Problems of accurate automatic navigation of NOAA/AVHRR and FY-1D satellite images

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Abstract - The problems of precise automatic navigation of AVHRR imagery were considered and an approach based on automatic computation of ground control points (GCP) and image deformation model was tested. The GCP automatic computation procedure is based on verification of sea-land separability hypothesis. The verification criteria using can increase significantly the reliability of GCP computation under complex weather conditions of the Earth observation. A scheme based on consistent orbital and attitude parameter correction is presented for the problem solution. The scheme may be used for navigation parameter forecasting of adjacent satellite passes. The problem of FY-1D image navigation was considered.

Keywords: AVHRR image navigation, ground control points, navigation parameter forecasting.

1. INTRODUCTION

A method of automatic full AVHRR image navigation has two parts: an image navigation model (i.e. direct and indirect coordinates mapping) and an automatic GCP identification procedure (Brunel 2000). There are some drawbacks of present works that can be mentioned: high percentage of images, where GCP identification procedure fails and absence reliable schemes of navigation accuracy control and navigation parameter forecasting (although some approaches were suggested (Brunel 2000, Baldwin 1995)). The problems considered in this paper are:

1) Operability improvement of GCP generation procedure under complex observation conditions.
2) Development and verification of a method for navigation accuracy control and navigation parameter forecasting.

2. AUTOMATIC GCP COMPUTATION METHOD

2.1 Overview

There are two basic approaches for decision of automatic generation of ground control point problem for NOAA/ AVHRR images: contour-based (O'Brien 1992, Eugenio 2003) and template-based (Bordes 1992, Liu 2002, Parada 2000, Pergola 2000, Purevdorj 2002). The first approach is based on overlap of a reference contour with image extracted one, in the second approach the brightness discrepancy between template formed on the base of the mask of the land/sea and the image is minimized. We have chosen the second approach, which is widely used in practice. The main drawback of the approach is its low reliability for images formed under complex weather conditions, first of all in the winter season for regions of high latitudes (ice, snow) (Dybbroen 2002), then up to 80% of images are not navigated (Brunel 2000). The basic reason of the approach failure can be as follows. After an estimation of optimum value of criterion for GCP generation it is necessary to estimate the statistical significance of the result and to relate it with accuracy of the GCP location.

2.2 GCP generation

A set of areas of reference land/sea mask is used for automatic GCP generation procedure. Each area should have a coastline with abrupt changes of the directions. The selection of appropriate image areas for GCP generation is carried out after performance of cloud filtration (Derrien 1993). An algorithm (Pergola 2000) was chosen as a base for GCP generation. A classical procedure for verification of sea-land separability hypothesis was taken (Furman 2002). There are two steps of the algorithm.

2.2.1 Step one: GCP optimal location computation

Land and sea brightness ($AVHRR_{land}$ and $AVHRR_{sea}$) is estimated preliminary. Three algorithms were tested and had similar effectiveness. The pixel brightness of template is the following:

$$\mathrm{RF}_{ch}(i,j) = AVHRR_{land} LSM(i,j) + AVHRR_{sea}[1 - LSM(i,j)] \quad (1),$$

where $LSM(i,j)$ - the sea/land mask (1 is for the land and 0 for other case), ch - channel number of the image (2 - visible channel, 4 - infrared). The criterion of the brightness discrepancy between template and image area is the following:

$$C(p,q) = \frac{\sum_{i,j}\{CM(i,j)[AVHRR_{ch}(i+p, j+q) - RF_{ch}(i,j)]^2\}}{\sum_{i,j} CM(i,j)} \quad (2),$$

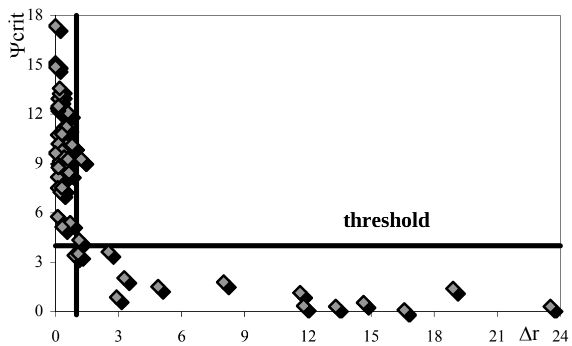
where p and q ∈ [-MER, MER], MER - maximal error of primary navigation (15 pixels), $CM(i,j)$ - cloudy mask for the reference area (0 - cloudy, 1- no). The optimal location estimation (p',q') is derived from minimization of function (2) by (p,q) with recalculation of $AVHRR_{land}$ and $AVHRR_{sea}$.

2.2.2 Step two: verification of sea-land separability hypothesis

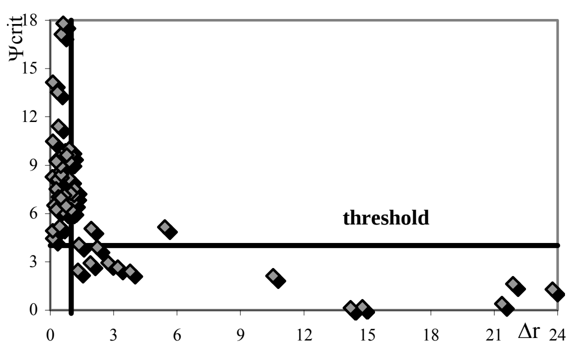
It was used a classical approach to verification, which is based on statistical significance calculation with the following parameter (Furman 2002):

$$\Psi_{\text{crit}} = \frac{\left| s_{land} - s_{sea} \right|}{\sqrt{(n_{land}-1)\sigma_{land}^2 + (n_{sea}-1)\sigma_{sea}^2}} \times \sqrt{\frac{n_{land} n_{sea} (n_{land} + n_{sea} - 2)}{n_{land} + n_{sea}}} \quad (3),$$

where s_{land} и s_{sea} - average brightness of the land and sea, σ_{land} и σ_{sea} - standard deviations and n_{land} и n_{sea} – pixel amount of land and sea of the area.



a)



b)

Figure 1. The dependence between Ψ_{crit} criterion and GCP accuracy Δr (distance between GCP location estimated automatically and manually one). a)-channel 2, b)-channel 4.

Ψ_{crit} is proportional to statistical significance and it was used for selection of "good" GCP navigated. Fig.1 shows the relation between Ψ_{crit} and navigation accuracy. Most of the points have accuracy 1 pixel or less, then Ψ_{crit} is bigger the value "threshold".

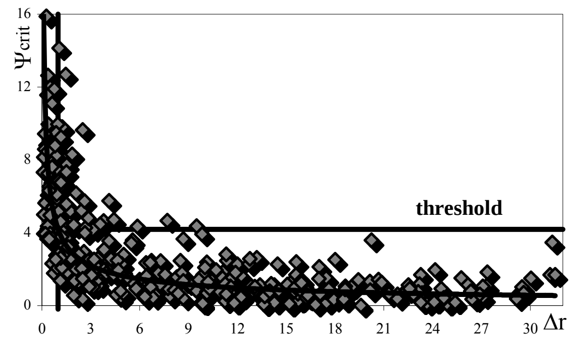


Figure 2. Dependence between Ψ_{crit} criterion and GCP accuracy Δr. Channel 4, no cloudy filtration.

It was taken an image set of north part of the Okhotsk sea on February-March of 2005 to estimate the limits of the algorithm, then weather conditions are complex. Significant amount of images had no GCP after cloudy and ice filtration. It was taken decision to refuse from any filtration and use Ψcrit only for "good" GCP selection. Fig. 2 shows the results of experiments. The accuracy decreased slightly and some amount of "wild" points appeared, but most points exceeded the threshold are good for automatic navigation. Thus, it is necessary to include "wild" point filtration procedure in the navigation algorithm.

3. IMAGE NAVIGATION RESULTS IN THE CASE OF GCP DEFINED MANUALLY

There are two approaches to image navigation when the radiometer motion is modeled. The first is to correct the satellite attitude (Brunel 2000, Rosborough 1994), the second is to correct the orbital parameters (Moreno 1993, Parada 2000). A method presented in this paper is based on the SGP4 orbital model, and both of these approaches were implemented and tested. In the first case the correction parameters are values of roll, pitch and yaw angles assumed to be a constant for a full image. In the second case the values of mean anomaly, mean motion, longitude of ascending node and inclination obtained from TLE bulletin are corrected. To compare these approaches, a manual GCP generation was used for 135 NOAA-12,15,17 images for time interval from 15 to 30 November, 2004. It is assumed that a manual procedure provides a subpixel error of GCP. After an attitude correction, the average module of GCP discrepancies (AMD) for the image set was 0.5 pixels and AMD maximum was 0.9. These values were 0.7 and 1.2 respectively after orbital parameter correction.

The analysis of the results has shows that the accuracy at the image edges may be significant after orbital parameter correction navigation. The attitude correction has shown small subpixel error. It can be explained that orbital parameter correction is able to compensate the image deformation induced by roll and pitch, can’t compensate the deformations caused by yaw.

The attitude correction doesn't provide a subpixel quality for a FY-1D imagery. In our experiments, AMD was above 2-3 pixels. FY-1D attitude isn't stable for one satellite pass.

4. AUTOMATIC NAVIGATION OF A SINGLE IMAGE.

Fig.3 shows the results of automatic navigation by the correction of attitude angles for winter season. 2σ criterion was used to separate "wild" points, where σ is a rms error of GCP locations. Near 10% of images have significant angle discrepancies (more 1 mrad) and one image have no GCP.

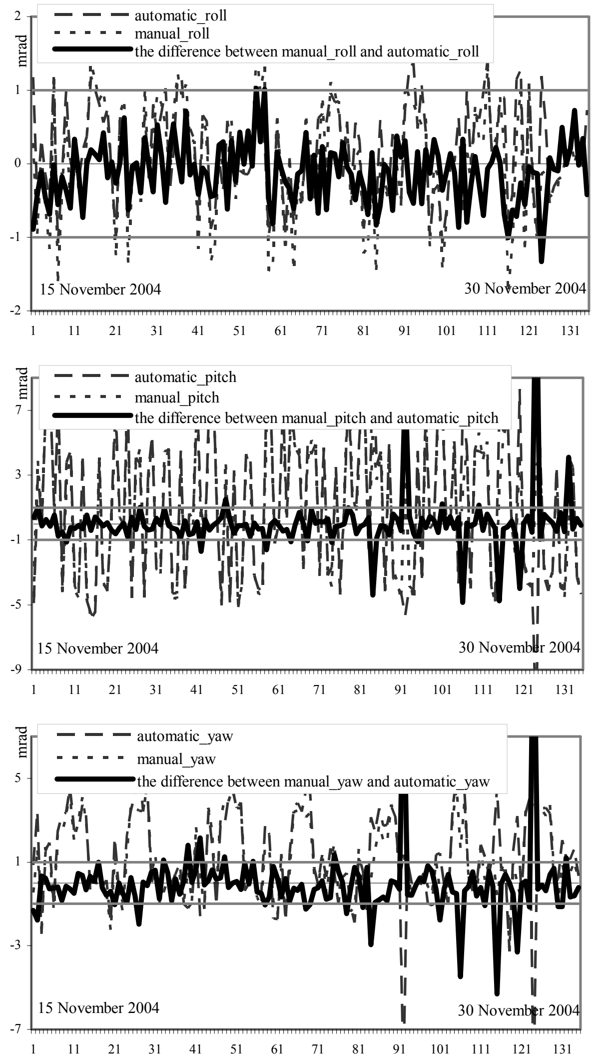


Figure 3. Comparison of roll, pitch and yaw estimations calculated automatically and manually for time interval November 15-30, 2004. 1 mrad is equivalent of 1 pixel accuracy.

Fig.4 shows average module of GCP discrepancies (AMD) of automatic and manual navigation procedures. Significant AMD was one time only. The analysis of this event has shown that it was satellite orbit correction during image reception. The figure does not explain significant angle discrepancies of fig.3. The number of GCP used for image navigation does not explain it too. Although 3% of images had less 5 GCP (10% had less 10 GCP), small amount GCP had no significant dependence on angle discrepancies.

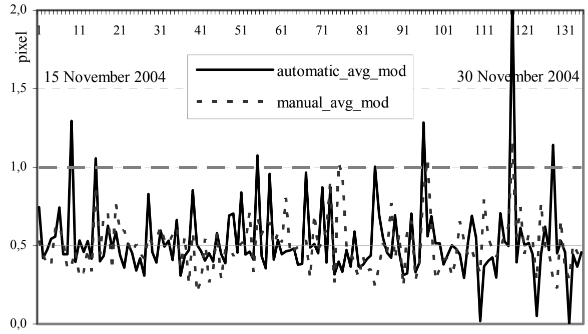


Figure 4. Average module of GCP discrepancies of automatic and manual navigation procedures.

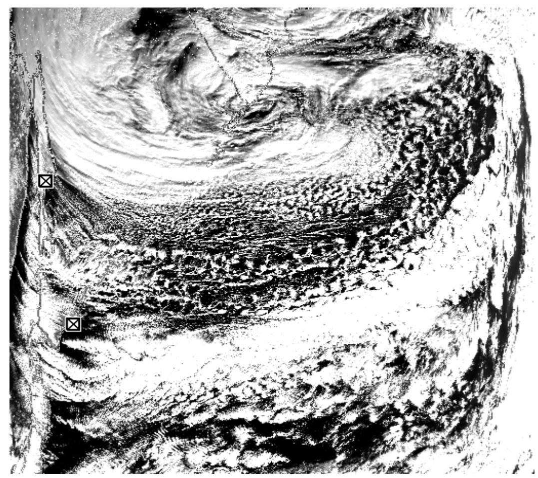


Figure 5. A sample of image (NOAA 17, November 29, charnel 2) when AMD was significant. ⊠ - GCP locations.

The analysis of significant angle discrepancies allowed to explain the phenomenon. Fig 5. shows the typical case, then all GCP allocated at the edge of the image. For quantitative estimation of this phenomenon the parameter "base by column" (BC) was calculated. BC is the ratio of maximum difference between GCP locations along the line direction (x coordinate) to the line length (2048 pixeles).

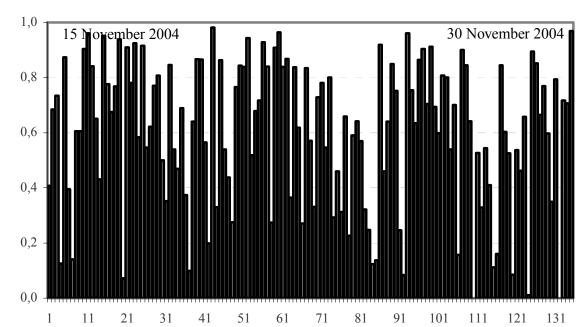


Figure 6. "Base by column" of GCP for 135 images for the time interval November 15-30, 2004.

All significant angle discrepancies were explained by low value of BC (0.4 and less). Thus, it is impossible to make accurate image navigation in Far-Eastern region for near 10% of images with attitude parameter correction nor automatically, nor manually.

5. SEVERAL IMAGE NAVIGATION SIMULTANEOUSLY. FORECASTING SCHEME.

Attitude parameters received for the images of satellite passes with numbers N-2, N-1, N+1, N+2 are recommended to use for image navigation of satellite pass N according to the paper (Brunel 2000). But the results of this approach are not described in details. We have tested this approach for NOAA-12 images. 18 pairs of images were used. Attitude angles of pass N-1 were used for pass N. Following results have been achieved. Average module of GCP discrepancies (AMD) for the set of images was 1.1 pixels, but two images had discrepancy more 2 pixels and maximum AMD was 2.9 pixels. Thus, the navigation errors are significant. It may be explained by inaccuracy of the telegrams, SGP4 model roughness and attitude angles variability.

By this reason the next experiment was devoted to SGP4 model verification for navigation purpose. Orbital parameter correction was made for pair images simultaneously. There were a set of two pair of images of satellite pass numbers N,N+6 and N+6,N+13 (time interval is in near 12 hours). Attitude parameters of image N+6 were calculated twice: for orbital parameters corrected by N,N+6 pair and by N+6,N+13 pair. Using different orbital parameters we had the same attitude angles with 1 pixel accuracy of the navigation. It may be considered as good accuracy of SGP4 model. And more, roll and pitch were stable and equal about 0, that may be explained by stability of these angles for 12 hours.

The last experiment was devoted to forecasting scheme of navigation parameter. The same data set was used in experiment, but the correction of orbital parameters was fulfilled by three images simultaneously (numbers N, N+1 and N+6). The parameters were used as orbital parameters of the image N+7. After this, the yaw angle was estimated for images of number N+6, which was used as yaw angle of the image N+7. The average error of N+6 image navigation of the data set (AMD) was 0.6 pixels and all images had navigation near 1 pixel. Thus, this approach can be used to navigate then GCP located at the edge of image. The forecasting accuracy was following. AMD for the data set was 1.1 and maximum of AMD was 1.7, i.e. all images had accuracy less 2 pixels. Thus the scheme of the forecast gives more accurate results, but need in more wide verification.

CONCLUSIONS

Verification of sea-land separability hypothesis for automatic ground control point generation can increase significantly the opportunity of image navigation under complex weather conditions of observation. Statistical significance criteria can be used for preliminary estimation of GCP quality generation.

Full FY-1D images cannot be navigated accurately by orbital and attitude parameter correction.

"Base by column" criterion may be used for the real navigation accuracy estimation. Its low value lead to necessity to use prediction scheme for accurate image navigation. A scheme based on consistent orbital and attitude parameter correction may be used for the problem solution.

REFERENCES

References from Journals

D. Baldwin and W. Emery. Spacecraft attitude variations of NOAA-11 inferred from AVHRR imagery // International Journal of Remote Sensing, 1995, Vol. 16, P. 531–548

P. Bordes, P. Brunel and A. Marsouin. Automatic adjustment of AVHRR navigation // Journal of Atmospheric and Oceanic technology, 1992, Vol. 9, P. 15–27

D. O'Brien and P. Turner. Navigation of coastal AVHRR images // International Journal of Remote Sensing, 1992, Vol. 13, No. 3, P. 509-514

P. Brunel and A. Marsouin. Operational AVHRR navigation results // International Journal of Remote Sensing, 2000, Vol. 21, No. 5, P. 951-972

M. Derrien, B. Farki, L. Harang, H. Legleau, A. Noyalet, D. Pochic and A. Sairouni. Automatic cloud detection applied to NOAA-11/AVHRR imagery. // Remote Sensing of Environment, 1993, Vol. 46, P. 246-267

A. Dybbroe, P. Brunel, A. Marsouin and A. Thoss. Accurate Real-time Navigation of AVHRR data at high latitudes // International TOVS Study Conference (ITSC), Vol. XII, Victoria, Australia, Feb. 28, 2002

F. Eugenio and F. Marques. Automatic satellite image georeferencing using a contour-matching approach // IEEE Transactions on Geoscience and Remote Sensing, Vol. 41, No. 12, December 2003, P. 2869-2880

Ya.A. Furman et al. Contour Analysis Introduction and its image and signal processing application // International Academic Publishing Company “Nauka” Russian Academy of Sciences, P. 273-282. / Moscow, 2002, 590 pages

H. Liu and J. McGregor. Automatic NOAA AVHRR image registration in mountains area // International Society for Photogrammetry and Remote Sensing (IAPRS), Vol. XXXIV, PART2, COMMISSION II, Xi’an, Aug. 20-23, 2002, P. 291-295

J. Moreno and J. Melia. A method for Accurate Geometric Correction of NOAA AVHRR HRPT Data // IEEE Transactions on Geoscience and Remote Sensing, Vol. 31, No. 1, January 1993, P. 204-226

M. Parada, A. Millan, A. Lobato and A. Hermosilla. Fast coastal algorithm for automatic geometric correction of AVHHR images // International Journal of Remote Sensing, 2000, Vol. 21, No. 11, P. 2307-2312

N. Pergola and V. Tramutoli. SANA: sub-pixel automatic navigation of AVHHR imagery // International Journal of Remote Sensing, 2000, Vol. 21, No. 12, P. 2519-2524

T. Purevdorj and R. Yokoyama. An approach to automatic detection of GCP for AVHRR imagery // Journal of the Japan Society of Photogrammetry and Remote Sensing, 2002, Vol. 41, No.1, P.56-65

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