A Bistatic Measurement Scheme for Revealing Signatures of Tree Defects in Radar B-scans

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***Abstract*—This paper proposes a bistatic measurement scheme to reveal the signatures of tree defects (e.g. cavities and decays) in radar B-scans. In this scheme, the transmitter and receiver are placed separately at two sides of the trunk, away from the trunk surface, and moved along the same direction on straight trajectories while obtaining the B-scans. The obtained B-scans are then processed using a Kaiser window and singular value decomposition. In the processed B-scans, the defect signatures appear obviously, demonstrating the advantage of the proposed scheme for defect detection. Compared with other measurement schemes, the proposed scheme allows obtaining defect signatures with a 17 dB signal-to-noise ratio improvement in radar B-scans.**

I. Introduction

The health monitoring of urban trees is vital to prevent tree-falling accidents. Among all non-destructive techniques, the radar has recently become popular for acquiring high-resolution images of tree interiors. The conventional radar measurements are conducted by an operator via moving the radar on a circumferential trajectory around trees. By applying signal processing techniques, including singular value decomposition (SVD) and background removal [1], the tree defects' signatures are revealed in radar B-scans. However, such a measurement configuration requires excessive manpower for even a single tree and thereby is not applicable to the health monitoring of a large number of trees in urban areas. To solve this issue, recently, a stand-off radar measurement configuration has been proposed for rapidly detecting tree defects [2]. In this configuration, the radar is moved on a straight trajectory, away from the tree surface, while performing the scans. By doing so, data collection and processing are completed in minutes, allowing the health monitoring of many trees in a short period of time. Nevertheless, the signatures of the tree defects in B-scans obtained by this stand-off configuration are often not easily visible by the eye since the signatures of defects merge with the first reflections from the tree trunk surfaces. To clearly reveal the signatures of the tree defects in B-scans, investigation of different radar measurement configurations is called for.

This paper proposes a bistatic measurement scheme to reveal the signatures of tree defects with a high signal-to-noise ratio (SNR) and a clear pattern in radar B-scans. The proposed measurement configuration leverages a transmitter (Tx) and a receiver (Rx) placed on two sides of the trunk separately and moved in the same direction during the scanning. Compared with the existing stand-off configuration and a commonly used reverse bistatic measurement configuration for underground detection [3], the proposed bistatic measurement configuration achieves a visible defect signature with an SNR improvement of 17 dB on the synthetic data. Additionally, real measurements are conducted on tree trunk models in the laboratory. The distinguishable defect signature in the processed B-scan validates the feasibility of the proposed scheme in real-world applications.

II. The Proposed Bistatic Measurement Scheme

The proposed bistatic measurement scheme [Fig. 1(a)], utilizes a pair of Tx and Rx placed at opposite sides of the trunk and moved in the same direction. The A-scans are collected with 2 cm steps during the movement and stacked to obtain a B-scan. Two reference measurement setups, including a common-offset stand-off configuration [Fig. 1(b)] and a reverse bistatic configuration [Fig.1(c)], are introduced to compare the performance of the proposed scheme.

In the test scenario, a realistic tree trunk model [Fig. 1] with three layers with/without a cavity has been simulated using an open-source forward solver [4]. Based on the measurement of dielectric properties of a real tree trunk sample, the relative permittivity and conductivity of the bark layer, cambium layer, and sapwood layer are set to [2, 16, 2.5], and [0.01, 0.15, 0.05] S/m, respectively. The thickness of these three layers, the cavity's diameter, and the trunk's height are set to 2.5, 1.5, 56, 25, and 40 cm, respectively. A Hertzian dipole radiating at 1 GHz (Tx) and a probe (Rx) are moved along one-meter-long trajectories placed 15 cm away from the trunk surface.

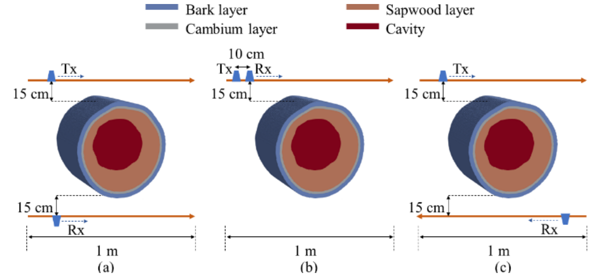

Figure 1. The configurations of (a) the proposed bistatic measurement, (b) straight scanning, and (c) reverse bistatic measurement schemes.

The B-scans collected by the proposed configuration are shown in Fig. 2(a). Two hyperbolas with off-center apexes caused by the cavity appear when compared to the B-scan of the healthy trunk. To better understand the B-scan, the signal transmission paths during the scanning have been demonstrated in Fig. 3(a). In addition to the electromagnetic (EM) wave received directly by the Rx, boundaries of tree layers and cavity introduce reflections, resulting in a total number of five visible hyperbolas in Fig. 3(b). The off-centered apex of each hyperbola represents the shortest propagation path during the scanning. Since the lengths of the propagation paths induced by the cavity (in green and yellow) are quite different from those induced by the wood layers (in red and purple) in Fig. 3(a), the corresponding hyperbolas in Fig. 3(b) are well separated from each other in the most of the traces, making defect signatures apparent in the B-scan.

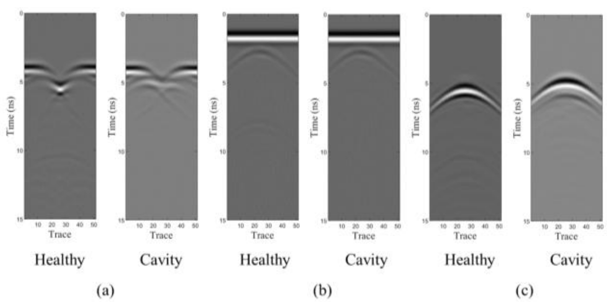

Figure 2. B-scans of the trunk w/out and w/ cavity obtained via (a) bistatic, (b) straight, and (c) reverse bistatic measurement schemes.

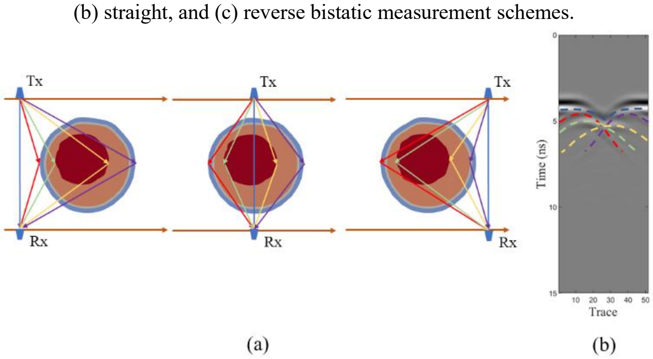

Figure 3. (a) The wave propagation paths and (b) B-scan pattern.

The B-scans of the two reference setups are shown in Figs. 2(b)-(c). Due to the proximity of the cavity and the trunk surfaces, the signatures of the cavity and front surface merged for the straight scanning, making it hard to distinguish, especially when the cavity is small. As for the reverse bistatic measurement setup, the EM wave received always goes through the trunk. Therefore, the propagation time is reduced when a cavity exists, making the entire pattern shift. Besides, even though some multiple reflections and internal reflections can be seen in the B-scans, the SNR of straight scanning and reverse bistatic measurement are 17 dB and 29 dB less than the proposed bistatic measurement scheme. The comparison results qualitatively and quantitatively demonstrate that the proposed measurement configuration yields a B-scan with an enhanced defect signature.

III. Validation of Bistatic Measurement

A set of measurements is conducted with trunk models with and without cavity to validate the enhancement achieved by the proposed bistatic measurement. In these measurements, two antennas operated from 0.5 to 3 GHz are connected to a Keysight vector network analyzer P5021A. A bucket filled with sand is used to mimic the trunk and a pot is placed inside to mimic the cavity. In the setup [Fig. 4(a)], the antennas are moved from right to left along a 0.8 m trajectory and used to collect A-scans every 2 cm. To denoise raw B-scans, a Kaiser window with a center frequency of 1.5 GHz and order of 5 is applied. To further reveal the reflections from the trunk's interior, covered by the strong direct coupling, SVD is used. After signal processing, it is observed that two hyperbolas with apexes around trace 15 and 23 appear in the cavity B-scan [Fig. 4(b)], which match the cavity position, demonstrating the capability of defect detection via the proposed measurement scheme.

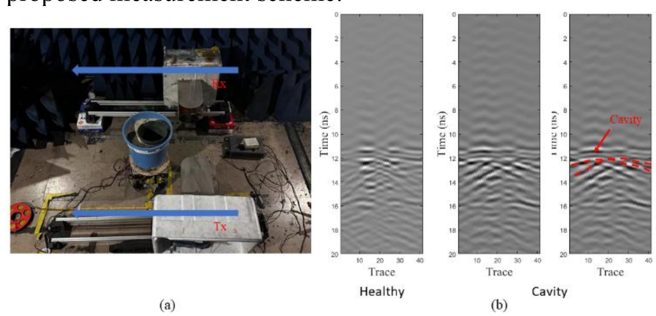

Figure 4. (a) The measurement setup and (b) processed B-scans.

IV. Conclusion

This study proposes a bistatic measurement configuration to reveal the tree defects in radar B-scan. Compared with commonly used measurement configurations, the proposed one yields an apparent defect pattern in the B-scan with a 17 dB higher SNR. After measurements are conducted with trunk models, a signal processing procedure is applied to B-scans to reveal the clear cavity signatures, demonstrating the proposed scheme's importance for tree defect detection.

Acknowledgment

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