AN INNOVATION APPROACH FOR DEVELOPING A 3D MODEL BY REGISTERING A MONO IMAGE ON A DTM

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ABSTRACT:

This paper is reflecting a study on developing and reconstructing a 3D model from registering an aerial image on a point clouds or a DTM. The point clouds has been chosen as the main data for reconstructing a 3D model. For achieving the aspects of the study, all objects were individually detected and extracted from the point clouds and captured in a particular layer in a CAD environment. Then each object will be converted to a raster format and will be registered on the image. This process is called the reverse registration in this study. Since the object segmentation and detection from a digital image is a complex process, the reverse registration is implemented in order to assist the process of the object detection from the image. This paper will discuss two methods of object detection from point clouds for the reverse registration. These methods were proposed and implemented for this study. Also, the paper will discuss the reverse registration and how this method improves the process of the object detection and extraction from the image. Discussion of reconstructing a 3D model from registering the digital image on a DTM or DSM (both of which developed from the point clouds data) is another goal of this paper.

1. INTRODUCTION

Reconstructing of 3D model from aerial images specifically, and in generic term from any type of images is now within the grasp of a vast variety of businesses. There are great benefits with rendering a 3D model for analysis and interpreting of the object, and consequently it has attracted the interest of the most businesses, government bodies, and developers and research groups. Due to implementing a reliable method for reconstructing a 3D model from images, a computer enhanced with a powerful graphic card is essential. Especially with development of computer graphic, the computer has been become easier to interact with, and better understanding and interpreting any type of data. Developments in computer graphics have had great impact in most of computer's applications as well as digital photogrammetry and remote sensing. Reconstructing a 3D model from a stereo image using a stereoplotter or a stereoscop is a well known technique in photogrammetry. In conventional fashion, a stereo model was reconstructed within a stereoplotter and coordinates of the interest points on the object or the terrain were extracted manually; however, in modern digital stereoplotters the process has been implemented automatically or it is better to say semi-automatically. Modern stereoplotters are able automatically to develop a Digital Terrain Model (DTM) or Digital Surface Model (DSM) from stereo images; nevertheless, there are other approaches for reconstruction a 3D model from non-optical sequence images such as those approaches has been implemented by Brahim et al. (2010) or Wei et al. (2009). Also there are some approaches for reconstruction a 3D model from mono image with help of the auxiliary data (Zhang and Tsui, 1998, Qian, 2010, or Chen and Kohatsu, 2007). In recent years with development of computer graphics, there is an interest towards reconstructing 3D model in computer for visualising, rendering, and objects analysing. In such a context, all platforms for developing a 3D model have to meet the requirements of the 3D modelling. Therefore, majority of the techniques have been developed based on integration of two or more sensors, while each sensor provides a particular data from the terrain or the object and with combining those data finally a comprehensive 3D model can be reconstructed. For example, Sportouche et al. (2009) reconstructed a 3D model with registering high resolution optical image on a SAR image. In their approach, two dimensional data were extracted from a mono image with implementing a number of constraints; they registered the extracted data on a SAR image. Tupin and Roux (2003) were developed a method that was very close to previous method. They also extracted planar data from images and registered on a SAR image. The main aspect of both methods was to detect buildings from SAR image which matches with their corresponding which already were detected from images due to reconstructing a 3D model. Dammann et al. (2006) reconstructed a 3D model by registering an optical image on a generated 3D model from Chirped Amplitude Modulation (AM) LADAR image. The purpose of registration of optical image on the constructed 3D model was to provide a texture to the 3D model. Homainejad (2011 a, 2011 b, and 2010) implemented an approach for reconstructing a 3D model by registering mono images on a generated DTM or DSM or 3D model. The approach consists of the following steps:

1- Dividing the image to sub area,
2- Each sub area was registered on its corresponding in the DTM or 3D model. In this step all pixel will be transformed to the 3D model space and will be converted to points. Each point included X, Y, and Z coordinates and intensity value which inherited from the image.
3- The output from this approach is a 3D model; however, it has an ortho-image characteristic as well.

This paper will discuss a new version of Homainejad's approach for reconstructing a 3D model by registering an image on a 3D model which was developed from the point clouds. The organisation of this paper is: the background and proposal will be given in the next section; study area will be given in section 3, the methodology, the result and analysis will be given in section 4, and section 5 will give a conclusion.

2. BACKGROUND AND PROPOSAL

The author is participating in a project on urban classification and 3D building reconstruction which has been proposed by ISPRS – Commission III (Working Group III/4). The core of the project is to evaluating the extraction of various object classes from digital imagery platforms such as digital aerial images and Laser Scanning data. The focus of the project was the registration of the aerial image on the Laser Scanning data for developing and reconstructing a 3D model. Therefore a set of digital aerial images and Laser Scanner data have been provided for this project. To accomplish the project's goals, the author proposed to implement a modified approach which was originally explained by Homainejad (2011a). The modified approach embraces following steps.

1. Interested objects will be extracted from the point clouds. In this step an operator which has been developed for this purpose, will apply on the point clouds data.
2. The extracted objects from the point clouds data will be converted to a raster format and will be registered on the image for assisting the process of object detection and extraction from the image.
3. The extracted objects from the image will be transformed and registered on a 3D model or a DTM which were developed from the point clouds for reconstructing a new 3D model.

The modification has been carried out on the process of the object extraction from the point clouds in order to improve the final result and speed up the process. In this proposal the process will not started from splitting the image to small areas. Instead, interested objects will be extracted from the point clouds. Then the extracted object will be transformed to the image for assisting segmentation and object extraction from the image. Basically in this study, two first steps of object extraction from the point clouds and transforming the extracted objects to the image space for improving the segmentation are called reverse registration. Figure 1 shows the process of proposal for this project. The object extraction can be implemented on the DTM, DSM, 3D model, or a point clouds. Since a point clouds data has been provided for this project, the focus of this study is to extract the objects from the point clouds data and consequently the mathematical model was developed in order to extract objects from the point clouds data. Most of studies in object extraction from Laser Scanning data have been focused on the signal processing or mathematical modelling which has been developed based on parameters of orientation of Laser Scanner beam with the surface of the object. For example, Silván-Cárdenas and Wang (2006) implemented Multiscale Hermit Transform (MHT) due to decompose signal for profiling the surface of terrain, or Kirchhof et al. (2008) and Bae et al. (2009) independently developed a mathematical model for object extraction from the point clouds based on parameters of orientation of Laser Scanner beam with the terrain. Since the provided point clouds from the terrain for this project did not include any pre-knowledge regarding to parameters of Laser Scanner orientation and received waveform, a few operators were developed and implemented for detecting and extracting interest objects from the point clouds or DTM which was developed from the point clouds, but only two of them will be discussed here.

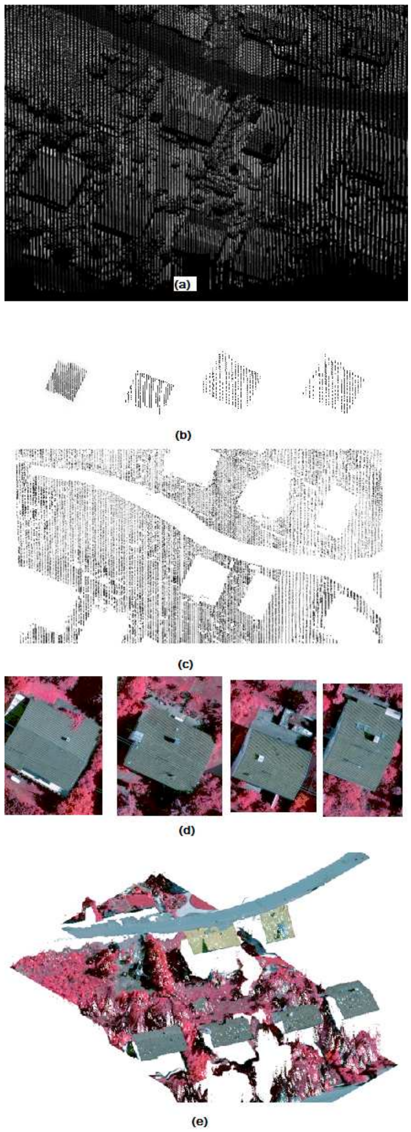

Figure 1. This figure shows the process of the proposal for this research study. Figure (1a) shows a point clouds from an urban area. Figure (1b) shows the extracted of four building in this area form the point clouds, and Figure (1c) shows the bare point clouds after subtracting all extracted object from the point clouds. Figure (1d) shows extracted buildings from the image after transforming and registering extracted building from the point clouds on the image. Figure (1e) shows an isometric view from reconstruction of the 3D model after transforming and registering extracted object from the image on the 3D model space or DTM developed from the point clouds.

The first operator has been developed based on curvature ($\boldsymbol{k}$) and signed curvature ($\boldsymbol{K}$) of the terrain at point p. The curvature of a surface at point p is:

$$\boldsymbol{k}(\boldsymbol{s}) = \|\boldsymbol{T}'(\boldsymbol{s})\| \qquad \textbf{(Eq. 1)}$$

Where $\boldsymbol{T}'(\boldsymbol{s}) = \boldsymbol{K}(\boldsymbol{s})\boldsymbol{N}(\boldsymbol{s})$ is derivative of unit tangent vector, $\boldsymbol{k}(s)$ is curvature of surface at point p, $\boldsymbol{N}(\boldsymbol{s})$ is the unit normal vector. The signed curvature $\boldsymbol{K}(\boldsymbol{s})$ indicates the direction in which the unit tangent vector rotate, as a function of parameter along the curve. Negative singe indicates the rotation is clockwise, and positive singe indicates rotation is counterclockwise. With extension of above equation in a 3D Cartesian space, the curvature will be:

$$\boldsymbol{k} = \frac{\sqrt{(z''y'-y''z')^2+(x''z'-z''x')^2+(y''x'-x''y')^2}}{(x'^2+y'^2+z'^2)^{3/2}} \qquad \textbf{(Eq. 2)}$$

Where the prime and double prime denote to the first and the second derivatives. According to the above equation we can analyse and then extract an object from a point clouds data. The algorithm for extracting an object from the point clouds will be compare the magnitude and the singe of the curvature at the point p and at the neighbouring points, when a significant change has been found the object will be isolated and then extracted.

The second operator is defining the curvature of each three points which build a surface. Let S be the polyhedral surface which the point clouds as its vertices (S ⊂ $\mathbf{R}^3$, p ∈ S), therefore the directional curvature function of surface S at point p is a quadratic form as expressed in the following (Taubin 1995):

$$k_p(T) = \begin{pmatrix} t_1 \\ t_2 \end{pmatrix}^t \begin{pmatrix} k_p^{11} & k_p^{12} \\ k_p^{21} & k_p^{22} \end{pmatrix} \begin{pmatrix} t_1 \\ t_2 \end{pmatrix} \quad \textbf{(Eq. 3)}$$

Where $k_p(T)$ is directional curvature of S at p in the direction of the unit length vector T (the tangent to S at p). Also $T = t_1T_1 + t_2 T_2$ which $\{T_1 , T_2\}$ is an orthonormal basis of the tangent space to S at p. Finally $k_p^{11} = k_p(T_1)$, $k_p^{22} = k_p(T_2)$, and $k_p^{12} = k_p^{21}$. In this study we assume $k_p^{12} = k_p^{21} = 0$, that means the vector of $\{T_1 , T_2\}$ is principle directions of S at p.

$$k_p(T) = \begin{pmatrix} t_1 \\ t_2 \end{pmatrix}^t \begin{pmatrix} k_p^{11} & 0 \\ 0 & k_p^{22} \end{pmatrix} \begin{pmatrix} t_1 \\ t_2 \end{pmatrix} \quad \textbf{(Eq. 4)}$$

With analysing the singe of k_p^{11} and k_p^{22} one can recognise the changes of the curvature and then the object can be extracted and isolated.

2.1 Proposal for extracting buildings

Firstly, no attempt was made in order to develop a template as a framework for detecting and extracting building from the point clouds in this study. Some studies assumed the buildings have a rectangular shape and mostly focused on detecting and extracting rectangular shapes from the images (Tupin and Roux 2003). We believe that there is no reason to assume all buildings have a rectangular shape. In generic term we logically accept that all buildings have a closed and regular geometric shape and most of buildings' roof has an elevation greater than 2 meters from the ground, as well as edges of roofs in most cases remain at the one level. According to the above knowledge, the operator which was developed based on either equation 2 or equation 4 searches for buildings within a defined area. It has to be noted that when speaking about detecting and extracting buildings in this study, it means to detect and extract the roof of buildings. After extracting buildings from the point clouds, all detected buildings will be checked and corrected before transform and register on the image. Then the buildings will be converted to raster format and then transformed and registered on the image. For transformation, an initial and rough orientation will be carried out. Then the algorithm will extract the corresponding building from the image according to the geometric information were obtained from the point clouds and using feature-based matching approach. Then each extracted building from the image will transform and register on the 3D models, the parameters of orientations were computed individually for each object as Homainejad (2011a) explained.

2.2 Proposal for extracting trees

For extracting trees from the point clouds, the algorithm mostly focuses on the Laser Scanner facts. New generation of Airborne Laser Scanners are able to record up to four backscattered waveforms returned from trees. Each emitted signal after hit the tree will penetrate to the ground, and each time when the signal hit the tree's branches a reflected waveform will return to the Laser Scanner. Unlike the returned waveform from a surface which forms a trace of a straight line, the returned waveform from trees scatters in an area. Therefore, for extracting a tree, or group of trees a grid is designed. The size of each cell of the grid is equal to the size of Laser Scanner footprint. Then the origin of the grid and bearing of its main direction will be defined. The algorithm will search according to the equations 2 or 4 and above initialisation inside each cell for **(i)** checking the density of point clouds inside of each cell, **(ii)** testing the variation of the curvature between points. If algorithm recognises the variation of the curvature is changing inside of each cell and the density is different with a defined criterion, then it will recognise and extract trees.

2.3 Proposal for extracting roads

Extracting road requires following initialisation. At the beginning a number of points on the road will be captured for initialising. The points include the start, the end, and changing directions points of the roads. Then the maximum and the minimum width of the roads will be measured. The algorithm according to these data and one of the equations 2 or 4 will detect and extract the road from the point clouds. Then the extracted road will be checked and corrected. Then the extracted roads will converted to raster data and will transform and register on the image for extracting the corresponding roads from the image. Finally, the extracted road from image will be transformed and registered on the 3D model.

2.4 Proposal for extracting crown land

Each object after extraction will be removed from the point clouds and finally after removing all extracted object a bare point clouds will be available. The bare point clouds will represent the crown land. In this case, the point clouds consists many gaps regarding to the extracted object that can be easily filled by different methods such as interpolation method, but it has to be aware sometimes the interpolation will fill an area which basically cut off for a development. A supervised interpolation has to be carried out for achieving the best result and reducing any error.

3. STUDY AREA

As mentioned earlier, the author is participating in an ISPRS test project on urban classification and 3D building reconstruction. The project focuses on reconstruction 3D model by using aerial image and Laser Scanner data. The test data set was acquired over Vaihingen in Germany. Three areas have been chosen for participants, nevertheless, each area has slightly different from two other areas, but each area includes building, road, and trees. Digital aerial images were acquired by Intergraph/ZI DMC camera with ground resolution of 8cm. Point clouds has been captured by Leica ALS50 system with point density of 4 pts/m^2. In this paper the results from two areas will be shown. The first area is in the centre of city with is characterized by dense development consisting of historic buildings having rather complex shapes; also the area includes trees. The second area includes multistorey buildings.

4. IMPLEMENTATION AND ANALYSIS

The focus of this research study is primarily on extracting objects from DTM or DSM which are generated from point clouds or the point clouds itself. Then transforming and registering the extracted object on the aerial image for assisting