AUTOMATIC BUILDING RECONSTRUCTION FROM VERY HIGH RESOLUTION AERIAL STEREOPAIRS USING CADASTRAL GROUND PLANS

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ABSTRACT

This paper describes an automatic 3D building reconstruction process from high resolution aerial stereopairs with the help of high scale digitised 2D cadastral plans. The cadastral external data is used in the image processing strategy to reduce the combinatory of the building feature extraction, grouping and reconstruction. Our approach is based on two main processes, the first aiming at modelling the inner surface of the building roof by roof planar hypotheses extracted by a 3D Hough transform on a fuzzy DSM and the second one aiming at recovering the 3-D outer limits of the roof by repositioning the cadastral 2D segments in 3D using the previous planar hypotheses and the image contrasts. Experimental results are presented and discussed and they show that is approach is very promising for the automation of complex building reconstruction.

1. INTRODUCTION

Automatic building reconstruction from aerial high resolution stereopairs has been a subject of constant attention from both photogrammetric and computer vision communities. Indeed, 3D CAD Building Models are necessary for 3D urban data bases and for many applications such as urban impact monitoring or virtual reality. Building these models by completely manual stereoplotting is very expensive. Research on automated building reconstruction is in great progress. Some building reconstruction techniques, e.g. based on parametric models, perform very well when the buildings are simple. Unfortunately, most of them suffer from building complexity (aggregations, non conventional multi slope roofs, etc.).

The reconstruction of complex multi planar slope buildings by image processing techniques (feature extraction , feature matching, feature grouping, etc.) is a very difficult and highly combinatorial problem which is often ill-posed. Some attempts to regularise the general reconstruction problem have already been carried out successfully with the use of external data: 1/25000 maps [Roux & al 1998], Laser Digital Surface Models [Wiedner & al 1995][Vosselman 99] or very high scale maps [Haala & al 1998].

This paper describes an approach using the geometric information of building ground footprints (planimetric polygonal description) which can be found in digital 1/1000 cadastral ground plans to inject knowledge in the image processing strategy in order to increase its efficiency and reliability to regularise the reconstruction problem and to be able to treat complex multi planar slope roof top buildings. In order to be able to extract all 3D features to elaborate a complete and precise description of all building structures over a square meter, we use very high resolution images (20cm, SNR=300) acquired with IGN's high quality digital aerial frame camera (SNR=300).

The cadastral geometric information provides global information on the building shape (orientation, angles), local information on features (approximate localisation of building edges) and above all focusing areas. Building feature extraction and matching, feature grouping techniques can thus be carried out on smaller areas and thus diminish the combinatory of the image processing reconstruction problem and consequently the computing times. Indeed, these focusing areas could be determined by the segmentation and the classification of a DSM derived from LASER data or generated from photogrammetric image matching techniques [Baillard 97][Paparoditis & al 2000]. On large surveys the cost would be heavier. Moreover, those processes are not yet totally reliable.

In the current approach, we suppose that the cadastral information is globally correct in shape and topology. The only kind of differences we will model and take into account in the processing between the 2D data and reality are geometric planimetrical shifts of about one meter which are most of the time due to the difference between the roof edge limits and the cadastral ground footprint corresponding to the projection of the building walls. Under these assumptions, we can decompose the roof reconstruction strategy into two main processes. The first looking inside the footprint for a set of planar faces describing the roof top. The second improving the geometrical localisation of the building footprint to fit the real roof limits.

2. DSM AND LOCAL FUZZY SURFACE RECONSTRUCTION

For a given building, we first build a Digital Surface Model inside the ground footprint given by the cadastral plan. This DSM is generated by matching windows with contour adaptive shapes [Paparoditis & al 98]. The only use of this DSM is determining the bounding volume of the roof to restrict the space of admissible solutions. This bounding volume (see Figure 1) is obtained by intersecting all the vertical planes lying on every segment of the ground footprint with the two horizontal planes of altitude respectively z_{min} and z_{max}. These framing altitudes are determined with the following geometrical constraint:

$$z_{min} = z_{median} - \alpha . L / 2 \qquad (1)$$
$$z_{max} = z_{median} + \alpha . L / 2 \qquad (2)$$

where:

- L is the length of the longest segment of the building cadastral line;
- α is a parameter depending on the maximal roof slope;
- $z_{mediane}$ is the median altitude of all the DSM samples.

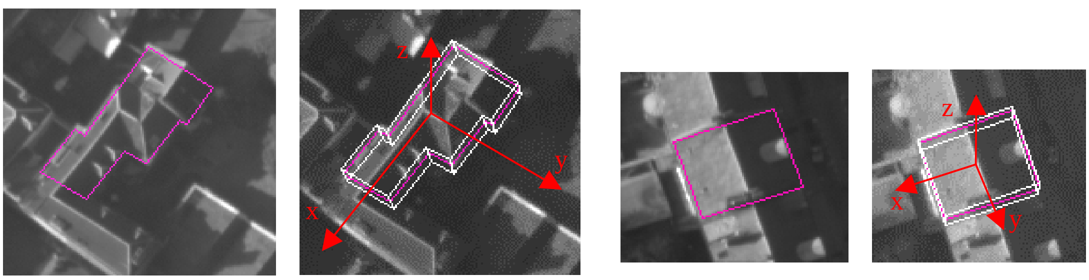

Figure 1 : a) cadastral line plunged in 3D at the median altitude of the inner footprint DSM. b) roof bounding volume

This volume is then sampled in voxels with a size depending on the ground pixel size of the images and on the base to height ratio of the stereopair. For every V(x,y,z) voxel, we can determine the related image positions in both images, extract small resampled 3x3 windows centred on these points, and calculate the correlation score of these two texture signals. We thus obtain what we call a “correlation volume” or a “fuzzy surface”. We use very small windows to have a very accurate and detailed rendering of all small structures inside the roof top (chimneys, dormer windows, etc.). These window sizes are possible thanks to the high SNR of our digital camera.

3. EXTRACTING ROOF PLANAR SURFACE HYPOTHESES BY A 3D HOUGH TRANSFORM

We suppose that the building roof can be modelled by planar facets. Our roof reconstruction strategy consists in extracting 3D planes hypotheses and looking for the optimal roof surface within all the surface hypotheses generated by the intersection of all the planes hypotheses. The roof planar hypotheses will be directly extracted from the correlation volume. Keeping all the information in the correlation volume, instead of working directly on the DSM, has two main advantages. The first is that we avoid choosing one best elevation value for each (x,y) which leads inevitably to well known ambiguities and errors inside the DSM which can have a major impact on the 3D features that could be derived from the DSM. We thus keep all z hypotheses for every (x,y). The second is that if one wants to generate a reliable enough DSM out of the stereopair, one will have to use much larger windows which would inevitably alter the rendering and make impossible the reconstruction of all roof micro-structures.

Many recent papers have addressed the extraction of roof planar hypotheses from Digital Surface Models [Cord & al 99] [Baillard & al 99] [Fradkin & al 99] [Vosselman 99]. Our approach is based on the 3D Hough transform considering that looking for planes in object space is the same problem as looking for 3D points in the Hough space. A plane can be described (as shown on Figure 2) by the equation:

$$Pl(\theta,\varphi,\rho) = \cos\theta\cdot\cos\varphi\cdot x + \sin\theta\cdot\cos\varphi\cdot y + \sin\varphi\cdot z - \rho = 0 \qquad (3)$$

$$\theta \in [0,\pi[\quad , \quad \varphi \in [0,\pi[\quad \text{et} \quad \rho \in]-\infty,+\infty[\qquad (4)$$

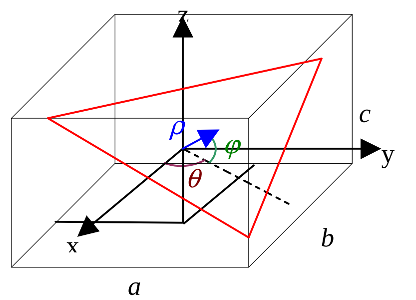

Figure 2 : representation of the plane by the parameters (θ, φ, ρ).

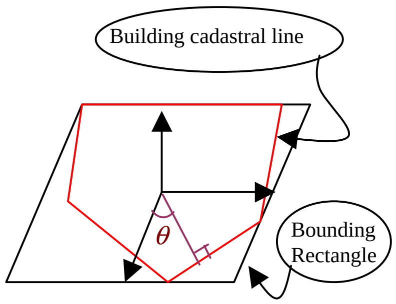

Figure 3 : directions perpendicular to the building facades

In our problem, the parameter space can be considerably limited. Indeed:

1) The plane normal vector is perpendicular to at least one of the directions of the building facades f_i : $\theta \in \{\perp f_0,\cdots\perp f_n\}$ as shown on Figure 3;

2) Roof slopes are beneath 45° : $\varphi \in \left[\frac{\pi}{4},\frac{3\pi}{4}\right]$;

3) $\rho \in]-R,R[$ and $R = \sqrt{a^2+b^2+c^2}/2$.

We associate to every voxel V(x, y, z) inside the correlation volume all the space planes. They are defined in the parameter space by the equation:

$$\rho = \cos\theta\cdot\cos\varphi\cdot x + \sin\theta\cdot\cos\varphi\cdot y + \sin\varphi\cdot z \qquad (5)$$

We apply the 3D Hough transform on the correlation volume. The Hough transform generates two accumulators: one for the correlation scores and an other for the number of points. Once the accumulation is finished, we normalise the correlation score accumulator by the number of points. The extraction of local peaks in the accumulator is carried out separately for every θ. The problem of 3D detection is thus transformed in an easier

2D detection problem. Before extracting all peaks, we apply a grey level morphological closing with a structuring element of a generous size. This filter allows the elimination of all peaks too close to the desired local peak. In other words, the size of the structuring element defines the minimal acceptable angle and distance between two neighbouring plans.

Planes passing by the volume corners and accumulating a small number of points can still have high scores. A threshold on the number of points can be used to reject these false hypotheses. This threshold can also reject correct hypotheses corresponding to planes with specific parameters. This problem occurs when the accumulator is not homogeneous. For instance, an accumulator cell can receive many more points than his neighbours for a given uniform image. This problem is essentially due to the sampling of the object space and of the parameter space. To reduce the influence of the sampling, one can determine dynamically the ρ parameter sampling [Guo & al 1999]:

$$\Delta\rho = \begin{cases} \sqrt{2}\cos(\varphi+\pi/4) & 0 \le \varphi < \pi/4 \\ \sqrt{2}\cos(\varphi-\pi/4) & \pi/4 \le \varphi < \pi/2 \\ \sqrt{2}\cos(\varphi-\pi/4) & \pi/2 \le \varphi < 3\pi/4 \\ \sqrt{2}\cos(\varphi+3\pi/4) & 3\pi/4 \le \varphi < \pi \end{cases} \tag{6}$$

This sampling enables a homogeneous distribution of the points inside the accumulator and also increases the amplitude of the peaks. This method gives very good results for 2D data (Figure 4). Sampling dynamically the correlation volume in 3D is a much more complicated problem.

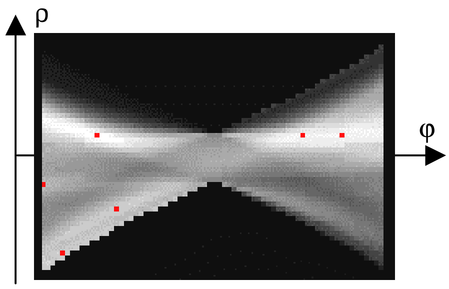

Figure 4 : Accumulator with θ = 0°, $\varphi \in \left[\frac{\pi}{4}, \frac{3\pi}{4}\right]$ and detected peaks

The results (Figure 5 and Figure 6) show all the roof planar hypotheses corresponding to all the peaks found in the accumulator for two different kind of buildings. The first one is a simple roof with two slopes and a large dormer window. The second is a complex six slope roof with three small dormer windows. In both cases even though the false detection are important, all the real roof planes are inside the roof planar hypotheses except for two of the three small dormer windows.

4. ROOF INNER SURFACE RECONSTRUCTION

We have not yet solved the surface reconstruction problem in the general case. We are currently working on this topic by integrating radiometrical, geometrical, and topological criteria to evaluate the global likelihood of every possible surface inside the surface graph composed by all the 3D facets made out of the intersection of all the 3D planar hypotheses.

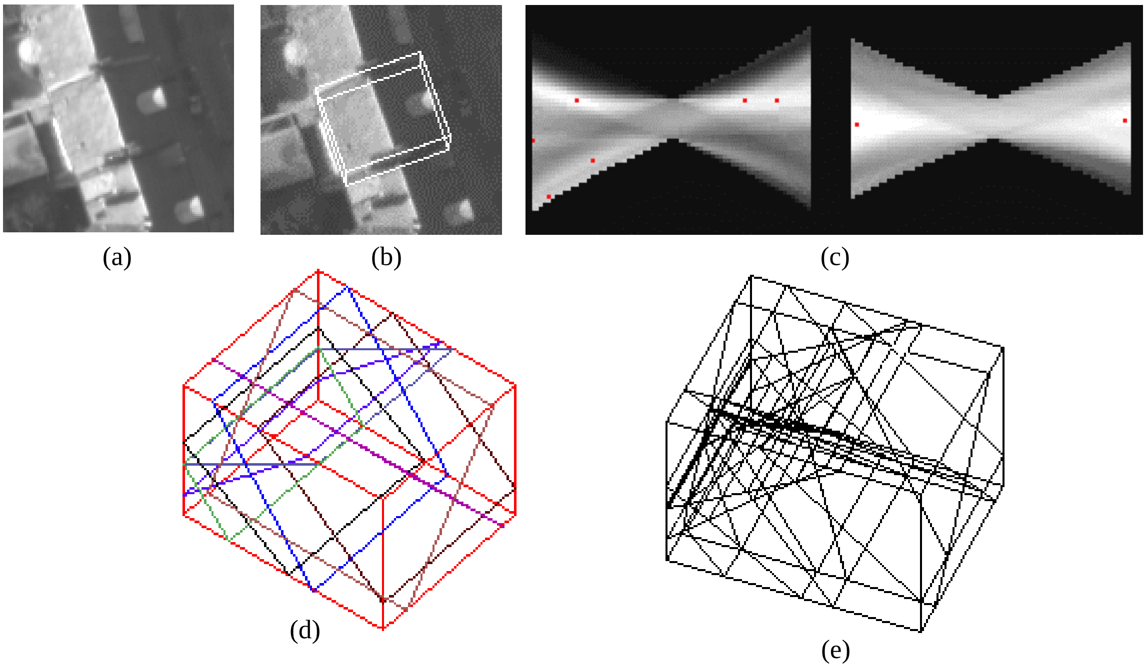

Figure 5 : a) two-slope building with a large dormer window ; b) bounding surface volume; c) the two accumulators for θ = 0° and θ = 90°. Six peak points have been detected (the two-slope planes and four false planes) and two and the second corresponding to the dormer window; d) set of planar hypotheses corresponding to all peak points; e) set of facets generated by the intersection of all hypotheses (124 facets).

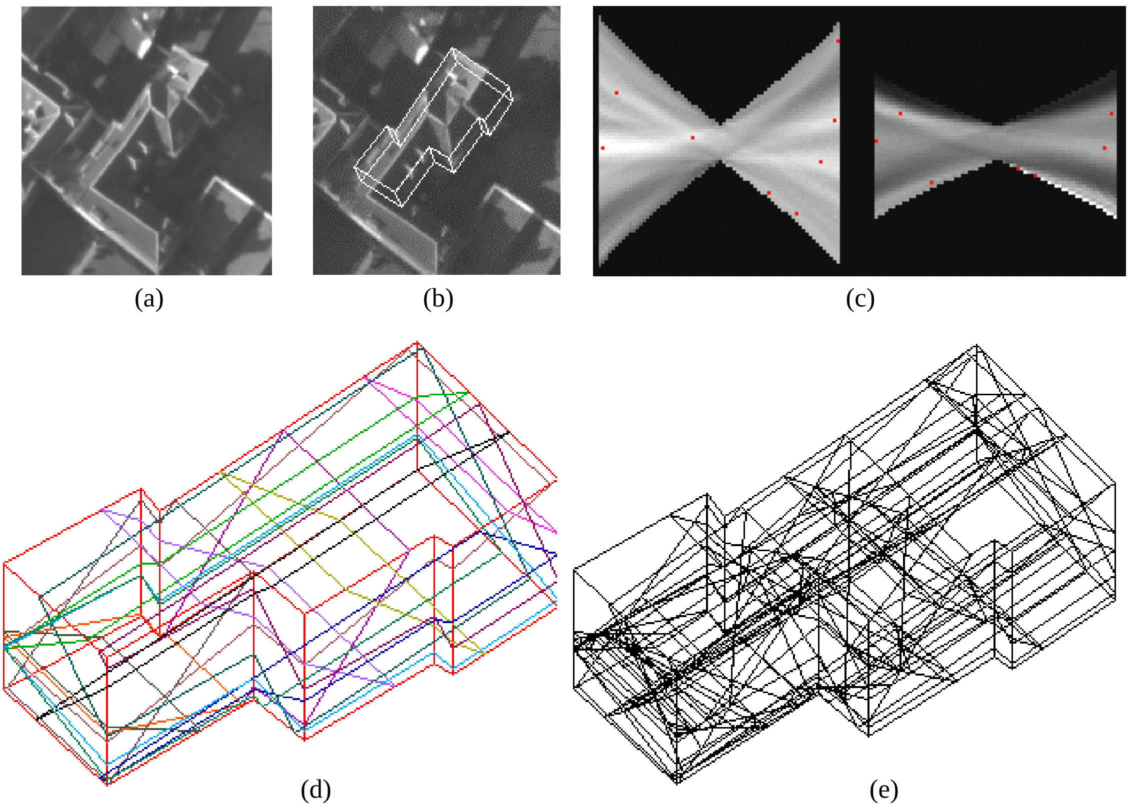

Figure 6 : a) Complex six-slope roof with three small dormer windows; b) bounding surface volume; c) the two accumulators for θ = 0° and θ = 90°. Eight peak points have been detected in the first and seven in the second. Eight of these fifteen peaks are good; d) set of planar hypotheses corresponding to all peak points; e) set of facets generated by the intersection of all hypotheses (438 facets).

For simple buildings, the problem is much easier. If we consider a two slope building, we need to determine the best couple of planes. The first plane would be one with the highest score and the second would be the best "opposite" plane. For instance if the best plane is inside the ($\theta = 0°$, $\varphi \in \left[\frac{\pi}{4}, \frac{\pi}{2}\right]$) parameter space, then the best opposite plane is the one in the domain ($\theta = 0°$, $\varphi \in \left[\frac{\pi}{2}, \frac{3\pi}{4}\right]$). From the four facets generated by the intersection of these two planes, we retain the two facets covering the whole building and having both, together, the best score.

5. 3D INDIVIDUAL REGISTRATION OF ROOF EDGES

Each segment of the building ground footprint is registered individually. The segment orientation is considered correct. Thus the segment registration problem can be reduced to the determination of one unknown parameter: the planimetric shift in the segment's orthogonal direction. For each elementary planimetric shift we plunge the segment in the 3D space with the roof surface computed previously. The score for each solution in the direction of surface's slope is calculated by integrating all the image gradient values lying under the corresponding line features in each image space. We retain the shift with the best score which is:

$$D = \underset{d \in [-s,s]}{\arg\max} (Sc_g \cdot Sc_d \cdot e^{-\alpha |d|}) \qquad (7)$$

where:

- d is the displacement in the plane and in the initial segment's orthogonal direction (as shown on Figure 8);
- s is a threshold of about one meter ;
- α is a weighting parameter;
- Scg, Scd the integrated values of the gradient norm along the projected segment hypothesis in both images.

The function is weighted by an exponential negative term to choose preferably the initial segment when the building edge contrast is poor.

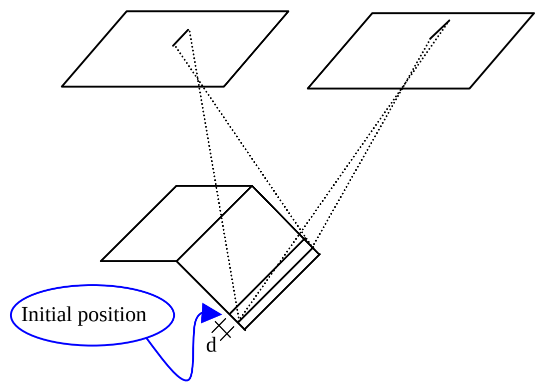

Figure 7 : 3D Edge registration with the use of image contrasts

The results of the 3D registration process are good when the roof edges are contrasted enough (see Figure 9).

6. BUILDING RECONSTRUCTION

Finally, in order to generate the complete building volume model, as shown on Figure 10, the vertical faces of the building model are recovered by intersecting all vertical planes lying on every segment of the ground footprint with the roof surface and a DTM which can be derived for example from a DSM computed on all the scene [Baillard & al 96].

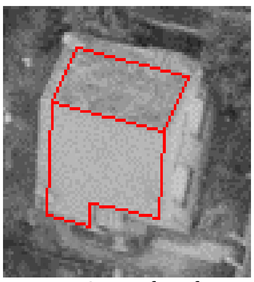

Figure 8 : roof surface generated with the hough transform

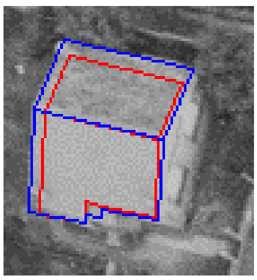

Figure 9 : new roof surface with edges registered with the image gradients.

Figure 10 : Roof surface plus the volume defined by the vertical walls

7. CONCLUSION

We have described an original system for the automatic reconstruction of 3D building models from aerial images and cadastral plans. The general strategy and the first results are very promising. The cadastral external information has been injected in all the image processing steps to diminish the space of admissible solutions and consequently the combinatory of the reconstruction problem which eases the extraction of significant features and building structures. All the algorithms described in this paper are guided from object space and can thus be extended naturally to highly overlapping images to increase the reliability [Paparoditis &al 00] of all our processing steps and especially to reduce the number of planar hypotheses to cut down considerably the combinatory of the roof surface reconstruction problem in the general case. We will very soon apply our system to a 20 cm survey acquired with the digital frame camera of IGN on the French town of Amiens with a sixty per cent stereo overlap both in the same flight strip and in two consecutive flight strips (every point of the landscape can be seen in up to 9 images).

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