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Using Picus® Sonic Tomograph to assess the health state of trees of monumental sizes

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Abstract: The aim of the study was to examine the usefulness of The Picus 3 Sonic Tomograph to assess the health state of trees of monumental sizes, which are an important part of the cultural landscape. In the study there were selected tree species *Tilia cordata, Gingko biloba* and *Ulmus glabra* growing in the vicinity of Lublin in different habitat conditions. Changes in the internal structure of the tree trunks were shown on the colour tomograms. Two tested specimens of *Tilia cordata* located in Radawiec Duży were intended to be cut down due to the construction of the ring road of Lublin. This made it possible to compare the obtained tomograms with the actual state of the inside of tree trunks after cutting down the examined trees. The results of Picus tomography *Ulmus glabra* and *Gingko biloba* growing in the historic park in Czesławice were confirmed by a visual assessment of trees. In each case the number of installed sensors influenced the image resolution and accuracy of the obtained tomograms. Diagnostics using sound waves is important in assessing the state of health of each tree, but it is especially recommended for testing of valuable trees. It allows for early diagnosis and selection of such protective actions to reduce to a minimum the destructive impact study on the body of the plant.

Key words: *Gingko biloba*, *Tilia cordata*, *Ulmus glabra*, trees of monumental sizes, PiCUS Sonic Tomography

Introduction

In recent years, new methods have been developed to enable the detection of infection and decay of the internal structures of the tree trunk using sound or electrical tomography. Nicolotti et al. [2003] used three different types of research methods: CT electricity, sound and ground penetrating radar, with different degrees of success, to assess the health state of urban trees. Out of these three methods, the most effective tool for the detection of the internal tissue decay of trees proved to be sound tomography, which according to the authors, precisely locates anomalies and estimates their sizes and shapes. Gilbert and Smiley [2004], who also evaluated the effectiveness of this method found that the average accuracy of the device is 89%.

Therefore, in order to obtain more accurate results, the use of sonic tomography combined with electrical resistance tomography is suggested. Both research methods complement each other providing a detailed picture of the inside of the examined tree trunk [Göcke et al. 2007]. Analysing the results of measurement of the tree, special attention in the picture is paid to the colours of the resulting tomogram – so-called map density of wood. Different colours represent different speed of sound inside the trunk, depending on the elasticity and density of wood [Allison and Wang 2015].

The colour shade from light brown to black corresponds to the speed of sound from 60 to 100 %, which is equivalent to a living and healthy wood tissue. Different shades of green colour match the speed of the sound wave from 40 to 60%, which means a slight deterioration of the wood structure. Pink colour defines the sound range from 20 to 40% and the colour shade from white to blue means the sound range from 0 to 20%. Thus, these are the weakest areas of the wood structure with progressive decay and the destruction of wood tissue [Chomicz 2007, 2010].

Security of the users of historic parks and avenues, with the trees of large sizes (tree monuments and trees of monumental sizes) is very important and requires precise diagnostic techniques for the detection of decay and other structural trunk defects of trees. Visual assessment (VTA) is still the starting point to carry out such studies [Matheny and Clark 1994, Mattheck and Breloer 1994, Hayes 2001, Pokorny 2003, Luley 2005].

However, the defects inside the tree trunks often remain invisible for an arborist or a botanist[Wang and Allison 2008]. For many years, the only available instrument for the detailed evaluation of the internal structure of the growing tree was Pressler borer. However, this method requires interference in the internal tissues of the tree. Its use in case of particularly valuable ancient trees is controversial [Chomicz 2010, Siewniak 2010]. Some research based on the resistance of the electric current flow or the resistance of the wood tissues were also carried out. In the first case, shigometer was used for the measurement [Shigo and Shortle 1985, Shortle and Smith 1987], and in the second -resistograph [Tattar et al. 1972, Costello and Quarles 1999].

As a result of the development of modern technologies in recent years, a number of alternative methods for the detection and localisation of the defects inside the trunk, which differ in a degree of invasiveness of measurement and the nature of information received (penetrometers, electrical conductivity meter, sound detectors and ultrasound, thermographs, radars and tomographs using X-rays etc.) have been developed. The most appropriate methods are those that reduce to a minimum the destructive impact of the study on the tree, and such is the acoustic tomography by means of the Picus tools [Chomicz 2010].

Sound tomography compared to other methods is very effective, even at early stages of wood decay [Wilcox 1988, Nicolotti et al. 2003]. In contrast to other instruments for detecting trunk anomalies, sound tomography does not require the drilling and breaking the natural barrier created by a tree in order to reduce and slow the spread of its decay [Kersten and Schwarze 2005].

In 2014 in Lublin Voivodeship 1 413 natural monuments were reported [Internet poz. 1]. On the list there were included trees and groups of trees, hedges, avenues, single and multi-species plant protection stations, scenic hills with trees, boulders, springfens et al. About 1 300 entries in the list were related to the protection of trees, which accounted for 92% of all natural monuments. Protected deciduous trees *(Angiospermae)* constituted more than 5 200 specimens belonging to 56 species. In terms of numbers prevailed: *Tilia cordata* Mill., *Quercus robur* L., *Fraxinus excelsior* L., *Carpinus betulus* L. and *Betula pendula* Roth.

Monumental deciduous and coniferous trees are distributed randomly and unevenly throughout Lublin Voivodeship. The bigger concentration of these trees is around Biała Podlaska, Lublin, Pulawy, Nałęczów, Zamość and Zwierzyniec [Pudelska et al. 2014]. In the group of *Gymnospermae* on the list of natural monuments there are located 17 taxa, and in terms of numbers in this group of trees predominate: *Larix decidua* Mill., *Picea abies* H.Karst, *Pinus sylvestris* L., *Ginko biloba* L. and *Pinus strobus* L. Protected conifers constitute approximately 4% of all monumental trees in Lublin region. Rare and alien species of coniferous trees are clearly found in places with warmer microclimate, eg. in the area of Nałęczów, with larger sizes of *Gingko biloba*, *Pinus strobus, Tsuga canadensis* and *Pinus nigra.*

Even small forms of environmental protection, eg. the protection of aged, individual trees, contribute to the preservation and promotion of the values of the natural heritage of the region [Pudelska et al. 2014]. Monumental trees provide scientific knowledge (including the phenomenon of dying trees, dendrological information, acclimatization of alien species), but they are also extremely helpful in promoting the voivodeship. Through their names ("Captain", "Warrant Officer", "Sergeant") they refer to the legends or real historical facts, remind the local heros of the village (a lime of Roman Rogiński or Kajetan Sawczuk avenue). Lublin natural monuments are often a part of the former compositions of the park and the avenue [Przesmycka 2011]. Poland is one of a few countries in Europe with quite a lot of old trees still preserved, both growing individually as well as in the form of an alley, or groups. Among them prevail: *Quercus robur*, *Tilia cordata* and *Fagus sylvatica* [Pacyniak 1988, Siewniak 1988, Kuźniewski 1996, Olaczek et al. 1996]. Many of these trees are located on the hiking, biking or horse riding trails [Kasprzak 2011, Przesmycka 2011, Machanik and Kurczewski 2014].

Materials and methods

The aim of the study was to examine the usefulness of PICUS 3 in the assessment of the health state of trees of monumental sizes. The analyses included four trees characterised by their monumental sizes, growing near Lublin in different habitat conditions. These were: two specimens of *Tilia cordata* growing in the lane at the provincial road No. 747 in Radawiec Duży, Konopnica commune and *Gingko biloba* and *Ulmus glabra* growing in the manor park in Czesławice. In case of the first two, copies of the tomograms obtained were supplemented with the photographic documentation showing the sections of logs immediately after cutting down the trees. Trees were located on the map using GPS with the help of the module forming part of the central unit (tomograph), and their height was measured by laser rangefinder Nikon Forestry PRO. The approximate age of the trees was assessed on the basis of the age tables by Majdecki [1980-86] and using the incremental factors developed by the International Society of Arboriculture and published in the Missouri Department of Conservation.

Applied sound tomograph allows for the assessment of the health state of the inside of the trunk in a virtually non-invasive way. The only factor which interferes with the structure of tissues are test pins screwed only in the necrotic cork layer. Pins and sensors attached to them are placed at the height of the expected infection or cavities after tapping the trunk with a rubber mallet. Their number depends on the diameter of the tree trunk measured and range from 12 to 16. Using the electronic caliper Picus Calliper the exact geometry of the tree trunk has been measured (Fig. 1).

In the case of monumental trees of considerable sizes, the measurement was made manually by means of the tape measure, due to the limited range of calipers. After entering the data to the main unit, sensors were connected and by means of electronic hammer blows, electronic sound waves detected by the sensors were generated (Fig. 2). Data, which was transferred to the computer enabled the analysis of the health state of the inside of the trunk in the form of the colour tomogram. Distribution of colours on the cross section of the trunk identified areas of different density of wood, which proves the presence of the internal defects, their size and location.

Fig. 1. The measurement of the geometry of the trunk using a digital caliper Picus Calliper [M. Dudkiewicz 2015]

Fig. 2. Electronic hammer used to generate sound waves [M. Dudkiewicz 2015]

Results

Tilia cordata Mill. – two examined trees were found in the lane of provincial road Nr 747 in Radawiec. The examination of the inside of the trunks was made on February 20, 2016 before the trees were cut down due to changes in the route of the S-19 road and the construction of the road junction "Lublin-Węglin".

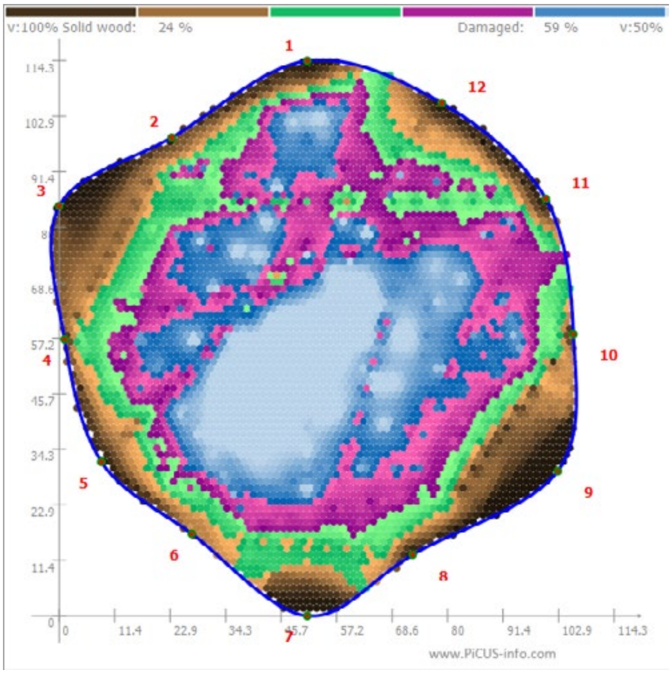

Fig. 3. Tomogram of the trunk section of *Tilia cordata* in the lanes of the provincial road in Radawiec (no. 11)

Fig. 4. General view of the small-leaved lime with clearly marked rupture and plunge loss in the trunk [W. Durlak 2016]

Fig. 5. Lime log after cutting, the visible part of an extensive process of decomposition of the core trunk [W. Durlak 2016]

Fig. 6. Leaved lime snag with advanced decay reaching below ground level [W. Durlak 2016]

On the first lime (51.214958°N and 22.386190°E) with the circumference of 375 cm, height of 16 m and the crown about 13 m, at the age of about 140-150 years, 12 measuring devices at the breast height were installed. The resulting tomogram confirmed the assumptions as to the poor health of the tree. It was found that there was an extensive damage to the internal structure of the trunk, covering 59% , with 24% of the tree surface in a good state. The decay of the wood had an increasing tendency toward the peripheral areas of the trunk (Fig. 3). In addition, there was observed a deep plunge loss in the tree trunk starting from the base of the branches with visible rupture to the height of 150 cm (Fig. 4).

Test results of tomograph PICUS confirm the visual assessment performed after cutting down the tree where the inside of the main stem was characterised by the extensive changes in the stem, covering large areas of the cross-section (Fig. 5). The cross-section of the stump also shows visible effects of decay processes of wood reaching deep inside it (Fig. 6).

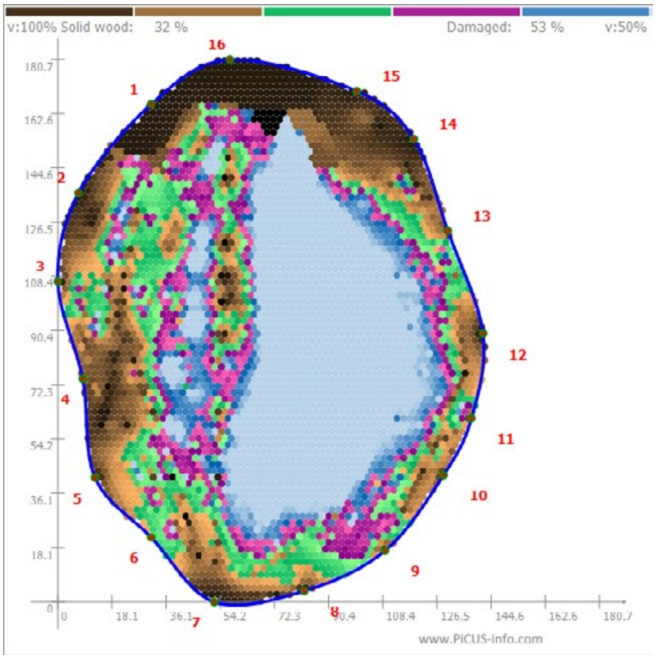

Fig. 7. Tomogram of the trunk section of *Tilia cordata* in the lanes of provincial road in Radawiec (no. 6)

Fig. 8. After cutting a tree with a visible part of the advanced decomposition process of the core trunk [W. Durlak 2016]

Fig. 9. Fragment of the upper part of the small-leaved lime logs with prominent progressive process of wood decay [W. Durlak 2016]

Fig. 10. *Flammulina velutipes* fruiting bodies on the trunk of leaved lime as the evidence of an advanced infection of the inner part of the trunk[W. Durlak 2016]

The second lime(51.215427°N and 22.385263°E) at the age of about 196-208 years, had the trunk circumference equal to 521 cm, height – 17 m, and the range of the crown – 15 m. On the trunk 16 measurement points were installed at a height of 100 cm from the ground level. The obtained tomogram revealed a deep degree of decomposition of the internal structures of the trunk area of more than 53% of the trunk. The healthy part of the trunk consisted of 32% of the total cross-sectional area of the trunk. In the trunk section there was seen the progressive decay in the western direction, where the destructive processes reduced a degree of strength of wood (Fig. 7). Inside the trunk after cutting there was seen extensive damage and an advanced level of decomposition from the butt end progressing to higher parts of the logs (Fig. 8 and 9). On the trunk from the north there were noticeable fruiting bodies of fungi of the genus *Flammulina*, which could have an impact on advancing of the infection process inside the trunk (Fig. 10).

Gingko biloba L. (51.303825°N and 22.262115°E) – tree at the age of about 162 years, growing in the manor park in Czesławice, Nałęczów commune is characterised by a large trunk circumference at a breast height of 544 cm. Its height is 21 m and the range of the crown – 17 m. The tested specimen gives the impression of a tree conjoined with several individual trees with a clear stratification of the stem structures that run to its base (Fig. 11).

On the trunk 15 sensors were installed at a height of 70 cm from the ground. Since the circumference of the trunk exceeded the maximum spacing of the arms of electronic calipers, the shape of the trunk could not be accurately mapped. Therefore, a standard shape in the form of a circle was accepted. The inside of the tested tree trunk on the tomogram shows a very large internal cavities, with only 14% of the cross -section of the trunk in a good condition while 77% is damaged wood. Clearly healthier parts are only on the edge of the trunk on the east side. The central part of the inside of the trunk is probably rotten which is shown by the light blue colour on the printout of the tomogram (Fig. 12). Health condition of the tree is therefore very worrying despite the fact that on the outside there are no symptoms of the progressive decomposition inside the trunk. The tree must be strictly monitored, mostly for security reasons and the proximity of the palace.

Fig. 11. General view of *Gingko biloba* [fot. W. Durlak 2015]

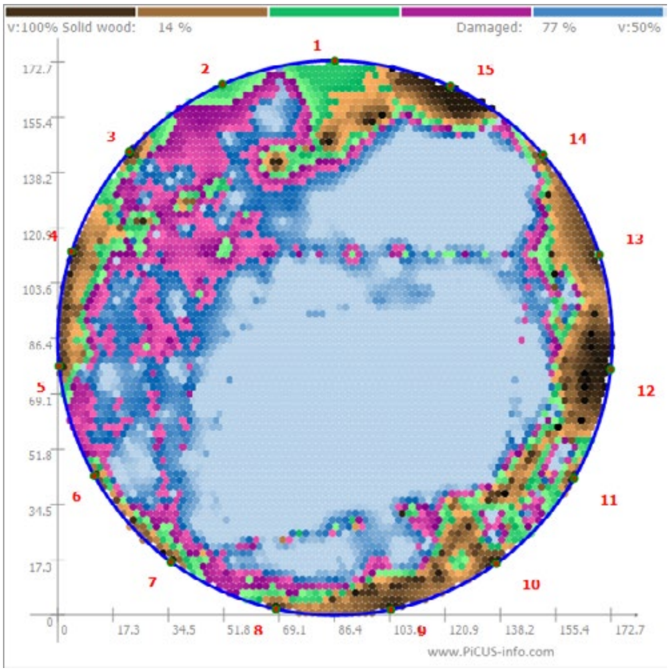

Fig. 12. Tomogram of cross-section of *Gingko biloba*

Ulmus glabra Huds. (51.303603°N and 22.262765°E) – the second representative of the tree stand in the park in Czesławice is characterized by more than 3 meter trunk circumference (308 cm), height equal to 32 m and the crown of over 16 m. The approximate age of this specimen is about 120-154 years. The tree has a characteristic**,** trunk basis for this species, with buttress roots. The trunk is not perfectly round. Accurate measurement by means of a caliper allowed for accurate mapping of its shape.

During the test, 12 sensors were installed at a height of 100 cm as a result of the initial diagnosis involving the tapping of a trunk with a rubber mallet at this altitude and hearing audible dull sounds. On the basis of the tomogram obtained, it was found that from the south-west develops a deep infection progressing towards the north-east. Infected wood covers 27% of the cross- section of the trunk and the wood technically efficient – 58% of the cross-section (Fig. 13). This confirms the photograph of a tree with a visible deep trunk loss having its beginning already at the base of the trunk and growing gradually upwards (Fig. 14). In spite of this, the tree is stable, but with time it will require more frequent monitoring.

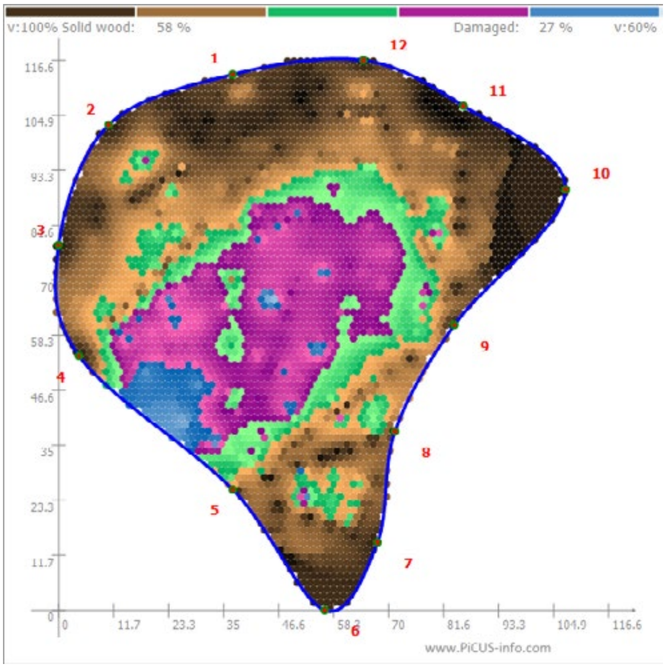

Fig. 13. Tomogram section of the trunk *Ulmus glabra*

Fig. 14. General view of the base of the trunk of elm [W. Durlak 2015]

Discussion

The applied method for assessing the health state of trees with the help of sound tomography belongs to the innovative research techniques which enable non-invasive analysis of the internal structures of a tree trunk. It is used for the detection of fungal infection leading to progressive decomposition of wood and the internal trunk defects [Wang et al. 2007, Wang and Allison 2008, Deflorio et al. 2008, Kazemi-Najafi et al. 2009, Chomicz 2010, Brazee et al. 2011].

This enables eg. the selection of infected trees or those with the decay of a core part of the trunk in forest plantations [Kazemi-Najafi et al. 2009]. This method is very useful to assess the health state of the aged trees with weakened vital forces, trees of monumental sizes or those that already exist in the registry as natural monuments. It allows you to safely assess the state of the old trees, especially valuable in the landscape, requiring care conservation [Pudelska et al. 2014]. The effectiveness of the method is very high [Gilbert and Smiley 2004]. With the help of acoustic tomography, the size of the decay of the internal structures of the trunk and its position can be quite accurately defined and at the same time it helps in the proper diagnosis of the status of trees [Rabe et al. 2004, Wang and Allison 2008].

The results of the studies allowed for the precise localization of changes caused by eg. the advanced decay inside the trunk.

It was also confirmed that the number of installed sensors influence the resolution of obtained tomograms. In sound tomography from 8 to 12 sensors are usually installed [Chomicz 2007] but it depends on the trunk circumference. The distance between the sensors should not be less than 12-15 cm [Göcke et al. 2007] and bigger than 50 cm [Manual PICUS Sonic Tomograph Q72 2010].

Such diagnostic method can be applied to the study of trees growing in public areas (parks, squares or streets) [Wang et al. 2007, Wang and Allison 2008] and in forests[Kazemi-Najafi et al. 2009, Brazee et al. 2011]. The results of the study confirmed the efficiency of acoustic tomography in the evaluation of the health state of trees growing in different habitats, both historical parks or in urban areas.

The present experiment thus confirms the efficiency of the method in which the trees diagnosed by PICUS tomograph showed in most cases extensive decay of the internal structures of the trunk.

Conclusions

1. Acoustic tomography allows to specify the defects and the size of the decay of internal structures of the tree trunks of large sizes.
2. Non-invasive examination of the inside of the tree trunks carried out with the help of PICUS Sonic Tomograph has a very high efficiency and accuracy.
3. The resolution of obtained tomograms is determined by the number of installed sensors. The optimum distance between the sensors should be 12-50 cm.
4. The exact location of the changes caused by the advanced decay detected by tomograph confirms the photographic documentation presenting the state of tree trunks after cutting.
5. Acoustic tomography method can be successfully used to assess the state of health of the trees age.

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Zastosowanie Picus® Sonic Tomograph do oceny stanu zdrowotnego drzew o wymiarach pomnikowych

Streszczenie: Celem badań było sprawdzenie przydatności tomografu dźwiękowego PiCUS 3 do oceny stanu zdrowotnego drzew o wymiarach pomnikowych. Do badań wybrano drzewa z gatunków *Tilia cordata,*, *Gingko biloba* i *Ulmus glabra* rosnące w okolicach Lublina w różnych warunkach siedliskowych. Zmiany wewnętrznej struktury pni drzew uwidocznione zostały na barwnych tomogramach. Dwa badane okazy *Tilia cordata* zlokalizowane w Radawcu Dużym przeznaczone były do wycinki ze względu na budowę obwodnicy miasta Lublin. Pozwoliło to porównać otrzymane tomogramy ze stanem faktycznym wnętrza pni drzew zbadanych po ścięciu. Wyniki tomografii okazów *Ulmus glabra* i *Gingko biloba* rosnących w Czesławicach zostały potwierdzone za pomocą wizualnej oceny drzew. W każdym z przypadków na rozdzielczość obrazu i dokładność otrzymanych tomogramów miała wpływ liczba założonych sensorów. Diagnostyka tomograficzna ma istotne znaczenie w ocenie stanu zdrowotnego każdego drzewa, ale szczególnie polecana jest przy badaniach cennych, wiekowych drzew. Metoda ta pozwala na wczesną diagnozę i wybór takich działań ochronnych, które ograniczą do minimum destrukcyjny wpływ badania na organizm rośliny.

Słowa kluczowe: *Gingko biloba*, *Tilia cordata*, *Ulmus glabra*, drzewa o wymiarach pomnikowych, tomograf PiCUS Sonic