Accurate and Automatic NOAA-AVHRR Image Navigation using a Global Contour Matching Approach

Francisco Eugenio[1], Ferran Marqués[2], Luis Gómez[3], Eduardo Suárez[1], and Eduardo Rovaris[1]

[1] Signal and Communications Department and [3] Electronic Department. University of Las Palmas of G.C.
[2] Signal Theory and Communications Department. Polytechnic University of Catalonia.
Campus Universitario de Tafira. Edificio de Electrónica y Telecomunicación
35017 Las Palmas de G.C., Spain
Tel: +34 928 452979; Fax: +34 928 451243
E-mail: feugenio@dsc.ulpgc.es

Abstract — The problem of precise and automatic AVHRR image navigation is tractable in theory, but has proved to be somewhat difficult in practice. Our work has been motivated by the need for a fully automatic and operational navigation system capable of geo-referencing NOAA-AVHRR images with high accuracy and without operator supervision. The proposed method is based on the simultaneous use of an orbital model and a contour matching approach. This last process, relying on an affine transformation model, is used to correct the errors caused by inaccuracies in orbit modeling, nonzero value for the spacecraft's roll, pitch and yaw, errors due to inaccuracies in the satellite positioning and failures in the satellite internal clock. The automatic global contour matching process is summarized as follows: i) Estimation of the gradient energy map (edges) in the sensed image and detection of the cloudless (reliable) areas in this map. ii) Initialization of the affine model parameters by minimizing the Euclidean distance between the reference and sensed images objects. iii) Simultaneous optimization of all reference image contours on the sensed image by energy minimization in the domain of the global transformation parameters. The process is iterated in a hierarchical way, reducing the parameter searching space at each iteration. The proposed image navigation algorithm has proved to be capable of geo-referencing a satellite image within 1 pixel.

1. INTRODUCTION

Images acquired by NOAA AVHRR satellites are subjected to different distortions due to the Earth's curvature and rotation, the spacecraft's speed, altitude and attitude, and the scan skew. These distortions, if not properly accounted for, will prevent meaningful comparison among images, particularly in sequential image analysis or multisatellite data studies. Image navigation is the process of performing the dual function of correcting the sensed image and transforming it into a known geographic reference map (called reference image).

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A good overview of existing methods of AVHRR image navigation is given by [4] and [6]. In these references, several models of varying complexity can be found. Failures in the satellite's internal clock, lack of knowledge concerning the attitude angles and inaccuracies in Kepplerian orbital elements give rise to the fact that even the most complex models do not offer the desired accuracy of errors of less than one pixel. In order to achieve this accuracy, Ground Control Points (GCPs) need to be used, as in [8], [9].

Manual selection of ground control points has been used, commonly, in practical applications. Obtaining a large number of GCPs across the whole sensed image is a very tedious, labour-intensive, and repetitive work. Moreover, it is subject to inconsistency problems, limited accuracy, and, in many instances, lack of availability of GCPs due to partial or total occlusions. Therefore, there is a critical need to develop automated techniques which require little or no operator intervention to navigate multitemporal and/or multisensor images when higher accuracy is desired. The automatization by area-based methods has been used in NOAA-AVHRR image navigation [2]. In area-based methods, a small window of points in the reference image is statistically compared with windows of the same site in the sensed image. The measure of similarity is usually the normalized cross correlation. However, the correlation measures become unreliable when images have multiple partial or total occlusions and their grey-level characteristics vary (e.g., day-time and night-time NOAA AVHRR data).

In contrast, feature-based methods are more robust and more suitable in these cases. There are two critical processes generally involved in the feature-based techniques [3], [7]: feature extraction and feature correspondence. This paper proposes a new feature-based approach to automated navigation of remotely sensed images. It uses a global contour matching that provides a basis for relocating AVHRR image pixels, which are first navigated, approximately, using a simple orbital model. The critical elements for an automated image navigation procedure are explored. These elements include feature extraction, contour initialization, and simultaneous optimization of all the reference image contours on the sensed image. Finally, the sensed image is re-navigated by the coefficients of the mapping functions.

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2. THE CONTOUR MATCHING ALGORITHM

The contours overlay that are obtained after processing the geographical data available at the CIA World Data Base I [1] are used as reference contours in the minimization process (reference image). The automatic global contour matching procedure is described in the subsequent sections.

2.1 Feature Extraction

Feature extraction is carried out in two steps. First, the sensed image $I(x,y)$ is convolved with a Sobel operator and the edges are detected. The Sobel operator is decomposed in two separable filters to speed up its computation. Detected edges are used to define a gradient energy map as follows,

$$S(x,y) = -|\overline{\nabla I(x,y)}|^2 \quad (1)$$

where $\overline{\nabla I}$ is the gradient intensity normalized to [0,1]. Since this edge detector used, unlike the Laplacian of the Gaussian operator or the Canny detector, does not include a Gaussian smoothing operation, it is appropriate to incorporate this feature into the gradient energy map. This facilitates the convergence to a better local minimum (contours to higher image gradients). The modified gradient energy map is defined by a 2-D convolution,

$$E_{edge} = S(x,y) * G(x,y) \quad (2)$$

where $G(x,y)$ is a 2-D Gaussian function and $S(x,y)$ is the gradient energy map as defined in (1).

In the second step, a cloudy overlay is obtained by a multi-band threshold method. Reliable areas (sea-land contours), to which reference image contours will be allowed to match, are obtained by means of this cloudy overlay and applying a morphological gradient to the cloud-sea and the cloud-land contours (non-reliable areas). Fig.1 shows the smoothed energy map gradient of reliable areas extracted from the image in Fig.2.

2.2 Contour Initialization

If an initial boundary is placed too far from the solution boundary, the contour might converge to an undesirable position. We propose an automatic initialization process for satellite images, based on the minimization of the Euclidean distance between the centres of gravity of closed boundaries in the reference image and the corresponding objects in the sensed image, the latter ones obtained by segmentation. Sensed image segmentation for the purpose of computing objects centroids is an important step in feature-based initialization system. There is no unique segmentation technique that can perform best in all types of images, and most segmentation techniques are image dependent [3]. In this paper, we use a non-spatial iterative threshold selection technique [5]. Once the objects are labelled in the reference and segmented images, by a sequential algorithm, we perform a local consistency test between images objects, using a look-up table that associate contours features (areas, centroids, open/closed contours) of the two images.

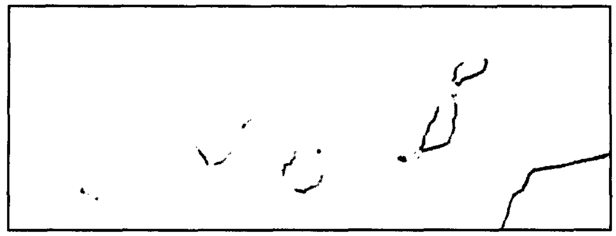

Fig. 1. Smoothed gradient energy map of reliable areas from the sensed image.

2.3 Contour Matching

The global contour matching approach is based on the simultaneous optimization of all the reference image contours on the energy map gradients of the sensed image. Energy is minimized in the domain of the global transformation parameters. It is often assumed that the relationship between sensed image, obtained from orbital model, and reference image can be expressed by a 2-D affine transform [4] [6], since the systematic errors has previously been compensated by the orbital model. We consider a three-step procedure:

(i) *Initialization of the affine transformation parameters and definition of the search space*: based on the initial matched contours, we use the mean distance between their corresponding centres of gravity as an initial guess of a first-order bivariate polynomial transformation, that in vector-matrix form is,

$$\begin{bmatrix} X_I \\ Y_I \end{bmatrix} = \begin{pmatrix} A_X & B_X \\ A_Y & B_Y \end{pmatrix} \cdot \begin{bmatrix} X_o \\ Y_o \end{bmatrix} + \begin{pmatrix} C_X \\ C_Y \end{pmatrix} \quad (3)$$

For each affine transformation parameter (3) $\{A_X, B_X, C_X, A_Y, B_Y, C_Y\}$, we define a vector which represents the search space for global minimization process.

(ii) *Multidimensional global search by optimization algorithm*: based on the transformed contour image and working in the domain of the affine transformation parameters, a new global contour location can be detected examining the following condition:

$$E_{global}^{(k)} = \sum_{i=1}^{m} E_{contour_i}^{(k)} = \sum_{i=1}^{m}\sum_{j=1}^{n_i} e(v_{ij}^{(k)}) < E_{global}^{(k-1)} \quad (4)$$

where m is the set of contours, n_i is number of points of each contour and $e(\cdot)$ is the energy of the *j-th* point of the contour after the *k-th* iteration. At each iteration, the affine parameters are obtained and the contours are updated to its new position:

$$x^{(k)} = \left[A_X^{(k)} \cdot A_X^{(k-1)} + B_X^{(k)} \cdot A_Y^{(k-1)}\right] x^{(k-1)} + \left[A_X^{(k)} \cdot B_X^{(k-1)} + B_X^{(k)} \cdot B_Y^{(k-1)}\right] y^{(k-1)} + A_X^{(k)} \cdot C_X^{(k-1)} + B_X^{(k)} \cdot C_Y^{(k-1)} + C_X^{(k)} \quad (5)$$

$$y^{(k)} = \left[A_Y^{(k)} \cdot A_X^{(k-1)} + B_Y^{(k)} \cdot A_Y^{(k-1)}\right] x^{(k-1)} + \left[A_Y^{(k)} \cdot B_X^{(k-1)} + B_Y^{(k)} \cdot B_Y^{(k-1)}\right] y^{(k-1)} + A_Y^{(k)} \cdot C_X^{(k-1)} + B_Y^{(k)} \cdot C_Y^{(k-1)} + C_Y^{(k)}$$

The process is iterated in a hierarchical way and when $E^{(k+1)}_{global} = E^{(k)}_{global}$, the contours have not found a position with less energy and so the process ends. A heuristic algorithm of global multidimensional search is used to perform the search of the new contour positions. To further accelerate the contours convergence and to save computational cost, we have adopted two strategies:

- Search by grouping affine transformation parameters.
- Reduction of the parameters searching space at each iteration.

(iii) *Re-mapping of the whole image*: Knowing the mapping function (5), the sensed image is transformed and resampled using nearest neighbor interpolation.

3. RESULTS

We have developed a user-interface for contour matching, in order to test different types of satellite images. The interface has been designed to be user friendly, easy to learn and to make easier the work of future users. The proposed algorithm has been tested in a large set of satellite images. Table 1 shows the results obtained in a subset of four NOAA 14-AVHRR images representing ascending and descending paths as well as different sub-satellites position. In Table 1, the captured data and the initial/final energy obtained in the minimization energy process are presented. We have used several GCPs for testing the accuracy obtaining errors within one pixel.

An example of a NOAA 14-AVHRR geo-referenced image is shown in Fig. 2, presenting Sea Surface Temperature (SST) data from an ascending pass taken on January 18, 1998 at 15:16:20 UTC. The image is 237*629 pixels and it depicts Canary Islands and NW Coast of Africa. In Fig.2, the correspondence between the reference and sensed images shows that the georeferencing, obtained by our algorithm is accurate to within a pixel error, for cloudless as well as for occluded zones.

Table 1. Results of NOAA-AVHRR image geo-referencing for four test cases.

Image Orbit number	**Trajectory Offset Nadir**	**Energy Initial/Final**	**N° GCPs**	**R.M.S.**
18 July 1997 13138	S/N 6.55°	- 0.016152 - 0.048656	10	**X** 0.95 **Y** 0.89
18 January 1998 15727	S/N -9.63°	- 0.004202 - 0.011672	6	**X** 0.71 **Y** 0.82
3 July 1999 23227	S/N -35.27°	- 0.022601 - 0.065913	12	**X** 0.95 **Y** 0.91
1 January 2000 25788	N/S -17.15°	- 0.033961 - 0.126707	9	**X** 0.66 **Y** 0.88
	R.M.S. Error Average			**X** 0.82 **Y** 0.88

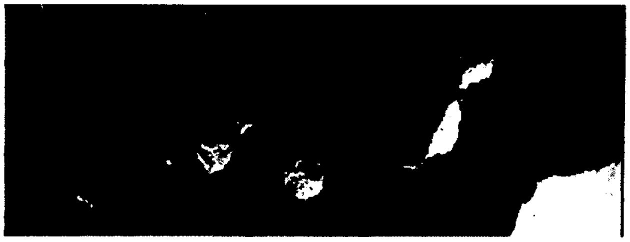

Fig. 2. Results of global contour matching approach applied to the NOAA14 -AVHRR image of 18 January 1998.

4. CONCLUSION

Experimental results using NOAA 14-AVHRR images from different dates and geographic areas have verified the robustness and accuracy of the proposed algorithm, demonstrating to be capable of geo-referencing satellite images within one pixel. We conclude that this type of algorithms is adequate for automatic navigating satellite images, even when they have partial or total occlusions and obtaining GCPs is very difficult or impossible. The method developed is generic and can be adapted to the registration of any multispectral and multisensor images.

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