AUTOMATIC 3D BUILDING INFORMATION EXTRACTION FROM A SINGLE QUICKBIRD IMAGE AND DIGITAL MAPS

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ABSTRACT Today's commercial high resolution satellite imagery such as that provided by IKONOS and QuickBird, offers the potential to extract useful spatial information for geographical database construction and GIS applications. Digital maps supply the most generally used GIS data probiding topography, road, and building information. Currently, the building information provided by digital maps is incompletely constructed for GIS applications due to planar position error and warped shape. We focus on extracting of the accurate building information including position, shape, and height to update the building information of the digital maps and GIS database. In this paper, we propose a new method of 3D building information extraction with a single high resolution satellite image and digital map. Co-registration between the QuickBird image and the 1:1,000 digital maps was carried out automatically using the RPC adjustment model and the building layer of the digital map was projected onto the image. The building roof boundaries were detected using the building layer from the digital map based on the satellite azimuth. The building shape could be modified using a snake algorithm. Then we measured the building height and traced the building bottom automatically using triangular vector structure (TVS) hypothesis. In order to evaluate the proposed method, we estimated accuracy of the extracted building information using LiDAR DSM.

KEY WORDS: Building Information extraction, Single Image, High Resolution Satellite image, QuickBird, Digital Map

1. INTRODUCTION

During the past few years, improvement in the resolution of satellite images has broadened the applications for satellite images to include areas such as GIS database construction and updating. Extraction of 3D building information from high resolution satellite imagery is one of the most active research topics. On single image performance, most studies applied the roof-bottom points or shadow length extracted manually using sensor models with DEM (Digital Elevation Model) (Willneff, J., 2005; Croitoru, A., 2004). It is not suitable to apply these algorithms for dense buildings. Therefore, an effective research was undertaken by Lee (2006) and Javazandulam (2007), which applied projecting shadow regions. However that method cannot be applied to buildings where the shadow end is not observable. We aim to extract building height and update the building polygon shape on digital maps using a single satellite image. First of all, co-registration between the QuickBird image and the digital map was carried out automatically using the RPC adjustment model, and the building layers of the digital map were projected onto the image. The building roof boundaries were detected using building layers from the digital map based on the satellite azimuth. The building shape could be modified using a snake algorithm. Then we measured the building height and traced the building bottom automatically using the triangular vector structure (TVS) hypothesis (Kim, 2006). The entire workflow is illustrated in Figure. 1.

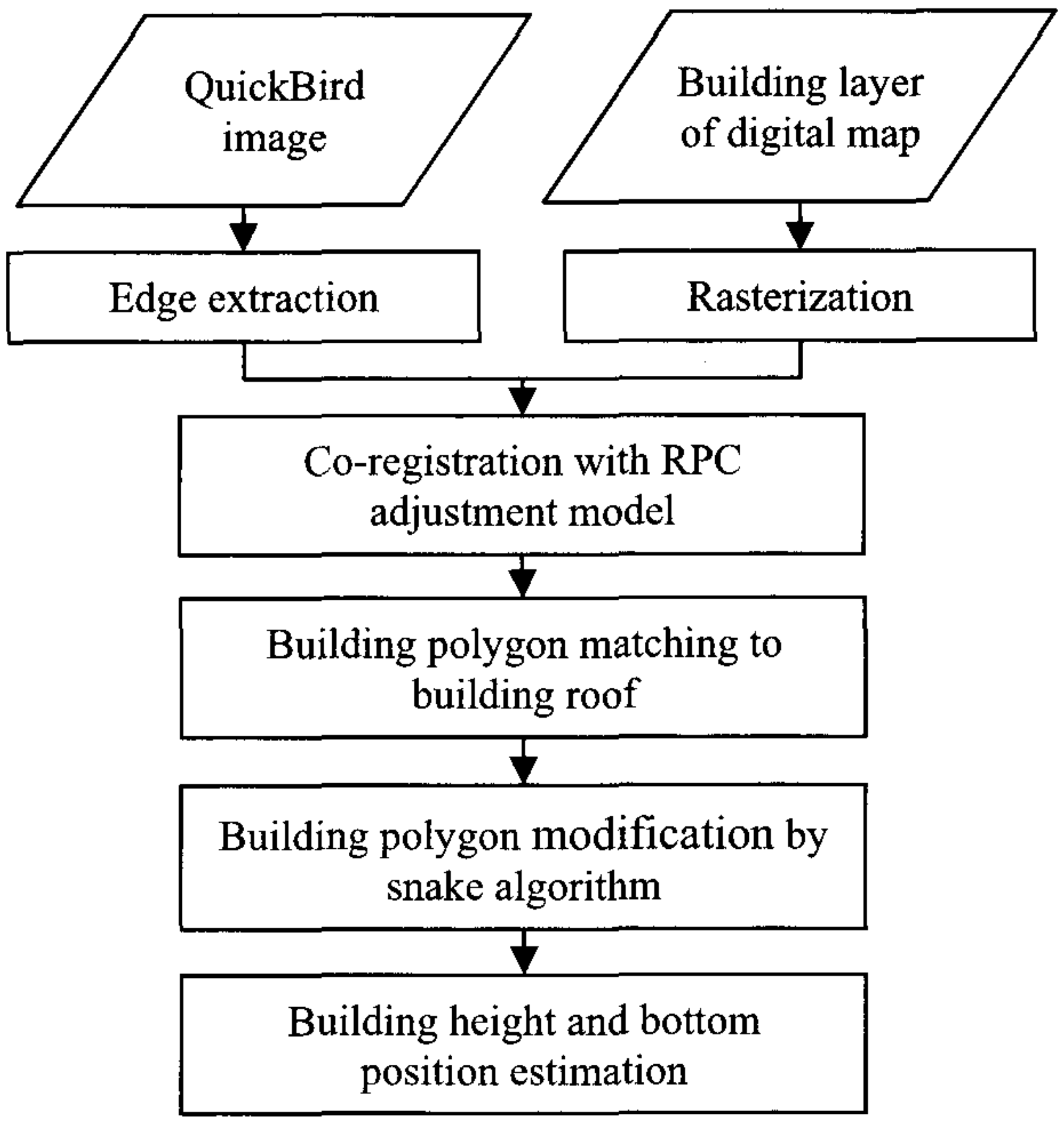

Figure 1. Flowchart

2. CO-REGISTRATION WITH RPC ADJUSTMENT MODEL

For registration of the high resolution satellite image, the RPC model is most generally used. Since biases or errors still exist after applying the RPCs the results need to be post-processed with a translation by several GCPs, or original RPC parameters can be refined with linear equations by more precise GCPs (Cheng, 2002). The

RPC adjustment model is the post-processed method that adds the adjustable function to denormalized RPC models. The adjustable function defined in the domain of image coordinates can be used to capture the discrepancies between the nominal and the measured image (Grodecki, 2003). For each image point i on image, the RPC adjustment model is defined as follows:

$$Line_i = \Delta p + p(\phi_k, \lambda_k, h_k) + \varepsilon_{L_i} \quad (1)$$

$$Sample_i = \Delta r + r(\phi_k, \lambda_k, h_k) + \varepsilon_{S_i} \quad (2)$$

where $Line_i$ and $Sample_i$ are measure line and sample coordinates of ith point, corresponding to the kth ground control or tie point with object-space coordinates (ϕ_k, λ_k, h_k);

Δp and Δr are the adjustable function expressing the differences between the measured and the nominal line and sample coordinates of ground control or tie points;

ε_{L_i} and ε_{S_i} are random unobservable errors;

p and r are the given line and sample, denomalized RPC model.

For QuickBird images, the first order polynomial is required as the adjustable function to achieve the best results (Cheng, 2006). The first order adjustment polynomial can be expressed as

$$\Delta p = a_0 + a_S \cdot Sample + a_L \cdot Line \quad (3)$$

$$\Delta r = b_0 + b_S \cdot Sample + b_L \cdot Line \quad (4)$$

where a_0, a_S, a_L, and b_0, b_S, b_L are the adjustment parameters for an image.

Commercial software such as OrthoEngine and Erdas Imagine provide this registration module using adjustment polynomials.

For co-registration between the QuickBird image and the digital map, we used the automatic co-registration method in the RPC adjustment model with the first order polynomial (Han, 2007). The algorithm consists of two steps: the coarse adjustment to estimate initial adjustment parameters and the fine adjustment to decide precise adjustment parameters. The coarse adjustment is the process to estimate approximate constant terms by Boolean operation between ground features obtained from the digital map and the edge obtained from the satellite image. In the fine adjustment, the modified iterative closest point (ICP) algorithm is used to precisely decide the first order and constant parameter. An advantage of this approach is that it does not necessarily require ground control point (GCP) and any manual work for co-registration between different kinds of data. Since the digital map is vector data, and the high-resolution satellite image is raster data, suitable corresponding features and the cost function to estimate their consistency should be selected between the different kinds of data. We chose a ground feature such as a road as the corresponding feature due to the relief displacement of the non-ground features such as buildings on the satellite image.

3. BUILDING INFORMATION EXTRACTION

In order to extract the building height and update the digital map, we performed several processes as follows. The building layer of the digital map was projected onto the satellite image and edges of the image were detected by Canny operator. Moreover the azimuths of the satellite and the sun from metadata were transformed to an image azimuth. The individual building roof boundaries were detected using the building layer from the digital map based on the satellite azimuth. The building shape could be modified using a snake algorithm. Then we measured the building height and traced the building bottom automatically using the triangular vector structure (TVS) hypothesis. In this approach, there are several assumptions.

1) The building of interest is represented by a polygon on the digital map.
2) The roof and bottom of the building have the same shape.
3) The building stands on flat ground.

3.1 Building Roof Detection

In the building layer of the digital map, there are building polygons, but their position and shape are often erroneous. To correct these errors, we detected the building roof polygon with building polygon on the digital map. On the satellite image, the roof and bottom are placed in the uniform angle of the satellite azimuth. The roof polygon can be detected by edge matching, moving the bottom polygon through the satellite azimuth. The roof polygon detected has horizontal position errors and a warped shape, the as same as the polygon from the digital map.

3.2 Building Polygon Modification

Currently, the building polygons on the digital map not only have planar position errors but also a warped shape due to inaccurate manual digitizing. We could correct the polygon shape using a snake algorithm. In our performance, the greedy algorithm was used, which was the iterative snake method. During each iteration, a neighbourhood of each point is examined and the point in the neighborhood giving the smallest value for the energy term is chosen as the new location of the point (Williams, 1992). The energy form of the greedy algorithm represents the sum following three terms. The total energy of the snake algorithm can be written as;

$$E(v(s)) = \int_0^1 \alpha(s)E_{cont}(v(s)) + \beta(s)E_{curv}(v(s) \quad (5)$$
$$+ \gamma(s)E_{image}(v(s))ds$$

The first and second terms are first order and second order continuity constraints respectively. The last term measures image edge strength. The weighting parameters α, β, and γ control the relative influence of the corresponding energy terms. The external energy of the snake model is constructed using a Canny edge detector (Canny, 1986). We let $\alpha = 1, \beta = 1,$ and $\gamma = 1.2$ because the image gradient has slightly more importance than either of the continuity terms.

3.3 Building Height estimation

To estimate the height of buildings conveniently from s single image, we used the automatic extraction method based on the TVS hypothesis. Its basic concept comes from this fact: the triangle consisting of each building's bottom point, its corresponding roof point and the shadow end point are always similar to one another in a single satellite image, because the altitude of the satellite and the sun are high enough to be considered that their projection angles are in parallel. In the first step of this approach, we can decide the reference triangle from satellite metadata. As shown in Figure 2, the reference triangle consists of point A (roof point), B(bottom point) and C(shadow end point). The direction angles of sides a and c are decided by the sun azimuth and the mean satellite azimuth respectively, and the length ratio between sides a and c can be calculated by the sun elevation angle and the mean satellite elevation angle.

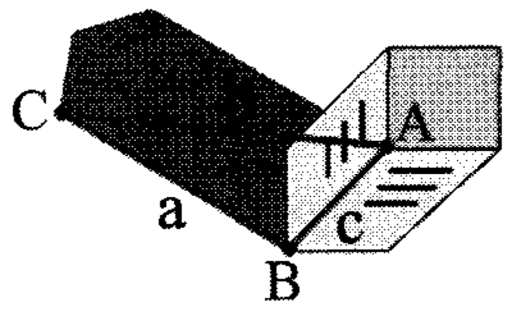

Figure 2. Conceptual diagram of reference triangle

For the building measurement, one or more sets must be observable among the following sets: a roof point and its bottom point on the side, a roof point and its shadow end point, a roof edge and portion of its corresponding shadow edge. In urban areas, the bottom or shadow end line is often not observable because there are dense buildings. Because we already have a building roof polygon, we can project the building bottom line and shadow by supposed building height. We performed two cases of edge matching; 1) building bottom line matching, and 2) shadow side line matching. If the building bottom is observable, the length of the building side c can be measured by bottom edge matching, and the building height can be calculated using the satellite elevation angle. Otherwise, we perform shadow side line matching and calculate the building height by the sun elevation angle. At this time, it is not necessary to observe the shadow end line because it is possible to estimate shadow line based on the TVS hypothesis if there is part of the shadow side line on the ground. Since only two side walls of the building can be shown in the image, we use two sides of the polygon and one shadow side line chosen by the satellite azimuth to perform edge matching. After the estimation of the building height, we can back-trace the building bottom polygon and decide the building bottom position.

4. EXPERIMENTAL RESULTS

To evaluate the suggested method, we applied it to a QuickBird panchromatic image, which has the sun azimuth of 160.5°, the sun elevation angle of 30.2°, the mean satellite azimuth of 199.3°, and the mean satellite elevation angle of 59.4°. Co-registration between the QuickBird image and the 1:1,000 digital map was carried out automatically using the RPC adjustment model and the building layer of the digital map was projected onto the image. We chose several test buildings and applied our approach to them. The following figures are examples showing the performance of the proposed method. As shown in Figure 3, the building polygons from the digital map are warped and depart slightly from the correct position, except in case (c). Therefore the roof polygons extracted are not fixed to the actual building roofs. The results of the roof modification, and height and bottom estimation can be identified in Figure 4. In the cases of buildings (a) and (b), both the building bottom and shadow boundary are observable, and their roofs have simple shapes. Accordingly, the modification of the building polygon and the estimation of the building height were performed successfully. Their RMSE errors between estimated height and LiDAR DSM were 0.06m and 0.34m respectively. Because the bottom boundary of the building in case (c) was not shown clearly, the building height is estimated by shadow line matching and its RMSE error is 1.08m. However the building in case (d) has a roof with a complex shape, and the boundaries of its bottom and shadow are unidentified. Therefore, the polygon modification and bottom edge matching resulted in an incorrect position and its RMSE error was 12.8m.

5. CONCLUSION

In this paper, we examined and proposed a new method of 3D building information extraction with a single high resolution satellite image and digital map. The building roof boundaries were detected using the building layer from a digital map based on the satellite azimuth. The building shape could be modified using a snake algorithm. Then we measured the building height and traced the building bottom automatically using the TVS hypothesis.

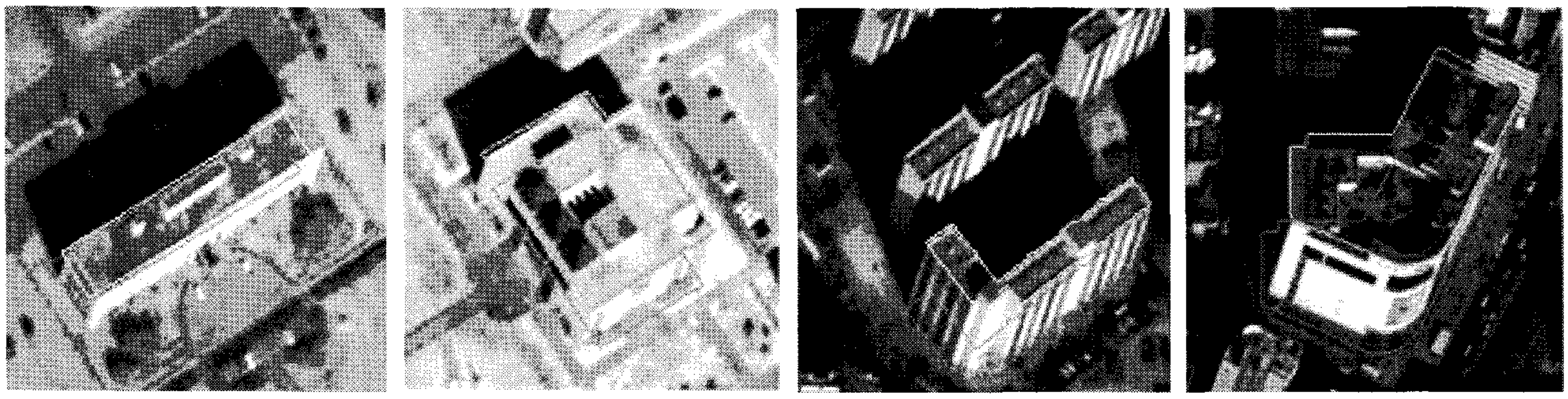
(a) (b) (c) (d)

Figure 3. Results of roof detection, red line, building of digital map and green line: roof detection result

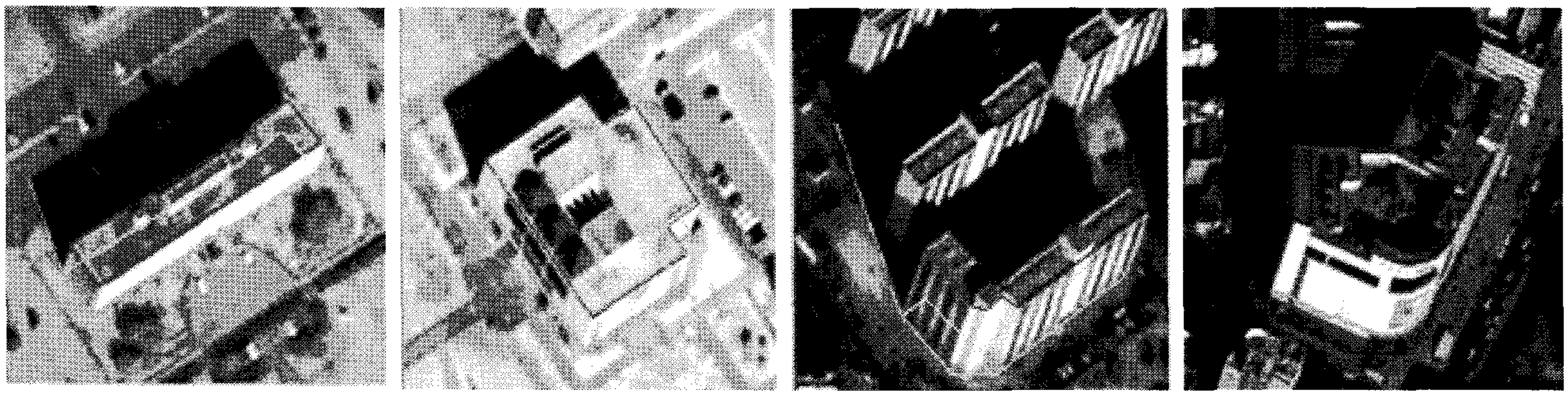
(a) (b) (c) (d)

Figure 4. Results of height and bottom estimation, blue line: roof modification result, pink line: height estimation and orange line: bottom estimation

With our experimental results, we could estimate the building height and modify the building polygon shape automatically. Our proposed approach was affected by the quality of the edge detection result of the image. Moreover it is necessary to apply this approach to more varied sites and different types of buildings, and evaluate the horizontal accuracy of the modified building polygons to verify its usefulness. These are now the topics of our ongoing research.

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