EVIDENCE OF WALLS IN OBLIQUE IMAGES FOR AUTOMATIC VERIFICATION OF BUILDINGS

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ABSTRACT:

With the availability of airborne sensor platforms capable of capturing multiple overlapping images, oblique images have become interesting not only for visualization but also for acquisition, verification and update of vector data. In recent years, techniques for automatic verification of buildings vector data have used building characteristics associated with roof colour, texture and height while oblique images contain wall façade information that can also be used to identify buildings. This paper presents a methodology to verify 2D vector datasets of buildings by searching in oblique images clues such as building edges, wall façade edges and texture. The 2D evidence in images taken from different perspective are transformed to 3D and then matched. Results from experiments clearly distinguish existing buildings from demolished ones. The assessment of a building is done by combining results from individual walls. Thus, besides overall building verification, the results are useful for discriminating demolished walls of modified buildings.

1. INTRODUCTION

Buildings are a type of man made topographic objects that are continuously changed. Thus, existing vector datasets require frequent revision. One task of updating these datasets is verification of the buildings for the purpose of removing from the dataset the demolished ones and capturing differences for changed ones.

Methods have been proposed for using vertical images for verification of building data. The data used is either airborne or high resolution satellite images. Some proposed approaches are image classification for simple buildings and for updating medium scale maps (Olsen et al., 2002; Knudsen, 2007). Other methods use DSM from stereo images (Matikainen et al., 2007; Rottensteiner, 2007; Champion et al., 2009) or LIDAR (Vosselman et al., 2004). Vertical images give information about the colour and texture of roofs, while a DSM gives information on the height of the captured scene. Oblique images contain additional information on building walls that may be useful for better recognition of buildings.

Research on utilisation of oblique images has gained interest in recent years. Measurements in single oblique images using a DTM of the imaged place can be done (Höhle, 2008). Oblique images are also used for texturing 3D models (Frueh et al., 2004; Grenzdörffer et al., 2008; Wang et al., 2008). It has also been shown that images matching using oblique images gives good results (Le Besnerais et al., 2008; Gerke, 2009). For purpose of building verification, a method has also been proposed (Nakagawa and Shibasaki, 2008). Old 3D models were projected into both old and new oblique images and cross correlation analysed. Most buildings are verified but it verifies 3D models and relies on the availability of old and new images.

In this paper we present an approach to verification of buildings in 2D cadastral datasets. The verification is done by using clues on walls availability in oblique images. Thus, oblique images required are those taken at angles large enough to allow recognition of building wall façade.

Façade information available in oblique images may be useful for identification of the number of floors or the use of a building such as industrial or apartments. However, we currently concentrate on identifying whether buildings, still exist or have been demolished or changed.

In the developed method several clues are converted to measures of existence of a wall. Each measure is a numerical value obtained by projecting images to the vertical wall being verified. One of evidence that we are looking for in images is about the wall façade edges that are expected in images taken from different perspectives and should match when projected to object space. The other evidence sought relates to the direction of the detected façade edges which are expected to be horizontal or vertical when projected to the wall plane. Additional evidence is also obtained from matching images from several viewing directions.

In the following, we first introduce the data used (Section 2) and how each of the measures is derived and used for obtaining a certain level of acceptance that a wall exists (Section 3). For this purpose fuzzy membership functions are constructed using a training sample of walls. Clues on existence or absence of a wall in images are complementary and require a way of combining them. A way of combining the measures for a wall and for a whole building is discussed in Section 4. Results of experiments will be discussed in Section 5 and conclusion in Section 6.

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2. DATA AND PREPROCESSING

2.1 Buildings verified

For this study 2D cadastral data of buildings of the city centre of Enschede, The Netherlands is used. The vector data is detailed, suitable for large scale maps (Figure 1). The corner points have a nominal location accuracy of 0.25 m. Existing buildings are visible in the images and demolished ones are obtained by simulation. In the data, some line segments are broken into segments representing different apartments. To obtain lines for the whole walls, we remove every middle point of any three consecutive nodes that are collinear.

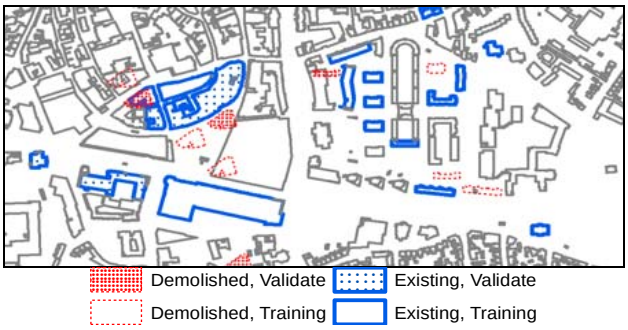

Figure 1: Part of 2D data of buildings of the city of Enschede

2.2 Oblique images

Oblique images from Pictometry Inc (BLOM Aerofilms) have been used. The system captures five images at the same time (Wang et al., 2008; Petrie, 2009). These images are captured at nadir, left, right, back and forward orientations. A scene is captured in multiple overlapping images. The data is available for cities of Europe with over 50,000 inhabitants, is updated every two years (Lemmen et al., 2007; Wang et al., 2008) and is available as Bird's View in Microsoft Bing Maps. Some parameters of the images are as in Table 1 and one of the images is shown in Figure 2.

Parameter	Value
Flying height (m)	920
Focal length of camera (mm)	85
Sensor size (mm)	36x24
Pixel size (μm)	9
Tilt (degrees)	50
Ground sample distance -GSD (cm)	10-16

Table 1: Some parameters of the Pictometry dataset used

The exterior and interior orientation parameters were obtained by incorporating scene constraints in the triangulation of oblique images (Gerke and Nyaruhuma, 2009). The RMSE at check points in object space was around 20cm for all three components after the self-calibration bundle adjustment.

Figure 2: Parortion of one of the images used - Image: ©Blom

3. WALL VERIFICATION MEASURES

Five measures for verification of a wall have been developed: 1) Lines Match Ratio, 2) Lines Direction Ratio, 3) Correlation Coefficient Ratio, 4) SIFT Match Ratio and 5) Building Edges Ratio.

3.1 Lines Match Ratio

A building wall is projected to images of different perspectives and then lines are detected in the images and used for verification. The main idea of matching lines for verification of building outlines was presented in (Nyaruhuma et al., 2010). In this paper other measures are developed and combined with the Line Matching Ratio. The Line Matching Ratio is briefly re-introduced here.

For each building being verified, for each image expected to contain the building or a part of it, and for each building wall expected to be visible in the image, straight line edges on wall façade are extracted. Building wall planar polygons are defined by the 2D vector data and approximate heights as described in (Suveg and Vosselman, 2000). The region containing a wall is selected by projecting the wall planar polygon to the respective image. This region is dilated for some pixels to ensure that building edges are within the region. This buffer is necessary due to the uncertainties in the 2D data used for constructing the wall plane as well as uncertainties in orientation parameters.

Line extraction in this work is done using the Förstner operator (Förstner, 1994). The algorithm extracts straight lines with sub pixel accuracy. Line segments (2D) that are extracted from different images expected to contain the same wall are transformed to line segments in object space (3D) in order to be compared. This is done by using image orientation information and the plane defined by the 2D vector data being verified. For each wall, all lines from different images are compared. Any two line segments are considered to correspond to the same wall edge if they have a similar orientation and the middle point of one segment is within some distance of the segment from another image (Nyaruhuma et al., 2010).

The Lines Match Ratio is the proportion of the total length of lines from different images that match in object space to the total number of lines detected for the wall.

A typical result of line matching is shown in Figure 3.The lines were detected from different images in which the building is visible, projected to the wall plane and then re-projected on the images as shown. The blue lines are those which are matched in at least two images while the red ones are those that did not match. The Lines Match Ratio is computed by dividing the total length of blue lines to the length of blue and red lines together.

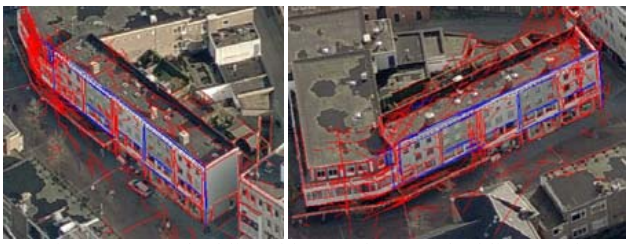

Figure 3: Matched line (blue) and unmatched lines (red)

3.2 Lines Direction Ratio

Many lines on building wall facade are normally vertical or horizontal. To find out whether a wall exists, lines detected in an image expected to contain the wall are projected to the wall plane, to obtain 3D lines which are tested for horizontal or vertical direction. The Lines Direction Ratio is then the proportion of the total length of horizontal and vertical lines to the length of all lines detected for a wall. This measure may be obtained even for one image because the plane in which the line is expected is known.

3.3 Correlation Coefficient Ratio

The Correlation Coefficient Ratio is obtained through image matching. Using orientation parameters, images from different perspectives are projected to the hypothesized 3D building wall and compared. A wall in images from different perspectives and corresponding rectified images are shown in Figure 4.

The normalised cross correlation coefficients are computed at each position of a small moving window such as 7 by 7 pixels. The Correlation Coefficient Ratio is then computed as the ratio of the number of positions with coefficients above a threshold to the total number of window positions.

Figure 4: A wall in two images from different perspectives and rectified images

An alternative to moving the window along the whole image is matching corner points. In this case corner points are detected from one of the images with the best perspective and matching is done around corresponding points in other images. Typical corner points are shown in Figure 5. In terms of processing speed this has an additional cost of detecting the corners but it has the advantage of processing only around the corners.

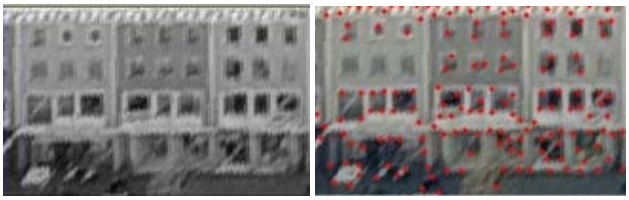

Figure 5: Corner points detected in one rectified image are used for image matching

3.4 SIFT Match Ratio

For this measure SIFT features (Lowe, 2004) are firstly detected from either of the rectified image portions. The SIFT features are matched and, to eliminate incorrect matches, the matching points are required to be within a small distance from the corresponding point. Figure 6 shows SIFT features(left) on two rectified images of a wall and lines pointing to matched SIFT points before eliminating wrong matches (middle) and correct matches (right).

The SIFT Match Ratio is computed as the ratio of the number of features correctly matched to the total number of SIFT features detected in the images.

Figure 6 SIFT features in two images (left), lines pointing on matched points - with some wrong matches (middle) and wrong matches removed (right)

3.5 Building Edges Ratio

This measure seeks to verify the vertical boundaries of walls in an image. Figure 7 shows the wall boundaries defined by 2D vector data, extended for some height and projected to an image. For every boundary, for every image expected to contain the boundary, lines are detected and projected to either of the walls forming the boundary to obtain 3D line segments. The resulting 3D lines are compared to the boundary lines.

For each of the two edges forming a wall, the number of images with lines matching the building edge is determined. The Building Edges Ratio is then the ratio of matches to the total number of tests. The highest value for the Building Edges Ratio possible is 1.0, when the two edges of a wall are obtained in all the images available and the lowest is 0.0, when no edge is obtained in any of the images.

Figure 7 Lines defined by 2D corner points and approximate height projected to an image

3.6 Using wall verification measures

Given a measure of Lines Match Ratio, Lines Direction Ratio, Correlation Coefficient Ratio, SIFT Match Ratio or Building Edges Ratio; we use the fuzzy logic (Zadeh, 1965) for obtaining

the membership of a wall to either of the two classes "wall exists" or "wall demolished". The fuzzy approach has been used in many works (Carlsson and Fullér, 1996; Sasikala and Petrou, 2001; Kumar et al., 2009). We only describe how it is used for this work.

Using training data, the fuzzy membership to the class "wall exists" at a given value of a measure is computed as the proportion of the number of existing walls to the total number of existing and demolished walls. The size of walls is also used as a weight. For example, if for all walls used in experiments, a total of 30 walls result to Lines Match Ratio of 0.9 with 25 of them from existing walls and 5 from demolished ones, then the fuzzy membership for "building exists" at Lines Match Ratio 0.9 is 0.83 $(25/30)$ and membership to "building demolished" is 0.17$(5/30)$.

Fuzzy membership curves for all measures have been derived from experiments as shown in Figure 9 and then curves have been generalized to fuzzy membership functions.

4. COMBINING MEASURES FOR A WALL AND FOR A BUILDING

4.1 Combining memberships for a wall

The evidence theory was introduced by Dempster and Shafer (Dempster, 1967; Shafer, 1976) and has since then been studied and applied in many research works (Tahani and Keller, 1990; Rottensteiner et al., 2005; Kumar et al., 2009; Frigui et al., 2010). The general intention is to give a higher weight to more reliable measures and vice versa for the less reliable ones in order to reduce the conflict that arises between measures. The problem is usually on how to quantify the reliability when there is conflicting evidence from different sources.

In our case we combine fuzzy memberships using weights. The weights, also here referred to as reliability is derived from memberships from different measures. A measure that returns a membership closer to 1 (exists) or closer to 0 (demolished) is assumed more reliable while close to 0.5 (equal membership to 'exists' and 'demolished'), assumed less reliable. To a decision maker, no conclusion can be made when the membership is 0.5 for both classes "wall exists" and "wall demolished". Reliability w_i is thus a deviation of a membership m_i from 0.5 and is computed with bias to memberships close to 0 or 1 by raising the deviation to a power n to obtain$w_i = \left(\frac{|m_i - 0.5|}{0.5}\right)^n$.
For example, if for 4 walls we obtain membership from Lines Match Ratios as 1.0, 0.5, 0.0 and 0.1, using the power of 4, the reliability for each of these will be 1.0, 0.0, 1.0 and 0.4. The measures that classify more walls into one class ("wall exists" or "wall demolished") are thus assigned more reliability.

For each wall we obtain the reliability of each measure and then the combination is an aggregation of the memberships obtained from all measures weighted by the reliability (Yager, 1988; Sasikala and Petrou, 2001).

For the number of measures $(a_1, a_2, ..., a_n)$ with reliability $(w_1, w_2, ...w_n)$ such that $w_i \varepsilon [0, 1]$ and normalized so that $\sum_1^n w_i = 1$, the combined membership is $F(a_1, a_2, ..., a_n) = \sum_1^n a_j w_j$.

For example, if for a wall only two measures are available and result to memberships 0.9 and 0.1, then they are of equal reliability of 0.4, which is normalized to 0.5 and then combined membership is 0.5. This is as expected because the memberships are very contradicting and we have no other reasons to select any one of them as correct or wrong. The result 0.5 implies complete ambiguity on whether the wall exists or is demolished.

4.2 Combining wall memberships for a building

The overall building verification is derived from memberships of different walls. For each wall a combined membership is obtained and then a summary measure is obtained as the mean of the wall memberships weighted by the wall sizes.

5. RESULTS

5.1 Fuzzy memberships for walls

A fuzzy membership function for each of the measures has been derived from experiments with a number of walls (total 500 walls) for existing and demolished (simulated) buildings (total 17 buildings). Figure 9 shows different membership curves for different measures. For each measure the x-axis is the measure and y-axis is the membership to class "wall exists". For example, the Lines Match Ratio curve shows for all values from 0.2 to 1 the corresponding membership is 1.

The measures have strengths and weaknesses that are used in obtaining the overall wall membership. Their characteristics can be generalized as follows.

Lines Match Ratio is generally reliable because it clearly distinguishes existing and demolished walls. When walls exists the match ratios are high and when the walls are demolished the match is low.

With SIFT Match Ratio, most existing walls result to the ratio above 0. When it is around 0 the membership is close to 0.5, that is half of the walls exist and another half do not. It is reliable for match ratios above 0.

Lines Direction Ratio has a big range of walls at around 0.5 memberships, not clear whether the walls exist or not, meaning less reliability but when it is at 0 nearly all walls are demolished. This is useful for identifying demolished walls even when the Lines Match Ratio is not available.

For Building Edges Ratio most existing and demolished walls result to 0.0 because many wall edges are not detected in the images. The Building Edges Ratio is then not reliable. This measure is therefore not useful for identifying demolished buildings. The measure is useful for identifying existing walls even when one image is available for an edge. The Correlation Coefficient Ratio is similar to the Lines Match Ratio while Correlation Coefficient -corners is similar to SIFT Match Ratio.

The reliability of the different measures in different contexts has been used in arriving at combined memberships. Notice that when multiple images for one facade are not available the only measures available are Building Edges Ratio and Lines Direction Ratio. If a wall is demolished then the only useful measure is Lines Direction Ratio because Building Edges Ratio is reliable for existing walls. The Lines Direction Ratio is also not generally reliable as there may be lines in images that result to 3D vertical and horizontal lines when a wall does not exist. The Lines Direction Ratio is more useful when there are no

multiple images and many lines are detected in images but none or very few are vertical or horizontal. Thus, we use the Lines Direction Ratio when the match ratio is close to 0.

5.2 Wall verification results

Combined memberships, for walls used for training and validation, have been computed as already described. The results in Figure 8 show that for actually existing walls the membership to class "wall exists" are close to 1 as expected while for demolished walls the result are close to 0, also as expected. There are some misclassified walls because occluded walls are included and will give a wrong result for single walls, but the overall merge for complete buildings is correct.

5.3 Building verification results

Using combined membership for walls the overall building membership has been computed as already described. The results Figure 10 show that for all existing buildings the membership to class "building exists" are close to 1 as expected while for demolished buildings the result are close to 0, also as expected.

6. CONCLUSION AND OUTLOOK

In this research it was shown that information on wall façades in oblique images can be used to reliably verify buildings in 2D vector dataset. Using the developed method, existing buildings result to memberships to class "building exists" close to 1 while, for demolished ones, the memberships are close to 0.

This method, besides providing the overall verification results, gives the result per wall, which may be used for updating the data if part of the building has been changed.

Further work includes more experiments to improve the membership functions used for determination of existing and demolished walls. We are also considering the use of Support Vector Machines for robust combining of evidence.

Our method requires a rough estimate of terrain and building height. For this purpose, a not very accurate DSM obtained by using the same oblique images (Gerke, 2009) may be used. Further work also includes incorporating evidence on roof and identification of walls occluded by other objects so that the search is limited to visible walls only.

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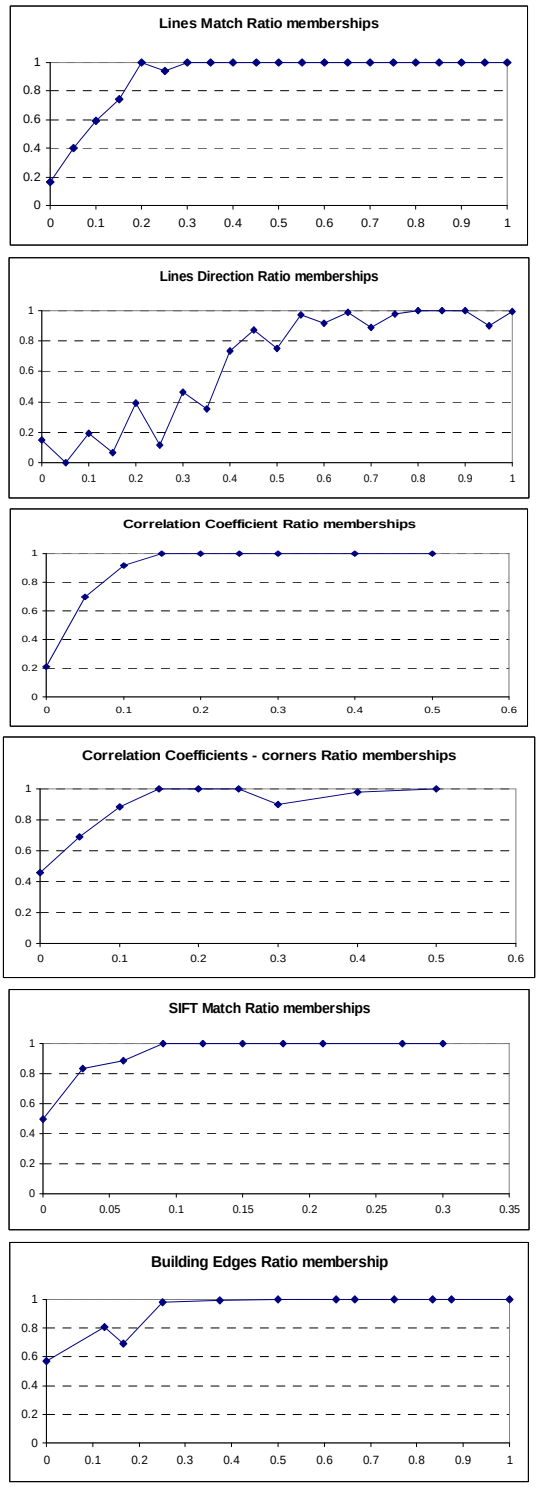

Figure 9: Fuzzy memberships - x-axis is measure and y-axis is the membership to class "wall exists"

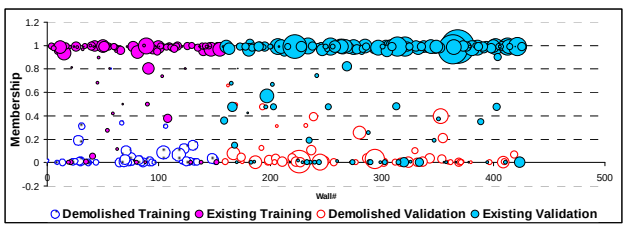

Figure 8: Wall memberships to class "wall exists"

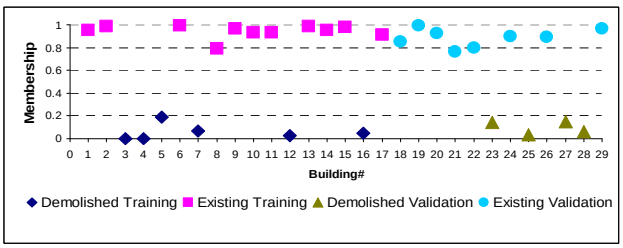

Figure 10: Memberships to class "building exists"

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