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USE OF LIDAR DATA AND SELECTED ALGORITHMS FOR DETERMINING THE FLOW LINES

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Abstract

This elaboration shows how to use Height Data by using airborne laser scanning (ALS) to delineation of flow lines which let to evaluation of water's flow on terrain.

Maps, which show flow lines, were generated by using GIS software and tools on testing areas. To achieve this goal were used methods of a single flow direction and multiple flow direction. Created maps which show directions of runoff, generated based on the DTM, were subjected to analysis. On the basis of these maps were evaluated the accuracy of determination of the flow direction on the testing areas by using individual algorithms.

Studies determining directions of runoff can and do have large application. They will serve the author as initium to create a network of watercourses needed to convert 3D image. This model of the network 3D will be an attempt to create a component BDOT10k in the form of three-dimensional.

Introduction

Quickly, easily, precisely – these terms can be safely attributed to the method of extraction of Height Data from airborne laser scanning (LIDAR). From these data we obtain accurate numerical models of terrain, which are use to execution of authentic spatial analysis in many diverse areas. Undoubtedly hydrology is the science that is closely associated with the lay of the land, and for which the DTM plays an important role in hydrological modeling. An important issue seems to be how the best delineation of flow lines because of the mutual relation between flowing water and form of land's surface. Distinction of runoff paths allows the determination of further phenomena necessary during modeling series of hydrological processes (e.g. accumulation of water

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runoff, Soil Moisture Index, the ability of material's transformation – including pollution, determination of catchment's boundaries and many others). Assuming that the digital elevation model acquired from laser scanning is a precise sourcing material, it becomes reasonable to compare the most commonly used algorithms used for the extraction of the drain line.

Material and Methods

The source data

As the source data for delineation of flow lines were used elevation data from airborne laser scanning (LIDAR) collected within the ISOK (pol. Informatyczny System Osłony Kraju). This is the system of the country's protection against extreme hazards especially against flood. It is a project in Poland which aims to help improve the effectiveness of flood risk management. These data are available at National Geodetic and Cartographic Resource. The data in raster format was used for the extraction of flow lines by using SAGA GIS software.

Research area

For selection of the study area were used the following criteria:

– diverse in terms of hypsometry;

– diverse in terms of changes in water relations (both natural area and the changes in water management);

– forest area and an area with visible valleys on orthophotomap.

Due to these assumptions were chosen two test areas being part of a map M-33-44-C-a-2-2 (close to Jagniątków, the Karkonosze Foothills) and N-33-69-B-c-1-3 (close to Kłos, the north-eastern part of the Chełmska Hill).

Choice of the right algorithm

There are many algorithms allowing to determinate the water flow directions by using a raster DTM model. The essence of such modeling is to use the law of universal gravitation (gravity), which shows that water's flow go down the slope, from cells being situated higher into lower (URBAŃSKI 2011). There are three kinds of methods to create flow pathways, defined by different algorithms: single flow direction, multiple flow direction and „stream tube" from one central cell (WILSON, GALLANT 2000). Undermentioned algorithms can be used to determine flow pathways:

Algorithm – Deterministic 8 (O'CALLAGHAN, MARK 1984). This algorithm is using for delineation of flow lines by calculating the difference in height between analysed raster cell and other, which surround her. Flow take place only to the one cell, for which obtained the highest value of the gradient (Fig. 1), hence this method is referred as single flow direction method (WOLOCK, MCCABE 1995).

Calculation of runoff takes place according to the following formula (1):

$$S_{D8} = \max_{i\,=\,1,8} \frac{z_9 - z_i}{h\phi(i)} \tag{1}$$

where:

z – the number of surrounding cell
h – resolution of GRID model
$h(\phi)$ – distance between the centres of cells, = 1 placed in the cardinal directions (north, east, south, west); the square root of 2 for others.

Algorithm Rho8 – Random eight-neighbour (random eight-node). Rho8 algorithm is a modification of the classical stochastic-deterministic algorithm D8. It also marks single flow direction, however, defining the gradient is done by introducing the so-called random factor (hence the name of the method – a random eight-node), which makes that results are not reproducible. It is done in order to avoid long, parallel flow paths generated by using D8 algorithm (FAIRFIELD, LEYMARIE 1991).

Algorithms FD8 and FRho8. Algorithms FD8 and FRho8 are recognized in literature as Multiple Flow Direction – **MFD** (QUINN et al. 1991). They are a modification of D8 and Rho8 algorithms. As the name suggests, flow takes place in many directions, whereby this method has application to the determination of divergent flow. Part of surface runoff flowing out to the neighboring cell is transmitted based on calculation by the following formula (2):

$$P_i = \frac{\max(0, s_i^a)}{\Sigma_{i=1}^{8}\ (\max(0, s_i^a))} \tag{2}$$

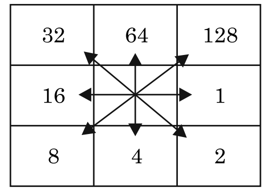
where:

s_i – the size of the slope between the central node cells and neighboring cells
a – constant positive (recommended value a = 1.1).

a

80	64	49	56	53
72	53	47	38	48
58	51	46	32	46
61	50	49	46	24
64	52	51	50	58

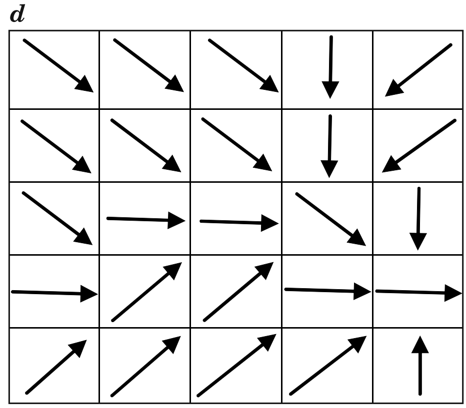
b



c

2	2	2	4	8
2	2	2	4	8
2	1	1	2	4
1	128	128	1	1
128	128	128	128	64

d



e

0	0	0	0	0
0	1	1	3	0
0	1	8	18	0
0	3	1	1	24
0	0	0	0	0

f

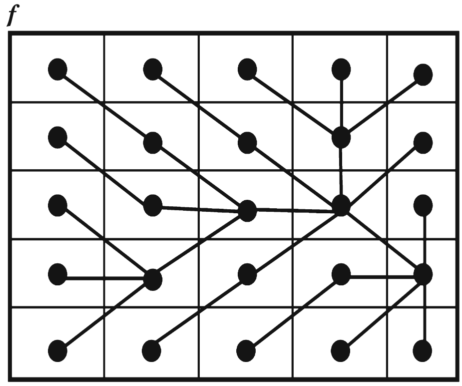


Fig. 1. Stages of determining runoff water with using the D8 method: *a* – DTM map, *b* – coding direction of flow using D8 method, *c* – map of the flow's direction, *d* – the direction of runoff on the map, *e* – map of runoff's accumulation, *f* – flow lines

Source: Urbański (2011).

Algorithm D∞ – Deterministic Infinity (TARBOTON 1997). The calculative method is based on the determination of runoff into two of the eight surrounding cells. Gradients of the biggest downslope is obtaining as a result of calculations made between the centre of the analysed cell and the centre of neighboring cells, which are connected with the eight triangles (Fig. 2).

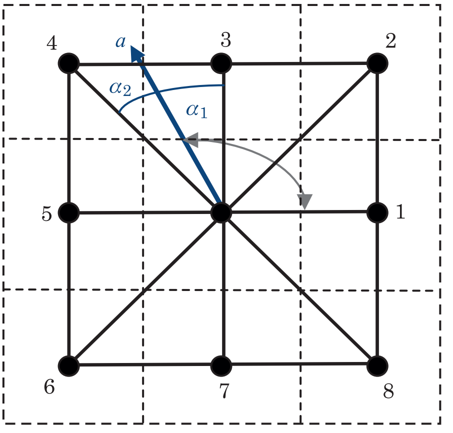


Fig. 2. Direction od runoff in the D∞ method: a – runoff direction, α_1, α_2 – angles which determine the flow direction

Source: TARBOTON (1997).

Algorithm MD∞ – Triangular Multiple Flow Direction. It is a combination of MFD and D8 methods. Centres of cells are connected by triangles and algorithm proposed by Quinn is using for calculations.

Algorithm KRA – Kinematic Routing Algorithm. To determine the flow direction are used particular rastra cell, which are represented by plane fitted into corner points of the cell. Height of cells are determined by interpolation of height of neighboring centre cells, in addition flow direction is defined as the angle in the range from 0 to 2π (LEA 1992). Dispersion of flow does not occur in this method and the direction is determined in constant way.

Algorithm DEMON – Digital Elevation Model Networks (COSTA-CABRAL, BURGES 1994). The direction of flow takes place in accordance with the terrain's drop to edge of DTM or to bottom of depression. It is directed whole to cell located below (when a specific direction of flow is a multiple of 90 degrees), or flow is split between two cells.

Algorithm BRM – Braunschweiger relief model. The direction of flow is maximum limited to three neighboring cells, to avoid excessive flow's dispersion (CONRAD 1998, PARK et al. 2009).

From presented above algorithms, to determine flow lines on the selected area, used two the most commonly used. These algorithms are D8 and MDF.

Method of determining flow lines

To elaboration was used a model of the terrain, with a regular grid with a mesh aperture of 1 meter, for which the average height error is in the range to 0.2 m.This model is available at the National Geodetic and Cartographic Resource. It was obtained from airborne laser scanning (ALS parameters are shown in Table 1) and interpolated on the base on points clouds for which the scan density on alanlyzed areas was 4pts/m^2 (the data saved in accordance with the standard 1.2 published in 2008 by the ASPRS – American Society for Photogrammetry and Remote Sensing).

Table 1

Basic Parameters ALS within ISOK

Parameters	Standard I: Non-urban areas
Transverse angle of scanning:	≤ + 25°
Density of points cloud:	≥ 4 points/m^2
Side overlap	≥ 20%
Height accuracy (mean error) of laser points	mh ≤ 0.15 m
Registration of intensity of reflected signals	yes
Conditions of photographic registration	medium format camera with color CCD with resolution greater than 30 M pixels
Flying height	helicopter 200–300 m areoplane 500–1000 m (max 6000 m)

Afterwards artificial artefacts were removed from DTM – „false sinks" – a collection of one or more cells, which from all sides are surrounded by other cells of bigger height value (URBAŃSKI 2011). Prepared in this way DTM was used to realise maps of surface flow. Extraction of flow lines occurred by using selected algorithms implemented in Saga GIS software. At the same time were assessed threshold values in order to determine of channel initiation threshold (Fig. 3). Received in the form of a vectorial network of flow lines were smoothed in order to obtain a better visualization.

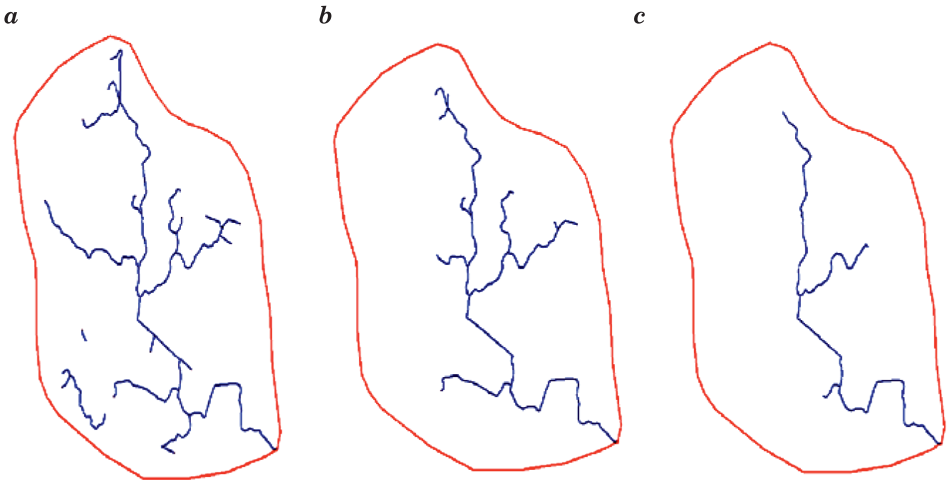


Fig. 3. The impact of the threshold value to determine density of the flow lines network: *a* – big, *b* – average, *c* – small

Results and Discussion

Comparison of algorithms D8 and MFD

Both applied algorithms gave similar results in determination of flow on the area of distinct valleys. On the analysed areas, marked out flow lines coincide almost the entire length (Fig. 4*a, b*) and the shape and course of the line is consistent with the land form.

Marked differences are visible when using both methods, in areas where hillside in big distances is rising in the same direction. Flow lines, delineated by using D8 algorithm, extracted as long, parallel lines (Fig. 4*c*). It is presented differently when using algorithms FD8 and FRho8, how it is in MFD method. On areas, where occurs changeless slope, parallel flow does not occur. Nonetheless, in many places lines demonstrating many branches of flow are formed (Fig. 4*d*).

Used algorithms do not work with determination of flow paths in areas with many drainage ditches. Faint gradient of height (minimum drop of the ditch is 0,02%, which is 0.2 m per 1 km) does not cause „disruption" in the surrounding terrain. As a result of it, determined sewage lines have compatible course with the general tendency of the terrain slope, which leads to creation of flow path's picture which does not refer to the hydrographic lines transfigured by human (Fig. 4*e*).

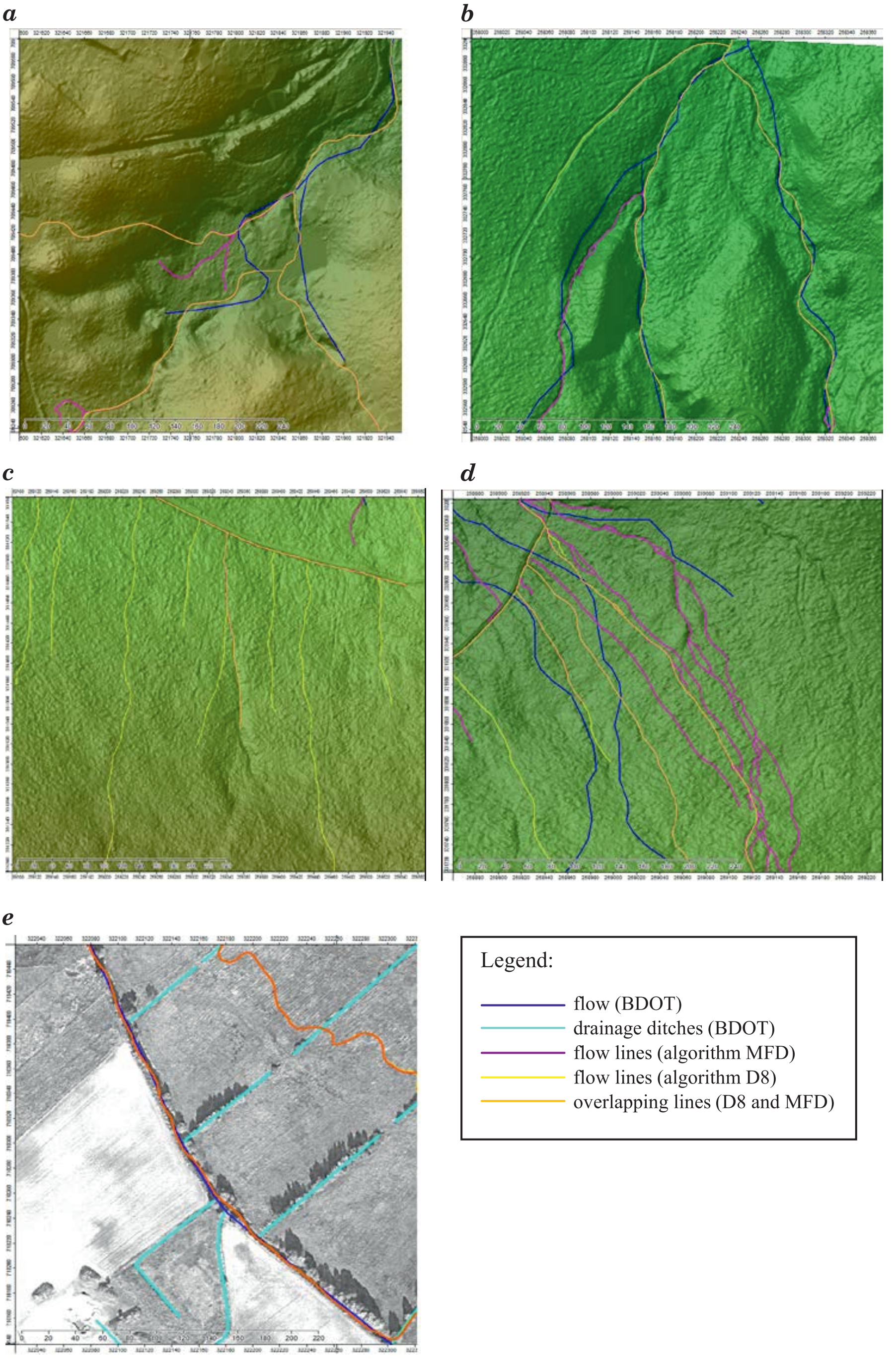


Fig. 4. Flow lines against DTM (forest areas) – sheets N-33-69-Bc-1-3 (*a*), M-33-44-Ca-2-3 (*b, c, d*) and orthophotomap – sheet N- 33-69-B-c-1-3 (*e*)

Analysis of delineated flow lines

This study delineating flow lines may help author to create a model of network watercourse in 3D, which will be a component of the three-dimensional Database of Topographic Objects (pol: Baza Danych Obiektów Topograficznych, BDOT10k, it is a database of topographic objects for whole Poland corresponding with detailed map with a scale of 1:10 000). Consequently, arisen flow path network was subjected to a comparative analysis with flow paths from BDOT in the next step. The source of geometry of flows from BDOT is primarily orthophotomap. In invisible places (e.g. woodland) is also acceptable acquirement of flow on the basis of other data, including topographic maps at a scale of 1:10000 (TECHNICAL GUIDELINES TBD 2008).

Drain lines delinated through the algorithms, in the next step was subjected to a comparative analysis with watercourses coming from BDOT10k, which allows to envolve the following conlusions:

– On forest areas with distinct valleys accurate results were obtained for drain lines delineated by algorithms D8 and MFD (the shape and course of the watercourse is harmonized with altitude model from ALS about 95%). Drain lines' shape delivered from BDOT10k is similar, but the differences in course between the lines from BDOT10k and delineated by algorithms D8 and MDF are in some places even 20 m (Fig. 4*a, b*), which means that results from BDOT10k are less precise. The superior precision of lines obtained by algorithms D8 and MDF is associated with using them to extraction as source data of DTM from ALS, while the source of drain lines' geometry deriving from BDOT10k is raster of topographic map.

– For non-forest areas with visible, clear valleys were obtained to deviations to 0.5 m in watercourses' geometry (between the drain lines coming from BDOT10k (for which the source of geometry is orthophotomap) and drain lines endeared by using algorithms D8 and MFD (Fig. 4*e*). This means that for such areas the accuracy of the geometry designation of watercourses is satisfactory for each of used methods.

– For areas with transfigured water management (areas with drainage ditches) are marked correctly only drain lines coming from BDOT10k, of which source of data is orthophotomap (Fig. 4*e*). Compatibility between existing drainage ditches and watercourses generated by the algorithms is only a few percent.

– In areas with steady slope (forest areas) none of methods is not without errors (Fig. 4*c, d*). Correctness of watercourses' determination should be further analyzed and confronted in the fieldwork.

Conclusion

Owing the fact that for almost all over the country there is precise DTM, is worth to use automatic methods, during acquiring flow lines. It helps to obtain a more accurate shape, course and is useful for BDOT update. Generating water network based on DTM is especially applicable to those areas where is lacking of adequate visibility on orthophotomap (e.g. forest areas), then should be use different sources of data like topographic maps. It is a very important issue because in Poland forest cover is almost 30% of total land area. In connection of using raster topographic map to delineate watercourses in these areas there is a problem of the accurancy of data collection associated with raster background, its calibration and also with interpretation of introducer!!. Based on this we can say that the geometry of watercourses in forest areas in BDOT10k is approximate. Therefore it is important for the extraction of watercourses, especially in those areas, to select as source of data elevation data obtained by LIDAR technology and use the known algorithms which delineate drain lines. Thereby delineated watercourses will have acquired a more accurate geometry, consistent with the model of altitude, and time of data acquisition will be also faster.

The study also showed that delineating flow lines should not be only base on one method (JASIEWICZ 2010). To get the best model of flow network, area of research should be divided into smaller fragments, for which delineation of flow lines will be the best. The selection of algorithm (the choice of its parameters, especially the so-called threshold) has a big impact on the demarcation of flow lines. Author conducts researches using different algorithms to determine their quality for the most accurate delineation of flow lines. The results of these works will be the subject of subsequent publications.

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