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Towards In-Line Measurements of Sawn Wood Surfaces

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Abstract. Metrology and characterisation of products' functional surfaces are of key importance in smart and sustainable manufacturing. By proper measures of resulting topography and dimension at the micro-cm level, higher process control can be achieved, leading to more efficient production with products closer to defined targets. Commercial surface metrology systems for lab- and in/on-line applications have increased in the last decades, but the wood sector has not yet benefited from this development. A better understanding of sawn wood topography combined with smart online metrology systems is expected to lead to a substantial reduction of waste in sawmill production, both by transforming waste pieces and sideboards into engineered wood products and by optimising the sawing process (e.g. by using thinner saw blades and reduced tolerances). It would also open new design possibilities and challenge the construction sector to replace today's materials with renewable raw materials. Additionally, sawmills will be less dependent on incoming timber dimensions. This study is the first step towards a better understanding of sawn wood topography and how relevant surface features can be detected and analysed to enable the next generation of functional wood surfaces for various applications. By identifying the measuring instrument's capability to capture surface topographical features of sawn wood, this paper discusses the requirements for efficient measurement techniques. It opens for future implementation of machine learning algorithms to in-line monitor and control the machining process. All tested metrology techniques showed promising results. To capture machining marks, the instrumentation needs to have lateral resolutions on the um level and a measurement area covering some cm; thus, the laser scanning system seemed to be a good compromise.

Keywords. surface characterisation, sawn wood, metrology, sustainable sawmill production

1. Introduction

Timber products are based on a renewable resource – the forest – and an increase in the use of wood in modern building constructions does contribute to carbon neutrality. However, only about 20% of the felled forest ends up in high-value products, such as boards, with a long lifetime. The rest is waste and low-value products such as low-quality boards with a short lifetime or chips and shavings. In Sweden alone, about 5,000,000 m^3

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of sawdust is produced yearly as a side effect of the production of sawn wood products [1]. Over-compensation of cutting parameters is one reason which reduces the material exchange by more than 1.5% per millimetre. Reducing the saw cut width would lead to better use of virgin wood material - a production increase corresponding to 75,000 m^3 sawn timber per mm reduced saw blade thickness is realistic, which would be further improved if dimensional stability could be increased [2]. To drive the development of new saw blades and improved dimensional control, the resulting surface topography of the sawn wood must be understood.

Industry 4.0 boosts the competitiveness of manufacturing industries through various technical and organisational changes brought about by the increasing networking of humans and machines. For the wood sector, log-scanning systems, such as X-ray computed tomography, detecting log shape and under-the-bark properties, such as knot type/volume and heartwood volume, have enabled better saw pattern optimisation, while advanced vision systems provide online board grading, cross-cut optimisation, and digital fingerprint systems [3-7] – all in the speed of a sawmill production (typically 160m/min). However, there is room for improvement where the wood industry can take advantage of technological spillovers or synergies from other sectors [8]. [9] have outlined four research challenges and technical gaps based on their review of wood machining focusing on the sawing process, where they conclude that the combination of "intelligent monitoring and multi-objective optimisation approaches should pave the way for controlling the sawing process so higher surface quality and cost-efficient machining is achieved". [10] discuss the concept of information-rich surface metrology, which "refers to the incorporation of any type of available information in the data acquisition and processing pipeline of a measurement process to improve the efficiency and quality of the measurement". Despite challenges in handling often product-specific data, the approach is expected to increase the utility of the measurement effort significantly.

The quality of wood surfaces links to many influencing factors related to wood properties, such as moisture content and its anatomical features, and operational parameters, such as cutting speed, tool conditions, and vibrations. The internal structure variations between different wood species make it troublesome to find general relationships between the factors. The structure number, based on the number and size of vessels and tracheids, and the portion of early/late wood, is one attempt to predict anatomical roughness [11]. However, machining marks are on a larger scale even though cutting conditions strongly relate to wood properties. For example, fibres non-parallel to the cut contribute to irregular surfaces due to the low tensile strength perpendicular to the fibres, leading to the separation of fibres instead of clean cuts and brittle fractures of wood cells [11]. Despite the vast amount of standardised surface texture parameters, profile or areal [12-13], few others than profile average height parameters are used. The most used parameters for wood surface quality seem to be the core height Rk, mainly related to edge radius (therefore a good indicator for tool wear), the reduced peak height Rpk, related to wood anatomy and the machining process (causing fuzziness on the surface due to fibrillation), and the reduced pit depth Rvk, mainly related to wood anatomy [8][11][14]. However, these values are strongly affected by any swelling or shrinkage of the wood [11], which is not often a problem for other materials. Research on final wood surface quality linked to roughness, defects and surface appearance exists. Still, the perceived quality is only one aspect a product should have, often assessed at the end of the production line. Other aspects, such as preparation for painting and glueing, are at least as important as they pave the way for a successful product. One example is green-glueing (meaning glueing of undried green wood), which could imply "a radically changed order of material flow in the production of value-added wood-based products" [15] as it allows for new products based on low-value timber like waste pieces and sideboards [16]. However, the technique is still sparsely used in industry today, partly due to excessive glue consumption [15]. Machining operations do leave recurrent marks, but wood is a heterogeneous biobased material where each type of wood has its unique internal structures and anatomy. As the industry develops, more precise surface qualities will be delivered, with higher demands on surface functions and treatments. If the topography of sawn wood were known and measurable, it could open doors for a more sustainable sawmill production with less resource waste and increased raw material utilisation.

One important key factor for sustainable production is the more intensive use of smart and customised metrology systems for topography and dimensional control or as feedback systems for continuous process adjustments. In sawmills, manufacturing occurs at very high rates and in extremely harsh environments, which is directly unsympathetic for advanced metrology systems. Yet no objective systems for surface roughness quality in production have been found by the authors. However, several researchers have contributed to the field. [17] developed a microwave-based method to image fibre structures in logs, which made it possible to locate knots as well as fibre orientation, both of high importance when it comes to sawing optimisation and surface quality due to the anisotropic behaviour of strength properties [18-19] but did not further explore any link to cutting performance. Others have used more conventional methods primarily intended for lab environments, such as optical profilers, scanning electron microscopy and/or stylus profilometers studying surface quality and its relation to wood anatomy/properties and process parameters, see, e.g. [20-22]. One exception is [23], who tested laser displacement sensors for surface topography and automatic defect detection in the production line for wooden window frames. Another interesting and relatively new technique is the gel-based photometric stereo profilometry, which is useful for studying biological surfaces [24-25].

The paper contributes towards in-line measurements of sawn wood surfaces by investigating the various wood surface features necessary to build the requirements for a measurement technique that can be implemented for in-line process monitor and control. It investigates different commercial metrology techniques for both lab and in-line applications to study surface texture. The aim is to define relevant and measurable surface characteristics for sawn wood surfaces. The effect of sawdust, vibrations and other disturbances might affect measurement results, but this was not the scope of this investigation and will, therefore, be addressed in further studies. The study is limited to spruce trees, which constitute the main share of the harvested volume in Sweden [26]. The long-term goal is to study the potential of using surface topography data to optimise and facilitate (new) manufacturing techniques for sustainable engineered wood products.

2. Experimental

Five surface measuring techniques were tested at laboratory and industrial scale to capture and analyse wood surface features. The first test included one sample (band sawing), which was measured with four of the measurement techniques included in the study: coherence scanning interferometry, structured light microscopy, Gelsight elastometric technique, and a laser scanning system. The measurements were taken at the same location at the sample within an area of approx. 12 mm x 12 mm; see Figure 1.

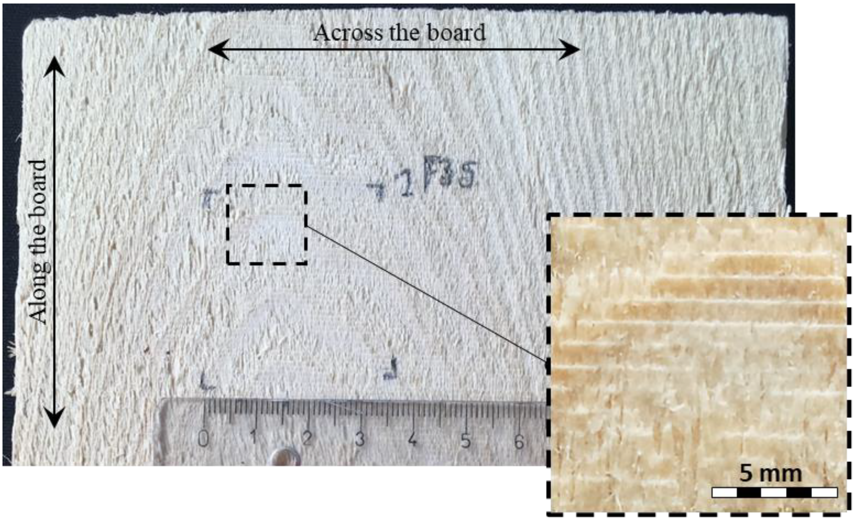


Figure 1: Band-sawn wood sample with visible machining marks and anatomical features (such as year rings). The marked area shows the relocated area in the first test.

The second test included boards (circular sawing), which were measured with three instruments: the laser scanning system, a board scanner in sawmill production, and a board scanner in a lab environment.

2.1. Surface measurement techniques

In coherence scanning interferometry (CSI), a non-contact and reflection mode interference microscope is utilized to capture two-dimensional images that are stacked along the optical axis [27]. The mechanical scanners allow the movement of the objective in the optical axis. The light from the source is focused onto the objective and the camera with the help of a beam splitter. The variations in the optical path caused by the topographical heights in the sample surface form the interference fringes, which are then imaged by the camera. CSI has the capability to measure from mm down to nm. In this research, a Zygo's NewView 9000 with a resolution of 3.15 µm in 'x' and 'y' direction with stitching capability to capture larger areas was used.

In structured light microscopy (SL), a predefined pattern of fringes is projected on the surface and the reflected light pattern distorted due to surface irregularities is recorded [28]. For structured light microscopy, the GFM MikroCAD was utilized with a measurement area of 25x19 mm^2 and a quoted resolution of 15.4 µm in the 'x' and 'y' direction.

The Gelsight technique (GEL) is a portable elastomeric tactile instrument which enables a fast and reliable approach using a gel membrane and a camera. The gel is pressed against the surface to be measured, and the membrane takes the form of the surface, which is recorded by a camera under illumination from LEDs from different directions [29]. The resolution of this instrument is 6.7 µm in the 'x' and 'y' directions, and it covers a measurement area of 16 x 14mm^2.

The laser scanning system (Laser) is based on laser triangulation and uses an image acquisition method that generates images based on a laser line illuminating the surface and recording it as 2D profiles [30]. The three-dimensional image is developed by stacking the 2D profiles by knowing the surface or instrument's movement and the instrument's configuration. The laser scanner investigated in this study was the micro-epsilon scanCONTROL 2900-100 with a resolution of 1280 pixels/profile. In this study, a measuring speed of 0.5 mm/s was used giving an approximate resolution of 70 x 20 µm in the ‘x’ and ‘y’ directions. In this study, the ‘x’ direction was across the board (see Figure 1), which means that the best resolution is along the boards. The specification of the laser scanner varies with the measurement setup.

The board scanners used have an accuracy on the mm level, meaning that the images are formed by a grit of measurement points separated by a few mm. They are measuring a whole board in a few seconds. Table 1 provides an overview of the resolution of the surface measurement instrument, measurement area, and estimated measurement time. Note that the measurement area differs between the instruments, but the time given is the minimum needed to cover at least the area of 12 mm x 12 mm.

Table 1. Surface measuring instruments and their specification with respect to measurement area, lateral resolution and time taken to measure the study surface area of approx.. 12mm*12mm.

Instrument	Accuracy (z-axis)	Lateral resolution	Measurement area [A]	Sampling rate	Measurement time for area 12mm*12mm
CSI	< 1 nm	3.15*3.15 µm	3.15*3.15 mm^2	< 2 s/A	60 min
SL	1.6 µm	15.4*15.4 µm	25*19 mm^2	5 s/A	5 s
GEL	4 µm	6.7*6.7 µm	16*14 mm^2	10 s/A	10 s
Laser	-	1280 pixels/profile	-	≤ 300 Hz	6 s

2.2. Surface Characterization

The surface topography analysis was made with the proprietary software MountainsMap; no additional filters or form-removing steps were applied to the measurements. However, oversized images were cropped to get the same size, i.e., 12mm x 12 mm. The areal surface parameters defined in ISO 25178-2 [13] are used to characterise the measured surface topography, especially the surface parameters root mean square height (Sq), reduced peak height (Spk) and reduced pit depth (Svk). Sq provides the square root of the mean square of the absolute values and is often associated with surface roughness and asperities. After the reduction process, Spk and Svk are calculated on the protruding peaks and pits from the core.

3. Results and Discussions

3.1. First test – four different lab-devices

Relocated surface images captured using the coherence scanning interferometer (CSI), the structured light microscope (SL), the Gelsight sensor (GEL) and the laser scanner (Laser) are shown in Figure 2. It is observed that only the Laser failed to capture the fibre features that are in the size of 50 µm in diameter, which is at the limit of what the instrument is capable of (see Table 1). The features left from the sawing process, which are in the size of 0.1-1mm (see Figure 3), are captured by all four instruments, which all have a quoted lateral resolution below 100 µm. This is in line with [14], who reported that measurement instruments require a resolution of around 200µm to capture machining marks and residual marks caused by saw blades.

The Laser has by far the largest size of measurement area, which is only limited by the length of the laser line. For the other instruments, the surface images need to be stitched to cover larger areas. The details in the image (which is built up of 25 stitched images) from the CSI measurement are at the expense of the acquisition time (see Table 1). For the second study, the Laser scanner was chosen to be compared to the board scanner due to its capability to cover large areas in a reasonable time and, at the same time, capture machining marks at a sufficiently detailed level. For a deeper understanding of how wood's anatomical features interfere with the saw blade (cutting conditions) and thereby be able to optimise the sawn process for different applications such as painting or glueing, more detailed images will most likely be needed.

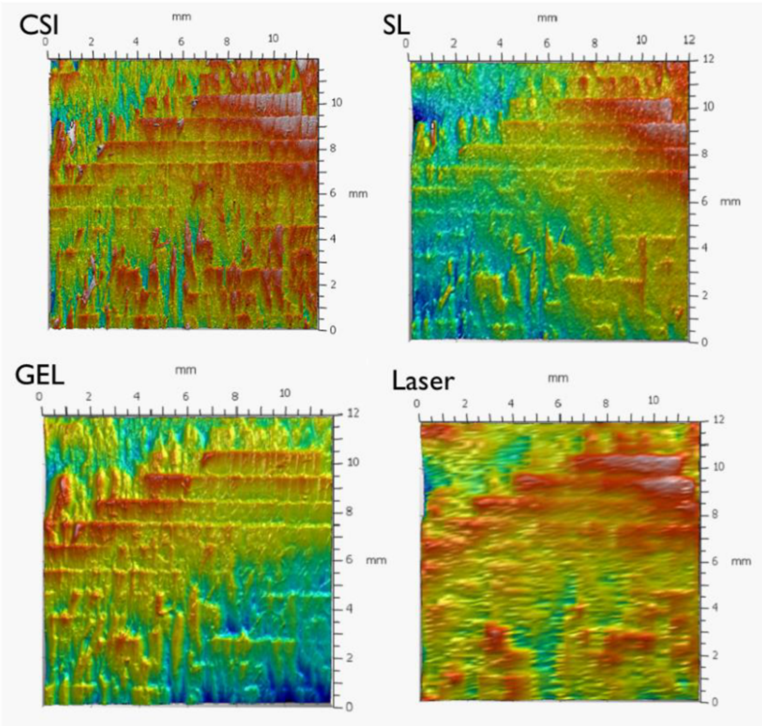


Figure 2: Surface topography of the wood sample surface (see figure 1) captured by CSI – the coherence scanning interferometer, SL – the structured light microscope, GEL – the Gelsight sensor, and Laser, the laser scanning system.

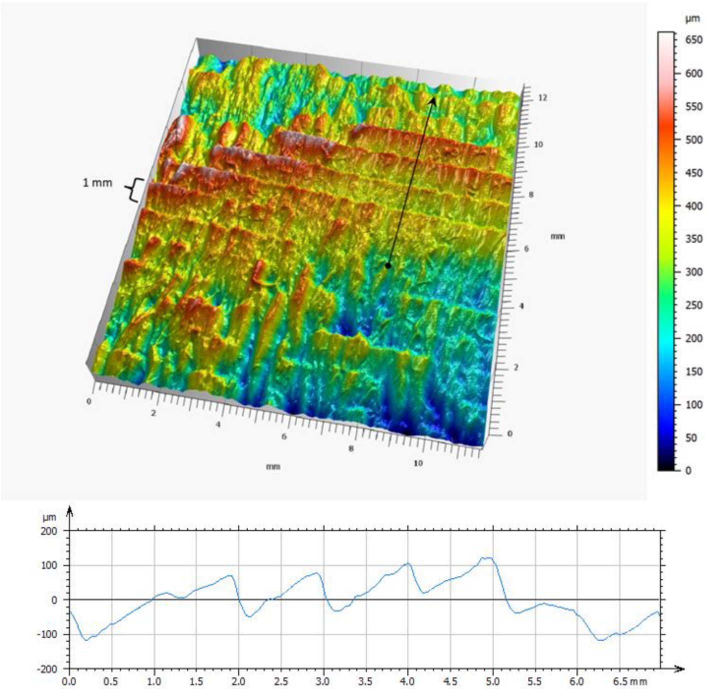


Figure 3: Image (12.8 mm x 11.6 mm) of a wood sample surface (see Figure 1) showing the order of the magnitude of relatively small machining marks. The image is taken using the Gelsight instrument.

3.2. Second test – laser scanner in the lab vs. the board scanner in production

Figure 4 shows a photo of the area measured in the second test, which was chosen due to the variety of features on the surface. Anatomical features (knots and annual rings) and marks caused by the cutting process (machining marks and steps) were present. The fuzziness is a combined feature, as unfavourable cutting conditions cause torn-out wood fibres. The measured images in Figure 4 represent the laser and board scanner measurements, respectively. Only the ‘saw seam’ and the ‘knot’ are big enough to be visible in the height data images based on the board scanner with today’s sampling rate, while the Laser managed to capture them all. The height of the ‘step’ varies along the board, but is measured to be less than half a mm.

The board scanner setup generates additional data, e.g. board thickness and knot positions, which is important information for cross-cutting or planing operations. Further, the measurements from the production showed that vibrations can significantly influence the measurements; thus, the vibrations need to be reduced and/or filtered before the measurements can be used for surface assessments.

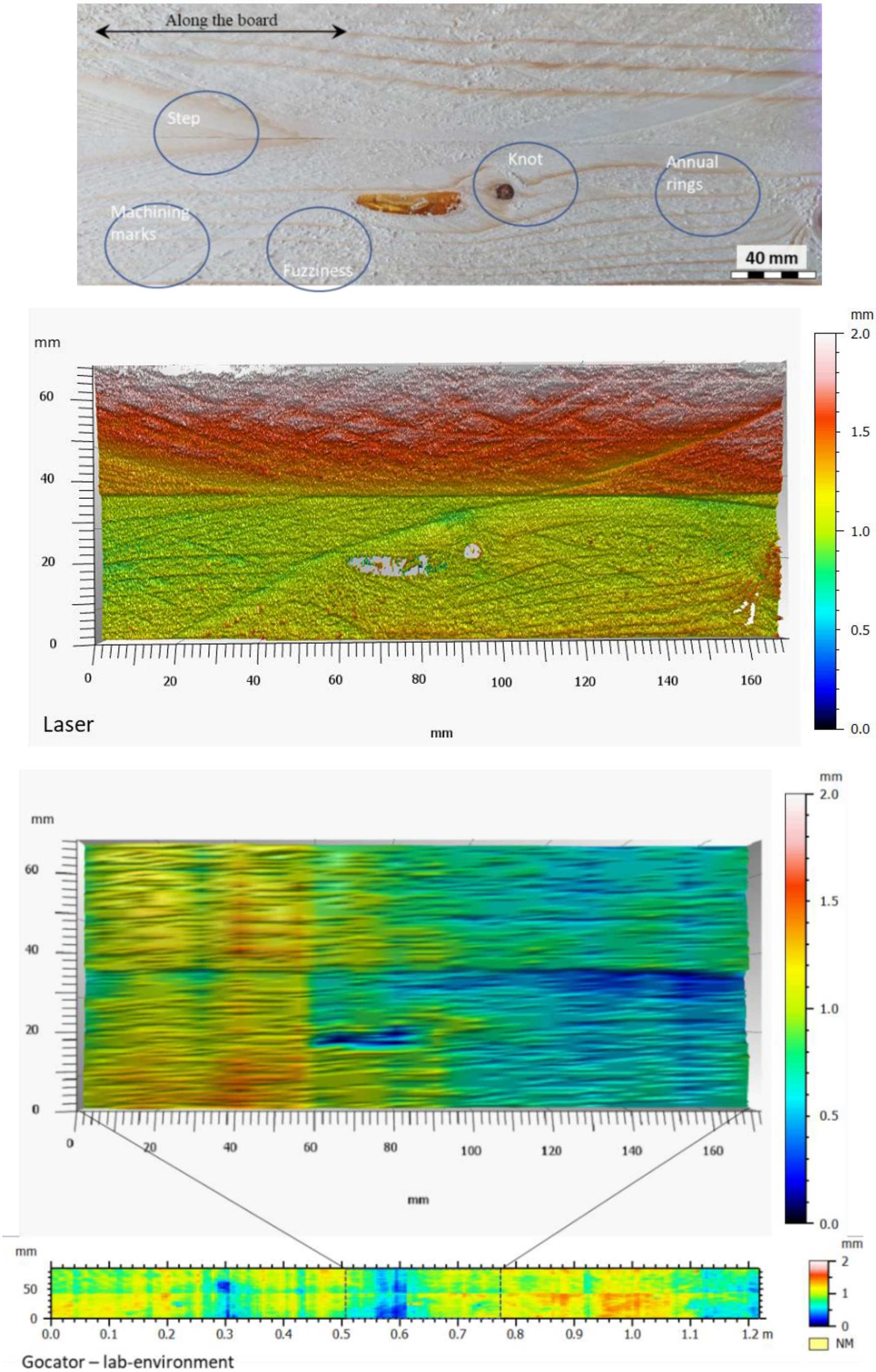
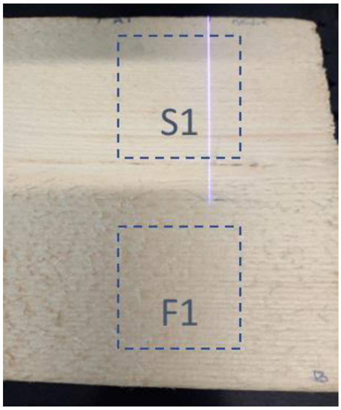


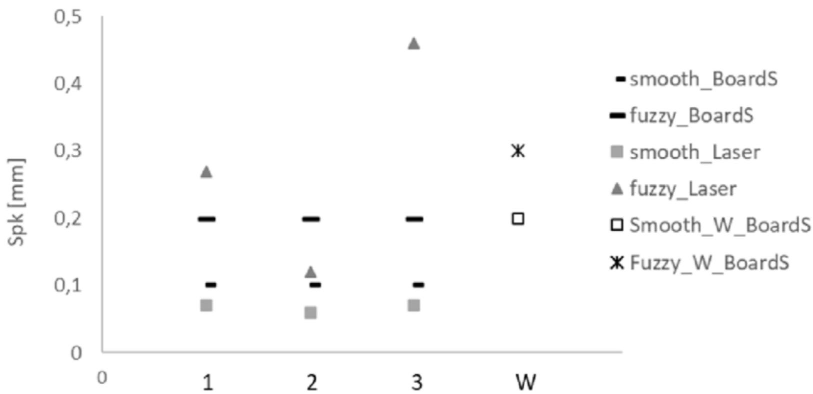
Figure 4: Upper, photo of the board's various surface features; and mid and bottom, Laser and board scanner (extracted from the board image) of the same area shown in the photo.

The thickness of a board is of interest since it forms the basis for decisions on next-coming process steps, for example, planing. In that case, fuzziness can cause problems because it makes the board appear thicker than it actually is. To overcome it, larger margins are used to guarantee that the sawn timber's thinnest point is at least as thick as the claimed thickness. Thus, the presence of fuzziness on the surface is of interest. A board where one half of the surface was relatively smooth and the other fuzzy is shown in the image in Table 2. The topography captured by the two different scanners was quantitatively compared using the areal surface parameters Sq, Spk and Svk. It could be concluded that both the Sq- and the Spk-value indicate a roughness variation in the surface; the values for the fuzzy surface are larger than the ones for the smooth one (see Table 2 and Figure 5). However, many more boards need to be investigated to identify the optimal evaluation area and range of scales required to represent the different features of sawn wood statistically.

Table 2. Surface measuring instruments and their specification with respect to measurement area, lateral resolution and time taken to measure the study surface area of 12mm*12mm. The photo shows the smooth (S1-SS3) and the fuzzy (F1-3) surfaces, respectively.

Measurement area_instrument	Sq [mm]	Spk [mm]	Svk [mm]
Smooth_S1_Laser	0.09	0.07	0.12
Smooth_S2_Laser	0.09	0.06	0.11
Smooth_S3_Laser	0.09	0.07	0.12
Fuzzy_F1_Laser	0.14	0.25	0.11
Fuzzy_F2_Laser	0.09	0.12	0.09
Fuzzy_F3_Laser	0.22	0.46	0.15
Smooth_S1_BoardS	0.1	0.1	0.1
Smooth_S2_BoardS	0.1	0.1	0.1
Smooth_S3_BoardS	0.1	0.1	0.1
Smooth_SW_BoardS	0.2	0.2	0.2
Fuzzy_F1_BoardS	0.2	0.2	0.2
Fuzzy_F2_BoardS	0.2	0.2	0.2
Fuzzy_F3_BoardS	0.2	0.2	0.1
Fuzzy_FW_BoardS	0.2	0.3	0.2





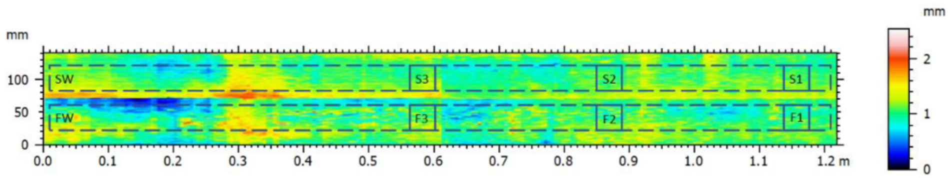


Figure 5: Upper, graph visualising the difference in Spk-value for the fuzzy and smooth surface areas. Lower, measurement area distribution on the board (1-3 are extracted areas in the size of 40 x 40 mm, W is the whole area).

4. Conclusions

As expected, wood surfaces are complex with anatomical features, features generated due to cuts of wood fibres in different directions (for example, fuzziness) and machining marks. Tested metrology techniques, both for lab and industrial applications, showed promising results. Especially the instruments based on the principle of laser triangulation have been found to be suitable for these applications, provided they have enough resolution and accuracy capabilities. To capture machining marks, the instrumentation needs to have lateral resolutions on the um level.

Further studies, including more samples, will be performed to describe various surface features of different sizes by quantitative parameters, and to understand where, how large and how frequent measurements need to be captured. If the topography of sawn wood were known and measurable, it would enable more sustainable sawmill production. For example, indications of tool change would lead to better process control with products closer to defined targets. It also opens the door for new design possibilities and challenges the construction sector to replace today's materials with renewable raw materials.

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References

[1] Skogsindustrins virkesförbrukning samt produktion av skogsprodukter 2015-2019 [Internet]. Sundsvall: Biometria; c2020 [cited 2023 Oct 26]. Available from: www.biometria.se/publikationer/statistik-och-rapporter/virkesfoerbrukningsstatistik/

[2] Fredriksson M, Svensson M. A sawmill simulation study of the volume yield changes when sawing with thinner kerfs. In: LeVan-Green S, editor. Renewable resources for a sustainable and healthy future. Proceedings of the 2020 Society of Wood Science and Technology International Convention; 2020 Jul 12-15; Virtual conference. Place of publication [unknown]: Publisher [unknown]; 2020. p. 363-76.

[3] RS-BoardScannerQ [Internet]. [cited 2023 Oct 26]. Available from: www.remasawco.se/produkter/rs-boardscannerq/

[4] The most innovative wood scanning solutions [Internet]. [cited 2023 Oct 26]. Available from: www.microtec.eu Accessed 2023-10-26
[5] Finnos your future [Internet]. [cited 2023 Oct 26]. Available from: www.finnos.fi/en/
[6] Laser measurement systems and sensors for the wood-industry [Internet]. [cited 2023 Oct 26]. Available from: www.limab.com
[7] WEINIG scanner systems: Recording everything at a glance [Internet]. [cited 2023 Oct 26]. Available from: www.weinig.com/en/solid-wood/scanner-systems.html
[8] Thibaut B, Denaud L, Collet R, Marchal R, Beauchêne J, Mothe F, Méausoone PJ et al. Wood machining with a focus on French research in the last 50 years. Ann. For. Sci. 2016 Mar;73(1):163-84. doi: 10.1007/s13595-015-0460-2
[9] Nasir V, Cool J. A review on wood machining: characterisation, optimization, and monitoring of the sawing process. Wood Mater. Sci. Eng. 2018 Apr;15(1):1-16. doi:10.1080/17480272.2018.1465465
[10] Senin N, Leach R. Information-rich surface metrology. Procedia CIRP 2018;75:19-26.
[11] Csanády E, Magoss E, Tolvaj L. Quality of machined wood surfaces. 1st ed. Switzerland: Springer International Publishing; 2015.
[12] ISO 21920-2:2021 Geometrical product specifications (GPS) — Surface texture: Profile — Part 2: Terms, definitions and surface texture parameters.
[13] ISO 25178-2:2021 Geometrical product specifications (GPS) — Surface texture: Areal — Part 2: Terms, definitions and surface texture parameters.
[14] Gurau L, Irle M. Surface roughness evaluation methods for wood products: a review. Curr. Forestry Rep. 2017 Apr;3:119-31. doi: 10.1007/s40725-017-0053-4
[15] Sterley M. Characterisation of green-glued wood adhesive bonds [PhD thesis]. Växjö: Linnaeus University; 2012. Available from: www.diva-portal.org/smash/get/diva2:525573/FULLTEXT01.pdf
[16] Adams RD. Adhesive bonding - science, technology, and applications. 2nd ed. Cambridge: Woodhead Publishing; 2021.
[17] Kaestner LA, Bååth L. Microwave polarimetry tomography of wood. IEEE Sens. J. 2005 Apr;5(2):209-15. doi: 10.1109/JSEN.2004.841343
[18] Bodig J, Jayne BA. Mechanics of wood and wood composites. 1st ed. [place of publication unknown]: Van Nostrand Reinhold; 1982.
[19] Kopač J, Šali S. Wood: an important material in manufacturing technology. J. Mater. Process. Technol. 2003 Feb;133(1-2):134-42. doi: 10.1016/S0924-0136(02)00217-0
[20] Ayanleye S, Nasir V, Avramidis S, Cool J. Effect of wood surface roughness on prediction of structural timber properties by infrared spectroscopy using ANFIS, ANN and PLS regression. Eur. J. Wood Wood Prod. 2020 Nov;79:101-15. doi: 10.1007/s00107-020-01621-x
[21] Schreiner F, Schmidt J, Thorenz B, Voigt M, Döpper F. Investigation of cutting force and surface quality in frozen wood sawing under varying influencing factors to improve the energy- and resource efficiency of sawing processes. In: Kohl H, Seliger G, Dietrich F, editors. Manufacturing driving circular economy [Internet]. Proceedings of the 18th Global Conference on Sustainable Manufacturing; 2022 Oct 5-7; Berlin. Lecture Notes in Mechanical Engineering. Cham: Springer; 2023. p. 166-74. doi: 10.1007/978-3-031-28839-5_19
[22] Conceição WS da, Matos RS, Melo I da C, Ramos GQ, Zayas FG, Fonseca Filho H D da. Measurement of wood surface roughness in Dinizia excelsa Ducke using an atomic force microscope. Acta Sci., Technol. 2022 Jan;44(1):e56509. doi: 10.4025/actascitechnol.v44i1.56509
[23] Sandak J, Orlowski KA, Sandak A, Chuchala D, Taube P. On-line measurement of wood surface smoothness. Drvna Ind. 2020 Jun;71(2):193-200. doi: 10.5552/drvind.2020.1970
[24] Any Material, Anywhere™ [Internet]. [cited 2023 Oct 26]. Available from: www.gelsight.com
[25] Wainwright DK, Lauder GV, Weaver JC. Imaging biological surface topography in situ and in vivo. Methods Ecol. Evol. 2017 Mar;8(11):1626-38. doi: 10.1111/2041-210X.12778
[26] Fakta om skog [Internet]. [cited 2023 Oct 26]. Available from: www.skogen.se/skogssverige/fakta-om-skog/
[27] Su R. Coherence scanning interferometry. In: Leach R, editor. Advances in optical surface texture metrology. London: IOP Publishing; 2020. p. 2.1-21.
[28] Isgro F, Odone F, Verri A. An open system for 3D data acquisition from multiple sensor. In: Di Gesù V, Tegolo D, editors. Computer architecture for machine perception. Proceedings of the Seventh International Workshop on Computer Architecture for Machine Perception; 2005 Jul 4-6; Palermo. Los Alamitos: IEEE; date of publication [unknown]. p. 52-7. doi: 10.1109/CAMP.2005.13
[29] Li R, Adelson EH. Sensing and recognizing surface textures using a gelsight sensor. In: [unknown], editor. 2013 IEEE Conference on Computer Vision and Pattern Recognition. Proceedings of the 2013 IEEE Conference on Computer Vision and Pattern Recognition; 2013 Jun 23-28; Portland. Place of publication [unknown]: IEEE; 2013. p. 1241-7. doi: 10.1109/CVPR.2013.164

[30] Cinal M, Sioma A, Lenty B. The quality control system of planks using machine vision. Appl. Sci. 2023 Aug; 13(16):9187 [17 p.]. doi: 10.3390/app13169187