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**Application of Vehicle-borne Laser Scanning for evaluation of damage of the forest roads (A case study)**

*Forest functions are different for each nation and depend on culture and social life. Forest management today has to meet a number of objectives. Planning of multi-functional forest road networks is one essential for meeting the aims of the sustainable forest concept. This paper is dealing with the application of the mobile laser scan technology for identification of forest road damage. Study area is located in the investigated territory at the School Forest Enterprise in Zvolen. Length of the experimental forest road was 2 050 m with 1L category. We divided the road into 41 sections. Every section was 50 m long. The scanner (8 units) we used was mounted on SUV category vehicle. The device recorded following data: average slope, average depth, maximal depth, minimal depth of potholes, maximal length, area, average depth, average width of potholes, length, width, depth for every section. Average speed of laser scanning was 24.8 km.h-1 during 4.95 min.* *We detected 6 790 potholes overall experimental section (165 potholes on single part of 50 m in average). Average volume necessary to fill the potholes in one section was 1.08 m3 (44.15 m3 per whole scanned road). The regression and correlation analysis confirmed that the number of potholes and total volume of potholes on individual road section positive correlated with distance the highest point of the road, i. e.: with increasing volume of downhill transported timber through the individual section). This technology proved itself as very effective and fast way how to detect the road damage and for calculation of total volume of material necessary for repair of the damages.*

***Key words****: laser scanning, vehicle mounted scanner, road damage*

**Introduction**

Properly built network of forest roads is necessary base for optimal management of forest stands. This network usually consists of one-strip forest roads [Klč, Novák, 2006]. The roads are important for development of the civilization and for maintaining the economic development [Lugo, Gucinski, 2000]. Management of the forests, forest harvesting, game management, recreational activities, fire protection also require accessing of forests by forest roads [Demir, 2007]. Parameters and requirements for forest roads are highly dependent on natural conditions and they must match with the way of forest management, economic and ecological factors [Potočnik, 1996]. Forest roads are the most important construction works in the forests for sustainable management of forests as a renewable natural source [Gumus, 2009].

Optimal spacing of the roads is dependent on various factors such as felling method, felling costs, value of felled timber, capacity of the forest landings, relief of the terrain, slope, accessibility of the stands for mechanization and possibilities of terrain for construction of the new roads [Sessions, 1986; Liu, Corcoran, 1993; Heinimann, 1987; Najafi et al., 2008].

The logging process considerable increases loading of the forest roads because of increased traffic of the logging and hauling mechanization. This process causes various road damages. Road damages are the phenomena that rise as a consequence of mechanical, physical, chemical and other factors causing damage of the surface of the roads. These factors also negatively affect operational functions and load capacity of the roads. Terrain survey with manual measurement of the road damages (length, width and depth) is currently used for evaluation of the damages in Slovak forestry. In public sector (public roads, highways) the more modern methods of evaluation of the road damages are used. One of the most advanced methods is the mobile laser scanning. Mobile mapping is currently used to process the data into 3D models and it is a topic of increasing importance since accurate and intelligent up-to-date 3D roadside information will be needed in the future, especially for vehicle and pedestrian navigation and location-based services [Kaartinen et al., 2012]. Laser scanning systems can be classified into four categories [Wu et al., 2013]:

* Satellite-based Laser Scanning (SLS),
* Airborne Laser Scanning (ALS, namely, airborne LiDAR),
* Mobile Laser Scanning (MLS, in full, Vehicle-borne Laser Scanning, VLS),
* Terrestrial Laser Scanning (TLS).

The SLS data have sparse sampling points and are not adequate for road surface scanning [Gong et al., 2011]. TLS data have the highest accuracy and sampling density and can be used for road surface scanning. However, the poor mobility of TLS restricts surveys for a long forest roads. ALS has the extraordinary capability in gathering highly accurate and dense elevation measurements. Numerous studies demonstrate that ALS data can be employed to investigate urban 3D morphology [Wehr, 1999] to extract building rooftops, footprints, and density information [Haala, Brenner, 1999] to estimate urban green volume [Huang et al., 2013] and to detect individual trees [Kim et al., 2011]. Nevertheless, due to the lower level of ALS precision [Baltsavias, 1999] the MLS is better for measuring and scanning of the road profiles. MLS allows for quick and cost-effective acquisition of close-range 3D measurements and modelling of road surfaces [Jaakkola et al., 2008]. Previous studies have demonstrated the great potential of MLS for street objects identification.

Main objectives of the study are: the test of practical usefulness of the road scanning device for recording of damages of the road surface, calculation of volume of the damages (volume of the material necessary to fill the damages) and distribution of damages along the road (dependence between distance and number of damages and average damage size per individual section).

**Material and methods**

We performed the measurementsat the School Forest Enterprise (SFE) near Zvolen. SFE is specialized enterprise connected with the Technical University in Zvolen and its purpose is to provide a base (forests) for both education of students of the university and for carrying the research in the fields of forestry, forest mechanization and forest ecology. Total area of the SFE is 9 724 ha. Main part of the area is in state ownership (9 106 ha). Total annual cut in 2016 was 68 236 m3 (16 094 m3 coniferous and 51 942 m3 broadleaved). Total length of forest road with paved surface is 190 km, terrain roads suitable for hauling at least seasonally 272 km, and total density of the roads is 47.5 m.ha-1. Total volume of timber transported in SFE from the forest landings in 2016 was 67 457 m3.

We used the detachable device for mobile contactless scanning and measuring of road profiles with high precision (ROADSCANNER) made by the KVANT s.r.o. [[www.kvant.sk](http://www.kvant.sk)] for the field measurements. The device was attached on the SUV category vehicle (Fig. 1), on its rear part. The hardware of the device was composed of following units:

* camera system for image capture of the scanned road,
* laser scanner (8 units) with high precision in infrared field,
* industrial mobile server,
* odometer,
* 2 gyroscopes,
* 3 accelerometers and a GPS antenna.

We used black and white industrial camera system for image capture of the scanned road, for assessment of visual details on the road. The camera was synchronized with scanner and mounted in heated housing.

The scanner possessed, with scanning speed 1 kHz to 5 kHz, field of view: 350 mm – 1000 mm. It recorded 1200 points per one profile (9600 for 8 sensors), resolution (X, Y) 0,27 mm – 0,80 mm, Z 0,150 mm – 0,550 mm, measurement height 450 mm. Laser class of the scanner 3B (< 500 mW), 808 nm, housing IP67.

Odometer: DMI (distance measuring indicator) with encoder for speed measurement, mount for the tyres, housing IP67.

Gyroscopes with sensitivity 30 g, 11 ms, vibration level 0.1 g2/Hz, 1 h/os, working temperature -40°C to +65°C, precision ±100 °/s.

Accelerometers: 3 accelerometers (x,y,z), acceleration 100 g - 11 ms, working temperature -55°C till + 95°C, precision of accelerometer < 20 μg / °C, resolution 5 μg, bandwitdh 150 Hz

We obtained following outputs from the device: international roughness index (IRI), rut detection, rut quantification, road quality assessment. Results were calculated during the measurement and were available for operator immediately. Point cloud is stored as well for further analysis.

The data were processed using the Road Scanner ver.2 software (Fig. 2). The software offers following outputs:

• raw data of scanned profiles available in 3D, in various formats e.g.: \*.stl, \*.xyz, \*.dat,

• hole detection (size m2, volume m3, average depth, maximal depth),

• crack detection (longest length, size m2, average depth, average width),

• rut detection (length, width, depth, water depth),

• international roughness index (IRI),

• measurement results (polygon, size m2, volume m3, average length,

• cost of repairs,

• google map visualisation (holes, cracks, IRI, rut),

• point cloud of data, results,

• module for viewing profiles (3D visualizer).

We chose a pawed forest road of 1L category [STN 736108] in SFE for test of the scanning device. This road is intensively used for transport of the timber and there are visible damages of the road. Road of this category allows timber transport throughout the year with bituminous surface with length of 2050 m, NW from Zvolen. The GPS coordinates of starting point are following: N 48° 36' 56.79892" E 19° 02' 42.13752"; and the end point has following coordinates: N 48° 38' 00.20363" E 19° 02' 52.33041" (ETRS 89). We started the scanning of the road from lowest point and finished at the highest, so we travel against natural direction of timber transportation. We divided the road into 41 sections (50 m each) with numbers starting from the lowest point to the highest (direction of the scanning). We recorded following data for each section: average slope, total volume of damages, number of damages, volume and area of average damage.

**Results and discussion**

Average speed of scanning was 24,8 km.h-1 and time of scanning the road was 4,95 min. We recorded 6790 damages of the road in total (44.15 m3 per whole scanned road), 165 damages in average per one section of the road. The frequency of the damages recorded on individual sections is uneven (Fig. 3), but there is visible decreasing trend of the number of damages with increasing distance. The trend is also confirmed by correlation and regression analysis of dependence of number of the damages on the distance from the start point of scanning. The analysis confirmed negative correlation (R = - 0.4713; p = 0.002) between observed values. It means that the least damages were recorded in upper parts of the roads and the number of the damages increased downhill with increased volume of timber transported through lowest parts of the road. This is caused by the fact that the timber is usually transported downhill and the volume of transported timber increase with secondary skidding roads and landings connected to the road.

Another important factor affecting the timber transport and load of the roads is slope of terrain. Average slope of observed road was 5.03° (min. 1.49º; max. 8.45º; St. dev. 1.49º). These slopes are within the range allowed by our technical standard [STN 736108] for roads of this category. The regression and correlation analysis did not confirmed the dependence between number of damages and slope as significant (R = 0.002; p = 0.990).

We also analysed the volume of damages (potholes, cracks etc.) in individual sections. Average volume of total sums of damages per individual sections was 1.08 m3 (min 65.80 dm3; max 3581.83 dm3; St. dev. 758.02 dm3). Dependence between distance from the start of scanning and total volume of damages per one section (Fig. 4) was confirmed as statistically significant of medium strength (R = -0.4474; p = 0.003). This dependence has the same properties as in the case of the number of damages, i. e. the volume of damages increases from the highest sections to the lowest with the direction of timber transport.

Average volume of individual damage was 7.38 dm3 (min. 2.69 dm3; max. 11.15 dm3; St. dev. 1.83 dm3).

Both of the values (total volume of damages and average damage per individual section) decrease with the distance from the start point of scanning (Fig. 4), but this trend is more visible in case of total volumes.

Average value calculated from the maximal depths of the damages in individual sections was 19.96 cm (min. 6.22 cm; max. 32.13 cm; St. dev. 5.00 cm), which may be considered as serious threatening the operation. Average depth calculated from all of the damages for individual sections was 4.48 cm (min. 1.26 cm; max. 7.12 cm; St. dev. 1.24 cm).

Total damaged area of the road was 807.52 m2, which is 9,8 % (width of road is 4 m and length 2050 m). Average damaged area per one section was 19.7 m2, which is 9,85 % (min. 3.94 m2; max. 51.02 m2; St. dev. 10.77 m2). Average area of individual damage was 0.12 m2 (min. 0.07 m2; max. 0.19 m2; St. dev. 0.03 m2).

**Conclusion**

Detailed survey of above mentioned characteristics is in forestry practice still carried out using pedestrian trips and manual measurement of individual damages. Speed of the human walk is about 4 - 6 km.h-1 and manual measurements take an additional time for obtaining data necessary for analysis of the damage. Using of vehicle mounted scanner allows to increase the speed of travel up to 40 - 60 km.h-1, which depends only on the road surface. In addition, collection of the data takes no additional time and it provides us with more detailed and very precious data for both research and purpose of practical operation (volume necessary for filling the potholes). Similar method (the 3D Lidar) was used for quantification of concrete material damages including mass losses due to vehicle collisions, reinforcement corrosion and surface erosions. The computed information provided engineers critical measurements for further damage analysis, which was not previously available using photogrammetry or plan photographic techniques. [Chen et al., 2013]. We can consider the technology as perspective for fully automatized recording of detailed and precious data about surface of forest roads, also for creation of precious 3D models of the roads and also for practical operation as there was mentioned above.

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C:\Users\Spravca\Desktop\roadscaner auto.tif

**Fig. 1 Scanning device mounted on the SUV car**

**C:\Users\Spravca\Desktop\roadscaner auto.tif**

**Fig. 2 Roadscanner software**



**Fig. 3 Correlation and regression analysis of dependence of number of the damages on the distance from the start point of scanning**

**Fig. 4 Total and average volumes of damages (potholes, cracks) per individual sections according the distance from the start of scanning**