

NIR-SWIR-Hyperspectral-Imaging supported surface analysis for the recovery of waste wood

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Abstract Cascading of waste wood requires a concept for recovery of solid timbers from deconstruction as a source of clean and reliable secondary feedstock for new wood and wood-based products. An essential requirement for the re-use of wood is a sufficient quality of the near-surface areas that must be free of contaminations like coatings or any wood preservatives. Due to the absence of industrial established automatic testing and sorting methods the possible potential for material re-use of recovered wood in the sense of cascading is not utilized so far. Hyperspectral-Imaging (HSI) is a promising method to improve the situation. In the study on hand results according to detection accuracy and limitations of NIR-SWIR-HSI are presented. As input material solid waste wood (e.g. different kinds of hard wood, soft wood, wood with paint or other coatings, particle boards, and medium density fibreboards) obtained from deconstructions is considered. First, the spectral structures of some different kinds of wood and contamination are examined. Desired are the so-called fingerprints according to significant characteristics in the spectra. The results have been incorporated in a database as training set. For classification tasks some decision trees based on PLS-DA (Partial Least Squares Discriminant Analysis) were exploited. These decision trees are then passed to an industrial NIR-SWIR-Hyperspectral-Imager for generating chemical images of the contaminated wood samples. Results

of some sorting experiments are presented. The aim of the tests was to find the limits for sorting throughput and purity. The tests revealed that the spectral differences are mostly large enough for automatic wood classification and sorting operations even at presence of inorganic wood preservatives. In this case the detectability and accuracy of classification depends much on preservative concentrations.

Keywords: NIR-SWIR-HSI, recovered wood, sorting, recycling.

1 Introduction

Cascading use can be defined as the efficient utilization of resources by using residues and recycled materials to extend total biomass availability within a given system [1,2]. For wood this mainly requires a concept for recovery of solid timbers from deconstruction or demolition waste as a source of clean and reliable secondary feedstock for new wood and wood-based products [3–5]. The re-use of wood presupposes a sufficient quality of the near-surface areas that must be free of contaminations like plastics, coatings or any wood preservatives that are used to extend the service life by preventing biodegradation.

Due to the absence of industrial established automatic testing and sorting methods the potential for material re-use of recovered wood in the sense of cascading is not utilized so far as it would be possible. Waste wood of lower grades e.g. often is a mixture of wood particles with contamination and/or coatings and pure wood particles which could be used as high grade wood – if there were suitable techniques to sort out the particles of lower grade. In addition to cascading use of wood, the production of energy (or better conversion) by combustion of demolition wood – as it is still the preferred method to exploit this kind of waste in most countries – needs an effective presorting. When e.g. CCA treated wood is burned, the resulting ash contains high amounts of chromium, copper and arsenic, may posing an environmental problem [6].

Crucial steps in the re-use of used wood are detection and sorting out of above mentioned contaminated items. Powerful in-line methods are required to perform the task. A holistic solution with industrial importance is not known until now. The separation of treated wood and

other contaminations from clean wood is today mainly based on visual, mechanical, magnetic or gravity sifting techniques and is done at different steps along the recycling chain. Sensor based automatic sorting techniques are the only solution to achieve higher levels of recovery and quality of waste wood from demolition and to increase considerably the proportion of a high value material use of waste wood.

NIR spectroscopy (NIRS), especially the NIR imaging techniques (Hyperspectral-Imaging (HSI) [7]), is best suited for the automated on-line sorting of high volumes of waste wood. It has a high discrimination power for organic contaminations and the necessary measuring speed and spatial resolution. In a recently published review on applications of NIRS in wood science and technology it is pointed out that on-line or at-line monitoring in wood industry is in a starting position. It is desired to bring HSI into industrial applications for the wood branch as next step [8].

The study on hand aims to support this task. Results according to detection accuracy and limitations of NIR-SWIR-HSI are presented. As input material solid waste wood (e.g. different kinds of hard wood, soft wood, wood with paint or other coatings, particle boards, and medium density fibreboards) obtained from deconstruction is considered. Spectral measurements on the input materials in reflection mode have been incorporated into a database as training set. For classification tasks some decision trees based on PLS-DA (Partial Least Squares Discriminant Analysis) were exploited. These decision trees are then passed to an industrial NIR-SWIR-Hyperspectral-Imager for generating chemical images of the contaminated wood samples. Discussion of some sorting experiments sums up the study.

2 State of the art

Matured timbers are divided into different quality groups, in Germany [9] e.g. into classes AI (quasi natural wood), AII (used wood without preservative treatments and without halogenated organic coatings), AIII (used wood with halogenated organic coatings but without preservative treatments), and AIV (preservative treated wood, except PCB waste wood). Unification of quality groups AII and AIII is in a state of thinking about. A fifth group, referred to as PCB waste wood,

falls within the scope of PCB/PCT (polychlorinated biphenyls / terphenyls) waste and should not be considered here deeper because it is quantitatively not of importance for re-use.

For recycling the reclaimed wood of categories AI, AII, and after extensive detachment of coatings also AIII can be used. The two biggest challenges are therefore the detection of halogenated organic coatings (mainly PVC coatings) that must be removed from AIII wood for re-use and the detection of wood preservatives to classify a piece as AIV wood, respectively. For these tasks, there are a number of “classical” analysis methods like Ion-Mobility Spectrometry (IMS) [10, 11], Thermography [12], Color Indicator Techniques [13], Laser-Induced Breakdown Spectroscopy (LIPS), and X-ray Fluorescence Analysis (RFA) [6, 14, 15]. The main disadvantages of all of these analytical methods are that they are either not space-resolved or too slow for on-line operations. One promising method for both space-resolved and fast on-line detection is NIRS in connection with digital image processing. This combination is called Hyperspectral [16] or Chemical Imaging, respectively.

As standalone method, NIRS for detection of wood preservatives is known for over two decades [17]. The non-destructive method has been refined continuously [18–25]. But NIRS only provides a mean spectrum (average measurement) of a sample, irrespective of the area of the sample scanned. As the spectra collected are averaged to provide a single spectrum, the information on spatial distribution of constituents within the sample is lost. The development of NIR-HSI, which combines NIRS with digital imaging, enables both spatial (localization) and spectral (identification) information to be obtained simultaneously. HSI thus have the potential of describing distribution of constituents within a sample. More than one decade after the release of the first affordable digital cameras that were sensitive enough for the NIR spectral range [26], HSI also appeared in the focus of wood research in a laboratory scale [27–30]. The complex of waste wood analysis by HSI regarding detection of contaminations and preservatives is a quite new field of applications and so far just applied on AIII and AIV wood [29, 30].

The investigations in [29,30] employed a NIR-SWIR-Hyperspectral-Imager¹. A key objective of the research was to find out whether NIR-SWIR-HSI is suitable to differentiate between various organic and inorganic wood preservatives qualitatively as well as quantitatively. As one result it could be claimed that it was possible to classify the spectra according to the chemical compositions at the surfaces of investigated sample/preservative combinations. Surprisingly this was found to be true not only for organic preservatives, but also for most inorganic ones. An explanation for this finding could be the formation of chemical reactions between the inorganic preservatives and the wood constituents, leading to significant changes in the spectral fingerprints. In at least the case of Cu(II) sulfate the preservatives could be detected quantitatively by NIR-SWIR-HSI.

3 Experimental details and results

For extension and curing of the findings in [29,30] the authors have launched two experimental series, one in laboratory scale (WKI study) and the other in industrial scale (RTT/PTS study). The first series considered the detection ability of VIS-invisible organic wood preservatives while the second ones deals with measuring of real world waste wood samples of different types and with different contaminations. In both cases the same kind of NIR-SWIR hyperspectral camera (RED-EYE 2.2) has been used. The RED-EYE 2.2 camera from inno-spec GmbH (Germany) is sensitive in the wavelength range from 1.100 nm to 2.200 nm. It consists of a transmission grating based spectrometer and a cooled extended InGaAs detector with 256 x 320 pixels (spectral x spatial). The full-frame-rate is 330 Hz. In both series spectral images were acquired using the push-broom imaging principle [7]. Samples were scanned over conveyor belts with 50 and 200 cm width at speeds of 10 and 200 cm/sec, respectively. For illumination halogen lamps powered with 250 W have been used. Due to the slower conveyor belt speed of

¹ By agreement, the NIR portion of the electro-magnetic spectrum is typically defined as ranging from the end of the visible spectrum (around 800 nm) to 1.700 nm. The SWIR portion of the spectrum ranges from 1.700 nm to around 2.500 nm. A uniform definition does not exist until today. Sometimes the whole region from 800 to 2.500 nm (12.500 to 4.000 cm⁻¹; 120 to 375 THz) is called NIR range.

the laboratory equipment (10 cm/sec to 200 cm/sec for the industrial equipment) the sample illumination was stronger in the first experimental series.

3.1 WKI study – laboratory scale

PCP (pentachlorophenole) and Lindane (hexachlorcyclohexan) were the most widely used wood preservatives in the 1960s until the 1980s. Lindane was also used as insect repellent (insecticide). Much demolition wood from this period is surface contaminated with these toxic ingredients. The preservatives are invisible and have been usually applied in rather low concentrations, typically in the range of milligrams of the agent (without solvent) per kg of wood.

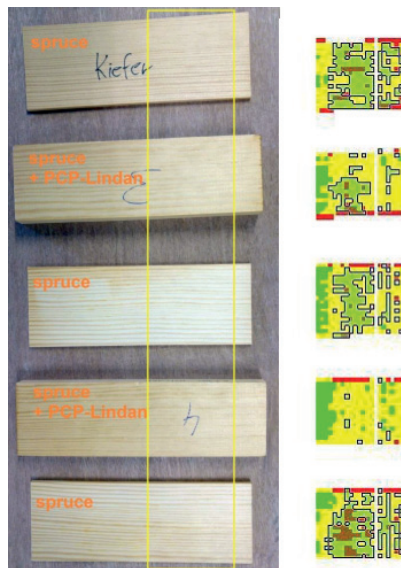


Figure 20.1: (left) Scene with wood samples; three without (from top No. 1, 3, 5), and two with PCP-Lindane treatment (from top No. 2, 4); the yellow box marks the area under evaluation. (right) Results of classification by principal component PC 1, areas probably without treatment are marked by black frames (see text).

For simulation planed samples of spruce wood, artificial treated with PCP-Lindane together with untreated reference samples were placed on a plywood background (Fig. 20.1, left) and scanned using the above mention experimental setup for series one. A region-of-interest of the scene comprising approx. 35 % of each sample's width (yellow box) was taken from the HSI and analyzed using the commercial software Evince from Prediktera (Sweden).

PCP-Lindane and other organic wood preservatives like tolylfluanid or tebuconazole show specific absorptions in a NIR range between approx. 1.300 nm and 2.100 nm [30]. Therefore it is useful to limit the range for HSI data evaluation to these bands and, if possible, to exclude the strong absorption band of water at around 1.900 nm. A principal component analysis (PCA) of the hyperspectral image in Fig. 20.1 (left) was carried out for the wavelength range 1.600 nm to 1.800 nm. Figure 20.2 shows the loadings for the first PC (principal component) – the maxima near 1600 nm correspond to expected absorptions typical for PCP-Lindane around this wavelength [30].

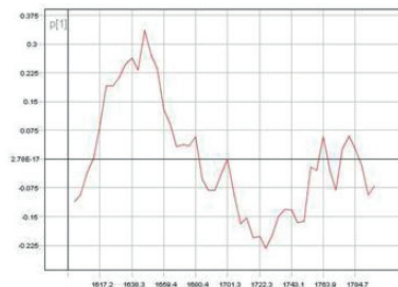


Figure 20.2: Loadings plot of PC 1 for wavelength range 1.600 nm to 1.800 nm.

The scatter plot of the PCs 1 and 2 (Fig. 20.3) shows no significant clusters, which could be used for a clear treated/untreated classification of the samples. But according to Fig. 20.2 information of the PCP-Lindane content can be expected in PC 1, and the values of PC 1 are suitable to classify the pixels in the HSI. At a certain level of the PC 1 value the segmentation correlates well with the apriority classification of the samples. Dark green dots in Fig. 20.3 and black borders in Fig. 20.1 (right) mark the pixels with probably low PCP-Lindane content.

From evaluation of series one it can be concluded that PCP-Lindane in the samples has been detected because wood species and surface properties were the same for all pixels in the HSI. However, these results are valid only for these conditions and material and the classification model must be re-calibrated for new wood material and/or other preservatives. Therefore, the findings can be considered just as a first step – there are several problems to solve for using NIR-SWIR-HSI to classify wood pieces by their content of organic preservatives and to apply this for industrial sorting applications.

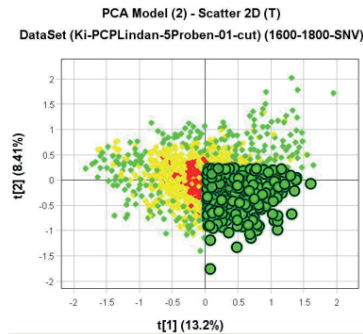


Figure 20.3: Scatter diagram of PC1 / PC2, classified pixels marked as in Fig. 20.1 (right).

3.2 RTT/PTS study – industrial scale

The objectives of second experimental series were the development and testing of NIR-SWIR-HSI measuring methods for the detection of contaminations on surfaces of real world waste wood. Especially in focus have been contaminations with paint or other coatings, wood products others than solid wood, e.g. MDF (medium density fibreboard), and extensive investigations on different wood material types, e.g. soft and hard wood. To be not beyond the topic and scope of the OCM conference only the developed methodology for the detection and separation of different types of wood materials that are painted with different coatings is described subsequently.

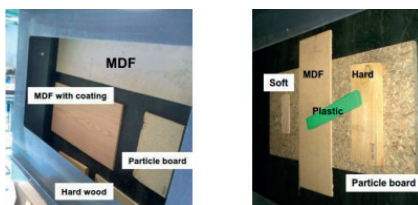


Figure 20.4: Samples of different wood material types and an extra piece of plastics (right, PS).

From a typical mixture of demolition waste wood randomly five different samples were chosen: hard wood (LH), soft wood (NH), wood with paint or other coatings (FA), particle board (SPAN) and medium density fibreboard (MDF), respectively (Fig. 20.4).

On the basis of a previously created database of well pre-treated spectra a multi-stage hierarchical PLS-DA decision tree as it is self-explanatory shown in Fig. 20.5 has been applied.

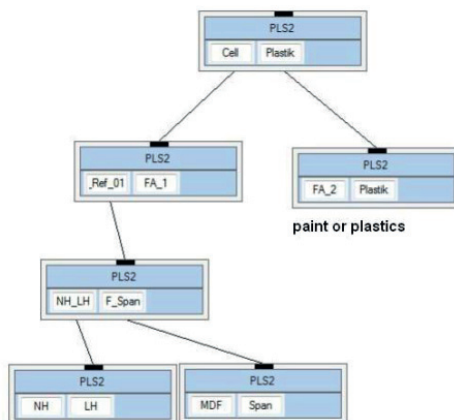


Figure 20.5: Multi-stage hierarchical PLS-DA classification tree.

This decision tree is then passed to an industrial sorting machine with a NIR-SWIR-Hyperspectral-Imager for generating chemical images of the wood samples (Fig. 20.6).

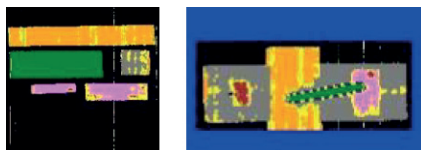


Figure 20.6: Chemical Image of samples from Fig. 20.4.

From Fig. 20.6 it can be slightly derived, that by applying of appropriate procedures of MIA (multivariate image analysis [7,29]) a separation of items and thus an automatic sorting by NIR-SWIR-HSI support is a capability.

4 Summary and Conclusions

The main objective of the study on hand was the extension and curing of published results in [29,30] that deal with the applicability of NIR-SWIR-HSI for the fast detection and sorting of waste wood treated with wood preservatives. It should also be studied whether the developed recognition procedures can satisfy high requirements from industry in terms of accuracy and robustness. Demonstrated on example of toxic PCP-Lindane (today banned as preservatives, however much often present in waste wood from demolition) it was found, that in case of VIS-invisible impregnated waste wood with rather low concentrations of the agent a classification is anyway possible. Nevertheless, much attention must be payed on spectroscopy, chemometrics and multivariate image analysis, respectively. Some pre-skills about the spectral structure of the possible types of impregnation seem to be essential. The perceptibility of organic coatings on different timber and wood products was proven on an industrial scale. As a side effect, even the type of wood material can be determined by NIR-SWI-HSI support.

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