Lab 45

CONCEPT FOR THE AUTOMATIC REGISTRATION OF SATELLITE IMAGES WITH A DIGITAL MAP DATA BASE [1)]

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BIOGRAPHICAL SKETCHES

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ABSTRACT

This paper describes the concept for a computer program system to automatically register digital satellite images to a digital cartographic data bank. A specific organization of this data bank is required. Programming for this system is under way.

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1. INTRODUCTION

The existence and use of a digital map data base depends on efficient means to update its contents. Digital satellite images could be used as one source of data for small scale maps, provided they can be efficiently related to the digital map. The computer compatible format of the data has caused us to start an investigation of the automatic registration of a digital satellite image with a map data bank (ARSIM), aiming at the development of an efficient computer program system for this task.

There exists a wealth of literature on the automatic registration of pairs of digital images (Anuta, 1970; Barnea and Silverman, 1972) and on digital map data banks (Cook, 1974). However, efforts dealing with the particular problem at hand are scarce. One development using aerial photography has been reported by Sties et al (1977). Most studies on up-dating of digital maps have been based on essentially manual registration of an image to the map (or vice-versa) and subsequent transfer of data to the digital map base (Masry and McLaren, 1977).

Based on a survey of literature on image registration, on digital line detection and on structural pattern recognition we have developed the concept for a computer program system for ARSIM. This system will be basically modular so that additional features can be added, and it will have a learning capability so that accumulated experiences can improve its performance.

Chapter 2 presents an overall view of the proposed system and the subsequent chapters treat its various elements. The entire system will be based on a digital image processing system called DIDAK which was developed for a general purpose computer environment at the University of Karlsruhe (Wiesel, 1977).

2. GENERAL SYSTEM DESCRIPTION

Figure 1 presents the general flow of operations for ARSIM. We have to start from a digital map base that is available in a format compatible with the image processing system DIDAK, which contains the satellite image to be registered.

Each pixel of a digital satellite image can be located in a map projection with a certain positional accuracy. For LANDSAT, maximum errors have been demonstrated to amount to not more than 5 km (Colvocoresses et al., 1973). Data used to achieve this accuracy are the satellite position and attitude values delivered with each image.

Following Nack (1975) we define in the digital image a square (rectangular) Area of Interest (AI) that is being processed at any given time. Using the map locations of the corner points of AI we define the corresponding map window (MW). In order to contain all of AI, the window has to be larger than AI due to the limited positional accuracy (compare Figure 2).

Features within MW are now sorted according to their probability of being identifiable in the satellite image. This probability can be (automatically)adjusted as the result of previous experiences. Consequently, the procedure has a learning capability. The most probable feature within MW is selected and a search begins in the image-AI to find the corresponding detail. The search is completed if a measure of similarity surpasses a preset treshold.

Next the identity of the map and image feature have to be verified by a comparison of neighbourhoods. This verification employs the structural information in the surroundings of a feature, thereby checking the compatibility of the partial "map-graph" with the representation of the partial "image graph" around the feature.

A last step is the search for a singularity of the feature so that a unique homologue pair of coordinates can be identified in both the image and the map.

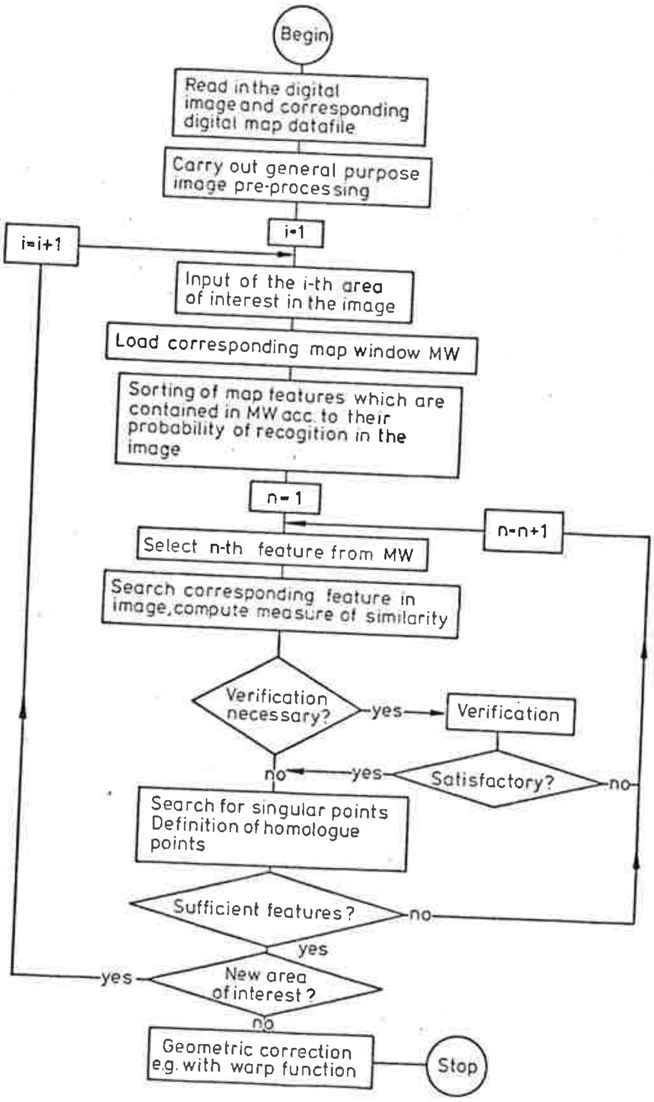

Figure 1: Flow-diagram of the operation of ARSIM (Automatic Registration of Satellite Images and Maps).

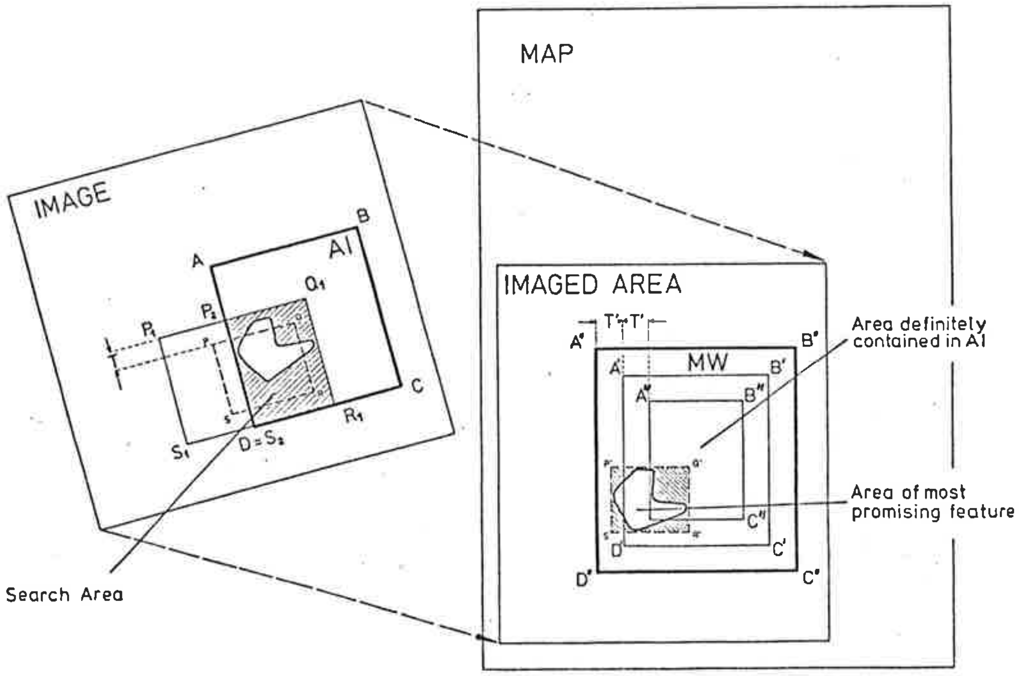

Figure 2: Search areas for ARSIM in the image und map. For explanation of the sequential searches compare Table 1. Distance T (and T') serve to account for the geometric errors of the satellite image.

(1)	A B C D $\in$ Image	$\longrightarrow$	A' B' C' D' $\in$ Map
(2)	A'B'C'D' + ε'	$\longrightarrow$	A" B" C" D" = Map Window MW
(3)	A'B'C'D' − ε'	$\longrightarrow$	A''' B''' C''' D''' $\in$ Map
(4)	Feature sorting	$\longrightarrow$	P' Q' R' S' $\in$ Map
(5)	P'Q'R'S' $\in$ Map	$\longrightarrow$	P Q R S $\in$ Image
(6)	P Q R S + ε''	$\longrightarrow$	P Q R S $\in$ Image
(7)	P Q R S $\cap$ ABCD	$\longrightarrow$	P Q R S $\subset$ Image: Search Area

Table 1: ARSIM - search areas as described in Figure 2.
ε' ... Region in map added to compensate for geometric incertidute; ε'' ... as ε', gut in the image.
ε', ε'' relates to distance T (T') of Figure 2.

The process continues with (a) either the search for another feature in the same AI and MW, or (b) it chooses another AI to add new homologue pairs of features in different parts of the image to improve the geometric relation between image and map. A sufficiently dense network of homologue features then permits the computational geometric transformation of the image into the map system or vice versa.

3. A DIGITAL MAP IN AN IMAGE PROCESSING SYSTEM

We have considered the possibility to convert the digitized map contents into the form of a binary image and to derive also a binary edge image from the satellite data. One then could apply the procedure of Nack (1975) to cross-correlate image and map. However, we soon convinced ourselves that this approach would only use a small fraction of the information contained in a map and also would provide unsatisfactory results due to the considerable differences that usually exist in a binary edge image and a map of the same region.

We therefore concluded that we should not only use the positional (geometric) information of the map but also its qualitative ("semantic" or topological) aspects. We have thus come up with a map data base that is designed for compatibility with a digital image processing system and digital images.

The image processing system contains a directory with pointers to the various images. According to Figure 3 this directory in turn has for each map one map-description:

MAP: = (Regionlist, line-list, structure, general information).

Region-list is a sorted list of descriptions of the different regions in the map; similary, the line-list contains a sorted list of descriptions of the different lines. Structure is a multi-list data structure in the form of a planar graph. Additonal information such as the type of map, its format, date of plotting etc. are contained in the general information.

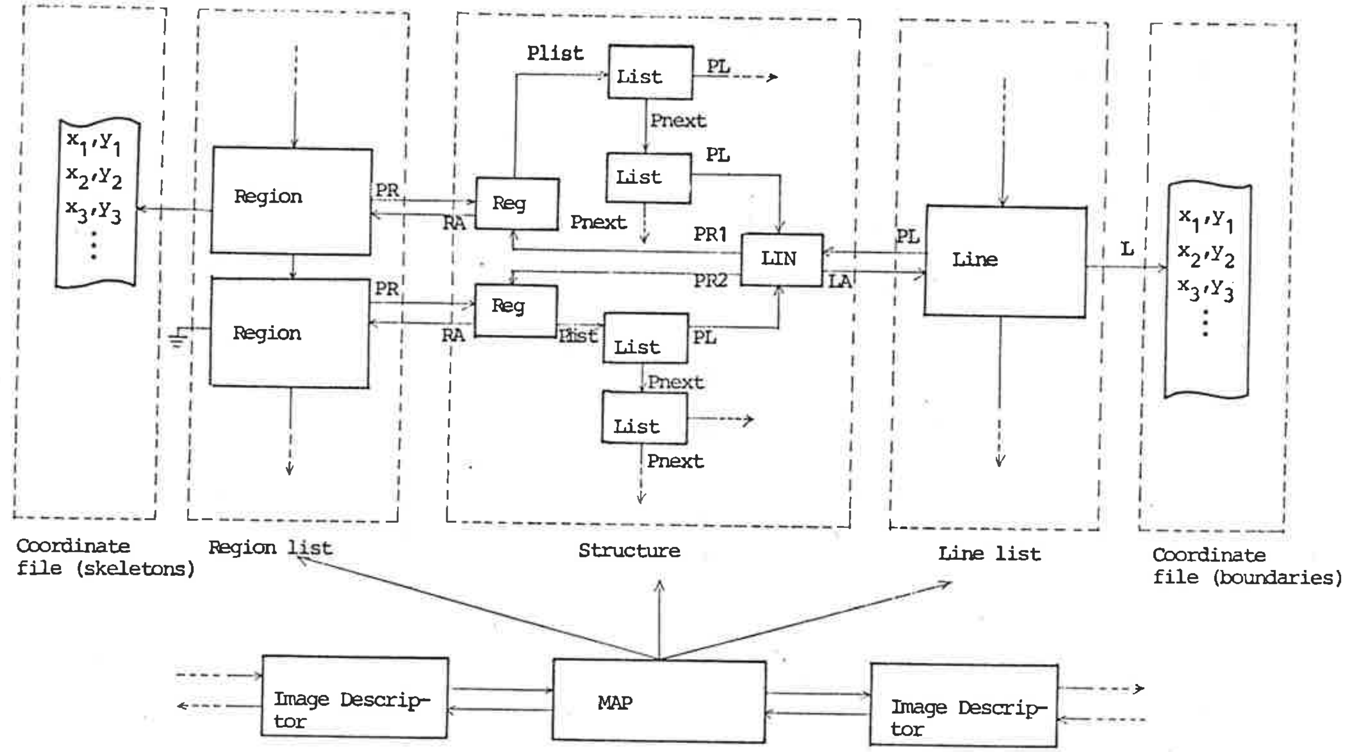

Figure 3: Organisation of a digital cartographic map data bank for ARSIM.
"Structure" represents graph of map contents.

For each region and line we plan to have the following information:

REGION: = (Region address RA, window, name or number, region type, pointer PR to structure, statistical measures depending on the type of region)

LINE: = (Line-address LA, window, name or number, line type, pointer PL to structure, starting point, end point, pointer L to the list of coordinates, statistical measures depending on the line type).

STRUCTURE: = (REG, LIN, LIST)

with

REG: = (PR-address, pointer RA to REGION, pointer PLIST to LIST)

LIN: = (PL-address, pointer LA to LINE, pointer PR 1 to REG, pointer PR 2 to REG)

LIST:= (LIST-address, pointer PL to line LIN, pointer PNEXT to LIST)

A particular characteristic of the digital map format consists of the separation of features in "regions" and "lines" that relate through a "structure". The borders of a region consist of one or more lines. For improved efficiency in subsequent searching processes we introduce together with each feature a "window"; this is a rectangular region containing the feature.

This map data base contains in addition to geometric information - in the form of coordinates lists - also descriptive information, e.g. on the type of region or line, its statistical measures (curvature, colour, variation in grey tones, texture etc.). It promises flexibility and added capabilities beyond those from a mere coded list of coordinates.

4. RECOGNITION OF PATTERNS (FEATURES) IN DIGITAL IMAGES

Step 3 of Figure 1 presents us with a list of map features likely to be identifiable in the image. The map features are selected by intersecting the rectangular window surrounding each feature with the map window MW. We face now the task of finding in the image a pattern or feature that pertains to the chosen map feature.

There exists a variety of pattern recognition methods developed in the area of artificial intelligence. In the present context we plan to concern ourselves with only some essential few. We intend, however, to preserve an option of adding more routines in the form of additional modules as experience accumulates.

Essentially we have to differentiate between (a) regions or areal features and (b) linear features. We will initially deal with three main processes for region analysis and one for line detection.

4.1 Region Detection

(a) The simplest method for assembling the pixels x_i belonging to a region R is by tresholding. We assume that the map feature provides information on its gray-scale or colour-scale limits in the satellite image. We now search either in parallel or in the entire image area that corresponds to the feature window derived from the map. Or we operate sequentially as in the method of "region growing" (Pratt, 1978). These operations are particularly suited to the search for areas of open water (lakes, coast line).

The result will be a simply-connected set M of picture points. The border line of the region has now to be identified, e.g. using an algorithm of Rosenfeld (1970). This border is the feature which in the next step is used to provide information on the geometric correction of the image (its registration).

(b) A somewhat refined method for the search of the region is obtained if we think of the gray values of an image as a digital

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4.2 Line Detection

Although linear features (rivers, roads...) could be considered to be "regions", we deal with them separately. We may now directly search for lines, using a sequential line detection algorithm and then compute a measure of correlation or similarity with the map feature.

Line detection may be achieved by appropriate skeletonizing of an image feature, using a skinning algorithm by Rosenfeld and Davis (1975). Generally we may not need to apply the analogue procedure to the map feature, provided it already is presented in a linear format. Correlation of homologue line features may follow the traditional lines of calculating a measure of similarity (Barnea and Silverman, 1971; Anuta, 1977). The equivalence of the two features may also be verified using character recognition techniques.

4.3 General Comments

Region and line detection may work in the chosen AI of the image, or on a preprocessed version of it. Acc. to Kelly (1971) it may be valuable to use a "planning procedure" by first reducing the AI to a smaller auxiliary image S. This would reduce image noise, storage requirements, improve speed and eliminate (small) patterns of little importance. We thus search for dominant features in S and then, given S, extend the search onto the original AI.

5. ASSIGNMENT OF HOMOLOGUE COORDINATES

After successful termination of the search of corresponding patterns of features we face the problem of assigning a unique pair of coordinates to a singular pixel in the image and its counterpart in the map. For this we may again have to resort to one of several algorithms. At this point we only consider the search for a singular point on the region border or line (discontinuity of the tangent) that has to be found in both image and map. It may also be the center of gravity of an extended region that has no height model (DHM). We then use a plane that is fit to the gray values of the image. All simply connecting points $P \in B$ with gray values within a certain limit ε off the adjusting plane E belong to the region, where:

plane E: $z(x,y) = ax + by + c$ a,b,c ...parameters
pixel p : $p = (x,y,z)$
Distance d: $d(p,E) < \varepsilon$

where d may be computed as follows:

$$d_1(p,E) = ax + by + c - z$$

or

$$d_2(p,E) = |ax + by + c - z| \;/\; \sqrt{a^2 + b^2 + 1}$$

(c) Another method is to start with the contour (border) of a region as given in the map. The map-coordinates are transformed to corresponding pixel numbers. The grey values of the estimated pixels can be used

- to compute a correlation measure and
- to correct the estimated contours in the image.

One may propose several solutions to both these tasks. A correlation measure may be obtained using a histogram over the picture region, the standard deviation is taken as the correlation measure.

The contour lines are corrected by elimination of picture points in the region next to contours and having a low frequency of occurrence in the histogram. Similarly one may add points which are outside the region but next to the contour, having a grey tone that has high frequency on the histogram.

A similar approach may be based on a plane fitted to the grey values and using deviations from that plane.

singular border points, or it may derive from a correlation of the two regions or lines to determine the required shift and rotation for optimum registration.

6. CONCLUSION

The task of registering an image with a digital map base is completed when the image- und map-coordinates of a number of homologue features are known. The actual transformation of the image is a matter of routine resampling using some sort of interpolation scheme and employing the image deformations encountered in the identified features. Since we deal with satellite images, we can justify the fact that we do not at this point consider effects of terrain relief. However, there is no doubt that this consideration could easily be implemented if it is found to be significant.

Presently we are in the process of programming for ARSIM. We plan to investigate a series of questions once the system is available. Among these questions are those concerning the optimum form of digital map data bases for the task, the optimum strategy for selecting the size of AI and MW, the most significant pattern recognition routines, the best choice of their parameters etc.

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