# OVERVIEW ON SENSING TECHNOLOGIES FOR REAL-TIME MONITORING OF WOOD PROPERTIES

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Forests are a natural resource of major economic significance to the world. In addition to direct employment, the wood industry has an indirect effect through demand for goods and services (particularly in rural areas) and diversifies income sources for many communities. In current wood manufacturing operations, knowledge and measurement of wood properties are essential to ensure that the right fiber is directed to the appropriate wood manufacturing company at the right time and the right cost to produce the right product. In order to accurately control the product quality before or during processing, there is the need of systems able of real time monitoring of wood properties. Among all the quality-related wood properties, wood density and wood moisture content are two of the most important, because they affect the efficiency of manufacturing processes. For example, moisture content (MC) data can be used to optimize log inventory management. Also measuring MC in the forest before hauling the wood to the mill allows reduction in transportation costs by avoiding transportation of unnecessary water. Density is related to stiffness and can be used to maximize fibre quality when bucking. Wood properties should be monitored not only in the plant, but also in the mill yard under variable environmental conditions. The paper presents the test of five sensing systems for in-line MC and density estimation of thawed and frozen logs as well as of boards. The first one is a near infrared hyperspectral imaging (NIR-HSI) system. The second one is a near-infrared (NIR) spectrometer. The third one was a time-resolved NIR transmittance system. The fourth one was a ground penetrating radar (GPR). The fifth was a unilateral magnetic resonance (UMR) device. The first one has the advantage of providing directly a 2D image of the wood sample, but it is not portable by contrast to the other systems. The best system for moisture content measurement is the UMR device, which allows also differentiating between bound and free water and which can be used on logs with barks. However, this technology is not yet operational as commercial systems still need to be designed. Also it requires a metal-free environment to operate and it cannot be used on frozen material. Except for the UMR device, estimation of MC and density was done through using partial least squares (PLS) regression models. MC was best predicted using the GPR (with a root mean square error [RMSE] of 7% and a coefficient of determination [$R^2$] of 0.95). The GPR has also the advantage to produce deep measurements because of its long wavelength and to be used without debarking the logs. The density parametrized as basic specific gravity (BSG) was best predicted using the NIR spectrometer (RMSE = 0.019, $R^2$ = 0.78). Air-dry density was estimated with a RMSE of 0.047 g. $cm^{-3}$ ($R^2$ = 0.56) using time-resolved NIR transmittance device and one single wavelength (846 nm). With the imaging system, the images were subject to a new processing method. They were first calibrated into reflectance. Then, bad pixels were found and replaced by a corrected value using a median filter. A new method was developed to find and remove abnormal spectra. It consisted of a combination of the *boxplot* method and principle component analysis (PCA). The remaining spectra were converted into absorbance spectra to be used in the PLS modelling. The best PLS model for both MC and BSG estimation was produced with the boards and by using raw spectra. They had an $RMSE_V$ of 10.8% and 0.007, respectively. PLS models were better with thawed logs than with frozen logs. PLS discriminant analysis (PLS-DA) was also applied to the GPR and NIR data for sorting log samples into three MC or BSG classes, species, or the log state (frozen and thawed). The overall accuracy of PLS-DA models were above 72% for both MC and BSG sorting and above 85% for the species and log state sorting. This paper shows that portable sensors based on various technologies could be used to determine wood properties. Such sensors could be used to reduce energy consumption, reduce waste, increase product quality and decrease production costs in the wood industry.