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Criterion for Objective Determination of Threshold Value in Filtering Surface Roughness Signal of Solid Wood After Machining with Fast Fourier Transform (FFT) Based Filter

Kriterij za objektivno određivanje vrijednosti praga osjetljivosti pri filtriranju signala hrapavosti strojno obrađene površine masivnog drva filtrom utemeljenim na brzoj Fourierovoj transformaciji (FFT)

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ABSTRACT • *The article presents the method for an objective determination of threshold value, needed for filtering out the anatomical roughness signal, with filter based on fast Fourier Transform (FFT), from surface roughness profile after machining. The method includes experimental preparation of solid wood surface by cutting in such a way to get a surface that can be considered to represent only anatomical roughness, with no other influence. Experiments were performed on radial cross section of solid oak wood (Quercus robur L.) so that the results could be compared with roughness profiles that were previously obtained in experiments after sawing with circular saw. From these samples and based on frequency analysis of anatomical roughness signals, the threshold value was determined to be 1.6 µm. The average value of R_a parameter of anatomical roughness for specimens of radial cross section of solid oak wood was 2.1 µm with standard deviation of 0.3 µm. The importance of choosing adequate sampling length in threshold determination, based on frequency analysis of anatomical roughness signal, was also established.*

KEYWORDS: *machined surface roughness; anatomical roughness, circular saw, solid wood, signal analysis, threshold, FFT*

SAŽETAK • *U radu je prikazana metoda za objektivno određivanje vrijednosti praga osjetljivosti potrebnoga za filtriranje signala anatomske hrapavosti filtrom koji se temelji na brzoj Fourierovoj transformaciji (FFT), i to iz*

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profila hrapavosti površine nakon strojne obrade. Metoda obuhvaća eksperimentalnu pripremu površine masivnog drva rezanjem na način da se dobije površina za koju se može smatrati da je samo anatomska hrapavost, bez ikakvih drugih utjecaja. Eksperimenti su izvedeni na radijalnom presjeku masivnog drva hrastovine (Quercus robur L.) kako bi se rezultati mogli usporediti s profilima hrapavosti koji su prethodno dobiveni u eksperimentima piljenja kružnom pilom. Iz tih uzoraka i na temelju frekvencijske analize signala anatomske hrapavosti utvrđeno je da se za vrijednost praga osjetljivosti može uzeti vrijednost od 1,6 µm. Prosječna vrijednost R_a parametra anatomske hrapavosti za uzorke radijalnog presjeka hrastova drva bila je 2,1 µm, sa standardnom devijacijom od 0,3 µm. Također je utvrđena važnost odabira primjerene duljine uzorkovanja pri određivanju praga osjetljivosti na temelju frekvencijske analize signala anatomske hrapavosti.

KLJUČNE RIJEČI: *hrapavost obrađene površine, anatomska hrapavost, kružna pila, masivno drvo, analiza signala, prag osjetljivosti, FFT*

1 INTRODUCTION
1. UVOD

Quantification of wood surface roughness after machining is still a complex problem that is not satisfactorily resolved. In scientific research, quality of machined surface is usually quantified by parameters defined in ISO 4287 (1997), and in industry it is usually based on subjective standards that include visual inspection and sensing of the surface by hand. According to Hendarto *et al*. (2006), the lack of wood surface evaluation methods is mostly caused by the fact that wood roughness also depends on factors related to wood anatomy caused by its nonhomogeneous structure. The problem of determination of appropriate techniques and parameters for the evaluation of surface quality in wood machining is also further complicated by the fact that the resulting measured surface profile after machining is the result of the interaction of workpiece material, machine tool, measuring instrument used for the measurement of surface profile and analysis of surface profile data (Sandak, 2005; Sinn *et al*., 2009). Measuring instruments used for the determination of surface profile can be roughly divided into contact and non-contact instruments. In laboratory measurements, contact instruments are mostly used and their universal characteristics are defined by ISO 3274 (1996). They give more reliable surface profile traces, if the appropriate parameters and stylus tips are used, where ISO 4288 (1996) can be helpful. It must be noted here that, for the assessment of wood surface quality, due to its surface characteristics, recommendations given by Gurau *et al*. (2006) and Gurau and Irle (2017) should be consulted.

For industrial use in on-line surface quality assessment of machined surface of solid wood, due to high passing speeds of workpieces in relation to measurement speeds of contact type surface roughness testers, this type of instruments cannot be used. In industrial on-line control only non-contact type of instruments can be used and, in that area, there are studies on the appropriateness of use of different non-contact measurement methods for the determination of surface profile of solid wood after machining (Lemaster, 1999; Sandak and Tanaka, 2003; Sandak *et al*., 2004; Sandak *et al*., 2020). Although, non-contact type instruments have advantages over contact type instruments in an industrial environment, it should be noted that there will be differences between profiles measured by contact and non-contact methods (Gurau *et al*., 2001; Sandak and Tanaka, 2003).

The analysis of surface profile data is another factor in the assessment of surface quality of wood. As already said, measured surface profile is mostly analyzed by methods and parameters defined in ISO 4287 (1997) and before that, it is filtered with standard filters. Usually, Gaussian filter defined in ISO 16610-21 (2011) is used for filtering out the roughness (or waviness) of the profile, but it has been shown that materials with sharp peaks and valleys pose a problem for standard filtering technique (Mills and Yoshino, 2019). If the standard Gaussian filter is used for filtering the surface profile of large porous wood species, there is evident raising of the roughness profile in the immediate vicinity of the pore edges that affects the evaluation of the surface roughness. It has been found that the Robust Gaussian Regression Filter (RGRF), now proposed by ISO 16610-31 (2010), gives better results (Fujiwara *et al*., 2004; Gurau *et al*., 2006; Sharif and Tan, 2011), but most of the research in evaluating the surface quality of machined surface of solid wood still uses standard Gaussian filters.

If the surface profile of solid wood after machining is adequately measured, the traced signal, which represents surface roughness of wood, is superposition of anatomical roughness of wood and machining roughness, which consists of tool marks left on machined surface and other machining related effects, like chipped or raised grain, fuzziness, etc. (Csanády and Magoss, 2011; Csiha and Krisch, 2000; Gurau, 2019; Lemaster, 2004). It can be hard to distinguish the effect of each component on the overall roughness and, depending on the wood species component, anatomical structure can have a significant impact on the overall roughness (Gottlöber, 2014). According to Gurau *et al*. (2013), the proper evaluation of the quality of a machined wood surface implies that irregularities due to wood anatomy are excluded from the numerical characterization of the surface profile. There are different approaches to removing irregularities due to wood anatomy from surface roughness measurements (Westkämper and Riegel, 1993; Magoss and Sitkei, 1999; Schadoffsky, 2000; Fujiwara *et al*., 2003; Gurau *et al*., 2005; Tan *et al*., 2010).

One way of looking at this problem is to consider the measured surface profile as a signal composed of anatomical roughness signal that represents irregularities due to wood anatomy and which can be represented by a random signal (Lemaster and Taylor, 1999), machining roughness signal, which is a random signal that represents non-periodic effects on machined surface due to machining (chipped grain, fuzziness, etc.) and periodic signals (for most of the wood machining processes) that represent tool marks. Due to different signal characteristics of individual components, different signal processing techniques can be used to try to separate the above-mentioned signal components and evaluate them accordingly.

In previous research by Đukić *et al*. (2022), a simple method for filtering out the periodic signal components due to teeth marks on machined surface after sawing with circular saw was proposed based on filtering with Fast Fourier Transform (FFT). That method includes the use of a threshold value, which is used as a limit below which all the frequency components in the analyzed roughness signal are set to zero. From this filtered signal in frequency domain, which is assumed to satisfactorily describe the periodic signal due to teeth marks in frequency domain, the time domain representation is obtained by Inverse Fast Fourier Transform (IFFT). In this way signals are obtained that, according to our assumptions, represent the part of surface roughness signal (periodic) due to tool marks and the other part (non-periodic, random) that represents anatomical roughness and machining induced roughness (processing roughness).

As was recognized in that research, one of the shortcomings was that the determination of threshold value was subjective (threshold value was determined by trial and error) and after further quantification of obtained signals, by calculating R_a and R_q values for these signals, it was not possible to objectively assess the individual impact of anatomical roughness and machining induced roughness on the overall surface quality.

The main goal of this research was to try to determine the objective method for the determination of threshold value. The idea was to measure the surface profile of solid oak wood (*Quercus robur* L.), which was prepared in such a way that the obtained surface profile could represent the anatomical roughness signal that can be used with previously obtained data from sawing experiments. Then the FFT of that signal can be obtained and threshold value can easily be calculated as the first number greater than maximum value of FFT of an anatomical roughness signal. It is also possible to calculate R_a and R_q values of the anatomical roughness signal and individual impact of machining induced roughness can be evaluated more easily.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

To measure the surface profile of solid oak wood (*Quercus robur* L.) that would represent an anatomical roughness signal representative of the surfaces that are obtained by resawing, and which could be compared with data from previous research (Đukić *et al*., 2022), three samples with average dimensions L x B x H = (500 x 220 x 21) mm were prepared from plainsawn boards. The average moisture content of specimens was 9 %. Surfaces for the determination of surface profile were prepared by cutting on the test device for orthogonal cutting in the laboratory at Biotechnical Faculty, Department of Wood Science and Technology in Ljubljana, Slovenia. The cuts were made in 90°–0° direction (McKenzie, 1961). The resulting texture of these surfaces was a combination of radial and tangential, but it was mostly radial because the samples were prepared from plainsawn boards.

Cutting parameters were set up to obtain Type II - continuous chip (Koch and Woodson, 1970). The cuts were performed with a cutter made from high-speed steel (HS) with W – 18 %, with rake angle $\gamma = 50°$, clearance angle $\alpha = 8°$. Cutting edge radius was around $\rho_0 \cong 4$ µm. The chip thickness was $h = 0.03$ mm and cutting speed $v_c = 0.5$ m/s. Measurement setup can be seen in Figure 1.

Surface roughness was measured with surface roughness tester Mitutoyo SurfTest SJ-500 (Ser. No. B0007 1808). The measurements were done in accordance with ISO 4287 (1997). The stylus tip radius was 10 µm and in accordance with the recommendations in ISO 3274 (1996), the λ_s profile filter cut-off was 25 µm and λ_c profile filter cut-off was 8 mm. Evaluation length was 40 mm. Stylus traversing speed was set to $v_s = 0.1$ mm/s, which then corresponded to spatial resolution of 5 µm between two measurement points. The sampling frequency was $f_s = 20$ Hz, so the maximum analyzed frequency component of the surface roughness signal was 10 Hz. Gaussian filter was used for filtering the R profile of roughness signal. Although its filtering disadvantages when used on profiles of wood species with deep valleys have already been mentioned, this type of filter was used in previous research and is still commonly used in most of the scientific research dealing with roughness analysis of solid wood surfaces. The

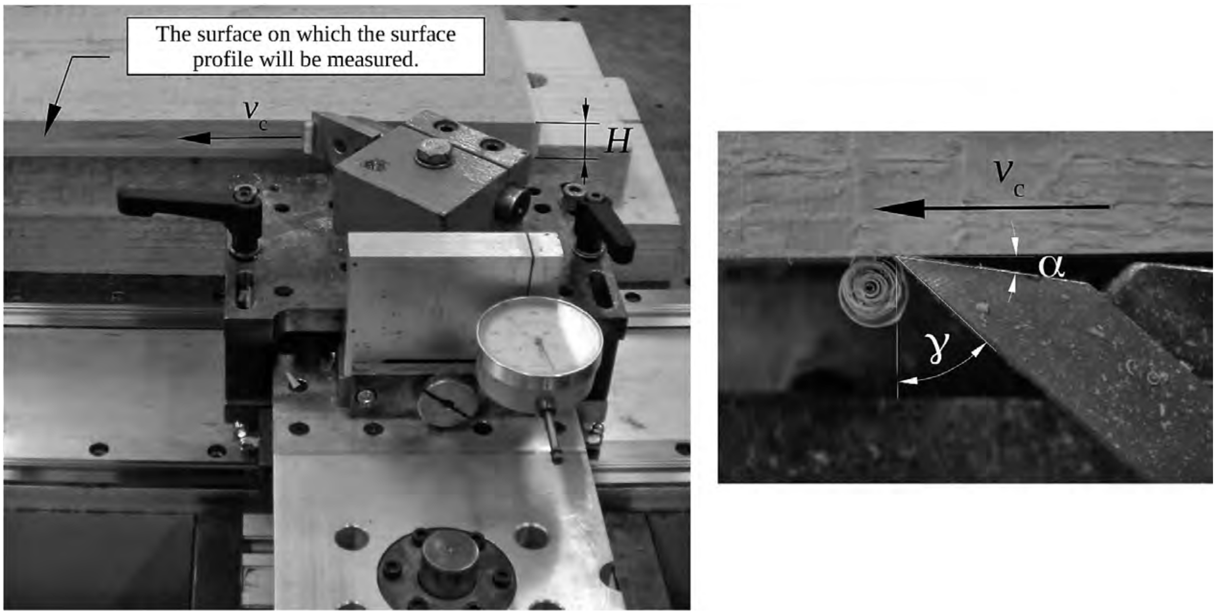

Figure 1 Cutting of test specimens of solid oak wood (*Quercus robur* L.) with average cutting width H = 21 mm in 90° – 0° direction with cutter made from high-speed steel (HS), with rake angle γ = 50°, clearance angle α = 8°, chip thickness h = 0.03 mm and cutting speed v_c = 0.5 m/s to obtain Type II - continuous chip

Slika 1. Rezanje ispitnih uzoraka od hrastovine (*Quercus robur* L.) na prosječnu širinu rezanja H = 21 mm u smjeru 90 – 0° oštricom od brzoreznog čelika (HS) te s prednjim kutom oštrice γ = 50°, stražnjim kutom oštrice α = 8°, debljinom odvajane strugotine h = 0,03 mm i brzinom rezanja v_c = 0,5 m/s kako bi se dobila strugotina tipa II (kontinuirana strugotina)

use of Robust Gaussian Regression Filter (RGRF) would be preferred here because the measurements were performed on solid oak wood that has deep valleys due to its anatomical characteristics, and raising of filtered profile in the immediate vicinity of wood pores is evident from measured profiles (Figure 2). The influence of distortions of filtered roughness profile introduced by using a Gaussian filter is assumed to represent systematic error in the evaluation of surface roughness parameters and it is assumed that on average it will affect all measured profiles in the same way, so the obtained parameter values can be compared. If the primary task is the accurate evaluation of the surface shape, then the use of RGRF filter is recommended.

Surface roughness measurement parameters were chosen to be the same as in previous research (Đukić *et al*., 2022), so that the results could be compared. Also, the recommendations specific to wood surface roughness evaluation, given by Gurau *et al*. (2006) and Gurau and Irle (2017), were considered.

Before the measurements, the roughness tester was calibrated with a working gauge that provides reference roughness profile with R_a = 2.97 μm (Mitutoyo, Ser. No. 393041807).

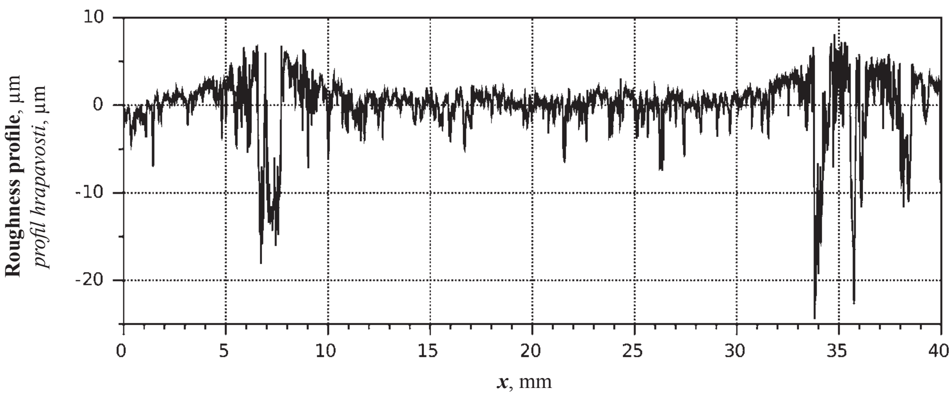

Figure 2 Anatomical surface roughness profile (R profile) sample of radial cross-section of solid oak wood (*Quercus robur* L.) measured with surface roughness tester Mitutoyo SurfTest SJ-500, with the λs = 25 µm, λc = 8 mm, evaluation length 40 mm, stylus traversing speed v_s = 0.1 mm/s and filtered with Gaussian filter

Slika 2. Profil anatomske hrapavosti površine (R-profil) uzorka radijalnog presjeka hrastovine (*Quercus robur* L.) izmjeren profilometrom Mitutoyo SurfTest SJ-500, s λs = 25 µm, λc = 8 mm, ocjenske duljine 40 mm, brzine pomicanja ticala v_s = 0,1 mm/s i filtrirano Gaussovim filtrom

During measurements, the stylus tip traversed the machined surface in the direction that would correspond to the direction of the feed movement vector (v_f) if these boards were to be sawn with circular saw along the grain with cutting height (H). It can be seen from Fig. 1 that the assumed direction of feed speed in sawing matches the direction of cutting speed vector (v_c) in preparation of the samples for the determination of anatomical roughness, which was conducted on the test device for orthogonal cutting.

On every test board, five measurements were taken on randomly selected measurement locations, which included wood pores. Measured surface profiles obtained in such a way were representative of the analyzed wood surfaces. In total fifteen roughness profiles with a total evaluation length of 600 mm were measured. Measured roughness profiles were exported to text files for further processing. For further analysis, scripts were written in Scilab software (https://www.scilab.org).

For every sample of measured anatomical roughness, signal R_a parameter was calculated as

$$R_a = \frac{1}{N} \cdot \sum_{i=1}^{N} |y_{ri}|$$

Where N is the number of samples in measurement and y_{ri} are the individual values of measured roughness in the given board sample.

Before frequency analysis, measured roughness profile signals were transformed from spatial to time domain, so that the results of frequency analysis could be obtained as a function of frequency instead as a function of wavelength.

As mentioned above, stylus traversing speed was set to v_s = 0.1 mm/s and corresponding spatial resolution was 5 μm. Time difference between the two samples was s.

For every measured roughness profile, Fourier transform was obtained with fast Fourier transform and graphically presented (Figure 3). Scilab software uses FFTW open-source C subroutine library for computing the discrete Fourier transform (https://www.fftw.org). Frequency resolution was 2.5 mHz.

After all the frequency spectra of individual samples were obtained, the highest recorded amplitude value was recorded. According to the procedure for filtering of machined surface roughness signal with FFT based filter (Đukić *et al.*, 2022), the threshold value needed for filtering was set to the first higher number rounded to 0.1 µm. From the analyzed frequency spectra, the value of threshold was set to 1.6 µm (Figure 4). All the frequency components of analyzed frequency spectra from machined surface roughness signal after sawing with circular saw below this value are assumed to be due to anatomical roughness. This is not exactly

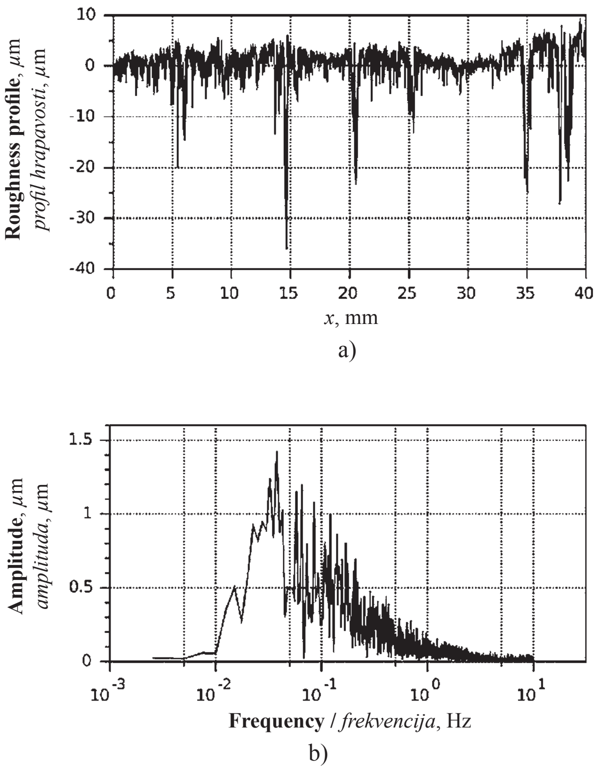

Figure 3 Sample of a) anatomical surface roughness profile (R profile) measured on radial cross-section of solid oak wood (*Quercus robur* L.) and b) frequency analysis of that signal
Slika 3. a) Uzorak profila anatomske hrapavosti površine (R-profil) izmjerenoga na radijalnom presjeku hrastovine (*Quercus robur* L.), b) frekvencijska analiza tog signala

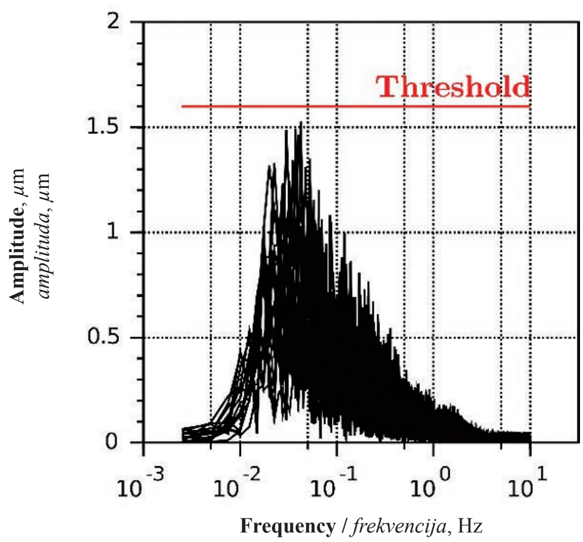

Figure 4 Frequency spectra of measured anatomical surface roughness signals and threshold used for further signal processing of surface roughness signals obtained from measurements on machined surface after sawing with circular saw
Slika 4. Frekvencijski spektri svih izmjerenih signala anatomske hrapavosti površine i prag osjetljivosti koji je služio za daljnju obradu signala hrapavosti dobivenih iz mjerenja na obrađenoj površini nakon piljenja kružnom pilom

true, because certain frequency components can have lower values due to tool marks, but it is assumed that they will not contribute significantly to the overall value of roughness signals due to saw teeth marks, reconstructed after filtering.

Further signal processing and filtering of previously measured roughness signals, obtained by measurements on the machined surface after sawing with circular saw, was conducted in accordance with the procedure explained in Đukić *et al*. (2022). The component of roughness signal that, according to our assumptions, should correspond to saw teeth marks on machined surface after sawing with circular saw, was determined by filtering with filter based on fast Fourier transform with the threshold value determined in this experiment. From this filtered signal, R_a values were calculated for every measured profile according to Eq. 1.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

In the previous research (Đukić *et al*., 2022), surface roughness profiles were obtained from the experiments carried out during longitudinal sawing of solid oak wood with values of feed per tooth equal to f_z = (0.02, 0.04, 0.07 and 0.14) mm and feed per one revolution of the saw blade f_o = (0.52, 1.04, 1.69 and 3.39) mm. With respect to roughness measurement parameters, corresponding values of frequency of occurrence of tooth marks was f_{fz} = (4.6, 2.3, 1.4 and 0.7) Hz and frequency of occurrence associated with any tool related phenomena that is related to one revolution of the saw blade was equal to f_{fo} = (0.19, 0.10, 0.06 and 0.03) Hz.

The value of threshold used in the previous research was 2 μm and this value was subjectively determined by trial and error. The difference between this value and the threshold determined by objective criteria based on anatomical roughness was only 0.4 μm. Due to this fact, after filtering roughness signals of machined surfaces, after sawing and reconstructing the part of the signal that should correspond to the saw teeth mark contribution to the overall roughness, there was no significant difference compared to the results published in the previous research. All conclusions related to the machined surface roughness after sawing solid oak wood with circular saw, which were presented in the previous research, can also be applied here. Frequency components due to saw teeth marks, which would correspond to f_{fz} values, are not visible due to low values of feed per tooth used in the experiment. This would result in correspondingly low values of theoretical saw teeth marks, and this signal would be hard or impossible to distinguish from anatomical roughness. This can be justified by the data presented in Đukić *et al*. (2023).

Comparison of the frequency spectra of anatomical roughness signals and machined roughness after sawing with circular saw in relation to threshold value can be seen in Figure 5.

From the signals obtained by measurement of anatomical roughness profiles, R_a values were calculated according to Eq. 1. The average value was 2.1 μm with pooled standard deviation (Figliola and Beasley, 1991) equal to $s(R_a)$ = 0.3 μm. This value (or similarly determined R_q value of anatomical roughness profile) can be considered as a value that can be used for removing the influence of roughness component due to wood anatomy from the measured surface profile after machining. It can be used in a similar context as a method based on structure number ΔF (Magoss, 2008; Csanády and Magoss, 2011) or method of anatomical roughness removal based on the Abbot-curve, as described by Gurau *et al*. (2005). This value can be compared with the data presented in Gurau *et al*. (2005) where, among other parameters, the mean R_a value of surface roughness after sanding solid oak wood with grit P120 was 4.78 μm and for processing roughness it was 2.24 μm. Assuming that the value of R_a parameter associated with anatomical roughness can be represented by the difference between values of R_a parameter for total and processing roughness, its value would be around 2.5 μm. That value agrees well with the value obtained in our research.

Calculated values of R_a parameters for machined surface after sawing and for profiles filtered with filter based on FFT with threshold value obtained in this research can be seen in Figure 6. Values of R_a parameters obtained from filtered profiles should represent the influence of saw teeth marks (processing roughness) on total roughness. If the results are compared to the results obtained in the previous research, there is no significant difference in the obtained values of R_a parameters after filtering. This is because the threshold value determined by trial and error in the previous research was chosen close to the value determined in this research. The threshold determined in this research is more objective and it can easily be replicated for other wood species.

The difference between values of R_a parameters of the machined surface roughness profiles and processing roughness was on the average 3.3 μm with standard deviation of 0.6 μm with data for f_z = 0.04 mm as the only outlier. On the average, the impact of anatomical roughness on surface roughness after sawing for f_z = (0.02, 0.04, 0.07 and 0.14) mm was correspondingly (22, 19, 17 and 15 %). This is in line with the expectations, because with higher feed speeds, the traces of saw teeth on the surface are increasingly pronounced.

In our model, components of roughness profile are non-periodic due to anatomical roughness and pro-

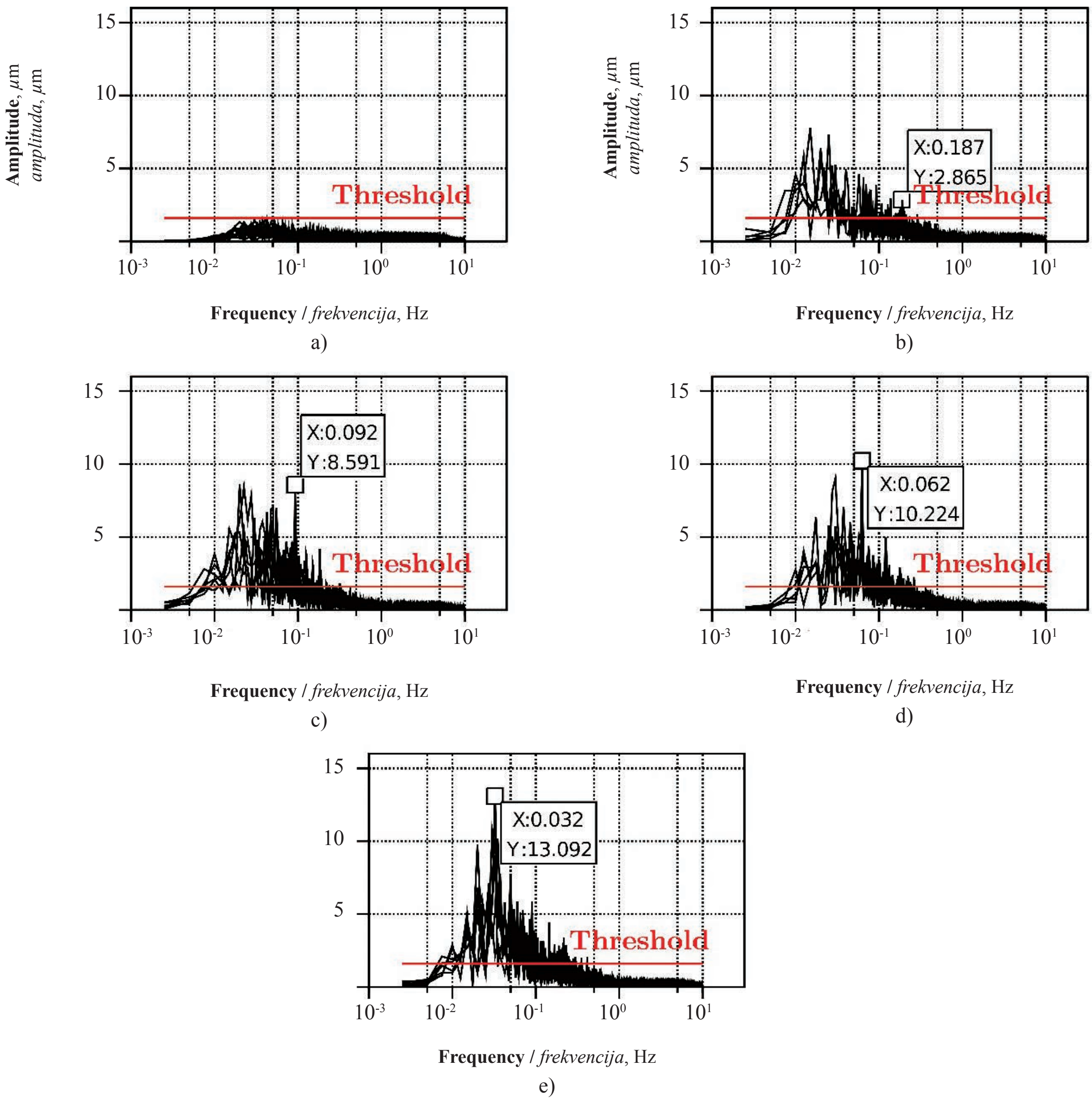

Figure 5 Comparison of frequency spectra for samples of measured surface roughness profiles against objectively determined value of threshold for: a) anatomical roughness, b) machined surface roughness after sawing with f_z = 0.02 mm, c) machined surface roughness after sawing with f_z = 0.04 mm, d) machined surface roughness after sawing with f_z = 0.07 mm and e) machined surface roughness after sawing with f_z = 0.14 mm

Slika 5. Usporedba frekvencijskih spektara za sve izmjerene uzorke profila hrapavosti površine u odnosu prema objektivno određenoj vrijednosti praga osjetljivosti: a) za anatomsku hrapavost, b) za hrapavost obrađene površine nakon piljenja s f_z = 0,02 mm, c) za hrapavost obrađene površine nakon piljenja s f_z = 0,04 mm, d) za hrapavost obrađene površine nakon piljenja s f_z = 0,07 mm i e) za hrapavost obrađene površine nakon piljenja s f_z = 0,14 mm

cessing roughness, which cannot be approximated by periodic functions, so they are represented as non-deterministic signals, e.g., noise. It is known that with averaging the noise is reduced (Smith, 1999). That proved to be the case even if the averaging is applied to the signals of anatomical roughness of solid oak wood (Đukić *et al.*, 2023).

To test how averaging would influence the data obtained in this study and correspondingly the threshold level, averaged frequency spectra of anatomical roughness signals and roughness signals obtained on machined surface after sawing with circular saw were examined. The averaged frequency spectra were obtained by calculating the average values for each frequency component of individual samples. It included the calculation of an average for each row (amplitudes for each frequency component were represented as column vectors) of all the frequency spectra of anatomical roughness and each frequency spectra of processing roughness for different values of feed per tooth. In the end, one averaged frequency spectra was obtained for each type of roughness. The results are presented in Figure 7.

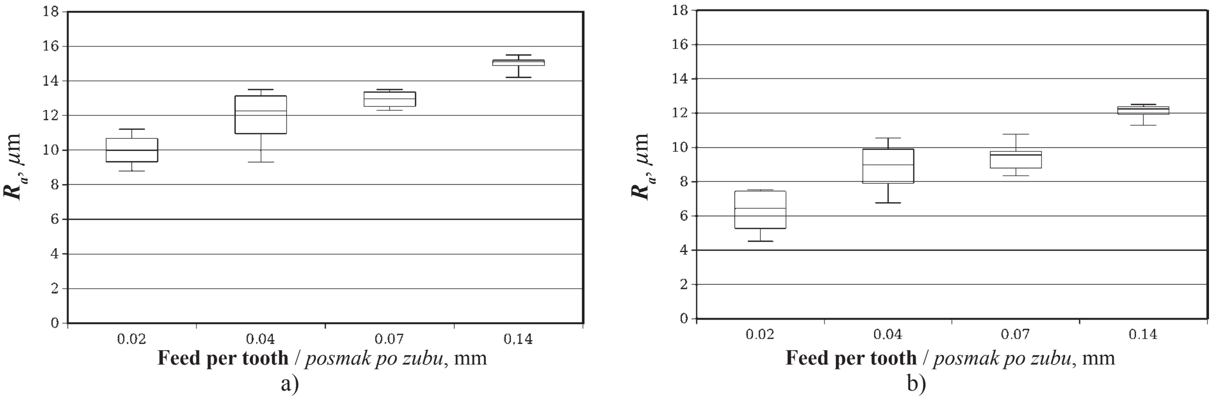

Figure 6 Machined surface roughness expressed through parameter R_a: a) after sawing solid oak wood with different values of feed per tooth and b) for processing roughness signal, after filtering total roughness signal with filter based on FFT and threshold obtained in this research

Slika 6. Hrapavost obrađene površine izražena putem parametra R_a: a) nakon piljenja hrastovine s različitim vrijednostima posmaka po zubu, b) za hrapavost zbog obrade, koja je dobivena filtriranjem ukupnog signala hrapavosti s filtrom na temelju FFT-a i praga osjetljivosti dobivenoga u ovom istraživanju

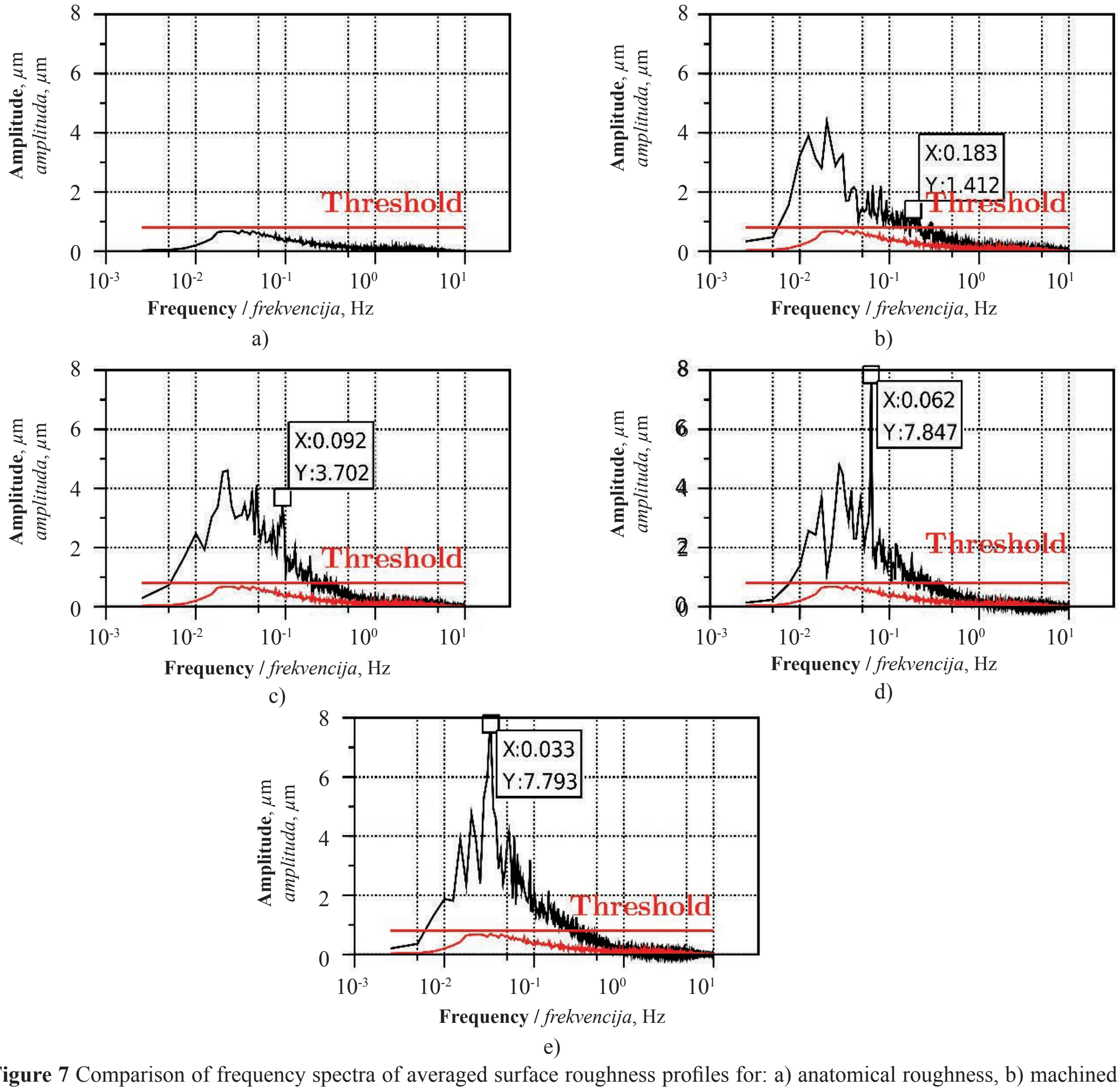

Figure 7 Comparison of frequency spectra of averaged surface roughness profiles for: a) anatomical roughness, b) machined surface roughness after sawing with f_z = 0.02 mm, c) machined surface roughness after sawing with f_z = 0.04 mm, d) machined surface roughness after sawing with f_z = 0.07 mm and e) machined surface roughness after sawing with f_z = 0.14 mm

Slika 7. Usporedba frekvencijskih spektara usrednjenih profila hrapavosti površine: a) za anatomsku hrapavost, b) za hrapavost obrađene površine nakon piljenja s f_z = 0,02 mm, c) za hrapavost obrađene površine nakon piljenja s f_z = 0,04 mm, d) za hrapavost obrađene površine nakon piljenja s f_z = 0,07 mm, e) za hrapavost obrađene površine nakon piljenja s f_z = 0,14 mm

If these results are compared with the results presented in Figure 5, it can be easily seen that, with averaging, the threshold level is twice smaller than previously determined. Also, with averaging, the periodic components are much easier to discern.

Therefore, it can be concluded that the threshold level should be determined from the similar roughness signal length to be used and with similar post-processing, because otherwise wrong conclusions could be reached.

4 CONCLUSIONS
4. ZAKLJUČAK

It can be concluded that the present experimental method can be used successfully for the determination of anatomical roughness of solid wood. From roughness profile obtained on such surface, threshold value for filtering out the anatomical roughness with filter based on fast Fourier transform (FFT) can be used. From the frequency analysis of anatomical roughness signals, obtained on the radial cross section of solid oak wood, a threshold of 1.6 μm was determined.

The average value of R_a parameter of anatomical roughness was 2.1 μm with standard deviation of 0.3 μm. The average impact of anatomical roughness on surface roughness after sawing for f_z = (0.02, 0.04, 0.07 and 0.14) mm was (22, 19, 17 and 15 %), respectively.

It should be kept in mind that the determination of the threshold based on frequency analysis must be carried out on the similar sampling lengths to be used in further analysis, due to the averaging effect. Otherwise, too low values of threshold could be used, and wrong conclusions could be reached.

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