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PRELIMINARY RESULTS OF THE MONUMENTAL TREE MONITORING BASED ON TERRESTRIAL LASER SCANNING - A CASE STUDY OF THE OAK BARTEK IN ZAGNAŃSK (POLAND)

WSTĘPNE WYNIKI MONITOROWANIA DĘBU BARTEK W ZAGNAŃSKU Z WYKORZYSTANIEM CHMUR PUNKTÓW NAZIEMNEGO SKANOWANIA LASEROWEGO

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KEYWORDS: LiDAR, TLS, 3D modeling, RevScan

ABSTRACT: In April 2013, the Laboratory of Geomatics launched the project under the acronym "Bartek 3D" in cooperation with the Research Section of Students from the AGH in Krakow, Pedagogical University and the Jagiellonian University as well. The main aim of the project is to monitor the biggest and probably one of the oldest trees in Poland - Oak Bartek in Zagnańsk (N 50°59'14"; E 20°38'59"), based on multi-temporal Terrestrial Laser Scanning (TLS) technology. One of the results of the project should be a 3D model of Oak Bartek and detection of the changes in the shape of the tree. Terrestrial Laser Scanning and the traditional forest inventory measurements were performed during the Leaf-OFF season in April 2013 and April 2014 and repeated in Leaf-ON period in July 2013 and October 2014 with using scanners: FARO FOCUS 3D, RIEGL VZ-400, LEICA C10 and RevScan (HandyScan). The results based on TLS technology showed some differences comparing to existing data obtained by traditional measurements for forestry inventory:
• Height (H) of the tree: altimeter Vertex (Haglöf) H = 29.31 m; H_{TLS} = 28.49 m;
• Trunk circumference (L) measured with stretched tape: L_{ST} = 9.80 m; adjacent along the shape of bark: L_T = 13.70 m; TLS measurments: $L_{TLS1/4}$ = 9.97 m oraz $L_{RevScan}$ = 13.54 m
• The average diameter at breast height (DBH_{130cm}) calculated on the basis of 3D basal area of stem $DBH_{TLS1/4}$ = 3.03 m (DBH_T = 3.12 m).

1. INTRODUCTION

Traditional measurement methods of forest stands and individual trees, including tree monuments, are based on the use of survey instruments such as rangefinders, hypsometers, total stations, calipers, compasses or just measuring tapes. Although such measurements are usually some approximation of the real values where measurement of the trunk diameter is usually carried out on the basis of only one measurement using calipers at the height of 130 cm above the ground or by measuring tape often not matching well the curvature of stem or bark with complex shape. Such measurements performed during e.g. forest inventory are still treated as a reference by foresters (Avery and Burkhart, 2002). Upon consolidation of a laser scanning technology, which has become like a new paradigm in the field of survey, the traditional methods used by foresters will be probably replaced by new technology in the very near future. Determination of selected tree parameters such as tree taper in a traditional way, unfortunately, requires cutting the tree and measure the trunk diameters in sections of 1.0 to 2.0 meters. Such measurements can be performed today using the terrestrial laser scanning technology (TLS) in a non-invasive way with even very accurate results. During terrestrial laser scanning process, besides tree measurements, other elements of the surrounding of 3D space, such as bushes, ground, low vegetation etc. are registered and investigated.

In April 2013 the Laboratory of Geomatics (Department of Forest Management, Geomatics and Forest Economics, Institute of Forest Resources Management, Faculty of Forestry, University of Agriculture in Krakow) launched the project under the acronym: "Bartek 3D". The goal of the geoinformation project was the monitoring of the largest and one of the oldest trees in Poland – the Oak Bartek. The activities were carried out with the participation of the scientific staff, undergraduate, graduate and Ph.D. students as well as members of the Section of Geomatic from of the University of Agriculture in Krakow. Also other students took part in the project like students from AGH University of Science and Technology in Krakow, Pedagogical University in Krakow and Jagiellonian University as well. The patrons of the project are the General Board of Environmental Protection in Warsaw (GDOŚ) and the General Director of the Polish State Forests National Forest Holding.

The project is based on the use of laser scanning technology, known as LiDAR (Light Detection And Ranging), dynamically developing over the recent several years. Laser scanning is a technological solution used in different areas of science and economy, particularly in the monitoring of natural environment and forest inventory (Andersen *et al.,* 2006; Drzewiecki *et al.,* 2014; Holmgren and Jonsson, 2004; Hyyppä *et al*., 2004; McGaughey *et al*., 2004; Szostak *et al*., 2014; Wężyk, 2008; Wężyk *et al.,* 2013). The measurement of the parameters of single trees and forest stands with the application of Terrestrial Laser Scanning technology (TLS) have been the objects of intensive studies and practical implementations for several years (Bienert *et al*., 2006; Fernández-Sarría *et al*., 2013; Henning and Radtke, 2006; Lichti *et al*., 2002; Pfeifer and Winterhalder, 2004; Pueschel, 2013; Watt and Donoghue, 2005; Wencel *et al*., 2008; Wężyk *et al*., 2007; Wężyk *et al.,* 2009). Terrestrial Laser Scanning (TLS) of single trees or inventory plots in the forest stands is usually carried out in one-station mode or multi- station mode, which of course prolongs the time of field work, but it allows to get data fully representing tree trunks and crowns and not only fragments of tree observed from one scanner position.

The technology of Airborne Laser Scanning (ALS) due to the ability to penetrate laser impulses through the tree crown to the topographic surface allows for the full representation of the terrain forms. The integration of TLS and ALS makes a completely new approach to modeling and visualization of trees and part of forest stands. Integrated point clouds in a precise way, allows the approximation of the surfaces running on the ground or the tops of the tree, considering the details of the objects or properly generalizing them. Two precise height models, obtained as a result of processing the point clouds, i.e.: Digital Terrain Model (DTM) and Digital Surface Model (DSM) enable to generate the derivative information, i.e. nDSM (normalized DSM). This model describes the relative altitudes of the objects occurring in the area, i.e.: tree stands, bio-groups and single trees. In the case of nDSM of the forest we can use another term; CHM - Crown Height Model (Wężyk *et al.,* 2008).

The goal of the project is the monitoring of the Oak Bartek (Quercus robur L.), carried out in repetitive terrestrial laser scanning. The carrying out works were planned for different phenological seasons, i.e. in the dormant period (November-April), when the Bartek Oak does not have the photosynthesis apparatus (Leaf-OFF conditions) and in the phase of the full vegetation (May-October; Leaf-ON). As the result of the project, the 3D models of the Bartek Oak and the analysis of archival descriptive materials were obtained. In this paper, the preliminary results of the Bartek Oak monitoring based on terrestrial laser scanning are presented.

2. OBJECT OF STUDIES

The Pedunculate Oak, which grows in Zagnańsk (Świętokrzyskie Voivodeship) called Bartek (Quercus robur L.) and it is the most famous Polish tree (N 50°59'14"; E 20°38'59"; Fig.1). It owes its popularity to its size, shape and mainly the age. Since 1954, it has been protected as the monument of nature. It is one of the biggest tourist attractions in Zagnańsk, as well as the whole area of the St. Cross Mountains. The Oak Bartek is numbered Nr 35/2007 in the register of the natural monuments in Świętokrzyskie Voivodeship (12 Dec. 2007).

The Oak Bartek for many years is the subject of many papers and publications that contribute to the popularization of knowledge about the tree and its protection. Some details of measurements of height, diameter at breast height, circumference and other parameters from the years 1829-1985 are presented below (Janicki, 1987; Table 1).

Fig. 1. The Oak Bartek (October 2014)

Table 1. Archival data (measurements from the years 1829-1985; Janicki, 1987)

Parameter / Year	**1829**	**1920**	**1959**	**1968**	**1985**
Diameter at breast height (DBH_{130}) [m]	2.52	2.65	2.83	2.87	3.06
Height of tree [m]	23.5	-	27.0	-	28.0
Estimated age [years]	800	-	1000	640	685
Trunk $_{BASE}$ circumference [m]	-	13.4	13.4	-	13.4
Trunk $_{DBH}$ circumference [m]	7.92	8.32	8.90	9.00	9.20
Stem volume [m^3]	29.40	-	36.92	-	-
Branch volume [m^3]	38.68	-	48.08	-	-
Total tree volume [m^3]	68.08	78.00	85.00	-	-

Fig. 2. Selected stand of the FARO FOCUS 3D scanner with the reference spheres

3. METHODS

Terrestrial Laser Scanning and the traditional forest inventory measurements of the oak were carried out twice in the Leaf-OFF period (April 2013 and 2014) and Leaf-ON (July 2013 and October 2014). State-of-the-art-technology ground-based scanners were applied in this project, i.e.: FARO FOCUS 3D (AGH in Krakow, IBL Warsaw and TPI), LEICA C10 (AGH) and RIEGL VZ-400 (Laser-3D). During the scanning, a local coordinate system was used for single scans. The TLS point clouds were obtained every time from several scanner positions (Figure 2) e.g. LEICA C10 (4 scanner positions), FARO FOCUS 3D (13 scanner positions) and RIEGL VZ-400 (23 scanner positions). In the study area, the reference spheres (radius 7.5 cm) were put for the process of matching the single Faro Focus scans. In case of LEICA C10 and RIEGL-VZ 400 scanners, the special tilt and turn targets were used. The FARO FOCUS 3D scan resolution was set to the 1/4 (6 mm on 10 m distance) of full scan. Additionally, applying digital built-in camera the RGB value of pixels were given to the point cloud obtaining realistic 2D or 3D "color scan". The vertical and horizontal spacing (resolution) for the LEICA C10 scanner was set for 0.02 m on 100.0 m distance. In case of RIEGL VZ-400 the angle measurement resolution was 0.001°.

To give the TLS point clouds, a right georeference GNSS measurements were performed in RTK mode with corrections obtained from ASG-EUPOS. The TLS targets got the georeference by measuring them with a tachymeter and the tachymeter network was georeferenced by GNSS measurements.

To make photographic documentation, the digital cameras (RICOH G700SE) equipped with GPS receiver and electronic compass were used. For additional traditional forest inventory measurements of the tree height, the altimeters Vertex IV (by Haglöf) was applied.

Faro Scene ver. 5.x (FARO) and Cyclone (LEICA) software were used in the processing of the TLS point clouds obtained from several stands. The processing of FARO TLS data started from matching the single point clouds from individual scans based on reference spheres (Fig. 3). We used approx. 20 spheres to match 13 single scans (293 million of points; Oak Bartek only 42 million points) together. The point cloud collected from scanner position no 1 was set as "master" scan (reference; XYZ = 0,0,0) and others point clouds were matched as "slave" scans using the spheres. In case of the LEICA C10 point clouds, we used special "tilt and turn" targets with positions registered using Javad Triumph-1 GNSS RTK receiver. In case of the point clouds collected with RIEGL no special targets were used. We decided that the one scan will be used as reference and others were matched with cloud-to-cloud approach using a planar surfaces such as stone, information boards, supports etc. All three matched TLS point cloud (FARO, LEICA and RIEGL) were processed separately in different coordinate systems. In near future we plan a global transformation of every TLS dataset to the one "reference" (probably RIEGL) coordinate system using precise GNSS and tachymeter survey (GNSS signal will be obtained on the parking place characterized by an open sky). All TLS datasets were converted and written to LAS (ver. 1.2) format. The classification of the TLS point clouds was carried out in the module of TerraScan (Terrasolid) software in order to discriminate vegetation, ground and low point class.

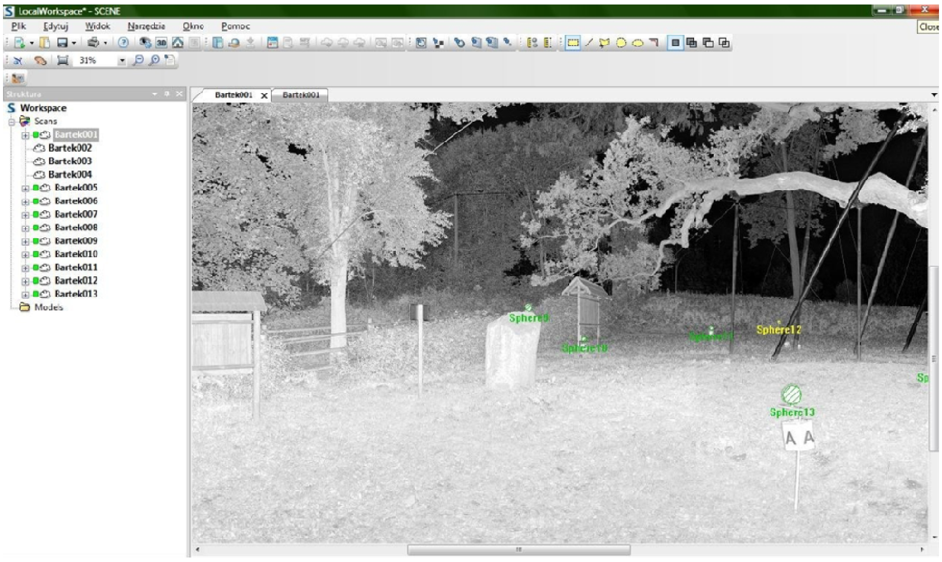

Fig. 3. Detecting and registering the reference spheres in a planar view – matching the single scans in FARO Scene software

The following stage of the work was 3D modeling of the point cloud. Processing huge amount of geodata by modeling objects means the transfer from the TLS points to sets (classes) representing objects (e.g. DTM, DSM, trees etc.). In further order, classified LiDAR points were used to approximate surface or fit planes of geometric figures (e.g. tree crown and trunk). Software applied to transform the point clouds TLS allows its visualization. It also allows many other operations connected with the direct measurements and calculations, e.g. volume (modeling of the cloud to geometric figures and surfaces). The basic action of the software operator is the measurement of tree diameter at the breast height (DBH) and the total tree height. The work of data analyst modeling the reality projected in 3D has to be supported by algorithms allowing the automation of the processing of hundreds of laser beams reflections, at the same time limiting its subjectivity. There are many possibilities of 3D modeling of the clouds of measured TLS points, allowing generating the surface or modeling individual fragments of the trunk by fitting cylinders or truncated cones. The modeling was carried out in different types of software: CAD, 3DReshaper (TECHNODIGIT) or SketchUp (Trimble).

To obtain reference model of DBH of the tree, very precise scanning with triangulation scanner RevScan HandyScan (by Creaform; Casp System; Fig. 4) was carried out in July 2013. The scanner has a scanning accuracy of 0.05 mm. Gathered point cloud was processed in Geomagic software (Fig. 5).

Fig. 4. Precise scanning of the trunk Handy Scan - RevScan (July 2013)

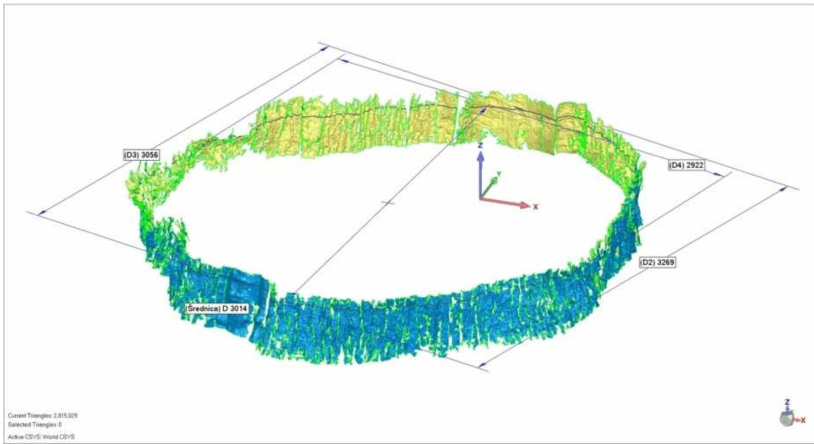

Fig. 5. Processing of the data from triangulation scanner RevScan – visualization of the trunk (height of DBH; HandyScan; Geomagic software)

4. RESULTS

Based on the TLS point clouds it was possible to generate a different views with data, in particular following images were created:

- the top view of the Oak Bartek (Fig. 6);
- the planar view of FARO FOCUS 3D measurements performed in April and July 2013 (Fig. 7);
- the 2.5D view of the classified TLS point cloud (Fig. 8).

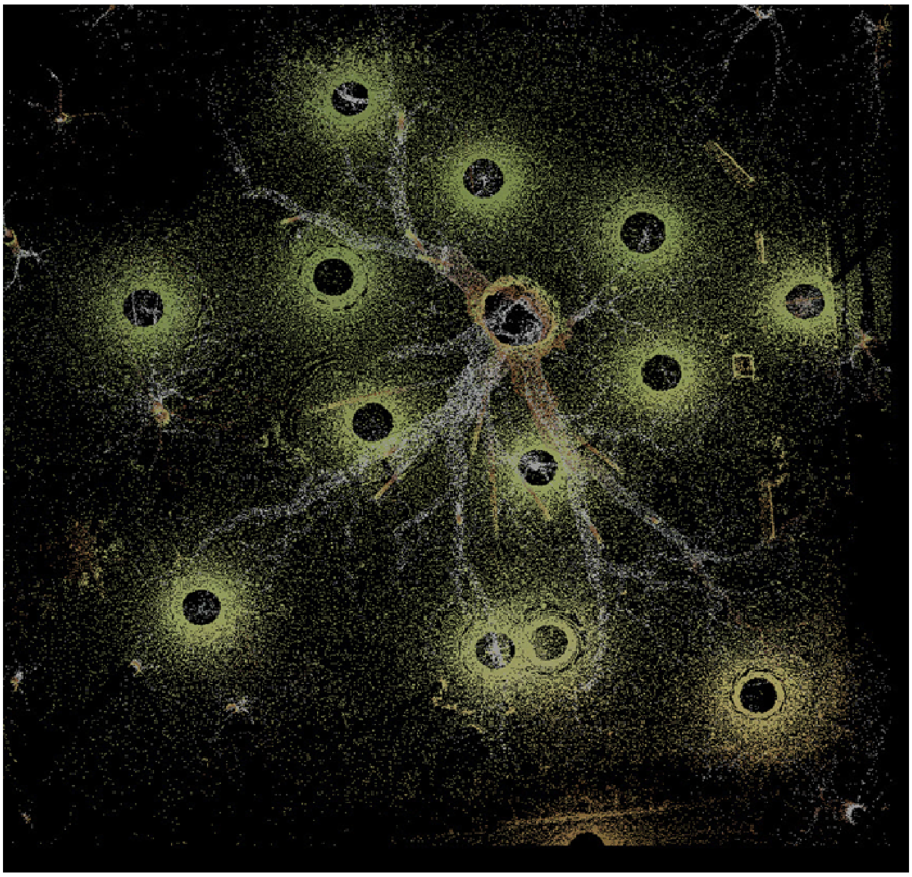

Fig. 6. The top view onto the TLS point cloud, color points by elevation (earth tones) with the scanner positions (black: no-data gaps excluding stem)

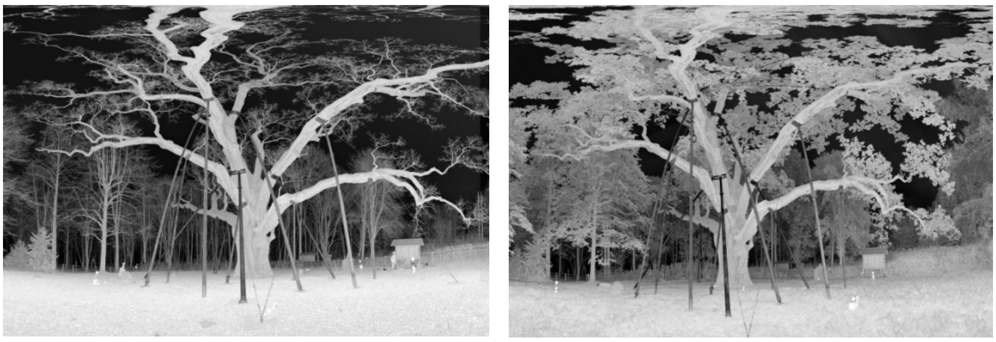

Fig. 7. The planar view of the TLS FARO FOCUS 3D - point cloud 360° x 320° (Intensity; April 2013 - left, July 2013 - right)

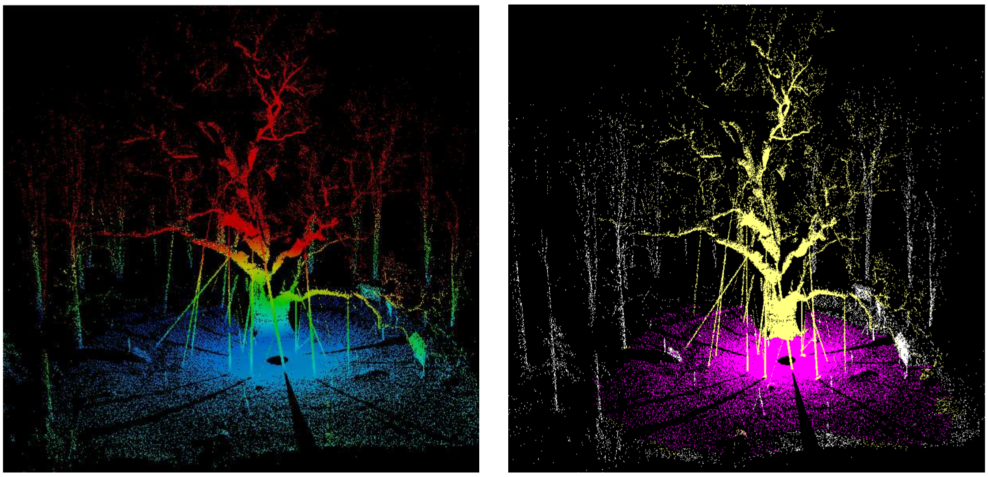

Fig. 8. The 2.5D view of the TLS point cloud. The color shows the relative height above the ground (left) and classes (right): ground – purple, Oak Bartek – yellow, other vegetation - white

The results of 3D modelling of the TLS point clouds in 3DReshaper are presented in Figure 9 while Figure 10 shows the part of trunk modeled based on the triangulation scanner RevScan (HandyScan) data.

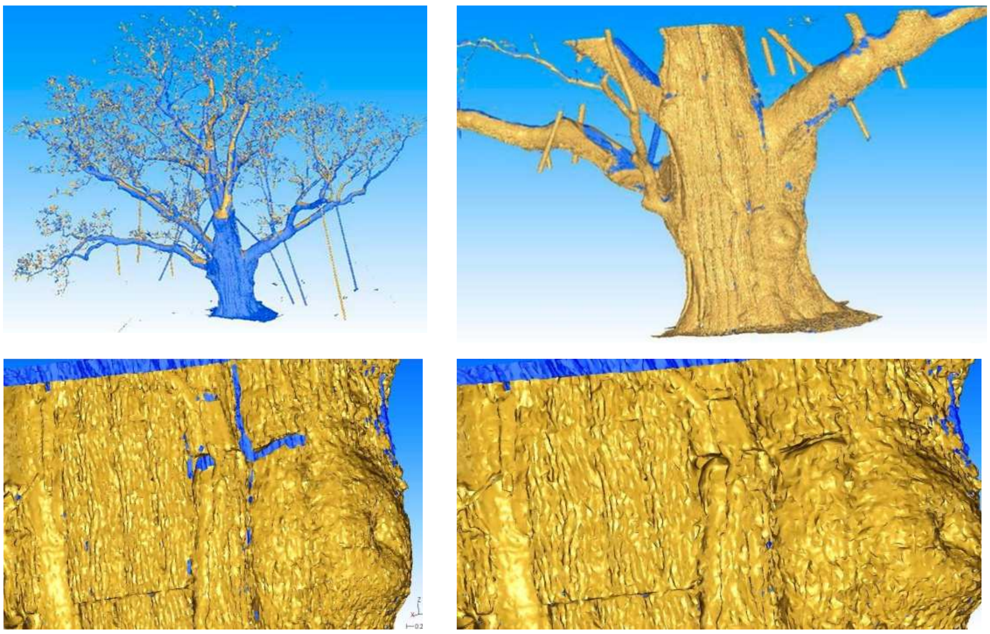

Fig. 9. Preliminary 3D model of the Oak Bartek (top) and filling the model gaps (bottom) using the 3DReshaper software

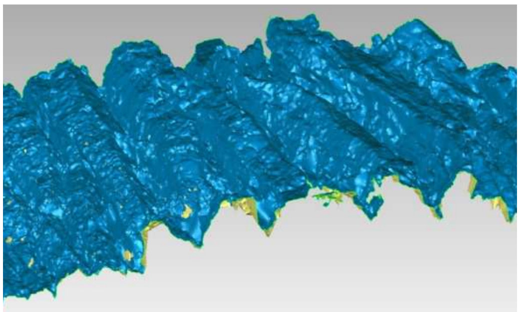
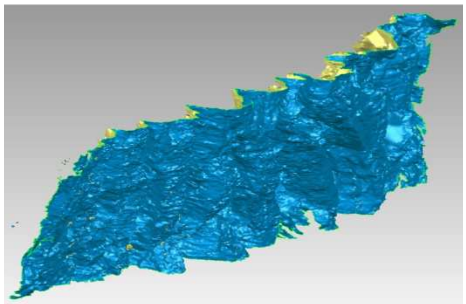

Fig. 10. Part of the modelled bark on the trunk based on the measurements performed with triangulation scanner RevScan (HandyScan)

The measurements results based on TLS point cloud (scanners: FARO, LEICA, RIEGL) showed certain differences in the relation to the data collected with traditional forest inventory methods (Table 2). Measurement using a traditional survey tape fitting the very complex shape of bark showed that trunk circumference (L) was 13.70 m which was a higher value (+3.9 m; 28%) than obtained from the survey performed with stretched tape (9.80 m).

Trunk circumference generated from the point cloud (TLS FARO) can take various values depending on the resolution (1/2 or 1/4) and the tolerance settings. For example trunk, circumference (L) generated without smoothing the mesh model has value 9.97 m for the 1/4 resolution. When the FARO FOCUS 3D was experimentally set to the 1/2 of full resolution, the circumference (L) arrived 10.90 m.

Precise measurements of the trunk using triangulation scanner RevScan (HandyScan; Casp System) allowed for a detailed determination of basal area (g) and a trunk circumference (L), which were respectively: 7.02 m^2 and 13.54 m. There were some problems generating the mesh because of the gaps in the RevScan point data. The reason for such gaps was the absorption of RevScan red laser light by chlorophyll compact in moose growing on the bark on the north and west aspect of the trunk. To compare the two dataset (point clouds: RevScan and FARO) - the RevScan was set as reference (local coordinate system). In first step the cloud registration was performed in CloudComapre software with setting aloud the 500000 random sampling limit. The calculated RMS was 0.0069 m. Other Cloud2Cloud matching function (Cloud Compare software; the nearest neighbor algorithm) showed that mean distance between two point clouds: RevScan (ref.) and FARO Focus 3D, was only 0.0029 m (Fig. 11).

Crown branches range in the traditional measurement in north-south and east-west direction is approximately 40 m and 30 m, respectively, while corresponding ranges obtained from TLS data are equal 37.9 m and 32.48 m, respectively. Based on the point cloud outline, the coverage crown projection A_{TLS} = 604 m^2 was calculated (Fig. 12).

Table 2. The measurements results based on traditional forest inventory methods and terrestrial laser scanning approach (TLS - scanners: FARO, LEICA, RIEGL; RevScan – very precise triangulation scanner)

Parameter	**Traditional forest inventory measurement (reference)**	**Terrestrial laser scanning approach**
Height of tree	Vertex (Haglöf) = 29.31 m	H_{TLS} = 28.49 m
Trunk circumference (L)	L_T = 13.70 m (adjacent along the shape of bark) L_{ST} = 9.80 m (stretched tape)	$L_{TLS1/4}$ = 9.97 m $L_{RevScan}$ = 13.54 m $L_{RevScan\ -SP10}$ = 10.90 m (Simplify Poligon, 0.1m tolerance) $L_{RevScan\ –SP50}$ = 10.55 m (Simplify Poligon, 0.5m tolerance)
DBH_{130cm}	DBH_T = 3.12 m	$DBH_{TLS1/4}$ = 3.03 m
Basal area (g)	g = 7.74 m^2	$g_{TLS1/4}$ = 7.23 m^2 $g_{RevScan}$ = 7.02 m^2
Stem dimensions	n.a.	N-S=3.25 m / E-W = 3.6 m

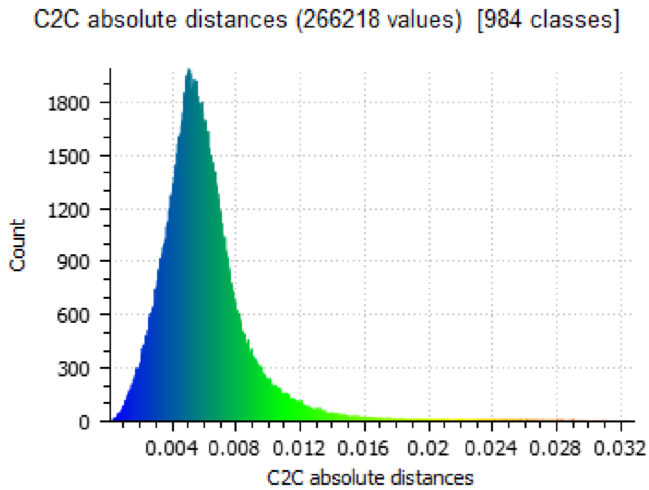

Fig. 11. Histogram of the mean distances between two point clouds: RevScan (reference) and FARO FOCUS 3D (Cloud Compare software)

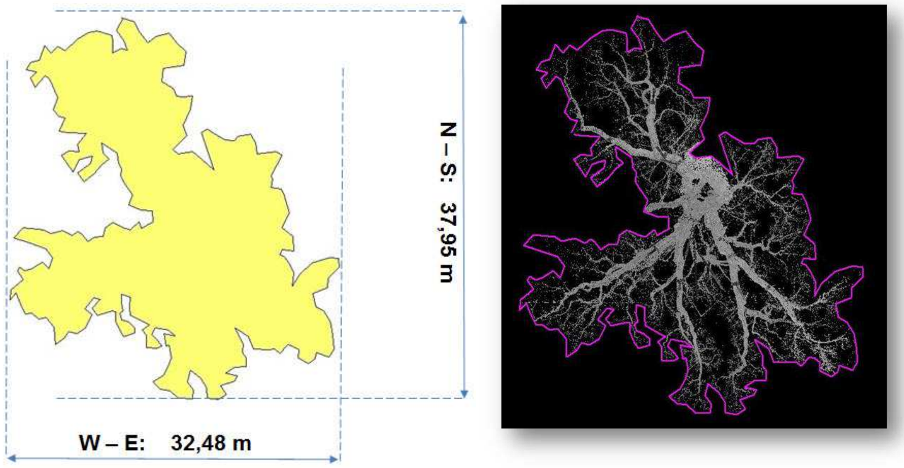

Fig. 12. The tree crown projection area (top view) - 604 m^2 (outline of the point cloud).

5. CONCLUSIONS AND FUTURE WORK

It should be stressed that modern LiDAR measurement technologies give the possibilities of the automation in the data processing and enable the acceptation of other than applied so far traditional solutions in the monitoring and nature conservation. The use of laser scanning data, to assess and document the present state of the Oak Bartek allows not only for the precise determination of its height, trunk circumference or DBH but in the future, owing to systematic scanning, we will possibly see if it is bending or if Oak Bartek is losing some branches. It has a great significance for a precious tree. Apart from that, the collected data allow capturing a precise appearance of the Oak Bartek in 2013 and repetitively, as well as in subsequent years.

One of the greatest advantages of the conducted project is the ability to performing tree measurements objectively with extremely high precision. In the first phase, the goal was to choose suitable methodology and selection of the scanner, which will ensure receiving accurate point clouds. In later years, this will serve the observation of the changes in the tree, such as: shape of boughs (fractures, loss), the growth of new branches and shoots, vitality, surface assimilation apparatus. The measurements from TLS will also enable precise analysis of changes in the statics of the tree what will be helpful for creating a protection infrastructure of the monument.

At the current stage of the project, the proper scanning methodology with the optimal distribution of the scanner positions is established. The testing phase was necessary to enter a phase of comparing TLS point clouds with each other (e.g. cloud to cloud method) in order to determine the changes of the monumental tree (e.g. fractures of boughs). In addition to monitoring of shape and statics of the tree, the modelling activities are carrying out. Creating models will enable reconstruction of the monument or its parts if needed. Today, one hardly thinks about creating monuments using 3D printers, but this technology will soon enter into our daily live and museums will fill slowly with virtual works of art such as point clouds. TLS technology allows us to create for our successors very accurate 3D measurements so that follow-up studies will be possible not only on the basis of archival analog records or publications but also on precise 3D models.

Further scenario of project „Bartek 3D" includes more TLS scanning, integration of TLS and ALS point clouds (from ISOK project), and executing making UAV (Unmanned Aerial Vehicle) flight to obtain photos for the needs to generate 3D models with the method of the dense point cloud matching (e.g. Semi-Global Matching - SGM algorithm). It is also planned to carry out the analysis of the Leaf Area Index and hyperspectral imaging as well (UAV). The precise measurement of BHD using RevScan or FARO freestyle scanner should be repeated in 2016. Also, the analysis of the direct influence of the surrounding on the tree and processing the archive cartographic materials in GIS are still under elaboration.

6. ACKNOWLEDGEMENT

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WSTĘPNE WYNIKI MONITOROWANIA DĘBU BARTEK W ZAGNAŃSKU Z WYKORZYSTANIEM CHMUR PUNKTÓW NAZIEMNEGO SKANOWANIA LASEROWEGO

SŁOWA KLUCZOWE: LiDAR, TLS, modelowanie 3D, RevScan

Streszczenie

W kwietniu 2013 roku w Laboratorium Geomatyki rozpoczęto projekt „Bartek 3D", realizowany przy współudziale Sekcji Studenckich Kół Naukowych z Uniwersytetu Rolniczego w Krakowie, Akademii Górniczo-Hutniczej w Krakowie, Uniwersytetu Pedagogicznego w Krakowie oraz Uniwersytetu Jagiellońskiego. Jako cel projektu przyjęto monitoring największego i jednego z najstarszych drzew w Polsce, tj. Dębu Bartek w Zagnańsku, (N:50°59'14"; E: 20°38'59"), prowadzony na drodze cyklicznego naziemnego skanowania laserowego. Jednym z efektów projektu ma być model 3D Bartka oraz opracowanie archiwalnych materiałów kartograficznych wraz z integracją wieloźródłowych danych w środowisku GIS.

Skanowanie wykonano w okresie bezlistnym (kwiecień 2013 i 2014) i powtórzono w ulistnionym (lipiec 2013, październik 2014). Wykorzystano nowoczesne skanery naziemne: FARO FOCUS 3D (dzięki uprzejmości AGH w Krakowie, IBL oraz firmy TPI sp. z o.o.), LEICA C10 (AGH), VZ-400 (RIEGL; Laser-3D) a także RevScan HandyScan firmy Creaform (Casp System).

Pierwsze wyniki pomiarów Dębu Bartek technologią TLS wykazały pewne różnice w stosunku do istniejących danych pozyskanych metodami tradycyjnymi:

- wysokość drzewa - wysokościomierz Haglöf Vertex: H = 29.31 m; analiza chmury punktów: H_{TLS} = 28.49 m;
- obwód pnia pomierzony naciągniętą taśmą mierniczą: L_{ST} = 9.80 m; przylegającą wzdłuż załamań i szczelin kory: L_T = 13.70 m; wyznaczony z pomiarów TLS: $L_{TLS1/4}$ = 9.97 m oraz $L_{RevScan}$ = 13.54 m;
- średnia pierśnica (DBH_{130cm} drzewa obliczona na podstawie pola przekroju $DBH_{TLS1/4}$ = 3.03 m (DBH_T = 3.12 m).

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