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IDENTIFICATION OF FLOW RESISTANCE COEFFICIENTS IN FLOODPLAIN FORESTS USING TERRESTRIAL LASER SCANNING

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Abstract: The paper presents a method of determining the resistance coefficient for waters in floodplain forests, using terrestrial laser scanning (TLS). Determining a drag coefficient hangs on correct determination of the shape drag coefficient for a single element in a group of trees. In order to determine the average shape resistance coefficient, the authors used a computational formula proposed by Lindner and Pasche, modified by Rickert [4]. Parameters to be determined in the equation include: a reliable diameter of trees and their spacing towards and perpendicular to the flow. The data was obtained using the technology of terrestrial laser scanning, carried out by means of the FARO LS 880 scanner, which uses the phase shift technology for measurements. The processing of the obtained data was based on a layer cut out of a 3D point cloud, which provided a basis for determining major taxation features, such as: trunk diameter, height of the tree and its location. For each tree in the area examined (floodplain areas near the estuary of the river Widawa) the coordinates of location in PUWG 1992/19 system as well as the diameter at the height of 50, 100 and 130 cm from the ground was determined. The obtained data were used to calculate the water flow resistance coefficient.

Streszczenie: W artykule zaprezentowano metodę wyznaczania współczynnika oporu przepływu wody w lasach na terenie zalewowym z wykorzystaniem naziemnego skaningu laserowego (TLS). Określenie współczynnika oporu sprowadza się do poprawnego wyznaczenia współczynnika oporu kształtu dla pojedynczego elementu wśród grupy drzew. Dla wyznaczenia uśrednionego współczynnika oporu kształtu autorzy wykorzystali formułę obliczeniową zaproponowaną przez Lindnera i Paschego w modyfikacji Rickerta [4]. Parametrami, które należy określić w równaniu są: średnica miarodajna drzew i ich rozstaw w kierunku przepływu oraz prostopadle do niego. Dane te uzyskano wykorzystując naziemny skaning laserowy, przeprowadzony przy użyciu instrumentu FARO LS 880, który dokonuje pomiaru z wykorzystaniem technologii przesunięcia fazowego światła (phase shift). Przetwarzanie uzyskanych danych oparto o warstwę wyciętą z chmary punktów 3D i na tej podstawie określono podstawowe cechy taksacyjne takie jak: średnica pnia, wysokość drzewa oraz jego lokalizację. Dla każdego z drzew na obszarze badań (tereny zalewowe ujściowego odcinka rzeki Widawy) wyznaczono współrzędne położenia w układzie PUWG 1992/19 oraz średnicę na wysokości 50, 100 i 130 cm od gruntu. Na podstawie uzyskanych danych wyliczono współczynnik oporu przepływu wody.

Резюме: В настоящей работе представлен метод определяния коэффициента сопротивления протекания воды в лесах на пойменных участках с использованием надземного лазерного сканирования (TLS). Определение коэффициента сопротивления сводится к правильному опрделению коэффициента сопротивления формы для отдельного элемента среди группы деревьев. Для опрделения усредненного коэффициента сопротивления формы авторы использовали расчетное уравнение, предложенное Линднером и Паше в модификации Рикерта [4]. В уравнении нужно определить следующие параметры: надежный диаметр деревьев и их расстояние согласно направлению протекания, а также перпендикулярно к нему. Эти данные были получены с использованием надземного лазерного сканирования, проведенного с употреблением инструмента FARO LS 880, который выполняет измерения с использованием технологии фазового сдвига света (phase shift). Разработка полученных данных базирует на слое, выделенном из тучи пунктов 3Д и на основании этого были определены основные таксационные свойства, такие как: диаметр ствола, высота дерева, а также его размещение. Для каждого из деревьев на исследуемом участке (пойменные участки отрезка реки Видавы вблизи устья) были определены координаты расположения в системе PUWG 1992/19, а также диаметр на высоте 50, 100 и 130 см от грунта. На основе полученных данных был рассчитан коэффициент сопротивления протекания воды.

1. INTRODUCTION

The biological development of the areas in question (i.e., the areas of high water river-bed and polders) changes the hydraulic conditions by increasing the surface roughness, and consequently increasing the water level ordinate.

Solving these problems involves mathematical modelling of high water flows and floodplain areas mapping. Hydrodynamic modelling allows for many problems to be analysed on different levels of the flood course. They are employed both when designing flood control protection and during a flood for the purposes of crisis management as well as forecasting the different processes caused by the flood. Many computer systems for water flow hydrodynamic modelling have been developed, e.g., HEC-RAS, HEC-HMS, MIKE 11. MIKE 21, FLUVIAL. These are usually software packages which may be used to solve the problem of water flow in any part of a river. The problem of modelling lies in the selection of an appropriate type of mathematical model, proper construction of a database to suit the computer model and making proper assumptions for boundary value problems in the modelling process. Data needed to carry out flow modelling includes among others the information relating to the shape of the flow area and hydraulic resistance, which in turn depend on the ground cover. In the currently offered high class software the values of resistance to motion are chiefly determined based on the “general flow law”. In particular, this refers to vegetation areas, where resistance to motion is dependent on the substratum and vegetation parameters. As the method is relatively new, the improvement and verification works are on the way. The article presents one of the selected elements of determining resistance to motion due to high vegetation, using the latest remote sensing techniques in the form of terrestrial laser scanning (TSL).

2. METHODOLOGY

The methodology of computing a river valley flow capacity defines high vegetation as one which is higher than the depth of flow and is hardly affected by hydrodynamic thrust of water [1].

The methodology of applying the so-called "general resistance law", used to describe the flow in rivers having a biological development, developed in Germany [2], takes into consideration movements caused by a tree stand, depending on its geometrical parameters, such as:

d_p – tree trunk diameter [m],

a_x – distance between tree trunks in the direction of flow [m],

a_y – distance between tree trunks perpendicular to the flow [m],

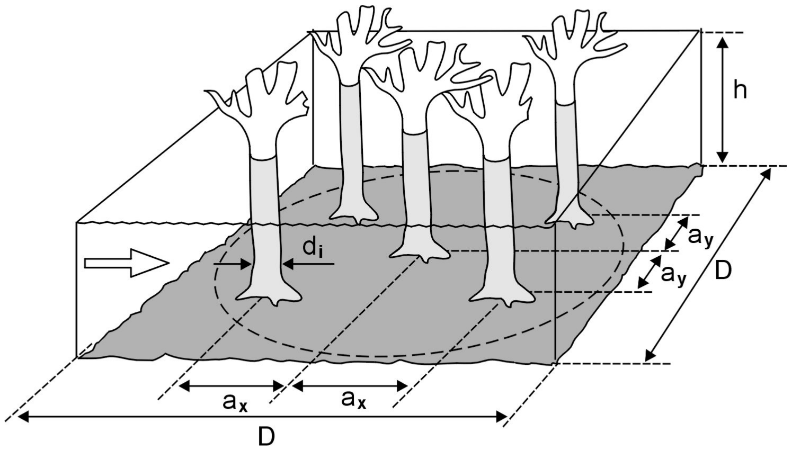

Fig. 1. Parameterisation of high vegetation

Flow drag due to high vegetation (its non-flooded part) is mainly linked to the resistance of the lump of vegetation which has been flown round. If there is a cluster of trees, the parameterisation of plants amounts to determining their average diameter d_p and spacing a_x and a_y (figure 1). The average non-dimensional coefficient of tree resistance is then computed from the following formula:

$$\lambda_r = C_{WR} \frac{4 \cdot d_p \cdot h \cos\alpha}{a_x \cdot a_y} \tag{1}$$

where:

h – flow depth [m],

α – angle of inclination of the area longitudinal section to the horizon,

C_{WR} – averaged shape drag coefficient [–].

To compute the coefficient C_{WR} Lindner quotes a dependence which is convenient to use for practical purposes in Rickert's modification [4]:

$$C_{WR} = \left[1{,}1 + 2.3 \cdot \frac{d_p}{a_y}\right] \cdot \left[0.6 + 0.5 \cdot \log\left(\frac{a_x}{a_y}\right)\right] + 2 \cdot \left[\frac{1}{1 - \frac{d_p}{a_y}} - 1\right]. \tag{2}$$

Estimating the values of parameters d_p as well as a_x and a_y requires time-consuming field studies. These parameters usually change in space. For this reason it is necessary to separate fragments which are characterized by a similar spatial features distribution and then determine their average values, which in calculations are considered reliable for a given part of area. The size and shape of vegetation test areas should depend on the type of tree stand and age class. In forest stocktaking works usually circular test areas are used. The circular shape is optimal due to its shortest circumference, thanks to which there are fewer border plants in the test area as compared to polygons (e.g., square). The size of circular test areas chiefly depends on the age class or development phase of a tree stand (different tree density index per area unit). It is believed that the test area should not contain more than 25 trees [3]. An optimal size of the test circle A may be determined as follows:

$$A = \frac{l}{L} \tag{3}$$

where:

l – optimal number of trees in the test area,

L – number of trees per 1 ha.

Hence:

$$D = 2\sqrt{\frac{A}{\pi}}. \tag{4}$$

High vegetation (tree stand) development may represent both an open polder area and a river valley zone, analysed from the point of view of flood threat. High vegetation (analysed in this study from the point of view of flow drag) is the one whose height of cylindrical trunk (t) equals or exceeds the depth of flowing water (h) (see figure 2).

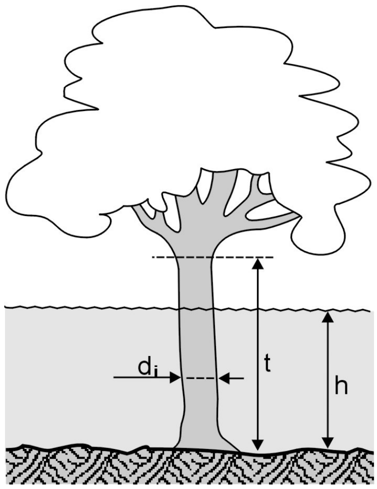

Fig. 2. High vegetation and its geometrical parameters during a high water flow

Ligneous plants in floodplain areas may occur in compact groups of trees or as single trees.

3. TREE STAND STOCKTAKING BY MEANS OF TERRESTRIAL LASER SCANNING

Terrestrial laser scanning (TSL), used in industry or architectonic stocktaking, is beginning to be noticed in forestry [7]. It allows obtaining a detailed image (a 3D point cloud) of forest areas, representing the spatial structure of a tree stand. An analysis of point clouds enables determining basic taxation features such as: trunk diameter (theoretically at any height), height of a tree or its location (density per area unit).

The principle of terrestrial laser scanning operation is similar to airborne scanning, the only difference being in the scanning device, which does not move in relation to the area being scanned (the device may rotate around its own axis). The system includes an emitter, i.e., a device producing a laser beam or a receiver, i.e., a device collecting a beam of data which returns after reflection. However, there is no need to register the change of device location during measurement (no INS system), as it is immobilized on a stand. Unfortunately, some producers do not equip their scanners with integrated GPS receivers, which would allow immediate working in a defined external system of coordinates. Calibration during TSL scanning is performed by assigning a correct location to one of the images, considered as reference (providing the scanner's XYZ coordinate), so that the whole point cloud can be correctly transformed.

Terrestrial laser scanning of circular areas in a tree stand is usually performed from the inside of the area and from 3 to 4 additional positions. Theoretically, this way all tree trunks should be displayed in 3D, assuming that the trunks do not obstruct one another. Point clouds of individual scans are integrated by means of special reference objects (balls, reflective labels), which are manually or semi-automatically identified in a planar image. Thus, a set of points XYZ is obtained, with coordinates from the reference scan [8].

Studies on the application of terrestrial laser scanning technology in flood control protection have been recently launched by Warmink, Middelkoop and Straatsma at the University in Utrecht [6]. They described an experiment in which a vegetation area index was measured and vegetation density was determined in the floodplain areas of the lower river Rhine in Holland. The researchers compared the laser scanning measurements with the direct ones. They concluded that the results obtained were good and suggested that conventional measuring methods could be replaced with the TLS technology. However, they also pointed out that in the case of forest areas with dense undergrowth the efficiency and accuracy of the new technology is considerably limited as compared to traditional methods. Nevertheless, since terrestrial laser scanner appears to be very useful in forest stocktaking, its application in hydrodynamic modelling of this type of areas will become more and more common.

4. AUTHORS' OWN STUDIES

The aim of the authors' own studies was to identify a possibility of using the laser scanning technology for determining parameters of trees (trunk diameter and the height of trunk up to the level of the crown) as well as their location in the test area. This is basic data for computing flow drag coefficients.

Fig. 3. The Widawa river valley with the research area marked with a circle (bird's-eye view)

The research was focused on the areas near the estuary of the river Widawa (figure 3). This area is covered with a ca. 150-m strip of forest on both sides of the river. The dominant forest-producing species are: oak and elm reaching the height of ca. 15 m and average diameter $d_p = 0.20$ m (figure 4).

Fig. 4. An ash-oak tree stand in the area analysed

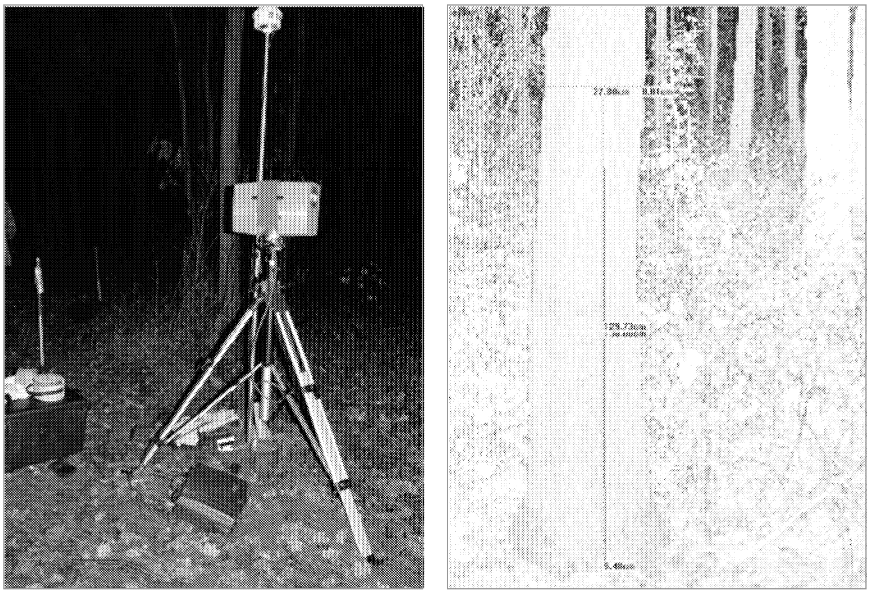

Fig. 5. A measuring instrument and example measurement of geometric characteristics of a tree (Tymków [5]).

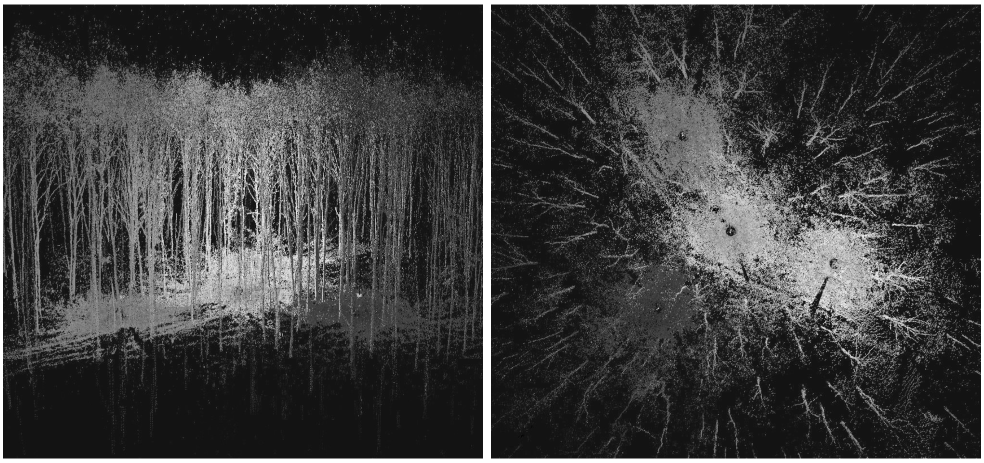

Fig. 6. Measurement stations – an image of 3D point clouds

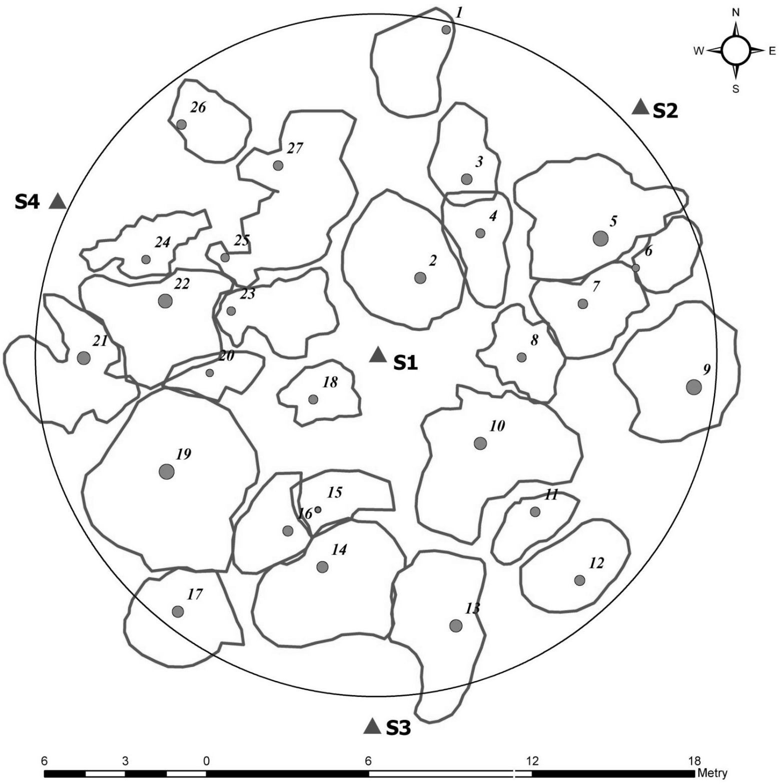

Fig. 7. A sketch of tree trunks' location (points) and the outline of their crowns (polygons) as well as measuring stations (S1–S4) on a circular area having a 12.62-m radius.

This area was chosen for testing because of its relatively little undergrowth and upgrowth, which usually considerably limit TSL measurements. Flow drag investigations have also been previously conducted in this area. The works were carried out in April 2007. The centre of the tree stand circular area was determined and three additional scanner stations were established. FARO LS 880 scanner was used, the measurements of which are based on the phase shift technology (figure 5). The scanner displays the area within 76 m horizontally (360 degrees) and vertically (320 degrees). Inside the circular area having a radius of 12.62 m (the area of 500 m^2) 5 reference zones of ca. 7-cm radius, visible from each scanner position (minimum 3 of them) were marked out. The works were started at the central station (central – S1) and continued at three other ones (S2–S4), which allowed obtaining four point clouds XYZ (figure 6). For each of the trees in the study area the location coordinates (in 1992 system) and diameter were determined at the height h_d = 50, 100 and 130 cm from the ground. A sketch of the trees location is given in figure 7. The table presents the coordinates (PUWG 1992/19) and tree diameters at the specified heights, computed on the basis of TLS measurements.

Table

A list of coordinates of the centres of tree trunks as well as their diameters at three measuring heights (50, 100 and 130 cm)

Tree number	X [m]	Y [m]	d_i [m]		
			h_d = 50 cm	h_d = 100 cm	h_d = 130 cm
1	2	3	4	5	6
1	356818.3	372957.1	0.17	0.17	0.16
2	356817.3	372947.9	0.24	0.23	0.21
3	356819.1	372951.5	0.22	0.20	0.20
4	356819.5	372949.5	0.20	0.18	0.17
5	356824.0	372949.4	0.31	0.27	0.28
6	356825.3	372948.2	0.18	0.17	0.14
7	356823.3	372947.0	0.21	0.19	0.18
8	356821.0	372944.9	0.20	0.17	0.17
9	356827.4	372943.9	0.29	0.24	0.28
10	356819.5	372941.8	0.28	0.23	0.23
11	356821.6	372939.2	0.18	0.16	0.18
12	356823.3	372936.7	0.23	0.17	0.19
13	356818.7	372935.0	0.29	0.25	0.23
14	356813.7	372937.2	0.24	0.22	0.21
15	356813.5	372939.3	0.12	0.10	0.10
16	356812.4	372938.6	0.21	0.18	0.19
17	356808.4	372935.5	0.21	0.23	0.21
18	356813.4	372943.4	0.24	0.19	0.17
19	356807.8	372940.8	0.34	0.32	0.28
20	356809.5	372944.4	0.17	0.15	0.14
21	356807.9	372945.0	0.24	0.24	0.24

1	2	3	4	5	6
22	356807.9	372947.1	0.29	0.26	0.26
23	356810.3	372946.7	0.19	0.18	0.16
24	356807.2	372948.5	0.17	0.17	0.16
25	356810.1	372948.6	0.17	0.16	0.16
26	356808.5	372953.5	0.20	0.18	0.18
27	356812.1	372952.1	0.19	0.18	0.18

5. COMPUTING FLOW RESISTANCE COEFFICIENT

The area was:

$$A = \frac{\pi D^2}{4} = 500.32\ \mathrm{m}^2 ,$$

covered with trees $n_d = 27$ pcs.

The average diameter d_p calculated based on the measurements at three heights over the ground for the flow depth 1:30 was:

$$d_p = \frac{\sum d_i}{n_i} = 0.2\ \mathrm{m}$$

where:

d_i – tree diameter computed as an average of tree measurements [m],

n_i – number of trees covering the area under stocktaking.

Substitute distance between the trees towards the flow direction a_x and crosswise a_y:

$$a_x = a_y = \sqrt{\frac{A}{n_i}} = 4.3\ \mathrm{m} .$$

The coefficient C_{WR} from Rickert's equation (2) is:

$$C_{WR} = 0.82 .$$

Then the average non-dimensional drag coefficient of the trees is:

$$\lambda_r = \frac{4 \cdot d_p \cdot h}{a_x \cdot a_y} \cdot C_{WR} ,$$

$$\lambda_r = 0.05 ,$$

where $h = 1.3$ – flow depth [m].

6. CONCLUSIONS

For the purposes of hydrodynamic modelling the characteristics of vegetation in floodplain areas are usually mapped using remote sensing methods, which provide both spectral data from satellite photographs and information on the heights from airborne laser scanning, or data obtained by a combination of the two methods [6]. There is also a possibility of using the State Forests database, which contains information on the stand of trees, their age and density (number of trees per 1 hectare). One should be aware, however, that vegetation development in floodplain areas is characterized by a considerable diversity. Yet we may distinguish some parts of areas in which the development is homogenous, and thus determine the average values of parameters which are considered reliable. Irrespective of the method used, it is necessary to obtain data verifying the current state of vegetation in an objective way. Preliminary results of studies using terrestrial laser scanning have revealed that the drag coefficient determined this way is characterized by high objectivity and accuracy, which seems important when computing the high water flow in floodplain areas covered with high vegetation.

The method presented requires further developing, since it does not generate drag coefficients in the case when vegetation does not consist of cylindrical elements and when water depth (h) is higher than the height of trunks (t), as measured from the tree crown. When the area is covered by shrubs and young trees and the flow depth (h) includes a part of high trees' crowns, the method should be enriched with a possibility of evaluating vegetation density (in vertical profile) on the basis of the TLS technology.

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