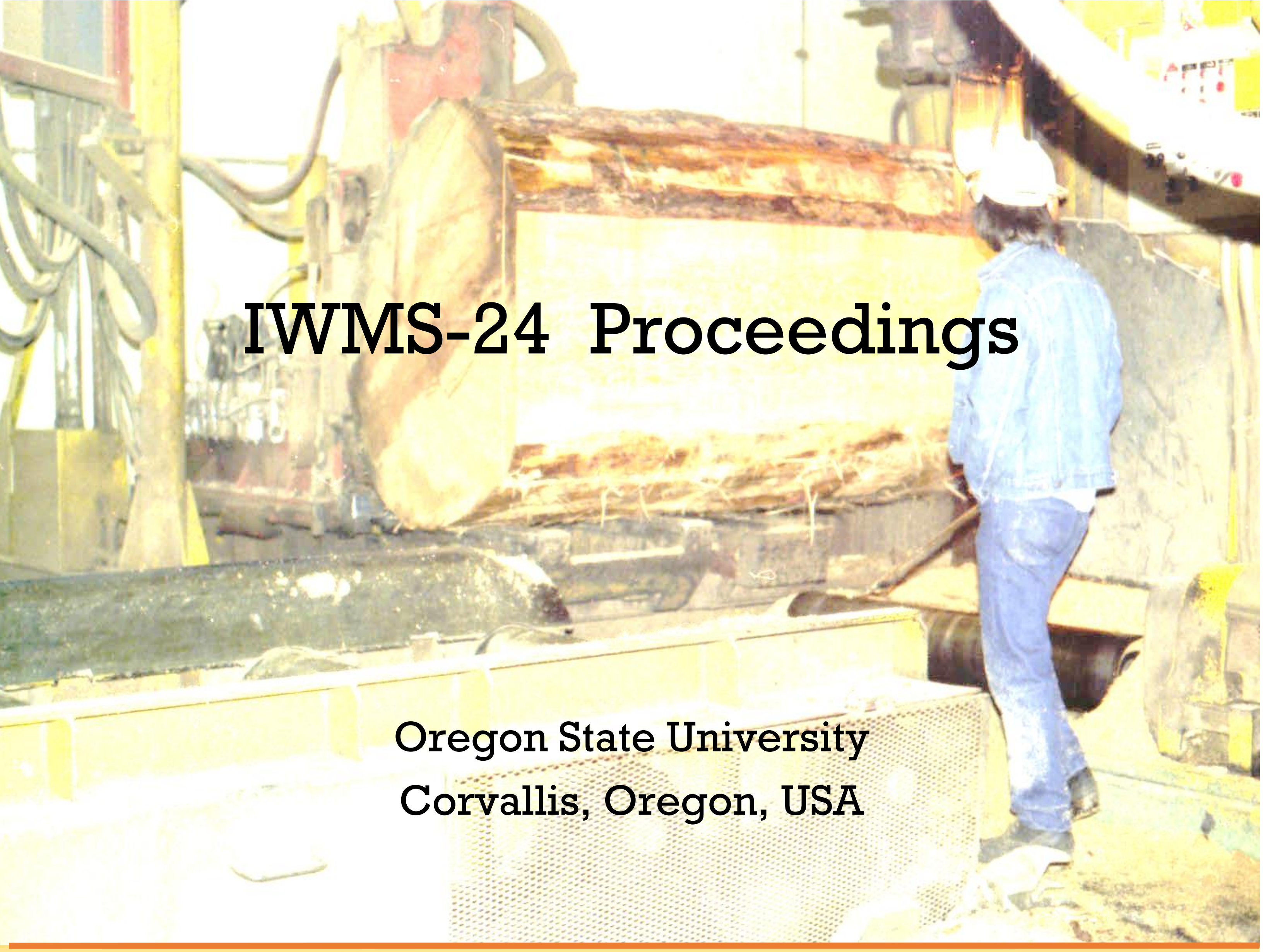
24 International Wood Machining Seminar

August 25-30, 2019



IWMS-24 Proceedings

Oregon State University
Corvallis, Oregon, USA

Editor: Gary S. Schajer, IWMS International Advisory Committee

Oregon State University
College of Forestry

FPInnovations

Welcome to IWMS-24 !

We, Eric Hansen and Scott Leavengood at Oregon State University and Darrell Wong at FPInnovations, Vancouver, Canada, are proud to be your hosts and to welcome you warmly to the 24th International Wood Machining Seminar. In 2017, the then Dean of the College of Forestry at OSU, Thomas Maness, agreed to host this event. He had been closely involved in the organization of the 13th IWMS held in Vancouver. Unfortunately, Thomas passed away last year, but I know that he would certainly have been excited and proud to welcome you to OSU's College of Forestry. You will get to tour and experience the Red Emmerson Advanced Wood Products Laboratory and see the ongoing construction of the new Peavy Hall, both buildings utilizing mass timber. These new additions to the College are a key part of Thomas' legacy. We have a great week planned for you, with plenty of technical content, much opportunity for great social interaction with friends, and for Post-Seminar Tour participants, the experience of our local industry. We much look forward to welcoming you on campus.

With good wishes,

Eric Hansen and Scott Leavengood
Oregon State University

Darrell Wong
FPInnovations

Preface

This is the 24th meeting of a series started in 1963 at the University of California, Richmond, originally named as the Wood Machining Seminar. In the early days, the meetings were based solely in Richmond, were of modest size, and were specialized solely on wood machining. For the 9th and subsequent meetings, the increasing success of the Seminars gave confidence to expand the scope of the discussions to encompass all aspects of wood processing and also to diversify the meeting sites to various centers of wood processing research around the world. This required a name change and thus the International Wood Machining Seminars were born. Since then, IWMS meetings have been held in nine different countries, always with strong attendance and with increasing diversity.

A central and distinctive feature of the IWMS meetings is the strong feeling of community among the participants, with numerous regulars of many years standing. Thus, in addition to being a high-level technical meeting, IWMS is also a gathering of both old and newly formed friends. Strong personal relationships and collaborations are both born and strengthened. New participants, particularly those at the start of their careers are warmly welcomed. In this way, the foundations developed by the established generation can be passed on to the new generation for them to build on and add their own contributions. It is the hope that they in turn will become regular IWMS participants and encourage the following generation. This was the dream of the original founders.

Welcome to IMWS-24, welcome to the technical sessions, but most particularly, welcome to the IWMS community.

With best wishes,

G S. Schajer

Gary S. Schajer
Chair, IWMS International Advisory Committee

Table of Contents

Oral Presentations

Keynote

Wood Machining

Sensors and Quality Control

Novel Products and Production Processes

Veneer Production

Sanding and Dust Mitigation

Poster Presentations

Vision System for On-line Monitoring of Wood Surface Roughness

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ABSTRACT

The latest development in the field of optics and microelectronics resulted in a new generation vision system capable of scanning surface topography with very high sampling frequencies. The blue color of illuminating light as well as novel systems for controlling ultra-thin laser line thickness allows measurement of the porous surface of wood with a triangulation method. Three alternative sensors were tested here in order to verify their suitability for determination of surface topography in the industrial environment. The scanning head was installed at the exit zone of the four-side profiling moulder and was set to scrutinize the wood surface shape line by line, immediately after profiling. The sensor was also tested for automatic detection of surface defects appearing on elements after sanding, wetting and painting with diverse finishing products. The set of pilot test results, together with an original algorithm for real-time surface defects detection, is presented.

Keywords: wood surface roughness, triangulation scanner, surface defects, on-line, at-line

INTRODUCTION

Surface roughness of products manufactured from wood is a critical property highly affecting product quality, its value and in-service life performance. In a majority of cases, the surface of wood is an effect of the material allowance removed with a sharp cutting edge. The magnitude of roughness depends on several factors, where material properties, machining process kinematics, cutting tool conditions and machining imperfections are dominant. The ability for monitoring surface quality at the early stage of the production process was always a desire of process engineers. Several methods were proposed for that purpose, but none of these were widely accepted by the wood industries. The superior methodology for surface roughness monitoring should be non-contact, very fast, allowing on-line (preferably in-process) assessment and accurate enough to detect undesired defects. The best surface roughness scanner should allow measurement not only of a surface profile but rather the whole surface area.

Wood surface measurements can be performed in industrial conditions assuming in-line, on-line or off-line strategies (Figure 1). In-line installation of the roughness sensor allows early detection of machining imperfections as the sensor monitors roughness directly after the cutting tool. In that case, the scanning frequency must be high enough to assure sufficient representation of the surface, considering very high feed speeds of modern processing systems. The sensor itself has to be very rigid and resistant to harsh environments (dust, vibrations, shocks, etc.). As an alternative to the in-line approach, surface roughness can be measured on the selected representative samples following an off-line strategy. In that case, the sample is removed from the production line and presented to the measurement system in a specially conditioned place (e.g., laboratory). Off-line measurement allows superior reproduction of surface topography, including whole area evaluation as well as high topography magnification and optimal resolution. An apparent limitation of this solution is manual operation and inability for continuous analysis of a very limited number of samples. In between in-line and off-line is, therefore, on-line strategy, where the roughness sensor is installed separately from the woodworking machines on the main conveyer or for-the-purpose separated by-stream measurement line. On-line installation of the sensor allows measurement of all (or at least a high fraction) of produced surfaces, substantially increasing reliability of the quality assurance system.

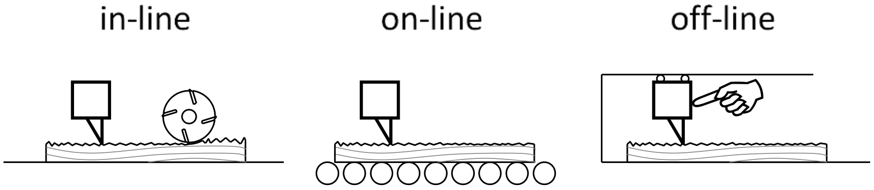


Figure 1. Assessment strategies for wood surface roughness in the production factory.

The latest development in the field of optics and microelectronics resulted in a new generation vision system capable of scanning surface topography. Interferometry, confocal microscopy or image stacking decomposition are methods widely used today for surface topography mapping in laboratories or off-line applications. On the other hand, triangulation systems allow for scanning surfaces with very high sampling frequencies, still assuring accurate surface roughness reconstruction [1]. Problematic red light scatter on the fibrous surface of wood has been recently minimized by implementing blue lasers as a source of light section [2]. In that case, short light wavelengths minimize laser line thickness, diminishing the unwanted "tracheid effect". Such triangulation systems have been recently introduced on the market but never tested for their suitability in wood industries.

The aesthetical function of wood surface becomes dominant in the highly customer-oriented market where several alternatives to wood are available in a variety of applications. One of the most demanding sectors is window production, where technical requirements for the surface quality of the final product are extremely high. Wood machining is an integral part of the production process of wooden window frames, where the surface generated by planing directly affects the sequence of following operations, especially surface finishing by coating or painting. In practice, it is very difficult to determine the state of cutting tools where these are required to be re-sharpened or replaced. The excessive presence of surface defects increases production costs and consumes qualified human resources for repairs. The challenge for this project was, therefore, to investigate the possibility of integrating state-of-the-art optical sensors in running production lines. Such sensors should scan the generated surface topography in-line or on-line, assuring autonomous operation and continuous data acquisition. Use of the sensor-derived data was to both:

- alert operators about presence of surface defects resulting in the wood cutting process, and
- determine optimal time for replacement of the cutting tools, assuring compromise between long service life of the tool itself and superior surface quality of products.

This manuscript presents some of the preliminary results obtained during a pilot industrial test, together with a prototype software solution developed for analysis of the data provided by the surface roughness sensor.

MATERIALS AND METHODS

Triangulation sensors

Three alternative sensors were identified for testing in order to verify their suitability for determination of wood surface topography in the industrial environment:

- Keyence LJ-7200 (scanned profile width: 62 mm, surface pixel width: 0.10 mm)
- Keyence LJ-7080 (scanned profile width: 32 mm, surface pixel width: 0.05 mm)
- Keyence LJ-7020 (scanned profile width: 7 mm, surface pixel width: 0.01 mm)

All sensors were equipped with similar CCD detectors but differed with optical components arrangement. As a result, with increasing of the scanning width, the spatial resolution (along the scanned profile) was reduced as well as accuracy for determination of the minute surface irregularities, such as wood anatomical components. Figure 2 presents an example of surface profiles acquired by three sensors from the same wood sample (in slightly different positions along the piece). It is evident that LJ-7200 covered a very wide part of the object, but the surface definition was relatively poor, especially when compared with LJ-7020. This disqualified the wide range sensor for further investigations of surface roughness assessment. However, this sensor has been identified as an optimal quality control tool for the accuracy of profiling complex frame shapes used in window production. Both LJ-7080 and LJ-7020 sensors were selected for further tests and integrated with production lines.

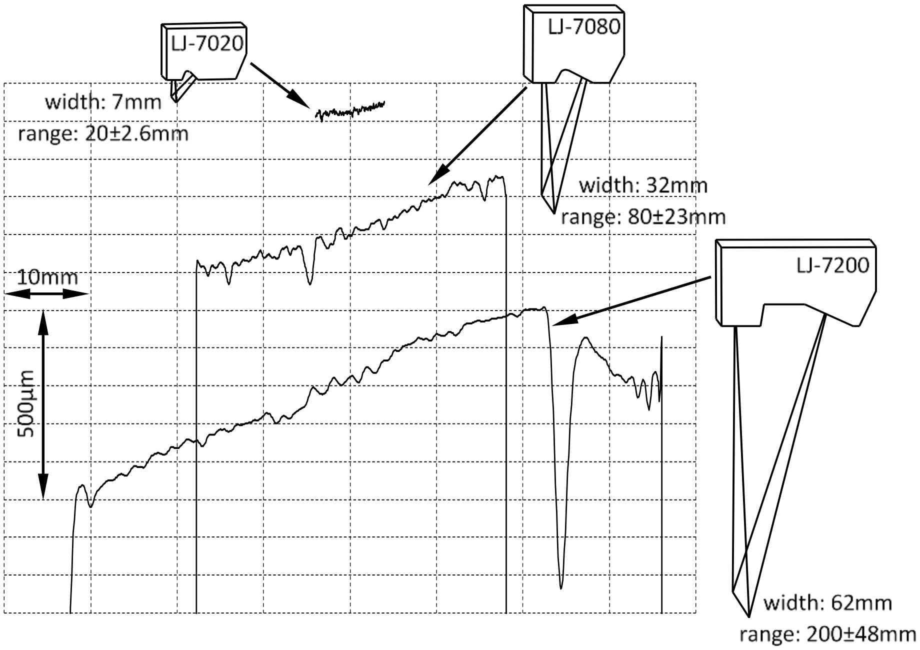


Figure 2. Examples of wood surface profiles acquired with tested sensors; Keyence LJ-7020, LJ-7080 and LJ-7200.

The scanning frequency of the triangulation scanners varied between 200 Hz and 2000 Hz, depending on the expected scanning density and available data for post-processing. Further increase was possible (top scanning speed = 16 µs/62.5 kHz), but, in that case, the spatial resolution of the surface maps decreases.

Two optional placements for the roughness sensor were recognised in the production line of the window producing factory:

- in-line: installed directly after the final planning head of the profiling moulder and before the water wetting station, and
- on-line: on the conveyer transporting elements between operations.

Both options were tested during the pilot, providing important decision-making observations and a series of topography maps acquired during scanning of the real produced elements. The in-line option was superior from the reliability point of view, assuring very fast and direct detection of surface defects − linking the surface quality with a specific cutting tool. An important disadvantage was limited access to the sensor due to restricted space available in the machine. It is expected that the optical sensor has to be frequently inspected and cleaned from dust present iaround the cutting tools. The second obstacle for in-line implementation was the fact that, according to the technological process, the wood surface of window frame elements was wetted in order to raise any loose fibres before implementing other operations. The wetting process resulted in dramatic changes of the wood surface roughness itself [3].

The on-line option was identified as superior for the pilot testing as it allowed measurement of real production samples as well as pre-selected specimens containing specific surface characteristics. In this case, the belt conveyor was adapted as a sample feeder, while the roughness sensor was fixed to the conveyor's mechanical frame. The feed speed was set at 5 m/min, what corresponded to the real production speeds used in the window frame factory.

In both cases (in-line and on-line) the data from sensors were acquired properly and stored on the computer hard disk for further post-processing.

Model samples

The engineers supervising the production process in the window factory pre-selected a number of samples representing diverse surface quality grades corresponding to different production stages and examples of surface defects commonly occurring on the produced wooden elements. The samples included: raw resources arriving from the suppliers – before profiling, wooden elements resulting from planing with different configurations of the grain angles, elements after surface sanding, elements with repaired defects by means of filling, finished wooden frames, assuming different coatings, colours and number of layers. The identification as well as description of surface defects was conducted in collaboration with process engineers and operators. The most problematic surface defect highlighted was torn grain.

Software for data post-processing

The quantity of data generated during wood surface scanning with investigated sensors was very high, requiring development of dedicated software tools enabling real-time data acquisition and mining. Custom software was developed in LabView 2017 (National Instruments) implementing the algorithm presented in Figure 3. The data were acquired as a stream directly from the triangulation sensor controller. These were post-processed twofold:

- grey scale image was generated to simplify visualization of the surface topography, and
- data were processed scan by scan, determining standardized surface roughness parameters.

The surface images (maps) were used for further detailed analysis by means of open-source software Gwyddion (http://gwyddion.net), which allowed filtering, flattening as well as computation of

3D surface roughness parameters, among others. However, from the industrial implementation point of view, the second approach (profile-by-profile analysis) was more efficient. The raw set of data collected from the sensor was first filtered to remove border artefacts and spikes (very narrow and high data points far from the mean line). The error of form was also removed by extracting linear fitting of the surface profile points r_i. Root Mean Square roughness R_q parameter was then computed according to ASME B46.1-1995 and ISO 4287-1997, as presented in equation 1:

$$R_q = \sqrt{\frac{1}{n}\sum_{j=1}^{n} r_j^2} \qquad \text{(eq.1)}$$

The roughness value was then confronted with the threshold, and the alert to the operator was generated in case of frequent overpassing the limit. The final adjustment of both threshold and allowed limit overpasses was not performed as it has to be confronted with real production requirements in the case of future implementation of the system.

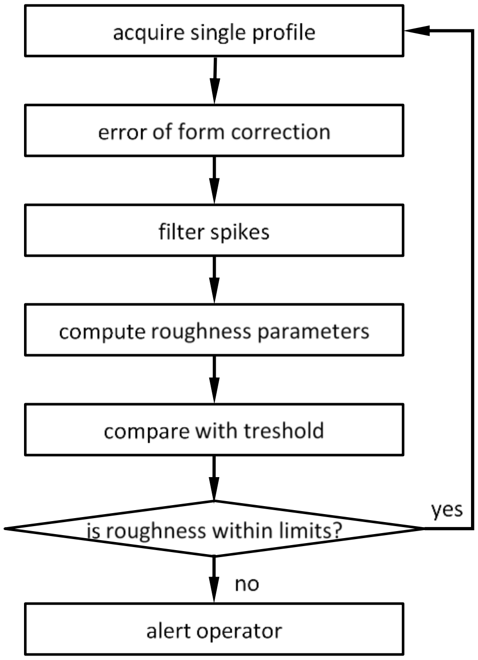


Figure 3. Algorithm for implementation of the simple monitoring system alerting machine operation about excessive surface roughness resulting from the machining process.

RESULTS AND DISCUSSION

A direct comparison of roughness profiles extracted for the 3D surface roughness maps for both sensors tested on-line is presented in Figure 4. It is evident that both provided very similar outlines of the profile, with LJ-7020 slightly more precise in representation of the short wavelength components. Both the spatial distribution of irregularities and these heights are perfectly matching. It indicates high suitability of both sensors for practical implementation.

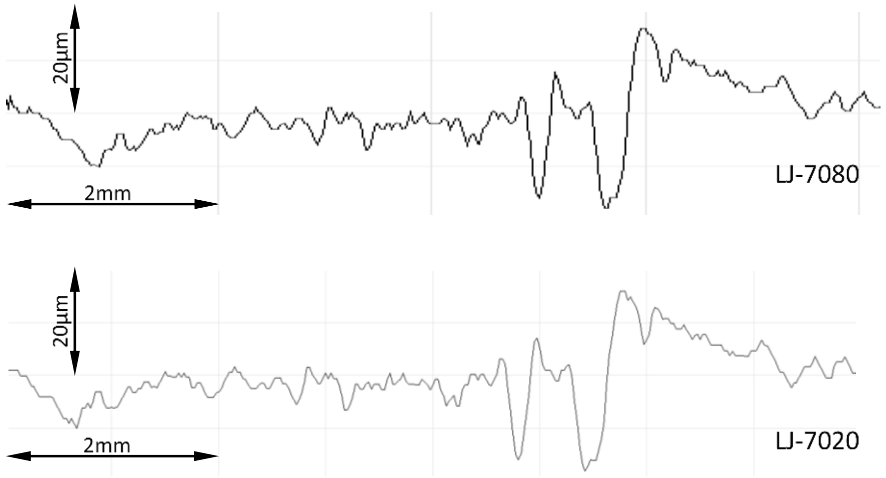


Figure 4. Comparison of surface profiles extracted from 3D map of painted wooden boards measured with Keyence LJ-7080 (top) and LJ-7020 (bottom).

The scanning frequency affects number of details (profiles) used for detection of surface defects. Figure 5 presents results from scanning of the same specimen with frequency of 200, 100 and 2000 Hz. The arrow corresponds to the same reference length. The spatial resolution is therefore 10 times higher in the case of 2000 Hz scanning, providing also 10 times more data to be processed in real-time. As the presence of torn grain was hardly detected on the 200 Hz scanning frequency, it was assumed that 1000 Hz was an optimal scanning frequency with 5 m/min feed speed of conveyor.

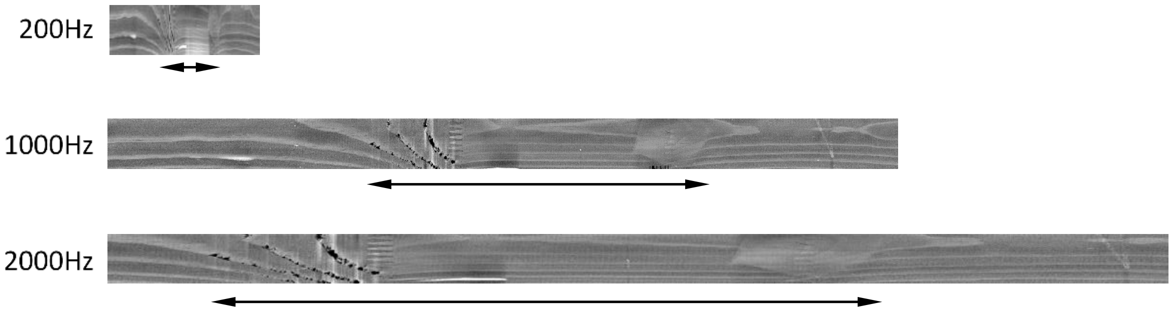


Figure 5. 3D surface irregularity map of wooden board including torn grain and filler scanned with different sampling frequencies and constant feed speed (5m/min).

Torn grain was the surface defect considered as most problematic for production managers. The specific characteristics of torn grain (void under the mean surface line of relatively high depth and width) allow automatic detection by simple thresholding of the surface image after filtering. Figure 6 presents an example of torn grain as sensed on-line with the triangulation sensor. It is also evident that the appearance of the surface profile corresponding to early and late wood differs. It is not clear, however, if the differences are affected by the anatomical structure topography or due to differences in laser light scattered on optically varying wood zones. Additional laboratory tests with benchmark references method are therefore required to ultimately define the triangulation sensors limitations.

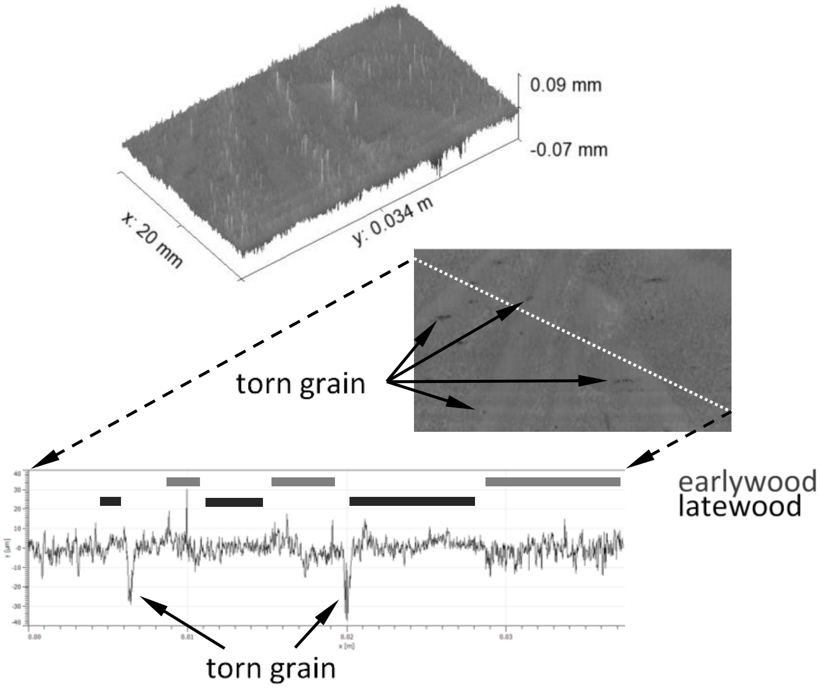
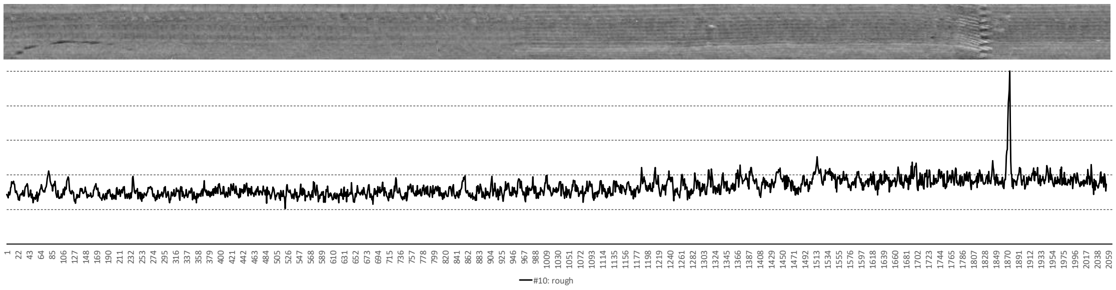


Figure 6. Torn grain identified on the 3D surface irregularity map of wooden board and on the surface profile extracted from that map (sensor LJ-7080).

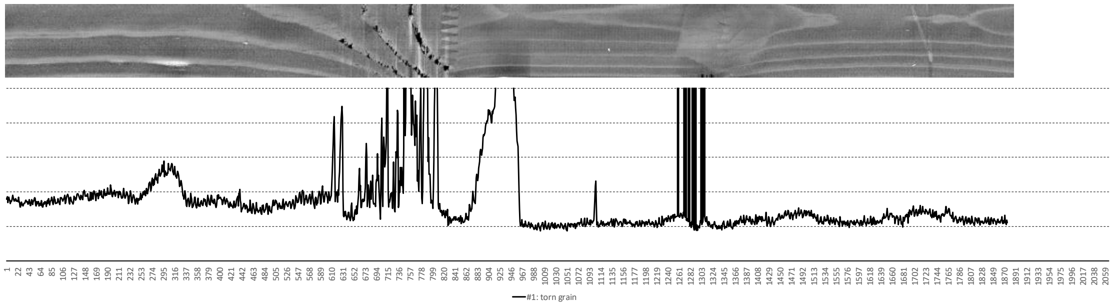
Other surfaces were also tested in the pilot installation, with some of the results summarized in Figures 7 and 8. The 3D surface map as generated on the basis of sensor readings as well as R_q roughness computed for each profile along the scanning length are presented for samples provided by the production managers. As already mentioned, it was rather evident to detect torn grain as these have high R_q values. The results follow expected trends, where following technological operations (with the exception of wetting) reduced overall roughness. The surface roughness of finished surfaces was smallest and most uniformly distributed along the sample length.

A comparative summary of these measurements is presented in Figure 9 as a histogram of R_q roughness determined for each sample. The roughest were rough planned board (#1) and excessive torn grain (#2), in contrast to the coated white sample (#8) with a single histogram peak in the lowest roughness bin. The histogram analysis was found as the most promising tool for real-time implementation of the on-line surface roughness measuring system. Again, final adjustments (setting the bin size, threshold level and its value) has to be defined case-by-case during routine operation of the scanner.

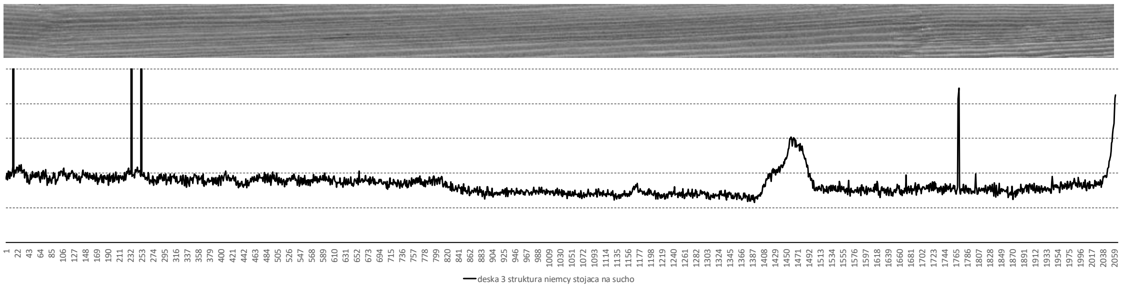
#1: rough planed board



#2: torn grain



#3: surface after wetting



#4: torn grain and sanding

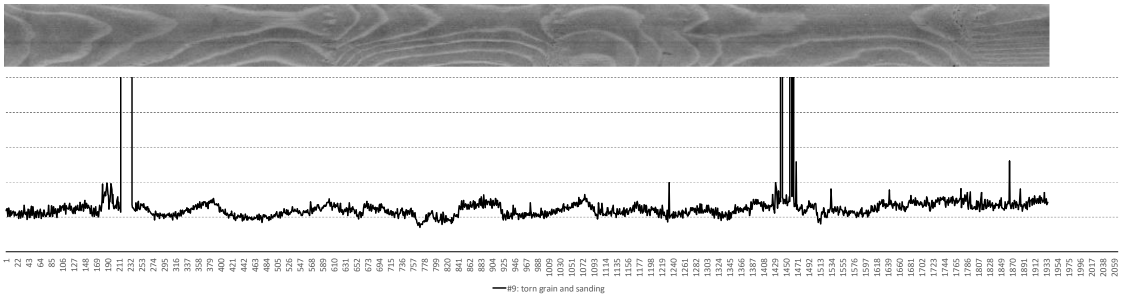
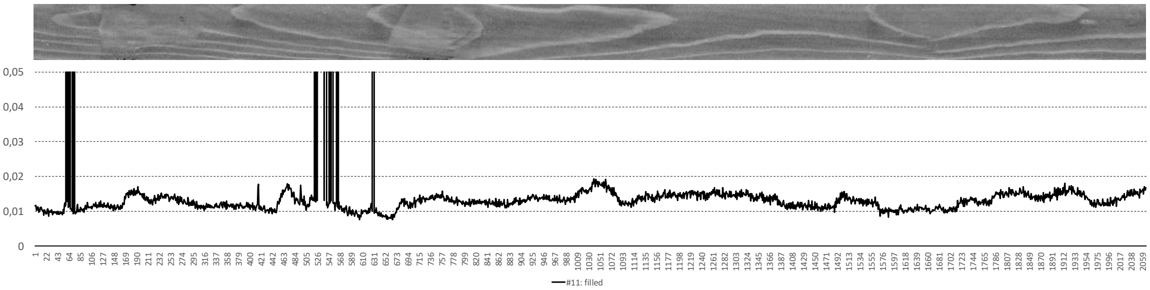
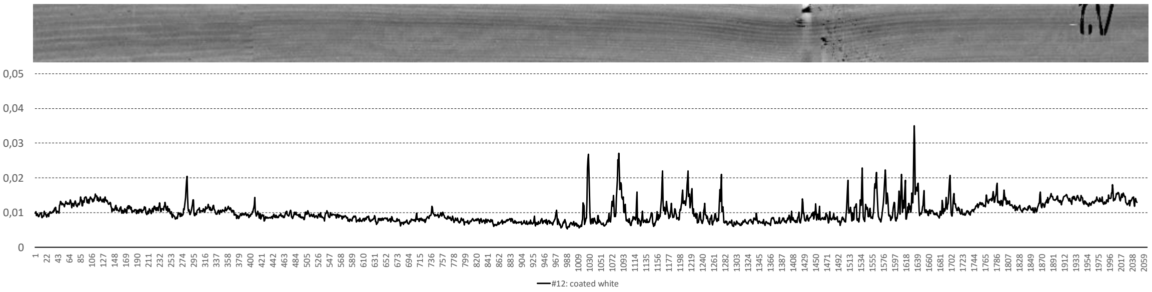


Figure 7. 3D surface irregularity maps and R_q roughness variation along the not-finished wooden boards scanned with Keyence sensor LJ-7080.

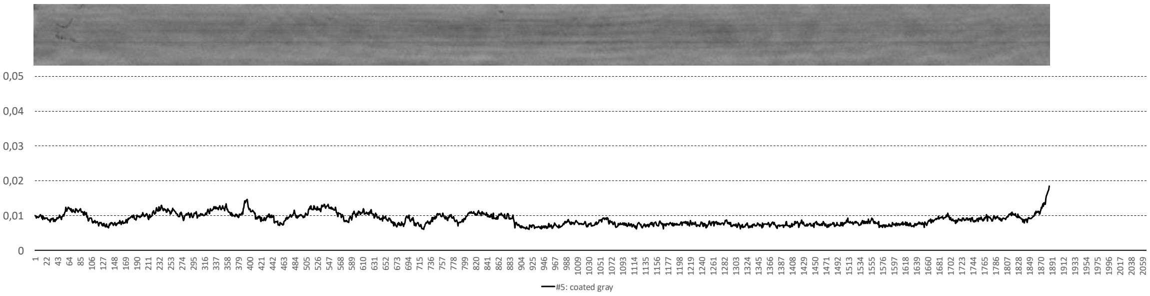
#5: sanded, defects filled with resin



#6: coated (white), with torn grain



#7: coated wood (gray)



#8: coated (white)

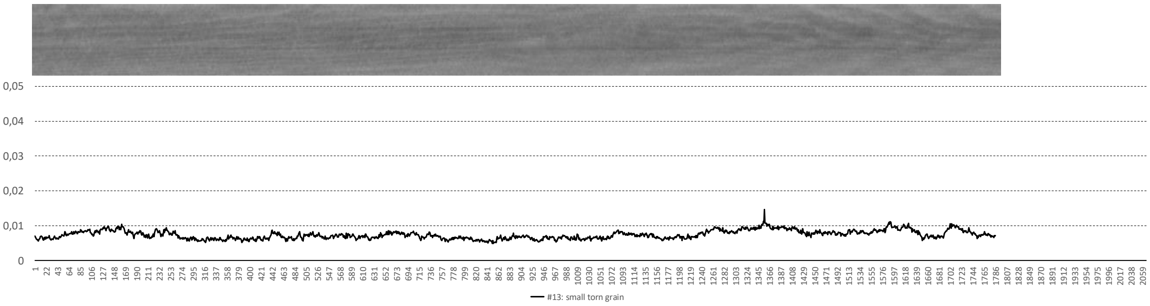


Figure 8. 3D surface irregularity maps and R_q roughness variation along the (semi) finished wooden boards scanned with Keyence sensor LJ-7080.

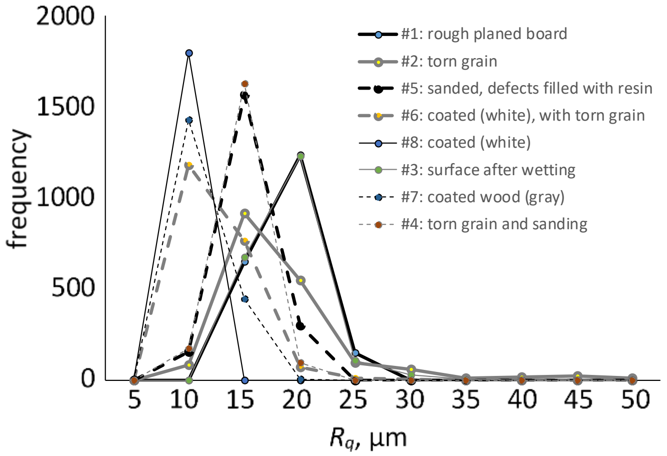


Figure 9. Histogram of R_q roughness parameters measured on-line with Keyence sensor LJ-7080 on different wood surfaces (feed speed 2m/min).

CONCLUSIONS

The research presented was triggered by discussion with production managers raising an emerging problem of wood surface roughness assessment in industrial realities. Optimal sensors for refined (Keyence LJ-7020) and accurate enough (Keyence LJ-7080) scanning of the wood surface topography were tested in an industrial environment in-line and on-line. Both sensors proofed its usability and were able to access surfaces of diverse qualities and finishing states. A simple algorithm for real-time data processing has been proposed and implemented as a prototype. The follow-up to this project is currently under development by creating a dedicated portable scanner for in-field inspection of produced elements with an optional integration to the processing lines.

ACKNOWLEDGEMENTS

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The anonymous window producer company and its production managers are acknowledged for allowing pilot tests on their production lines. Thanks to Keyence Europe, and especially Tomasz Michalski, for renting sensors and technical assistance during the pilot tests.

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