Reconstruction of 3D building structures from IKONOS images through monoscopic line and shadow analysis

Tae-Yoon Lee*, Taejung Kim

Department of Geoinformatic Engineering, Inha University

253 Yonghyun-dong, Namgu, Incheon, Korea

*sie0@inhaian.net, tezid@inha.ac.kr

Abstract: Extraction of man-made objects from high resolution satellite images has been studied by many researchers. In order to reconstruct accurate 3D building structures most of previous approaches try to assume 3D information obtained by LIDAR or stereo analysis. They use high resolution images only to locate such 3D information in image space and define accurate building boundaries. However we argue that monoscopic image itself contains many clues of 3D information. When images are taken at oblique angles vertical lines of buildings can be extracted. Moreover shadows can explain heights of the corresponding objects. Since sun elevation and azimuth angles as well as sensor elevation and azimuth angles are mostly given in satellite metadata, it is possible to detect vertical lines and shadow lines automatically. Then by measuring the length of vertical lines or shadow lines we can estimate the height of buildings. On the other hands, we may determine building height interactively by projecting shadow regions for a given building height onto image space and by adjusting building height until the shadow region and actual shadow in the image match. Experiments with IKONOS images showed that the idea of monoscopic line and shadow analysis for extracting building height was feasible. The main paper will report the results of experiments together with quantitative assessment of performance.

Keywords: Feature extraction, shadow analysis.

1. Introduction

Man-made objects extraction from high resolution satellite imagery has been studied by many researchers in recent years ([1-4]). In extraction of man-made objects, extraction of 3 dimensional (3D) information of building is a matter of great importance for 3D urban modeling, 3D map, etc. In order to reconstruct accurate 3D building structures most of previous approaches try to assume 3D information obtained by light detection and ranging (LIDAR) or stereo analysis. They used high resolution images only to locate such 3D information in image space and define accurate building boundaries.

Satellites provide metadata such as scene geometry, acquisition time, geolocation, etc. The scene geometry includes azimuth angle and elevation angle of the sun and those angles of the satellite when satellite image data is acquired. This information can indicate the direction of vertical lines of a building and the direction of building shadows within the image space. This paper proposes an algorithm that uses information for 3D information extraction of building from a single image. The algorithm proposed here determines building height interactively by projecting shadow regions for a given building height onto image space and by adjusting the building height until the shadow region and actual shadow in the image match. We used monoscopic IKONOS images and their metadata for experiments. We will show the results of height determination by our algorithm and their accuracy.

2. The algorithm for 3D information extraction of building

Fig. 1 represents the overall algorithm. To extract the building height, we first calculate scene orientation angle with respect to the true north and we select the corner points of a building roof manually. The initial height of the building selected s set to zero and we adjust the height by the keyboard. As we set a building height, the vertical line of the building and the region of shadow areas are drawn in the image. If the shadow region matches against actual shadow on the image, we determine that height as the building height.

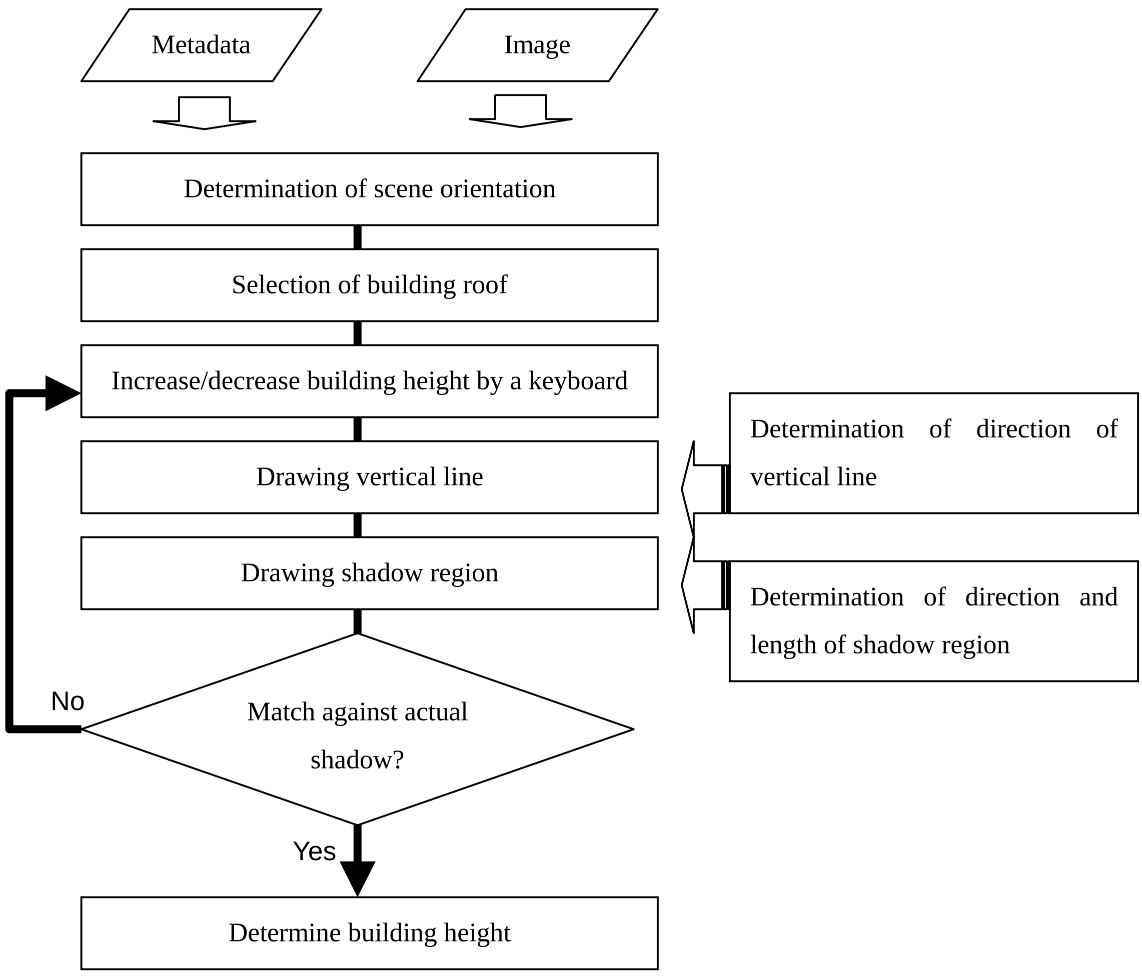

Fig. 1 Flow chart of total procedure

1) Direction of scene orientation

The algorithm proposed uses azimuth and elevation angles of the satellite and those of the sun. These azimuth angles are given with respect to true north. Usually the direction of true north is not identical to the image north (or image column axis). Therefore, we first calculate the rotation angle (Rn) between the true north and the north of image. Rn is calculated by latitude and longitude coordinates of 4 corners of the image specified in the metadata.

2) Direction of vertical lines

The direction of vertical lines of buildings within a satellite image can be determined by the azimuth angle of the satellite. The azimuth angle of the satellite is defined as the clockwise angle measured at image between the plane containing the North Pole and the plane containing satellite. The azimuth angle indicates the direction of satellite on the image. This direction is the same direction of vertical lines as any vertical lines will the come towards the center of perspective, which is the satellite. Direction of vertical line on an image can be determined by this azimuth angle and the scene orientation angle Rn (see Fig. 2).

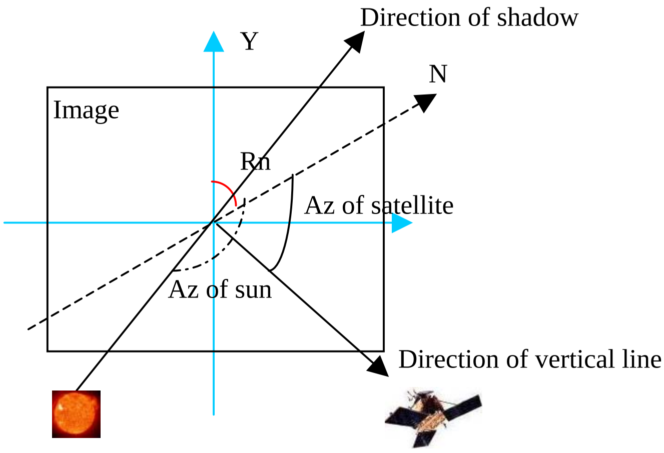

Fig. 2 Vertical line direction on image

3) Direction of shadow cast by buildings

The shadow direction cast by buildings can be determined by the azimuth angle of the sun. Similarly, the direction of shadows on an image can be determined by the sun azimuth angle and Rn (Fig. 2).

4) A relation between the length of shadow lines and the length of vertical lines

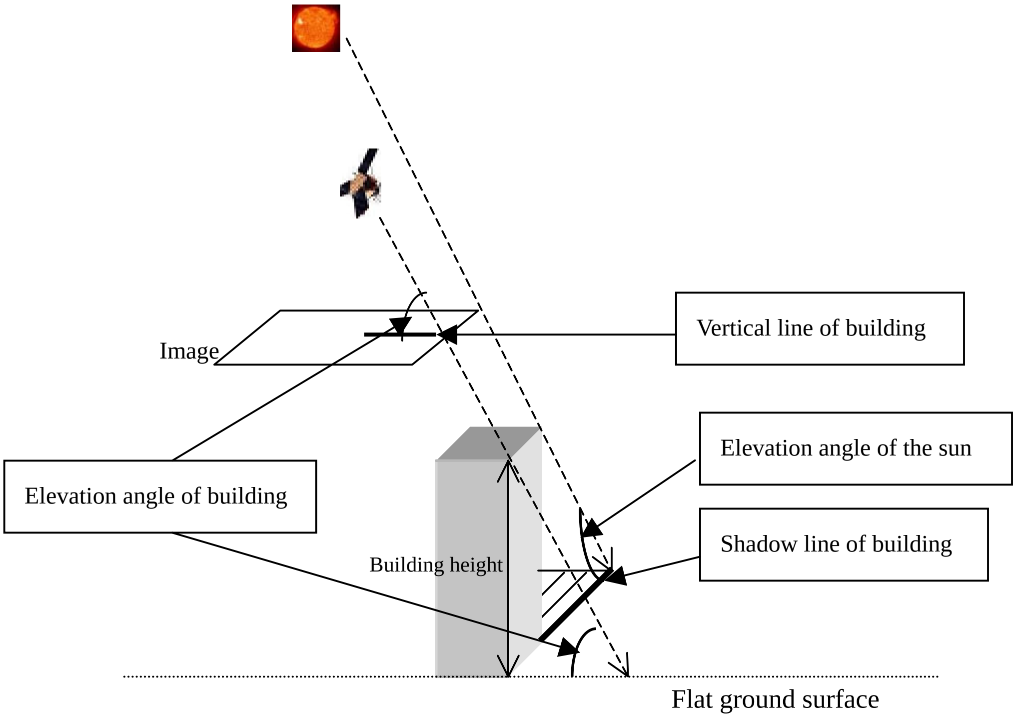

Fig. 3 A relation between the length of shadow lines and the length of vertical lines

The length of a vertical line, if visible in the image, can be determined by the elevation angle at the satellite and building height (Fig. 3). Similarly, the length of shadow can be determined by the elevation angle of the sun and building height. Since the length of vertical lines and that of shadow lines are both related to building height, we can relate the two properties as below:

$$SL = \frac{H}{\tan(Elevation_{sun})} = \frac{VL \times \tan(Elevation_{satellite})}{\tan(Elevation_{sun})} \tag{1}$$

In Eq. (1), SL is the length of shadow lines, H is the building height, VL is the length of vertical lines. We can calculate building height if we know the length of vertical lines and that of shadow lines by Eq. (1).

5) 3D information extraction of building

3D information is extracted by manual operation. As Fig. 1 shows, operator must select 4 corners of a building roof on the image. Those 4 corners are start points of vertical lines. The vertical lines are drawn on image as an operator increases the building height by + 1m sequentially. The same time, shadow region is drawn on the image. The length of shadow region increases by the increase of building height. The operator adjusts the length of shadow region until it match against actual shadow on image. When shadow region and actual shadow in the image match, the building height at that moment is accepted. Since we now have the correct building height, we can calculate the correct vertical line segments in the image. we can then transfer the boundaries of building roofs along the vertical lines to get the footprint of building at ground level.

3. Experiments

1) Used data

IKONOS images used were acquired in 2001. They constitute a stereo pair (Fig. 4). As indicated in Table 1, each image has different values for the azimuth angle and elevation angle of the satellite and those of the sun. Fig. 4 shows a part of IKONOS image used to experiment. Image ID 1 is left image and 2 is right image in Fig. 4.

Table 1. Geometric information of images

Image ID	Satellite		Sun	
	Azimuth	Elevation	Azimuth	Elevation
1	46.0332	66.50039	163.8771	32.75480
2	151.8080	69.55422	164.1390	32.80824

Fig. 4 Part of IKONOS image used

2) 3D information extraction and verification method

Using the algorithm explained in the previous section, we extracted 3D information of building. To verify the result of building height extracted by the algorithm proposed, we manually calculated building height by measuring tie points on the building and on the ground, by calculating 3D coordinates for the tie points and by calculating the difference between the two.

4. Results

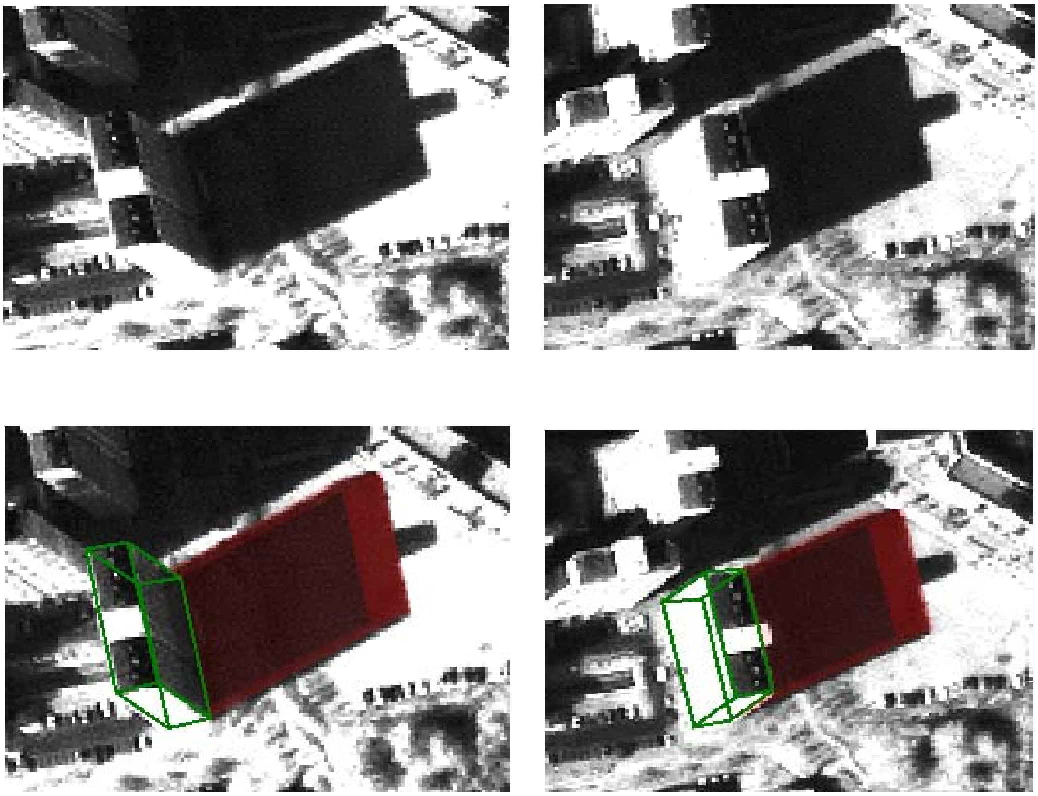

Fig. 5 Images of building construction extracted

Fig. 5 shows images of the result by the algorithm when building height is extracted on image. The lower part of Fig. 5 shows building on image before drawing 3D building structure. The upper part of Fig. 5 shows building structure drawn and shadow region matched against actual shadow. The building height extracted is 41 m in each building on Fig. 5.

We extracted 30 building height from 7 region in the image (Fig. 6). We selected apartment regions and labeled such as A, B, …G on each region. To verify building height extracted by algorithm, we measured tie points for the same 30 buildings and calculated the height. We assumed that building height by this stereo analysis is true building height.

The result of building height verification is shown in Table 2. In Table 2, “Building region ID” field shows label of region selected, “Number” is a number of building, which is extracted height in region, “RMS error” shows different between building height extracted by the algorithm proposed and building height calculated by stereo analysis.

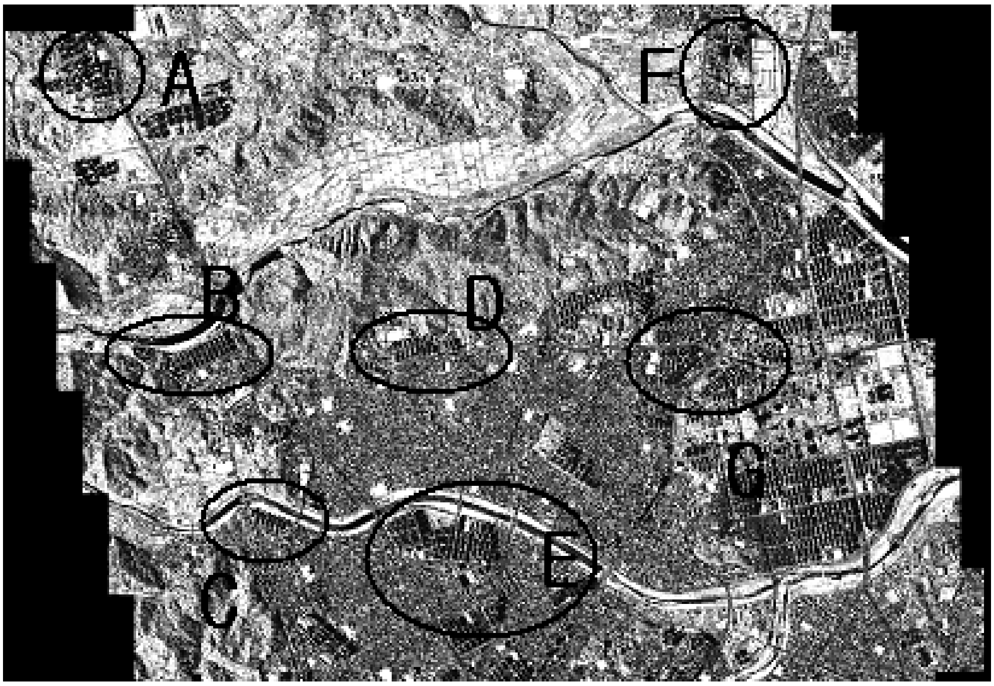

Fig. 6 Regions for verification on image

The total RMS error was 1.48431 m (Table 2). The number of buildings whose height error was over ±2 m was seven. The maximum error was 2.5493 m.

Table 2. The result compared height of building extracted between monoscopic image and stereo pair images

Building region ID	Number	RMS error (m)
A	3	0.73160
B	4	1.57617
C	3	1.72103
D	3	0.45669
E	4	1.39438
F	4	1.82731
G	9	1.62985
Total	30	1.48431

Main cause of error seemed the effects of ground relief or the presence of small objects within shadow region. Fig. 7 shows an image of a building with 2.5190 m error. A part of circle on image shows the shadow shape changed by ground relief.

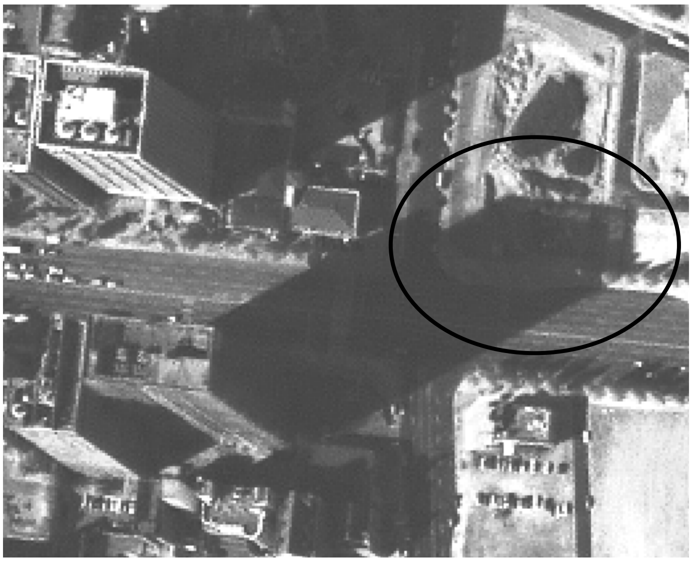

Fig. 7 Effective of ground or other objects

5. Conclusions

This paper proposes an algorithm to estimate building height by analysis vertical line and shadow areas on monoscopic satellite image. The algorithm is supposed to work on flat ground surface. The total RMS error of the experiment results was 1.48431 m. The algorithm proposed showed the feasibility of extracting 3D information from monoscopic analysis.

References

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