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AUTOMATED DEM EXTRACTION FROM THE KOMPSAT-1 EOC IMAGES

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ABSTRACT : This paper reports experiments carried out for DEM extraction from the KOMPSAT-1 EOC images. The KOMPSAT-1 is the first Korean remote sensing satellite launched in December, 1999. It has a high-resolution (6.6m) earth imaging sensor (EOC) and a sensor for ocean color monitoring (OSMI). The focus of this paper was to develop appropriate algorithms for DEM generation from the EOC images and to analyze the quality of DEMs generated. Automated DEM generation requires several steps of processing, which typically consists of camera modeling, stereo matching and interpolation. For camera modeling, the algorithms proposed by Orun and Natarajan [1994] was tested and showed good results. For stereo matching and interpolation, the techniques developed in-house [Park et al., 2000] were used. Using these algorithms, DEMs were generated automatically from the EOC images and the accuracy of them was in the range of root mean square error of eight to 13 meters. These results were compared with DEMs generated from SPOT scenes using the same algorithms over the same area. The comparison showed that DEMs from the EOC had an improved accuracy and contained finer details of the earth surface compared to those from the SPOT. It seemed that, when proper techniques used, the KOMPSAT-1 EOC could be used for high-accuracy DEM generation.

1. INTRODUCTION

Extracting a Digital Elevation Model (DEM) or reconstruction of a three dimensional surface model is one of the crucial steps in topographic application of satellite images. This requires several steps of processing, which typically consists of camera modeling (or image orientation), stereo matching, interpolation, etc. For some well-known satellite images such as the SPOT, several algorithms have been proposed to provide methodology of DEM extraction [Orun and Natarajan, 1994; Gupta and Hartley, 1997; Al-Rousan et al., 1997].

The KOMPSAT-1 (Korea Multi-Purpose Satellite) 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. The main mission of the KOMPSAT-1 EOC is the provision of spaceborne imagery for 1:25,000 scale mapping.

This paper reports on the experiments carried out for DEM extraction from the KOMPSAT-1 EOC images. The focus of this paper was to develop appropriate algorithms for DEM generation from the EOC images and to analyze the quality of DEMs generated. For camera modeling, the existing technique developed for the SPOT [Orun and Natarajan, 1994] was tested with the EOC images. For stereo matching, an in-house developed algorithm [Park et al., 2000] was modified for the EOC images.

Using these algorithms, DEMs were generated automatically from the EOC images and the accuracy of them was in the range of root mean square error of eight to 13 meters. For comparison, a DEM was generated from SPOT images over the same area using the same algorithms. The comparison among them showed that DEMs from the EOC had an improved accuracy and contained finer details of the earth surface compared to those from the SPOT. It seemed that, when proper techniques used, the KOMPSAT-1 EOC could be used for high-accuracy DEM generation.

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

2. EXPERIMENT DATASET AND DEM EXTRACTION METHODS

Two stereo pairs from the KOMPSAT-1 EOC and one from the SPOT were used for experiments. Table 1 summarizes the characteristics of each pair. The two EOC stereo pairs cover Taejon and Nonsan area of Korea, respectively. One SPOT pair was chosen to cover both Taejon and Nonsan areas so that the coverage of DEMs from the SPOT pair and from each EOC pair overlaps. (Note that the swath of SPOT is larger than that of the EOC.) All pairs were selected to have minimum possible gaps of acquisition dates between the left and right images within a pair. Two EOC pairs have indeed very small time gaps. The SPOT pair with a time gap of one month was the best one available. Figure 1 shows the EOC and SPOT images used for experiments (only one image from each stereo pair is shown). The image on the top left is the EOC image over Taejon and on the bottom left, the EOC image over Nonsan. The image on the right is the SPOT image used. The dottedrectangles on the SPOT image indicate the stereo coverage of EOC pairs (the middle one the EOC Taejon and lower left the EOC Nonsan). Crosses in all images are the location of ground control points (GCPs) used for experiments. Note that the number of GCPs used in each pair varies.

Table 1. The characteristics of stereo pairs used for experiments

Sensor	KOMPSAT-1 EOC		SPOT
Area	Taejon	Nonsan	Taejon and Nonsan
Acquisition Date	9 March 2000 (Left) 1 March 2000 (right)	1 May 2000 (Left) 28 April 2000 (Right)	15 Nov. 1997 (Left) 14 Oct. 1997 (Right)
Tilt Angle (negative when tilt to the west)	26° (Left) -4° (Right)	19°(Left) -12°(Right)	4.2° (Left) -28.7°(Right)
Spatial Resolution	6.6m		10m
No of pixels, lines	2592, 2796		6000, 6000
Swath (Field of View)	17Km (1.42°)		60Km (4.13°)
No. of GCPs	30	25	21

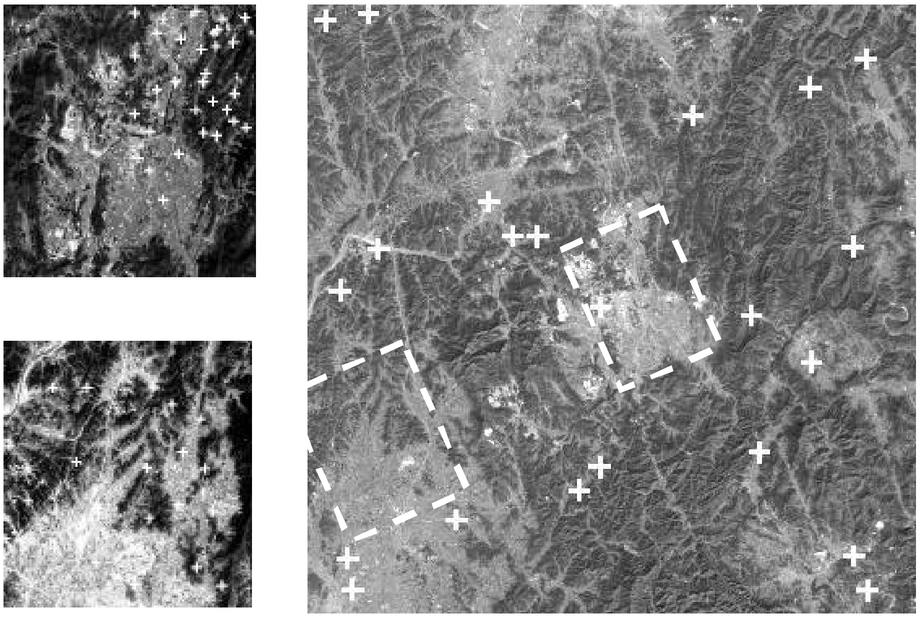


Figure 1. EOC images over Taejon (Left Top) and Nonsan (Left Bottom) and the SPOT image used

DEM extraction was carried out repeatedly to each of three pairs. Firstly, camera modeling proposed by Orun and Natarajan (ON Model) was performed to the left and right image of a stereo pair independently. 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. Next, 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 ON model [Kim et al., 2000]. After stereo matching, an interpolation algorithm developed in-house [Kim et al., 1999] was applied to generate a DEM. This 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. DEMs generated were compared with the DTED (Digital Elevation Terrain Data) produced by USGS (U.S. Geological Survey).

3. CAMERA MODELING AND ABSOLUTE ORIENTATION

As mentioned earlier, the ON model was tested for camera modeling of KOMPSAT-1 EOC images. The ON model is based on the modified collinearity equations for linear pushbroom images [Orun and Natarajan, 1994]. This model assumes the position of the satellites and yaw variation as second polynomials of time and roll and pitch variation as constants. In order to have a reliable solution, the ON model requires ephemeris data of the satellite. The ON model was originally developed for the SPOT images and is known to give good accuracy at moderate complexity [Orun and Natarajan, 1994].

Image acquisition scheme of the KOMPSAT-1 is, however, different from that of the SPOT. Both are on sun-synchronous orbits but the KOMPSAT-1 is on an ascending one whereas the SPOT descending. The KOMPSAT-1 adopts a body-tilting mechanism for off-nadir viewing whereas the SPOT has tilting mirrors. Attitude control scheme is also different and so are the amount of pitch and raw orientations of the spacecraft at imaging. The ON model was tested with the EOC images to check whether it could work under these differences. Ephemeris data provided with the EOC images were used for tests.

Camera modeling using the ON model was carried out to each image of each stereo pair (total six images). 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 error of the EOC images was 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. In all cases error figures were lower than one pixel, which was desirable. It seemed that the ON model could be used for camera modeling of the EOC images.

Table 2. Accuracy of camera models (root mean square errors (RMSE) in pixels)

Image	EOC Taejon (left)		EOC Nonsan (left)		SPOT (left)	
No of Model points	Model RMSE	Check RMSE	Model RMSE	Check RMSE	Model RMSE	Check RMSE
8	0.4	0.9	0.36	0.73	0.08	0.53
9	0.39	0.92	0.36	0.75	0.13	0.55
10	0.54	0.85	0.39	0.74	0.17	0.57
11	0.61	0.83	0.42	0.71	0.27	0.54
12	0.61	0.83	0.48	0.66	0.28	0.57
13	0.66	0.81	0.46	0.69	0.28	0.59
14	0.65	0.83	0.48	0.72	0.29	0.62
15	0.63	0.85	0.47	0.77	0.32	0.57
16	0.63	0.86	0.48	0.77	0.34	0.54
17	0.64	0.88	0.49	0.76	0.34	0.55
18	0.65	0.93	0.49	0.79	0.37	0.46

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 conjugate 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.

Table 3. Accuracy of absolute orientation

Image	EOC Taejon	EOC Nonsan	SPOT
Horizontal accuracy (RMS error)	4.24m	2.84m	3.56m
Vertical accuracy (RMS error)	4.97m	2.39m	9.51m

In the table, the absolute orientation errors 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 EOC Nonsan pair has the smallest error. In order to focus this paper on DEMs, the error of absolute orientation has not been investigated further.

4. STEREO MATCHING AND DEM EXTRACTION

The stereo matching algorithm used here (EpiMatch) 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 (such as the ON model) 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 EpiMatch 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 speed was the time taken to match a single 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. 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.

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

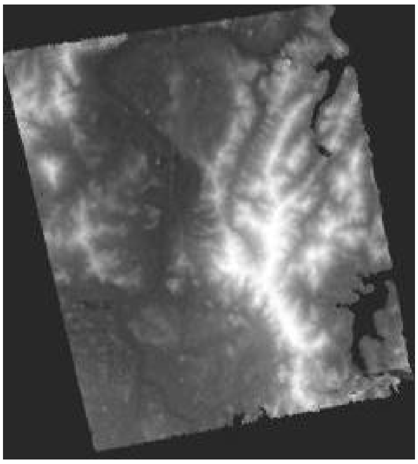
Sensor	KOMPSAT-1 EOC		SPOT
Area	Taejon	Nonsan	Taejon
Match speed (msec/point)	1.03msec	1.05msec	1.09msec
DEM Average error	-0.55m	2.38m	-1.28m
DEM RMS. error	12.85m	8.82m	31.99m

The match speed appeared more or less the same for the three pairs except the slight overhead due to the size of data files (The SPOT Taejon had the largest number of match points, the EOC Nonsan the next, and the EOC Taejon the smallest.) DEM average error tells whether there is any bias on a DEM and the values on table 4 say that all three DEMs were OK. DEM RMS errors for the EOC were much lower than that for the SPOT. However, this is not very surprising, taken the fact that EOC has finer resolution (6.6m) than the SPOT (10m). See Figure 2 for further comparison of DEM quality.

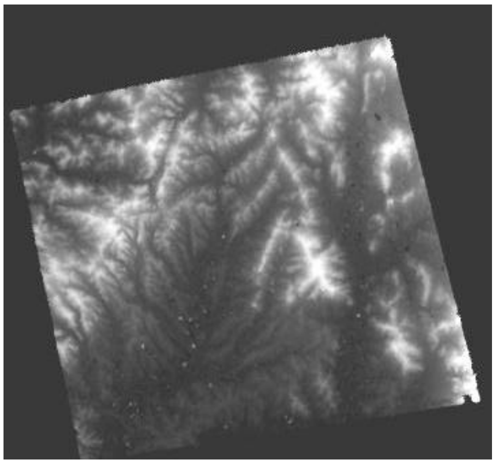
In Figures 2(a) and (b), the two DEMs show very fine structures of topography over the Taejon and Nonsan areas. In figure 2(a), the DEM also delineated the boundaries of Daechung lake correctly (the blank regions on right top and right bottom). The accuracy of the DEMs was around 13 m. The EOC Nonsan pair had wider stereo coverage than the EOC Taejon pair as shown in the figure. Except a few blobs, which appeared to be errors, Figure 2(b) shows very fine details of Nonsan area. As the absolute orientation accuracy for the EOC Nonsan was very high, the accuracy of the DEM from the EOC Nonsan was also high (RMS error of 8 meters).

Since the SPOT pair had much wider stereo coverage, the size of the DEM from the SPOT was the largest. In Figure 2(c) the areas covered by DEMs from the EOC Taejon pair and the EOC Nonsan pair were illustrated by rectangles. The DEMs from the SPOT pair contained more blobs than DEMs from the EOC images. The accuracy was not as good as DEMs from the EOC images (RMS error of 31 meters). This degradation in the accuracy seemed partly due to the resolution effect (10m for the SPOT and 6.6m for the EOC) and partly due to the fact that there was a time gap of one month between the left and right images of the SPOT pair. From mid October to mid November in Korea, land cover undergoes severe changes due to harvest and the shift of season from the autumn to the winter. Due to this factor, one cannot directly compare the accuracy of DEMs from the EOC pairs and from the SPOT pair and declare the superiority of the EOC images. However, it seemed that DEMs from the EOC pairs could delineate finer details of the topography at higher accuracy than the DEM from the SPOT pairs.

(a) DEM from EOC Taejon by ON-EpiMatch



(b) DEM from EOC Nonsan by ON- EpiMatch



(c) DEM from SPOT by ON- EpiMatch

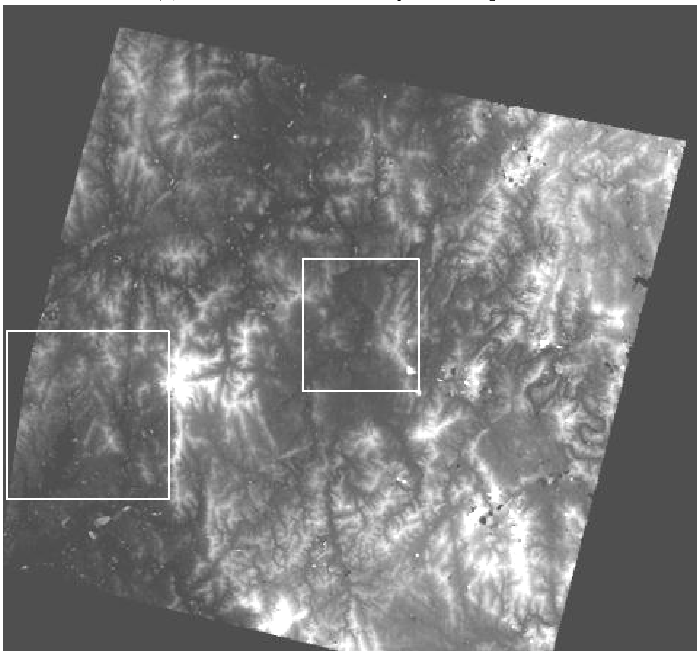


Figure 2. DEMs generated from each stereo matching for each test area.

5. DISCUSSION AND CONCLUSION

The purposes of this paper were to report the development of DEM generation techniques for the EOC and to check the accuracy of DEMs from the EOC. This paper showed that the algorithms proposed by Orun and Natarajan [1994] and the epipolarity-based stereo matching algorithm [Park et al., 2000] could work for automated DEM generation from the EOC. This paper also showed, in comparison with the DEM from SPOT images as well as the ground truth data, that DEMs from the EOC images contained finer details of topography and their accuracy was very favorable. The authors hope these findings help the KOMPSAT-1 EOC data user community.

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