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ORIGINAL PAPER

The use of the acoustic tomograph and digital image analysis in the qualitative assessment of harvested timber – case study

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Abstract

Accurate qualitative evaluation of grown and harvested wood is a key issue from the point of view of its subsequent economic evaluation. With the current trend of global climate change and large volumes of wood damaged by harmful agents, automated methods of wood quality assessment are becoming more and more important. The work aimed to verify the applicability and significance of the results of using the acoustic tomograph for the qualitative assessment of selected tree species logs. Ten samples of log sections of non-coniferous and coniferous trees were evaluated, on which an image analysis of qualitative features was performed on a cross-section from their digital photograph and the image output of an acoustic tomograph software. The results were compared with each other and the accuracy of qualitative feature identification by acoustic tomograph was evaluated. At the same time, the results of the image analysis of the qualitative feature were compared with its assessment through STN EN 1309-3. It was shown that, when evaluated according to the Standard, qualitative features were overestimated by an average of 29.19% compared to the acoustic tomograph and by 28.22% compared to the digital photograph. The use of the acoustic tomograph confirmed a good level of accuracy in the identification of qualitative features even on logs of harvested wood, although it is primarily intended for the qualitative evaluation of standing trees.

Key words: wood logs; qualitative sorting; qualitative feature; image analysis; acoustic tomograph; ImageJ software

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1. Introduction

With the development of technologies, there is also the development of possibilities for image analysis and non-destructive methods for quantitative and qualitative assessment of wood (Gurau et al. 2013; Alfieri & Correa 2018). Even if the technologies are based on relatively well-known principles of computed tomography or acoustic tomography, the price of equipment that could be deployed in forestry operations is still mostly at an unprofitable level (Gilbert et al. 2016; Gergeľ et al. 2020, 2022; Ondrejka et al. 2021). There are several methods for determining the qualitative structure of standing trees. However, not all methods provide sufficiently robust data or sufficient image quality (Arciniegas et al. 2014). Current methods in forestry operations rely primarily on the visual assessment of quality with their physical measurement and assessment in accordance with the valid STN EN 1309-3 Standard. Qualitative features that are evaluated on the basis of the areal extent of occurrence are measured as a proportion of the circumcircle area around the feature, from the area of the log end. They are thus systematically overvalued when they occur with an irregular form. More accurate results would be obtained by evaluating them based on a precisely calculated area using image analysis software (Suchomel & Gejdoš 2010; Gejdoš et al. 2014). These methods of visual assessment are also the basis for real-time quality assessment of wood for specific products (Hietaniemi et al. 2014).

Acoustic tomography methods were developed earlier for standing trees, while methods based on X-rays and CT scanners were developed for log sections of harvested wood. The main reasons for using non-destructive methods according to the authors Schimleck, et al. (2019) are mainly the protection of investments in raw-wood materials, potential reduction of wood processing costs, easier use in field measurements, fast data collection in real-time, the ability to identify the most suitable measurement applications and reduce the variability of quality classes of assortments (Wang et al. 2009; Potkány et al. 2018). The use of acoustic tomography for the assessment of harvested timber is rather rare (Goh et al. 2018; Olaoye & Ojo 2022).

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With the current trend of global climate change and large volumes of wood damaged by harmful agents, automated methods of wood quality assessment are becoming more and more important. The work aimed to verify the applicability and results in the significance of using the acoustic tomograph for the qualitative assessment of selected tree species logs. Since this method was primarily developed for standing trees in the forest, the goal was to verify the accuracy of this method also on smaller sections that are not firmly connected to the soil through the root system. The goal was also to verify the applicability of this method to refine the quality assessment of harvested timber. Such use of this method makes sense in the image analysis applied in the qualitative assessment of harvested wood as well as in the research-educational process for more dynamic development of these methods in forestry operations.

2. Material and methods

2.1. Acoustical analysis

The samples for analysis consisted of ten pieces of logs ranging in length from 30 cm to 1.2 m from the trees Spruce (*Picea abies*) – 4 pieces, Beech (*Fagus sylvatica*) – 3 pieces, Ash (*Fraxinus excelsior*) – 1 piece and Oak (*Quercus robur*) – 2 pcs. Sample preparation consisted in positioning the sensors of the Rinntech ARBOTOM acoustic tomograph. The number of placed sensors varied from 5 to 9 depending on the perimeter of the log (Fig. 1). Subsequently, an acoustic analysis of the internal structure of the log took place with output to the ARBOTOM 2.11 software (Fig. 2).

2.2. Qualitative features analysis

Only qualitative features of wood were analyzed, which are evaluated based on their surface area from the cross-

Fig. 1. Log preparation and acoustical analysis.

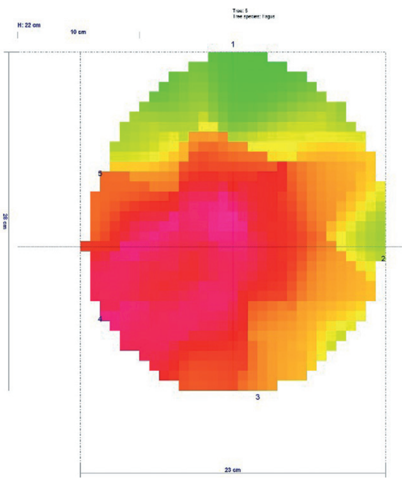


Fig. 2. Output from ARBOTOM 2.11 software.

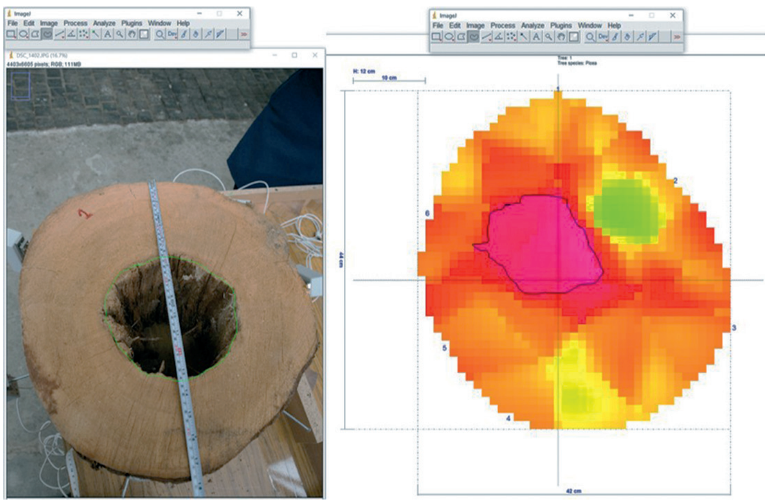


Fig. 3. Image analysis of qualitative feature area from digital photo and ARBOTOM software output in software ImageJ v.1.52a.

sectional area (rot, false heartwood). Each feature was measured based on the principles of measurement and evaluation in STN EN 1309-3 and its area share from the face area was evaluated. A digital photograph was taken with a Nikon D850 camera of each cross-section on which a quality feature was analyzed.

From the image output from the ARBOTOM 2.11 software and the digital photograph, an analysis of the surface range of the qualitative feature was performed using the software ImageJ v. 1.52a. From this analysis, the cross-sectional area and the area of the qualitative feature were calculated (Fig. 3). Subsequently, the percentage share of the qualitative feature was calculated on the digital photograph and the image output from the acoustic tomograph software.

Subsequently, the calculated area ranges from the identified qualitative feature on the digital photograph, and the image from the ARBOTOM 2.11 software, were compared with each other. The results of this analysis were also compared with the method of evaluating the surface range of the qualitative feature by STN EN 1309-3. The obtained results provide information about the accuracy of image analysis using an acoustic tomograph.

3. Results

The results part is focused on the comparative analysis of the qualitative feature area range assessment based on the valid legislation (STN EN 1309-3) and image analysis in the ImageJ program from a digital photograph and a digital image created by an acoustic tomograph software (Table 1). Fig. 4 shows the results of the image analysis for the qualitative feature areas obtained from a digital photograph and an image created by an acoustic tomograph software. The results are expressed in percentages of the qualitative feature share from the total cross-section area on the ten analyzed samples. 7 samples were analyzed for the qualitative feature of rot (samples no. 1–6; 10), 2 samples the qualitative feature of false heartwood (samples no. 8–9) and on one sample reduced wood density around the stem (sample no. 7).

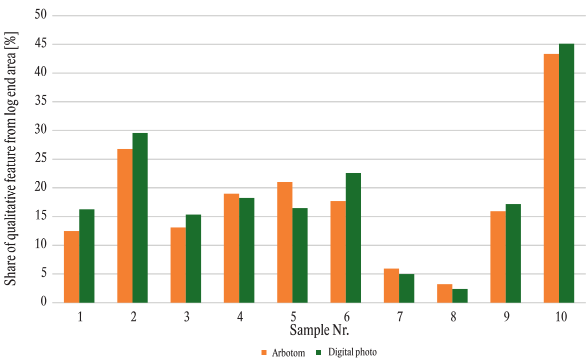
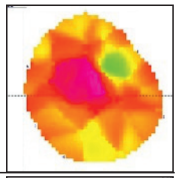
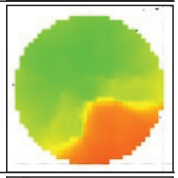
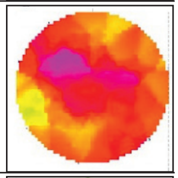
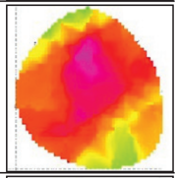
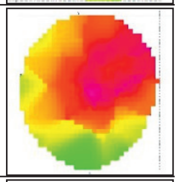
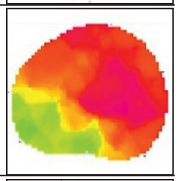
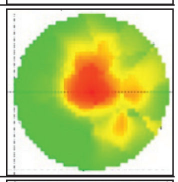
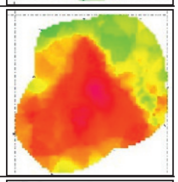
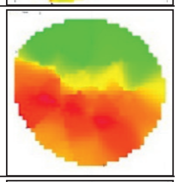
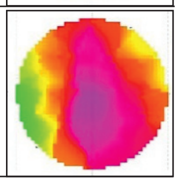


Fig. 4. Areas of qualitative features in percentage share from logs ends determined by ImageJ software.

Table 1. Samples in digital photo and Arbotom software assessment.

Sample Nr./Tree species	Digital photo	Arbotom software
1) *Picea abies*		
2) *Picea abies*		
3) *Picea abies*		
4) *Fagus sylvatica*		
5) *Fagus sylvatica*		
6) *Picea abies*		
7) *Quercus robur*		
8) *Fraxinus excelsior*		
9) *Fagus sylvatica*		
10) *Quercus robur*		

Based on the specified reference dimension (diameter of the cross-section), the cross-section areas and the given qualitative features were outlined and calculated in the ImageJ software. The results could be partially affected by the subjective approach and to some extent small inaccuracies in determining the qualitative feature from the image (manual analysis). The results obtained by image analysis can thus be characterized in both approaches (digital photography and acoustic tomograph) as relatively accurate in determining the surface extent of the occurrence of the given qualitative feature.

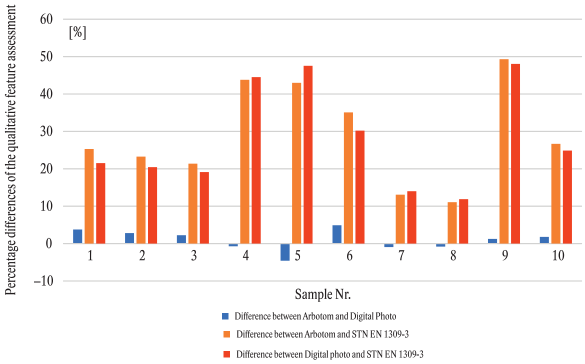


Fig. 5. Qualitative feature area differences between Arbotom, Digital Photo and STN EN 1309-3 assessment.

Fig. 5 shows the differences in the percentage shares of qualitative features from the log cross-section area evaluated from digital photography and acoustic tomograph software. At the same time, the difference between the area of the qualitative feature by STN EN 1309-3 and the evaluation of the qualitative feature area through image analysis in the ImageJ software from a digital photograph and the image output of an acoustic tomograph is evaluated.

In most cases, the area share of the qualitative feature from the digital photograph was slightly higher, than the area share of the qualitative feature identified from the image, which was created by the acoustic tomograph. A higher area share of the qualitative feature from the image created by the tomograph was only for samples no. 4, 5, 7 and 8. However, the identified differences did not exceed 5% in any sample, which we can attribute to the subjective error of the human factor during the manual evaluation of the image analysis. On average, the difference between the feature area from the digital photograph and the image created by the acoustic tomograph represented 0.97%. Based on this, we can conclude that the acoustic tomograph provided relatively accurate results of the qualitative features evaluation, compared to their real range based on image analysis.

When evaluating qualitative features according to the STN EN 1309-3 method, it is clear that, especially in the case of features that have an irregular shape, there will be a systematic overestimation of their surface area, since the diameter of the circle that describes such a feature on the cross-section is evaluated and subsequently expressed the share of this qualitative feature diameter from the total sample diameter of the cross-section. This overestimation is obvious in comparison with both the analysis from digital photography and the analysis of the output from the acoustic tomograph. On average, qualitative features were overestimated by 29.19% compared to acoustic tomograph and 28.22% compared to digital photography.

Thus, the results confirm fundamental differences in the approach to the assessment of quality features with a wide range through valid legislation and more accurate image analysis from digital images.

4. Discussion

Qualitative features that are evaluated based on their surface area belong to the very frequently occurring features on raw wood (Gejdoš et al. 2021). In the process of their evaluation based on valid legislation, their overall extent is systematically overestimated. Our results showed that this overestimation, especially in the case of an irregular feature shape, can approach the level of up to 30%. We recorded similar results in the analysis of the false core on 63 beech sections, where the difference in evaluation from a digital photograph using the ImageJ software and through the standard was 28.2% (Gejdoš et al. 2014). In the work (Gejdoš et al. 2019) it was identified that when using the image analysis method in the ImageJ software, it would be possible to achieve a qualitatively higher classification of the section in up to 56% of cases, compared to the evaluation under STN EN 1309-3.

Son et al. (2021) identified a positive correlation of 67% with acoustic tomography compared to the invasive micro-drilling method. Our results show that this agreement is at a higher level. Strobel et al. (2018) proposed an interpolation procedure to quantify holes in standing trees based on computed tomography results. They proved that even with this method, relatively accurate results can be achieved, but they cannot match direct measurement and image analysis in terms of accuracy. Wu et al. (2018) evaluated the reliability of acoustic tomography in comparison with the resistance drilling method on a sample of 147 trees from 33 species. They found that acoustic tomography provides sufficiently reliable results. Equally good accordance between these methods is also observed by Martinis et al. (2004).

Cristini et al. (2021) compared three different acoustic tomographs, finding a significant difference on standing trees with one device. Furthermore, they found that the differences between the devices are reduced during the cut-outs, and the moisture content of the wood of the examined samples can also significantly affect the results. In general, this confirms our results, which speak of the suitability of using acoustic tomography also on harvested trees (sections).

A more accurate and detailed assessment is also offered by non-destructive methods based on computer tomography, which makes it possible to increase the evaluation of coniferous logs by 15% and non-coniferous logs by 24% (Gergeľ et al. 2019). However, these technologies are still too economically demanding for forestry praxis.

Angulo-Ruiz et al. (2021) confirmed the applicability of this method also in the qualitative evaluation of trees on energy plantations. In general, it is thus possible to claim that the chosen method can contribute to the precision of the qualitative evaluation of timber logs, especially in the case of the occurrence of qualitative features that are evaluated on the basis of the surface area.

5. Conclusion

The results showed that in the case of applying the image analysis procedure with the help of software, it would be possible to achieve significantly more accurate results in the evaluation of qualitative features based on the surface area, compared to the approach by STN EN 1309-3. However, changing the approach would require legislative changes and consensus from the wood processing sector as well.

The use of the acoustic tomograph confirmed a good level of accuracy in the identification of qualitative features even on logs of harvested wood, although it is primarily intended for the qualitative evaluation of standing trees. The fact that the log being evaluated is not firmly connected to the soil through the root system did not appear to be a problem with this method of evaluation. Subsequently, the acoustic tomograph can be used for the qualitative assessment of these log sections also in laboratory conditions, especially for educational and scientific purposes.

In the future, it will be important that these methods start to be used more in the qualitative assessment of trees and forest stands. In combination with terrestrial laser scanning, it can bring great progress in the field of automated quality assessment and an assortment of trees and forest stands even before they are harvested.

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