DEM GENERATION FROM MULTISENSOR STEREOPAIRS - AVHRR AND MSS -

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Commission IV

KEY WORDS: **Stereoscopic, Global DEM Generation, AVHRR, MSS.**

ABSTRACT

There are several studies on digital elevation model (DEM) generation from multisensor stereopairs. One of the critical condition for generating global DEM is the availability of cloud free images. By combining NOAA AVHRR and Landsat MSS, which can be widely obtained from huge archives, it is possible to create DEM using a stereopair with the MSS providing the nadir looking view and a part of the AVHRR providing the off-nadir view. Since a spot size of AVHRR is more than one-kilometer, stereo matching must be accomplished by sub-pixel accuracy.
Test project conducted around Mt. Olympus, USA, demonstrated a vertical accuracy of approximately 320-m. Though the accuracy is low, this result shows that this method has potential for creating DEM within the accuracy of the Digital Chart of the World, which is the only digital source covering all over the world except some regions where data is missing, and for filling elevation data in blank regions.

1. INTRDUCTION

Geographic information is indispensable for understanding global environment. In particular, elevation data is one of the most basic geographic information. Thus projects of development of global one-kilometer resolution digital elevation model (DEM) are ongoing by compiling existing digital elevation data such as the Digital Chart of the World (DCW) and the Digital Terrain Elevation Data (DTED). Yet in a few regions , there are no existing digital elevation data. In order to fill elevation data in these blank regions, it is feasible to take applications of remote sensing technology.
In case of using optical sensors, availability of cloud free data is critical, because probability of existing cloud is very high in some regions. Satellites which can be obtained stereopairs are limited. As an alternative way, there are some studies of DEM generation from stereopairs by combining with different sensors (Raggam and Almer, 1991 and Storey, 1993).
NOAA and Landsat have long histories and many scenes are available in the world. However the resolution of NOAA Advanced Very High Resolution Radiometer (AVHRR) is low and AVHRR is not seemed to be suitable for digital elevation data extraction. By the adaptation of the basic idea of Cracknell and Paithoonwattanakij (1989) method to stereopairs of AVHRR and MSS, correlations between AVHRR image and MSS image are performed with sub-pixel accuracy of AVHRR resolution, and approximately one-kilometer grid DEM are generated from the detected parallaxes. The accuracy of obtained DEM are compared with the accuracy of DCW and possibility of filling digital elevation data in blank regions of DCW is discussed.

2. APPROACH TO GENERATING DEM USING AVHRR AND MSS

2.1 Basic Idea of DEM generation using AVHRR

For elevation data extraction, stereopairs are needed. AVHRR has wide field of view (FOV) and the scan angle is ± 55.4 degree from the nadir. Using some range of AVHRR scene from the nadir, we can use it as a off-nadir view image for one of stereopair. Since a spot size of the AVHRR on the ground is relatively large compared with terrain of the earth, even rough terrain can not be obtained without measurement of high precision of parallax.
Image-to-image correlation technique is used for parallax detection. This technique is also used for registration between two images. Accuracy of correlation between AVHRR scenes for image registration are approximately 0.6 pixel - 0.7 pixel (Kelly and Hood, 1991). This accuracy is insufficient for detecting parallax against the earth terrain. For example, if B/H ratio is 0.5 and AVHRR pixel size is one-kilometer on the ground, the vertical accuracy of detectable elevation is more than one-kilometer.
Cracknell and Paithoonwattanakij (1989) showed a more accurate registration method that Landsat MSS image are used for AVHRR image registration. According to their result, the accuracy was approximately 260-m. Though this accuracy is not still sufficient for this study, it is anticipated that

adaptation of this method in a small area corresponding to MSS scene will improve the accuracy because they used many MSS scenes rectified separately for rectifying a whole AVHRR scene.
For extraction of terrain, MSS image providing a nadir looking view and a part of a AVHRR image providing the off-nadir view were used as a stereopair image (Figure 1).

2.2 Discussion on AVHRR image as a off-nadir view

The specialty of using AVHRR image as off-nadir view is that a spot size on the ground becomes larger along the scan angle from the nadir. Figure 2 shows long radiuses, short radiuses and interval distance from the adjacent pixel along the scan direction. Upper axis shows elevation angle from the ground point. Because of curvature of the earth, a scan angle from the satellite is not equal to the elevation angle from the ground point. Conditions for detecting parallax with high sensitivity are (a) a pixel to be high resolution on the ground, (b) high B/H ratio between a stereopair and (c) less distortion between two images for high correlation. Near nadir image of AVHRR meets (a) and (c), and off-nadir image of that meets (b).
Figure 3 shows the relation between sensitivity of detecting parallax and pixel location from the nadir. If a parallax is detected with 0.1 pixel accuracy of AVHRR at 500 pixel from the nadir, the sensitivity of elevation is approximately 260-m. Though sensitivity does not change drastically at off-nadir pixels, low correlation is anticipated because of distortion of image.
Range approximately from 350 pixel to 500 pixel from the nadir across the track would be suitable for generating DEM. In this range, B/H ratio is from 0.40 to 0.60.

2.3 Important factors for precise DEM generation

(1) Relative registration of stereopair images
Prior to the parallax detecting process, precise relative registration of stereopair must be carried out. If registration was done separately, it would be impossible to detect parallaxes within sub-pixel accuracy. In order to carry out the most accurate registration between two images of a stereopair, using rectified MSS image, image-to-image registration method is applied to AVHRR image.
(2) Similarity of stereopair images
NOAA and Landsat are sun-synchronous orbit satellites. Landsat passes the equator in the morning. There are two types of NOAA satellites. One passes the equator and the other passes the equator in the afternoon. For reducing the shadow effect against image correlation, AVHRR scenes acquired in the morning such as NOAA-10, NOAA-12 must be selected. As for wavelength of stereopair images, near infrared is suitable because of less noise effect. Thus NOAA AVHRR Channel 2 (0.725-1.10 μ m) be selected in AVHRR channels. The range of wavelength of channel 2 covers approximately both wavelength of Landsat MSS band3 (0.7-0.8 μ m) and band4 (0.9-1.1 μ m). The spectral response curve of channel 2 indicates a peek in the range of band 3 (National Oceanic and Atmospheric Administration, 1991). Therefore band 3 is selected.
The near infrared has much sensitivity of vegetation changes. Thus stereopair should be selected in the same season. Selecting procedure is as follows. At first cloud free MSS scene is selected from archives. Secondly AVHRR scene which does not have cloud in the same part corresponding to the MSS scene is selected from archives. For searching the similar vegetation condition, AVHRR scene is sought day by day from the same date of MSS scene. AVHRR scene can be obtained every day; consequently the probability of obtaining cloud free AVHRR scene is very high because time difference between two scenes is small in the same day.

2.4 Sub-pixel Correlation

As mentioned in 2.2, a pixel spot size on the ground changes depending on scan angle. A interval of pixel distance is smaller than the pixel spot radius along the scan line. This mean that each spot overlaps the adjacent pixel spot. To avoid resampling effect of AVHRR pixels, AVHRR pixels treat as a coordinates file and both systematic correction and rectification of AVHRR scene is applied to coordinates. Coordinates file include information of pixel value, satellite zenith angle and spot size.
MSS image are degraded to AVHRR resolution by simulating AVHRR spot with MSS pixels. Image-to-image correlation between a reference window on AVHRR image and a search window on MSS image are accomplished. A maximum correlation can be identified to accuracy of MSS pixel size (80m) (Figure 4). Since sensor are different, normalized correlation (correlation coefficient) should be computed for correlation.
This method is applied to both rectification of AVHRR and detection of parallax between AVHRR image and MSS image.

2.5 Flow of Experiment

As a test area, a scene including Mt. Olympus (elevation 2428-m) in Washington State, USA was selected. MSS scene is from Landsat 5 and AVHRR is from NOAA 12. Acquisition date of both two scenes is September 16, 1992. The range of AVHRR scene corresponding to MSS scene is approximately from 330 pixel to 500 pixel from the nadir along the scan line.
The flow of experiment is following (Figure 5).
(1) Rectification of MSS
Using the points from Digital Line Graph (DLG) produced by US Geological Survey (USGS) as ground control points (GCPs), systematically corrected MSS scene was rectified.
(2) Systematic Correction of AVHRR
Raw AVHRR image was systematically corrected as a coordinates file using orbit model. This was done using the AVHRR Data Acquisition and Processing System (ADAPS) support routine developed by EROS Data Center, USGS (Eidenshink, 1993).
(3) Rectification of AVHRR
Points along a coastal line were selected from the AVHRR pixels as provisional GCPs. Corresponding points in MSS images were selected by above described

sub-pixel correlation method. First order polynomial coefficients based on MSS pixel coordinates were calculated. The polynomial coefficients were applied to AVHRR coordinates. Systematically corrected AVHRR coordinates were rectified using the polynomial coefficients.

(4) Detection of Parallax and Computation of Elevation

Parallaxes were detected by sub-pixel correlation method. As indicated in the figure 6, an intersection of two looking vectors from the ground points is calculated. In practice two vectors does not intersect, thus a center of a minimum segment of a line between two vectors was calculated.

(5) Evaluation

Elevations were evaluated using 3-arc second DEM produced by USGS.

3. TEST RESULTS

3.1 Registration Accuracy of a Stereopair

MSS scene was rectified with root mean square error (RMSE) of 64-m. AVHRR coordinates were rectified using the MSS scene as reference images. Thirteen AVHRR pixels were selected as GCPs and image-to-image correlation was achieved. Table 1 shows the result. RMSE changes slightly in case of more than 5 by 5 reference window. It seems that RMSE 100-m would be reached a limit, considering conditions such as MSS IFOV, MSS rectification RMSE, incomplete way of AVHRR pixel simulation by MSS pixels etc.

3.2 Accuracy of Generating DEM

Elevations of all points in AVHRR scene corresponding to MSS scene (185-km by 170-km) except sea area were calculated. The number of points was 19380. Some points were rejected as miss-matching points. Conditions of miss-matching points are (1) correlation coefficient is less than 0.5; (2) distance between two looking vectors is more than 500-m; (3) the difference between an original elevation and an elevation after applied median filter is more than 500-m. Except these points, elevations were evaluated with USGS DEM. Table 2 shows the result.

4. DISCUSSION AND CONCLUSION

Elevation accuracy of a map is defined normally by the contour interval. According to National Map Accuracy Standards by USGS, 90% linear error (LE) is within half of contour interval. For example 1:1,000,000 scale map has usually contour line with intervals of 500-m or 1000 feet (300-m); the RMSE is 152-m or 91-m respectively. RMSE 320-m, the result of this experiment, does not meet the criterion. In case of DCW, the source map scale is 1:1,000,000 but 90% LE is ± 610-m (Defense Mapping Agency, 1992). This criterion is corresponding to RMSE 371-m. This fact indicates that the proposed method has potential to fill elevation information in contour blank regions within the accuracy of DCW; however the accuracy of DCW might be better than the criterion in most of regions where contours existing.

Since RMSE of elevation is 320-m and the mean of B/H ratio is approximately 0.5, it means registration accuracy of a stereopair is less than 160-m. This shows that it is possible to rectify AVHRR using GCPs even from non coastal pixels.

As future plans, one of a refinement way of DEM accuracy is using multi-direction's AVHRR scenes providing the off-nadir view and MSS scene providing nadir view like triplet matching. Another way is to use sensor with higher resolution and wide FOV. Satellites, ADEOS-II and EOS-AM1, which will be launched in 1998, will have a sensor of 250-m resolution on the ground with wide FOV. The sensor's names are GLI and MODIS respectively. By applying the same method to a stereopair of these sensor and Landsat TM, more accurate DEM generation is expected.

ACKNOWLEGEMNT

This research was done during the author's stay at EROS Data Center, US Geological Survey / UENP GRID Sioux Falls, supported by STA Long-Term Scholarship program of the Science and Technology Agency, Government of Japan.

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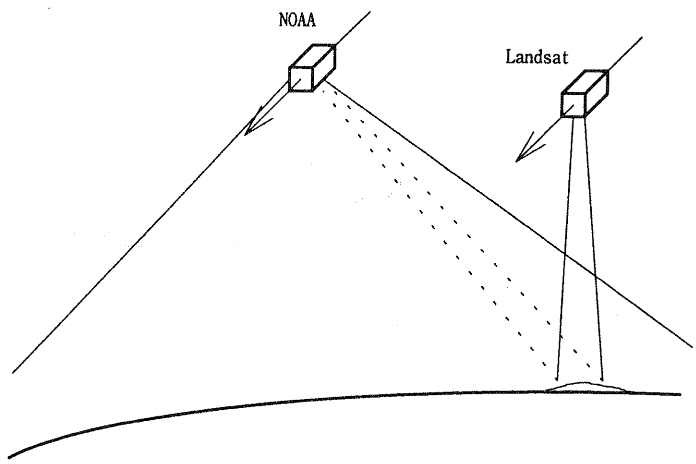

Figure 1 Conceptual Figure of Stereoscopic Vison
by NOAA and Landsat

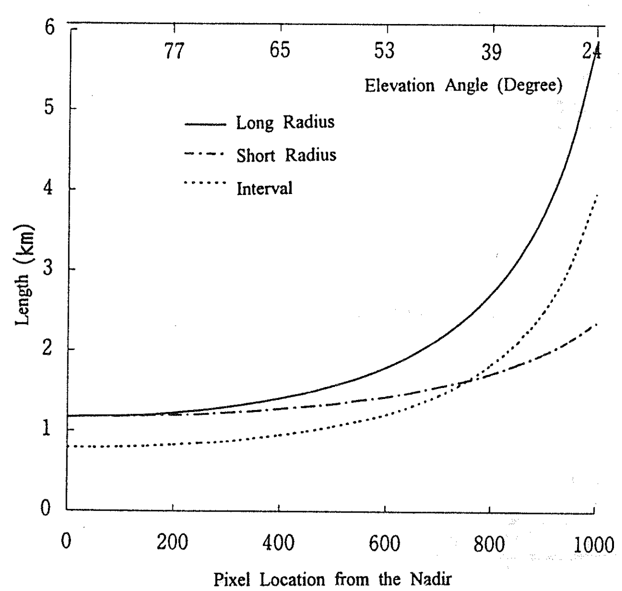

Figure 2 Sopt Size and Interval Changes from the Nadir

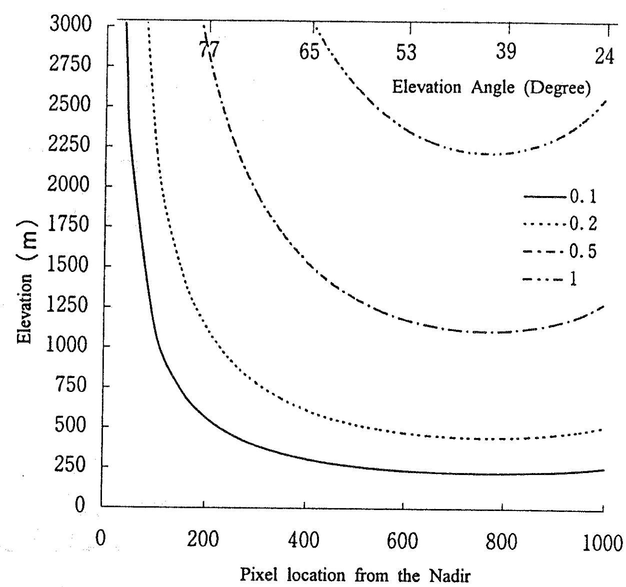

Figure 3 Sensitibity of Elevation by Detected Parallax

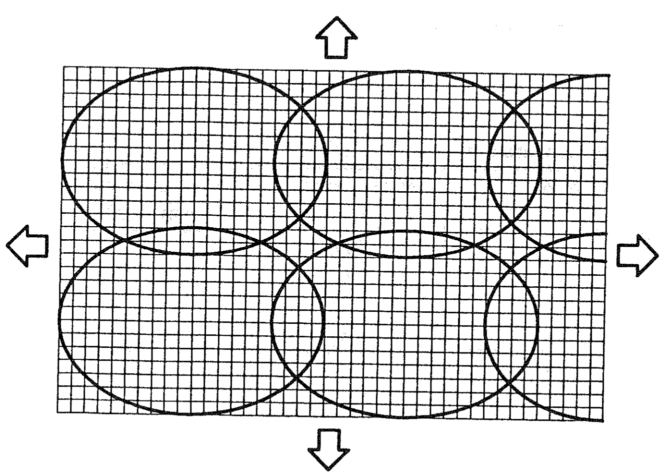

Figure 4 Conceptual Figure of Matching by MSS Pixel Size

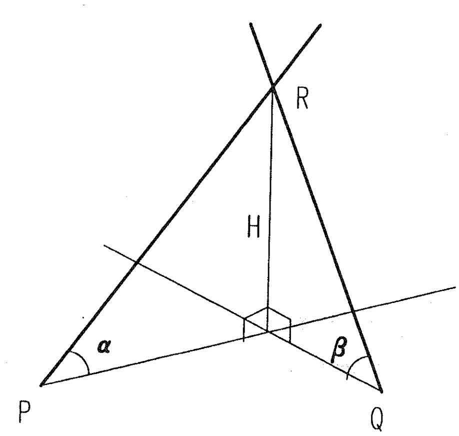

Figure 6 The Relation between Elevation and Two Vectors
from the Spots on the Ground

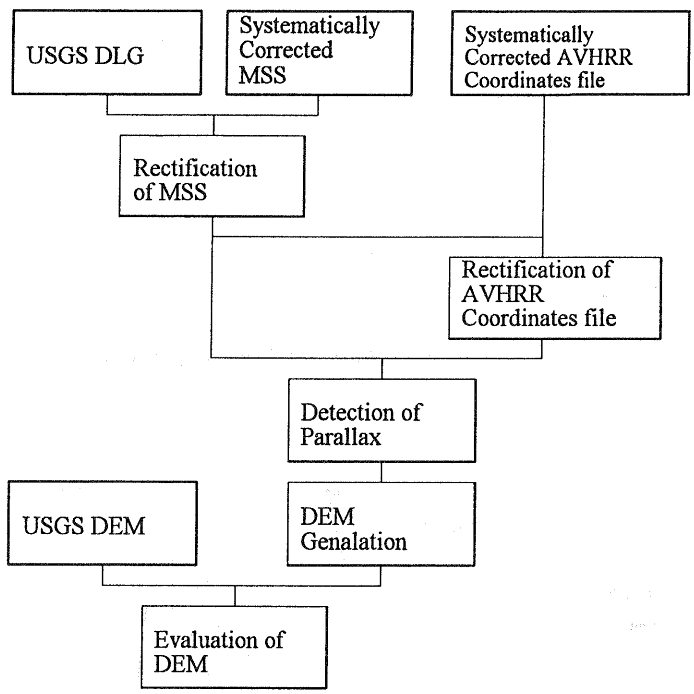

Figure 5 Flow Chart of DEM Genaration

Table 1 Residual ERROS of Registration between MSS and AVHRR

Window Size	RMSE(m)
3x3	7560
5x5	152
7x7	113
9x9	121
11x11	111

Table 2 RMSE of Elevation compared with USGS DEM

Window Size	RMSE(m)	Avarage (m)	Miss-matching Points 1)	Miss-matching Points 2)	Miss-matching Points 3)
7x7	353	-57	187	284	115
9x9	339	-56	102	71	20
11x11	333	-52	43	16	4
13x13	329	-46	13	3	7

1) Correlation Coefficient < 0.5 2) Distance Between two Vectors > 500-m
3) Difference between the elevation and the elevation conducted Median Filer > 500-m