DIGITAL IMAGE PROCESSING FOR AUTOMATION IN ARCHITECTURAL PHOTOGRAMMETRY

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Digital image processing techniques open the opportunity to accelerate the architectural photogrammetric process and to relieve the operator from a lot of tedious tasks. Therefore he can concentrate on the interpretation of the features on the building. Beside semi-automatic measurement tools another field of attention is the development of automatic recognition techniques for selected objects in digital images. The use of special feature extraction algorithms and the development of interpretation models for this purpose are briefly discussed. Based on advanced image processing techniques, some intermediate results for the recognition of stones will be presented.

1. DIGITAL IMAGE PROCESSING IN ARCHITECTURAL PHOTOGRAMMETRY

The classical stereophotogrammetric and the bundle adjustment approach for architectural photogrammetry requires an enormous amount of interactive work, of which the greatest part is very tedious and wastes the high capacity of the human operator, e.g. the monotonous mapping of joint contours or the acquisition of window frames. On the other hand, the interactive restitution in architectural photogrammetry requires high level interpretation, a lot of a priori knowledge and specific experience, i.e. the identification of building styles and the acquisition of characteristic shapes. Due to the complexity of these tasks and the lack of solutions offered by classical pattern recognition and image analysis, an automation of this specialized human work is difficult.

1.1 Advantages of Digital Architectural Photogrammetry

The only way to relieve the operator from the less pretentious tasks are digital techniques. They can be used in every stage of the photogrammetric process, starting with image acquisition by digital cameras, the necessary measurements for the orientation process, the restitution and even the visualization of the results.

If we use pure digital techniques in architectural photogrammetry we can start the orientation immediately after the image acquisition without waiting for the results of the time consuming photo-chemical process. The images can be viewed for quality control at the site. Further we don't have quality losses as results from copy processes and media transfers. Digital images have a stable geometry. No film shrinkage, no bleaching or relief of the photographic layer from the carrier can occur.

In the simplest case a low level image processing software makes it possible to use a low cost PC as a comparator to measure image coordinates. This releases the users of photogrammetric systems from the demand for expensive hardware.

Better software contains tools to support the user during the measurement of image coordinates, the analytical orientation and restitution [*Fellbaum* 1992]. New algorithms, as presented in this paper, support the operator with semi-automatic measurement tools. Techniques for the fully automatic restitution of some features, like bricks, are under development.

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Proeceedings of the *Second Turkish-German Joint Geodetic Days* at Berlin, May 27-28-29, 1997
Istanbul Technical University 1997, pp. 541-548.

1.2 Problems of Digital Architectural Photogrammetry

Today, even the image acquisition for digital photogrammetry has to be conducted using analogue cameras, because digital cameras with a sufficient resolution are still much to expensive. After scanning the paper copies of the images we use digital techniques for the measurement of image coordinates.

Using this approach, digital photogrammetry can be applied on pictures acquired more than hundred years ago by ALBRECHT MEYDENBAUER on glass plates of 40 x 40 cm^2. New contact copies of the images are digitized on a cartographic scanner, delivering up to 15.000 x 15.000 pixels per image which require 225 Mbytes of storage per image. Other problems result from the fast development in computer techniques. Whereas we can use the analogue images acquired by MEYDENBAUER we have problems to read digital image data we have stored 10 years ago on magnetic tapes. If we still have a tape station to read the media, in many cases we don't have software to import this data.

Due to the lack of cheap and appropriate stereo monitors a stereoscopic restitution is not jet available for low cost systems. Only stereo techniques make a sufficient line based restitution possible. To achieve comparable results by bundle oriented restitution techniques is only possible objects consisting of accurately defined points and need much more interactive work.

2. INTERACTIVE MEASUREMENT

2.1 Image Improvement

One of the techniques to support the operator in the photogrammetric process is to improve the quality of the images. Commercial software packages contend interactive control elements, at least for brightness and contrast.

Fig 1: Example of a Histogram Equalization for local contrast improvement (left before, right after the operation.

Using tools like a Histogram Equalization (Fig. 1), local operations can be used to improve brightness and contrast depending on the environment and to avoid large black and white areas without image information. Images treated with such operators provide a much better interpretability.

2.2 Indirect Measurement

Another tool to improve the measurement of points are indirect measurement techniques. Many points in architectural images are defined as the intersection of straight edges at the object. Even, if the point is not exactly defined or hidden behind an obstacle in the foreground the point may be measured by defining at least two points on each of the straight edges in each available image, which define the point (Fig. 2). Such an indirect measurement is much more accurate than a direct measurement of the points.

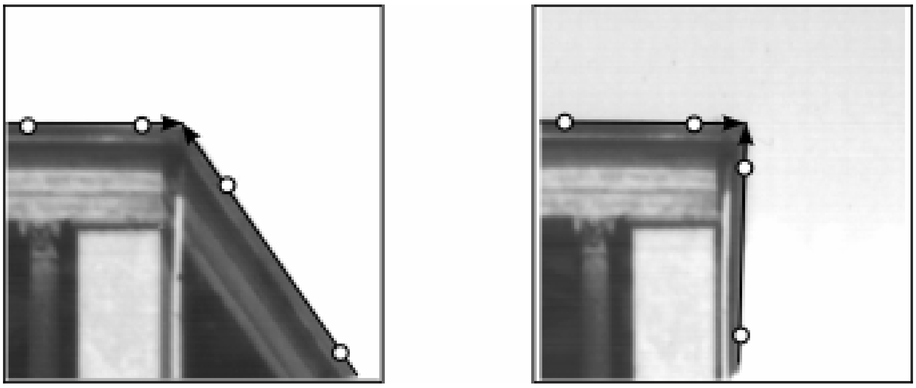

Fig. 2: Indirect measurement of points by intersection of straight lines

3. SEMI-AUTOMATIC MEASUREMENT

Special attention is put on the possibilities to support the interactive point measurements by digital image processing techniques, like matching. Whereas commercial systems only provide an automatic measurement of reseau crosses, this paper describes the semi-automatic measurement of identical points for the bundle adjustment and for the restitution process. For these purposes matching techniques are used. But they need sufficient initial values which are provided by various geometric constraints.

3.1 Semi-Automatic Measurement for Interior Orientation

In most commercial photogrammetric systems the measurement of the reseau crosses on scanned images of semi-metric cameras is the only task, where digital image processing techniques are used. It is a very tedious task to measure, for example the 121 crosses on an image of a Rolleiflex 6006 metric. Different techniques to solve this problem have been developed. Usually two reseau crosses have to be measured interactively, the others are measured automatically. Used approaches are matching with a synthetic reference matrix or searching for the pattern consisting of two intersecting lines.

3.2 Semi-Automatic Measurement of Tie Points

For relative orientation and bundle adjustment a large amount of tie points is required. The more and better distributed tie points are, the better results can be anticipated. Matching techniques are well suited for the measurement of tie points. A point in the first image is defined by its position in the image matrix. An area around the point, e.g. 15 x 15 pixels, is

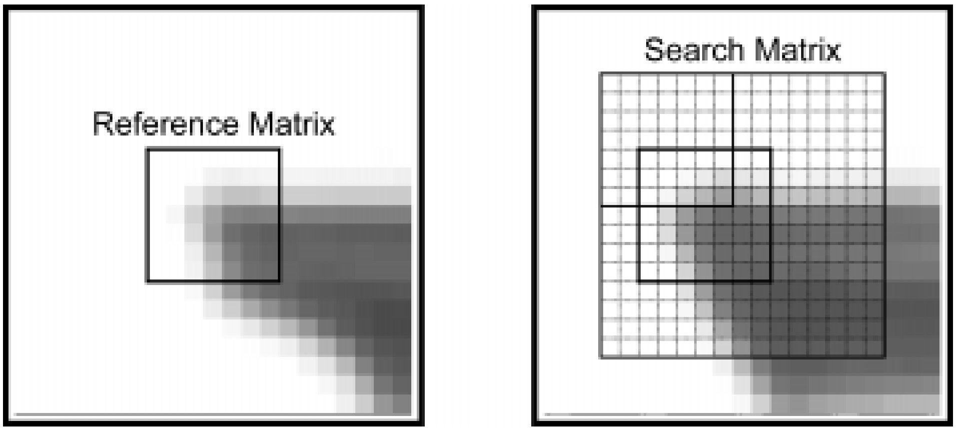

Fig. 3: Classical matching approach, as used for measurement of tie points

defined as reference matrix. In the second image a larger area around the anticipated position of the corresponding point is defined. Between the reference matrix and the corresponding matrix in the search area the correlation coefficient is calculated. The corresponding point is anticipated at the position with the maximum correlation coefficient. There are further techniques for the measurement of tie points available, like least-squares matching [*Wewel* 1996] or feature based matching [*Förstner & Gülch* 1987]. We examine this techniques for application in architectural photogrammetry.

All this approaches need initial values for the definition of a suitable search area. In aerial photogrammetry initial values for the definition of the search matrix can be derived from the parameters of the photo flight. In architectural photogrammetry a much wider variety of image constellations must be considered. Therefore it is necessary to define a search area interactively. This makes sense, because it takes longer to measure a point exactly, than only defining the search area, and matching techniques provide sub-pixel accuracy. Because of the very different viewing angles on the same point, it is necessary to inform the operator about the result of the matching process and wait for the decision of the operator, whether he accepts the result or not.

3.3 Semi-Automatic Measurement for the Restitution

If orientation data are available, it is possible to reduce the search area of a correlation process. Vertical Line Locus (VLL) is a technique to reduce the search area of matching

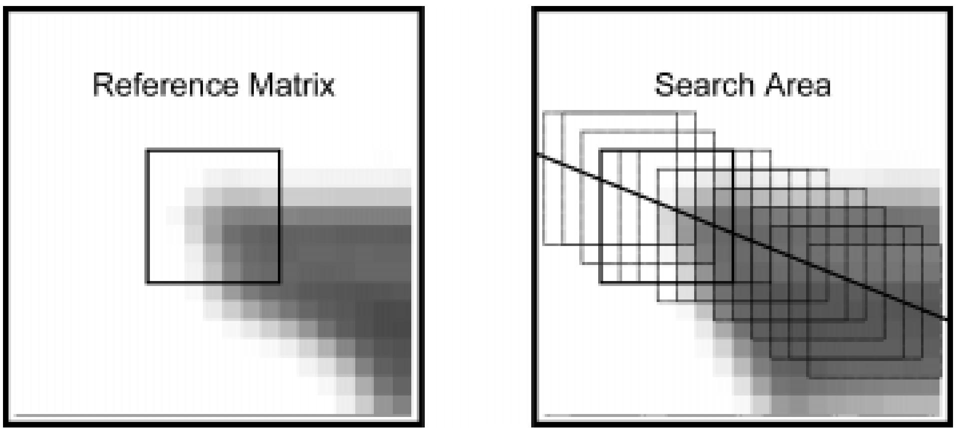

Fig. 4: Matching along the epipolar line in the restitution process

processes in aerial images by defining a vertical line in the object space and calculating the correlation coefficients of the two image matrices according to a point along this line [*Cogan & Hunter* 1984]. Adapting this for architectural approaches is difficult, because no horizontal line is suited to replace the vertical line in any arrangement. Another approach is to define a master image, in which most of the restitution work can be done. To accquire the 3D coordinates of a point, it has to be measured interactively in the master image. A correlation process along the epipolar line searches the corresponding points in one or more *slave images* (Fig. 4). Resulting from a reduced search area the probability of failures is significantly reduced and the process is accelerated.

This relieves the operator from the time consuming sequential measurement of points in subsequent images. After each change of the image on the screen the operator has to search the cursor in the image. A lot of blunders in architectural photogrammetry result from a confusion of similar looking object points. The eyes of the operator stay on the master image if the matching result is acoustically announced.

4. DIGITAL IMAGE ANALYSIS

For many purposes a detailed restitution result is required. To provide a facade plan with each single brick or stone an enormous amount of interactive work is necessary. Classical image analysis tools, like edge or line detection tools, produce open polygons with a lot of gaps. Many algorithms have been tested [*Marr & Hildreth* 1980, *Canny* 1986, *Deriche* 1987, *Haralick & Shapiro* 1992, *Shen & Castan* 1992], they work fine in many situations, but no approach delivered sufficient results from all test data. Therefore a new image segmentation approach has been implemented.

4.1 Image Segmentation using the Watershed Transformation

The watershed transformation is an approach based on mathematical morphology to divide an image due to discontinuities. In contrast to a classical area based segmentation, the watershed transform is executed on the gradient image. We obtain the gradient information

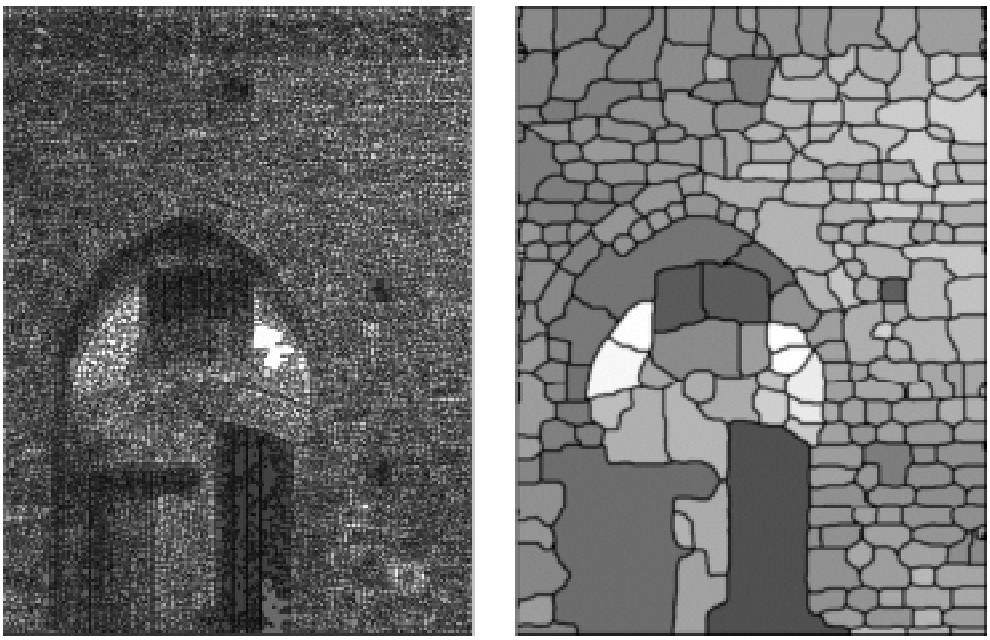

Fig 5: Results of Watershed Transformations: a) over-segmentation (left), b) incorrectly merged segments (right)

using the algorithm proposed by *Deriche* [1987]. A watershed is a small region that can not assigned definite to an influence zones of a local minimum.

For applying the watershed transform, an algorithm proposed by *Vincent et al.* [1991] was used. The intensity values are sorted and are stored in a table in order to achieve an efficient execution. The transform can be calculated without the gradient image using the table and neighborhood relations. A result of the watershed transform is shown in Fig. 5a.

It is evident that the segment sizes are very small and that uniform areas are splitted. The reason for the so-called over-segmentation is the sensibility of the gradient to noise. However, since watershed regions correspond one-to-one to the regional minima of the gradient surface, the number of regions can be reduced by elimination of the regional minima.

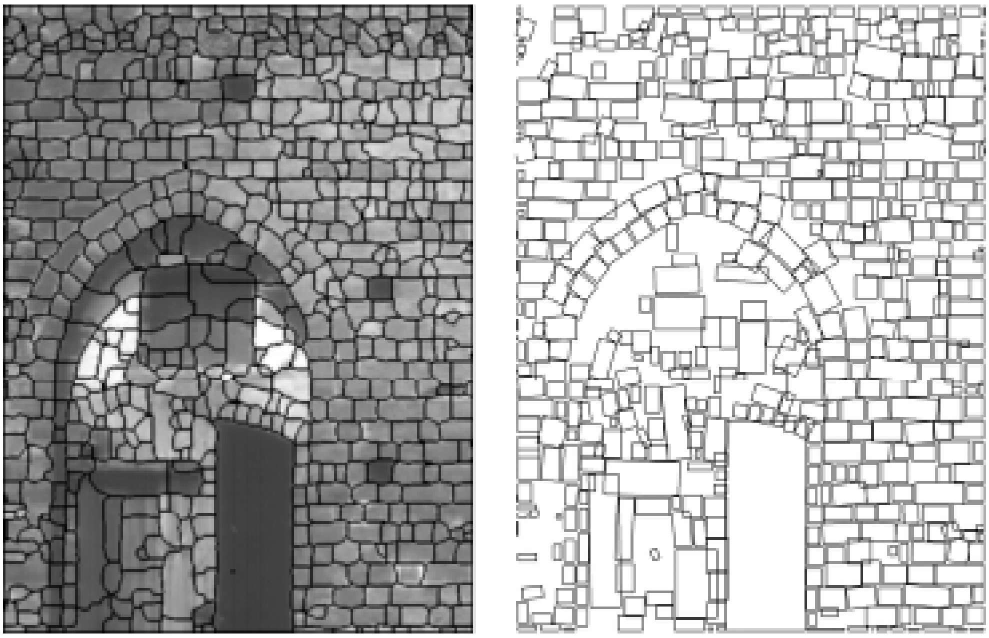

Fig. 6: a) Result of the watershed transformation with smoothing (left), b) Simple description of the segments using graphical primitives (right)

An obvious approach is the smoothing of the gradient image, e.g. using a gauss filter. The noise will be reduced and the segments will grow depending on the standard deviation σ. The choice of a very large σ may lead to incorrect merged segments (see Fig. 5b). A segmentation result of the watershed transform using a smoothed gradient with an appropriate smoothing parameter for the bricks is shown in Fig. 6a. In contrast to other segmentation algorithms, the method is very powerful for the extraction of joint structures in the upper area on the right side. A problem introduced by the smoothing process are the shifted positions of the contours. For simple object structures a description by graphic primitives using a form factor may be sufficient (see Fig. 6b). The correction of object contours with an arbitrary shape is more difficult.

4.2 Shape Improvement Using Active Contours

Active contours have the ability to conform to different contours within an image. In order to find the real contour of a stone using the active contour model it is important to specify an initial curve. A rough approximation to the desired contour in the image is supplied by the shifted contours of the watershed algorithm that also defines an outer boundary (see

Fig. 7a). The optimization process will minimize the contour's energy based on *the energy function.*

The *internal energy* consists of the rigidity of the active contour and the maximum change in the tangent vectors of the curve. In addition, the distance between contour points should be minimized and the shortest contour length is desired. The external forces are defined by the *constraint energy* and the *image energy* of a contour. The constraint energy attracts points on the active contour to points in the image and image energy describes how the contour conforms to the gray-level gradient within the image. Details concerning active contours can be found by *Kass et al.* [1988].

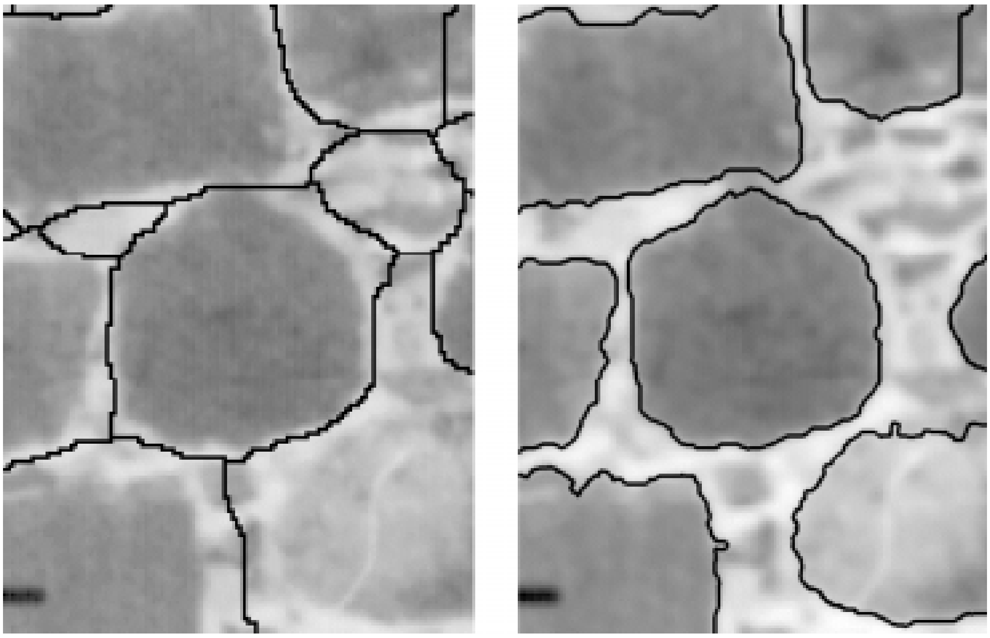

Fig. 7: a) Shifted contours of the watershed transformation using a smoothed gradient (left), b) Result of the optimization using Active Contours (right)

The result obtained by the energy minimization using a dynamic programming technique is shown in Fig. 7b. A major advantage of the active contour model is that the viscosity feature of the watershed segmentation process is also a feature of this approach. On the other hand, it is not easy to find appropriate parameters for multiple active contours and the optimization process is not very robust.

4.3 Merging of Watershed Regions using Fusion Criteria

Another approach to prevent the over-segmentation is the merging of small neighbored segments using fusion criteria. After applying the watershed transform this criterion is calculated for every region. The values are normalized to the maximum gray level and the regions are filled with the resulting values.

The so-called mosaic image can be used for another watershed transform during an iterative process. The merging may be based on differences in region means, the gradient along regions or on combined region variance. A lot of features are used to characterize the merging process, i.e. simple texture features like the mean value, variance and entropy. Using the region mean value, the quality is comparable with the results obtained by a classical region-growing approach.

5. CONCLUSIONS

Due to the complexity of architectural imagery no fully automatic photogrammetric restitution can be anticipated for the near future. But there are a lot of fields of research, where steps towards a supported processing may be anticipated in the next years. One approach is to support the photogrammetric operator during his work, the other is to extract selected but numerous objects automatically from the digital imagery by suited digital image analysis techniques. Further progress can be anticipated by using edge based approaches instead of the classical point based restitution techniques. This approaches together will accelerate the architectural photogrammetric process.

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