UTILIZING AIRBORNE LASER ALTIMETRY FOR THE IMPROVEMENT OF AUTOMATICALLY GENERATED DEMS OVER URBAN AREAS

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ABSTRACT

Airborne laser altimetry is a highly efficient and accurate method of obtaining data for the determination of visible surface topography. With minimal processing, the laser data can provide coordinates of points on the visible surface with high spatial frequency and precision. Although this technology has benefits compared to photogrammetric techniques, there are limiting factors due to the laser data having no thematic information. These limitations may be overcome by utilizing aspects of both laser altimetry and photogrammetry in the surface determination process.

The research described in this paper has been undertaken to accurately determine the visible surface in urban areas using airborne laser scanner data and digital aerial images. In this research, edges detected in the aerial images are used to refine the digital surface model (DSM) produced from airborne laser scanner data. The three dimensional edge information allows improvement of the laser DSM by providing accurate horizontal locations of the surface discontinuities. Therefore the laser data and the edge information are merged to obtain the benefits of each data set, facilitating the generation of an accurate surface model.

The paper presents preliminary results of testing undertaken using an algorithm developed to combine laser data and photogrammetric data. The data set used in the testing is an urban site covering Ocean City, Maryland, USA.

1 INTRODUCTION

Highly accurate models of the visible surface in urban areas are becoming widely used in many applications, such as digital orthophoto production, three dimensional (3D) city modelling and 3D building reconstruction. Methods for generating surface models of urban areas include using laser scanner data and using digital photogrammetric methods. Both methods of DSM generation have advantages and limitations.

The research presented in this paper utilizes information from laser scanner data and photogrammetric data to produce an accurate model of the visible surface. There are two phases to the project. In the first phase, surfaces are created from each data source and are accurately registered to the same coordinate system. The second phase consists of the extraction of edge information from the photogrammetric data, which is used to delineate surface discontinuities in the urban scene. By merging the edge information and the laser data for surface generation, a DSM which more closely represents the actual scene can be produced.

Digital photogrammetric methods of automatic surface reconstruction have become widely used due to the efficiency and cost effectiveness of the production process, especially in open or flat areas, and when using small and medium scale imagery (Krzystek and Ackermann, 1995). However, most software packages perform poorly in areas with abrupt height differences, such as those occurring frequently in urban areas (Haala, 1999). The degradation in performance can be caused by failures of the image matching process (Axelsson, 1998). Such failures may be due to factors like lack of texture in the images (Haala, 1994), poor image quality, shadows in the images, occlusions, surface discontinuities (Haala *et al.*, 1997) and foreshortening (Schenk and Toth, 1992). The problems occur when using digital photogrammetry in urban areas result in inaccuracies in the DSM, which can be seen in the smoothing effect on surface discontinuities (Baltsavias, 1999; Haala, 1999; Toth and Grejner-Brzezinska, 1999). Research continues into overcoming the problems of deriving DSMs using large-scale imagery and digital photogrammetric techniques (Cord *et al.*, 1999; Gooch *et al.*, 1999; Veidman and Krupnik, 1999).

One of the benefits of photogrammetry is that the imagery contains more information than just the position of pixels in the images. Grey-value changes in the images allow the identification and classification of objects, such as buildings or vegetation, and can be used to detect edges in the images, which often indicate the location of surface discontinuities (Baltsavias, 1999; Fradkin and Ethrog, 1997; Haala and Anders, 1997).

Laser scanning is recognized as an accurate data source for DSM generation in urban areas (Haala *et al.*, 1997). The spatial resolution of the data is dependent on several factors, such as flying height, flying speed and scanner frequency (Lemmens *et al.*, 1997). Characteristics and performance of laser data systems have been discussed by many researchers (Ackermann, 1999; Axelsson, 1998; Baltsavias, 1999; Fritsch, 1999; Hug and Wehr, 1997; Kilian *et al.*, 1996; Lohr, 1998; Vaughn *et al.*, 1996). Calibration methods and the errors which may occur in the data have also been investigated (Fritsch and Kilian, 1994; Hu *et al.*, 1998; Huising and Gomes Pereira, 1998; Lemmens, 1997; Lemmens *et al.*, 1997; Kilian, 1994). Data processing and filtering methods have been described by Axelsson (1999), Hug and Wehr (1997), Kilian *et al.* (1996) and Knabenschuh and Petzold (1999).

Laser data consists of coordinate information only, and therefore lacks thematic information (Ackermann, 1999; Axelsson, 1999; Haala *et al.*, 1997; Kraus and Pfeifer, 1998; Petzold *et al.*, 1999). Laser data provides accurate points with high spatial frequency, however breaklines are not present in the data (Kraus and Pfeifer, 1998), and therefore the position of surface discontinuities can only be estimated or calculated by methods such as segmentation of the range data (Haala *et al.*, 1997; Vosselman, 1999). To illustrate this point, Figure 1 presents an elevation image showing high-rise buildings in laser data. The edges of the buildings are not well defined, though a high spatial density of the laser data points is indicated by the 'ragged' nature of the edges, as also noted by Vosselman (1999).

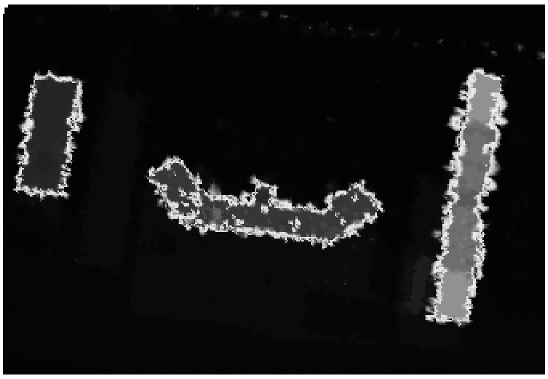

Figure 1. Plan view showing laser data.

Investigations and observations comparing DSMs produced from laser data and those derived from digital photogrammetric methods have been made in several research studies. In areas of the imagery lacking texture or contrast, the image matching might not provide accurate results whereas the accuracy of the laser is not affected (Baltsavias, 1999; Kraus and Pfeifer, 1998). Image matching produces a smoother DSM than the laser data at surface discontinuities (Baltsavias, 1999; Haala, 1999; Toth and Grejner-Brzezinska, 1999), however photogrammetric data have a higher planimetric accuracy than laser data (Baltsavias, 1999).

The complementary nature of the two data sources has been widely recognized and the approach of combining them has been suggested by researchers for several years (Fritsch and Kilian, 1994; Haala, 1994). This suggestion has been reiterated recently (Ackermann, 1999; Axelsson, 1999; Baltsavias, 1999; Brenner, 1999; Csathó *et al.*, 1999; Fritsch, 1999; Haala, 1999; Haala and Anders, 1997; Toth and Grejner-Brzezinska, 1999; Vosselman 1999). The approach of using imagery to provide edge information has been highlighted by several researchers (Ackermann, 1999; Axelsson, 1998; Csathó *et al.*, 1999; Haala and Anders, 1997), and is the main concept of the approach undertaken in this research.

The approach presented in this paper utilizes the beneficial properties of both photogrammetric data and laser data to produce an accurate DSM. Digital stereo imagery can provide accurate horizontal information regarding the location of surface discontinuities. The laser data provides accurate elevations, however does not contain accurate location information of the surface discontinuities, as illustrated in Figure 1. Thus the two data sources are merged to obtain the advantages of each, and therefore facilitating the generation of an accurate surface model.

Testing of the research approach has been undertaken using an urban site covering Ocean City, Maryland. Laser data and aerial images, acquired on the same day by NASA and NGS respectively, are used. Preliminary experiments have been performed to test and refine the algorithm. This paper presents the surface registration and the data fusion components, describes the data set and details the results from the initial experimentation.

2 PROPOSED DATA INTEGRATION APPROACH

The research presented in this paper utilizes information from laser scanner data and photogrammetric data to produce an accurate model of the visible surface. The conceptual approach consists of two phases. In the first phase, surfaces created from each source are accurately registered to the same coordinate system. The second phase consists of extracting edge information from the photogrammetric data, which is used to delineate surface discontinuities in the urban scene. By merging the edge information and the laser data for surface generation, a DSM that more closely represents the actual scene can be produced.

2.1 Surface Registration

The surface registration is undertaken to determine the transformation parameters between the laser surface and the photogrammetrically derived surface. Theoretically, the two data sets should be on the same coordinate system, however the systematic errors inherent in the laser data may introduce a misalignment between the two surfaces, which must be eliminated before data fusion may be performed accurately (Kraus and Pfeifer, 1998). The misalignment has been observed in the data sets used for the initial testing of the algorithm, validating the incorporation of the surface registration component into the algorithm.

The registration is performed to find the transformation parameters between the surfaces. These parameters are used to transform the laser data to the coordinate system of the photogrammetric data, as these data have higher planimetric accuracy compared to the laser data (Baltsavias, 1999). The determined transformation parameters must be as accurate as possible to ensure no unnecessary degradation occurs in the accuracy of the surface generated from merging the data sets.

The algorithm was developed specifically for matching visible surface models of urban areas produced using different acquisition methods, and in particular, surfaces from airborne laser scanner data and surfaces automatically generated using photogrammetric data. The registration algorithm solves for three translation parameters, three rotation parameters and one scale factor. The surface points are not interpolated to a regular grid and there are no identifiable conjugate points in the surfaces. For more detailed information on the algorithm and the results of testing, the reader is referred to Postolov *et al.* (1999).

2.2 Data Fusion

The main emphasis of the research project is to develop an algorithm to produce accurate visible surface models of urban areas, utilizing both laser data and photogrammetric data.

The data fusion component utilizes edges extracted from the stereo imagery to obtain accurate horizontal locations of surface discontinuities. The edges are defined in three dimensions and are used as breaklines when merged with the transformed laser data. A new surface is generated using the merged data, which is expected to have a higher accuracy than the surface derived from either of the separate data sets.

The conceptual approach formulated in this research proposes that the edges representing surface discontinuities are automatically derived as 3D line segments from the stereo imagery using edge extraction and feature matching techniques. Initial research has been undertaken into the automatic extraction of 3D line segments.

The edge pixels are detected in each image of the stereo pair of digital images. At present, the optimal zero-crossing operator (Sarkar and Boyer, 1991) is used for the detection of the edge pixels. The edge pixels are analyzed to find connected lines and using these lines, straight line segments are determined. Line segments are used as they adequately describe man-made objects and can be more accurately located than point features when using feature matching techniques (Fradkin and Ethrog, 1997). Also, each line segment can be easily described using the start and end points of the segment and the gradient of the line.

For each straight line segment in the first image, the second image is searched for a matching segment. To make the searching of the images more computationally efficient, a coarse to fine approach is utilized, and constraints are applied to the search process, including epipolar and ordering constraints (Grewe and Kak, 1994). The stereo imagery has exterior orientation parameters which allow the 3D coordinates of the line segments to be determined when the matching of the line segments is completed.

The automatic extraction of edges has certain limitations which must be addressed. Using automatic extraction methods, not all surface discontinuities are detected due to factors such as foreshortening and lack of contrast in the imagery. There might be a number of incomplete or incorrect breaklines, and other breaklines may be detected that do not represent surface discontinuities may be detected. Instead, these breaklines may refer to visual edges in the images, which are purely changes in grey value, such as line markings on roads. The effect of including these breaklines in the data fusion process is to be investigated.

For this research, the most important edges to be detected are the discontinuities between the roof and the ground. These areas are important to the accurate representation of the visible surface, as they contain dramatic changes in elevation.

The detected breaklines are expected to be mainly rooflines, however to properly define the surface, the ground level near the rooflines must also be determined. Therefore, the roofline will be projected vertically onto the ground surface to produce a new breakline, thus describing the surface at ground level as well as roof height. The location of the new breakline must be slightly offset outward from the roofline, as the triangulation process being used does not allow points to exist with the same horizontal location, as would be the case for a vertical plane.

The elevation of the ground surface at the location of the foot of the building must be determined. It is proposed that the laser data in the areas surrounding the breakline be searched. In the general case of the breakline delineating a surface discontinuity which is a roofline, it is expected that one side of the breakline will have points of higher elevation than the other side. The lower elevations will be assumed to be the elevation at ground level. Therefore, the new breakline will be generated and assigned the elevation of the ground points in that area.

In the current testing of the data fusion algorithm, manually measured breaklines are used. These breaklines are adequate to test the validity of the algorithm and to assess the implementation of the approach.

The laser points which occur on the breaklines are eliminated, again due to the triangulation process not accepting points with identical horizontal locations. The triangulation process is used to generate a TIN which utilizes the laser data points and constrains the triangles to follow the breaklines. The inclusion of the elevation information to the triangulation provides the digital surface model produced using the laser data and the photogrammetric data.

4 PRELIMINARY TESTING AND RESULTS

The initial testing was carried out using a data set over Ocean City, MD, which includes digital stereo imagery and laser data. The data set covers different types of areas, including residential areas, flat terrain, beach front, dunes, canals and high-rise buildings. Only a small portion of a residential area has been used for the initial testing of the algorithm.

The laser data have been filtered so as to only retain the first laser measurement and not any subsequent measurements from the laser sensor. The laser data has also been transformed to the coordinate system of the photogrammetric data using the parameters determined by the process surface registration. The two data sets are therefore on the same coordinate system and are representing the same surface. Laser points in the new data set are eliminated if they occur within close proximity to the breaklines. A filtering process is undertaken to eliminate points within a horizontal buffer zone of the line segments representing the surface discontinuities. The breaklines and the laser data are then merged to create a new data set.

The most significant surface discontinuities occur due to buildings, thus the rooflines of buildings are collected and used for the data fusion. As only the rooflines are measured, the surface at the ground level will not be adequately defined. Therefore, to better define the visible surface, it is necessary to incorporate measurements at ground level surrounding the buildings. This is accomplished by vertically projecting the horizontal position of the roofline to ground level. The elevation of the ground at that point is estimated using the surrounding laser data points. The breakline from these new points is slightly offset from the position of the roofline, as the triangulation procedure does not accommodate points with exactly the same horizontal position.

4.1 Surface Generation and Registration

Initial surfaces were generated to enable the registration of the two data sets. A digital elevation model (DEM) was generated using the softcopy photogrammetry program OrthoMax, under the Erdas Imagine environment. The laser surface used for the registration process is shown in Figure 2.

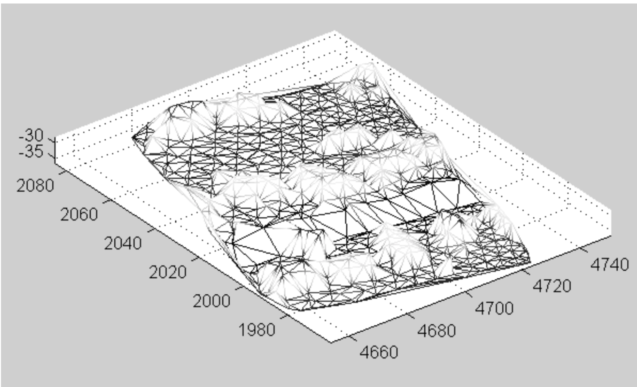

Figure 2. Laser surface used for registration.

The transformation parameters were determined using the developed registration algorithm. As a check on these results, roof breaklines were measured analytically to produce planes, and the laser points which occurred in the vicinity of these planes were used in the registration process, therefore providing a result which was not dependent on automatic DEM generation techniques. The results were of similar magnitude in each case, with the vertical shift between the surfaces being approximately one meter. Further details are provided in Postolov *et al.* (1999).

4.2 Results of Data Fusion

For the current experimentation, the breaklines have been measured manually using an photogrammetric workstation. Roof breaklines were collected over a residential area in the stereo model. The laser points are filtered to delete points which fall on breaklines or within a certain distance of the breaklines. A small area is shown in Figure 3 to more clearly present the information. The same area is presented in the following figures. The surface generated from the laser data is shown in Figure 4.

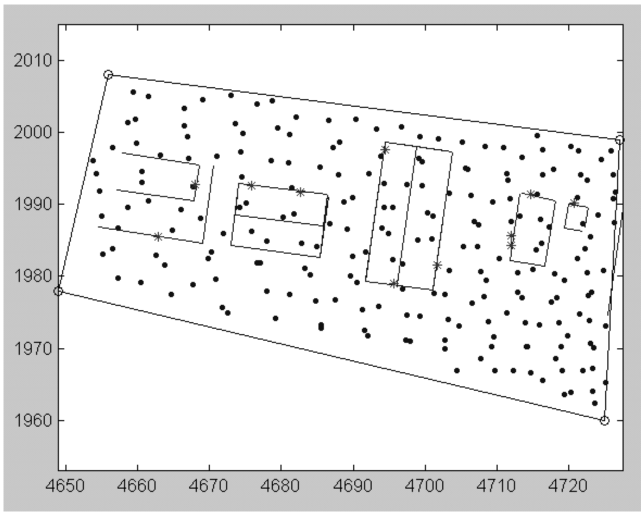

Figure 3. Breaklines and laser points.

A new surface is generated using the merged data. Constrained triangulation is used to enforce the use of the breaklines. The surface using the merged data is shown in Figure 5. Comparing these surfaces, the merged surface provides a better representation of the buildings than the surface generated using only the laser data.

The breaklines used up to this point only define the rooflines. To more accurately define the buildings, the roofline is projected on to the ground surface and used as a breakline, thus defining the walls of the buildings in addition to the roofs. The result of this process is shown in Figure 6.

Comparing the surfaces, the surface utilizing both the breaklines and the laser data better defines the buildings than either of the surfaces generated using a single data acquisition method, and that the projection of the roofline to the ground surface is necessary to accurately define the buildings.

5 CONCLUSIONS

This paper describes the development of a general scheme for the integration of laser and photogrammetric data. This scheme includes the development of a surface registration algorithm and a data fusion algorithm. Initial testing of the integration algorithm has been carried out using data over Ocean City, MD, and has shown that the surface is more accurately represented than when using either data set separately.

The approach presented in this paper is applicable to the determination of accurate visible surface models for the generation of true orthophotos in urban areas. The use of the rooflines to determine surface discontinuities will allow the production of an orthophoto that does not have the distortions associated with the inaccuracies in the surface models which are inherent in automatically generated DEMs. Continued research is being undertaken into the automation of the approach, to extract the edges of the rooflines and to determine the ground height in these regions.

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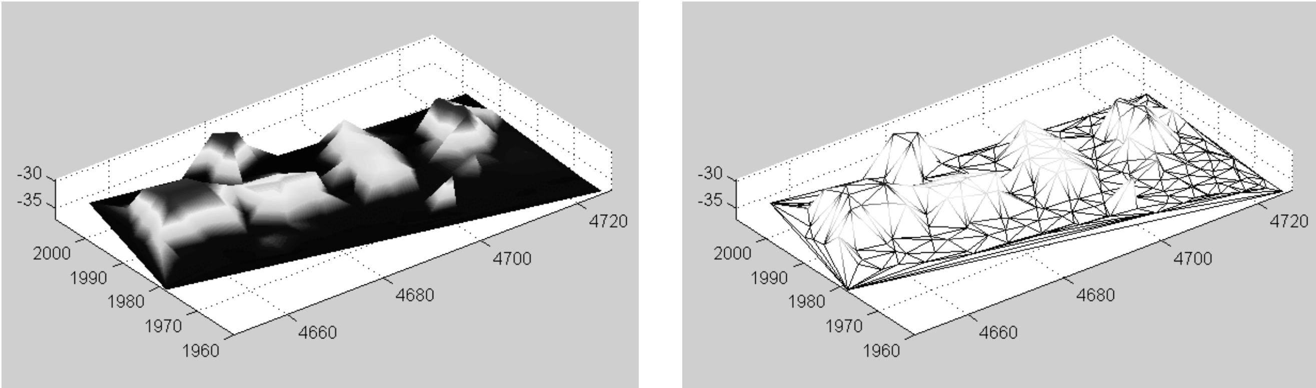

Figure 4. Surface from laser data.

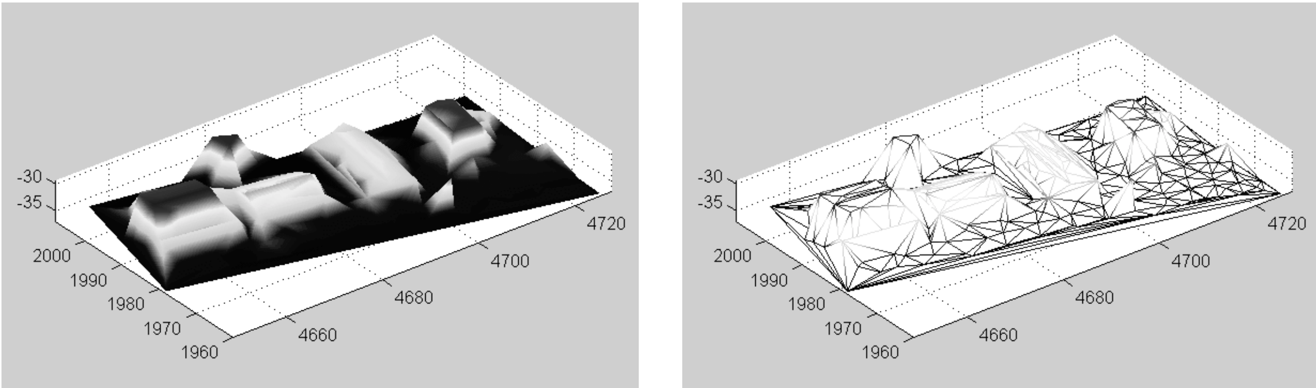

Figure 5. New surface using breaklines and laser data.

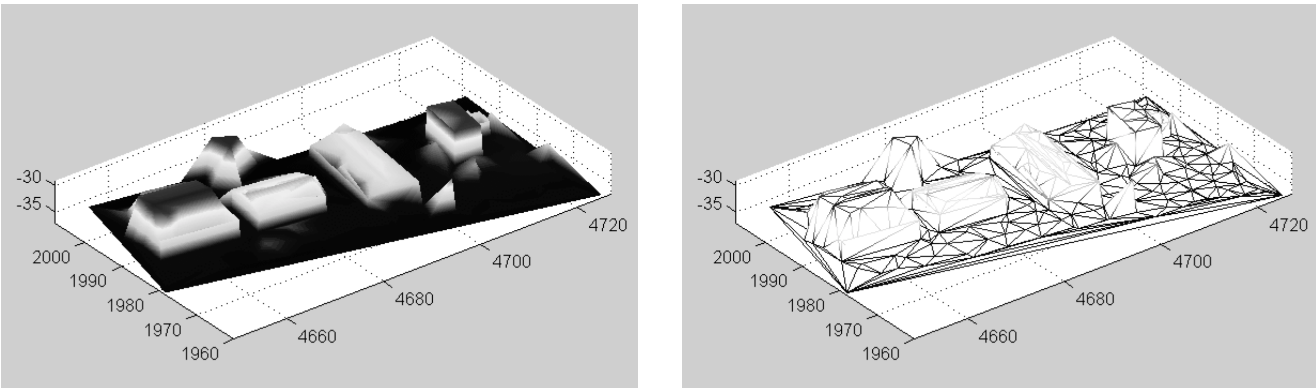

Figure 6. Incorporation of vertical projection of roofline to ground surface.

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