ON MATCHING IMAGE PATCHES UNDER VARIOUS GEOMETRICAL CONSTRAINTS

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ABSTRACT

Image matching plays an important role in digital photogrammetry. Finding conjugate points occurs in different photogrammetric tasks. Image matching is usually performed in two steps: determining approximations and computing precise conjugate locations. In this paper we are concerned with the second aspect, that is, the image patches are already close to their final position. An image patch analyzer determines which matching primitives should be used first. Based on the results other primitives can be activated. The process terminates if a predefined level of confidence is reached or if no further improvements are to be expected. The matching process can be geometrically constrained, for example, along vertical lines, epipolar lines or by fixing one image patch in its location.

KEY WORDS: Matching, Conjugate Points, Geometric Constraints.

1. INTRODUCTION

Image matching – finding conjugate points – plays an important role in digital photogrammetry. It is an essential operation of many basic photogrammetric procedures, like automatic orientation or DEM generation (Schenk *et al.*, 1990). Much research in digital photogrammetry has been devoted to matching, including theoretical as well as implementation issues. The results are reported in numerous publications and technical papers.

One of the first products of digital photogrammetry are digital photogrammetric workstations (or softcopy stations). They will have a great impact on how daily photogrammetric tasks are handled (Kaiser, 1991). For one, they provide the operator with all functionality of the analytical plotters. The major difference between softcopy stations and analytical plotters is the fact that the operator views the 3-D stereo model directly on the display screen. More important, softcopy stations offer an unprecedented opportunity for automation. This is the first time that digital photogrammetric methods are implemented a in real production environment. This is as encouraging as it is challenging for the research community to transfer and commercialize research results. The process of automating routine tasks has just started. Since it is a very complex problem, results will probably not meet the high expectations for quite some time (Schenk and Toth, 1992).

In this paper we report about the preliminary phase of a project with the objective to automatically keep the floating mark of a softcopy station on the ground (or dot on the ground, for short, DOG). The idea is that after a stereo model is oriented the operator is not forced to set the measuring mark (3-D cursor) precisely on the ground. If the function is evoked the system will do it automatically. To automatically place the floating mark on the surface is a problem of finding conjugate points in both image patches. In other words, when an operator slightly moves the floating mark in the XY plane, then the proposed algorithm should automatically find the corresponding Z coordinate and move the measuring mark accordingly (adjust Z). Consequently, these application-specific conditions immediately define the scope of the matching techniques feasible to solve the correspondence problem. We investigated the concurrent application of different matching methods with good localization results. In the following, conceptual issues and some major subtasks are discussed.

2. OVERVIEW OF THE PROPOSED ALGORITHM

2.1 Application Specific Conditions

A variety of different matching methods are now available, each with its specific advantages and disadvantages. In order to narrow down the set of possible techniques suitable for our project, the application characteristics must be considered:

- digital stereo model is oriented
- good approximations for conjugate points are given
- optional epipolar image geometry
- parameter adaptability
- relatively small size of the image patches

The exterior orientation is necessary to move between image and object space. It is used to constrain the movement of the floating mark. Also, it allows for employing object space matching methods (Helava, 1988).

Since the operator will keep the measuring mark fairly close to the ground, good approximations for the conjugate points can be assumed. Thus, image patches always sufficiently overlap.

As shown in (Kaiser, 1991) epipolar geometry can be easily achieved on softcopy stations, thus it is worth taking advantage of that special geometrical condition. Sometimes the

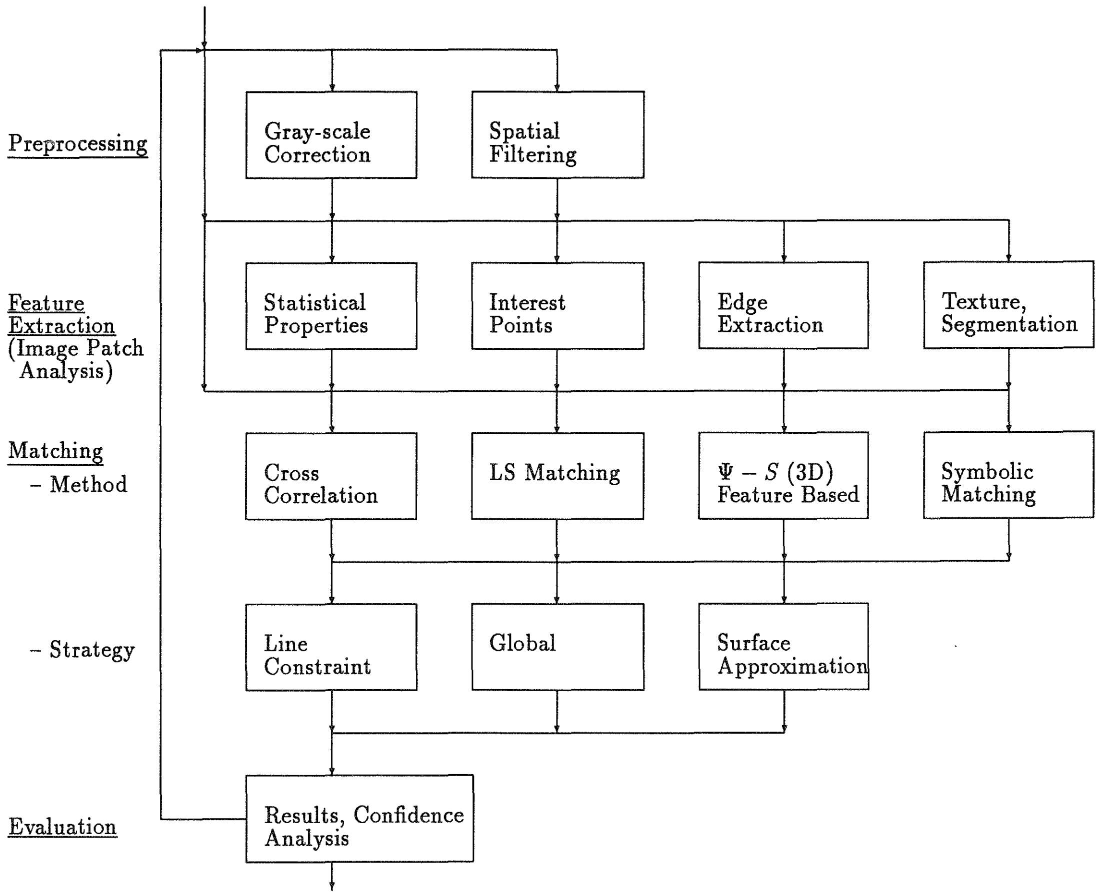

Figure 1.
Flowchart of the DOG system.

images are not resampled but converted on the fly during display operation or data processing. Usually, the operator moves the floating mark quite slowly. Therefore, the image patches of a current matching operation may have very similar image characteristics like neighboring patches. This means that certain parameters of the previous (neighboring) matching operation can immediately be used for the processing strategy of the current patches. For example, surface direction can be approximated at one side of the patch, or texture based segment data and basic statistics can reveal occlusion situations.

The patch size in our application is more an implementational than algorithmic issue. However, it is still important since most matching methods are very timeconsuming and our application needs a quasi real-time response (the processing time should not take longer than what an operator would need).

2.2 Structure of the Algorithm

Based on conditions imposed by our application the default matching method is cross correlation (Ackermann, 1984). If the current patch has enough texture information, the foreshortening is negligible and there is no occlusion or other artifact, then correlation performs well. Since these conditions are not always met, other methods must be used. A first key issue is to find and parametrize the image characteristics (called actual features in this paper) of the patches. This problem itself is as complex as the matching, because ideally it would address many high-level paradigms of scene analysis and image interpretation. Because of the lack of a robust, scene independent matching scheme, an iterative hierarchical strategy is proposed. Figure 1 shows the flowchart of the proposed DOG method. The suggested system has five processing levels:

- Patch preprocessing
- Feature extraction - image patch analysis
- Matching procedure
- Matching strategy
- Evaluation - result analysis

The patches may be subject to some image enhancement. Scaling the pixel intensities or histogram equalization can compensate for bad contrast. Spatial filtering, like median or Gauss operators can remove noise or unneccessary details which may be important for scale-space algorithms.

Feature extraction provides clues about the patch and may guide the selection of the most appropriate matching method. The basic statistical properties, like mean, median, minimum and maximum intensities, standard deviation, autocorrelation, etc. provide additional patch information.

Local features are grouped into three classes:

- Interest points can produce target matching locations (Zong *et al.*, 1991).
- Edges can be matched (Schenk *et al.*, 1991). Although their localization is weak, the matched edges are relatively reliable. Therefore they may render good approximations for other methods with precise localization properties.
- Texture values and texture based segmentation are useful for detecting shadows, water bodies, and the like. Matched segments provide good global matching constraints.

In the context of our DOG project, matching procedure refers to the matching method in general. We use four methods:

- Cross correlation
- Least squares matching
- $\Psi - S$ feature based matching
- Symbolic matching

Cross correlation and least squares matching methods are discussed in the next sections. The $\Psi - S$ feature-based matching is a very reliable technique to obtain numerous matching points with fair localization accuracy. In our implementation a scalable *LoG* operator generates the edges. The edges are sorted and transformed into the $\Psi - S$ domain where a global matching takes place. Symbolic matching is very useful for global matching (Zilberstein, 1991). Due to implementation issues its use in our project is limited to the 1-D case. We presently use it in profile matching.

Matching strategy refers to constraints how the extremes are sought. Based on the original DOG objective – automatically adjust Z (find conjugate points, compute Z coordinate and drive the floating mark) – the conjugate location is confined to the vertical line which translates into two lines in the image planes. Since occlusions may block out certain segments of the constraint line, global methods are superior to cope with this case. Although the terrain is modelled in least squares matching by the shape parameters, a significantly better approach is to use a priori surface approximations (Schenk *et al.*, 1990). Based on the surface data the patches are warped and in this format, basically free from terrain relief distortion, normal cross correlation is used. Since the surface data are quite sparse it is very critical how the surface interpolation algorithm performs.

The most crucial component of our DOG project is the evaluation and performance analysis of the results. The evaluation module serves as a system controller to implement a data driven algorithm. Typical operation tasks are:

1. The two patches directly go to the statistical module (the preprocessing is skipped unless specified by the user).
2. The results of the image patch analysis are compared to data obtained from the neighboring patches; if significant differences are found then the other three feature extraction modules are activated, otherwise the same sequence of module processing is executed used for the neighboring patches (it may also include other feature extractions) .
3. After executing a matching function (a defined sequence of module operations) the matching results are compared to the results of the neighboring patches and to predefined global parameter values. If everything is all right the new Z value is computed and the process terminates.
4. If in (3) the results are not satisfactory then based on built in rules the matching sequence – in whole or part – is modified and a new computation starts; this is repeated until a satisfactory solution is found; if all strategies are exhausted, the process terminates with a message that matching is impossible.
5. If in (2) the comparison fails, the system controller assigns the initial matching strategy according to the results of the three feature extraction modules, then point (4) is executed.
6. Upon termination, the parameter set and the last processing sequence are saved for the next application of the DOG function.

In summary, the system controller can be considered as a data driven, self-organizing, adaptive system which finds the optimal matching strategy to any data input from a list of prestored computation sequences. The performance of module computations is measured in the usual parameters, like the absolute and relative value of the correlation coefficient in cross correlation, or residuals and variances in least squares matching, or the relative number of matched edges in $\Psi - S$ feature based matching, etc. The system controller can be viewed as two tables, one containing matching sequences and the other consisting of rules on how to evaluate the results. Tables are extended to include experimental results, thus the system can learn. Under normal conditions the neighboring image patches are similar enough and the search process for optimal strategy is called only where there are significant scene changes in the images.

2.3 Cross Correlation

Cross correlation matching can be used in all three geometrical constraint strategies. Less important details, such as window size, which may be determined from statistical properties, are omitted, and the typical epipolar condition (correlation window becomes a line) is assumed in the following description.

Line Constrained Search

The search line can be easily determined from the XY coordinates of the floating mark, and from the assumption that the current Z value is quite close to the real surface value. Thus the Z coordinate of the possible P surface point should be in the range:

$$\begin{aligned} Z_p^u &= Z_c + dZ \\ Z_p^d &= Z_c - dZ \end{aligned}$$

where Z_c is the current elevation of the floating mark and dZ is the search range defined by global constraints. The two extreme points, Z_p^u and Z_p^d are projected to both left and right photo planes by collinearity equations and then transformed into image coordinates, yielding the two search lines. As a next step, the correlation windows are moved along the search lines and the coefficients are computed. Under ideal conditions there is only one pair of conjugate points pointing to the desired surface location, and for this point the correlation coefficient is likely to have a maximum value. The analysis of the correlation curve around the maximum gives some indication about the reliability of the maximum. Using a band of parallel search lines can further improve the reliability of the results. In this case a correlation ridge is obtained, and its analysis can lead to more reliable results. In general, independent global matching should be applied to increase the confidence level of the matching results.

Global Search

In this case the correlation window is moved within the entire patch area, and a 2-D correlation function is computed. The shape of the correlation function may help to confirm or drop our hypothesis about a location, although it is not necessarily feasible to determine directly the desired location.

Surface Warping

If true surface data are available, then the distortion of the image patches caused by terrain relief can be totally removed. In this case, cross correlation is concerned only with texture information, and reliable results are obtained. Surface data may be known for the previous patches, but in general the true surface is never available, and therefore it must be approximated. Based on our experience (Schenk *et al.*, 1990), with $\Psi - S$ feature based matching, enough reliable surface points are obtained. Nevertheless, the surface data are still quite sparse and a surface interpolation algorithm must be used. Through hierarchical iterations the surface approximation usually improves. It is appreciated that in this process the interpolation algorithm itself plays an important role (Al-Tahir, 1992). A bad approximation strategy can slow down the convergence or even make the surface diverge.

2.4 Least Squares Matching

In general, least squares matching can be similarly constrained as cross correlation. The general approach is:

$$g_2(x,y) = h_0 + h_1 \cdot g_1(a_0 + a_1x + a_2y, b_0 + b_1y + b_2x) \quad (1)$$

Eq. 1. can be simplified if epipolar geometry exits:

$$g_2(x) = h_0 + h_1 \cdot g_1(a_0 + a_1x) \quad (2)$$

The surface data can be used to set better initial values for the adjustment procedure.

3. EXPERIMENTS, RESULTS

A prototype version of the proposed solution in the DOG project has been implemented on Intergraph workstations. Most of the modules are operational. As of writing this paper extensive tests have been performed, and the system controller tables have been built.

The first observations are:

- the major modules perform as expected
- the basic cross correlation matching works well for reasonable test data (for example, with fixed X and Y increments it automatically collects DEM grid points)
- the automatic parameter tuning is difficult and needs good initial values
- the deterministic approach of the system controller is not optimal
- it is quite complex to define the rules

In summary, the preliminary test results are encouraging. Theoretical investigations are needed to analyze the results and to parametrization the confidence level. On the implementation side, the growing number of rules and module sequences justifies the use of an off-the-shelf expert system (Schenk and Toth, 1991). The accuracy tests will include large numbers of varying image data, and more independent operators are needed to provide the ground truth for performance evaluation.

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