ISPRS Journal of Photogrammetry and Remote Sensing 126 (2017) 168–179

Contents lists available at ScienceDirect

ISPRS Journal of Photogrammetry and Remote Sensing

journal homepage: www.elsevier.com/locate/isprsjprs

Comparison of low-altitude UAV photogrammetry with terrestrial laser scanning as data-source methods for terrain covered in low vegetation

Wojciech Gruszczyński *, Wojciech Matwij, Paweł Ćwiąkała

AGH University of Science and Technology, Poland

ARTICLE INFO

Article history:
Received 10 March 2016
Received in revised form 19 January 2017
Accepted 22 February 2017

Keywords:
Unmanned aerial vehicle
Terrestrial laser scanning
Land relief
Ground filter

ABSTRACT

This article juxtaposes results from an unmanned aerial vehicle (UAV) and a terrestrial laser scanning (TLS) survey conducted to determine land relief. The determination of terrain relief is a task that requires precision in order to, for example, map natural and anthropogenic uplifts and subsidences of the land surface. One of the problems encountered when using either method to determine relief is the impact of any vegetation covering the given site on the determination of the height of the site's surface. In the discussed case, the site was covered mostly in low vegetation (grass). In one part, it had been mowed, whereas in the other it was 30–40 cm high. An attempt was made to filter point clouds in such a way as to leave only those points that represented the land surface and to eliminate those whose height was substantially affected by the surrounding vegetation. The reference land surface was determined from dense measurements obtained by means of a tacheometer and a rod-mounted reflector. This method ensures that the impact of vegetation is minimized. A comparison of the obtained accuracy levels, costs and effort related to each method leads to the conclusion that it is more efficient to use UAV than to use TLS for dense land relief modeling.

1. Introduction

Modern measurement technology enables fast, remote and dense measurement and determination of point coordinates, which in turn allows the development of detailed land relief models. Such models have many applications, some of which require terrain data from two or more series of measurements. Land relief models are used for construction plans or survey maps. They are also used to determine changes in the geometry of a site, identified as uplifts/subsidences caused by natural (e.g. landslide) or anthropogenic (e.g. mining) factors. A detailed relief map also enables the performance of many archaeological, hydrological and geological analyses (e.g. Bemis et al., 2014; Castillo et al., 2011; Chiabrando et al., 2011; Immerzeel et al., 2014; Mesas-Carrascosa et al., 2014; Niethammer et al., 2012).

Unfortunately, the quality of such land surface models is biased not only by inaccurate measurement and reference, but also by vegetation covering a given site. This is a factor that, to a greater or lesser extent, affects all surveying methods in which measurements are taken automatically at target, as opposed to at a beacon placed at a known level above ground as in the case of more traditional surveying techniques. This cannot be considered as a flaw since randomly located points are measured, which inevitably results in vegetation being surveyed too. The thicker the vegetation, the fewer points are measured directly on the land surface. In the discussed case, measurements taken of vegetation and not directly of the land surface are considered to be noise that should be filtered out as much as possible.

Since aerial and terrestrial laser scanning became available on the market, data from such sources has contributed notably to improving the quality of studies in various fields (e.g. geographic information systems, cartography, forestry, industry, spatial planning). Currently, there is a tendency to complement or even entirely replace that technology with unmanned aerial vehicles (UAV) bearing digital photographic cameras. This allows the generation of precise point clouds representing the land surface and existing infrastructure. However, data obtained by means of this technology remain unclassified and impaired by measurement noise, which clearly causes errors during any subsequent analysis. That is why many recent studies have tackled the issue of data filtering and classification.

Considering the particularities of data acquisition and filtering methods, we can distinguish between macro- and micro-scale

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* Corresponding author.
E-mail address: wgrusz@agh.edu.pl (W. Gruszczyński).

http://dx.doi.org/10.1016/j.isprsjprs.2017.02.015

technologies. The macro-scale ones include aerial laser scanning (ALS) in particular, which is the focus of the majority of recent studies. One of the most common filtering methods is progressive TIN (triangulated irregular network) densification (PTD) (Zhang et al., 2003; Zhang and Lin, 2013). The algorithm operates in five main steps: (i) eliminating outliers in the data, (ii) specifying filtration parameters, (iii) selecting seed points, (iv) constructing the TIN and (v) iterative densification of the TIN. A different method for filtering data from a variably shaped terrain focuses on the curvature of the surface (Hua et al., 2014). Its authors propose that points be classified in a multi-iterative process consisting of the creation of a data pyramid and taking account of the deflection parameter of individual cells belonging to a grid created for filtration. A multi-stage approach towards filtration is also applied by many other researchers (Mongus and Žalik, 2012; Véga et al., 2012). It has become standard practice to divide a surveyed site into a grid of squares (Hui et al., 2016) and to select points by taking account of their height as a filtration parameter. In the case of urban point-cloud segmentation, one can additionally assume that in an urban landscape there exist a large number of typical architectural planes (Kim et al., 2016). In such a situation, one can perform point cloud selection by applying analysis of neighboring points, which includes the normal vectors of a surface fitted in the point cloud. This additional parameter accelerates analysis and offers an advantage when working on ALS or TLS (terrestrial laser scanning) data.

Point selection and classification algorithms are also applied in the micro-scale range, to both TLS and UAV data (Guarnieria et al., 2009; Panholzer and Prokop, 2013). They are mainly used in urban conditions to help create 3D models of the site surface and existing infrastructure. Researchers in this field (Weinmann et al., 2014, 2015) suggest a segmentation method that depends on geometrical features of individual point-cloud fragments. This concept is based on four main elements: (i) neighborhood selection, (ii) feature extraction, (iii) feature selection and (iv) classification. Its authors prefer to use a spherical range to look for neighboring points, and introduce the parameter k to indicate the number of included points. Next, sets of specific features defining the shape of a selected object are generated. The last step is based on a learning algorithm that classifies an entire cloud after random samples are entered. Some terrestrial scanners equipped with a receiver able to record a multi-return signal allow a classification similar to that used for ALS data. In such cases, a morphological filter (Hui et al., 2016) and a selection of final reflections can be used for classification (Pirotti et al., 2013). The applied filters are based on the progressive shift of a filtration window. A strategy that involves changing the size of the grid squares has been applied previously (Zhang et al., 2003). In this case, however, and in contradiction to earlier propositions, the authors suggest a gradual decrease in the size of the squares. Filtration consists in a gradual selection of the highest and lowest points in a given set and, based on that, performs segregation according to a chosen classification.

Data from UAVs equipped with digital cameras can also be filtered and selected by means of similar methods. This is especially important if one's aim is to obtain results similar to those provided by the methods described above (Niethammer et al., 2012; Turner et al., 2015).

The case discussed herein differs slightly from those mentioned above. It concerns a site whose area is rather small and that is covered in low-growing vegetation. The key challenge is to minimize the impact of vegetation on the obtained land relief model in order to allow the survey results to be used to map terrain deformations (uplifts/subsidences). That is why this article does not deal with segmentation or classification (i.e. type recognition) questions, which are essential to the solutions offered by the algorithms in the quoted sources.

Section 2 describes the testing site, surveys and data processing method. Section 3 presents the results of the applied filtering. Section 4 discusses the results against the background of the state of the art. Finally, Section 5 summarizes the tests and presents brief conclusions. All the algorithms described herein and applied for the purposes of this article were implemented in the MathWorks MATLAB 2015a environment. The applied local minimum search algorithm was implemented by Carlos Adrián Vargas Aguilera.

2. Materials and methods

An undeveloped, naturally formed and grass-covered slope located in the Upper Silesian Coal Basin was chosen as the testing site. The elevation difference between the lower, southern end of the site and the upper, northern end is about 14 m. The east-west inclination is much smaller. Fig. 1 shows a contour map of the testing site, including its division into two different vegetation zones. Most of the surveyed site was covered in relatively sparse and low-mowed (for the purposes of the survey) grass (A). However, part of the site had not been mowed and was covered in 30–40-cm tall grass (B); see Figs. 1 and 2. Only the northern part of the testing site (Fig. 1) was measured with use of a total station (see Section 3.1), so for the southern part of the site there is no reference survey.

The Upper Silesian Coal Basin has long been an area of underground mining. That is why its land geometry may change over time. Thus, the site had to be surveyed in short intervals in order to ensure that both the surface geometry and the vegetation remained unchanged, allowing a comparison of the results of different surveying methods.

2.1. Description of the survey

The site was surveyed over a few days using TLS, a UAV-borne system and a total station. All the measurements were connected

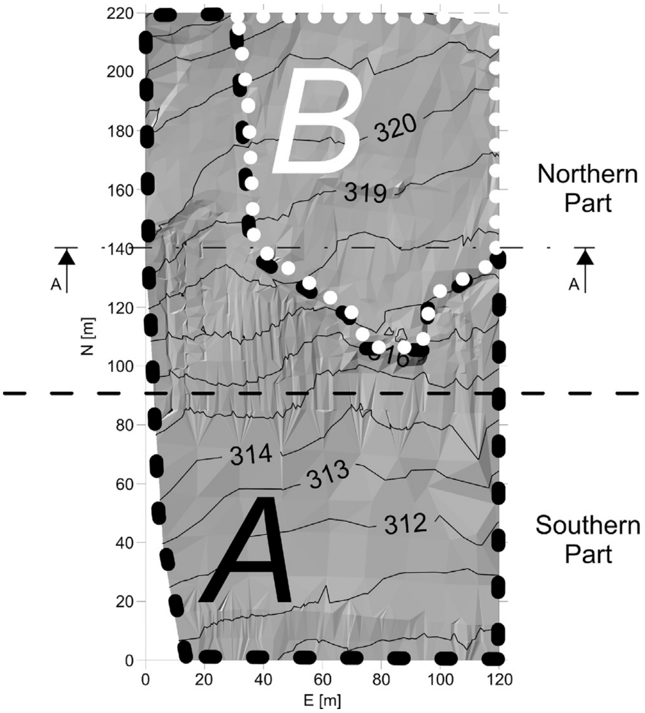

Fig. 1. Contour map of the testing site divided into two different vegetation zones. A – short grass, B – tall grass. Only the northern part of the testing site was measured with use of a total station.