High Speed Surface Assessment of Wood and Wood-Based Composites

by

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ABSTRACT

Surface quality is an important concern in many areas of the woodworking industry. One of the focus areas of the Wood Machining and Tooling Research Program (WMTRP) is the development of on-line surface quality monitoring systems for wood machining applications. Through monitoring of surface quality, feed speeds, spindle speeds and tool changes can be optimized and the number of rejected parts can be minimized. One example of this would be making adjustments in process variables such as feed speed and/or spindle speed to maintain acceptable levels of surface quality as the cutting tool becomes worn. Currently, research at North Carolina State University on surface quality evaluation is divided into three categories: hardware (optimization of existing optical profilometer systems for wood machining applications); parameter extraction techniques (identification of the surface parameter set or sets that can quantify, characterize, and identify surface irregularities); and decision making schemes (which allow the end-user to make decisions on the state of the machining operation). One of the products of this research has been the development of an optical profilometer suitable for field use on woodworking machinery. This device utilizes a laser beam and lateral effect photodiode to measure the relative height of the wood surface. The on-line version of this optical profilometer system is currently intended for use as a tool in observing general trends in workpiece surface quality over the course of a production run and is not intended to categorize workpiece surface quality characteristics on a piece by piece basis. Advanced signal processing schemes are currently being investigated to enable the system to evaluate individual surfaces as to desired quality for inspection purposes.

INTRODUCTION

Surface quality assessment is an important quality control tool for manufacturing facilities including those in the woodworking industry. From a critical examination of the surface of the workpiece, the producer can determine the final product quality, general wear of the cutting tools, as well as errors that are starting to arise in the machining centers themselves. Through monitoring of surface quality, feed speeds, spindle speeds and tool changes can be optimized and the number of rejected parts can be minimized. One example of this would be making adjustments in process variables such as feed speed and/or spindle speed to maintain acceptable levels of surface quality as the cutting tool becomes worn. In addition, since wood is a highly variable material, the monitoring of the machined surface can alert the producer to variations in the workpiece such as reaction wood,
high moisture content, and cross grain in solid wood products as well as product quality deviations such as pitting in wood-based composites.

This paper describes the work that is in progress at the NC State University Wood Machining & Tooling Research Program. Work is underway in three areas: hardware (optimization of existing optical profilometer systems for wood machining applications); parameter extraction techniques (identification of the surface parameter set or sets that can quantify, characterize, and identify surface irregularities); and decision making schemes (which allow the end-user to make decisions on the state of the machining operation). One of the products of this research has been the development of an optical profilometer suitable for field use on woodworking machinery. This device utilizes a laser beam and lateral effect photodiode to measure the relative height of the wood surface. The on-line version of this optical profilometer system is currently intended for use as a tool in observing general trends in workpiece surface quality over the course of a production run and is not intended to categorize workpiece surface quality characteristics on a piece by piece basis. Work is underway to investigate the scanning techniques that may be required to insure complete information of the surface. This includes multiple sensors to detect and separate "edge effects" from the main surface, diagonal scanning to insure detection of directional defects such as tool marks and chatter, and "complete" three dimensional scanning. Advanced signal processing schemes are also currently being investigated to enable the system to evaluate individual surfaces as to desired quality for inspection purposes.

BACKGROUND

Much literature has been published on the need for and use of surface assessment systems. The reader is referred to the work by Whitehouse (1994) for a general discussion of the field of surface assessment. In addition, works by Lemaster and Dornfeld (1983), Lemaster and DeVries (1992), and Lemaster and Beall (1996) describe work that has been conducted previously on investigating the use of an optical profilometer to measure the surface texture of wood and wood-based composite products.

Hardware

The method used in this research is a variation of the reflectance method, whereby the positional change of the reflected laser light into the detector is correlated to changes in the test surface height. In this method, a laser spot is projected on the workpiece surface and the reflected light is focused on the surface of a lateral-effect photodiode. The change of the position of the reflected laser spot on the surface of the detector is correlated to the vertical height change of the workpiece. By moving a workpiece beneath the detector and recording the change in the position of the laser spot, a two dimensional surface profile is obtained that is very similar to that obtained by the traditional stylus system (Figure 1). The resulting surface profile is then analyzed according to traditional U.S. and international standards (ASME B461-1995). This method is non-contact, high speed, and since it measures position changes of the reflected light and not spot intensity, it is insensitive to color changes of the workpiece.
Previous work by the authors has utilized a component-type profilometer system. The new system is one of many commercial laser-based range finders that are currently on the market. A preliminary investigation found a good compromise between price, resolution, and scanning speed. Figure 2 shows a comparison between the laboratory-based profilometer and the commercial system.

The commercially available sensor that was chosen was the MTI Microtrak 7000 with the MT-600 sensor head. This head had a resolution of 5 µm (0.0002 in.) and a more diffuse laser “spot” measuring 150 x 250 µm. The other detectors typically had laser spot sizes in the order of 50 µm in diameter. None of the commercially available detectors had a laser line instead of a laser spot. In fact an added feature of many detectors was the smallness of the laser spot. Previous work (Lemaster, 1995) demonstrated that a laser line was more desirable than a laser spot because a laser line yielded a more regular surface profile from a surface with a periodic waviness pattern machined in the surface. This laser line acts as a “front-end” filter and is not as sensitive to wood structure and some fiber tearing. While there is probably an “ideal” laser spot/line size for each type of machined wood surface, there has not been any significant research conducted in this area. The MT-600 head yielded satisfactory results for waviness and some larger roughness surface
irregularities but could not distinguish between fine roughness details such as that found when comparing surfaces sanded with fine grit sandpaper. The detector had a scanning rate of 20 kHz.

Work has been conducted to determine the effectiveness of using this type of system in a variety of applications. Jouaneh et al. (1987) demonstrated the use of this system to measure warp and twist of pencil slats moving beneath the detector at 10 per second. Lemaster and Beall (1996) demonstrated the potential of using this type of detector for detecting surface defects in medium density fiberboard. Lemaster (1997) demonstrated the use of the system for solid wood.

Surface Descriptors

One of the major challenges of surface quality assessment is the quantitative evaluation of the surfaces. Many parameters have been investigated by other researchers. The literature is full of descriptors extracted from the surface profile that can describe the surface by function or form (Dagnall, 1986; ASME B46.1-1995). There is no single parameter or set of surface descriptors recommended for a particular application. The determination of the "best" parameter or set of parameters to evaluate a given surface is often derived by tedious trial and error. Because of the tediousness of the procedure, many producers keep their analysis techniques proprietary. What has resulted is many surface descriptors with no recommendation as to which parameters to use. Whitehouse (1982) described a "parameter rash" that had occurred resulting in much confusion. He suggested the use of only a few parameters to reduce the confusion. In a similar article, Thomas (1981) stated that "the proliferation of redundant parameters was the historical consequence of the predominating influence of instrument manufacturers over users." He suggested a classification scheme consisting of an average roughness parameter, skewness, high-spot count, and extreme density for engineering purposes.

A similar but not identical set of parameters was chosen by the authors based on evaluation of the surfaces of many types of wood and wood-based products. A measure of the average roughness, $R_{aq}$, a measure of "extremes" $R_{t}$, a measure of whether the surface defects are above or below the average surface, skewness, $R_{sk}$, and a measure of the shape of the surface defects, $R_{kt}$. In addition, the authors use the power spectrum of the surface profile to detect any "periodicity" in the surface such as tool marks or scallops. This approach is suitable because a surface profile is often composed of both random and periodic components. The periodicity is often introduced by copying of the tool onto the workpiece or by the vibration of the tool or workpiece; whereas randomness is often introduced by the detachment of material from the workpiece (Staufert, 1979). Brock (1983) discusses the advantages and requirements of using analysis for a variety of surfaces. Ber and Braun (1968) have also shown that the power spectral densities of surfaces obtained by turning, grinding, and lapping are dissimilar. The magnitude of the peaks in the power spectrum yield a measure of the periodicity as well as the wavelength of the periodic feature on the surface of the workpiece. This surface descriptor can tell an operator if a knife finish or multiple knife finish is present. Figure 3 shows a graphical definition of the parameters chosen for this research.
Figure 3: Graphical definitions of surface descriptors.

Surface Simulations.

To demonstrate the usefulness of these surface descriptors, a series of simulated surfaces are shown below with the resulting surface descriptors. Filtering was done to separate the longer wavelength "waviness" from the shorter wavelength "roughness". The bandpass filters were set from 3-14 marks per 25 mm for the primary waviness ($W_1$), 15-30 marks per 25 mm for the secondary waviness ($W_2$), 30-50 marks per 25 mm for the primary roughness ($R_1$), and greater than 50 marks per 25 mm as the secondary roughness ($R_2$). Figure 4 shows a plot of a sawtooth wave similar to what could be generated from a standard circular sawblade. Figure 5 shows the same wave with a random component added to it to simulate fuzzy grain. Figure 6 shows the same multiple waveform as shown in figure 5 but with a localized surface defect such as torn grain added to it. As can be seen from the surface descriptors shown in each plot the $R_{q2}$ could more readily detect the occurrence of the fuzzy grain while the $W_{tm1}$ was more sensitive to the simulated torn grain. The primary skewness ($W_{sk1}$) showed that the surface with "tearout" had a greater negative skewness than the other surfaces. This meant that a "below the surface" defect was present. In addition, the frequency domain showed that the surface had a "periodic" pattern with a frequency of occurrence of 10 tool marks per 25 mm.

Figure 4: Simulated Sawtooth Wave and Resulting Frequency Plot.
Moulder Tests

In a series of laboratory experiments, wood samples were generated on an industrial moulder (Weinig Model 22A). The moulder is a feed through type machine which operates at feed speeds in the 8 to 48 meters per minute range and has a cutterhead spindle speed of 6,000 RPM. The machine is equipped with five horizontal cutterheads. The commercial detector was mounted on a portable stand that is not connected to the moulder. This arrangement has the advantage of being “de-coupled”, in terms of vibration, from the moulder. The stand can be arranged so that the specimen being scanned has already exited from the cutters so that cutterhead vibration will not be transferred to the surface detector. The objective of the first series of test was to determine if the system could detect if the knives on the moulder had been jointed or not. The blades in the four knife head were sharpened and the head was installed in the moulder. Pre-dressed maple was fed through the moulder at a feed speed of 17 meters per minute. The specimens were scanned while being machined in the moulder. The blades were then jointed and another set of specimens were machined. Figure 7 shows surface profiles of the two cutting conditions. As can be seen, the
profilometer was able to detect the differences of the cutting conditions while the moulder was operating at industrial speeds. The knife marks that occurred at 3 and 10 marks per 25 mm disappeared once the blades were jointed.

![Figure 7: Frequency Spectra of Surfaces from Unjointed (A) and Jointed (B) Blades at Industrial Speeds (17 m/min.).](image)

The objective of the next series of experiments was to determine the ability of the surface quality evaluation system to detect changes in the surfaces of the workpiece caused by tool wear. Pre-dressed maple, 1 meter long, was fed though the moulder at a feed speed of 17 meters per minute. A four knife head was used but only one blade was sharpened while the other three blades were ground back (0.050”) to insure a single knife finish. After the head was installed on the moulder, four maple samples were machined and scanned. The knives were then worn by machining five particleboard specimens that were 2.5 meters long. After wearing the knives, four more specimens were machined and scanned. This was repeated until a total of 25 passes were completed. The surfaces were scanned over a distance of 200 mm, 20 mm away from the leading edge of the specimen. As the blade wore, the surface waviness decreased and the overall surface roughness increased due to chipping in the blade. Figure 8 shows a plot of the average $W_{q1}$ and $R_{q2}$ for the waviness and roughness of the specimens.

![Figure 8: Magnitudes of Surface Descriptors as a Function of the Number of Wear Passes.](image)
Multiple Scans

Other work that is underway by the WMTRP is the categorizing of different surfaces and the resulting surface descriptors into a Wood Surface "Atlas". This will allow industry and researchers alike to get a mental picture of the type of surfaces and the surface descriptors that can be expected from a variety of processes (i.e. moulding, sawing, abrasive planning), errors of processing (i.e. tool wear, cutterhead unbalance), and workpiece material (i.e. maple, oak, pine, particleboard, and MDF). This atlas will contain the micrograph of the wood surface, a 3D scan of the surface, a 2D profile of the surface, a frequency plot, as well as a summary of the resulting values of the surface descriptors. Figure 9 shows a 3D plot for a particleboard sample that had a ridge (snake) occurring along its surface due to a piece of metal in the particleboard. The 3D scan consisted of 16 profile scans spaced 0.25 mm apart. From the figure, the ridge is clearly visible along with a large peak caused by the metal particle reflecting the laser light.

![Figure 9: 3D Plot of a Particleboard Sample With a Ridge Along the Surface Caused by a Metal Particle Imbedded in the Surface.](image)

Decision Making Schemes

Continuing work at North Carolina State University is also addressing the issues of what inspection or business decisions to make regarding surfaces that have been analyzed. The decision of "accept" or "reject" is one that researchers have found to be highly subjective. Typical acceptability thresholds are defined by the end-user and are often adjusted to meet changing business criteria. A historical trending system for process monitoring and individual part inspection is currently under development. A traditional control chart scheme has been adapted and modified for use in a red - yellow - green system of reject – consider further - accept, where thresholds are settable by the end-user. The system is software driven and has been designed to offer as much flexibility as possible to the user with regard to which parameters to monitor and the basis for monitoring. It is expected that further development will continue to make this product even more accessible and customizable to fit the needs of an ever more competitive industry.
SUMMARY

This paper illustrates some of the work that is currently underway to develop an online surface quality assessment system. Tests have shown that this system is capable of detecting, characterizing, and quantifying a variety of surface defects from a variety of wood and wood-based composites. Field trials are currently underway to help manufacturers customize the set of surface descriptors as well as establish the acceptance criteria that will be used in the statistical process control portion of the system to alert the manufacturer when an unacceptable condition has occurred.

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LITERATURE CITED


