Building verification from geometrical features

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ABSTRACT: Assessing the presence of man-made structures thanks to aerial or satellite images is crucial for applications like damage assessment, change detection or geographical database update. A step towards automation is welcome for these applications since image analysis by human experts is costly, time consuming and error prone. Semi-automatic procedures offer a practical solution by speeding up image analysis and limiting human intervention to difficult cases.

We present a semi-automatic approach to verify the presence of buildings in airborne images from geometrical features. Buildings described as polygons in a geographical vector database are scored according to matching features of linear edge segments detected in image. The score integrates proximity, parallelism and mutual coverage of image segments and corresponding polygon edges. The human operator interacts with this automatic scoring by specifying a threshold to highlight non verified buildings, the polygons of which are superimposed in red on the image. After visual inspection, the operator can update the database or mark some buildings as changed, depending on the application.

INTRODUCTION

Assessing the presence of buildings from aerial or satellite images is of high concern for applications such as damage assessment, change detection or geographical database update. In these applications, a step towards automation is welcome since the traditional image analysis by expert operators is costly, time consuming and error prone.

Fully automatic solutions suffer from the wide variety of object appearance in images due to illumination and perspective changes. This arises from the variability of the sensor and sun position implying changes in point of view and occlusions, reflection (modifying measured intensity) and shadow casts. Introducing human supervision in the process, the so-called semi-automatic procedures can offer a practical solution with automatic and possibly fast image analysis, requiring human intervention only for doubtful cases.

A very good example of semi-automatic approach concerns the development by MATIS laboratory (Institut Geographique National, France) of a platform to combine several automatic and user-assisted processes to produce 3D city models using aerial and 2D ground maps (Flamanc et al. 2003). As their objective is to create 3D city models, they focused their work on building reconstruction, providing two automatic approaches (one model driven and one data driven) and allowing user interaction for building reconstruction through central roof ridge delineation or roof model instantiation. As presented in Müller et al. (2005), a system to assess building presence can combine geometric (object size and shape), photometric (intensity) and structural (shadow, neighbours) features.

The Signal and Image Centre of the Belgian Royal Military Academy has developed an automatic system to estimate the urbanisation changes using SPOT5 images and the National Geographic Institute vector database (ETATS project, Lacroix 2006). This development does not address change detection at the level of individual buildings but at the level of built-up areas.

We present in this paper a semi-automatic approach to assess the presence of buildings described as polygons in a vector database thanks to geometrical features detected in an airborne image. The approach exploits the specificity of straight lines associated to roofs as discriminative cues for building detection. Building polygons of the database receive a score depending on edge contrast, proximity, parallelism and mutual coverage of linear edge segments detected in the image. The human intervention consists in the visual inspection of building polygons highlighted by the automatic scoring procedure.

In the following, section 2 details how the geometrical features are extracted from the image and how these help scoring building polygons in order to highlight possible unverified building. Section 3 presents results of the implemented approach. Section 4 concludes the paper, including perspectives for future work in building verification.

1 APPROACH

We propose to verify the presence of buildings described in a geographical database as polygons thanks to a visible airborne image of 30 cm per pixel resolution. At this resolution, buildings exhibit distinctive linear features like building or roof borders, roof ridges or building shadow profiles. The proposed approach first detects linear segments in the image as they are very likely to refer to human-made structures. Each building polygon is then checked by matching its edges with detected image segments, issuing a score related to the confidence in the building presence. Finally the operator is shown the image superimposed with green (verified) or red (rejected) polygons, according to the score values and a threshold that the operator can select from the histogram of building scores.

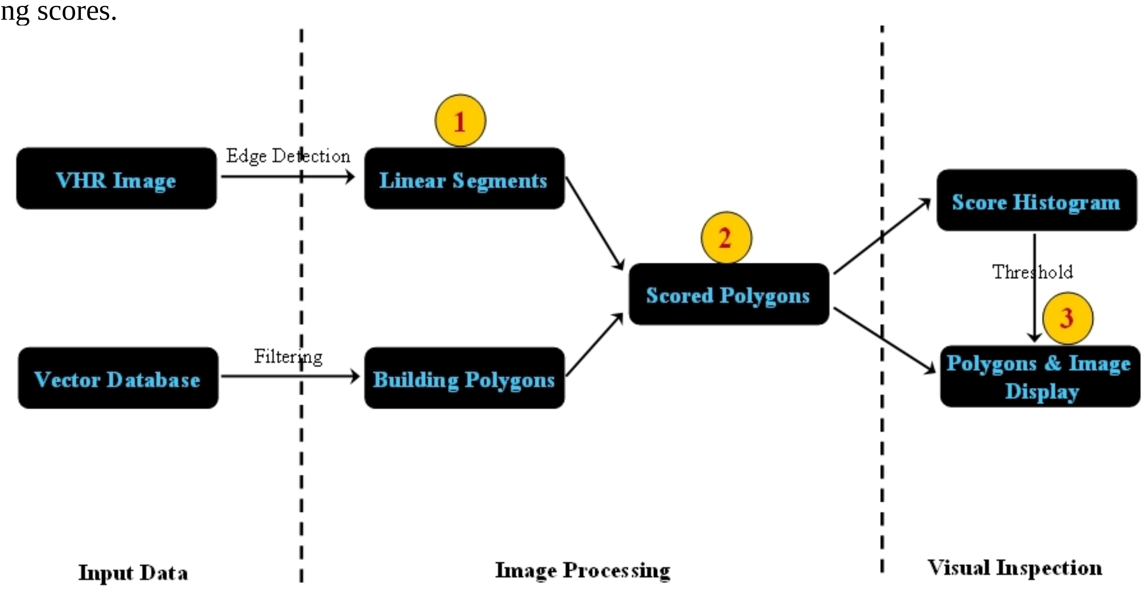

Figure 1. Approach overview.

1.1 *Detecting linear segments*

Image linear segments mostly relate to human structures. In the case of buildings, roof ridges or shadow casts typically exhibit clear linear features. We detect linear segments by selecting pixels with sufficient gradient, link them into segments and filter out these which are not straight enough.

We measure the horizontal and vertical derivatives Gx and Gy at pixel (x,y) of image I:

$$Gx = I(x+1,y) - I(x-1,y) \quad \text{and} \quad Gy = I(x,y+1) - I(x,y-1) \tag{1}$$

to derive the gradient vector whose amplitude G and orientation θ are:

$$G^2 = Gx^2 + Gy^2 \quad \text{and} \quad \tan(\theta) = Gy/Gx. \tag{2}$$

As most buildings exhibit a clear contrast, we eliminate edge pixels corresponding to low gradient by imposing a minimal value on G (*min_grad*).

Segments are obtained by a linking procedure which consists in connecting neighbouring pixels with sufficient gradient and consistent orientation. In our implementation, scanning the image from top to bottom and left to right, each pixel of sufficient gradient is retained as segment seed. Then pixels are added to growing segments as long as the strongest pixel (maximal gradient) of the three 8-neighbors ‘perpendicular’ to the seed orientation has enough gradient (*min_grad*) and consistent orientation (absolute difference less than *max_θ*, 22 °).

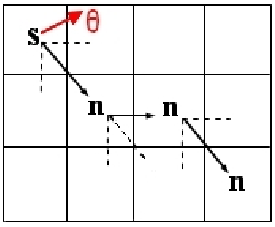

Figure 2: Linking procedure. ‘s’ is seed pixel, ‘-’ indicate neighbour candidates as implied by the seed orientation θ shown by the arrow. ‘n’ are pixels chosen by maximal gradient.

Curved segments are rarely associated to building outlines. We first reject short segments (*min_length*) which give little support and do not allow for precise straightness estimation. We then impose a maximal straightness (*max_straightness*) value to keep segments likely to correspond to human-made structures. Segment straightness is computed thanks to the moment of inertia of segment pixels with the elegant algorithm presented in Beumier (2006). This implementation is computationally effective and defines the straightness as a value in pixel corresponding to the standard deviation of pixel distance relative to the minimal inertia axis (zero for a perfect straight line).

1.2 *Scoring Polygon*

The objective of scoring a polygon is to estimate a confidence level for the presence of a building from the support of linear segments detected in the image. Each edge of a polygon is compared to image linear segments (detected as detailed in 2.1) to derive an edge score based on proximity, parallelism and mutual coverage. Individual edge scores are combined to give the global polygon score.

For each edge of a polygon, all the linear segments detected in the image are positioned relatively to the polygon edge thanks to four measures: d1, d2 and i1, i2 (Fig. 3). d1 and d2 are the signed distances (> 0 outside the polygon, < 0 inside) of segment ends to the polygon edge. i1 and i2 give the indices of segment ends along the polygon edge so that $-I1 < i1 < i2 < Length+I1$, I1 allowing for small localisation imprecision (a few pixels).

We define the following measures:

a) MC, the mutual coverage, equal to $i2-i1$, is defined as the projection of the segment on the polygon edge, clipped by this edge;
b) D, the average signed distance of the segment to the polygon, equal to $(d1+d2)/2$;
c) P, factor of parallelism, equal to $abs(d2-d1)/MC$, which is 0 for parallel segment and edge;
d) R, the reward value, equal to $(0.5*MC)/edge\_length$, which is the confidence assigned by the edge – segment pair, accounting for the ratio of the mutual coverage divided by the edge length. The factor 0.5 is necessary to allow for more confidence when several overlapping segments contribute to the same polygon edge.

Several cases may occur:

1) If $(P < P1)$ AND $(abs(D) < D1)$, the segment is parallel and close to the polygon edge. This is depicted by segments ‘SegA’ in Fig. 3.;
2) If $(P < P1)$ AND $(D1 < -D < D2)$, the segment, inside the polygon, is likely to correspond to a roof ridge, depicted in Fig. 3. by segment ‘Seg B’;
3) If $(P > P1)$ AND $(D < 0)$, the segment may correspond to a diagonal roof ridge (‘SegC’ in Fig.3.). For this we check if any segment end (d1,i1 and d2,i2) is close to the vertices of this polygon edge.

The edge score is initialized to 0 and increased by R for each occurrence of those 3 cases. The final value is saturated to 1.0.

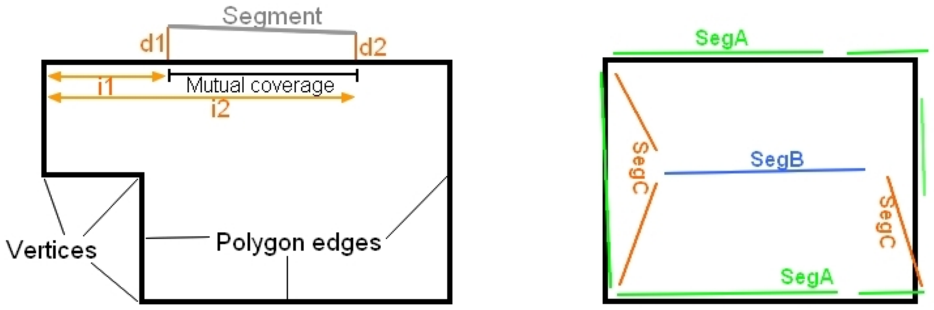

Figure 3. Definitions for the building polygon and segment matching.

To derive the polygon confidence from the individual edge scores, we sum up the contributions of each polygon edge and divide by the number of edges:

$$\text{Polygon score} = \sum edge\_score(i) / (num\_edges) \quad (3)$$

In the current implementation, the parameters I1, P1, D1 and D2 are quite flexible to allow for registration imprecision, image variability and support from other elements. In particular, the values D1 and I1 (typically 5 pixels, 1.5m) allows for support of shadow cast if the sun elevation is high. Parameter P1 (typical value is 0.05, 3°) allows for gable roofs which under some perspective may lead to segments not parallel anymore to the roof polygon as delineated in an ortho-photography.

Aside from segment to edge scores, translation and rotation measures can be derived for each matching pair. This can be used at the polygon level to obtain a best rotation and translation transformation as image registration or database values can be inaccurate. This information can help fine registration.

1.3 *Displaying results*

Assessing the presence of buildings described by the vector database is based on the confidence with which building polygons are supported by linear segments detected in the image, globally measured by the polygon score as detailed in 2.2. The approach is semi-automatic in the sense that the final decision about building presence is taken by a human operator after visual inspection.

The operator typically selects a threshold, possibly from the histogram of polygon scores, to highlight a few buildings clearly unsupported by the image. Such building polygons are superimposed on the image in red while supported building polygons are drawn in green. Visual inspection of the image for unverified polygons enables to draw conclusions on the origin of the missing buildings. The operator can accordingly update geographical information or mark the building as changed, depending on the application. For new constructions, his attention will be drawn by linear segments not assigned to any building.

2 RESULTS

The presented approach was applied to a Belgian region for which we gracefully received from IGN (Belgian National Geographical Institute) a couple of aerial images (pixel size 30 cm) and the road and building layers of a vector database (1/10000) covering the region.

Building verification results are obtained from visual inspection, interpreting the image in the vicinity of building polygons. The automatic classification into verified or unverified building is dependent on the score threshold.

Figure 4. Building verification results: polygons of verified buildings in green and unverified ones in red; blind alleys circled by light blue ellipses and phantom building polygons by white circles.

Interestingly, the vector database contains phantom buildings and blind alleys. Phantom buildings are database polygons which do not correspond to any real building, which may be planned or destroyed constructions or database errors. Blind alleys are squares ending a road (“cul-de-sac”) and are described in the database as a polygon (Fig. 4). In experiments, phantom buildings were weakly supported by linear edges. Three blind alleys out of six received image support parallel and close to polygon edges due to road limits implying false acceptance errors. Setting the threshold to the largest score of phantom building polygons, 27 out of 670 (4%) buildings were falsely rejected and three were erroneously accepted. Many errors arose from small buildings (less than 30 m^2).

The parameter values detailed in the previous sections were justified by common sense considerations. A slight modification of them does not change much the results. More importantly, tuning these parameters is of little use since the natural variation in roof appearance due to parallax limits the quality of the 2D geometrical match, especially because we dispose of a 2D database. The confidence in building presence will be better assessed by other information.

In particular, shadow strongly supports building presence. It is partially addressed in the presented approach if proximity and parallelism constraints are loose enough to support segments due to shadow, like for instance if the sun is high in the sky (small shadow). A specific handling of shadow has shown the increase of robustness in verification, for instance in solving the problem of blind alleys (Beumier 2007).

3 CONCLUSIONS

We presented a semi-automatic approach to building verification from airborne images. Building polygons described in a geographical database are scored according to linear segments detected in the image. A threshold is set by the operator to highlight the buildings insufficiently supported by the image. The operator can then further inspect image data and depending on the application, update the geographical information or mark the area as changed or damaged.

This work represents one of the steps to realize man-made structure verification and detection. Additional information will be gathered (road network, colour, shadow, height) from several aerial or satellite images (spectral images, vegetation index, stereo pairs). The next two major improvements are foreseen with the integration of 3D measures from stereo pair and shadow verification from darker areas.

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