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AUTOMATIC NOAA AVHRR IMAGE REGISTRATION IN MOUNTAINS AREA

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ABSTRACT:

This article presents a new and novel approach to accomplish AVHRR data navigation with errors of less than 0.9 km in the middle latitude regions. The AVHRR channel 4 counts and GTOPO30 elevation data and image correlation method are used. This approach is suitable for both day and night passes. It can also be used for other satellites with thermal sensing radiometers.

A two steps approach is implemented. The first step is to obtain the first approximate navigation (initial navigation). The second step is to refine the initial navigation. The first step uses a physical elliptical orbit model, the Brouwer-Lyddane orbit prediction package, to determine satellite position and velocity, and uses a generic algorithm for computing earth location values to obtain longitude and latitude for pixels in the AVHRR image. The second step uses an automatic ground control points (GCPs) method to adjust the first approximation to obtain highly accurate geo-registration for this AVHRR image.

In the automatic GCPs method, the templates with fixed geo-locations are extracted from AVHRR image and the correlation coefficients between every template and the elevation image (target window) are calculated. The template and target window is the best matched at the location where the correlation coefficient has the maximum value. The difference between longitude and latitude of the central pixel of the template and the matched sub-window of the target window is the error of the initial navigation. Subtract the error from the initial navigation, the AVHRR image navigation is refined.

To quantitatively test the refining results. The high resolution coastlines from GMT (The General Map Tools, developed and maintained by Paul Wessel and Walter H. F. Smith.) package are superimposed onto the AVHRR image. The navigation errors are obtained from comparing the location difference of the coastlines from GMT and from AVHRR image. NOAA12 AVHRR images of early, middle and end of each month form January to August 1999 are used to test the performance of this algorithm. This paper also discusses the efficiencies of different correction methods and the effects of template's size on the accuracy. The accuracy of this method is less than 1 km in the middle latitude areas.

1. INTRODUCTION

In the past 10 years, many efforts have been put on developing the methods for automatically navigating AVHRR ((Cracknell and Paithoonwattanakij, 1989),(Emery, Brown and Nowark, 1989),(O'Brien and Turner,1992),(Bordes, Brunel and Marsouin,1992)). All of these methods are using coastlines as unique features to locate the AVHRR image. These methods are efficient for images with coastlines can be recognized clearly. But for the AVHRR images without coastline in it or the coastlines are obscured by clouds, these methods cannot be used any more. Another restriction is they can only be used for day time passes, because they use the visible images. This paper prompts a new method which is suitable for AVHRR images with mountains present in it and can be used for the day and night time passes.

2. PRINCIPLES

A two steps approach is implemented. The first step is to obtain the first approximate navigation (initial navigation) by using a physical elliptical orbit model, the Brouwer-Lyddane orbit prediction package to determine satellite position and velocities and using a generic algorithm for computing Earth location values to obtain longitude and latitude for pixels in AVHRR image. The second step is using an automatic GCPs method to

obtain highly accurate geo-registration for the AVHRR image. The details of the first step is referred to the web site of NOAA KLM User's Guide (Kidwell, Goodrum and Winston, 1998). The follows are the detail of the second step.

NOAA AVHRR channel4 is a thermal channel. It detects infrared radiations from sensed objects. From Stefan-Boltzmann's radiation law

$$E = \sigma\, T^4$$

Where σ =5.67 $\times$ 10^{-8}Wm^{-2}deg^{-4},E is radiation emitted by a black body with temperature of T Kelvin degree. So an object with higher temperature radiates more energy out. In the mountain areas the temperature of the ground decreases with the elevation increasing. The mountain ridges have lower temperature and radiation while mountain valleys have higher temperature and radiation. In the NOAA AVHRR channel 4 raw images, the object with higher temperature has small count, the object with lower temperature has larger count. It is reversely coded. So the mountain ridges have higher value than valleys. It is similar on the elevation image, the mountain ridges have higher values, mountain valleys have small values. The same scene has identical features in a NOAA AVHRR channel 4 image and an elevation image. So in theory, the AVHRR channel 4 image and elevation image can be closely correlated on the same scene. In this paper the elevation data is from

GTOPO30(a global digital elevation model (DEM) resulting from a collaborative effort led by the staff at the U.S. Geological Survey's EROS Data Center in Sioux Falls, South Dakota.).

To calculate the correlation between the GTOPO30 elevation image and an AVHRR channel 4 image, an image matching method is used. In this paper, the image cross –correlation method is used. Before going to the details, the definitions of template, target window and searching window have to be made here. A ground control point (GCP) sub-region (a subregion with the GCP at the center) in the AVHRR channel 4 image is called a template. The sub-region for the same GCP in the elevation image is called target window. Moving a template over the elevation image, the corresponding subregion in the elevation image is called searching window. The geographical location of a template, target window and searching window is defined as the geographical location of the central point. The initial navigation error is the difference between the geographical location of a template and corresponding target window. Subtract the error from the AVHRR image's geographical coordinates, the navigation of this AVHRR image is refined.

The location of a template is known. In order to find the right location of the target window, the cross-correlation coefficients are calculated between the template and the searching window with the highest cross-correlation coefficient is the location of the target window.

3. DATA

3.1 Elevation Data

The elevation data used here are from GTOPO30. GTOPO30 is a global data set covering the full extent of latitude from 90 degrees south to 90 degrees north, and the full extent of longitude from 180 degrees west to 180 degrees east. The horizontal grid spacing is 30-arc seconds (0.0083333333333333 degrees). The horizontal coordinate system is decimal degrees of latitude and longitude referenced to the World Geodetic System of 1984 (WGS84). The verticle units represent elevation in meters above mean sea level. The elevation values ranges from –407 to 8,752 meters. In this data set, ocean areas have been masked as "no data" and have been assigned a value of –9999.

The south island elevation data are extracted from GTOPO30 and the size of elevation image used here is 1800×2160 points, the northern end is $S31°$,the southern end is $S49.991667°$, the western end is $E165°$, the eastern end is $E180.0041506°$.

3.2 Templates Locations

34 geo-location fixed templates (see figure 1) are extracted along ridges of the mountains over the South Island from AVHRR image. Although the geo-location of each template is fixed, the ground objects corresponding to it may vary for different satellite passes due to the error of the initial navigation. That means the subregion is not always the same area for each template.
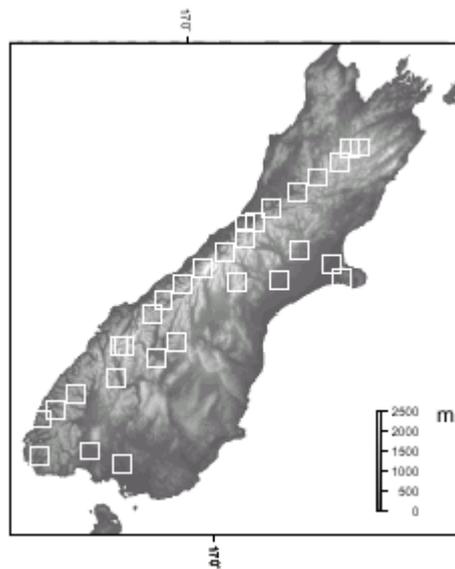
Figure 1. Location of predefined templates

Because of the inclination of NOAA polar satellite orbit, the scan line AVHRR is not perpendicular to the longitude of the Earth. The angle between NOAA polar satellite orbit and longitude of the Earth is not 90 degree. But the image pixels are aligned along longitude in the GTOPO30 elevation image. So we must extract the templates along the longitude and latitude to obtain data set comparable to elevation image. For most passes, the position intervals between two successive pixels in longitude and latitude is about 0.018 and 0.008 degrees in New Zealand region so the size of template is chosen initially as 0.18×0.08 degree ^{2} for 10×10 points, another two set of templates of size of 0.18×0.12 degree ^{2} and 0.24×0.18 degree ^{2} are also going to be tested.

4. CORRECTING THE NAVIGATION ERROR

4.1 Extracting Searching Window

Template matching by correlation is time consuming. One way to speed it up is to obtain the approximate best match location first and then just move the template on target image within predefined varying range. In this study, the AVHRR image is first navigated with a physical orbit prediction model. The accuracy of the first approximation is within 20 pixels (the image is resampled, 1 pixel equals 0.9 km at middle latitude areas.). Here considering the worst case, the maximum error of initial AVHRR navigation is assumed to be within ± 30 pixels. So the template is moving within 30 pixels range around the original position in the GTOPO30 image when searching for the right location of the target window.

The templates are extracted from raw AVHRR channel 4 image for each GCP area. The searching window is obtained by locating pixels in the elevation image according to the geolocation of each pixel in the template. For each pixel in a template, the corresponding point in the elevation image is obtained as follows:

$$P_e = (180.0041506 - long_t)\big/0.0083333333 \qquad (1)$$

$$L_e = (49.991667 + lat_t)\big/0.0083333333 \qquad (2)$$

P_e and L_e are column and row number respectively in the elevation image; and $long_t$ lat_t are geographical longitude and latitude of the pixel in reference window.

In this way, we can obtain the initial guess of the corresponding GCP sub-window in the elevation image for every template. Move the whole sub-window within 30 pixels in row, column and both and calculate correlation coefficient r for every shifted window (searching window). The searching window having the largest r is the target window.

4.2 Calculating the Displacement Vector

The searching window having the maximum r is the best match window. The geolocation of the best match window is assumed to be the location of the corresponding target window. Now define (P_{ci}, L_{ci}) as the center of the initial (without shifting) window, and (P_{cb}, L_{cb}) as the center of the best match window. Then, we have error of initial navigation:

$$\Delta long = long_{cb} - long_{ci} \qquad (3)$$

$$\Delta lat = lat_{cb} - lat_{ci} \qquad (4)$$

Where $\Delta long$ and Δlat are respectively the longitude and latitude error of navigation. The displacement vector can be determined as follow:

$$|disp| = \sqrt{\left(\frac{\Delta long \times \pi}{180}\right)^2 + \left(\frac{\Delta lat \times \pi}{180}\right)^2} \qquad (5)$$

$$\alpha = \pi + atan2(\Delta long, \Delta lat) \qquad (6)$$

where $|disp|$ is the magnitude value or length (modular) of the displacement vector. α, ranging 0--360° anticlockwise with 0° as the line angle pointing towards right horizontally, is the direction angle of the vector; atan2 is the c++ programming language function which return value between $-\pi$ to π.

4.3 CORRECTION

4.3.1 Template Usability

Due to the presence of the clouds or other factors, although the correlation coefficients can still be calculated, some template may not be usable. From figure 2, we can see there is too much diversity among the displacement vectors. They cannot be all used for correction. Some template have lower correlation coefficients, some have high correlation coefficients but the error vectors have different directions Apparently, it is not

appropriate to use all of them. Decisions has to be made to discard some template. From (Bordes et al., 1992), for an AVHRR image of about 3000-4000lines the navigation error does not vary very much. The following criteria are used to select the usable templates:

- the coefficient is higher.
- the displacement vectors are in the same direction.
- The deviation is not too large.
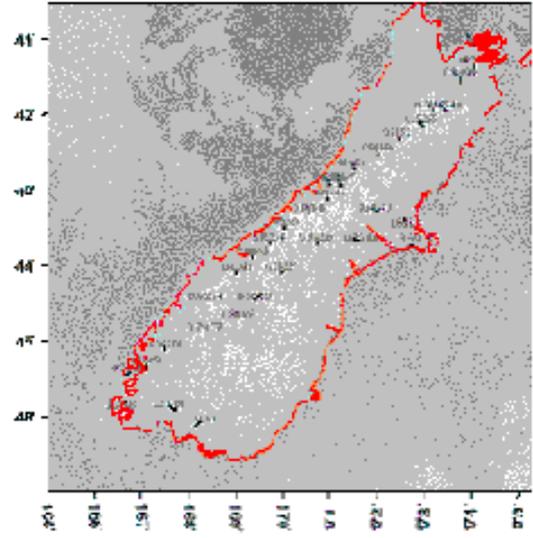
Figure 2. Displacement and coefficients in NOAA12-40816

So, for a template, if:

1. $r > 0.8$

2. $\dfrac{\Delta long}{\overline{\Delta long}} > 0$

3. $\left| \dfrac{\Delta long - \overline{\Delta long}}{\overline{\Delta long}} \right| < 0.25$

4. $\dfrac{\Delta lat}{\overline{\Delta lat}} > 0$

5. $\left| \dfrac{\Delta lat - \overline{\Delta lat}}{\overline{\Delta lat}} \right| < 0.25$

are met, then it is tagged as usable. The first rule is to make sure that the template and reference image are highly correlated that means they have high similarity. The second is to keep the consistence of error vector direction along longitude, means they are in the same direction along longitude. The third is to keep the consistence of magnitude in longitude, means they don't change too much. The forth is to keep the consistence of error vector direction along latitude. The fifth is to keep the consistence in magnitude in latitude.

4.3.2 Simple Shift Correction

Usually New Zealand is covered within 2000 lines of AVHRR data and it is assumed that the navigation error is nearly

constant in the same scene. The navigation error is calculated by averaging errors over all usable templates:

$$long_{shift} = \frac{1}{n} \sum_{i=1,n} \Delta long_i^* \qquad (7)$$

$$lat_{shift} = \frac{1}{n} \sum_{i=1,n} \Delta lat_i^* \qquad (8)$$

where $long_{shift}$ is the mean navigation error in longitude direction, lat_{shift} is the mean error in latitude direction. $\Delta long_i^*$ is longitude error of the number i accepted template and Δlat_i^*0 is latitude error of the number i accepted template. n is the number of accepted templates. The final navigation can be obtained by subtracting the error from the initial image navigation data which are gained by using the physical model.

5. VALIDATION

After the navigation correction, the high resolution coastlines from GMT package (Wessel and Smith, 1995) are superimposed onto the AVHRR image and 12 different coastline segments are chosen (see figure 2),where sharp corner can be easily recognised as test references.

From the 32 times enlarged zoom window on the screen, we can obtain the location difference between the high resolution coastlines and the coastlines on the AVHRR image. NOAA12 AVHRR images of early, middle and end of each month from January to August 1999 are used to test the performances of this algorithm, the testing results are shown in the table 1.

Δx_i and Δy_i are initial navigation errors along longitude and latitude in kilometre. Δx_r and Δy_r are errors of the refined navigation. Three different template sizes are used: T_1 is 0.18 degree by 0.08 degree; T_2 is 0.18 degree by 0.12 degree; T_3 is 0.24 degree by 0.18 degree.

The maximum error along longitude is –9.9 km for the initial navigation, -3.4 km for T_1, -3.8 km for T_2 and –3.7 km for T_3. The minimum error along longitude is 0.1 km for the initial navigation, 0 for T_1 and T_2, -0.5 km for T_3.

The maximum error in latitude is 9.5 km for the initial navigation, -3.3 km for T_1, 3.5 km for T_2 and –3.2 km for T_3. The minimum error in latitude is 2.4 km for the initial navigation, 0 for T_1, T_2 and T_3.

We can see that the mean error in latitude direction is reduced remarkably while it is not so in longitude direction, but the standard deviation of errors in longitude direction show remarkable improvement.

6. CONCLUSION

This paper described a novel automatic AVHRR image navigation method. Validation of this new method was conducted with 13 NOAA12 passes of January to August of 1999. Image cross-correlation was used in automatically locating searching windows in elevation image. The similarity of terrain features in elevation image and AVHRR thermal band 4 count image was proven an usable characteristic in automating GCP satellite remote sensing image navigation.

The effects of size of the templates on the performances of the cross-correlation over AVHRR channel 4 data and GTOPO30 elevation data was discussed. The template size of 0.18×0.12 degree^2 is the best to use compared to the size of 0.12×0.08 degree^2 and 0.24×0.18 degree^2. The probable reasons are when the templates are too small the extracted features may not be unique; When templates are too big the features may be too complicated to be represented.

Three correction approaches, simple shift, segment shift and multi shift polynomial transformation, were compared. The simple shift can achieve high accuracy, less than 1 km, for most passes. But when the error along longitude is larger than 6km, this method have errors as large as –2.32 km with std of 1.71 km along longitude for NOAA_12_41620. The segment shift method can reduce the std a little bit for the same pass to 1.44. But when most of the GCPs are covered by clouds, it may introduce some extra error to some part of the image. The polynomial transformation method can improve the performance of the method and lead to higher accuracy navigation for NOAA_12_41620 with error and std along longitude is –2.25 and 0.45. But the number of active GCPs must be more than 3 to conduct the polynomial transformation.

Overall the approach promoted here for AVHRR image navigation is an automatic method with high accuracy. Because it uses the thermal channel raw data, it can be used for both the day time and night time passes. This method can be extended to other satellites having infrared thermal sensors carried on board to automatically derive accurate image navigation.

Orbit number	initial				0.08×0.18				0.12×0.18				0.18×0.24			
	Δx_i		Δy_i		Δx_r		Δy_r		Δx_r		Δy_r		Δx_r		Δy_r	
	mean	std	mean	std	mean	std	mean	std	mean	std	mean	std	mean	std	mean	std
39984	0.98	0.72	4.66	0.34	-1.68	0.95	-0.56	0.52	-1.54	0.82	-0.91	0.44	-1.83	0.72	-0.56	0.28
40176	0.07	0.55	2.46	0.35	-0.35	0.70	2.67	0.59	0.00	0.61	2.46	.61	-1.26	0.76	0.00	0.35
40375	0.83	0.69	4.77	0.52	-0.56	0.95	0.0	0.44	-1.26	1.17	-0.14	0.52	-0.42	1.01	-0.12	0.27
40816	-0.77	0.86	2.81	0.52	-1.12	0.91	-0.35	0.35	-1.05	0.91	-0.35	0.62	-0.25	0.87	-0.31	0.35
41051	-3.58	1.67	2.81	0.33	-1.19	1.29	-0.14	0.30	-1.33	1.53	-0.49	0.58	-1.90	1.55	0.21	0.33
41250	-1.61	0.59	3.02	0.91	-0.21	0.30	-0.21	0.30	0.00	0.00	0.00	0.00	-0.35	0.78	-0.70	0.86
41364	-4.42	1.35	2.11	0.50	-0.70	1.22	-0.21	0.30	-0.56	0.91	-0.35	0.60	-1.05	1.61	-0.35	0.35
41477	2.81	0.78	2.11	0.78	0.00	0.78	-0.70	0.78	-0.70	0.78	-0.70	0.78	-0.70	0.78	0.00	0.00
41620	-6.95	1.73	2.11	0.37	-2.39	1.76	-0.91	0.62	-2.32	1.71	-0.77	0.69	-2.60	1.11	-0.49	0.62
41833	-0.98	0.72	1.68	0.95	0.00	0.88	0.00	0.00	-0.14	0.28	0.00	0.00	0.70	0.62	2.25	0.52
42181	2.25	0.28	3.93	0.72	-1.97	0.28	0.84	0.52	-1.68	0.34	0.70	0.44	-1.68	0.34	-0.42	0.34
42338	-4.77	0.82	4.49	0.56	-2.25	0.69	-0.70	0.77	-2.67	0.69	-0.42	0.56	-2.39	0.72	-0.28	0.34
43056	-2.81	0.00	6.67	0.35	-0.70	0.00	-0.70	0.00	-0.35	0.35	-0.35	0.35	-0.70	0.00	-0.70	0.00
mean	-1.46		3.39		-1.01		-1.01		-1.17		0.02		-0.94		-0.10	
std	2.81		1.44		0.80		0.80		1.05		1.28		0.94		0.83	

Table 1. the error(km) of initial and refined (simple shift) navigation for NOAA 12 from January to August 1999

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