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# AUTOMATED DEM EXTRACTION OF URBAN AREAS FROM MULTI RESOLUTION SATELLITE IMAGES

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**ABSTRACT:**

This paper reports experiments carried out for automated extraction of a digital elevation model (DEM) from satellite images. In particular, this paper focuses on DEM extraction from dense urban areas where there are occlusions, shadow and height discontinuities. These properties have been known to create many problems in stereo matching and for automated DEM extraction. Using satellite images at various resolution, a DEM extraction algorithm was applied and the output DEM quality, on urban areas was studied. We tested SPOT images at 10m resolution, EOC images at 6.6m and IKONOS images at 1m resolution. These images include the same urban area in Daejeon city. Because IKONOS images do not provide the ancillary data, we use Gupta and Hartley's(1997) DLT model in camera modeling procedure. We carried out accuracy assessment using USGS DTED for SPOT, EOC DEM and 23 check points for IKONOS. It showed that SPOT DEM had about 38m RMS error, EOC DEM 12m RMS error and IKONOS DEM 6.5 m RMS error. IKONOS DEM had more error than SPOT, EOC DEM with respect to image resolution. However with IKONOS images we could make DEMs in complex and dense urban areas. These experiments show that our algorithm can generate urban DEM from 1m resolution and that, however, we need to improve the algorithm to minimize effects of occlusion, building shadows, and height discontinuity on DEMs.

## 1. INTRODUCTION

A DEM for urban areas is a tool in many civil engineering applications. In the past, these DEMs were prepared from contour line and low or middle resolution satellite stereo images. The DEM from low/middle resolution and contour line is unsuitable for urban modeling. However, The advent of IKONOS images has enabled to be produced a precise and accurate urban DEM from high-resolution stereo images.

In this study, we used a DEM extraction algorithm developed in-house. This algorithm was developed originally for the SPOT images (Park et al., 2000). It was based on the recent findings on epipolarity of linear pushbroom images (Kim, 2000; Gupta and Hartley, 1997), which described the epipolarity of linear pushbroom as hyperbolic curves not as straight lines. Instead of resampling linear pushbroom images to reconstitute epipolar geometry, this algorithm utilized the knowledge of epipolar curves of linear pushbroom stereo pairs for the estimation of search regions and the determination of patch shapes.

This algorithm has been reported to work well with SPOT satellite images at 10m resolution (Park et al., 2000) with improved accuracy and speed compared with other commercially available software package. Although this algorithm is not designed to cope with occlusions, shadow and height discontinuities of urban areas, this algorithm will be used for test to check the performance of "conventional" stereo matching algorithm on urban areas and to discuss how to improve "conventional" stereo matching algorithm to cope with such difficulties.

The following section will briefly describe the characteristics of test datasets and the layout of experiments carried out here.

## 2. EXPERIMENT DATASETS AND DEM EXTRACTION METHODS

For experiments in this paper, three types of satellite images were used. Table 1 summarizes the characteristics of each pair and ground control points(GCPs) that used in camera modeling. The first one was SPOT panchromatic image. The ground sampling distance of this image is 10m. At this resolution, it is generally assumed that the occlusions, shadow and height discontinuities of urban areas are not distinguishable in the image. DEMs from images at this resolution can tell how these properties on urban areas affect the DEM quality.

The second type of image used was images from the KOMPSAT-1 (Korea Multi-Purpose Satellite). The KOMPSAT-1 is the first operational remote sensing satellite of Korea, which was launched in December 1999. The KOMPSAT-1 carries two cameras; the EOC (Electro-Optical Camera) for high resolution (6.6m) earth observation, and the OSMI (Ocean Scanning Multi-spectral Imager) for ocean color monitoring. The KOMPSAT-1 EOC provides high quality images at panchromatic bands with the swath of 17km. Images at this resolution can observe certain unique properties (such as shadow) of urban areas to some extent. Some properties (such as height discontinuities) are not well discernable. These images were tested to check the effect of characteristics of urban areas at this resolution.

The third type of image used is images from the IKONOS. It is well known that the IKONOS image has 1m resolution and can describe very fine details on urban areas. Occlusions, shadow and height discontinuities can directly be observed of the images at 1m resolution. It is a real challenge to extract DEMs of urban areas from images at this resolution. The DEM

generation algorithm, which is designed to work at 10m resolution, will be tested with the IKONOS images.

The test site we selected was "Daejeon" city of the Republic of Korea. Three stereo pairs (SPOT, KOMPSAT, and IKONOS) have been prepared to cover the same (dense) urban areas. The figure below shows the SPOT, EOC and IKONOS image used. On the image, the extent of KOMPSAT image is shown as the white dotted rectangle and the extent of IKONOS image as the black dotted rectangle. Note that crosses are ground control points used for camera modeling.

| Sensor | SPOT | EOC | IKONOS |
|---|---|---|---|
| Region | Chungnam | Daejeon | Daejeon |
| Acquisition Date | 97.11.15 (Left) 97.10.14 (Right) | 2000.3.9 (Left) 2000.3.1 (Right) | 2001.11.19 (Left) 2001.11.19 (Right) |
| Tilt Angle (negative when tilt to the west) | 4.2° (Left) -28.7° (Right) | 26° (Left) -4° (Right) | N/A |
| Resolution | 10m | 6.6m | < 1m |
| Swath Width | 60Km | 17Km | 11km |
| GCPs | 21 | 30 | 18 |

Table 1. The characteristics of stereo pairs used for experiments and a number of GCPs that used in camera modelling
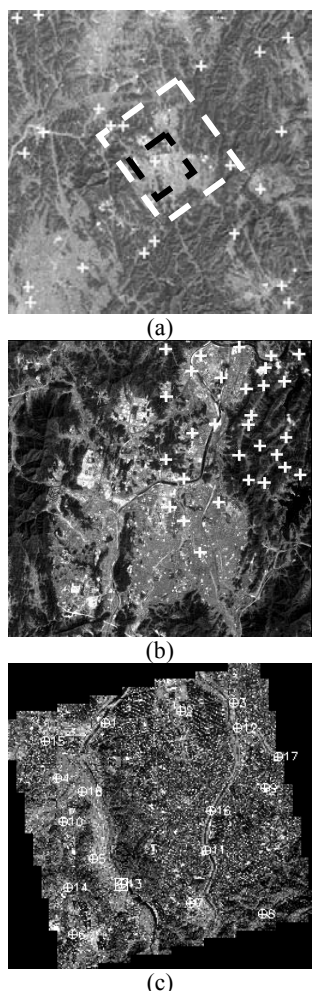

(a)


(b)


(c)

Figure 1. Satellite stereo images used for experiments and the extents of KOMPSAT and IKONOS images. The cross are locations of GCPs; (a) SPOT Chungnam, (b) EOC Daejeon, (c) IKONOS Daejeon

To each stereo pairs, a series of experiments were carried out as illustrated in figure 2 briefly. At first, camera modeling was performed to the left and right image of a stereo pair independently. Camera modeling is the process of establishing geometric relationship between an image coordinate and a ground reference coordinate. For this process, GCPs acquired by DGPS(Differential Global Position System) surveying were used. We used Gupta and Hartley's DLT model(here by "DLT model") in this step.

After camera modeling, absolute orientation was carried out. The meaning of absolute orientation here was the process of performing space-intersection using independently generated left and right camera models and of checking the accuracy.

As a following procedure, stereo matching was carried out. The stereo matching algorithm used here was the one developed in-house (Park et al., 2000) based on the knowledge of epipolarity derived from the pushbroom sensor model(Kim et al., 2000). The next procedure, an interpolation algorithm is based on a Gaussian interpolation but carries out hole filling, blunder removal and DEM boundary editing automatically based on some measures developed(Kim et al., 1999).

The final step was accuracy comparison with ground truth data. SPOT & EOC DEM generated were compared with the DTED(Digital Elevation Terrain Data) produced by USGS(U.S. Geological Survey). IKONOS DEM was compared with the 23 check points that surveying with DGPS.
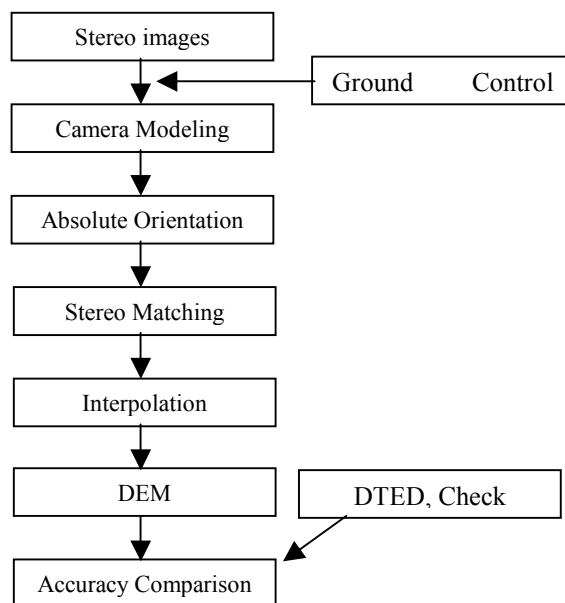


Figure 2. Procedure of DEM extraction experiments carried out

## 3. CAMERA MODELING AND ABSOLUTE ORIENTATION

As mentioned earlier, Camera modeling using the DLT model was carried out to each image of each stereo pair. The GCPs for each image were divided into modeling and check GCPs. While varying the number of modeling points incrementally and the number of check points decrementally, camera modeling was repeated with each combination of the modeling and check points. Table 2 summarizes the accuracy of camera models established with a different number of modeling points.

Only results from the left images are shown here. For all images, check point errors were higher than modeling point errors but the difference was not severe. Modeling and check errors of the EOC and IKONOS images were though a little higher than that of the SPOT image. The number of points used for modeling did not have significance if it was over, say, ten to twelve.

| Image | SPOT Chungnam(Left) | | EOC Daejeon(Left) | | IKONOS Daejeon(Left) | |
|---|---|---|---|---|---|---|
| GCP ID | Model Error | Check Error | Model Error | Check Error | Model Error | Check Error |
| 8 | 0.32 | 0.81 | 0.64 | 3.54 | 0.85 | 4.00 |
| 9 | 0.33 | 0.67 | 0.79 | 1.33 | 1.09 | 2.12 |
| 10 | 0.33 | 0.67 | 0.85 | 1.48 | 1.14 | 1.99 |
| 11 | 0.34 | 0.6 | 0.90 | 1.16 | 1.15 | 1.79 |
| 12 | 0.33 | 0.64 | 0.86 | 1.25 | 1.15 | 1.83 |
| 13 | 0.32 | 0.68 | 0.88 | 1.46 | 1.11 | 2.05 |
| 14 | 0.34 | 0.71 | 0.85 | 1.41 | 1.10 | 2.07 |
| 15 | 0.38 | 0.66 | 0.83 | 1.22 | 1.17 | 1.98 |
| 16 | 0.41 | 0.61 | 0.80 | 1.02 | 1.16 | 2.22 |
| 17 | 0.4 | 0.68 | 0.79 | 1.07 | 1.21 | 2.31 |
| 18 | 0.41 | 0.72 | 0.78 | 1.12 | 1.28 | N/A |

Table 2. Accuracy of camera models(RMS in pixels)

Once camera models are set up for both left and right images of a stereo pair, it is possible to calculate 3D ground coordinates from left and right image coordinates of a correspondence point. DEM accuracy is more affected by the accuracy of this space-intersection than accuracy of individual camera models. Accuracy of absolute orientation was tested by calculating 3D ground coordinates from the left and right image coordinates of a GCP and with the left and right camera models and checking the difference between the calculated ground coordinates and GPS measured coordinates. Table 3 summarizes the accuracy of absolute orientation in each pair.

| Sensor | SPOT | EOC | IKONOS |
|---|---|---|---|
| Area | Chungnam | Daejeon | Daejeon |
| Horizontal Accuracy (RMS Error) | 3.18m | 5.14m | 1.14m |
| Vertical Accuracy (RMS Error) | 4.94m | 6.37m | 0.94m |

Table 3. Accuracy of absolute orientation

In this table, the absolute orientation errors for EOC & SPOT pairs were small, not bigger than the amount equivalent to one pixel in both vertical and horizontal directions. (A part of this reason was because the GCPs used for space-intersection was the ones used for camera modeling as well). The absolute orientation errors indicate whether the left and right camera models obtained from the camera modeling process can be used together for calculation of 3D coordinates. The IKONOS Daejeon pair has near one pixel error with respect to resolution.

## 4. STEREO MATCHING AND DEM GENERATION

The stereo matching algorithm used here was developed originally for the SPOT images (Park et al., 2000). It was based on the recent findings on epipolarity of linear pushbroom images (Kim, 2000; Kim et al., 2001) where collinearity-based camera models were assumed. This algorithm utilized the knowledge of epipolar curves of linear pushbroom stereo pairs for the estimation of search regions and the determination of patch shapes. A normalized zero-mean cross correlation was used as a similarity measure.

For the three stereo pairs, the DEM extraction and the in-house developed interpolation were executed on a MIPS R10000 SGI-IRIX workstation with 128Mbytes memory and at a CPU clock rate of 175Mhz. Table 4 summarizes stereo matching results and DEM accuracy. Match rate was the time taken to match a singe conjugate pair. It was derived by measuring total time spent to match the entire stereo coverage and dividing the time by the number of match points. In case of SPOT and EOC, DEM average error and DEM root mean square (RMS) error were obtained by comparing DEM height and DTED height at each grid point of the DEMs. IKONOS DEM was compare with 23 check points.

| Sensor | SPOT | EOC | IKONOS |
|---|---|---|---|
| Area | Chungnam | Daejeon | Daejeon |
| Match Rate(msec/point) | 1.04 | 0.924 | 9.83 |
| DEM Average Error | -5.78m | 0.31m | -1.0m |
| DEM RMS Error | 38.88m | 12.08m | 6.55m |

Table 4. The stereo matching results and DEM accuracy from each stereo pairs

The match speed of IKONOS Daejeon image is slower than SPOT, EOC images because IKONOS image size bigger than other images. The results show that IKONOS DEM RMS error is over six pixels with respect to 1m resolution and is caused by building occlusion, shadow, and height discontinuities. According to Zhou and Li(2000), IKONOS will provide an absolute planimetric accuracy of 12m and a vertical accuracy of 8m without ground control points, and a planimetric accuracy of 2m and a vertical accuracy of 3m with the addition of GCPs. However, It's difficult to compare directly with Zhou and Li(2000)'s results because IKONOS scene has different aspect.

After applying stereo matching, to each stereo pair, the following DEMs were obtained(figure 3). The DEM from the SPOT pair has the RMS error of 38.88 meters. It contained fine topography of the ground but it has a few blobs and holes. This is partly due to the fact that the stereo pair used for test has a time gap of one month between the left and right images of the SPOT pair. From mid October(left image) to mid November(right image) in Korea, land cover undergoes severe changes due to harvest and the shift of season from the autumn to the winter.

The DEM from KOMPSAT stereo pair has more detailed topography of the earth surface(figure 4). The accuracy of the DEM was around 12.08 m RMS error. The DEM from IKONOS has more fine details of the earth surface(figure 5). The accuracy of the IKONOS DEM is 6.55m RMS error.
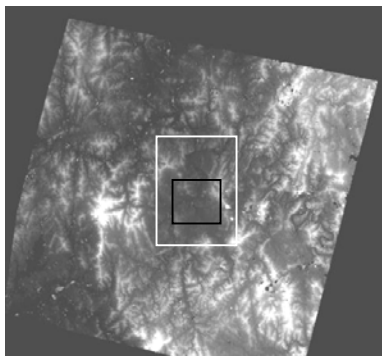
Figure 3. A DEM generated from SPOT stereo pair. The white rectangle is the extent of DEM from KOMPSAT stereo pair and the black from IKONOS.
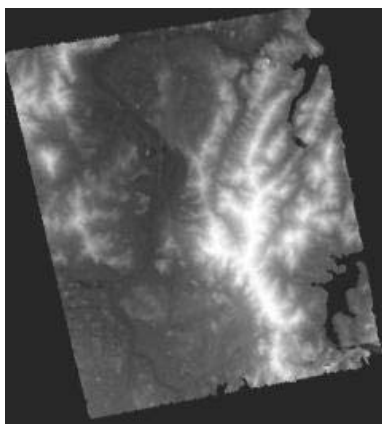


Figure 4. A DEM generated from the KOMPSAT stereo pair
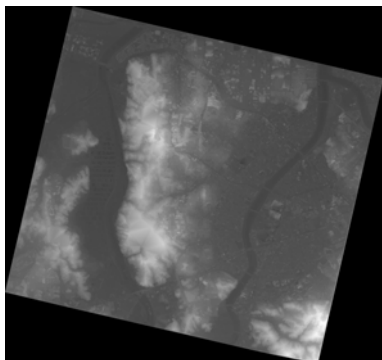


Figure 5. A DEM generated from the IKONOS stereo pair

The quality of DEMs over urban areas is highlighted in the following figure 6, figure 7 and figure 8. The characteristic of SPOT image(figure 6) show that the occlusions, shadow and height discontinuities of building region are not distinguishable. In the DEM from SPOT images, it is difficult to distinguish apartment buildings and large industrial buildings with the DEM alone(figure 6). However, it showed that a group of large buildings are represented as hilly areas. Note that in the figures, the histogram is heavily stretched on purpose.

In the DEM from KOMPSAT images (figure 7), it is also difficult to distinguish individual apartment buildings and large industrial buildings with the DEM alone. The building blocks

appeared to be grouped together. It is very interesting to see that the DEM looks to have more errors that the DEM from SPOT images, in particular around high apartment buildings. It seems that shadows are the main cause of this problem.
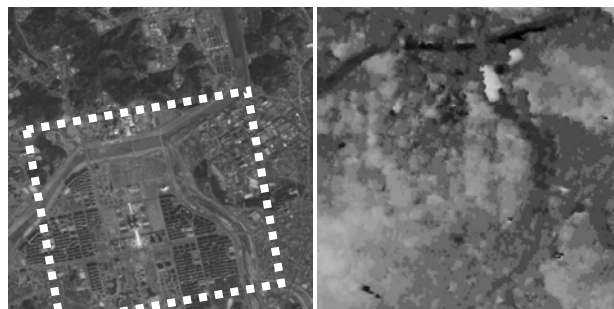


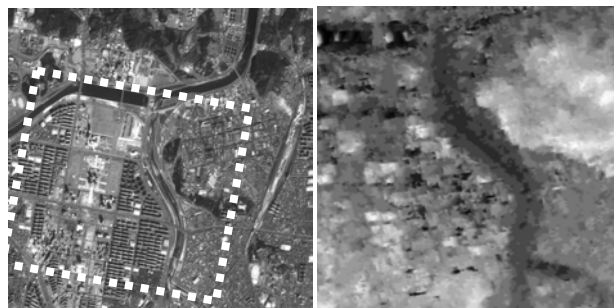Figure 6. The quality of DEM of urban areas from SPOT stereo pair



Figure 7. The quality of DEM of urban areas from KOMPSAT stereo pair

IKONOS DEMs over urban area are shown in figure 8. Unlike SPOT and EOC DEMs, IKONOS DEMs show a comparatively dense and complicated urban structure. In the DEM from IKONOS images (figure 8), it is very exciting to see that large industrial and apartment buildings can be distinguished in the DEM. It is also very encouraging to see that height at roof of buildings was preserved well. Only due to the shadow and occlusion, the boundaries of buildings appears "smeared". It is also very interesting to see that shadow seems to contribute the quality degradation most. The white rectangle is the same region on IKONOS images and DEM. In order to view more detail, we enlarge the region of the black rectangle.

Finally, we carried out editing IKONOS DEM using layer of building in 1/1,000 digital image. We use Er-mapper 6.0 and the results of 3D images is figure 9. The line in the 3D image is a road vector. The results show that our in-house algorithms can generate high precise DEM with IKONOS images and show the possibility using in urban modeling.
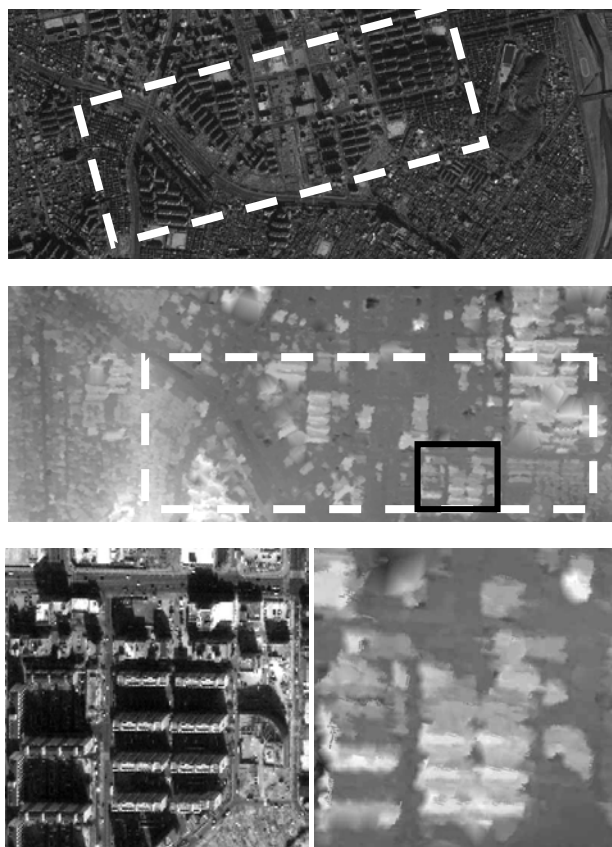
Figure 8. The quality of DEM of urban areas from IKONOS stereo pair



Figure 9. IKONOS DEM 3D building image. The line is a road vector from 1/1,000 digital map.

## 5. CONCLUSION

This paper reports experiments carried out for urban DEM extraction from satellite images with various resolution. We used three types of satellite image. The first one was SPOT images(10m resolution), the second one was EOC scenes(6.6m resolution) from KOMSAT-1, and the third one was IKONOS stereo pairs with 1m resolution.

The focus of this paper was put to check whether in-house DEM generation algorithms for SPOT satellite images can be applied to the IKONOS and EOC images and to compare with each other that the DEM in urban area.

The results showed that SPOT DEM had about 38m RMS error, EOC DEM 12m RMS error and IKONOS DEM 6.7m RMS error. IKONOS DEM had more error than SPOT, EOC DEM with respect to image resolution. There is a blundering of building boundary that be caused by building shadow, and a null cell that be a result of a occlusion. In addition area based matching algorithms cannot overcome building discontinuity.

However we could refine IKONOS DEM in complex and diverse urban areas by 1/1,000 digital map.

## ACKNOWLEDGEMENTS

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