Structural Matching and Its Applications for Photogrammetric Automation

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ABSTRACT:

The technology for stereo image matching has been extended from the area based correlation via the feature based matching to the structure based matching. In this paper a newly developed method for the structural image matching is introduced. An evaluation function based on the mutual probability of a possible matching is deduced. An informed tree search method is applied to search the best matching. In order to keep the search time acceptable for the photogrammetric applications, a series of strategies are worked out and integrated into the search method. For the data acquisition of the structural description the methods for the image preprocessing, edge detection, line extraction, image segmentation, feature point extraction, direction-invariant correlation and topology extraction are also mentioned. With all these means together the fully automatic recognition of the corresponding image objects is realized without to know any a priori information and without to have any relation assumptions about the digital images. Some examples for the applications of the structural matching in the fully automatic relative image orientation and in the tie point recognition for the automated digital triangulation are demonstrated. The results show that with the application of the developed methods and the corresponding program system for the structural matching the digital photogrammetry has reached its highest automation level. The "black box" philosophy for digital photogrammetric operations is further realized in this contribution.

1. INTRODUCTION

Image matching is a basic issue in computer vision and in digital photogrammetry. The methods for image matching can be divided into three classes, i.e. signal based matching, feature based matching and structure based matching [Lemmens, 1988].

The signal based matching is also called area based matching. It refers to determine the correspondence between two image areas according the similarity of their gray values. The cross correlation and the least square correlation are the well-known methods for signal based matching. These methods need a very good initial position and direction of the two areas.

The feature based matching determines the correspondence between two image features. In photogrammetry the feature point matching is often applied in the last few years [z.B. Li, 1988; Schenk, 1990; Greenfeld et. al., 1991; Tang/Heipke, 1993]. The initial values for feature based matching need no more so accurate as for signal based matching. But some a priori information e.g. the approximate orientation parameters, the image overlaps etc. is still necessary to know. So it is not suitable for the fully automatic recognition of the corresponding image objects.

The structure based matching is usually called structural matching or relational matching. The structural matching establishes a correspondence or homomorphism from the primitives of one structural description to the primitives of a second structural description [Haralick/Shapiro, 1993, p594]. A structural description is defined by a set of primitives and their interrelationship. E.g. the structural description of a digital image consists of the image features and the relations among the features. The term relational matching refers sometimes only the matching of two relations [Haralick/Shapiro, 1993]. Therefore in this paper the term structural matching is used. Because in the structural matching not only image features but the topological and geometrical relations are also used for determination of the correspondence, the image matching tasks can be fully automated without any a priori information.

The concept for structural matching is originally developed by experts in computer vision. In photogrammetry there was a first research using structural matching to solve the matching problem between the image patch and the description model of a control point [Vosselman/Haala, 1992]. But many photogrammetric tasks can benefit from the structural matching, e.g. the automatic relative and absolute orientation, the automated aerotriangulation, the automatic data acquisition for the digital elevation model, the object localization and recognition, the image analysis and understanding, and so on. So it should be further investigated. The problems to be solved about the structural matching are mainly the efficient acquisition of the structural descriptions and the operational approach for the matching of the structural descriptions.

Since a few years we have undertaken a project to develop a digital photogrammetric system for the automatic reconstruction of the object surface, in which the structural matching has been investigated as a major issue. In this paper the achievements will be reported. A newly developed approach for the structural matching is introduced. An evaluation function for a possible matching has been deduced according to the principle of the maximum likelihood estimation. It is based on the mutual probability of a matching. In the practice the mutual probability is easy to calculate. An informed tree search method is applied to search the best matching. In order to keep the search time acceptable for the photogrammetric applications, a series of strategies have been worked out and integrated into the search method. These are the substructure theory, the unit ordering, the best minimum matching, the geometric constraints, the adaptive correction, pyramid structures and so on. For the data acquisition of the structural descriptions the methods for the image preprocessing, edge detection, line extraction, image segmentation, feature point extraction, direction-invariant correlation and topology extraction are also developed. With all these means together the fully automatic recognition of the corresponding image objects is realized without to know any a priori information and without to have any relation assumptions about the digital images.

In following sections the developed method for the structural matching is introduced. Some application examples about the fully automatic relative orientation of any stereo image pairs and the automated digital aerotriangulation are then illustrated. They show with the application of the structural matching method the digital photogrammetry has reached its highest automation level. The "black box" philosophy for photogrammetric operations, which has been predicted by some photogrammetric experts [e.g. Achermann, 1991], is further realized in this contribution.

2. AN APPROACH FOR STRUCTURAL MATCHING

2.1 Structural Description

The structural matching establishes a correspondence between two structural descriptions. A structural description of a digital image includes the radiometric, geometrical and topological information of the image. This information can be divided into features and relations as the Figure 1 shows. All the feature points, lines and regions are also

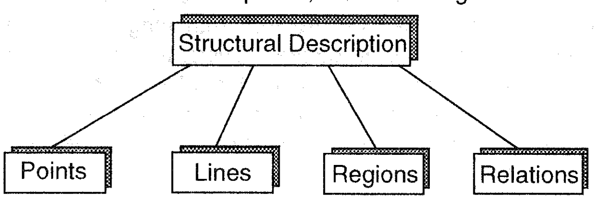

Fig. 1: Structural description of a digital image

called primitives. Each kind of primitives and relations can be described by several attributes. E.g. a point primitive p_i can be described by:

$$p_i = \{coordinates = (x, y), gray = g, gradient = t\} \quad (1)$$

and a relation r_j between two lines can be described by:

$$r_j = \{lines\ l_m, l_n, cross = yes, angle = \alpha\} \quad (2)$$

The goal of the structural matching is to find out a correspondence or homomorphism (i.e. the best matching) from the primitives and relations of one structural description to the primitives and relations of second structural description. The available primitives and relations of a digital image are enormous. Two digital images are usually only partly overlapped, so the right matching of the two descriptions is only a part correspondence of all primitives and relations. One primitive (or relation) of the first description may be matched with one or several or no primitive (or relation) of the second description. Therefore there may be many possible matches between two structural descriptions. So the search time for the best matching can be very long. In order to solve the structural matching problem quickly and correctly, the topics like evaluation function, search method, correctness check and the efficient extraction of the structural description etc. must be researched and resolved.

2.2 Evaluation Function

Suppose we match two digital images and use *DL* for the structural description of the first image and *DR* for the structural description of the second image. According to the maximum likelihood estimation the best matching of the two descriptions h_b should have the maximal conditional probability among all possible matches h_1, h_2, ..., h_k:

$$h_b = \max_i P(h_i/DL, DR) \quad (3)$$

Using Bayes-Formula $P(h_i/DL, DR)$ is equal to:

$$P(h/DL, DR) = \frac{P(DL, DR/h)\,P(h)}{P(DL, DR)} \quad (4)$$

It can be known from the equation (4) that maximizing $P(h_i/DL, DR)$ is equal to maximizing $P(DL, DR/h_i)$. So the mutual probability $P(DL, DR/h_i)$ can be taken as an evaluation index for the goodness of a possible matching. Since:

$$P(DL, DR/h) = \sum_{i,j} P(DL_i, DR_j/h)\,P(DL, DR/DL_i, DR_j, h) \quad (5)$$

where the subscripts *i* and *j* represent the primitives of the descriptions, the mutual probability $P(DL, DR/h_i)$ is also quite simple to calculate in practice.

2.3 Search Method

The tree search methods are often used to find out the solution in many artificial intelligence problems [Nilson, 1982]. A search tree for the structural matching can be

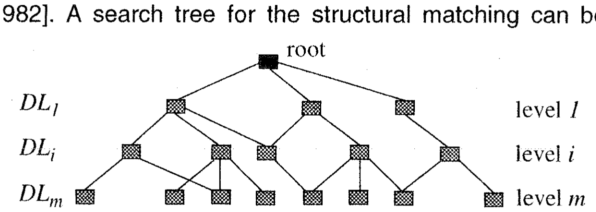

Fig. 2: a search tree

schematically demonstrated in Figure 2. Each level of the tree represents a primitive or a relation (both called an unit) of the first description. Each node represents a possible matching of two units. The nodes in the last level are also called tree leaves. Each path from the root to a leaf is a possible matching. The tree search methods can be divided into two types: blind search methods and informed search methods. The blind search methods treat all the tree nodes equally, so they usually take a long time to find the solution. The informed search methods use some measures to evaluate the nodes and firstly try the node which might lead to the solution. An investigation of the search methods can be found in [Vosselman, 1994, Wang, 1994], here will not be repeated.

An informed search method is developed for the structural matching. It uses the probability of the tree nodes to guide the search. In order to reduce the search time, which increases exponentially to the primitive numbers of the structural descriptions, some further measures are developed and integrated into the search method. They are the sub-structure concept, unit ordering, best minimum matching, geometrical constraints, adaptive correction etc.

With the sub-structure concept the primitives and relations of a structural description is integrated according to some rules so that the primitive volume can be strongly decreased. In the case of the structural matching for two digital images the structural description can be reorganized as the Figure 3 shows, because in a digital image

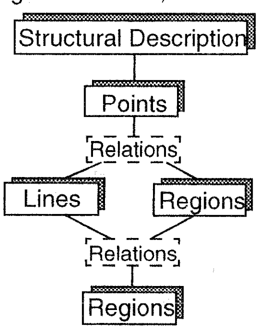

Fig. 3: Integrated sub-structures

the points, lines and regions are interconnected with certain relations and the attributes of a point primitive can be calculated more accurately and reliably than those of a line or a region. The geometric relations have also numerical attributes. Therefore they can be treated similarly as the features. The topological relations is used as constraints.

With the unit ordering the primitives or the primitive groups are reordered according to their probabilities, so that the units, which lead more likely to the solution, are visited earlier than the others.

Table 1: Example for search method

image	size (pixel)	units in structural description			
		points	lines	regions	relations
first	*140x140*	*174*	*77*	*68*	*>319*
second	*140x140*	*157*	*81*	*52*	*>290*

	sub-struct.	recogniz. sub	time	computer
first	*174*	*35*	*2'20"*	*PC486 33MHz*
second	*157*			

If some relations exist between two structural descriptions (e.g. affine or perspective transformation), they can be used to guide the search paths, so that the search time can be strongly reduced. The best minimum matching and the geometrical constraints together provide the geometrical relations of two descriptions. If the best minimum matching is wrong, which is very unlikely because of the unit ordering, it will be corrected by means of the adaptive correction.

With all these measures together the best matching can be found quickly and reliably. The search method is also simply applicable in the practice. Table 1 is an example to show the efficiency of the search method.

2.4 Correctness Check

After the best matching is found out, it will be checked for correctness. This can be done by the magnitude of its probability and by the geometric condition, because there is a strict condition between two perspective images, i.e. the coplanarity condition. After the coplanar adjustment based on the matched points not only the parameters of the coplanar equation, but also a variance of the points can be achieved. This variance can be used to judge the correctness of the matching because the a priori variance of the points is available.

In order to compute the coplanar parameters without knowing the initial values of the relative orientation parameters a linear mathematical model for the coplanar equation has been developed. This linear model can be applied not only for checking the correctness of the best matching, but also for the relative orientation of convergent images. A complete introduction of this linear orientation method and its applications can be found in [Wang, 1995].

2.5 Extraction of structural descriptions

For the generation of a structural description the feature points, lines, regions and their interrelations must be extracted from the digital image. An original image is usually very large. In order to reduce the information volume the image pyramid will be firstly generated. The Gauss pyramid is used here. The structural matching will be only carried out on the smaller pyramid levels, which should be firstly preprocessed (e.g. edge-protected smoothing etc.) Then the matched points will be transmitted and new points will be added between each two pyramid levels until to the original image.

The fast and precise extraction of the image features are very important for the implementation of the structural matching. The Förstner-Operator [Förstner/Gülch, 1987] with some modifications to increase the point accuracy [Wang, 1994] is applied for the point extraction. The attributes of a feature point could be their coordinates, gray value, gradient, weight and variance. In order to get the point relationship to the lines and regions, there are five type of the points defined as the following:

$$Point\ \ type = \begin{cases} 0 & single\ \ point \\ 1 & point\ \ by\ \ a\ \ line \\ 2 & point\ \ on\ \ a\ \ line \\ 3 & T-crossing \\ 4 & X-crossing \end{cases}$$

The correlation coefficient of two image points is also a very important attribute of point primitives. Since the image orientation is unknown, a method for the cross correlation based on the gradient direction has been developed [Wang, 1994]. So it is independent of image directions.

Image edges are firstly extracted by means of a one-dimensional operator, which is developed for the fast and efficient extraction of edges. The lines, which connectivity must be unique, are extracted from the edges with the mathematical morphological transformation [Wang, 1994]. The attributes of a line could be the begin and end point, average gray value, line length, line strength, and line curvature etc. A line have also defined relations with other lines and regions.

The regions are extracted with the methods of image segmentation. A boundary lines based region growing method has been developed for the region extraction, which benefits from the advantages of both contour-oriented methods and region growing methods [Wang, 1992 and 1994]. A region can be described with reference coordinates, region size, boundary size, gray value, variance, region form etc. The region form can be presented with the moment coefficients or the Fourier Transformation coefficients.

There are five kinds of relations considered in the work. They are point to line, point to region, line to line, line to region and region to region relation. the geometric relations (e.g. angle of two crossed lines) are treated similarly as the feature primitives, and the topological relations (e.g. T-crossing) are used as the constraints.

The work flow of the structural matching can be demonstrated with the Figure 4. With the success of the structural matching the corresponding image points of digital stereo

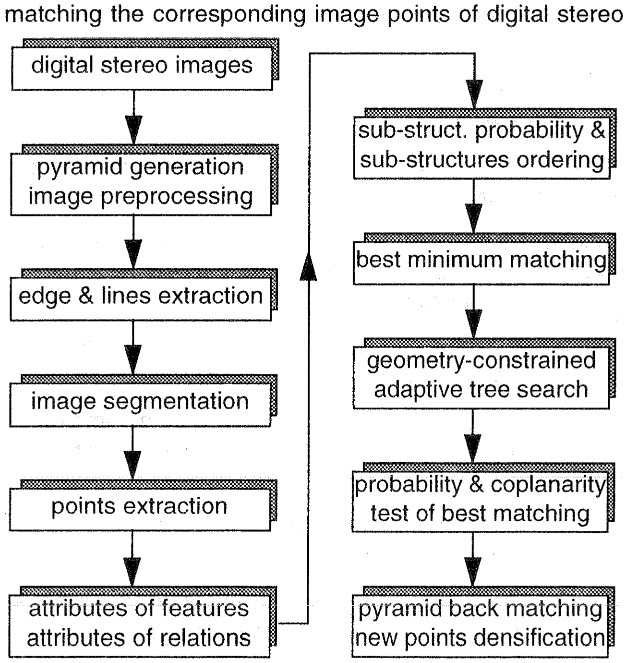

Fig. 4: flow chart of structural matching of two images

images can be recognized fully automatically without knowing any a priori information such as image overlap and image orientation parameters.

3. APPLICATIONS

The structural matching methods can be applied in the cases, where a correspondence between two data descriptions should be found, e.g. two- or three-dimensional object recognition between images and maps or models, object reconstruction etc. In photogrammetry the problems such as the automatic relative orientation, the automatic data acquisition for DTM, the automatic aerotriangulation, the automatic recognition of control points and other describable objects can be completely solved by the structural matching methods.

Since a few years a program system for the photogrammetric automation has been developed under Microsoft Windows and is transferred to a Silicon Graphics machine at our institute. Its aim is to solve the photogrammetric tasks such as automatic orientation, triangulation and surface reconstruction with highest automation grade. The aim is reached by using the structural matching method. Following are two examples for the application of the structural matching in automatic orientation and triangulation in photogrammetry with the developed program system. The data acquisition for DTM and surface reconstruction can also be fully automated with the structural matching, even though from the non-metric images or line scanner images. Due to the limited page number the corresponding examples will be given in other papers [e.g. Wang, 1994].

3.1 Fully automatic relative orientation

Figure 5(a) displays a stereo image pair in close range photogrammetry. It is a convergent pair with up-down configuration of the photographic centers. Without to know

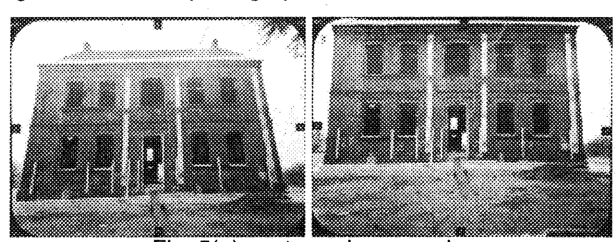
Fig. 5(a): a stereo image pair

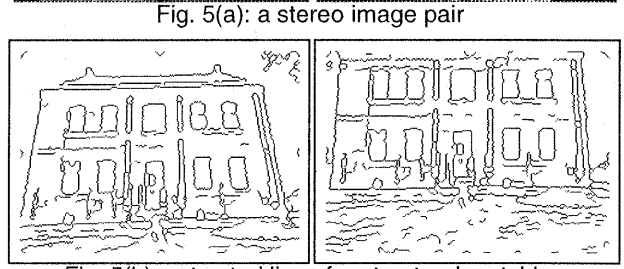
Fig. 5(b): extracted lines for structural matching

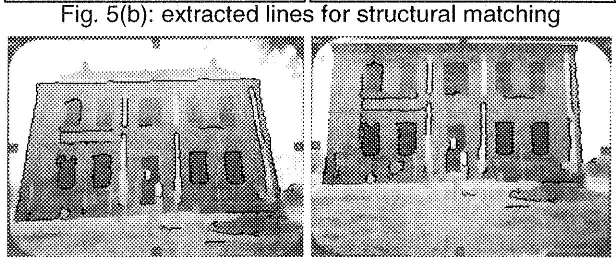
Fig. 5(c): recognized lines by structural matching

any other information except digital images the corresponding image points can be recognized by the structural matching and the parameters of the coplanar condition can be computed with the developed linear method. Figure 5(b) shows the extracted feature lines for the structural matching. Figure 5(c) shows the recognized feature lines on the images by the structural matching. The five conventional relative orientation parameters can be obtained if the interior orientation parameters are known. Table 2 shows several important parameters of the example, where β_X

Table 2: automatic relative Orientation parameters

original image size	structural match. level	recognized points	point MS error	total time
1444x1975	*180x246*	*26*	*0.074pixel*	*7' 22"*
β_X	β_Z	φ_2 *(g)*	ω_2 *(g)*	κ_2 *(g)*
-0.086	*-0.345*	*-0.001*	*-9.756*	*-0.063*

and β_Z are the ratios of the base components in X and Z direction to Y direction. The total time of the whole computation from the pyramid generation till the calculation of the relative orientation parameters on the original image level takes about seven minutes by a PC486/33MHz.

3.2 Automated Aerotriangulation

Since a few years automated aerotriangulation are under investigation [Schenk/Toth, 1993; Tsingas, 1991]. The main work to be automated is the tie points transfer and measurement. The conventional methods in this area have difficulties for the automatic block preparation, i.g. to determine connections, overlaps and some initial matched points for each model in the whole image block, if there is no approximate values available. The structural matching is just the right method to solve this problem. The example shows that with the structural matching the tie points can be recognized fully automatically in the whole image block without any a priori information.

Fig. 6(a) shows a image block with 3x2 images. An operator has digitized the images simply according to the image numbers. So two images from the different stripes have a rotation about 180°. In addition there is also no consideration about the flying direction. Therefore the photographic centers in the same stripe have a up-down configuration instead of usually left-right. This complicated case is not rare, if the operator is not highly qualified in photogrammetry or if the digital images come directly from digital scanners. An automated photogrammetric system should be able to deal with this case too. The conventional methods are not suitable for it. Only with the structural matching the tie points can be recognized fully automatically. The structural matching is used for each two images. Fig. 6(b) displays the recognized lines and points by the structural matching. A large number of tie points can be obtained on the original image level from the transfer and densification of these recognized points and lines on the reduced images. the accuracy of matched image points is around 0.1 pixel in the example.

4. CONCLUSIONS

The "black box" philosophy for photogrammetric operations, which means the automation in photogrammetry, has been predicted by some photogrammetric experts [e.g. Achermann, 1991]. With the application of the structural matching this philosophy is further realized. In this contribution the fully automatic recognition of the corresponding image objects is realized without to know any a priori information except the image data, even though for the irregular or non-metric images. Many photogrammetric tasks can reach their highest automation level by means of the structural matching. The paper has shown that the relative image orientation, the tie point transfer and measurement for the automated aerotriangulation and the other image matching tasks can be fully automated with the application of the developed methods and program system for the structural matching. The time for autonomous photogrammetry is coming.

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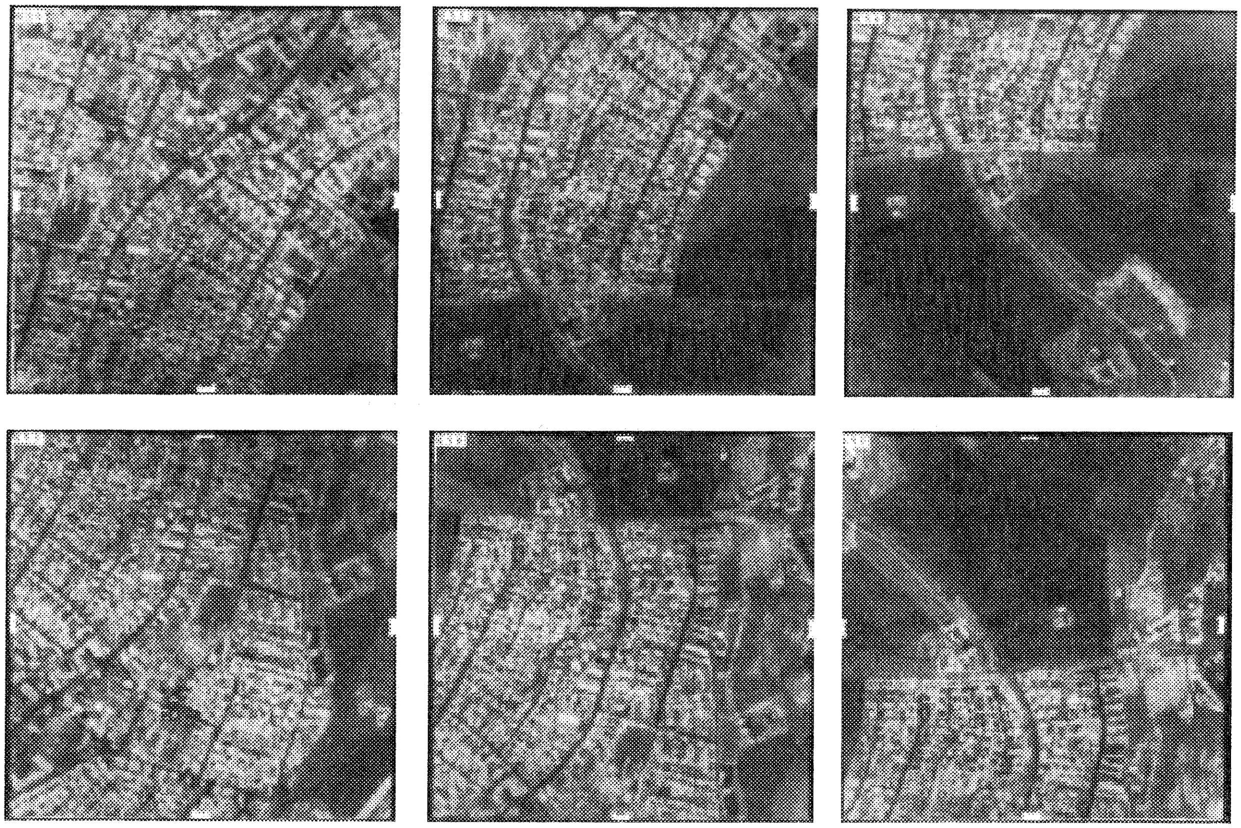
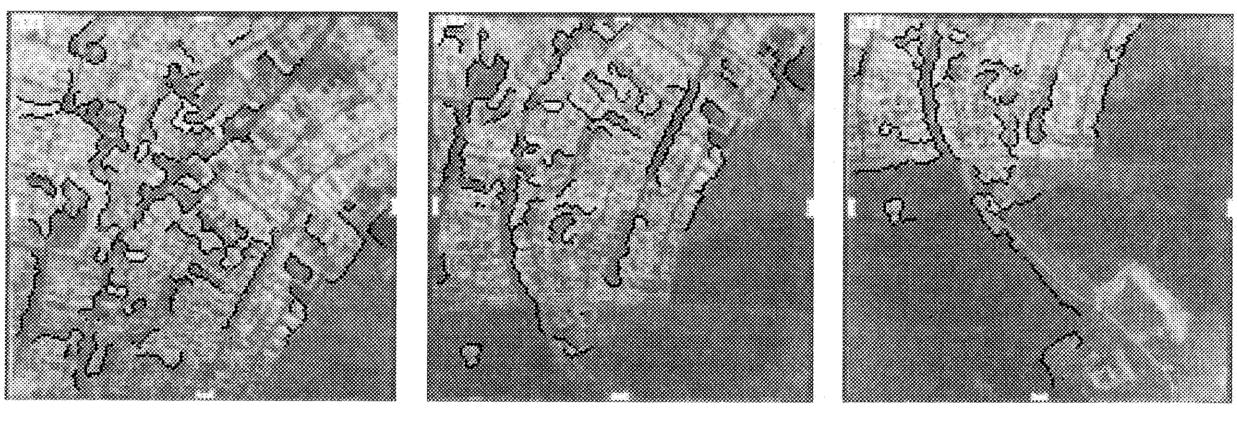


(a): The original digitized image block at the highest pyramid level. The images are simply digitized with keeping the position of the image number up-right, therefore some models have a $\kappa = 180°$, and the photographic base line in a stripe is up-down.



(b): The recognized lines and points on images from the structural matching

Fig. 6: Structural matching for the fully automatic recognition of tie points for automated aerotriangulation