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## EVALUATION OF THE ROAD SURFACE QUALITY INSIDE THE ROAD TUNNEL

### HODNOTENIE KVALITY POVRCHU VOZOVKY V CESTNOM TUNELY

#### Abstract

The paper discusses a method for quantitative evaluation of the road surface based on processing of the cloud of 3D points. The points are measured by high-speed laser scanner mounted on the vehicle. Such approach allows to scan the road surface without the need to stop the traffic inside the tunnel. The obtained data are processed in offline mode. The processing algorithm evaluates the structure (texture) of the surface, which has the direct impact on the safety of the road transport.

#### Abstrakt

Článok sa zaoberá metódou kvalitatívneho hodnotenia povrchu vozovky, založenou na spracovaní mračna 3D bodov. Body sú získané meraním pomocou vysokorýchlostného laserového skenera namontovaného priamo na vozidle. Tento prístup umožňuje skenovanie povrchu vozovky bez nutnosti zastaviť premávku v tuneli. Získané dáta sú spracovávané off-line. Algoritmus spracovania dát hodnotí štruktúru (textúru) povrchu vozovky, ktorá má priamy dopad na bezpečnosť prevádzky na cestnej komunikácii.

#### Keywords

3D data processing, road surface degradation, laser scanner, surface texture, road safety

## 1 INTRODUCTION

Degradation of the road surface (defects like potholes, cracks, humps, waves, ruts or depressions) has direct impact on both comfort and safety of the road traffic. It also influences the lifespan of the vehicle components since it causes excessive vibrations and shockwaves. Drivers during the effort to anticipate the defects sometimes make dangerous maneuvers, which increase the risk of an accident. Since the constantly increasing intensity of the road traffic shortens the lifespan of the road surface, its quality has to be checked periodically. The aim of this paper is a method which would allow early detection of the defects on the road surface.

There are several methods and devices developed for the measurement of the road surface's defects. Manual methods of the measurement are recently replaced by methods based on electronic measurement devices. Large group of measurement devices are based on laser measurement. These systems estimate the distance between the device and the road surface from the measured time of flight of the laser impulse. Laser scanning of the surrounding environment is also deployed in

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multiple areas of the industrial sector. Many authors develop methods for processing the data obtained by laser scanning. In many cases, terrestrial or 3D scanners (rangefinders) are used for capturing the 3D model of the environment. In some cases, it is not possible to use 3D scanners; they have to be replaced by 2D scanners. Then it is necessary to consider the position of the scanner itself into the computation of the 3D model.

Our research is aimed mainly for the road and railway traffic. In these areas it is not possible to stop the traffic flow for couple of hours in order utilize 3D scanner. Therefore, our device is designed to use 2D scanner while utilizing the sensor fusion of readings obtained by the scanner, GPS receiver and INS (Inertial Navigation System). Then the cloud of points is computed, and the surfaces are found and textured. The textures are captured automatically from the recordings of cameras. Resultant model is stored in .obj format containing all cuts (views) of the environment. [1]

## 2 BASIC PROPERTIES OF THE ROAD SURFACE

The basic property of any surface is its roughness. Several methods have been developed to measure it. Roughness of the road surface is caused by the interaction between the road and the wheels of vehicles. From the geometrical point of view, the roughness is the 3D texture of the surface or the formation of grains of the stone on the surface of the road (macrotexture) and the surface defects on the surface of the grains (microstructure). Roughness may also be defined as the property of the surface characterized by the friction between the wheels of the vehicles and the road surface. Therefore, it is the reactive friction force which allows the transfer of the thrusting or braking force from the wheels. The force is quantified by the coefficient of friction defined as the ratio between the friction force and the normal force pushing the object to the surface. Evaluation of the slip resistance the road surface is a very complex task. The problem of the road surface evaluation is problematic due to the large number of factors affecting the friction between the wheel and the road, e.g. tread pattern of the tire and its depth, type of the tire, inflation pressure of the tire, type and weight of the vehicle, suspension and braking system of the vehicle, load balance of the cargo in the vehicle, season of the year, temperature, presence and thickness of the water film at the road surface, contamination of the road surface, geometrical shape of the road, intensity of the traffic, age of the road surface, degradation of the top layer of the road, type of the filling stone grains etc. Quantification of the influence of each factor to the friction force is difficult since it is not possible to separate one factor and set its value to some chosen value in the real environment.

From the qualitative point of view, the most significant influence on the friction force have the roughness of the road surface, presence of the water film, the type of the tire, its quality and the speed of the vehicle. In order to evaluate the roughness of the road surface, its texture has to be analyzed. The texture can be categorized by the amplitude and wavelength of the surface defects:

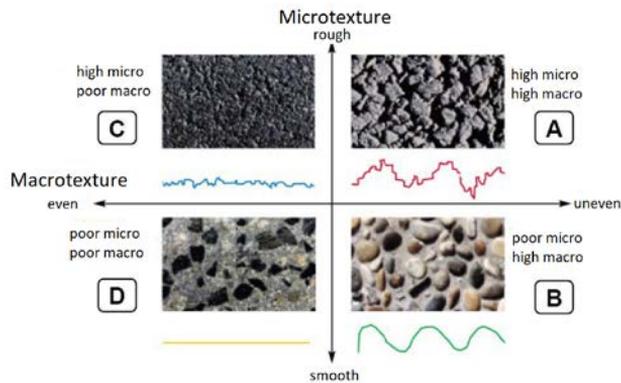
- microtexture,
- macrotexture,
- megatexture.

Megatexture is irrelevant w.r.t. the roughness of the surface. It influences only the driving comfort and the wear of the vehicle components. During the interaction between the wheels and the road surface the megatexture decrease the normal force hence decreasing the friction.

Influence of the macrotexture is the most significant in case when water is present on the road surface. The macrotexture drains the water out from the surface which prevents the aquaplaning effect.

Microtexture provides adhesion – it affects the friction force at the microscopic level. The microtexture has the greatest influence on the friction force at low speed and dry surface. In order to maintain optimal non-sliding conditions of the road surface it is necessary to keep the properties of microtexture and macrotexture within acceptable range. Road surface can be categorized into 4 categories by the levels of microtexture and macrotexture (Fig. 1):

- A – rough and uneven – the surface has high level of microtexture and macrotexture,
- B – smooth and uneven – the surface has poor level of microtexture and high level of macrotexture,
- C – rough and even – the surface has high level of microtexture and poor level of macrotexture,
- D – smooth and even – the surface has poor both microtexture and macrotexture.



**Fig. 1** Categories of the road surface

The term “uneven” surface is defined as macrotexture with average peaks higher than 1.0 mm. The surface is “rough” when its microtexture has peaks greater than 50  $\mu\text{m}$ . In order to define the properties of the surface more precisely, not only the average height of the peaks but also the density of the peaks (wavelength of the surface computed as the average distance between two nearby peaks) is relevant. Best level of the roughness is achieved when the wavelength is 3 to 20-times higher than the average height of the peaks. It is clear that the roughness level increases with the average height of the peaks in microtexture and macrotexture but decreases with the structural wavelength.

Besides the height of the peaks and the structural wavelength an important role has the morphology (orientation) of the peaks. The shapes of the peaks can be divided into two categories [1]:

- positive texture (Fig. 2a),
- negative texture (Fig. 2b).



**Fig. 2** Types of the surface texture

Mentioned properties can be measured by manual or automatic methods. Manual methods are:

- Estimation of the roughness by direct measurement,
- Measurement of the roughness by pendulum, Measurement using leveling device, Measurement by special ruler.

Automatic methods are for example:

- measurement using VIDEOCAR system,

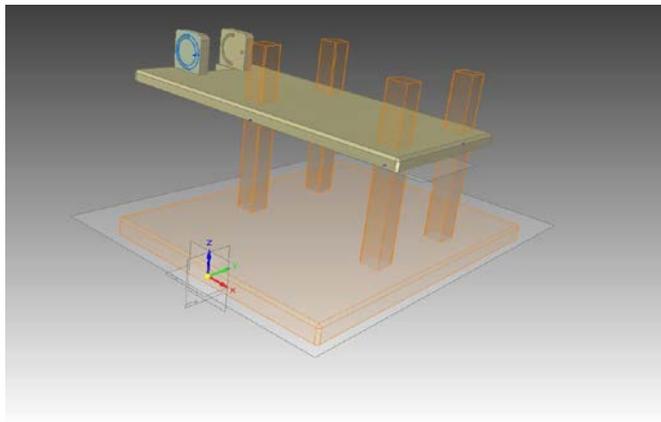
- measurement by Profilograph GE system.

Concept of the measurement device. Main requirements for the road surface measurement are:

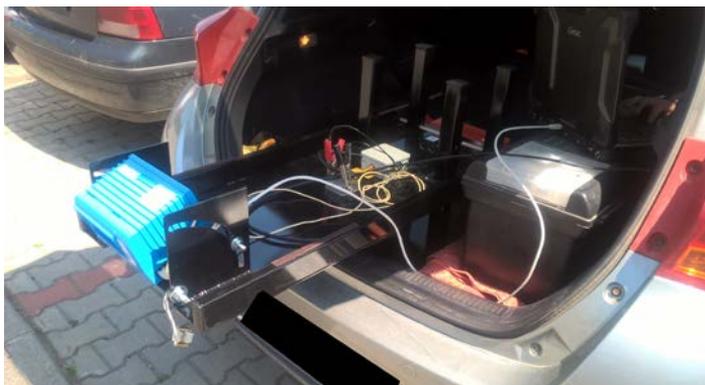
- Mobile measurement – it is required to measure the surface of the road during the movement inside the traffic flow.
- Suitable placement of the scanner – according to the current laws.
- Versatility – the measurement device can be mounted on various platforms.
- Power supply – the scanner requires reliable 24V DC power supply.

If all the requirements are met, the measurement is possible and repeatable. Therefore, it is necessary to know as much details of the sensor (laser scanner) as possible. In order to achieve mobility of the system, it should be mounted on vehicle. Since the measurement will be conducted in real traffic flow, the vehicle has to meet the current legislative. Therefore, we have used an automobile, which is widely available.

Standard automobile has supporting edge in the trunk. The edge has to be bridged by a suitable construction with the scanner at its end. The traffic laws allow the cargo to reach 40 cm out of the shape of the vehicle without mandatory sign marking the oversized cargo. In order to keep the variability of the setup, the construction must allow the change of the scanner's tilt. These requirements resulted in configurable stand (see design in Fig. 3 and real configuration in Fig. 4).



**Fig. 3** Virtual model of the stand for the laser scanner



**Fig. 4** Practical measurement setup

For the measurement itself we have chosen laser scanner LMS 400 manufactured by SICK company, which allows to measure distance in 2D space in the angular range 70 degrees. It is an active sensor equipped with red laser ( $\lambda=650\text{nm}$ ), with the output power 7,5mW Cat. II (dangerous for eyes, safe for skin). LMS 400 uses time-of-flight measurement based on phase shift of a sine wave modulated signal. The distance is then computed from the modulation frequency, measured phase shift and the speed of light. The scanning frequency is configurable in the range from 360 to 500 Hz and the angular resolution configurable in the range  $0.1333^\circ$  to  $1^\circ$ . The average error of the distance measurement is  $\pm 4$  mm and depends on the reflectivity of the measured surface and the distance. The manufacturer states the maximal error  $\pm 9$  mm for 6,5% reflectivity and  $\pm 3$  mm for 100% reflectivity. [2]

The data from the LMS 400 scanner can be processed online or offline. The data are transferred from the scanner into the PC via TCP/IP in real time or they can be stored into a file and then processed.

In our case we have used offline data processing from the file captured by SOPAS software. The software allows to capture whole communication between the PC and the scanner and to store it to the file or to capture and save only the measured values. The second way is simpler and more effective since the distance is stored directly in millimeters. For example:

„1250;1245;1245;1241;1238;1233;1229;1226;1224;1217;1217;1213;1207;1205;1204;1198;1197;1192;1191;1188;1185;1181; ..... ;1238“.

The main disadvantage of this solution is the lack of any flow control. The first way (storing whole communication) is more complex but allows to check the data flow by the timestamp of each message received from the scanner. It also allows to add XOR control sum into the telegram. The data are stored in hexadecimal format; therefore, they require preprocessing [3]. Example of a message from the scanner:

„RECEIVE 12:47:56.796 - SI A 425C0000 3E800000 0118 04ED 04E1 04E6 04D1 04CF 04E0 04C7 04CC 04C6 04C2 ..... 04D3“

The count of computation cycles is identical to the count of points measured by one cycle of the scanner. After each computation cycle the index of the computed 3D point is incremented. The value of z-axis (along the movement of the vehicle) is incremented after each scanning cycle. The coordinates of the  $i$ -th point in the  $n$ -th scanning cycle are computed by following equations:

$$x_{in} = d_{in} \cos \left[ \left( \alpha_{0n} + i \cdot \Delta \alpha_n + 90 \right) \frac{\pi}{180} \right], \quad (1)$$

$$y_{in} = -d_{in} \sin \left[ \left( \alpha_{0n} + i \cdot \Delta \alpha_n + 90 \right) \frac{\pi}{180} \right], \quad (1)$$

$$z_{in} = z_{i(n-1)} + v \cdot \Delta t. \quad (1)$$

where:

$x_{in}, y_{in}$  and  $z_{in}$  – coordinates of the measured point,

$\alpha_{0n}$  – initial angle in degrees,

$i$  – index of the current point within given scanning cycle,

$\Delta \alpha_n$  – angular increment for given scanning cycle in degrees,

$\Delta t$  – scanning period in seconds,

$v$  – speed of the vehicle in  $\text{m}\cdot\text{s}^{-1}$ ,

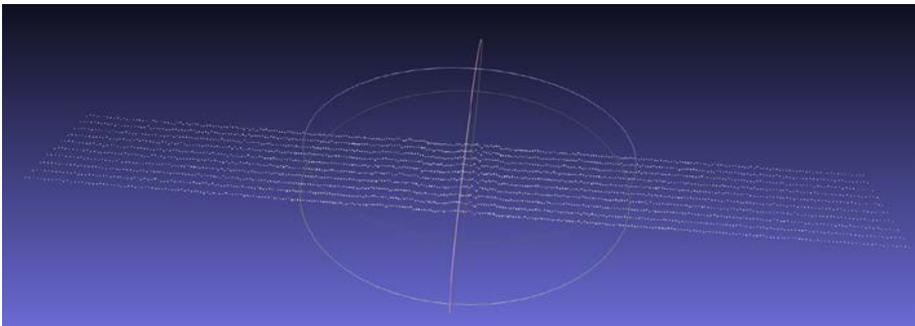
$d_{in}$  – distance of the  $i$ -th point in the  $n$ -th scanning cycle from the axis of the scanner,

$n$  –index of the scanning cycle, incremented by each scanning cycle.

The algorithm also creates metadata used for the computation of the surfaces of the measured object. If some point is measured with large error (caused e.g. by invalid reflection), this point will not be taken into account and it is replaced by the previous point. The algorithm is implemented in MATLAB by following code snippet:

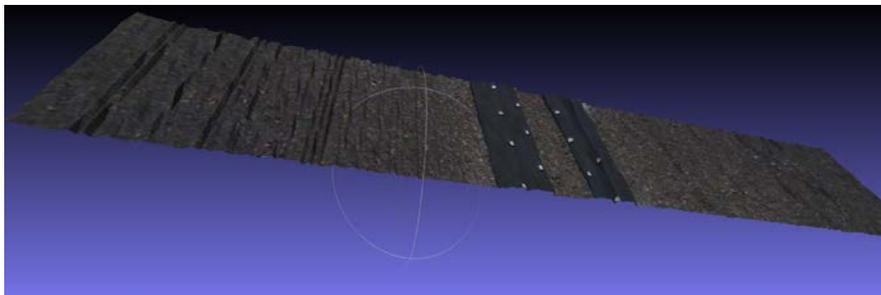
```
d = fscanf(fileIN, '%d',1);
pom = fscanf(fileIN, '%c',1);
if (d == 0)
    x = cos((a+(j-1)*difa)*pi()/180)*(c/1000);
    y = sin((a+(j-1)*difa)*pi()/180)*(c/1000);
    fprintf(fileOUT, 'v %d %d %d\n', x, y, i*(20/1000));
    A((i-1)*N+j,1) = (i-1)*N+j;
    A((i-1)*N+j,2) = 0;
else
    x = cos((a+(j-1)*difa)*pi()/180)*(d/1000);
    y = -sin((a+(j-1)*difa)*pi()/180)*(d/1000);
    fprintf(fileOUT, 'v %d %d %d\n', x, y, i*(20/1000));
    A((i-1)*N+j,1) = (i-1)*N+j;
    A((i-1)*N+j,2) = 1;
    c = d;
end
```

The result of the code snippet can be visualized by Fig. 5.



**Fig. 5** Example of the processed cloud of points visualized in 3D space

Then the cloud of points is transformed into array of surfaces by following method:  $i$ -th point in the  $n$ -th scanning cycle is connected with the  $(i+1)$ -th point in the  $n$ -th scanning cycle and with the  $i$ -th point in the  $(n+1)$ -th scanning cycle. Then we connect  $(i+1)$ -th point in  $n$ -th scanning cycle with  $(i+1)$ -th point in  $(n+1)$ -th scanning cycle and  $i$ -th point in  $(n+1)$ -th scanning cycle. For example, we connect points  $[i, n] = \{[1,20], [2,20], [1, 21]\}$  and  $\{[2, 20], [2, 21], [1, 21]\}$ . After placing the texture to the processed surfaces (triangles), we obtain 3D model with the image texture (see Fig. 6).



**Fig. 6** Example of the measured 3D model with applied visual texture

### **3 CONCLUSION**

Proposed method for scanning the surface of the road is capable to capture the profile of the road by measurement vehicle moving directly in normal traffic flow. The output of the measurement contains information about the character and the location of the defect on the road surface. The character (texture) of the defect is captured by laser scanner, the location is obtained by combination of inertial navigation system and odometry (standard satellite navigation does not work inside the tunnel). The obtained information can be used to support the maintenance of the road surface, especially nearby road tunnels. We believe that early detection and repair of the defects significantly decreases the cost of the maintenance and decreases the down-time of the road tunnel (time when the tunnel has to be closed due to the maintenance). That would result in more effective and safer road transport. The information about the road surface can also be processed in long-term, which may provide support for the research of compounds used for maintenance of the road surface.

### **ACKNOWLEDGMENT**

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