On the Applicability of Laser Scanning for Evaluation of the Pavement Serviceability Parameters

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Abstract. Pavement performance is influenced by man factors such as climate and environmental conditions, traffic and operational conditions and type of pavement. These factors cause a pavement deterioration what leads to the restriction of the pavement serviceability or pavement efficiency. The pavement serviceability is the ability of the pavement to fulfil the service function represented by the actual values of variable parameters such as pavement surface roughness, surface evenness, pavement surface condition. The state of the pavement is assessed using different performance indicators when International Roughness Index (IRI) is most used. This approach allows to classify the state of the pavement in the pavement management system as a most used indexing, generalizes the pavement surface to the response of the testing car tire and the pavement. Laser scanning presented in this paper is able to bring the knowledge about the real pavement surface considering the accuracy of the method and equipment. Realized laser scanning proved the applicability of this method for the measurement of the pavement surface. Because of the complex knowledge of the pavement surface morphology, we can evaluate the pavement serviceability in terms of roughness, surface evenness or even pavement surface condition (rutting or cracks).

1. Introduction
Pavement performance is influenced by man factors such as climate and environmental conditions, traffic and operational conditions and type of pavement. These factors cause a pavement deterioration what leads to the restriction of the pavement serviceability or pavement efficiency. The pavement serviceability is the ability of the pavement to fulfil the service function represented by the actual values of variable parameters (pavement surface roughness, surface evenness, pavement surface condition). The pavement efficiency is the ability to resist against the loading until the ultimate limit state is reached.

The evaluation of the pavement serviceability is important part of the pavement management system. Collection of data via visual observation or in-situ measurements is required to analyse the need of pavement rehabilitation. Because of extent of the pavement network, the quick measurement methods are adopted, such as continuous measuring using diagnostic equipment attached on the test
Considering the pavement serviceability, a combination of visual inspection and the measurement of the longitudinal and transversal unevenness is applied. The state of the pavement can be assessed using different performance indicators such as Pavement Condition Index (PCI), Present Serviceability Index (PSI) and International Roughness Index (IRI). Recently, machine learning algorithms have been used for this purpose as well [1,2]. Most studies on pavement performance modelling are based on IRI [3].

This approach allows to classify the state of the pavement in the pavement management system, but IRI index generalizes the pavement surface to the response of the test car tire and the pavement. Laser scanning presented in this paper is able to bring the knowledge about the real pavement surface considering the accuracy of the method and equipment. This brings the possibility of complex examination of the surface in terms of texture investigation or the surface profile estimation using spectral analysis [4,5]. The investigation of the nature of pavement surface profile using laser scanning is presented further.

2. Pavement unevenness
The road unevenness of the pavement surface represents the main source of kinematic exciting effects causing the vibration of the road vehicles. Unevenness is the main source of dynamic excitation that acts on the vehicle elements such as tires, axles and the cab. It also causes a discomfort for the vehicle crew. The road unevenness is introduced using the function of the initial profile $u(x)$.

The road unevenness can be characterized as a deviation of a small value between real and medium road profile. Classification of height unevenness on roads was adopted at the XVII World Road Congress in Brussels in 1987 [6]. Surface irregularities can be classified from various aspects.

Spatial aspect:
- transverse unevenness,
- longitudinal unevenness.

Amplitude of unevenness:
- micro-unevenness, it affects the friction between the tire and the road,
- macro-unevenness, it affects the magnitude of the force causing the vertical movement of the wheel.

Shape of unevenness:
- periodical unevenness consisting either of waves of approximately sinusoidal or cosine form or periodically repeated unevenness,
- local discrete unevenness,
- random unevenness.

Within the frame of macro-unevenness, we distinguish between the so-called texture and the unevenness itself. The texture-to-unevenness interface is usually a wavelength that corresponds to the length of tire footprint of the vehicle. The texture and unevenness characteristics in the sense of [6] are listed in Table 1 and Table 2.

| Texture       | Wavelength (mm) | Unevenness (mm) |
|---------------|-----------------|------------------|
| Micro-texture | 0.001 - 0.250   | 0.0 - 0.2        |
| Macro-texture | 0.250 - 10.00   | 0.2 - 1.0        |
| Mega-texture  | 10.00 - 300.00  | 1.0 - 50.0       |
Table 2. Characteristics of unevenness

| Waves  | Wavelength (m) | Unevenness (mm) |
|--------|----------------|-----------------|
| Short  | 0.3 - 5.0      | 1 - 20          |
| Middle | 5.0 - 15.0     | 5 - 50          |
| Long   | 15.0 - 100.0   | 10 - 200        |

Longitudinal unevenness for roads and highways is considered in the wavelength range of 0.3 to 100.0 m and amplitude wavelength in interval 0.3 to 100.0 mm obtained by multiplying by 0.001.

2.1. Spectral analysis

Power spectral densities of unevenness are determined experimentally. The results of experimental measurements of different road surface quality according to standard ISO 8608 are shown in figure 1. It can be seen that if the coordinates on the vertical and horizontal axes are plotted in the logarithmic scale, the power spectral density can be well approximated by the line.

Figure 1. Classification of roads according to height unevenness [5]
According to figure 1, it can be written:

\[ \log S_u(\Omega) = \log S_u\Omega_0 + n \times (\log \Omega_0 - \log \Omega), \]

or also:

\[ S_u(\Omega) = S_u\Omega_0 \times \left( \frac{\Omega}{\Omega_0} \right)^n, \]

where:  
- \( S_u \) is power spectral density (m\(^3\)),  
- \( S_u(\Omega) \) power spectral density of amplitude (m\(^3\)),  
- \( n \) path frequency (cycles/m),  
- \( \Omega_0 \) reference path angular frequency (rad/m),  
- \( \Omega \) path angular frequency (rad/m).

Standard ISO 8608 sorts the roads according to the quality of the surface into 8 categories marked A to H. The coefficient \( k \) is to be set \( k = 2 \). The values of the constant \( S_u\Omega_0 \) for the reference path angular frequency \( \Omega_0 = 1.0 \) rad/m are given in Table 3.

### Table 3. Classification of roads according to height unevenness

| Class of road | Degree of unevenness \( S_u\Omega_0 \) (m\(^2\)/m) at \( \Omega_0 = 1 \) rad/m |
|---------------|-------------------------------------------------|
| A             | Lower boundary | Geometric centre | Upper boundary |
| B             | 0 | 1 \times 10^{-6} | 2 \times 10^{-6} |
| C             | 2 \times 10^{-6} | 4 \times 10^{-6} | 8 \times 10^{-6} |
| D             | 8 \times 10^{-6} | 16 \times 10^{-6} | 32 \times 10^{-6} |
| E             | 32 \times 10^{-6} | 64 \times 10^{-6} | 128 \times 10^{-6} |
| F             | 128 \times 10^{-6} | 256 \times 10^{-6} | 512 \times 10^{-6} |
| G             | 512 \times 10^{-6} | 1024 \times 10^{-6} | 2048 \times 10^{-6} |
| H             | 2048 \times 10^{-6} | 4096 \times 10^{-6} | 9192 \times 10^{-6} |
|               | 8192 \times 10^{-6} | 16384 \times 10^{-6} | 0 |

3. Laser scanning of the pavement surface

A testing segment of regular utilizable pavement was defined for laser scanning and following analyses in software. Terrestrial laser scanning method using fixed standpoint for each scanning session was adopted. Scanning procedure and evaluation of obtained data are described in following chapters.

3.1. Experimental pavement section

Straight section of the flexible asphalt concrete pavement with minor longitudinal inclination was selected (figure 2). The pavement is regularly utilized by the passenger cars, occasionally by the heavy vehicles. No rutting or extensive cracks were observed on the pavement surface via visual inspection of the section. Because IRI parameter is determined in the tire footprints line, the pavement surface profile was processed in this manner considering the arrangement of the heavy vehicle used for investigation of the vehicle-pavement interaction.
Figure 2. View on the pavement section for laser scanning

The composition of the pavement was also available for the measured pavement. Since the complete reconstruction of the road took place only a few years ago, the contractor provided the actual composition of the road, so we know thoroughly what materials the monitored section is made of. The composition of the pavement is given in Table 4.

| No. of layer | Material                     | Designation | Thickness (mm) | Elasticity modulus E (MPa) | Poisson's ratio (-) |
|--------------|------------------------------|-------------|----------------|---------------------------|--------------------|
| 1            | Stone mastix asphalt         | SMA         | 40             | 5500                      | 0.33               |
| 2            | Asphalt concrete             | AC          | 80             | 6000                      | 0.30               |
| 3            | Coated aggregate             | CA          | 100            | 3000                      | 0.33               |
| 4            | Mechanically reinforced aggregate | MRA      | 300            | 600                       | 0.25               |
| 5            | Crushed gravel               | CG          | 200            | 350                       | 0.30               |
| 6            | Subgrade                     | S           | -              | 90                        | 0.35               |

3.2. Spatial scanning instrumentation
Leica ScanStation C10 laser scanner was used for experimental measurements and performing a spatial scan. ScanStation C10 is a pulsed laser scanner that contains, in addition to a laser scanning system, a precision biaxial compensator, internal batteries, a touch screen control computer, integrated hard disk, automatic video camera and high-resolution camera and a laser plummet (figure 3). Before each scan, it’s possible to specify whether the scan will be performed in the mirror rotation mode or the oscillating mode. The scanner has a full field of view (360° × 270°). The operational range is up to 300 meters at 90% reflectivity and a scan speed of 50,000 bps with the model surface precision of 2 mm [7].
3.3. Data processing

The pavement surface and the adjacent vicinity were rendered as a cloud of points with spatial coordinates. Data were processed in Leica Cyclone Register 360 software. Point cloud of the pavement and vicinity from the laser scanning is plotted in figure 4.

![Figure 3](image-url)

**Figure 3.** Scheme of the scanner Leica ScanStation C10 (left), general view with battery (right); a – handle, b – rotating mirror, c – battery compartment B, d – circular level, e – socket for power supply, f – antenna, g – ON/OFF button, h – USB socket, i – stylus, j – touchscreen user interface, k – battery compartment A, l – ethernet socket [7]

![Figure 4](image-url)

**Figure 4.** Spatial 3D view of the scanned and evaluated pavement section with adjacent vicinity

A grid of $0.25 \times 0.25$ m with a general dimensions of $4.0 \times 110$ m was generated by interpolation from the cloud points. Terrain heights were read at the nodal points of the raster. CloudCompare software was used to process the spatial scan. The obtained data were processed and interpolated in two profiles spaced 1.98 m from each other. MATLAB software was used for this intermediate step. These lines represent the centre-line of the tire footprints of the heavy vehicle used for the investigation of the vehicle-pavement interaction system.
4. Results and Discussion
Data from laser scanning were processed according to the approach in chapter 3. Considering the centre-line of the tire footprints, a pavement surface propagation was plotted along the 110 m section of the scanned pavement. Propagation of the pavement surface in given profiles is plotted in figure 5 and figure 6.

![Figure 5. Evaluation of pavement unevenness for the scanned section for left profile](image1)

![Figure 6. Evaluation of pavement unevenness for the scanned section for right profile](image2)

The power spectral densities of unevenness were determined using experimental data following mathematical data processing via MATLAB software [8]. Power spectral density was assign to each of the profiles related to the tire-footprint [9]. In both cases, the pavement is classified in category B (very good surface) with $S_u(\Omega_0) = 4.0 \times 10^{-6}$ m$^2$/rad/m in right profile and $S_u(\Omega_0) = 4.2 \times 10^{-6}$ m$^2$/rad/m in left profile. Considering these results, we can claim that the pavement surface is of very good quality which was confirmed by the visual inspection [10,11].

5. Conclusions
Realized laser scanning proved the applicability of this method for the measurement of the pavement surface. Because of the complex knowledge of the pavement surface morphology, we can evaluate the pavement serviceability in terms of roughness, surface evenness or even pavement surface condition (rutting or cracks). As mentioned above, it’s possible to classify the pavement surface using spectral power density approach. Data can be further analysed and are not limited to only index classification such as IRI parameter. Correlation relations with existing performance indicators can be developed for better applicability of this method to existing pavement management systems.

Laser scanning equipment can also be mounted on a test car and can provide continuous measuring of larger sectors of the road infrastructure. This leads to large set of data when adoption of the
machine learning procedures is well applicable. Complex evaluation helps to improve the pavement management system in terms of decision processes of pavement rehabilitation or degradation models of pavements.

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