Combined X-ray Diagnostics of Heterogeneous Biological Material

P. Fiala[1], **P. Koňas**[1], **M. Friedl**[1], **P. Šmíra**[2], **P. Dohnal**[1], **M. Hanzelka**[1], **and A. Nasswettrová**[2]

[1]Department of Theoretical and Experimental Electrical Engineering
Brno University of Technology, Kolejni 2906/4, Brno 612 00, Czech Republic
[2]Thermo Sanace s.r.o., Chamrádova 475/23, Ostrava-Kunčičky 718 00, Czech Republic

Abstract— The problem of finding a suitable diagnostic procedure for the examination of structural components of buildings has been closely analyzed in recent years. In this connection, the major interest is currently directed towards wood as a type of heterogeneous material; the utilized diagnostic procedures are under constant development to enable broad industrial application in the future. Within the research presented in this study, a new diagnostic method based on X-ray imaging has been proposed and tested. The technique utilizes the reduction of imaging information into 2D/3D planar projection, and it allows us to image clearly the rate of material damage by displaying the weighted damage rate. Another method is based on acoustic identification of structural elements infest ed with wood-destroying insects.

1. INTRODUCTION

Currently, the protection of wooden structural components against decay fungi and wood-destroying insects is widely realized through the use of the thermal treatment technique, which has been known and applied in Germany since the 1930s. The principle of this method consists in heating the related wooden structures by means of hot air whose temperature does not exceed 120°C; the duration of the process corresponds to 4–10 hours. The generated heat is accumulated inside wooden components of the structure under treatment, and the temperature of these components may reach as high as 60°C within the cross-section. The laboratory experiments involving the discussed diagnostic methods and damage recognition were described within reference [1]. In the following sections of our analysis, outdoor applications of these procedures will be described.

2. EVALUATION OF MECHANICAL PROPERTIES OF WOODEN STRUCTURAL ELEMENTS

The design of a mobile workstation which satisfies the requirements concerning the resolution accuracy of the evaluated image, (RTG image point −87/125 μm) [9], is shown in Fig. 1. The realized workstation is indicated in Fig. 2.

The following-described system can be used to monitor and evaluate the condition of wooden elements. As shown in Fig. 7 [1], the damage rate can be effectively determined and the presence of pests such as old-house borer (Hylotrupes bajulus) evaluated [2–11], Fig. 2.

The localization of wood-destroying insects was tested on laboratory samples which, in a defined manner, had been purposely infested with larvae of Hylotrupes bajulus, Figs. 3–4.

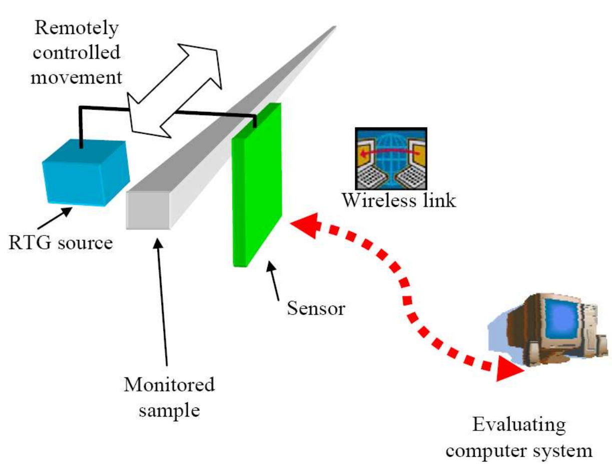

Figure 1: Diagram of the system for the monitoring of structural elements.

Figure 2: Experimental setup for the monitoring of structural elements.

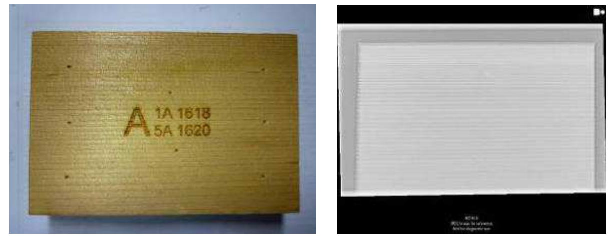

Figure 3: An uninfested sample wooden element.

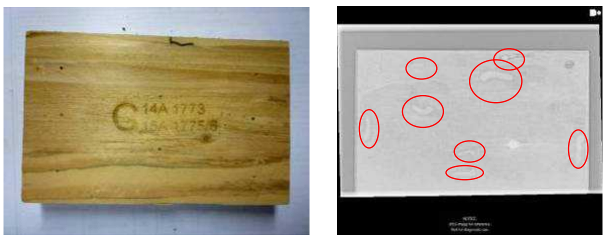

Figure 4: A sample wooden element attacked by the insect: Infested regions are marked in red.

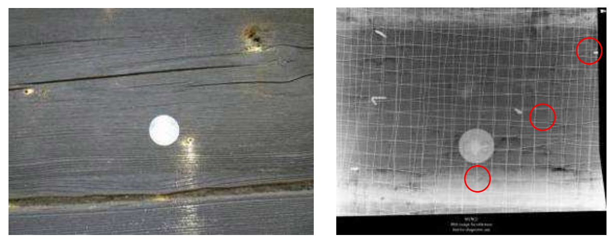

Figure 5: A sample wooden element attacked by the insect. The sample is combined with a plaster coating and netting wire; the larvae were found at spots marked by the red circles. Measured on 1 June 2012 at the gristmill in Kozlovice, the Czech Republic.

In real conditions, we conducted various experiments to obtain multiple types of information; thus, we also examined and obtained data on wooden elements combined with other materials (Fig. 5). In the data evaluation process, optical instruments are applied to create the 3D sharpening effect (image filtering), which enables us to determine the presence and position of Hylotrupes bajulus larvae with a probability of 60–90%. The evaluation may be impaired by image artefacts such as the netting wire in Fig. 5.

3. ACOUSTIC IDENTIFICATION OF AN ACTIVE WOODWORM LARVA

Sound recordings prove the presence of an active woodworm. However, as pest identification within such recordings would be time-intensive in outdoor measurements, which may last for several hours, special detection software was created. The software utilizes a suitable algorithm to ensure automatic and, in comparison with the manual mode, up to thirtyfold faster seeking of the moments of woodworm activity. Graphical output from the program is shown in Fig. 8; in the timeline, the pest active moments are indicated in red, while the noise is marked in green. The recordings presented in the figure are 4400 s and 100 s long, respectively. By means of this software, we can easily perform time analysis of a multi-hour record and locate spots of the woodworm activity. Then, the record (Fig. 7) can be started at red-marked times within the obtained diagram.

In the course of the trial outdoor RTG measurement, we also measured the sound track of the pest in a biological material, and the related processing results exhibited open activity of the pest. More concretely, the insect is active on a track recorded in one room of a house (Hukvaldy, Moravia, the Czech Republic) on 1 June 2012, Figs. 7 and 8. Using the software developed at the Department of Theoretical and Experimental Electrical Engineering, Brno University of Technology, the sound track can be accurately analyzed to enable the location of the pest activity spots.

Trial measurements of the insect activity in damaged wooden samples were realized by means of a sensor, and the related results are shown in Fig. 4.

The obtained results indicate that the applied measurement method can be successfully used to prove the activity of wood-destroying insects in a biological material, Fig. 7. The following diagrams introduce graphical output of the detecting program (Fig. 8) as well as the recording of the pest activity (Fig. 7).

Figure 6: Measuring configuration of a fonendoscopic device for long-time recording.

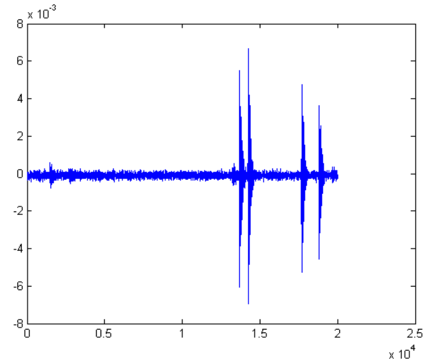

Figure 7: Recording of acoustic detection of an active pest.

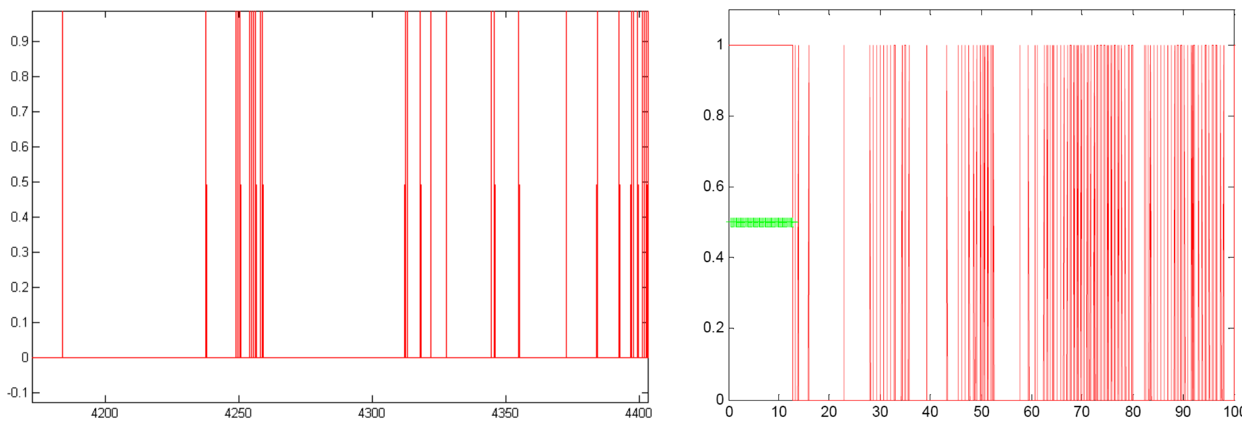

Figure 8: Graphical output of the program for acoustic detection of an active pest within the recording.

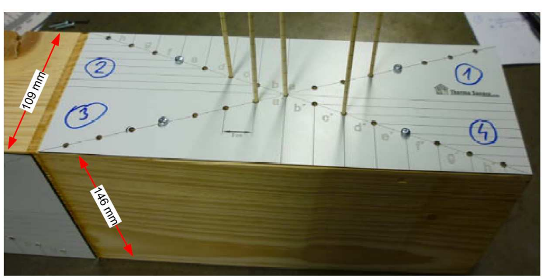

Figure 9: Instrumental box enabling the localization of an object inside a biological structure.

Figure 10: Tools for the localization of an object inside a biological structure.

4. LOCALIZATION OF AN OBJECT INSIDE A BIOLOGICAL STRUCTURE

To facilitate the localization of a woodworm inside a biological structure, the scanning of the object must be performed from no less than two angles (ideally 90°). In this measurement, the pest is represented by a pin, mainly because metal is perfectly identifiable in an RTG image. While laboratory conditions enable us to measure the object in all three axes of the three-dimensional system, real measurements performed on a saved (treated) roof may not allow such configuration owing to the structure of examined buildings. For that reason, the measurement was realized for two angles, namely 0° and 90°. Through further processing, the obtained images helped us to gain insight into the location of the object (a pest larva) in a biological structure. A convenient setup (phantom) was manufactured to support the measurement, Fig. 9.

We manufactured gauges with calibrated length guidelines to facilitate localization of the object inside the fabricated openings. The guidelines are applied (with 10 mm spacings) along the entire length of the gauges; this procedure allows pre-defined orientation and reading of the guidelines

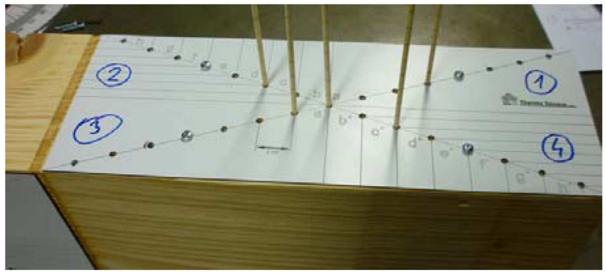

Figure 11: The measured study "A" for the localization of an object inside a biological structure (deployment of the objects is as follows: $d_1 = 7\,\text{cm}$, $a = 6\,\text{cm}$, $c_2 = 2\,\text{cm}$, $b_3 = 12\,\text{cm}$, $c_4 = 4\,\text{cm}$).

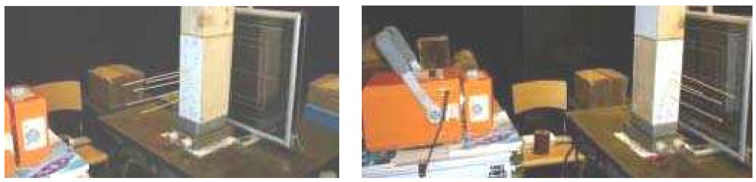

Figure 12: Views of the study "A" configured for the measurement of object localization inside a biological structure.

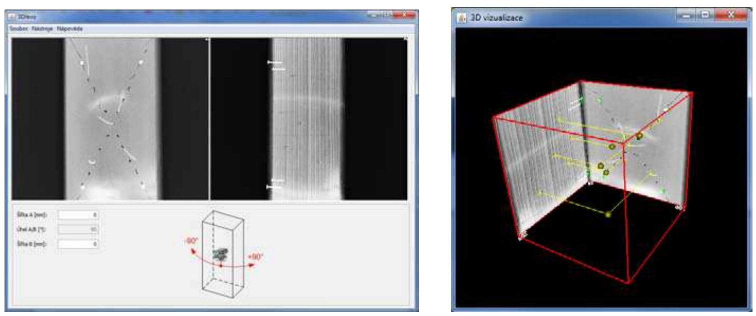

Figure 13: Final RTG images of situation "A", 3D evaluation of the phantom object localization.

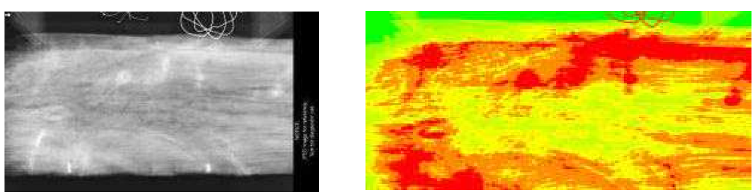

Figure 14: Sample PT23-SE2- evaluation of the object volume damage.

during their insertion into the measuring setup. Before the real measurement, an 8 mm long metal phantom was pressed into one end of each gauge (Fig. 10) to improve the contrast of the resulting RTG image and simplify the detection of the pest.

The actual measurement was performed from all three sides of the instrument (studies "A", "B" and "C"), always from two views reversed by 90°. Within each study, metal rollers were inserted into engraved marks to facilitate the calibration of distance during the evaluation of the image. Below we present only the results for study A, Figs. 11, 12, and 13. The quality and/or damage rate evaluation of a structural element is shown in Fig. 14.

5. CONCLUSIONS

We designed and tested an X-ray transparent diagnostic method for 2-D imaging and 3-D quality evaluation with respect to the assigned image parameters. The parameters were set in such a manner as to enable the imaging of shot sections showing the rate of damage to the heterogeneous structure building.

In this context, we also tested acoustic monitoring methods for determining the presence and position of wood-destroying insects in wooden elements. The quality and/or damage rate diagnostics were realized using real structural timber, including wooden supporting members.

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