ROOF TYPE DETERMINATION FROM A SPARSE LASER SCANNING POINT CLOUD

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ABSTRACT

A method for determining a roof coverage type and a building height from a sparse laser scanning point cloud was introduced in Hofman (2008). This model driven approach utilizes 2D building outlines from the Digital Cadastral Map (DCM) and orthoimages in addition to an airborne laser scanning point cloud. Its results were unsatisfactory, since the determination of roof types was not reliable. Thus, a practical application of this method was not possible. While searching possibilities for its improvement, it was discovered that derivation of roof edges from orthoimages was the weakest point in the workflow.

A new model driven method is presented, which is suitable for buildings with a rectangular plot. Based on four predefined roof types, a subset of a point cloud is divided into several groups corresponding to roof planes. The best fitting planes are found by means of least squares adjustment with an iterative exclusion of outliers. The most probable roof type is selected by an evaluation of a number of points excluded from the calculation. Results of this new approach were applied on datasets from three test sites (Brno, Sobotka and Pardubice-Polabiny) which are presented. In spite of a very low density of laser points (1.5 and 0.25 points per m^2) the method reveals very good results. The success rate of correctly determined roof cover types is 91% and 80% for the point cloud density of 1.5 and 0.25 points per m^2, respectively.

Key words: 3D building model, laser scanning, model-driven

1. Introduction

Airborne Laser Scanning (ALS) is still a relatively new technology of Remote Sensing. During the last decade it was found to have many applications in the field of geoinformatics. Digital surface models and digital terrain models (DSM/DTM) can be derived automatically from laser scanning point clouds. Extracting geometrically correct 3D city models is a more complicated task that requires interpretation and abstraction from an original DSM (Haala, Brenner 1997). Stereophotogrammetry is a traditional method used for the derivation of spatial models of objects. Accurate position of edges and their lengths combined together with high level of detailed mapped objects can be named as advantages of images in comparison to irregular point cloud. In contrast, a direct representation of spatial objects in laser scanning data allows for a higher degree of automation and more precise determination of heights and position of roof planes (Kaartinen et al. 2005). Different data sources complement each other because they can have different advantages and disadvantages. Thus, a combination of different data sets is a logical approach suggested by many authors, e.g. Huber et al. (2003) or Wang (2007). On the other hand, this approach increases the complexity of the problems to be solved (Hofmann 2005) and can cause a loss of speed and level of automation of the process.

A method of roof type modelling based on ALS data, building outlines from digital cadastral maps (DCM) and orthoimages was presented in (Hofman 2008). The results that determined the type of the roof from imagery were not satisfactory. Therefore, the aim of this study is to present an improved and more reliable method for the detection of roof types that is applicable on a sparse ALS point cloud. A high degree of automation is an important requirement for the solution. On the other hand, high versatility was not the ambition of the authors and the method is suitable only for rectangular buildings and four predefined roof types.

The second chapter introduces the methodology and results of the initial work combining point clouds, imagery and building outlines and it is based on the diploma work of one of the authors (Hofman 2008). The third chapter describes an improved methodology. The two following chapters present the data sets that were used and summarise the achieved results. Conclusions are drawn in the last chapter.

Methodology based on a combination of ALS, DCM and orthoimages

The main aim of the initial work described in (Hofman 2008) was, in addition to evaluation of existing solutions, to develop a method of deriving 3D models of buildings from ALS data that would fulfil the following requirements:

- highest possible degree of automation,
- applicability on a sparse point cloud (e.g. 1.5 or 0.25 points per m^2).

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A model driven approach was chosen due to the low density of a point cloud and the requirement of a high degree of automation. It means that the scale and rotation of predefined simple building models were modified to match the input data (Schwalbe 2005). The main advantage of such approach is low complexity (easier automation of the whole process) and low requirements on data quality. On the other hand, only predefined roof types can be modelled. Although the chosen approach was suitable for a sparse point cloud, there were reasons to question whether the amount of points was sufficient for a reliable modelling of roof planes for smaller houses. Kaartinen et al. (2005) mention that ALS data reveals more precise information in heights, position of roof planes and intersections of these planes. In contrast, roof edges can be more precisely detected in images. Thus, coloured orthoimages with the spatial resolution of 0.5 m were utilised. Edge detectors were applied and a roof type was determined by a correlation of binary images of derived roof edges and predefined roof types. Point clouds were used afterwards for calculation of a building height. ALS points and image patches corresponding to a modelled building were selected based on 2D building outlines from DCM.

The method was tested on 50 buildings from the towns of Brno and Sobotka, but the results were not satisfactory. Roof types that were determined using a correlation between edges derived from orthoimages and predefined roof shapes showed to be incorrect in case of one third of tested buildings. In contrast, the second part of the method concerning deriving the building height performed well and with expected accuracy. A detailed description of this approach including the results is available in the diploma thesis of the first author (Hofman 2008).

Improved methodology based only on a combination of ALS data and DCM

The analysis of the workflow and results achieved with the above described method raised the question if the combination of imagery and ALS data was necessary. A new approach utilizing only ALS data and 2D building outlines from DCM was therefore investigated.

With respect to the low density of a point cloud and the requirement of a high level of automation, a model driven approach was again chosen. Only buildings with rectangular (and squared) outlines were investigated. Moreover, only four roof types were considered (compare Figure 1):

- flat roof (with horizontal or inclined roof plane),
- gable roof (in this case two types can be discerned according to the orientation of the gable),
- hip roof,
- pyramid hip roof.

The entire workflow was programmed in the Python 2.6 script language and geoprocessing tools of ArcGIS 10 were also included. The algorithm sequentially creates subsets of the laser point cloud according to the building outlines saved as a GIS layer. The building outlines are simplified to a rectangular form (see Figure 2) and the corners of the rectangle are saved.

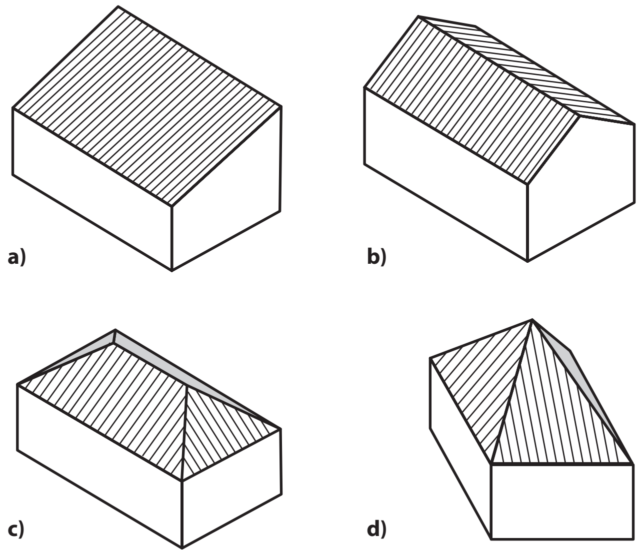

Fig. 1 Basic roof types – flat (a), gable (b), hip (c) and pyramid hip (d) roof. Source: Ptáček (2002–2004) – modified

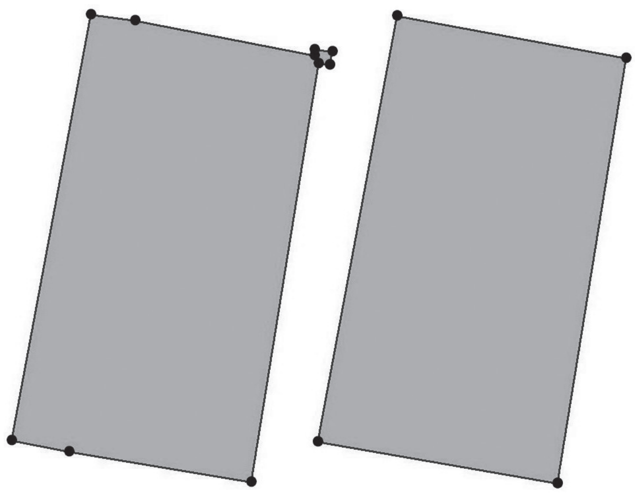

Fig. 2 Simplification of the building outlines and decreasing the number of vertexes to four. Source: authors, graphical user interface of ArcInfo 10

Provided that the evaluated roof has a shape of one of the four models, the laser points can be divided into groups corresponding to single roof planes. This division is done according to the horizontal (x, y) position of the points. In the case of a flat roof all points belong to one plane, in the case of a gable roof to two planes and in the case of a hip roof to four planes as depicted in Figure 3.

An analytical expression of a best fitting plane is found for each group of points by means of least squares adjustment (point heights are used as observations). The

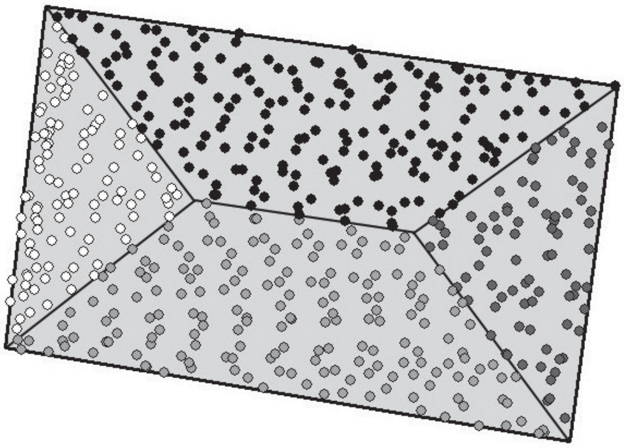

Fig. 3 An example of a division of laser points to four roof planes in the case of a hip roof. Source: authors, graphical user interface of ArcInfo 10

Fig. 4 Points that are excluded from the calculation in the case of fitting a gable roof model (left) and a hip roof model (right) to a hip roof type. In the case of a gable roof model, the points on the hip ends were excluded, as well as, points corresponding to a tree next to the house (marked in the grey colour). In the case of the hip roof model, the four best fitting planes were defined and the amount of points left out was considerably smaller. Therefore, the hip roof model was chosen as the most suitable of the evaluated roofs. Source: authors, graphical user interface of ArcInfo 10

laser scanning data was not filtered in the pre-processing step. Thus, they may contain a number of points that do not belong to the roof planes but to chimneys, dormers, vegetation in the building neighbourhood or building walls. These outliers significantly change the position and/or orientation of the modelled roof planes; therefore, it is necessary to exclude them from the calculation. If the vertical distance of at least one point from the best fitting plane exceeds the given threshold, the most distant point is left out and the position of the plane is calculated again. This iterative process continues until all vertical distances are smaller than the threshold value. The threshold is set in accordance with the vertical accuracy of the point cloud. The value of 0.2 m was chosen for the datasets described in the following chapter.

The above mentioned iterative calculation is repeated for all selected buildings and all types of predefined roof models. In the case that the roof type does not fit, the majority of points are excluded by the algorithm. The more points that are left in the calculation, the higher the reliability is to determine roof type. The roof model with the highest ratio of points kept in the calculation is selected as the correct one (see Figure 4).

The flat roof model is the only exception in the described evaluation procedure. The other roof types show similarities to the ideal case of a perfectly flat roof. In the case of a slightly bent plane there was even a better agreement with the predefined models. Thus, the following criterion was introduced. If the amount of excluded points is 20% smaller for a flat roof model in comparison to other models, the angle between adjacent planes is calculated. In case their inclination does not differ more than 10°, the roof is considered as flat. The suitability of stated threshold values was verified empirically.

The presented methodology was tested for two point cloud densities, namely 1.5 and 0.25 points per m^2.

2. Data

Tests of both methods were carried out on the same data set from the towns Brno and Sobotka in order to have comparable results. Moreover, the improved method was also assessed on another data set from the area of Pardubice.

The private company Geodis Brno provided airborne laser scanning data from the area of Brno in a text format (coordinates x, y, h). The height accuracy was 0.1 m; the diameter of the laser beam footprint on the ground was approximately 0.2 m. The average point density was 24 points per m^2. Thus, the point cloud was thinned out in order to achieve the required density of 1.5 and 0.25 points per m^2 (see Figure 5). The data set consisted of six saddle roof buildings from the centre of the town. A lot of points belonging to objects above roof planes and to walls of the buildings were present in the data set.

Point clouds from the towns of Sobotka and Pardubice were provided by the Surveying Office of the Czech Office for Surveying, Mapping and Cadastre (COSMC) and were acquired with the scanner LMS Q680 of the

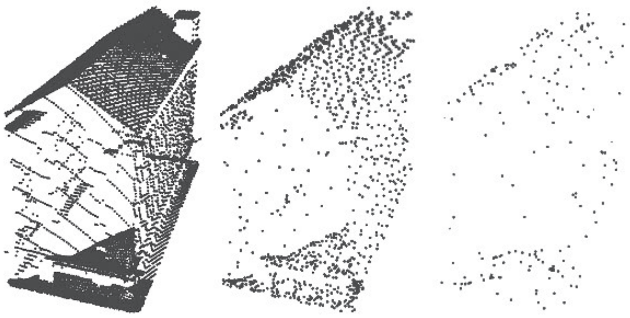

Fig. 5 Example of a point cloud of a building from the area of Brno. The original point cloud with the point density of 24 pt./m^2 (left) and thinned point clouds with the density of 1.5 pt./m^2 (middle) and 0.25 pt./m^2 (right). Source: authors, graphical user interface of ArcInfo 10

Riegl company. Similarly to the Brno data set, the data was delivered in a text format (coordinates x, y, h) with the accuracy in height of 0.1 m but their density was only 1.5 points per m^2. In the case of Sobotka, 36 buildings from the town suburbs were available. Due to rural characteristics of this area, the majority of simple roofs were partially covered with trees. Blocks of flats, part of a residential area and industrial buildings, portray the structure of the third data set, the urban area of Pardubice-Polabiny.

The described data sets contained original point clouds; any filtering algorithm was not applied in the pre-processing step. The building outlines were extracted from the digital cadastral map (DCM) and they were provided by COSMC in the shape file (.shp) format.

3. Results

Automatically determined roof types were visually compared with an original point cloud and orthoimages in order to verify the results of the applied algorithm. The results are summarised in the Table 1. Altogether 460 buildings were processed. A success rate of 91% and 80% was achieved in cases of the point cloud density of 1.5 and 0.25 points per m^2, respectively. In contrast, only 69% of roof types were determined correctly when an original algorithm utilizing edge detection in orthoimages was applied (Hofman 2008).

Tab. 1 Success rate in determination of roof types based on airborne laser scanning point clouds and building outlines

Roof type	*Number of evaluated roofs*	*Correctly modelled*			
		1.5 pt./m² (number of roofs)	*1.5 pt./m² (%)*	*0.25 pt./m² (number of roofs)*	*0.25 pt./m² (%)*
Flat	220	209	95.0	195	88.6
Gable	183	174	95.1	153	83.6
Hip	20	18	90.0	13	65.0
Pyramid	16	16	100.0	8	50.0
Other	21	0	0.0	0	0.0
Total	460	417	90.7	369	80.2

Source: authors

Considering only the tested roof types, it can be concluded that in average 95% of roof shapes where determined correctly in the case of point cloud density of 1.5 points per m^2. The total success rate of the method is lower due to 21 rectangular buildings, which roof types did not fit to any of the predefined models. This drawback of the method could be partially eliminated by increasing the number of predefined roof types. On the other hand, this would also increase the calculation time and it would be difficult to include all existing roof shapes.

Looking at the results of roof type determination from a very sparse point cloud (0.25 points per m^2), the success rates decreased in general. Especially small buildings, that caused problems because the number of points was too low for a reliable modelling of roof planes. A greater sensitivity of different roof types to the point density can be observed from Table 1. While the success rate dropped only slightly down in the case of flat roofs, its decrease was more considerable in the case of gable roofs and it went down almost 50% in the cases of hip and pyramid roofs. The reason is in the relative complexity of the roof types. While in the case of the flat roof the number of points was sufficient to model only one plane, its division to two or four groups meant a lack of points for reliable modelling of the corresponding number of separate planes.

4. Conclusion

An improved method for detection of roof types from a sparse point cloud acquired by airborne laser scanning was introduced. The success rate of correctly determined roof types was 91% and 80% in the cases of point cloud density of 1.5 and 0.25 points per m^2, respectively. In comparison to the previously applied approach, utilising not only a laser scanning point cloud and building outlines from a digital cadastral map, but also orthoimages (Hofman 2008). The new method reveals better results even in the case of extremely low point density. In order to be able to create 3D models of complex buildings, an extension of the algorithm of a segmentation procedure that divides building outlines to rectangular parts can be applied. A disadvantage of the presented method is especially low versatility and a low level of detail of the final models. The amount of roof types is limited to predefined shapes; it is not possible to include roof objects such as dormers or chimneys. The main advantages are suitability of the algorithm for a sparse point cloud and a fully automated process.

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RÉSUMÉ

Určení typu střešního pláště budov z řídkého mračna laserových bodů

Metoda představená v článku měla za cíl automatickým postupem detekovat typ střešního pláště i ve velmi řídkém mračnu laserových bodů. Aby bylo možné tyto požadavky splnit, byla zvolena metoda řízená modelem, která zpracovává pouze budovy s obdélníkovým tvarem. Na základě předem vybraných testovaných typů střešního pláště bylo mračno bodů podle polohy rohů rozděleno do několika souborů odpovídajících střešním rovinám. Těmito body byla pomocí metody nejmenších čtverců iteračně prokládána regresní rovina s postupným odstraňováním odlehlých bodů. Na základě podílu bodů ponechaných ve výpočtu byl zvolen nejpravděpodobnější typ střešního pláště.

Postup byl testován celkem na 460 budovách z oblasti města Brna, Sobotky a Pardubice-Polabiny. Navzdory velmi nízké hustotě dat (1,5 a 0,25 bodů/m^2) dává metoda velmi dobré výsledky. Podíl správně určených budov dosahuje 91 % při hustotě 1,5 bodů/m^2 a 80 % při 0,25 bodech/m^2. Nevýhodou uvedeného postupu je především nízká univerzálnost a detailnost výsledných modelů. Naopak velkou výhodou je možnost práce i s velmi nízkou hustotou vstupních laserových bodů a plně automatizované zpracování.

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