Evaluation of GPR surveys for assessment of trees condition in urbanized areas

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Abstract: Modern measuring equipment is sometimes used for applications, for which it has not been originally designed. For example Ground Penetrating Radar (GPR), designed for subsurface structures analysis, can be used for tree tomography. Radar utilizes the phenomenon of propagation of the electromagnetic waves in a physical medium. Measurements can be carried out in situ, in a non-invasive manner on a living tree. Collected data allow for the tree condition determination. It is possible to detect voids and internal structure. Geophysical investigations can provide an estimation of the risk of falling of the trees. These methods also allow determination of the production quality of the tree by detecting knots inside the structure. Available literature shows only limited examples of the usage of other geophysical surveys, such as the ultrasound and geoelectrical method. However, in many cases these measurements are performed on samples in the form of profiles cut from the felled trees. Presented study was conducted on a set of 8 ash trees growing in the Krakow city parks. The measurement was carried out with high frequency antenna – 1600 MHz. Due to the lack of available literature and limited experience of the authors, only trees with known condition were tested. Despite many attempts, the authors were not able to developed a reliable measurement methodology which would allow for unambiguous classification and interpretation of results. In most cases, the results of the study permitted determination of the trees condition. However, some echograms, of the surveyed trees with visible voids pointed to a different tree state and misclassification. Despite that, the research results seem to be promising and the authors believe in the usefulness of the further development of measurement method along with its extension to other trees species.

Keywords: GPR, tree, EM wave, forest management

INTRODUCTION

With the development of the geophysical measuring techniques the possibility of its non-standard use is increasing. It is often observed in the case of the Ground Penetrating Radar (GPR). The primary use of the instrument was the measuring of the subsurface layer of the earth's crust. It is still used in researches dealing with: geology (e.g. localization of structures, measurements of formation thickness in Mazurek & Łyskowski (2014)), engineering (e.g. determining the course of underground installations), and archaeology (localization of artefacts beneath the ground). An example of the non-standard use of the method can be tests performed on the water surface (conducted from a pontoon or ice sheet) that are designed to scan the bottom of a water basin. Another physical medium, which is a frequent subject of research, are concrete objects due to the fact that the method works well for penetrating floors, walls, and ceilings of buildings (e.g. Mazurek & Łyskowski 2012).

As an experiment, it was decided to perform measurements on objects that were not subjects of the authors' researches before. It was decided that an interesting issue is the location of cavities in the trunks of growing trees. Despite the thorough literature studies, no precise hints on research methodology were found. Examples of studies on discs cut out perpendicularly to the trunk axis (Nicolotti et al. 2003), and on root systems (Barton & Montagu 2004, Cermak et al. 2000) were found. In literature, one can also find works on the analysis of the electromagnetic wave amplitude used to locate objects' defects (Butnor et al. 2009), and the effects of trees scanning using antennas with frequencies up to 1000 MHz (Lorenzo et al. 2010). Careful analysis of the literature resulted in main aim of this paper – verification if the GPR method eligible for process of detection internal structure of trees for purpose of eliminating ones with inferior quality and those which can threaten public safety.

GPR METHOD

The GPR method is one of the geophysical research methods. It is based on the phenomenon of propagation of electromagnetic waves (EM) in the medium (Annan 2001). It allows localization of structures that are beneath the surface of the earth, concrete and other mediums. The propagating EM wave is reflected, scattered, diffracted, and attenuated (Reynolds 1997). The simplest GPR system consist of a transmitting antenna with a transmitter, receiving antenna with a receiver, a central unit, and an encoder (Karczewski et al. 2011). The central unit synchronizes the clocks both in the transmitter and the receiver, sends an impulse to the transmitter so it could generate, with the use of transmitting antenna, an electromagnetic wave. Wave reflected at the structure boundaries with different electrical properties reaches the receiving antenna and the receiver records the time in which the wave arrives and its amplitude. The central unit controls the data recording in the computer memory (Reynolds 1997).

Currently manufactured antennas operate in the frequency range from 10 MHz to 6,000 MHz. During the process of antenna selection, one must follow the principle, which states: the higher frequency at which the antenna operates, the smaller depth range and higher resolution it has (Annan 2001). Thus, with the use of high frequency antennas one can detect smaller objects, provided that they are located at a small depth (Karczewski et al. 2011, 79–83).

The end result of the GPR measurements is a collection of the traces on which a double time of EM wave propagation and its amplitude is recorded, the so-called echogram (Fig. 1). It is a graph in which the x-axis maps the profile length, and the y-axis represent the time which should be converted to depth after the determination of the wave propagation velocity (Łyskowski & Mazurek 2013). In order to calculate the value, the time-depth conversion is necessary. Therefore, it is vital to determine the velocity of the EM wave propagation.

For the purposes of this study, the measurement of the value was performed via wide-angle reflection and refraction (WARR) profiling. However, the result of this profiling was not interpretable. The information about the velocity of the relative dielectric constant of wood was taken from the literature. This allowed to make a conclusion that the parameter depends on the moisture of the studied object. It was found that the European species of trees have a moisture content ranging from 6 to 30 percent. In this range, the dielectric constant can vary from about 2.5 to 7 (TANEL 2006). It was also found that the dielectric constant of wood is within the 2–5 range. However, such values are given for the measurements conducted in the room temperature (Simpson & Tenwolde 1999), and is not assigned to growing trees. Hence, its value was determined to be 6, which is a value assigned to trees of a moisture content above 20%. The calculated EM wave propagation velocity in the medium is given as the quotient of the EM wave propagation velocity in vacuum (c = 0.3 m/ns) and the square root of the relative permittivity of the studied medium (Łyskowski & Mazurek 2013). In the end, it was posited that the velocity value equals 0.11 m/ns. In order to perform survey, following measurement parameters were used: distance interval (in cm) – 0.009712; time window (in ns) – 66.994572; stacking – 8. Those parameters were optimal choice for fast and precise acquisition of information in every centimetre of tree structure.

THE STUDY AREA

The study was performed in Krakow on Benedyktyńska street (under consent ZIKiT/S/37851/13/UZI/28270 of 2.05.2013). It was conducted on deciduous trees and to be exact on ash trees.

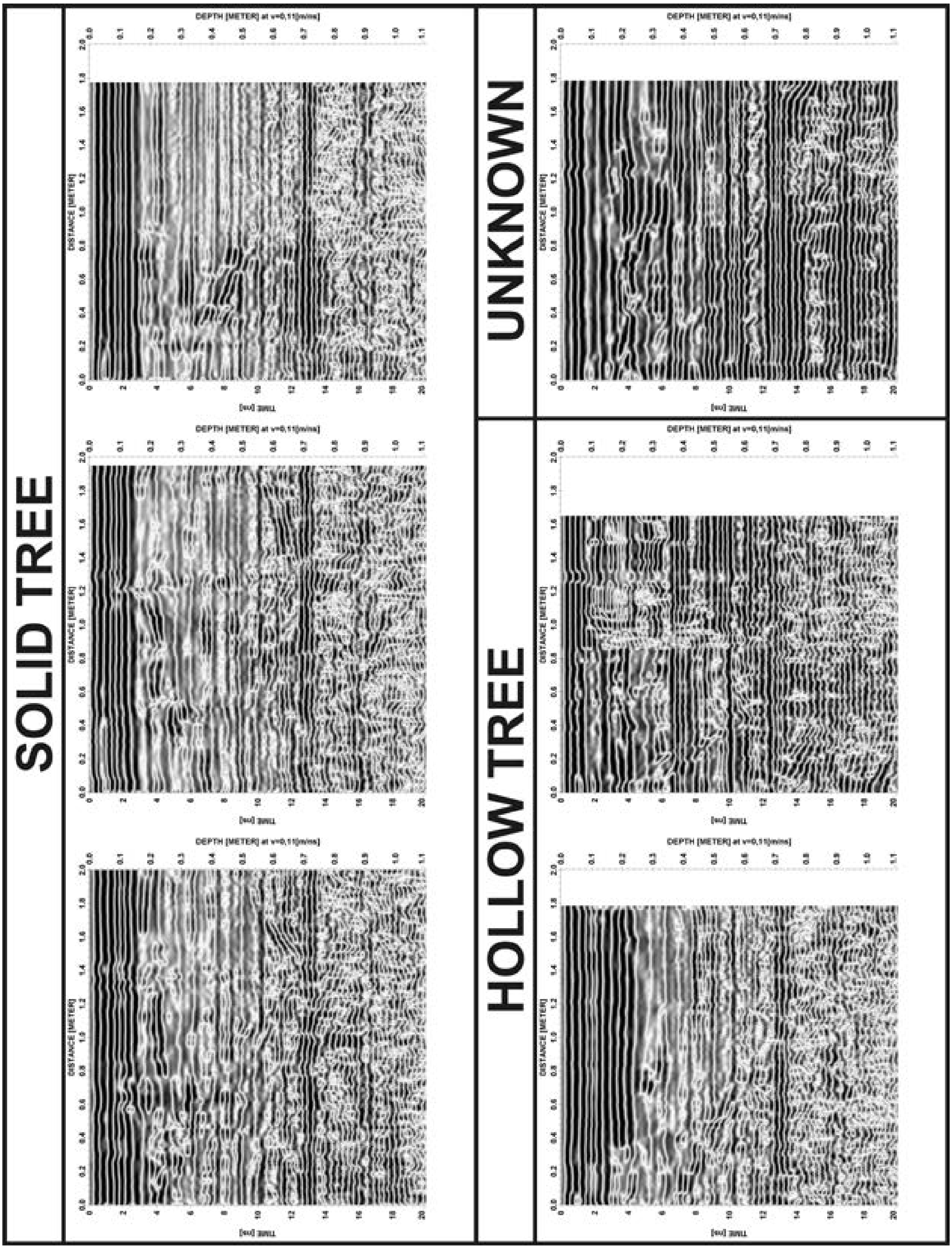

Fig. 1. *Echograms resulting from GPR measurements of trees. On the left: three echograms of measured solid trees. On the right: three echograms of hollow trees (including one qualified as a tree of unknown condition)*

Due to the authors' lack of experience in the field of GPR trees measurements, individuals with known condition were chosen. Objects classified as hollow were characterised by extensive defects visible from the outside. In the trees study pool were: four individuals with visible cavities and with girt sizes (in meters): 3.21, 3.91, 2.06 and 2.88; and four individuals classified as solid ones and with girt sizes: 2.2, 1.9, 1.8 and 2.7 (the measurements were made at a height of 1m from the ground level). During the measurements, if shape of tree had not been similar to the circle, profiles where carried out in place of wider diameter.

RESULTS

Before interpreting the results, it is necessary to process them. For this purpose, a simple mathematical functions are used. Their aim is to improve the signal-to-noise ratio. Used procedures are intended to i.a. the shift of first breaks picking to the level zero (move starttime – the names of procedures are taken from ReflexW program). Frequency filters are also used to remove noise (e.g. bandpassfrequency), enhance the amplitude value (e.g. time gain) or smooth it out in order to eliminate the temporary distortions of the signal (e.g. average, or stack traces) (ReflexW Manual 2009). Note that the interference in the raw data should be as small as possible. Too extensive or incorrect processing may result in e.g. generating artificial anomalies on the echogram.

Scans that are presented bellow have been subjected to the multiple independent sequences of processing in order to select the best final results.

While determining the tree condition on the echogram (Fig. 1), the presence of visible changes in the structure was taken into consideration. The scans on which singled out anomalies are likely to be derived from the larger knots or changes of the inner structure indicate that the tree is solid. The visible thickness limit of the tree, due to the varying diameter, cannot be unambiguously determined. During the propagation outside the tree structure, the amplitudes of the EM wave are recorded at noise level, which can be seen in most of echograms.

Hollow trees were chosen on the basis of parallel reflections propagating in time that were observed on the echogram. However, it is necessary to mention that on every scan such anomalies can be observed in the first few nanoseconds of recording. Their sources are i.a. propagating wave in the air and the surface wave. There were also often visible structures within the tree which were recorded on the preserved fragments of the trunk.

Echogram, which could not be clearly interpreted resulted in the classification of the tree as of an unknown condition. It may be due to the fact that the EM wave emitted by the antenna is not precisely targeted and when it propagates. It records wave amplitude values that are mapping simultaneously the preserved fragments of the tree and the voids. It is possible that in the case of small-sized cavities, it can be observed the phenomenon of mutual masking of internal structures.

DISCUSSION

Measurements were carried out with usage of two frequencies of shielded antennas: 1600 MHz and 800 MHz. Due to the lower resolution and greater depth penetrating range, echograms from 800 MHz antenna were inferior quality. It was decided to present only results from higher frequency antenna. Low depth penetrations antennas (above 1,000 MHz) are resulting in more reliable data, which can be seen in other publications, e.g. Mazurek & Łyskowski (2012).

Studying the results one should analyse the phenomenon of electromagnetic wave propagation in the tree. The internal structure of the studied object is characterized by its complexity. In the tree it is multi-layered (wood grains). Electromagnetic wave that is emitted during the measurement is repeatedly reflected, bended from internal boundaries, and propagates deeper into the medium. In addition, considerable moisture causes increased attenuation of the electromagnetic wave. Initially, measurements were carried out using single shielded antenna with a frequency of 1,600 MHz, however, the results were not satisfactory. This were the classical reflective profiling (Karczewski et al. 2011: 112–114) and were conducted from ground up to about second height meter of a tree specimen. It is possible that because of the numerous diffractions and strong wave damping effect, the wave generated by a single transmitter was too week in order to reach the receiver and be recorded.

Another experiment was intended to conduct a tree tomography (Karczewski et al. 2011: 127–128) with two identical shielded 1,600 MHz antennas measuring tree at the same height point. Results of the classical tomography transpired to be difficult to interpret and inconclusive. Extremely interesting were the outcomes of the classical reflective profiling which were conducted simultaneously during the tomography technique measurement. The phenomenon of superposition resulted in enhancement of the amplitude via mutual strengthening of the EM waves from both transmitters. Overlapping waves reaching the receiver made it possible to record useful information. Amplification of the signal by the second transmitter resulted in the fact that the returning impulse had sufficient amplitude allowing the recording of the anomalies within the tree structure. Schematic diagram of the measurement and EM wave propagation in simplified tree can be seen on Figure 2.

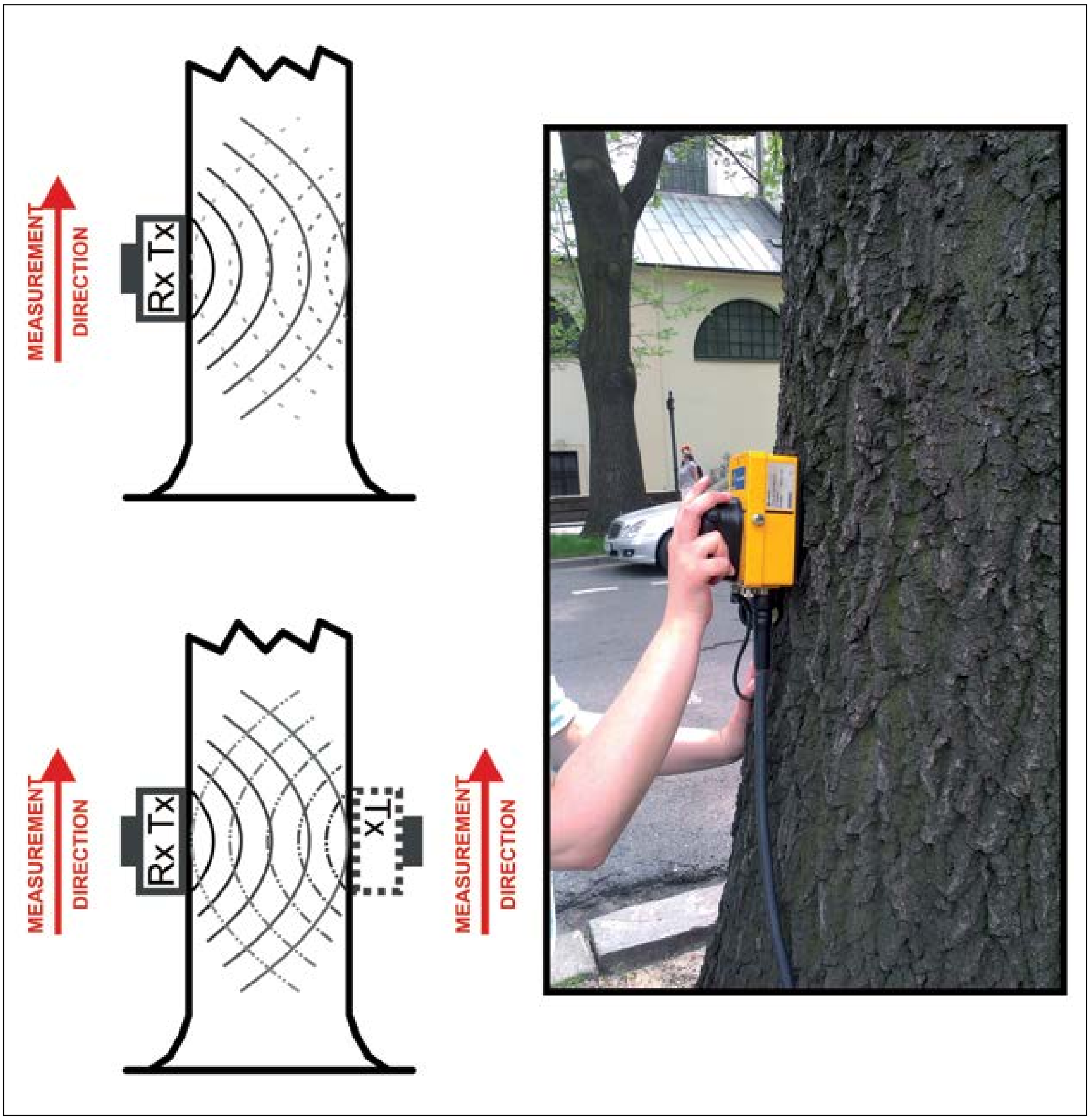

Fig. 2. *Schematic diagram of EM wave propagation in the tree (Tx – transmitter, Rx – receiver). On the top: classical reflective profiling. On the bottom: reflective profiling with enhancement of the amplitude via mutual strengthening of EM wave. Note that both antennas on the diagram contain working transmitter and receiver, omission of Rx symbol on second antenna is simplification. On the right: photography of measurement in situ*

This theory was confirmed by several measurements and the fact that only results after such measurement reflected the tree condition in a proper manner.

There should be mentioned one more thing that connects whit echogram interpretation. During the time depth conversion the velocity of EM wave is assign to whole echogram. The hollows in trees filled up with air also gain the velocity of solid parts. Because of this, the velocity value of air (very similar to one of the vacuum – 0.3 m/ns), which is almost three times higher and reflects in faster propagation of wave, gives reduced depth. Due to this fact, hollow trees diameter cannot be precisely calculated. And determining this value was not considered as any aim in this research.

CONCLUSIONS

The conducted tests indicate the enormous potential of the radar method in case of determination of the tree condition and its productive potential. This thesis is confirmed by the numerous publications that have been indicated in the Introduction part of this manuscript. Diagnosing defects and structure will improve the efficiency of the forest management. Development of the experimental pool and modification of the already-established measurement methodology can be expected to improve the results. It is connected with the implementation of this type of research in forests and parks. The expected end result is to bring the research to the stage that allow e.g. elimination of the individuals that are likely to fall. Recognition of the tree internal structure will also allow pre-selection and support of the pre-production processes in order to eliminate trees of the inferior quality.

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