Automatic Extraction of Oblique Roofs for Buildings from Point Clouds Produced by High Resolution Color-infrared Aerial Images

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SUMMARY

Automatic creation of the 3D city models and keeping up to date are important topics in many disciplines. Generating the 3D city models quickly and automatically depends on producing some of models' details (buildings, vegetation, roads etc.) and digital elevation model. Nowadays, the aerial laser scanner system and the aerial imaging technologies are preferred for collection of the digital elevation models and 3D city model details.

This study presents an automatic detection technique for extraction of building oblique roof and vegetation from dense image matching point clouds by Semi Global Matching (SGM) algorithm applied on high resolution colour-infrared (CIR) digital aerial images. The high resolution (GSD 8 cm) colour-infrared images from Vaihingen-Data Set (ISPRS benchmark Project, consisting of historic buildings with roads and trees) were used for producing the coloured 3D point clouds by SGM.

The study consists of three steps; firstly, the vegetation points were detected by using NDVI mask from the infrared-coloured 3D point clouds. Then, the bare-earth points were extracted by Progressive TIN densification algorithm from the 3D point clouds that have been eliminated the vegetation points. As a final step, the oblique roof planes were obtained by Random Sample Consensus (RANSAC) from the latest point cloud without the vegetation and the bare-earth points. The results were evaluated by comparing to manually acquired reference building data. Three quality measures (Completeness, Correctness, and Quality) were used for accuracy assessment. According to the quality measures, the proposed algorithm is successful for automatic extraction of oblique roof planes.

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1. INTRODUCTION

The planning of the city, the creation and updating of Geographic Information System, analyzing the result of natural disasters, to observe of the changes in urbanization in periods and to perform the analysis about them are necessary for the 3D city models. In order to create the 3D city models primarily, the digital surface models of the related area (DSM) should be produced. In order to generate the digital surface model is needed the sufficient points coordinates in three dimensions of the same region. The satellite and airborne imaging technology or airborne laser scanning systems have come to the fore.

There are many studies for extraction of details by the using of the airborne laser and imaging technology together (Habib et al., 2011, Demir and Baltsavias, 2012, Kwak and Habib, 2013, Macay Moreira et al., 2013).

The building models has been tried to be extracted with using the raw LiDAR data and the images of the study area in some of these studies (Habib et al., 2011, Demir and Baltsavias, 2012). For other studies (Kwak and Habib, 2013), only the raw LiDAR data was used with recursive minimun bounding rectangle (MBR) for generate roof rectangular models. Considering the other similar studies (Macay Moreira et al., 2013) building models were generated by using surface model that obtained from digital images and LiDAR data. For general flowcharts, only laser scanning data or laser scanning and images datas that evaluated together, aimed to creation of the various 3D models and exctraction of building. There are many satellites and airborne technology for providing high resolution images but nowadays unmanned aerial vehicles are became widespread because of its practical and economical properties for small area. The unmanned aerial vehicle's imaging characteristics affect the planned study directly (Colomina and Molina, 2014). In a separate study, 3D point clouds obtained from unmanned aerial vehicles images are used in various area (Rosnell and Honkavaara, 2012). There are a few studies about building extraction from point clouds that obtained from pixel-based image matching and these studies should be developed (Omidalizarandi and Saadatseresht, 2013, Pamungkas and Suwardi, 2015, Omidalizarandi and Saadatseresht, 2013)
The quality of the study that previously made and will be made, is changeable and it depends on the density of point clouds, accuracy of 3D points and the classification's quality. In this study, the aim is creating a dense 3D point clouds from the high-resolution images and extraction of the oblique roof's points from these data.

2. STUDY AREA AND DATA

The high resolution (7680×13824, 12 µm pixel, GSD=8 cm) colour-infrared images from Vaihingen-Data Set (ISPRS DGPF Project, consisting of historic buildings with roads and trees) were used for producing the coloured 3D point clouds by SGM. The size of study area images were nearly 280×210m (**Fig. 1**).

Fig.1 The study area

3. METHODOLOGY

Firstly, the free or commercial image processing programs (VisualSFM, Agisoft PhotoScan, NFrame Sure etc.) have tested for creating the point clouds with the images have orientation parameters are known. The 3D coordinates were assigned to the each pixel by the help of image matching process with these package programs. The performances of the programs have been tested and the previous studies (Remondino et al., 2013, Ahmadabadian et al., 2013) were analyzed about the programs.

The nFrames that uses SGM (Semi Global Matching) algorithm has the best results of test about the time and the amount of getting points. SGM can provide opportunities to get 3D coordinate for all pixel nearly by pixel-vise image matching (Hirschmül in 2008).

The vegetation and oblique roofs were tried to extraction from the point clouds obtained by SURE with consideration of color information and the surface geometry of the buildings oblique roofs. Related work of processing steps are as follows (**Fig. 2**).

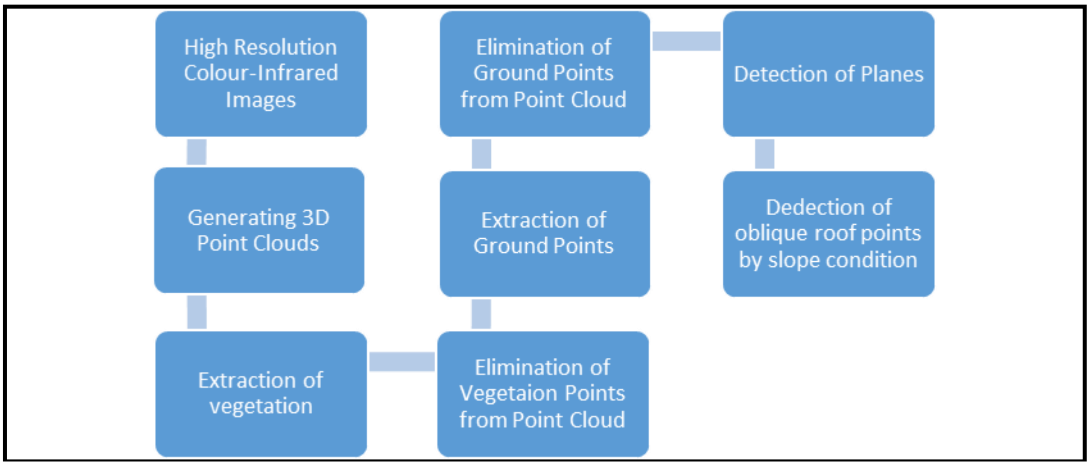

Fig. 2 The process steps

At first stage, the pixels of vegetation has been determined largely by consideration of the near-infrared band values with calculated vegetation index given in Eq. 1.

$$NDVI = \frac{NIR-Red}{NIR+Red} \quad (1)$$

Detection of the vegetation points were provided with the points colour values and the 3D coordinate information.

The total amount of points in point cloud was decreased by removing of vegetation points for future steps. The ground points of study were determined by TIN densification algorithm from the point cloud that include man-made structures but removed vegetation points. Then the ground and vegetation points have been removed from the main point cloud data. The points that represent the plane have been extracted by the iterations of Random Sample Consensus (RANSAC) algorithm from the eliminated point cloud. RANSAC algorithm, one of the commonly used method in lirerature, is able to give the most accurate results from the samples, containing errors up to 50 % level (outliers) or mismatches (Hartley and Zisserman, 2000).

Raw data can be evaluated with RANSAC by following a simple procedure, firstly a required error threshold is decided for the selected test data set as a next step confidence interval and number of iterations are also set by the user discrete models are iteratively created and kept separated from each other until required threshold is reached by the algorithm. The model generated by the selected data for the test set and the new data obtained from this model are kept separate from the other data to be re-evaluated in subsequent processes if the desired error threshold value is not exceeded.

Steps for RANSAC:

- Random selection of points from the data,
- Creating a model with selected points (line, plane, etc.)
- Calculation of the error of other points for the model,
- Continuing the same process until the T_{iter} times,

The RANSAC iteration count according to equation (2).

$$T_{iter} = \left[\frac{\log \varepsilon}{\log(1-q)} \right] \qquad (2)$$

In equation (2), T_{iter} the number of iterations; q sampling probability; and ε the probability of required threshold value (Tomasi and Kanade, 1991).

At the last stage, the buildings points without the vegetation and ground points were extracted but also a small amount of the vegetation and ground points that couldn’t eliminate from the main point cloud were stored. Only the oblique roof points from all planes in the point cloud were extracted by the intensity and slope condition (25%) from point cloud. Extraction the planes of man-made geometric structures that have various geometric shapes, means that to represent of structure’s area that covers on earth.

The following equations are accepted for accuracy analysis that automatically generated layers of detail and layers of reference that evaluated on pixel base.

In these equations, *Corr* gives the matching rate of calculations, *Comp* rate of automatic detection and *Quality* gives the quality percentage of the study (3). In equations, TP (true positive) is an entity classified as an object that also corresponds to an object in the reference, FN (false negative is an entity corresponding to an object in the reference that is classified as background, and FP (false positive) is an entity classified as an object that does not correspond to an object in the reference (Rutzinger et al. 2009; Shufelt 1999).

$$Corr = \frac{TP}{TP + FP}$$

$$Comp = \frac{TP}{TP + FN} \qquad (3)$$

$$Quality = \frac{TP}{TP + FN + FP}$$

4. RESULTS AND DISCUSSIONS

In this study, only the extraction of the oblique roof points were analyzed from points clouds that obtained from high resolution colour-infrared images, without LiDAR data. The Correctness: 0.78, Completeness: 0.99 and Quality: 0.78 were calculated from layers of detail that generated automatically and layers of reference for the accuracy analysis. The layers are shown below (Fig. 3).

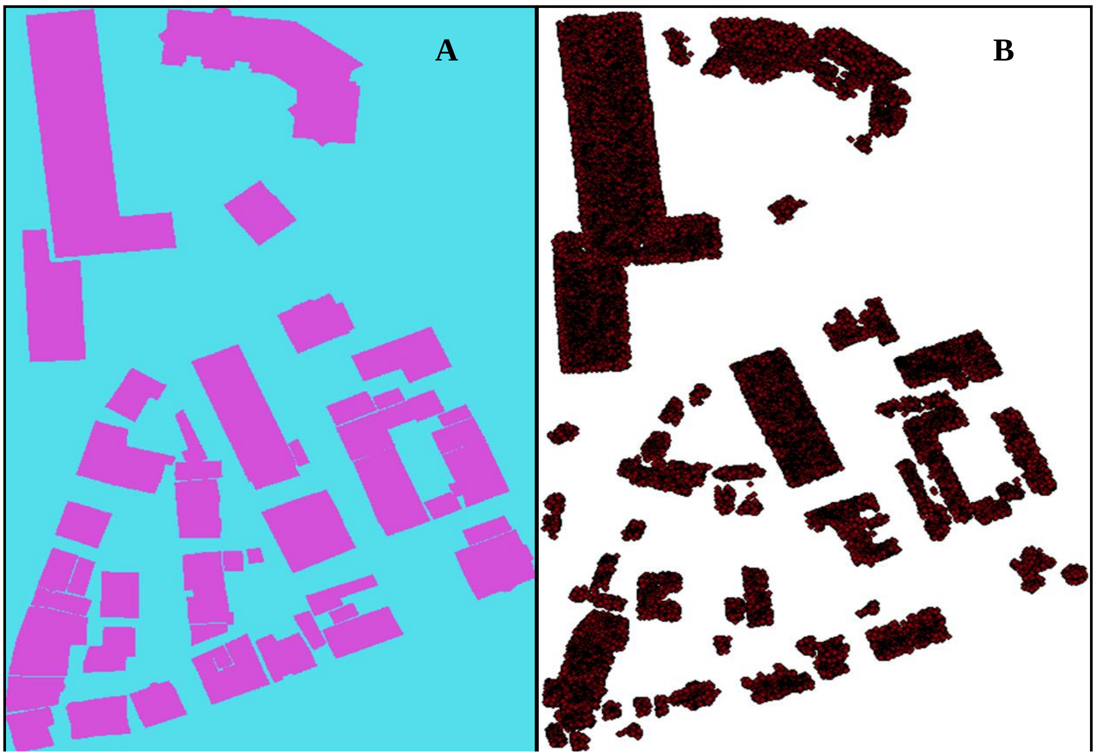

Fig. 3 The reference layer of details (A) and the layer of details' points that detected automatically (B)

There were some blanks on building's roof because of the unmatched pixels which were falling over shadows of dense building, shadows of high vegetation and the parts of plane without slope (Fig. 4). Because of these conditions some of accuracy rates were low.

Fig. 4 The blanks on the roofs (1. The flat plane, 2. The falling over shadow of dense)

It expected that, if the high resolution images can be taken in less shadow condition and more overlap, the blanks will degrease and the Correctness and Qualty rates will increase. The automatic extracted points of oblique roofs with blanks are shown below (Fig. 5).

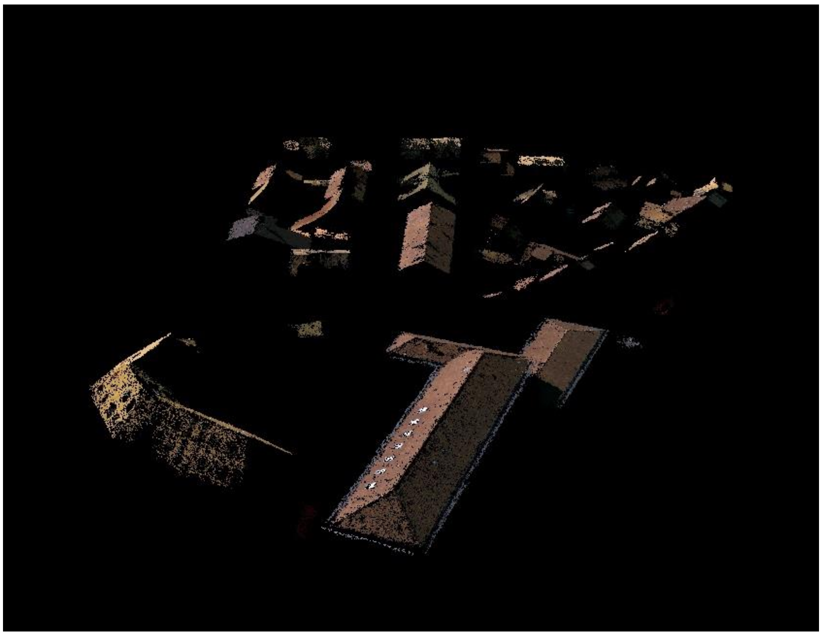

Fig. 6 The oblique roof points

5. CONCLUSIONS

As a result of study, the 3D points cloud was produced by using the high resolution overlapped images as an alternative to laser scanning technology. The oblique roofs' points were extracted automatically with the Correctness: 0.78, Completeness: 0.99 and Quality: 0.78 rates, in the last point clouds that eliminated the vegetation and ground points.

Some gaps on oblique roof were observed because of shadow, vegetation and some of flat part of buildings. Extraction of all oblique and normal roof plane automatically are required for 3D city models. For future study, it was planned that extraction of all type of roofs automatically and creation of a prototype 3D city model with all roof's planes.

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