AUTOMATED BUILDING EXTRACTION: COMPARISON OF PARADIGMS AND EXAMPLES

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Commission V, WG V/1

KEY WORDS: LiDAR, Aerophotogrammetry, Building extraction, Topographic mapping, Optimization

ABSTRACT:

This paper compares the paradigms of LiDAR and aerophotogrammetry in the context of building extraction and briefly discusses two roof building contour extraction methodologies. The assets and drawbacks of both data capturing system have been reported several times. In general, empirical and theoretical studies have confirmed that LiDAR methodologies are more suitable in deriving building heights and in extracting planar roof faces and ridges of the roof, whereas the aerophotogrammetry are more suitable in extracting building roof outlines. The first roof contour extraction methodology is based on a Digital Elevation Model (DEM), which is generated through the regularization of an available LiDAR point cloud. First, in order to detect aboveground objects, the DEM is segmented through a recursive splitting technique, followed by a Bayesian merging technique. The aboveground object polygons are extracted by using vectorization and polygonization techniques. Finally, the building roof contours are identified among all aboveground object polygons extracted previously, taking into account roof features and a Markov Random Field (MRF) model. The second methodology addresses the geometric refinement of laser-derived 3D roof contours by using high-resolution aerial images and a MRF model. First, 3D roof contours are projected onto the image-space. Then, the projected contours and the straight lines extracted from the image are used to establish an MRF description. The solution of the associate energy function provides groupings of straight lines representing roof building contours, which are topologically reconstructed based on the topology of the projected contours. Examples of applications are provided for both approaches.

1. INTRODUCTION

Data acquisition for mapping and GIS using photogrammetric techniques has traditionally been performed via the manual extraction of cartographic features from images of the terrain surface ranging in scale from 1:3000 to 1:90000 (Sowmya and Trinder, 2000). Although manual extraction is adequate in terms of accuracy and reliability, it is time-consuming and expensive. On the other hand, due to imperfections in the image acquisition phase and in the scene complexity, feature extraction from imagery and LiDAR data is too complex to be fully automated. Building extraction methodologies are very important in the context of spatial data capture and updating for GIS applications. These methodologies can be based on either LiDAR or photogrammetric data or even on a combination between them.

Rottensteiner et al. (2005) described an algorithm for roof line delineation from LiDAR data. Basically, roof boundary and roof ridges are derived separately and combined to form a consistent polyhedral model. Vosselman (1999) described a similar approach for the polyhedral reconstruction of buildings from LiDAR data. Methodologies based on photogrammetric data have been proposed for over 20 years. For example, Fua and Hanson (1987) proposed a methodology for locating and outlining complex rectilinear cultural objects (buildings) in aerial images. More recently, Müller and Zaum (2005) proposed a methodology for building detection in aerial images. First, a region-growing algorithm is used to segment the entire image and then the buildings and vegetations are separated by a classification procedure based on a set of geometric and photometric features derived for each segmented region. Several approaches have been proposed to explore the synergy between LiDAR and photogrammetric data. Haala and Brenner (1999) combined multispectral imagery and DEM (Digital Elevation Model) derived from LiDAR data for separating building from vegetation. In Sohn and Dowman (2003) buildings are independently extracted from Ikonos imagery and DEM/LiDAR data and, then, the results are combined to remove inconsistencies. Vosselman (2002) combined LiDAR, plan view, and high-resolution aerial image data to automatically reconstruct 3D building. The plan view is used as reference to extract polyhedral building model from LiDAR data. The high-resolution aerial images are used to refine the roof boundaries. This paper compares (Section 2) the paradigms of LiDAR and aerophotogrammetry in the context of building extraction and briefly discusses (Section 3) two roof building contour extraction methodologies. Finally, the paper is finalized in Section 4 presenting some final considerations.

2. LIDAR VERSUS AEROPHOTOGRAMMETRY

Figure 1 shows prominent characteristics of the paradigms of LiDAR and aerophotogrammetry. In LiDAR paradigm, the scanning system basically comprises a laser beam, corresponding to the instantaneous field of view, and a moving mirror that allows the scanning of the whole field of view. The time interval from a laser beam emission to its backscattered echo detection is measured and transformed into
range by considering the light speed in the atmosphere. The backscatter energy is also recorded, but for only one wavelength. As shown in Figure 1(a), a laser beam is represented by a straight line segment between the laser emitter (E) and an object space point (P). Point P can be determined with no redundancy by the range EP, the position of point E supplied by GPS (Global Positioning System), and the orientation of the laser beam supplied by an INS (Inertial Navigation System).

![Figure 1. Paradigms. (a) LiDAR; and (b) Aerophotogrammetry (Adapted from Kraus (2002))](image)

In aerophotogrammetry paradigm, passive solar radiation backscattered by objects in the field of view of the camera is recorded in the images. The backscattered radiation can be spatially organized into pixel grids in different wavelength bands. In geometric sense, a stereo pair of images can be viewed as two directed ray bundles intersecting in the object space. As a result, each object space point (P) is defined as the intersection between two homologous rays (Figure 1(b)). Although GPS and an INS are highly desirable to directly measure the position and orientation of every ray bundle, both positioning systems are optional.

Building extraction using LiDAR data or photogrammetric data shows advantages and disadvantages. Table 1 presents some relevant elements for analysing the weak and strong points of each paradigm in the context of building extraction. In order to reconstruct polyhedral-like buildings it is necessary to basically extract from the data (image and/or LiDAR) planar roof faces and rectilinear building boundaries. Other building parts, like the walls and roof ridges, are derived from the geometric entities extracted from the data. The extraction of planar roof is more reliable and accurate when accomplished from LiDAR data. This is usually true because roofs are usually homogeneous in optical images and, as a result, it is very difficult to extract dense positional information along them using photogrammetric techniques. Moreover, the opposite takes place when using LiDAR-based techniques. In addition, roof plane orientation is better when using LiDAR data than using photogrammetric data. This is a direct consequence of the fact that the LiDAR-based heights are more accurate than ones extracted from photogrammetric data. Since LiDAR roof face planes are well-defined, roof ridgelines derived by intersection of these planes are well-defined as well. Concerning the extraction of building boundary, the use of photogrammetric data is advantageous because positional information along break lines is dense in photogrammetric images and poor in LiDAR data. As a result, if one wants to accurately extract building boundaries, photogrammetric data should be used in order to accurately detect and delineate edges related to building boundaries. In general, fine details, like edges, corners, chimneys etc., should be extracted with the help of photogrammetric images. Finally, photogrammetric images are also necessary to attribute accurate and complete semantic meaning to a whole building or to parts of a building.

Kaartinen et al. (2005) presented an empirical evaluation that supports the theoretical analysis discussed above. The study compares accuracies obtained with aerophotogrammetry and LiDAR in building extraction. It consists of four test sites, three in Finland and one in France. The following data was used in the evaluation tests: aerial images, camera calibration and image orientation information, ground control points, LiDAR data, and cadastral map vectors of selected buildings. Evaluation tests were carried out by 11 participants, leading to 3D building models. These 3D models were numerically compared to ground reference data. The main conclusions drawn from the tests are:

- Photogrammetric methods were more accurate in determining building outlines. However, site-dependent variations of LiDAR results were verified due to mainly differences in point density and in complexity of the building structure.
- Concerning building length determination, as expected LiDAR-based methods were not as accurate as photogrammetric methods. It was verified that LiDAR-based results were strongly dependent on the complexity of the buildings, rather than on the point density.
- LiDAR-based methods proved to be more efficient than the photogrammetrically-based methods in the derivation of building heights and planar roof faces. As a result, ridges of the roof and roof inclination were also better determined when using LiDAR-based methods. Moreover, it was verified that height determination accuracy followed exactly the LiDAR point density.
- The degree of automation was higher for LiDAR-based method, but it was affected by the complexity of the building.
- The plane target accuracy was inversely affected by the degree of automation, but almost no similar correlation was found for the target height accuracy.

A general conclusion is that hybrid approaches combining LiDAR and photogrammetric data can potentially deliver results with better accuracy, reliability, and completeness than ones obtained using either LiDAR or photogrammetric data.

<table>
<thead>
<tr>
<th>Comparison elements</th>
<th>LiDAR</th>
<th>Aerophotogrammetry</th>
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<tbody>
<tr>
<td>Break lines</td>
<td>Poor positional information</td>
<td>Dense positional information</td>
</tr>
<tr>
<td>Homogeneous regions</td>
<td>Dense positional information</td>
<td>Poor positional information</td>
</tr>
<tr>
<td>Positional accuracy</td>
<td>Better in altimetry</td>
<td>Better in planimetry</td>
</tr>
<tr>
<td>Semantic information</td>
<td>Poor</td>
<td>Rich</td>
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Table 1. Complementarity of the aerophotogrammetry and LiDAR paradigms in building extraction
3. BUILDING EXTRACTION METHODOLOGIES

In this section we briefly discuss our experience in building extraction from LiDAR and photogrammetric data. In the last years we have developed two building roof contour extraction methodologies, one based on LiDAR data and another based on a combination of LiDAR and aerial image data.

3.1 LiDAR-based roof contour extraction methodology

Galvanin et al. (2008) proposes a methodology for automatic extraction of building roof contour from LiDAR data. The methodology is based on two steps: 1) Extraction of aboveground regions (buildings, trees etc.) from a Digital Elevation Model (DEM) derived from LiDAR data (Figure 2(a)); and 2) Building roof contour recognition (Figure 2(b)).

In the first step (Figure 2(a)), the DEM is segmented in order to subdivide it into two classes of homogeneous regions, as follows: aboveground regions and background regions composed by the ground objects. First, the quadtree-based recursive splitting technique is applied to the DEM to generate an initial segmentation, where any distinction is done between aboveground regions and background regions. In the following, an MRF (Markov Random Field)-based Bayesian merging technique is applied to the previously segmented DEM to minimize the fragmentation and to separate the ground and aboveground objects. In this model the height values are modeled as a function of a general mean and random effects. The prior distribution for the random effects is specified by the Conditional Autoregressive (CAR) model. The posterior probability distributions are obtained by the Gibbs sampler.

In the second step (Figure 2(b)), the building roof contours are identified among all aboveground objects extracted previously. Aboveground regions are now structured as a RAG (Region Adjacency Graph), where each node corresponds to an aboveground region. An MRF-based modeling is used to model roof contour knowledge, allowing the recognition of only the interest object, i.e., the roof contour. Taking into account roof features, like area, rectangularity (angle between principal and secondary axes of each aboveground region), and angle between principal axes of each pair of aboveground regions, an energy function is developed based on the MRF model. The optimization of the energy function allows the identification of the optimal configuration of roof contours. This is a problem of MAP (Maximum a Posteriori) estimation, which in our case is solved by the Simulated Annealing algorithm.

An example of application is shown in Figure 3. The LiDAR intensity image (Figure 3(a)) is presented only for visualization purpose of the test area. Figures 3(b) and (c) present the first and second steps’ results, respectively.

Figure 3. Example of application. (a) LiDAR intensity image; (b) Aboveground regions; and (c) Building roof contours

Figure 3(b) shows that 15 aboveground regions are extracted in the first step of the methodology, in which 14 of them are building regions. In the second step, 12 out of 15 aboveground regions are identified as building roof contours (Figure 3(c)). This result can be considered satisfactory, since only two building roof contours were not extracted (i.e., about 14% false negatives) and no roof building contour was incorrectly identified (i.e., no false positive).

3.2 Roof contour extraction methodology based on a combination between LiDAR and photogrammetric data

As shown in the figure 4, in Dal Poz (2008) is proposed a methodology that comprises the image registration of the 3D roof contours, the extraction of the image straight lines that are nearby the projected LiDAR roof contours, and the establishment of
the energy function \( (U(x)) \) based on an MRF model, the solution of the energy function by applying a minimization algorithm, and the completion of the detected straight lines' groupings for reconstructing the refined image-space roof contours.

Figure 4. Flowchart of the methodology

The projection of the 3D roof contours onto the image-space and the extraction of the image straight lines that are nearby the projected LiDAR roof contours are preprocessing steps. The first step consists of transforming the 3D roof contours' vertices into the LC-image coordinate system by using standard photogrammetric techniques. The second step is carried out by the Canny edge detector, which is followed by an edge linking and polygonization techniques and a simple perceptual organization technique for merging collinear straight lines. The image straight lines are used to construct an MRF model expressing building roof shapes according to the photogrammetrically-projected LiDAR roof contours. The associated energy function is optimized by a modified brute force method, resulting in a grouping of straight lines for each roof building contour. The last step consists of reconstructing the topology of the groupings, thus enabling the refined image-space roof contours to be generated.

Figure 5 shows a test building to exemplify the performance of the methodology. A polyhedron model of the same building is available and was derived from a LiDAR point cloud. The interior and exterior orientation parameters of the camera are also available.

Figure 5. Test building

Figure 6. Projected LiDAR straight lines

Figure 6 shows the projected LiDAR straight lines obtained through the projection of the 3D roof contour. The resulting polygon is relatively close to the building roof edges, as a small registration error of about 5-pixel maximum is present.

Figure 6. Projected LiDAR straight lines

Figure 7. Extracted building roof contour

Figure 7 presents the result obtained by the methodology. The final result is better than the projected LiDAR polygon because most parts of the refined polygon are improved to some degree. The proposed methodology was not able to provide satisfactory results along four sides of the refined polygon. The roof gable defined by the straight lines 4 and 5 remains with a poor geometric description. The roof details neighboring the straight lines 13 and 15 were poorly described due to a basic reason. The geometric descriptions of the corresponding parts of the polyhedron extracted from the 3D laser data are not enough to be handled by the proposed approach properly. Finally, based on the above analysis, the completeness and correctness of the result are 100% and 79% \( (\cong 15/19) \), respectively.

Figure 7. Extracted building roof contour
4. FINAL CONSIDERATIONS

This paper presented an overview of the paradigms of LiDAR and aerophotogrammetry in the context of building extraction and briefly presented our recent experiences in the building extraction topic. The principal assets and drawbacks of the LiDAR and aerophotogrammetric systems in building extraction were discussed. LiDAR-based methodologies are more suitable in deriving building heights and in extracting planar roof faces and ridges of the roof, whereas photogrammetrically-based methodologies are more suitable in extracting building roof outlines. These general conclusions were confirmed by the empirical studies conducted by Kaartinen et al. (2005). In the second part of the article we briefly presented our recent experience in the subject of building extraction. Two building roof contour extraction methodologies are reported, one being based on LiDAR data and another being based on a combination of both data type. A final comment is that automated building extraction methodologies should take advantages of the synergy between both data sources.

ACKNOWLEDGEMENTS

This paper was carried out with support of CNPq, National Council for the Scientific and Technological Development – Brazil, and FAPESP, São Paulo State Foundation for Research Development - Brazil. LiDAR data was supplied by LACTEC – Technological Institute for Development, Brazil.

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