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主　論　文　の　要　旨

論文題目　Construction of combinative nondestructive measurement system for wood properties
（木材物性に関する組み合わせ非破壊計測システムの構築）

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論　文　内　容　の　要　旨

According to “Annual Report on Forest and Forestry for FY2016”, the report indicated that sugi (Japanese cedar) and hinoki (Japanese cypress) are the key planting trees in planted area/tree species in 2015. Nowadays, the price of wood product is increasing as the forest resource is decreasing. How to use wood with its best advantage and most effectively in engineering applications is still a crucial issue. Various approaches have been developing to evaluate the properties of wood including the destructive and non-destructive methods. The moisture content and density are also the major characteristics that affect to the wood’s application and use. Capacitance sensor and near infrared (NIR) spectrometer are becoming popular for wood material. Both techniques are nondestructive, rapid and without sample preparation; however, they have limitations. Capacitive sensors are not the fastest technology and can be slower than competing technologies. NIR spectroscopy has problems with a large data required calibration. Therefore, the purpose of this study was to investigate two devices and conducted analyses to achieve the best value regression model to develop a better procedure for experimentally assessing the density and moisture content (MC) of veneer and timber.

Research 1: Predicting the moisture content and density of veneer by combining of Capacitance sensor and NIR spectroscopy

The moisture predictability of veneers from the green to air-dried state is higher than that from fiber saturation point (FSP) to air-dried state. However, the result for estimating density is not significantly change between two range of MC sample. Generally, prediction for MC is higher than for density of veneers because capacitance sensor and NIR spectrometer based on the dielectric

property of wood and chemical components directly related to the amount of water within samples. The results vary to thickness of veneers with the highest accuracy being 6 mm thickness, a little lower in 12mm and 2 mm thickness. When predicting for the whole samples of all thickness, the results decrease lightly due to the extension of thickness variable. A significant point in this study, as comparing to two techniques together, capacitance method is lower than NIR technique, however, the prominent results achieve when combining these methods together. The accuracy is improved in each kind of thickness, as well for the whole sample of all thickness. This work was to highlight the potential of the NIR spectroscopy combined with capacitance sensor as a tool capable of providing useful information for researcher and industrial company assessing the veneer samples. This approach is rapid, high possibility for estimation of MC and density. It is possible to design a new protocol which would be combined capacity and NIR light at two wavelengths to predict the density and MC simultaneously for wood and wood-based materials.

Research 2: A new approach based on a combination of capacitance and NIR spectroscopy for estimating the moisture content of timber

This study demonstrates a new nondestructive approach for predicting the MC of timbers from the green to the air-dried state by coordinating wood capacitance and NIR absorbance at two informative wavelengths. Such an approach would be highly accurate, quicker, and involve simpler analyses based on a much-reduced dataset. This study employed MLR and PLS to build predictive models. Three calibrations were implemented from the data obtained by a capacitance sensor and NIR spectrophotometer, that data being processed individually or in combination. All calibrations achieved good results in [Green to FSP], yielding a high accuracy for coefficient of determinations in cross-validation, but the results in [FSP to air dried state] had the smaller standard error of prediction. In both of MC ranges and in all calibrations, the predictions on cross-section were higher than that on the tangential section because of the anatomical characteristic of wood material. New method was studied as combining the data of capacitance and NIR absorbance at two informative wavelengths, and the predictive models were developed under two kinds of functions: Multiple linear regression and Logarithm regression. This new calibration improved the accuracy in [Green to FSP], and NIR-PLS calibration was better in [FSP to air dried state]. Depend on the MC ranges, two functions (linear and nonlinear regressions) had the different performance in [Green to FSP], and it may not be statistically analysis in [FSP to air dried state]. This research provides the basis for a new analytical method for estimating MC of timber, as well as to assess other properties of wood and wood-based materials. It may be feasible to construct a new device which mainly consist from capacitance sensor,

two LEDs (to make the two-wavelengths), photodetectors and sensors. It will be suited to on-site or online applications in the future.

Research 3: The relationship between the capacity of wood, MC and density of veneer and timber for many wood species and the relationship of the 'slope' with oven-dried density

When using the capacitance to predict MC and density of wood, the results were affected by many factors like density, thickness, wood species, so on. One of parameter can show the relationship between the capacity, MC and density of wood together which is the slope. The slopes were calculated from the relationship between capacitance and MC under the linear regression, each species with its density value will correspond to one slope's value. Therefore, the slope can be represented for the influence of sample's density in prediction of MC. Different species commensurate to different slopes and had different coefficient of determination (R_2) in predicting MC. In this study, the relationship of slopes and oven-density from the thin to thick thickness of 14 wood species indicated that the best-chosen regression was logarithm function. Thinner samples of a specific species will be affected to the slopes much more than the thicker samples. Compare to density, higher density had lower slopes. On the other hand, the higher slope showed the stronger relationship between the capacitance and MC of wood. So, the slopes can be considered as one of significant parameter to show the relationship between the capacitance, moisture and density of wood.

General Conclusion

Capacitance sensor and NIR spectrophotometer are non-destructive, rapid and high accuracy applied to evaluate MC and density of veneer and timber with a good result. The predictability on the cross section was higher than the results on the tangential section because the anatomical structure of wood. From green to air-dried state, the accuracy prediction of veneer and timber is higher than the results of MC under FSP. When coordinating capacitance and NIR absorbance at two informative wavelengths achieved a better predictability compare to using devices separately. Besides, this way can overcome some drawbacks of each device. Capacitance, MC and density of veneer and timber can be evaluated through the 'slope' parameter. Higher slope stronger relation of capacitance and MC, thinner sample higher slope, heavier species smaller slope. From the above result, it suggests the new ideal for a new device which can combine the capacitance and NIR absorbance at two wavelengths, applying for measurement of MC and density of wood.