Improved log sorting combining X-ray and 3D scanning – a preliminary study

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ABSTRACT

Quality sorting of sawlogs is becoming more and more common. This is the result of increasing production of customer specific products in combination with high raw material prices.

Today, log quality sorting is being based on either 3D or X-ray scanning techniques. Previous research has shown that sorting accuracy is improved when using multivariate models to combine variables from both 3D and X-ray scanners. There is however a potential of further improving the sorting if 3D and X-ray data are combined at an earlier stage; from the measured 3D shape a better estimate of the X-ray path lengths through the log may be found, thus enabling the calculation of a log density profile from the measured X-ray attenuation.

The development and evaluation of such a technique is the topic of current research at SP Trätek and Luleå University of Technology in Skellefteå. Preliminary results show that the method is good at calculating large scale properties such as heartwood content and heartwood and sapwood densities. When looking for smaller geometric objects, e. g., knot whorls, extra care must be taken so that observational errors from the 3D scanner do not compromise the X-ray data.

Software simulating industrial X-ray scanner data from CT-scanned logs has also been developed. A very good agreement was found between simulated data and actual data from an industrial installation. This underlines that such a simulation tool is very valuable when developing algorithms for industrial X-ray scanners.

INTRODUCTION

Grounds for quality sorting of sawlogs

For a long period of time, sawmills have had a strong focus on productivity. The standard methods of improving profits has been either making efforts to improve volume recovery or increasing the volumes of sawlogs passing through the mill. Today, the competition for sawlogs is fiercer and raw material costs are rising, comprising an increasingly large amount of the total costs of the mill.

Consequently, it is has become ever more lucrative for sawmills to focus on value recovery and quality of sawn products rather than just outgoing volumes. One way of doing this is sawing products carrying specific combinations of dimension and grade, better corresponding to customer demands and thus yielding better value. In order to achieve this, keeping an efficient raw material use, it is important to get it right from the beginning, identifying the right sawlogs for each product; hence quality sorting of logs before sawing is becoming more and more common.

Quality sorting using optical 3D scanners

Quality sorting of sawlogs requires the ability to predict quality of sawn goods from log measurements. Many sawmills already sort the timber based on length and diameter measures obtained from optical three-dimensional (3D) surface scanners (Figure 1). These scanners also yield information about taper, bumpiness and other variables that may be used to estimate the log quality (e.g. Grace 1994, Jäppinen and Nylinder 1997, Oja et al. 1999). Such predictions, using partial least squares (PLS) modelling on 3D data in the quality sorting software Kvalitet On-Line (Anon. 2007*b*), has proven successful and become widely spread in Sweden.

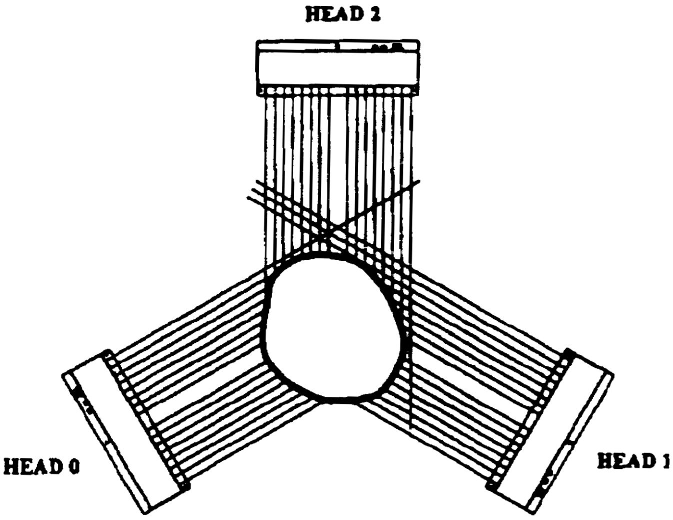


Figure 1. Schematic description of an optical 3D surface scanner (Dashner 1993).

Quality sorting using X-ray scanners

Still the quality information obtainable from 3D scanners is limited, since it is based solely on outer shape properties of the log. An extensive evaluation (Grundberg et al. 1990) of different measurement techniques showed that inner properties of logs are best measured using X-rays.

X-ray scanning by computed tomography (CT) is too slow for industrial applications but may be used to obtain precise measurements of wood density (Lindgren 1991). The high quality images captured have proven very useful for research purposes, e.g., the Swedish pine stem bank, a collection of CT images gathered by Grönlund et al. (1995).

In order to improve speed, industrial X-ray scanners only use a limited number of fixed measurement directions (e.g. Aune 1995, Grundberg and Grönlund 1995). Many authors have developed algorithms analyzing images from such detectors, including calculation of knot structure (Pietikäinen 1996), annual ring width (Wang et al. 1997), outer shape (Oja et al. 1998, Skatter 1998) and strength of sawn products (Oja et al. 2005). Figure 2 shows the principle of a successful two-directional X-ray LogScanner for Scots pine (*Pinus sylvestris* L.) developed by Grundberg and Grönlund (1995), being in use at seven sawmills as of October 2007. Today the use of X-ray scanners is increasing and, likely, more installations will follow.

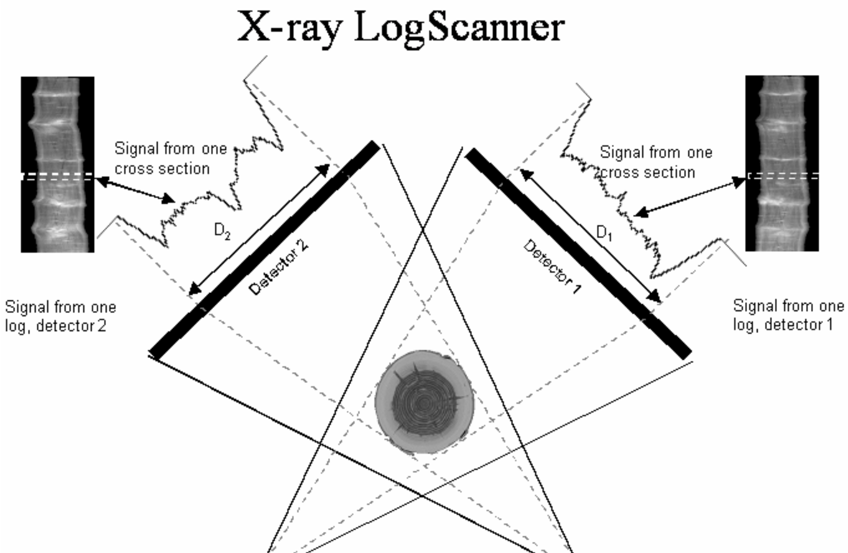


Figure 2. Schematic description of the X-ray LogScanner developed by Grundberg and Grönlund (1995), image from Oja et al. (1998).

Quality sorting combining X-ray and 3D scanners

Oja et al. (2004) made a comparison between the grading performances of X-ray and 3D scanning techniques and also investigated possible benefits from using a PLS model combining parameters from both methods. The study showed that 57% of sawn boards were correctly graded when using 3D scanning, 62% when using X-ray LogScanner and 66% when combining data from both scanning methods. The highest possible result, with ideal log grading, was 81%. The study concludes that the combination of 3D and X-ray scanning seems very promising and suggests that future studies should focus on fully utilizing the possibilities of combining the two techniques. The combination could also be expected to give better diameter measurements, joining the ability of the X-ray LogScanner to handle varying bark thickness with the ability of the 3D scanner to handle irregularly shaped cross-sections (Oja et al. 1998). Yet another reason for investigating the benefits of such a combination is that a 3D scanner is already present at most mills installing an X-ray LogScanner, and thus do not present any substantial extra investment costs.

By combining raw data from 3D and X-ray scanners at an earlier stage it would be possible to obtain improved density profiles of the logs. A density profile of the log can be obtained if the LogScanner signal is compensated for the varying travel path lengths of the individual photons through the wood (Grundberg et al. 1990). The best travel path compensation is found from the real shape of the log, which in practice is not known. Instead, algorithms developed should use the best shape information available, namely the shape measured by the 3D scanner. The hypothesis is that such a combined technique would lead to improved assessments of heartwood and sapwood densities and would allow for better identification of, among other things, heartwood content, knot whorls, annual ring distance and rot.

The aim of this study is consequently to develop algorithms combining X-ray and 3D data using travel path compensation and to evaluate whether the methods developed have a potential of improving quality sorting at sawmills.

MATERIALS AND METHODS

Data collection

In order to enable the development of quality sorting algorithms based on 3D and X-ray data, it was an essential first step to collect a well defined data set. A large sawmill in the north of Sweden, which had recently installed a one-directional LogScanner, was chosen as host for the project and a total of 435 Scots pine sawlogs, originating from 13 different diameter classes in the range of 150 to 300 mm, were picked out. Each log was individually ID marked and had its top heartwood diameter and annual ring distance manually measured. The logs were then sent through the log sorting station, where data from the RemaControl X-ray LogScanner and the MPM Engineering 3D surface scanner were recorded.

Once all available log data had been collected, the logs were sawn using suitable 2X-patterns, forming a total of 870 centre yield planks. The grades of the sawn planks with respect to knots were established manually by the mill’s lumber grader as well as automatically using a FinScan Boardmaster equipment. Eventually, the dried planks were sent to a finger jointing facility where their knot free zones were determined.

Combining 3D and X-ray data using travel path compensation

The development of algorithms combining raw data from the 3D and X-ray scanners using travel path length compensation and was performed using MatLab 7 (Anon. 2007*c*) and Visual Studio 2005 (Anon. 2007*a*).

Data were combined on cross-section level according to the principle shown in Figure 3. For each X-ray cross-section, the corresponding 3D cross-section was located and inserted into a simulation model of the X-ray scanner. Since both scanners are located along a common carrier line, right next to each other, it was assumed that the rotational position of the logs did not change between the scanners.

Vibrations do however introduce an uncertainty in the exact horizontal and vertical position of each cross-section. Thus the positions of the 3D cross-sections are being individually adjusted in order to achieve best possible matching with X-ray cross-sections.

Once the 3D cross-section has been properly positioned in the simulation model, the travel path lengths through the wood for photons hitting each detector pixel are being calculated. With knowledge of the radiated X-ray spectrum as well as the absorption and travel length along each ray path, the average density at each ray path is being calculated (cf. Grundberg et al. 1990) and arranged together as a density profile of the cross-section.

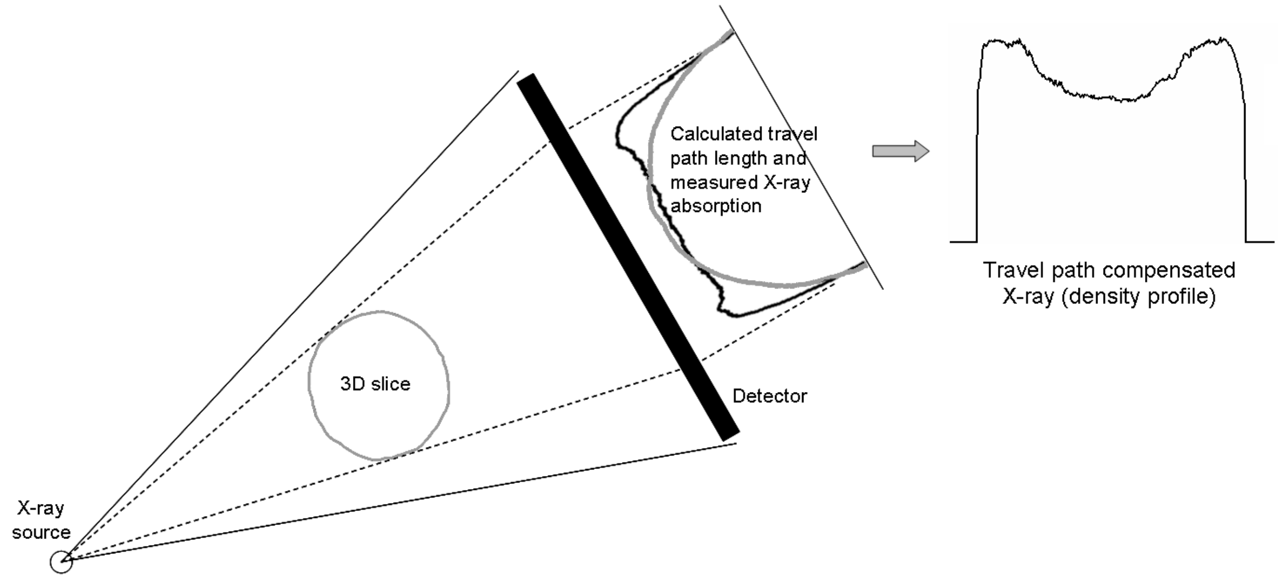


Figure 3. Principle for density profile calculation from an X-ray (black) cross-section and a 3D (gray) cross-section. The 3D cross-section is inserted into a simulation model of the X-ray LogScanner and the travel path lengths through wood of photons hitting each detector pixel are calculated (gray). A density profile may then be found by combination of measured X-ray absorption and calculated travel path length.

Simulating an X-ray LogScanner from CT data

In order to validate the travel path algorithms and the density profiles calculated, as well as to allow for further algorithm development classifying knot whorls, rot and other internal artefacts, well defined source data is essential. A data set suitable for this purpose is the Swedish pine stem bank, a collection of more than 600 CT-scanned Scots pine logs. These logs are well defined regarding knot structure and other quality parameters and CT images are available for every 10 mm of the log.

When developing the X-ray LogScanner, Grundberg and Grönlund (1995) wrote algorithms that could simulate LogScanner data using CT images from the Swedish pine stem bank. The implementation however had become obsolete due to computer platform change and due to higher resolutions now being available for both CT images and LogScanners. Thus a new simulation code was written, better suited for the demands of this project.

The new simulation code was verified by the X-ray scanning of a knot rich sawlog at the host sawmill. The sawlog was then brought to the tomography lab at Luleå University of Technology in Skellefteå where it was scanned with the same settings used for the Swedish pine stem bank. Rotational position of the log was kept track of, so that it could be scanned at the same position in both equipments. LogScanner data could then be simulated and compared to the data actually collected at the sawmill. The access to the full set of CT, X-ray LogScanner and 3D data for the same log also allowed for comparison between calculated density profile and actual density of the log.

RESULTS AND DISCUSSION

Travel path compensation

The study presented in this report has focused on the development of algorithms that combine raw data from 3D and X-ray scanners at an earlier stage in order to obtain improved density profiles of the logs. A comparison between raw X-ray LogScanner data and travel path compensated data is shown in Figure 4. A preliminary evaluation of the method show advantages as well as disadvantages of performing calculations on travel path compensated data rather than raw data.

Great advantages include the possibility to compensate for log shape irregularities and that the method enables direct reading of density from the images. This should make it easier to compare logs of different sizes and facilitate the development of general algorithms. It should also be easier to determine the heartwood border and the heartwood content and better measures of heartwood and sapwood densities can be expected.

The main difficulty lies in the step of finding the right 3D shape for a given X-ray cross-section. Firstly, there is some uncertainty in the identification of correct 3D cross-section and secondly there is also an uncertainty in the exact position of the log at the X-ray scanner. Furthermore the method transfers measurement errors from the 3D scanner into the X-ray data, e.g., an underestimate of the log diameter would cause an overestimate of the density profile of the cross-section. For this reason, extra care must be taken when looking for small artefacts ranging over a few slices, such as knot whorls, so that any localized measurement errors do not compromise the data.

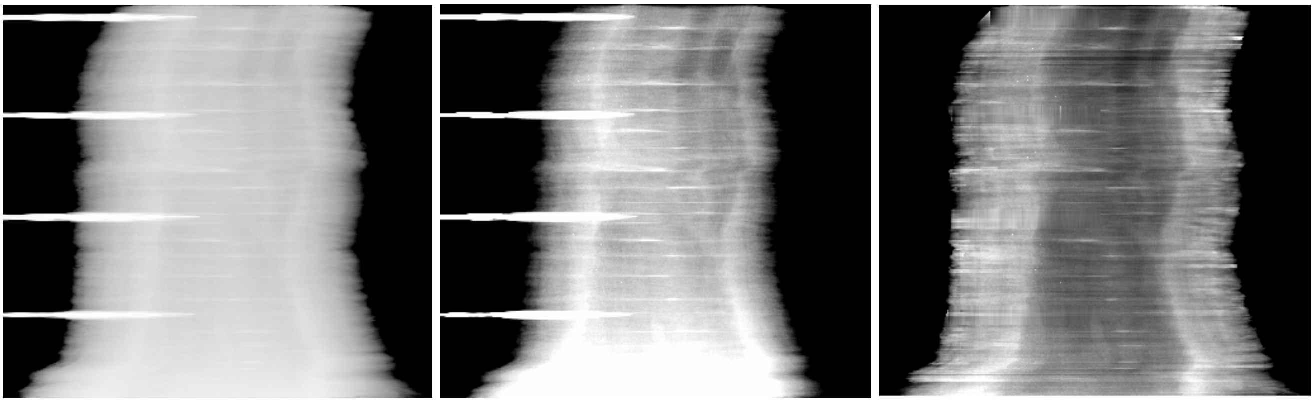
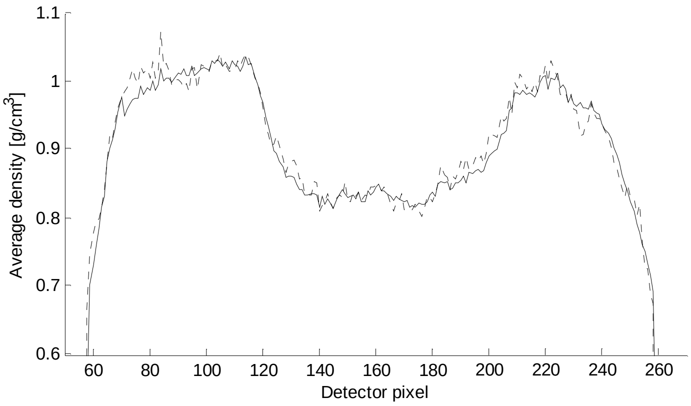


Figure 4. (a), (b): Raw LogScanner data, X-ray absorption depends on density as well as travel path. (a) shows the full data range whereas (b) shows a zoomed data range, better exposing internal artefacts as well as the varying absorption along the log due to varying diameter. (c): Travel path compensated LogScanner data showing the density profile of the log. Uncertainty in the combination of 3D and X-ray data can be seen as bright or dark radial lines at the edge of the log, where the relative uncertainty of the travel path is greatest.

Density calculations

Figure 5*a* presents a density profile of a single cross-section within the log as well as an average over five neighbouring cross-sections. The average green density along a ray path in the sapwood area of the log is 1.0 g/cm^3, which corresponds quite well to the true green density measurements obtained from the CT image (Figure 5*b*), ranging from 0.90 g/cm^3 (inner sapwood) to 1.0 g/cm^3 (outer sapwood).



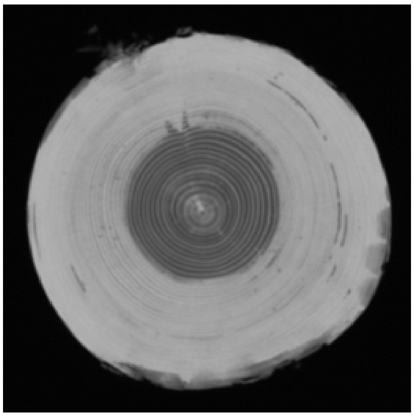


Figure 5. (a): Green density profile of a log cross-section, the dotted line shows a single cross-section and the solid line shows an average over five neighbouring cross-sections. (b): CT image showing the corresponding log cross-section. Dark pixels represent low density while bright pixels represent high density.

The average green density, ρ_a, along rays passing through the heartwood area of the log is around 0.83 g/cm^3. This figure is a combination of heartwood, ρ_h, and sapwood, ρ_s, densities along the rays:

$$\rho_a = h \cdot \rho_h + (1 - h) \cdot \rho_s$$

The difficulty lies in finding a good estimate of the percentage of path being travelled through heartwood, *h*. The algorithm finding this percentage is yet to be completed but preliminary calculations may be performed using estimated values. Looking at the density curve (Figure 5*a*), heartwood diameter can be estimated to be around 45% of the total diameter (90 pixels vs. 200 pixels). Thus, green density of heartwood close to the pith would be around 0.62 g/cm^3. For a ray passing further out from the centre of the log, e. g., having an *h* value of 33%, heartwood green density would be about 0.48 g/cm^3. Measurements within the CT image reveal a true heartwood density ranging from 0.50 g/cm^3 close to the sapwood up to 0.60 g/cm^3 close to the pith.

Although being performed only at a single position of a single log, these preliminary calculations suggest that green density values obtained by the method are not unreasonable. Further material for testing may be obtained by CT-scanning small parts of industrially scanned logs or by simulations from the stem bank (see below).

LogScanner simulations from CT

Figure 6 shows a comparison between industrially gathered and simulated X-ray LogScanner data, the agreement between the images being very good. This strongly supports the stance that simulation of LogScanner data from well defined CT images is a suitable method of obtaining source data for the development of X-ray LogScanner algorithms.

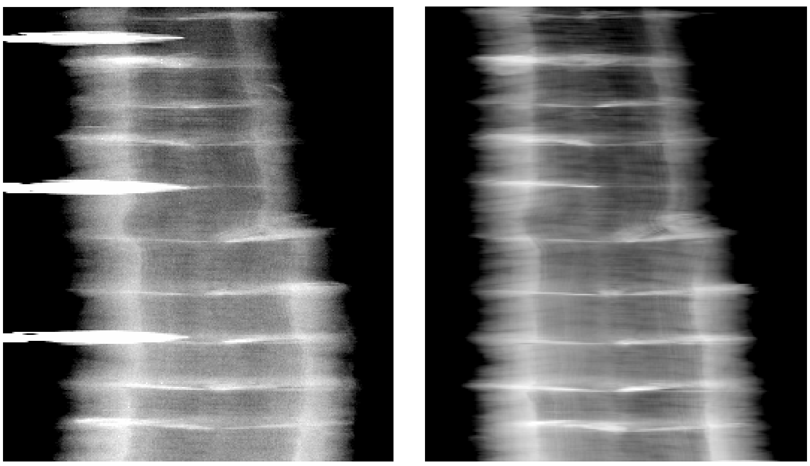


Figure 6. LogScanner data from an industrial installation (left). LogScanner data simulated from CT images (right).

CONCLUSIONS

This preliminary study has concluded that the combination of X-ray and 3D data using travel length compensation is a very promising technique for determining a density profile of the log. The technique will also facilitate the development of general algorithms for characterization of inner properties of sawlogs.

Preliminary green density values obtained for both heartwood and sapwood seem reasonable. However, more work need to be spent on development of rigorous methods for finding the heartwood density and final algorithms must be tested on a larger data material.

It has also been concluded that X-ray LogScanner data simulated from CT images well correspond to data from actual industrial installations. Even though being unaffected by vibrations and other disturbances experienced in industrial environment, such simulations constitute a very good tool for the development of X-ray LogScanner algorithms.

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