Features of assessing the evenness of road surfaces using laser road scanners

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Abstract. Road pavement evenness is one of the basic parameters characterizing road quality. Evenness influences car wear, fuel consumption, transportation costs, emotional state and comfort of drivers and passengers, and many other parameters. Assessment of road pavement evenness, which is widely used all over the world, has a number of features that do not allow to correctly assess an evenness at bridges, viaducts and other structures. Moreover, particularities of laser scanners operation do not allow to compare the obtained data with data obtained with the help of a three-meter straight-edge. The paper suggests ways to solve problems in question, which enable significantly improving quality of evenness assessment at such important transport infrastructure objects as bridges, overpasses and viaducts. There is also a solution to compare the data of transverse evenness obtained by laser scanners with data obtained with the help of a three-meter straight-edge that will permit to use these data later for comparison with standard values.

1. Introduction

Road pavement evenness (roughness) influences car wear, fuel consumption [1], transportation costs, emotional state and comfort of drivers and passengers, and many other parameters. In current practice related to pavement evenness assessment, the most widely used evenness parameter is the IRI (International Roughness Index) [2], which is calculated by summing fluctuations of prediction model of the “golden car” [3]. Fluctuations are simulated by special software according to the measured profile of the road pavement. Profile can be measured with the help of equipment of 4 classes.

The 2nd class equipment is used most widely; it is generally a measuring complex based on laser sensors that measure the distance between the level at which the sensor is located and the pavement surface. After adjusting for the angle of measurement, the profile of road pavement is obtained. Laser sensors have shown the best resistance to atmospheric phenomena and other disturbances and today are actually the standard for such equipment. A feature of all laser sensors is a very small diameter of laser trace on pavement. Another feature of the general equipment operation is that the distance between the measured points ranges from 50 to 300 mm. It depends on equipment design determined by the manufacturer. To calculate the IRI, it is sufficient to take measurements with a step of 300 mm. However, with such step, a number of important points can be lost that can have a significant impact on car traffic comfort [4]. To calculate the IRI, RoadRoof or ProVAL software can be used.

2. Investigation of evenness at bridges and other objects
Laser sensors used in the 2nd class equipment for assessing evenness give a laser trace on pavement surface within 2-5 mm (Figure 1) that enable actually determining pavement texture.

Figure 1. Laser trace on pavement.

Frequency of laser sensors operation is (according to the manufacturers’ data) in the range from 2 to 16 kHz. Such operating speed can be achieved under ideal conditions. In real practice, taking into account necessary storage time of laser sensor and speed of ports and other equipment operation, measurement frequency is from 200 Hz. However, even such speed is excessive and most of the data is simply ignored or not obtained, since they are not needed to calculate the evenness of road pavement according to IRI. But this data can be especially valuable for analyzing such objects as bridges, overpasses and others. As a rule, such places have defects influencing evenness (Figure 2).

Figure 2. Defects on the bridges of Ukraine.

A lot of defects of bridges are caused by presence of joints of reinforced concrete slabs [5-8]. These places require constant maintenance and very often are in poor condition. Typical profiles corresponding to such types of defects were analyzed as well as models of such profiles were developed in this work. Based on the developed profiles, vehicle movement was simulated to calculate the IRI. Simulation and calculation were carried out by ProVAL software.
Figure 3 shows one of typical profiles and the result of movement simulation along it.

![Graph showing typical profiles and movement simulation](image)

As it is shown at the diagram, the instantaneous IRI values are quite high. Fluctuations of the vehicle caused by such defects continue for a long time. Calculation of average IRI values for the section of 10 m length containing a single defect was also carried out using ProVAL software. Calculation results show that for a number of defects the average IRI value can exceed 4 m/km that is the boundary value of evenness in terms of safety.

**Figure 3.** One of typical profiles and the result of movement simulation along it.

**Figure 4.** Laser scanning complex LVS-4-KNAHU

Laser scanning complex LVS-4-KNAHU (Figure 4) has been used for laser scanning of the pavement and calculating evenness according to IRI at 4 experimental sections, which contain bridges. Table 1 presents the basic results of the experiment.
Table 1. Results of experiment.

| Number of the object | Evenness according to IRI, m/km for 10 m length section containing a defect |
|----------------------|----------------------------------------------------------------------------------|
|                      | Profile measured by 20 cm step | Profile measured by 2 cm step | Evenness value obtained for the defect model |
| 1                    | 2.57                             | 3.86                            | 3.56                                           |
| 2                    | 3.39                             | 4.82                            | 4.74                                           |
| 3                    | 1.86                             | 2.42                            | 2.66                                           |
| 4                    | 3.62                             | 4.64                            | 3.99                                           |

The first column of Table 1 shows evenness values obtained under pavement surveying with usual step. Low values of evenness can be explained by the fact that the laser beam of a sensor may not fall or partially fall into the joint between the beams of the bridge. Therefore, this defect does not influence the value of evenness. Column 2 presents evenness values for the profile measured with a significantly smaller step. These values are usually slightly larger than the theoretical ones obtained with the help of defect model. This is due to the fact that along the section length there may be additional defects that increase the overall value of evenness.

3. Using a laser scanner to determine lateral evenness (rut)

The peculiarity of scanning system laser sensors operation, namely, small area of laser trace on road pavement, causes problems under determining lateral evenness of roads [9,10]. In Ukraine, as in many other countries, a three-meter straight-edge (in some countries, two-meter straight-edge) is used to determine lateral evenness or tracing rut (presence of rut). A straight-edge is put down across pavement and the distance between the straight-edge surface and pavement is measured using special device (Figure 5).

![Figure 5. Using straight-edge and gage rod to determine tracing ruts.](image)

Scheme for determining lateral evenness using present-day laser scanning systems is not significantly different (Figure 6).
All sensors of laser scanning system are located on the same level. From this level, sensors measure the distance up to the surface of pavement. However, during measurements on stone mastic asphalt surfaces there are some problems. Structure of such pavement is shown in Figure 7.

As opposed to other types of pavements, surface of stone mastic asphalt is not solid. There is a significant distance between crushed agents, which very often is larger than a trace from laser sensor. Thus, laser beam may not fall on pavement surface, but fall into the gap between adjacent grains of stones. During experimental studies, it was found that this phenomenon is systematic. At the same time, it is impossible to unambiguously determine which of the sensors measured the distance up to the surface of a pavement, and which measured the distance in the gap between the grains of stones. Therefore, it is impossible to compare the obtained values with the values obtained with the help of a three-meter straight-edge. When measuring with three-meter straight-edge it actually has place an averaging of values over the width of gage rod, which is 5 cm. The lower edge of gage rod is in contact with peaks of stones and measurements are made from this level (Figure 8).

It was experimentally established that the difference between measurements with using laser systems and a three-meter straight-edge can be 5-20%.
Solution to this problem may be to change operating modes of laser scanner. In places, where it is necessary to measure lateral evenness, the laser scanner has to perform at the maximum frequency and the obtained data should be processed separately. Under operating speed of measurement and maximum frequency, data can be collected every 5 mm.

As in the case, if a gage rod is used, it is necessary to collect data over 5 cm. Thus, it is possible to get about 10 points, from which it is necessary to select the minimum values, which will be the calculated ones. So, the measurement will be as identical as possible to the measurement with using a gage rod and a three-meter straight-edge.

4. Conclusions
Present-day laser scanning systems have technological capabilities providing significant increase of useful data amount. In case of appropriate software upgrades, it is possible to record profile of road pavement of such objects as bridges with small step that enables identifying various specific defects. Detailed profile survey enables assessing the impact of joint condition at bridges on ride comfort as well as giving more information about their condition. Design feature of laser sensors does not allow to determine lateral evenness on roads with stone mastic asphalt pavements. This problem can also be overcome by introducing a special high-frequency mode of pavement survey in places where such measurements are necessary. Solution of this problem is also possible through software upgrades with introducing separate report for recording such data.

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