Automatic Image to Map Registration Based on Genetic Algorithm

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Abstract: -This paper, introduces a novel multiresolution method for automatic image registration with respect to image-to-object spaces based on key features consideration. The present approach is designed to be completely independent from the sensor type and any prior information on the exterior orientation. Moreover, in the proposed procedure, Genetic algorithm (GA) is used to match the corresponding features and fit the satellite image on the vector map by optimizing the transformation accuracy on checked and control points. The potential of the proposed method is evaluated using IKONOS imagery and corresponding digital vector map. During the time lapse between the generated map and image acquisition, considerable changes have also occurred in the city. This method has proved to be very efficient and reliable for automatic registration of satellite imageries based on digital maps.

Key-Words: - Automatic Registration, Satellite Imagery, Digital Maps, Genetic Algorithm, Multiresolution

1 Introduction

With the ever increasing number of remote sensing satellites, advances in data fusion and the functionality of modern geographic information systems, the use of multi-image spatial information products is swiftly becoming commonplace. However, in order to meet the requirements of the user, each individual image making up the multi-image product needs to be expressed in the same geometric reference frame. This means the images have to be accurately registered to geodetic co-ordinate system (e.g. maps).

Although, manual registration of satellite imagery is well established, the procedure can lead to inaccurate results, and can be slow to execute, especially if a large number of images need to be registered. The subject of automatic image registration addresses, and in many cases solves, the problems associated with manual image registration. However, there still exist a number of scenarios where automatic image registration is not well developed and robust paradigms have not been established for image to map registration [5, 10, 15].

This paper, introduces a novel multi-resolution method for automatic image to map registration based on key point features consideration. Polynomial transformation was mentioned as a major tool for transforming all tie points from image space to object space.

2 proposed methodology

The overall strategy for our proposed registration method may be expressed by the following interrelated three phases (Figure 1):

1- Multi-resolution Representation
2- Feature Extraction
3- Image to Map Registration.

In the following, the main components of the each phase will be described with more detail.

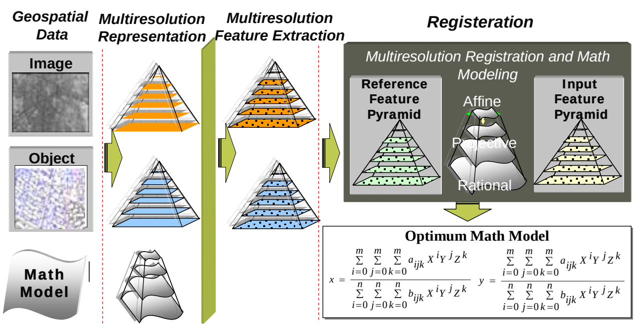


Fig. 1: proposed automatic registration method

2.1 Multiresolution Representation

The main requirements needed for most of registration algorithms is approximate values of two corresponding points which is related to the interrelation mathematical model of images and object (i.e. digital map). The best known solution to derive these approximations is to construct multi-resolution representation of information and start the matching process at a low resolution level (i.e. from the top of the image and object pyramids). This can provide rough approximate values for the successive levels of image pyramids.

2.1.1 Multiresolution Representation of Image Space

Construction of image pyramids in this project is carried out according to wavelet transform. The wavelet transform features are used because wavelet transforms convey both space and time characteristics and their multi-resolution representations enable efficient hierarchical searching [3, 4].

2.1.2 Multiresolution Representation of Object Space

Multiresolution representation of object space refers to the generation of abstract features from a rich spatial database. There are no standard definitions for multiresolution representation of vector maps, and each researcher has defined them based on his/her perspectives or application area [2].

In our project, the purpose of multiresolution representation is to produce a good map, balancing the requirements of accuracy, information content and legibility referring to the corresponding satellite imagery. It encompasses the modification of the information in such way that it can be represented on a smaller surface, retaining the geometrical and descriptive characteristics.

In proposed method, construction of object pyramids, involves three stages of Partition of map objects, Mesh simplification and Polygon merging. In the first step, the vector map is separated to the polygon classes by the major and minor roads network. Mesh simplification principles are used to construct vector pyramid levels for reasons of combination and simplification of polygons. In order to merge polygons (third step), neighbouring polygons can be found in the data set by Delaunay algorithm. In this step, by checking the bounding of the polygons, neighbouring objects with or with out common edges are detected and merged.

2.1.3 Multiresolution Representation of Mathematical Models

Successful exploitation of the high accuracy potential of satellite imageries depends on the ability of the mathematical models for the sensor modeling. Mathematical modeling approaches for orientation and registration of imageries and corresponding objects have been investigated by different research groups [6, 9, 13, 16]. The presented formulations conceptually can be divided into two main groups: *Rigorous Sensor Models* (RSMs) and *Generic Sensor Models* (GSMs).

RSMs reconstruct the spatial relations between remotely sensed imagery and the ground scene based on using conventional colinearity equations. The method is highly suited to frame type sensors and non-linear effects caused by lens distortion, film distortion or atmospheric effects are dealt with by additional parameters or by corrections after the linear transformation. Such image-specific parameters often include the approximate sensor position coordinates and sensor attitude angles at the time of image collection. As RSMs basically are non linear models, the linearization and the requirement for the good knowledge of the initial values of the unknowns are inevitable. Nevertheless, most of high resolution satellite vendors (e.g. Space Imaging) do not intend to present their sensor ephemeris data. There is consequently a need for a range of alternative practical approaches in the conditions that we could not easily apply the RSMs.

GSMs are presented as a sophisticated solution for overcoming the RSMs limitations. Although GSMs have been adopted a decade ago [7, 14], the attempts to study both theoretical properties and empirical experimental results have started to appear only recently and are still seldom reported. Tao and Hu [16] proposed an iterative least squares solution method to a GSM. The numerical properties and important practical issues on these models, including stability, accuracy of the solution, and the required number and distribution of ground control points (GCPs), are investigated by tests using various data sets, including simulated data, aerial photogrammetry data as well as SPOT data [16].

Most of high resolution satellite vendors (e.g. Space Imaging) do not intend to present their sensor models and precise ephemeris data. This means that a large number of parameters are unknown, and will not be able to be determined from the imagery alone. So, in this study the tests are conducted based on a multi-resolution representation of GSMs mathematical models, i.e. Rational functions in the form of: Direct Linear Transformation (DLT), 2D Projective, and 3D affine models.

Rational Functions use a ratio of two polynomial functions to compute the x coordinate in the image, and a similar ratio to compute the y coordinate in the image.

$$x = \frac{p1(X,Y,Z)}{p2(X,Y,Z)} = \frac{\sum_{i=0}^{m_1}\sum_{j=0}^{m_2}\sum_{k=0}^{m_3} a_{ijk} X^i Y^j Z^k}{\sum_{i=0}^{n_1}\sum_{j=0}^{n_2}\sum_{k=0}^{n_3} b_{ijk} X^i Y^j Z^k} \quad (1)$$

$$y = \frac{p3(X,Y,Z)}{p4(X,Y,Z)} = \frac{\sum_{i=0}^{m_1}\sum_{j=0}^{m_2}\sum_{k=0}^{m_3} c_{ijk} X^i Y^j Z^k}{\sum_{i=0}^{n_1}\sum_{j=0}^{n_2}\sum_{k=0}^{n_3} d_{ijk} X^i Y^j Z^k}$$

where x, y are normalized pixel coordinates in the image space; X, Y, Z are normalized 3D coordinates on the object space, and a_{ijk}, b_{ijk}, c_{ijk}, d_{ijk} are polynomial coefficients. The polynomial coefficients are called rational function coefficients (RFCs).

2.2 Feature Extraction

By construction the multi-resolution representation of image and object, key points are extracted from both of image and objects in all of pyramid levels.

2.2.1 Feature Extraction in Image Space

Based on the generated image pyramids, the implemented system extracts and constructs feature pyramids by applying a modified Moravec operator (Eq. 2) to each layer of the image pyramids [5].

$$i_p = i + \frac{\sum_{k=1}^{M-1}\sum_{i=1}^{N} g_2'^2(k,l)(k+\frac{1}{2}) + \frac{1}{2}\sum_{k=1}^{M-1}\sum_{i=1}^{N-1}\left[g_3'^2(k,l) + g_4'^2(k,l)\right](k+\frac{1}{2})}{\sum_{k=1}^{M-1}\sum_{i=1}^{N} g_2'^2(k,l) + \frac{1}{2}\sum_{k=1}^{M-1}\sum_{i=1}^{N-1}\left[g_3'^2(k,l) + g_4'^2(k,l)\right]} \quad (2)$$

$$j_p = j + \frac{\sum_{k=1}^{M-1}\sum_{i=1}^{N} g_1'^2(k,l)(k+\frac{1}{2}) + \frac{1}{2}\sum_{k=1}^{M-1}\sum_{i=1}^{N-1}\left[g_3'^2(k,l) + g_4'^2(k,l)\right](k+\frac{1}{2})}{\sum_{k=1}^{M-1}\sum_{i=1}^{N} g_1'^2(k,l) + \frac{1}{2}\sum_{k=1}^{M-1}\sum_{i=1}^{N-1}\left[g_3'^2(k,l) + g_4'^2(k,l)\right]}$$

where $g(i,j)$ denote the mean values of squared grey value differences along the horizontal, vertical, and two diagonal directions over a window of the size $M \times N$, i_p and j_p denote the coordinates of the centre of features.

In addition to point features the Moravec operator is also modified to detect corners, intersections and centres of gravity. The constructed feature pyramids therefore include the feature attributes. These attributes will greatly contribute to the Genetic algorithm as described in section 2.3.1.

2.2.2 Feature Extraction in Object Space

Referring to the vector structure of digital maps, basically it is just need to identify the proper key nods of line intersections or polygons vertexes with a threshold for extraction of key nods.

2.3 Image to Map Registration

By construction of image and feature pyramids, in this stage, for each feature in the feature pyramid of image, based on corresponding mathematical model, a search area is constructed on the corresponding feature pyramid of digital map. Now to identify the conjugate features the Genetic algorithm is employed. The main advantage of Genetic algorithm is its fast rate of convergence compared to the other searching methods.

The Genetic algorithm starts with the selection of population of features and followed by the determination of a so called criterion function which can comprise different similarity measures (e.g. feature attributes) and geometric constraints (e.g. affine transformation parameters). Using this criterion function a new population is constructed by decomposition of the old population using a so called Cross-Over operator. The procedures are repeated until a small subset of the population with a specific pattern best satisfies the criterion function.

2.3.1 Genetic Algorithms Concepts

John Holland and his colleagues formally introduced genetic algorithms (GAs) in [11]. GAs are based on the natural concept of evolution, suggesting that diversity helps to ensure a population survival under changing environmental conditions. GAs have intrinsic parallelism and are iterative procedures (Figure 2).

They maintain a population of P candidate solutions encoded in the form of chromosome string of some alphabets, typically the binary symbols "*0*" and "*1*". The initial population can be selected heuristically or randomly. For each generation, a fitness function, representing the quality of each candidate solution, is evaluated. Fit candidates, those with fitness value higher than certain threshold, will be selected for the reproduction in the next generation. The selected candidates are combined using a genetic reproduction operation called “crossover”. The crossover operator exchanges portions of the chromosome to produce better candidates with higher fitness in the next generation. The “mutation” operator is then applied to perturb the string of the chromosome to guarantee that the probability of searching a particular subspace of the problem space is never zero [1]. This prevents the algorithm from becoming trapped in local optima [8, 12]. The whole population is evaluated again in the next generation. The process continues until a termination criterion is reached. The termination criteria may be finding an acceptable approximate solution, reaching a specific number of generations, or convergence of the solution (Figure 2).

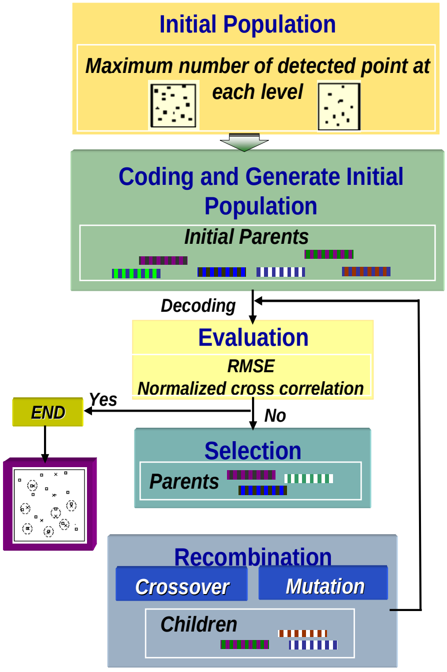


Fig. 2: Genetic Algorithms Concepts

2.3.2 Feature Based Matching Based on Genetic Algorithms

Chromosome Encoding: Using a bit string encoding scheme for chromosome string, the validity of conjugate pointes is encoded as shown in Figure 3. A *1-bit* field is used to represent the possible situation of individual conjugate point validity, in data set. The aim of coding is to create a representation of conjugation (value *1*) or non-conjugation (value *0*) of each pairs of points. This allows any combination of points to be modified

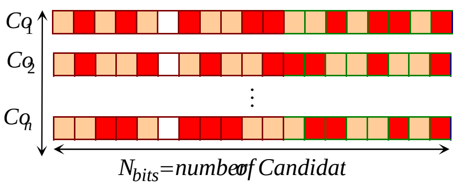
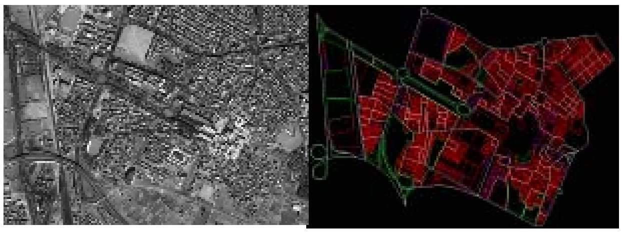


Fig. 3: Encoding of *n* conjugate candidate into *n* bit chromosome string

Objective Function and Selection: The objective function in image registration is to minimize the RMSE of math modeling residuals. For individual selection, we select highly fit individuals with higher fitness values. The mating is then performed randomly using the crossover operation. Finally, using the mutation rate of *0.05*, each selected individual is mutated by randomly altering one bit in the chromosome string. The position of the bit to be altered is also randomly selected. The crossover used in this research is the single-point uniform crossover. The termination condition is to stop the GA search procedure after the solution converges or a pre-specified number of generations are reached.

4 Experiments and Results

The potential of the proposed method is evaluated using IKONOS imagery and corresponding digital map of the city of Tehran, Iran (Figure 4). The maps have been produced in 2002 from 1:4000 aerial photographs by National Cartographic Centre (NCC) of Iran. The satellite imagery was acquired on 2004. During these two years time lapse between the generated digital map data and the IKONOS image acquisition, considerable changes have also occurred in the city.



A **B**

Fig. 4: Selected Dataset, IKONOS image of TEHRAN (A), Corresponding 1:2000 digital map (B)

Registration process is performed hierarchically using five–layer image pyramids. Each pyramid layer has four times reduced resolution in relation to its previous layer (Figure 5).

Table 1 shows the independent results for each pyramid layer obtained by the Genetic algorithm process. A comparison between the number of the detected features in each layer and the number of matched points clearly indicates how the Genetic algorithm process has eliminated some of the points in each layer (see Table 1). These are the points for which, the geometric and the radiometric conditions have not been satisfied according to the Genetic algorithm parameters setting (Figure 5).

The RMSE values obtained by the GA based registration method are given in Table 2. As this Table shows the RMSE values for the first layer are *0.76*, *1.09* and *0.94*, *1.23* pixels in the *x* and *y* image coordinate of the check and control points respectively.

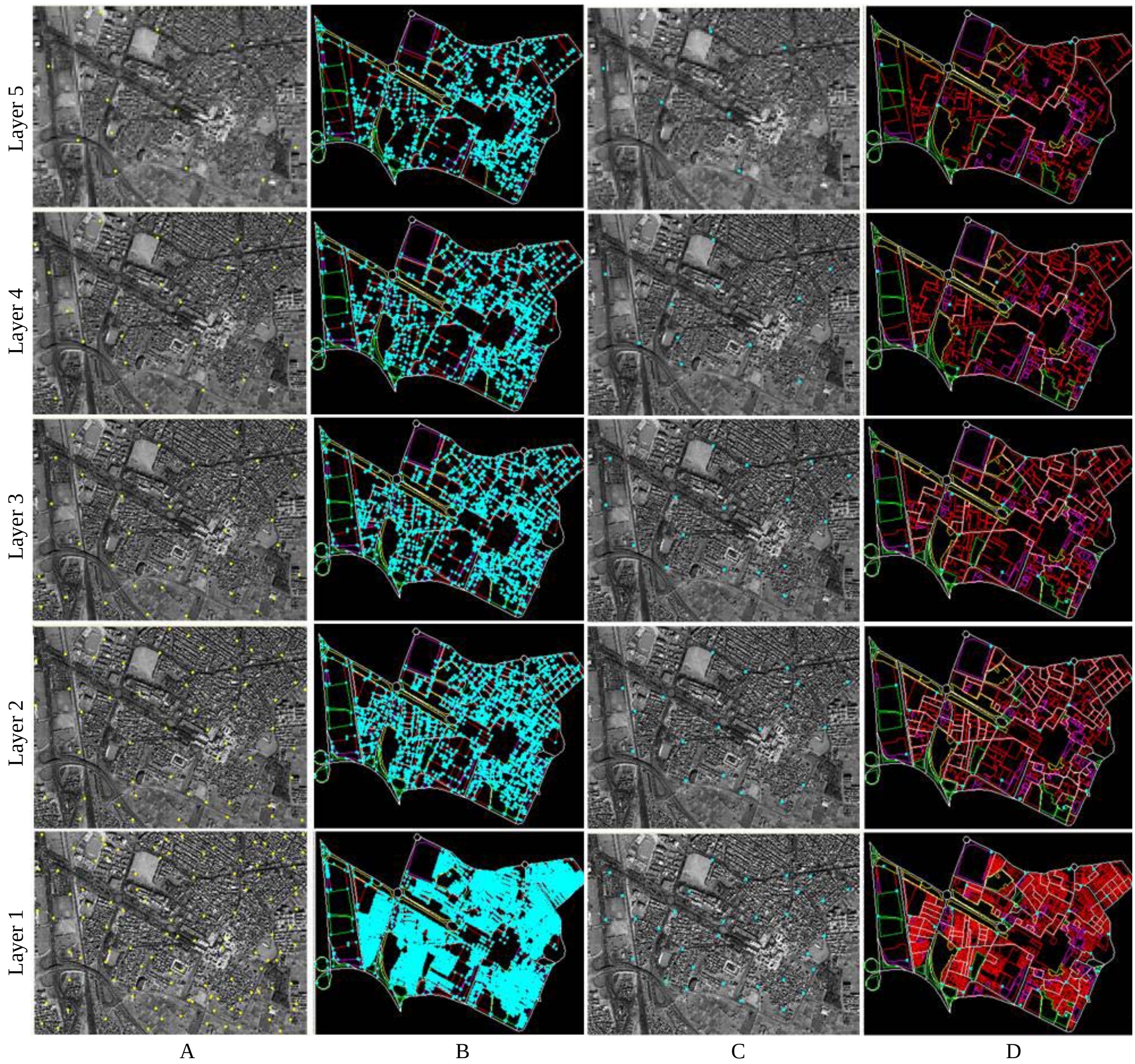


Fig. 5: Image pyramid with extracted point (A), Vector map pyramid with extracted point (B), Matched points in each Layer of image pyramid (C), Matched points in each layer of vector map pyramid (D),

Table 1: The number of matched points and the corresponding residual errors on different layers

Layer	Image Extracted Points	Map Extracted Points	Conjugate Points	Generation	Math model	Order	RMSE (m)	
							X	Y
5	12	115	7	100	P2=P4=1	2D-1	18.08	27.02
4	18	237	11	200	P2=P4	3D-1	10.40	16.56
3	31	496	20	300	P2=P4	3D-2	4.24	7.82
2	54	973	32	400	P2=P4	3D-3	1.92	2.01
1	85	1834	41	500	P4 =P2	3D-3	0.82	1.04

Table 2: The number of matched points and the corresponding residual errors in first layer

Layer	Match Points	Control Points	Check Points	RMSE On Control		RMSE On Check	
1	41	30	11	0.76	1.09	0.94	1.23

4 Conclusion

The proposed automatic registration method discussed in this paper, has proved to be very efficient and reliable for automatic registration of satellite imageries based on digital vector maps. The implemented methodology has the following characteristics:

- Utilization of a multi-resolution representation of information and mathematical models.
- Employing a Genetic algorithm for conjugate feature identification and modeling.

In spite of the success which is gained in the implementation of the presented method, the topic by no means is exhausted and still a great deal of research works are needed. These research works should be focused mainly on the development of a more sophisticated Genetic algorithm, interest operator and matching strategy. All of these are currently under investigation in our institute.

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