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Multi-Sensor and Multi-Way Analysis of Modified Wood in Service

Anna Sandak[1, 2], Jakub Sandak[1, 3], Marina Cocchi[4]

1. InnoRenew CoE, Izola, PRIMORSKA, Slovenia

2. Faculty of Mathematics, Natural Sciences and Information Technology, University of Primorska, Koper, Primorska, Slovenia

3. Andrej Marušič Institute, University of Primorska, Koper, Primorska, Slovenia

4. Department of Chemical and Geological Sciences, University of Modena and Reggio Emilia, Modena, Italy

ABSTRACT

This research presents a multi-block approach used for merging experimental data collected by measurement of modified wood in service. Characterization of sample appearance (colour and gloss) is merged with near infrared spectral data that decodes information regarding chemical composition. Data fusion results as well as interpretation are discussed and compared with results obtained by models based on a single sensor. Finally, a multi-way approach for modelling of wood deterioration has also been tested and discussed.

INTRODUCTION

Recent advancements in development of scientific instruments provides numerous alternative methods that might be highly useful for assessment and/or monitoring of materials' properties. In that case, the combination of information provided by several sensors is a superior scenario. It increases the overall knowledge on the investigated phenomenon, which is not attainable by analysing data from a single source. However, multi-sensor evaluation demands an innovative approach for the data analysis, which can be addressed by implementing several data fusion strategies. Time series data generated within this research refers to a multi-sensor measurement that can be arranged as a data cube of dimensions: samples *x* sensors *x* measurement time. Parallel factor analysis (PARAFAC) was used therefore to study trilinear datasets.

MATERIALS

A set of six radiata pine (*Pinus radiata* D. Don) samples representing different commercially available modification processes was selected for the demonstration. Weathering performance of these materials was compared with the not treated wood of Scots pine (*Pinus sylvestris* L.), being commonly considered as a standard reference material (#5). The wood modification processes included: thermal treatment with penetrating oil (#1), thermal treatment with silicate treatment (#2), thermal treatment with coating (#3), furfurylation (#4), thermal treatment (#6), and acetylation (#7). The natural weathering experiment was carried out for 12 months, starting the experiment in March 2017 and assuring the southern exposure of samples. Materials' characterization included measurement of the colour (*CIE L*, a*, b**), surface scanning with office scanner (to analyse image and to calculate RGB and HSL colour coordinates), gloss (in two cardinal fibre directions), as well as measurement of spectra in NIR range.

Spectroscopy: Near infrared spectra were collected with a Vector N-22 Fourier-transform NIR spectrometer produced by Bruker Optics GmbH (Ettlingen, Germany). The system was equipped with a fibre optic probe and the measurement range was between 12000 cm-1 to 4000 cm-1 (833 to 2500 nm). The spectral wavenumber interval was 3.85 cm-1 with zero-filling equal to 2. The spectral resolution was 8 cm-1 and 32 internal scans were averaged at each spectrum. The background was measured every hour on Spectralon® resin. Three measurements were taken on each experimental sample.

Analysis: Multi-block algorithm, in particular Parallel factor analysis (PARAFAC) was identified as a suitable method for the purpose of this research, allowed combining multiple measurements taken on the same objects (aka samples) or over the same or similar periods of time (for a time-dependent system). In order to enhance information extraction, the data acquired by the different measuring devices were compressed and integrated by Data Fusion methodology. A mixed low/mid-level data fusion approach was applied. In fact, CIE L*a*b*, RGB, HSL, and gloss variables were simply concentrated (low-level), while the NIR spectroscopic data were first compressed by PCA (retaining the four components' scores as features) in order to reduce the number of variables and filter out the noise. In this way, a three-way data array has been obtained with modes corresponding to: x exposure time x fused variables/features x treatments. The numerical calculations were performed as well with the PLS Toolbox software (Eigenvector Research, Inc.).

RESULTS

In the PARAFAC decomposition by using two factors, the majority of the information (88.6%) was captured by factor/component 1, while factor 2 explained 4.8% of variance. The data were arranged with mode 1 corresponding to time, mode 2 to measurement, and mode 3 to different wood sample types (modification processes). It can be clearly seen that for all investigated samples monotonous increase with time can be noticed for component 1. This means that all the investigated materials follow certain patterns of deterioration related to progress of the weathering process. Analysis of mode 2 results (component 1) reveals that the CIE L* parameter was most influenced by weathering progress. Other parameters providing important information include CIE b*, gloss (measured in both directions), RGB parameters (measured for both earlywood and latewood), as well as luminosity measured for earlywood. Mode 3 of the PARAFAC model encodes an influence of the modification process on the weathering kinetics. It can be observed by analysing component 1 that material #1 (thermal treatment with penetrating oil) exhibits minor changes due to weathering, contrary to material #5 and #7 (reference and acetylated pine, respectively).

CONCLUSIONS

This paper presents an alternative concept for fusion and multi-way analysis of multi-sensor data related to performance of modified wood in service. Data Fusion consents to capture and highlight in the most efficient way the contribution and synergy of the different sensors, i.e. the different techniques providing information regarding their aesthetics and chemical composition. Additionally, the capability of multiway approach to handle the three distinct sources of variability in separate modes allowed interpretation of time influence on measured variables and treatment method on weathering kinetic.