Prilog istraživanju uticaja stanja teksture površine puta sa aspekta dinamičkih karakteristika motornih vozila

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Informacije koje vozač prima od okoline i vozila uključuje informacije o makro i mikroprofilu puta, vibracijama i buci podсистema, odstupanju vozila od željene putanje, obrtnog momenta na točku upravljača, spoju pneumatika i tla i sl. U ovom radu će biti reči o površini puta na mikropolanu, tj. o mikroneravninama puta. Ukazaće se na neophodnost poznavanja parametara teksture površine puta, koji su od značaja za dinamičke pobude motornih vozila. Mikroprofil, odnosno njegovo stanje će biti identifikovano primenom teorije matematičke obrade fotografija, a dobijeni podaci su zbog malog broja uzoraka, preliminarneog karaktera. Međutim, razvijeni postupak identifikacije parametara površine puta stvara uslove detaljnijih istraživanja, što može biti korišćeno tokom daljih istraživanja dinamičkih karakteristika motornih vozila.

Ključne reči: vozilo, put, mikroneravnine, fotografije, tekstura, dinamičke karakteristike

1. UVODNA RAZMATRANJA

Informacije koje vozač prima od okoline i vozila sadrži informacije o makro i mikroprofilu puta, vibracijama i buci podсистema, odstupanju vozila od željene putanje, obrtnog momenta na točku upravljača, spoju pneumatika i tla i sl..

Ovaj problem je opisan u [1], pa ovde neće biti predmet pažnje, već će se ista posvetiti površini puta na mikropolanu, tj. teksturi mikroneravnina puta. Imajući u vidu da stanje površine puta ima uticaja na upravljivost, oscilatornu udobnost, bezbednost i buku pneumatika, a time i buku vozila, kontakt pneumatika i tla-kočenje i sl., ocenjuje se celishodnim da se stanje površine puta ocenjuje savremenijim metodama. Preciznije rečeno, mikroprofil, odnosno njegovo stanje će se identifikovati primenom teorije matematičke obrade fotografija.

Većina istraživača se slaže da mikroprofil pripada grupi slučajnih procesa i zbog toga on izaziva slučajne oscilacije vozila [1-8]. U ovom radu, pažnja će se posvetiti teksturi površine puta. Preciznije rečeno, učiniće se pokušaj da se na osnovu nje, primenom matematičke teorije obrade fotografija, razvije metoda za ocenu oštećenja kolovoza, jer su ona u tesnoj vezi sa pobudama od mikroneravnina puta, odnosno pomenutim dinamičkim karakteristikama vozila.

Napominje se da su zbog malog broja korišćenih fotografija, rezultati preliminarneog karaktera. Međutim, razvijeni postupak identifikacije parametara površine puta stvara uslove za detaljnija istraživanja, što može u narednom periodu biti korišćeno tokom istraživanja dinamičkih parametara motornih vozila.

2. NEKE NAPOMENE O MATEMATIČKEOJ OBRADI FOTOGRAFIJA

U opštem slučaju [3] put predstavlja prostornu površinu, slika 1.

Sl. 1: Prikaz mikroprofila puta prostornom površinom

Matematički je ona definisana izrazom:

$$z = z(x, y) \quad (1)$$

Pri identifikaciji parametara fotografija koristi i 2D Furijeova transformacija, o kojoj će ovde ukratko biti reči. Naime, na osnovu (1), „2D“ Furijeova transformacija u kompleksnom obliku je data izrazom [10,11]:

$$Z_{xy}(u, v) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} z(x, y) e^{-j2\pi(ux+vy)} dx dy \quad (2)$$

gde su „u“ „v“ kružne učestanosti za „x“ i „y“ osu.

Poznavanje kompleksne veličine (2) omogućava izračunavanje inverzne Furijeove transformacije:

$$z(u, v) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} Z_{xy}(u, v) e^{+j2\pi(ux+vy)} dudv \quad (3)$$

Analogno se mogu napisati i izrazi za diskretnu „2D“ Furijeovu transformaciju.

$$Z(k, l) = \frac{1}{\sqrt{MN}} \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} z(m, n) e^{-j2\pi(k\frac{m}{M} + l\frac{n}{N})} \quad (4)$$

Inverzna „2D“ Furijeova transformacija je data izrazom:

$$z(m, n) = \frac{1}{\sqrt{MN}} \sum_{k=0}^{M-1} \sum_{l=0}^{N-1} Z(k, l) e^{+j2\pi(k\frac{m}{M} + l\frac{n}{N})} \quad (5)$$

Treba uočiti da se izraz (4) može napisati u obliku kompleksih brojeva, tako da kompleksni oblik izražen Ojlerovom formulom uvodi pojam modula i faznog ugla, o čemu ovde dalje više neće biti reči, a čitaoci se upućuju na [9,10].

U narednom tekstu ćemo ukazati na elementarne pojmove o fotografiji. U najkraćem, fotografija predstavlja matricu sa pikselima kao elementima [11-15]. Kod obrade fotografija se najčešće koristi osmobarbitni koncept, kod koga su amplitude svakog piksela definisane nivoima od 0 do 255 (crno bela fotografija). Obično se kao 0 uzima crna, a 255 bela boja, tako da u osmobarbitnom konceptu možemo imati 256 nijansi boja. Kod fotografije u boji (načesto se koristi model sa tri boje: crvena-zelena-plava, - na engleskom RGB, i YCbCr-kombinacija boja koja se koristi kod TV prijemnika, videti [13]), pa tada 24-bitni pristup $8 \times 8 \times 8 = 256 \times 256 \times 256$ daje približno 16 miliona kombinacija [11-15]. U literaturi se, imajući u vidu način na osnovu kojeg se definišu amplitude – nivoi, obično podrazumeva da to predstavlja energiju boja [11-13].

Kako je ova materija kompleksna i detaljno prikazana u [11-15], o njoj ovde neće biti više reči. Za obradu fotografija u radu je korišćen softver Japanskog profesora Nobutaka Kuroki (Kobe Univerzitet) koji je poklonio autoru [15]. Razvijeni softver je posedovao mogućnost obrade fotografija, primenom „2D“ Furijeove transformacije, i to u direktnom i inverznom smeru, kao i mogućnost korišćenja filtera za obradu RGB i YCbCr fotografija. Napominje se da je prilagođen za slike rezolucije 256×256 piksela, ali je omogućeno i učitavanje i drugih dimenzija (izlazni rezultati su istih dimenzija kao i za original slike).

3. METODA

Da bi se stvorili uslovi za istraživanje karakteristika teksture puteva uz korišćenje teorije obrade fotografija, bilo je neophodno fotografisati karakteristične površine puteva. Ocenjeno je da su od interesa za analizu asfaltni, autoput, put od kocke i makadamski put u dobrom i oštećenom stanju. Cilj ovog rada je bio da se utvrdi mogućnost korišćenja teorije obrade fotografija pri oceni vrste i kvaliteta puteva u Srbiji, pa su napravljeni snimci površina puteva u okolini Kragujevca, uz korišćenje aparata Sony a900, Model DSLR-A900.

Tokom fotografisanja aparat nalazio na stalku visine 1, m sa objektivom čija je osa bila normalna na površinu puta. Pri tome su bili isti ili slični vremenski uslovi (osvetljenje) i isti parametri fotografskog aparata. Kako cilj istraživanja nije bilo da se definišu kriterijumi za procenu oštećenja, izabrane su deonice sa manjim oštećenjima površine puta. Teksture posmatranih deoniceputa puta su prikazane na Slikama 2-5.

Sl. 2: a) asfaltni put, b) oštećeni asfaltni put

Sl. 3: a) autoput i b) oštećeni autoput

a)

b)

Sl. 4: a) put od kocke, b) sa oštećenjem

a)

b)

Sl. 6: a) dobar asfaltni put, b) sa oštećenjima

a)

b)

Sl. 5: a) put od makadama, b) sa oštećenjem

4. OBRADA I ANALIZA PODATAKA

Primenom softvera Reshade sve fotografije sa Slika 2-5 su dovedene na istu rezoluciju, a primenom „2D“ Furijeove transformacije i softvera [14] izračunati su spektri amplituda, koji su prikazani rasterski na slikama 6-9, pri čemu je amplituda spektara data u logaritamskoj razmeri.

Analizom Slika 6-9 se može utvrditi da su beline najintenzivnije na sredini fotografija, a time i najveće amplitude spektara, a to govori da su svetle nijanse boje, odnosno njihova energija, više koncentrisane oko sredine fotografija, a što se može lako objasniti činjenicom da su spektri softverski centrirani [7,8]. Treba uočiti da u slučaju postojanja oštećenja, javljaju i amplitude čije su koordinate udaljenije od središta fotografija.

Očigledno je, takođe, da rasteri spektara zavise od vrste puta i oštećenja. U ovom slučaju, primena rastera za analizu fotografija nije svrsishodna, jer ne omogućava detaljniju brojčanu analizu podataka. Pomenuti softver je imao i mogućnost iskazivanja rezultata i u brojčanom obliku, što je omogućilo crtanje grafika. Radi dalje analize, nacrtane su „3D“ slike svih spektara, a koje su delimično prikazane na slikama 10 i 11, na primerima autoputa i puta od kocke, respektivno.

Tabela 1. Minimalne, maksimalne i efektivne vrednosti modula 2DFFT

Tip puta	Minimalne vrednosti		Maksimalne vrednosti		Efektivne vrednosti	
	Normalni	Oštećen	Normalni	Oštećen	Normalni	Oštećen
Asfalt	0.03474	0.09879	36713.46484	35763.33203	134.27808	132.82439
Autoput	0.00527	0.00164	40672.92969	45103.74609	147.00155	127.18898
Kocka	0.05153	0.12381	49894.74219	49772.85938	144.11108	143.86129
Makadam	0.01674	0.03356	52528.84375	53160.01563	147.99343	150.31067

Radi detaljnije analize, ocenjeno je celishodnim da se izračunaju minimalne, maksimalne i efektivne vrednosti svih izračunatih spektara. To je učinjeno primenom ptoograma Analsigdem [16], a rezultati dati u Tabeli 1.

Analiza podataka iz Tabele 1 pokazuje da je najveća minimalna vrednost energije (spektara amplitude boja) kod autoputa, a najveća kod kocke (za ispravan i oštećen kolovoz).

Najveću energiju boja imamo kod makadamskog, a najmanju kod asfaltnog puta (normalna i oštećena površina). Pri tome su efektivne vrednosti manje kod oštećene putne površine, osim u slučaju makadamskog puta, što se objašnjava činjenicom da je kod oštećenih tekstura puteva prisutnija tamnija nijansa boja.

Sl. 7: a) autoput b) autoput sa oštećenjima

Sl. 8: a) put od kocke b) sa oštećenjem

Sl. 9: a) put od makadama b) sa oštećenjem

Sl. 10: a) Spektar amplituda za površine asfaltnog i b) oštećenog asfaltnog puta

Sl. 11: a) Spektar amplituda za površinu od kocke
b) oštećene kocke

Očigledno je da nivo oštećenja ima uticaja na energiju boja tekture površine puta, pa se u cilju definisanja kriterijuma za ocenu potrebe za sanacijom moraju vršiti daleko obimnija istraživanja (na razim lokacijama, sa unapred definisanim tipovima oštećenja površine i sl).

Pored toga, dodatnim istraživanjima tekture putne površine bi se definisali i parametri koji utiču na dinamičke karakteristike vozila, jer razvijena metoda to omogućava.

5. ZAKLJUČAK

Razvijena metodologija istraživanja karakteristika tekture površine puta se može primeniti pri definisanju dopuštenih oštećenja kolovoza pre sanacije. Definisanje kriterijuma za ocenu oštećenja zahteva daleko obimnija istraživanja, što nije bio cilj ovog rada. Dobijeni podaci su od velikog značaja jer omogućavaju identifikaciju parametara pobuda motornih vozila koje imaju veliki značaj za njihove dinamičke karakteristike.

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A Contribution to the Research of the Influence of Road Surface Texture from the Aspect of Dynamic Characteristics of Motor Vehicles

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Information that driver receives from the environment and vehicle includes information on the macro and microprofile of the road, vibration and noise of the subsystem, deviation of the vehicle motion from the desired path, torque at the steering wheel, tire-road contact area, etc. This paper will focus on the road surface area at the micro plan level, i.e. on the micro unevenness of the road. The necessity of having relevant information on the parameters of road surface texture, significant for dynamic excitations of the motor vehicle, will be pointed out. The microprofile, i.e. its state, will be identified using the theory of mathematical processing of photographs, and the obtained data are due to a small number of samples, of a preliminary character. However, the developed procedure for identifying the road surface parameters creates conditions for more detailed research, which can be used during further research of the dynamic characteristics of motor vehicles.

Keywords: Vehicle, Road, Microprofile, Texture, Dynamic characteristics.

1. SOME NOTES ON MATHEMATICAL PROCESSING OF PHOTOGRAPHS

0. INTRODUCTION

The information that driver receives from the environment and the vehicle contain information on the macro and micro profile of the road, vibration and noise of the subsystem, the deviation of the vehicle motion from the desired path, torque at the steering wheel, tire-road contact area, etc.

This problem is described in [1], so it will not be the discussed further here, but the attention will be directed to the micro aspect of road surface, i.e. texture of road microprofile. Bearing in mind that the state of the road surface has an impact on the handling, oscillatory comfort, safety and noise of the tires, and thus the noise of the vehicle, the contact of the tire and the ground, braking, etc., it is considered appropriate to analyze the state of the road surface with more modern methods. More precisely, microprofile, or its condition, will be identified using the theory of mathematical processing of photographs.

Most researchers agree that microprofile belongs to a group of random processes and therefore causes random vehicle oscillations [1-8]. In this paper, attention will be paid to the texture of the road surface. More precisely, an attempt will be made to develop a method for assessing roadway damage, using the mathematical photo processing theory, because the damage is closely related to the excitations coming from the road microprofile. It is noted that due to the small number of used photographs, the results should be considered to be of preliminary character. However, the developed procedure for identifying the parameters of the road surface creates the conditions for more detailed research, which can be used for the next period during the research of the dynamic parameters of motor vehicles.

In general [3], the path represents a spatial surface, Fig. 1.

Fig. 1: Road microprofile presented by the spatial surface

Mathematically, it is defined by the expression:

$$z = z(x, y) \quad (1)$$

In identifying parameters of photographs, 2D Fourier transform is used, which will be briefly referred to here. Based on (1), the 2D Fourier transform in the complex form is given by the expression [10,11]:

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$$Z_{xy}(u, v) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} z(x, y) e^{-j2\pi(ux+vy)} dx dy \quad (2)$$

where u and v are circular frequencies for "x" and "y" axis.

Knowing the complex value (2) allows calculating the inverse Fourier transform:

$$z(u, v) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} Z_{xy}(u, v) e^{+j2\pi(ux+vy)} du dv \quad (3)$$

Analogously, expressions for the discrete "2D" Fourier transform can also be written:

$$Z(k, l) = \frac{1}{\sqrt{MN}} \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} z(m, n) e^{-j2\pi(k\frac{m}{M} + l\frac{n}{N})} \quad (4)$$

The inverse 2D Fourier transform is given by the expression:

$$z(m, n) = \frac{1}{\sqrt{MN}} \sum_{k=0}^{M-1} \sum_{l=0}^{N-1} Z(k, l) e^{+j2\pi(k\frac{m}{M} + l\frac{n}{N})} \quad (5)$$

It should be noted that the expression (4) can be written in the form of complex numbers, so that the complex form expressed in the Euler formula introduces the concept of a module and a phase angle, which will not be discussed here, and the readers should refer to [9,10].

In the following text, the elementary concepts of photography will be pointed out. In the shortest, the photograph represents a matrix with pixels as elements [11-15]. When processing photos, the 8-bit concept is most often used, where the amplitudes of each pixel are defined at levels 0 to 255 (black and white photograph). Usually, black color is taken as 0 and white as 255, so in the 8-bit concept 256 color shades can be achieved. For color photography (a three-color model is usually applied: red-green-blue, in English RGB, and YCbCr-color combination used for TVs, see [13]), then 24-bit access $8 \times 8 \times 8 = 256 \times 256 \times 256$ gives about 16 million combinations [11-15]. In the literature, given the way in which amplitude - levels are defined, it usually implies that it represents the color energy [11-13].

Since this matter is complex and shown in details in [11-15], there will be no more discussion about it here. For the processing of photographs, the software [15] was used by Japanese professor Nobutaka Kuroki (Kobe University) kindly given to the author of this paper. The developed software had the ability to process photos using 2D Fourier transform, both in direct and inverse direction, as well as the ability to use filters to process RGB and YCbCr photographs. It is noted that the software is

adjusted for 256x256 pixels resolution, but it is also possible to load other dimensions (outputs are the same dimensions as for the original image).

3. METHOD

In order to create the conditions for exploring the characteristics of the road texture using the photo processing theory, it was necessary to photograph the characteristic road surfaces. It is estimated that asphalt, highway, road from cube and macadam road in good and damaged condition, are of the interest for analysis. The aim of this paper was to determine the possibility of using photo processing theory in assessing the type and quality of the roads in Serbia, so that road surface images were taken in the vicinity of Kragujevac, using the camera Sony a900, model DSLR-A900.

Fig. 2: a) Asphalt road; b) Damaged asphalt road

During the shooting, the camera was located at a height of 1 m with a lens whose axis was normal on the surface of the road. The weather conditions (lighting) were the same or similar (lighting) and the parameters of the camera were the same. Since the purpose of the research was not to define the criteria for the assessment of damage, sections with minor road surface defects were selected. Textures of the observed road sections are shown in Figures 2-5.

4. PROCESSING AND ANALYSIS OF THE DATA

Using the Reshade software, all the photos in Figures 2-5 are brought to the same resolution, and using the "2D" Fourier transform and software [14] the amplitude spectra were calculated, and shown in raster in Figures 6-9, where the amplitude of the spectra is given in logarithmic scale.

a)

b)

Fig. 3: a) Highway; b) Damaged highway

a)

b)

Fig. 5: a) Macadam road; b) Damaged macadam road

a)

b)

Fig. 4: a) Basalt cubes; b) Damaged basalt cubes

a)

b)

Fig. 6: a) Good asphalt road; b) Damaged asphalt road

Fig. 7: a) Highway; b) Damaged highway

Fig. 9: a) Macadam road; b) Damaged macadam road

Fig. 8: a) Basalt cubes; b) Damaged Basalt cubes

4. PROCESSING AND ANALYSIS OF THE DATA

Using the “Reshade” software, all the photos in Figures 2-5 are brought to the same resolution, and using the “2D” Fourier transform and software [14] the amplitude spectra were calculated, and shown in raster in Figures 6-9, where the amplitude of the spectra is given in logarithmic scale.

Analysis of the Figures 6-9 shows that the whites are the most intense in the middle of the photographs, and therefore the largest amplitude of the spectra, which indicates that the bright shades of color, or their energy, are more concentrated around the middle of the photographs, which can be easily explained by the fact that the spectra are software-centered [7,8]. It should be noted that in the case of damage, amplitudes whose coordinates are farther from the center of the photos also occur.

It is also obvious that the rasters of spectra depend on the type of the road and the degree of damage. In this case, the application of raster for the image analysis is not appropriate, because it does not allow for a more detailed numerical analysis of the data. The mentioned software also had the ability to display results in numerical form, which enabled the drawing of graphics. For further analysis, “3D” images of all spectra are drawn, which are partially shown in Figure 10, on the example of the asphalt highway, and Figure 11 the example of the Basalt Cubes road.

The data analysis, partially shown in Figures 10 and 11, confirms the facts stated with the interpretation of rasters, i.e. that the largest amplitude is in the center of the photos.

Fig. 10: a) Amplitude spectra of asphalt road; b) Amplitude spectra of damaged asphalt road

Fig. 11: a) Amplitude spectra of Basalt Cubes road; b) Amplitude spectra of damaged Basalt Cubes

Table 1: Minimum, maximum and effective values of the 2DFFT

Type of the road	Minimum value		Maximum value		Effective value	
	Normal	Damaged	Normal	Damaged	Normal	Damaged
Asphalt	0.03474	0.09879	36713.46484	35763.33203	134.27808	132.82439
Highway	0.00527	0.00164	40672.92969	45103.74609	147.00155	127.18898
Cubes	0.05153	0.12381	49894.74219	49772.85938	144.11108	143.86129
Macadam	0.01674	0.03356	52528.84375	53160.01563	147.99343	150.31067

For a more detailed analysis, it was considered appropriate to calculate the minimum, maximum and effective values of all calculated spectra. This was done using the Analsigdem software [16], and the results are given in Table 1.

The analysis of the data from Table 1 shows that the minimum value of energy (spectra of color amplitudes) refers to highway, and the largest to cube road (for correct and damaged road).

The highest color energy is found in the macadam, and the smallest in the asphalt road (normal and damaged surface). The effective values are less in the damaged road surface, except in the case of a macadam road, which is explained by the fact that the darker color shade is present in the damaged road textures.

It is obvious that the level of damage has an effect on the color energy of the road surface texture, so in order to define the criteria for assessing the need for reparation, far more extensive research must be carried out (at various locations, with predefined types of surface damage, etc.).

Besides, additional exploration of the road surface texture would also help define the parameters that influence on the dynamic characteristics of vehicles, which is enabled by the developed method.

5. CONCLUSION

The developed methodology for the research of characteristics of road surface texture can be applied in defining the permitted levels of damage of the roadway before the repair. Defining the criteria for assessing damage requires far more extensive research, which was not the goal of this paper. The data obtained are of great importance as they enable the identification of the parameters of the motor vehicle excitations that have a great significance for the vehicle dynamic characteristics.

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