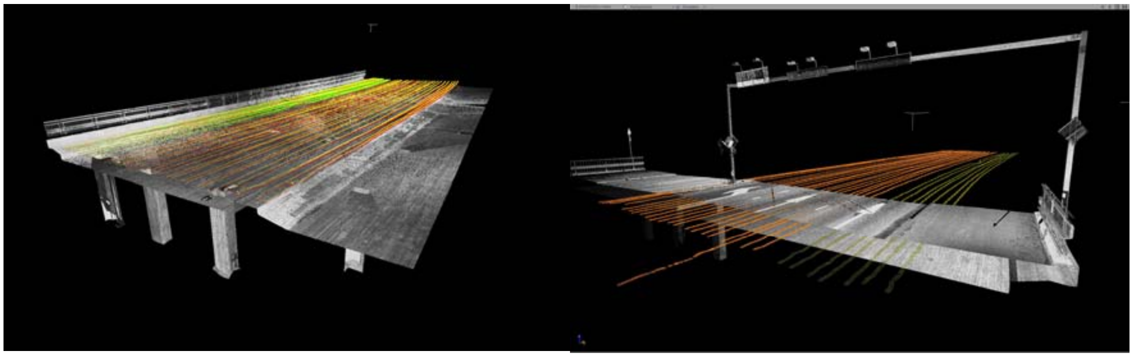

Fig. 12. A combined 3D point cloud of the bridge. The colored portions of the combined point cloud (left picture) are measured by GPR and the grey portions by laser scanning. The orange portions (right picture) are from the lower surface of the asphalt layer, the green portions from the reinforcement.

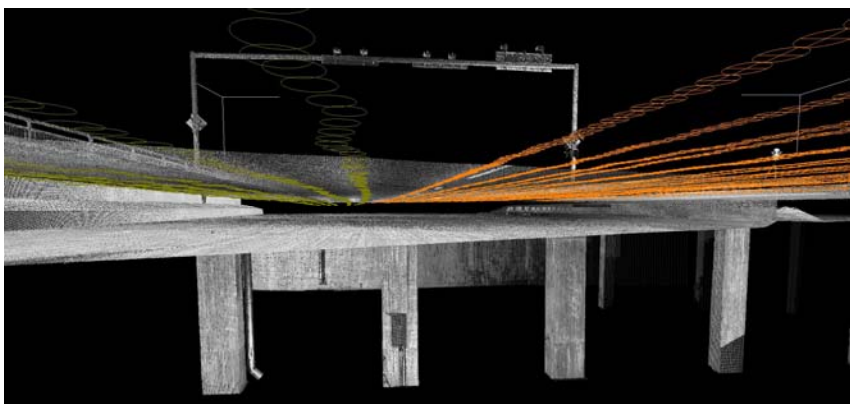

Fig. 13. Combined 3D point cloud of the bridge. The orange portions are the points of lower surface of the asphalt layer, the green portions are from the reinforcement.

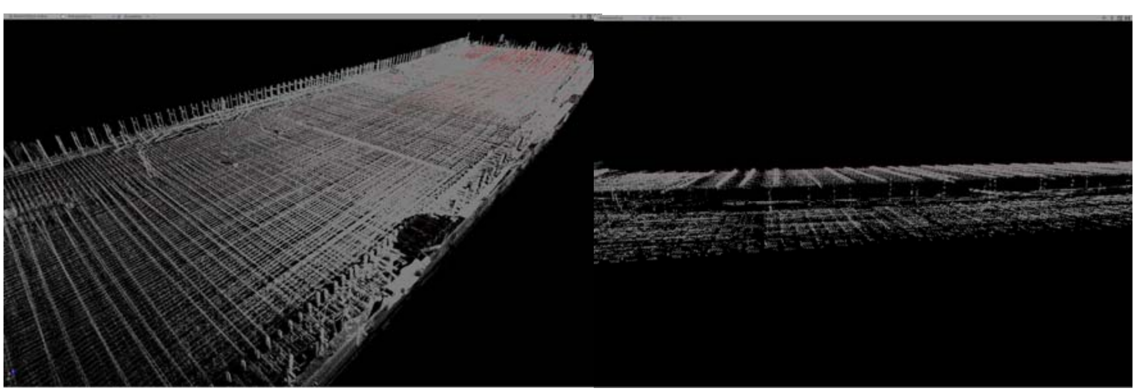

Fig. 14. The point cloud of the reinforcement (red points measured by the GPR, grey ones by the laser scanning).

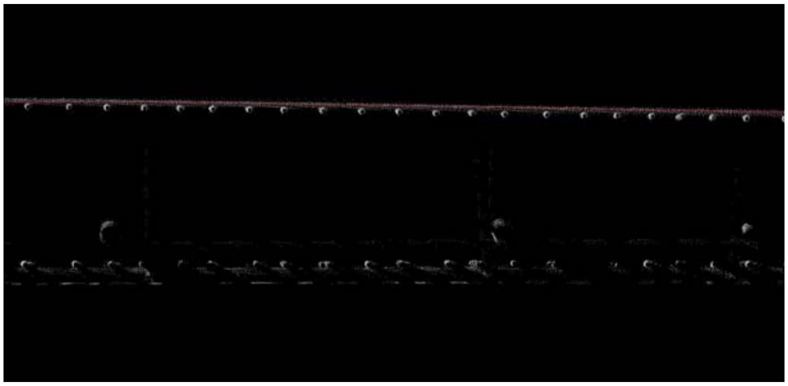

Fig. 15. The point cloud of the reinforcement (red points measured by the GPR, grey ones by the laser scanning).

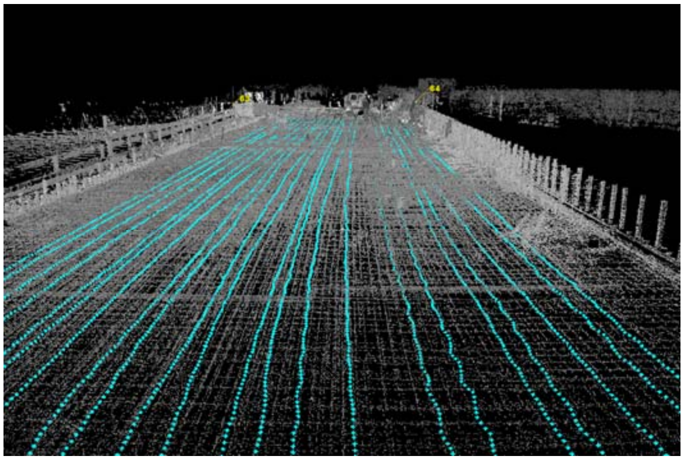

Fig. 16. The point clouds of the reinforcement (cyan points measured by the GPR, grey ones by the laser scanning).

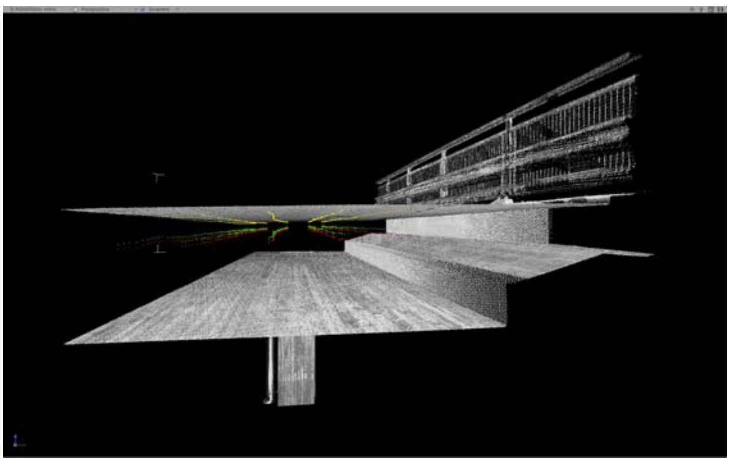

Fig. 17. Combined 3D point cloud of the bridge. The yellow portions are the points of upper concrete surface, the red and green portions are from the reinforcement.

There is an inconsistency in the observations. The point cloud measured by 2.6 GHz antenna from the lower asphalt surface may more likely be the concrete surface, or there is some systematic error. Based on the combined point cloud, the GPR observations seemed to be accurate when measuring the reinforcement. There was no reference result (laser scan point cloud) from the lower asphalt surface, thus it was impossible to make any comparison, and a definitive conclusion has not been made.

For the bridge sidewalk, there were different structural layers between the concrete deck and the asphalt layer. Looking at Fig. 19, if the green line was the upper surface of the concrete deck, it seems to go a little too far down.

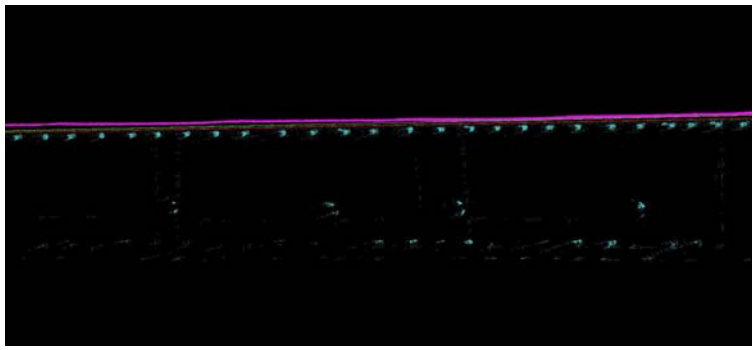

Fig. 18. Comparison of laser scan and GPR results – deck surface and reinforcement.

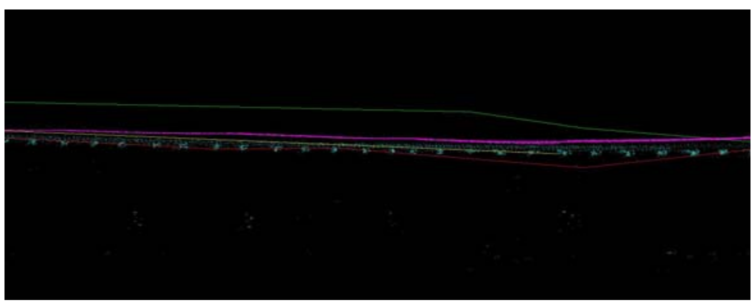

Fig. 19. Comparison of laser scan and GPR results – bridge sidewalk, deck surface and reinforcement.

4 CONCLUSIONS

The combination of the laser scan and GPR measured 3D point clouds was successful. The point cloud measured by GPR from the reinforcement was quite accurate based on the reference laser scan point cloud. Some inconsistency was noted in the GPR measurement of the concrete deck, indicating that the accuracy and reliability of measurement of GPR method needs further to be improved.

It can be seen that illustration the combined (laser scan and GPR) point cloud in the same picture is challenging. Clearer information can be achieved when performing the comparisons and analyses separately, surface by surface. Generally, the easiest method was to utilize different cross sections in the comparisons.

In the experiments, the RTK-GNSS method was used for high-accuracy 3D positioning of the GPR device. The reference targets were measured using a robotic total station. More accurate results would have been achieved if the robotic *kinematic* total station had been used. This was, however, not available for the experiment, and project resources did not allow the development of the software.

Future research should investigate the information transfer between measured GPR 3D point clouds and 3D product models created by bridge designers. Also the transformation and illustration of GPR measured attributes and features in 3D point clouds needs to be developed. For example, the absorption of frequencies measured by the GPR could be presented point by point through adding decibel values into the x, y and z coordinates. More analysis possibilities could be achieved when transferring the measurement results into the 3D product model of the bridge. In addition, better collaboration with bridge designers for the more detailed analysis of bridge health could be developed. Considering long-term possibilities, time propagation of the structural health of bridge could be tracked and visualized based on both geometric and feature-based measurement methods like 3D GPR, in order to best to determine the changes in the quality of structures, and perhaps develop predictive models.

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