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Review

Sensing wood decay in standing trees: A review

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ABSTRACT

The decay of wood in a standing tree is often the cause of tree failure. However, the accurate measurement of decay and the non-invasive sensing is still in its infancy. A review of the current sensing methods commonly used for decay detection in standing trees is presented. Methods are compared in terms of the fundamental of measurements, hardware implementation, damage caused to tree and the ease of use. Invasive technique with decay detecting devices, such as increment borer, borescope, decay detecting drill, shigometer, fractometer and radiographic meter, and non-invasive technique involving electrical resistance, microwave, nuclear magnetic resonance and acoustic methods are discussed. This review paper aims to help researchers in this field to identify the remaining issues.

Contents

1. Introduction

During tree decay assessment, conventional diagnostic methods are mainly based on visually inspecting trees for the occurrence of external indicators of decay including evidence of structural weakness (e.g. wounds from pruning, dead bark, etc.), often followed by instrumental analyses aimed at assessing the localization and the extent of the decay. Standing trees have to be evaluated to maintain in situ structural integrity. A statistical test was carried out in both urban sites, including parks and streets, and forest sites, including protection forests in western Italian Alps, using conventional visual inspection and multiple Polymerase Chain Reaction (PCR) based methods. After visual inspections, wood chips were sampled through a tested drill-based technique to identify decay fungus. Multiplex PCR-based methods are used as molecular analysis of internal wood tissues to diagnosis the wood decay fungi. The results suggested that diagnosis based on visual inspection under-

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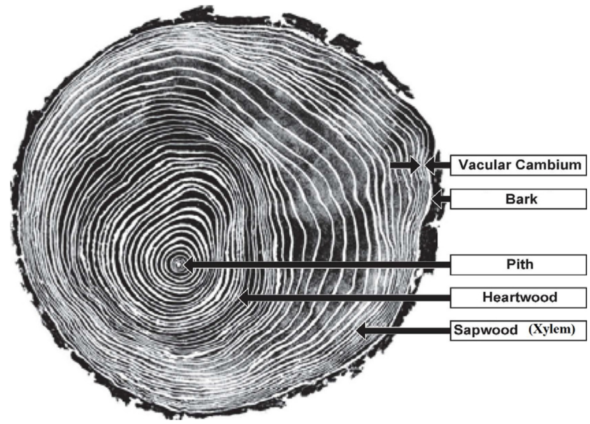

Fig. 1. Transverse section of a trunk.

estimated on average more than 90 per cent of infected trees, with a similar situation in both environmental contexts (91.8 per cent in urban sites vs. 92.4 per cent in forest sites) [1]. This represents a serious problem as in the early and intermediate stages of infection, tree decay could be overlooked.

The diagnosis of wood decay fungi in standing trees based on multiplex PCR does not allow to infer the localization and the extent of the decay column [2]. For such purposes, decay detection using other instrumental analyses can be broken into two categories: non-invasive and invasive; relatively to the bark and the xylem. Bark is the protection outer layer while xylem, is also known as sapwood, is the living wood. The heartwood is the non-conductive wood found as a core in the middle of most trees. The transverse section of a tree is shown in Fig. 1. Decay detection devices for trees will be either invasive or non-invasive. This definition is based on the fact that penetrating into the xylem could cause damage due to wounding or fungal attack and then affect the value of that trunk, while penetrating only the bark usually would not (Garrett, 1997).

In the next sections, we provide a comprehensive review of the literature on techniques that can detect decay and cavities in standing trees. The purpose of this review is to establish current achievements and evaluate the potential for the application of decay detections in standing tree. All reviewed techniques are classified based on the way they deal with two key issues: measurement fundamental and hardware implementation. This paper aims to help researchers in this field to identify the remaining issues.

2. Invasive technique

Invasive technique involves penetrating the xylem for detecting decays in tress through commercially available devices such as increment borer, borescope, decay detecting drill, shigometer, fractometer and radiographic meter (X-Ray and Gamma Ray).

The increment borer is a common forestry tool to extract a core from a tree to be visually inspected and measure to determine tree growth rate, age and soundness. Increment borers are screwed into the tree and the only decay that will be detected is at the point of drilling – decay pockets could be missed; therefore, this technique involves boring more than one hole and possibly many holes around the circumference at different angles and at various heights.

Like the increment borer, borescope requires drilling a hole, or several holes, into the xylem, to have remote visual inspection inside of a tree for decay. It normally comes with accessories including small video cameras and zoom lenses for video documentation purpose.

Decay detecting drill, which is also referred to as the resistograph method, applies constant drilling pressure to penetrate sound tree. The speed and rotation of the drill is constant [3,4]. The turning moment required to maintain constant drilling speed is equal to drilling resistance and is recorded graphically in relation to drilling depth. Decay is detected by a sudden change in spacing between the lines on the record.

Shigometer is a battery-operated and lightweight field ohmmeter, which consists of a twisted wire probe [5]. This technique requires a drilled hole into the xylem, so a pulsed direct current can be injected into it through a probe. The electrical resistance readings are measured and as wood becomes decayed, the resistance progressively decreases.

A Fractometer is a device to measure the elasticity and fracture strength of wood. It breaks the radial increment core along the direction of the fiber to measure the fracture strength of cores removed from the standing tree with an increment borer. In addition, it measures longitudinal compression strength for a wood core sample [6–8]. However, the breaking strengths expected of sound wood need to be known [9]. The application requires comparison to known standards and to decay-free samples taken from the same tree [10].

As for the X-Ray or Gamma Ray radiographic technique, the wood samples can be obtained destructively (harvesting the trees and cutting wood cross-sections) or non-destructively (extraction with an increment borer) under laboratories experiment [11]. The wood samples are then radiated with accelerating voltage (kV), heating tube current (mA) of the cathode. The wood decay can be detected by a decreasing wood density due to the biodegradation of cell wall components [12]. Being much smaller than light waves, x-rays cast sharp shadows to identify grain. The ionizing radiation technique has drawbacks. It is potentially dangerous as the equipment that generates radiation consumes much electric power. Wrapping the equipment around a tree in the forest is rather difficult hence, X-Ray or Gamma Ray radiographic technique is more applicable in sawmills to automatically determine the optimum cutting strategy for each log [13].

3. Non-invasive techniques

3.1. Electrical resistance (ER)

ER technique is based on the wood moisture content, secondary compounds, number of ions, cell structure, and other factors [14–19]. The ER tends to decrease with increase in moisture content, and the effect of moisture content on the ER below the fiber saturation Point (FSP) is stronger than above the FSP [20]. The electrical properties of a tree change with the decay. As the fungi consumes the cell structure, metal ions, in particular potassium are released [21]. These ions are mobile in the humid front of the decay thereby provides a much lower resistivity.

Generally, sample trees are tested using a multichannel ER measurement system where each electrode is clipped and attached to a nail that are tightly forced into the xylem. However, the ER system is less invasive than the Shigometer device, because the electrodes are only driven into a depth of 10 mm xylem rather than placed in a predrilled hole into heartwood [22]. The ER technique can be used as a non-invasive technique to evaluate standing trees, discolored wood, decay, and roots [18,23]. It was used to evaluate the health of canyon live oaks [24] and as an index of the general metabolic activity of the Caribbean pine [25]. Also, Picus Treetronic device (commercially ER electrodes by Argus Electronic, Rostock, Germany) that consisted of an array of electrodes were evenly placed around the tested tree in a horizontal plane to determine the position of the sapwood-heartwood boundary [20].

In another ER approach, Relative Impedance in situ Examination method was implemented to detect tree decay by using a