CIPA International Symposium '97 - International Committee for Architectural Photogrammetry,
Photogrammetry in Architecture, Archaeology and Urban Conservation, Göteborg, Sweden, Oct. 1-3, 1997.

TOWARDS AUTOMATION IN ARCHITECTURAL PHOTOGRAMMETRY USING DIGITAL IMAGE PROCESSING

ALBERT WIEDEMANN and VOLKER RODEHORST

Technical University of Berlin
Department for Photogrammetry and Cartography
Straße des 17. Juni 135, Sekr. EB9
D-10623 Berlin, Germany

albert, vr@fpk.tu-berlin.de

KEY WORDS: Architectural Photogrammetry, Automation, 3D Measurement, Digital Image Analysis

ABSTRACT

This paper describes some approaches towards an automation in architectural photogrammetry using digital image processing. We present techniques for semi-automatic 3D measurement and the application of digital image analysis to support the extraction of facade primitives. The proposed semi-automatic 3D measurement is used for the determination of tie points for the orientation and the interactive restitution process. The use of digital image analysis in architectural photogrammetry allows the automation of various low-level tasks. Exemplary, we introduce some approaches for a computer assisted generation of a facade map from gray-level photographs. Some results for the mapping of joint contours, i.e. for irregular stones, are presented.

1. AUTOMATION IN ARCHITECTURAL PHOTOGRAMMETRY

Architectural photogrammetry is well suited to extract information from images, required for documentation, restoration and reconstruction. During the last three decades, there have been enormous improvements in the analytical photogrammetry, providing much better orientation techniques. Contrary, quite a few improvements can be notified in the restitution process. For example, the sequential measurement of corresponding points in two or more digital images is a step back, compared to the traditional stereo restitution.

In Architectural Photogrammetry two restitution techniques are widely used. The first is the stereophotogrammetric approach. Images are acquired in a stereo constellation with nearly parallel viewing directions straight to the baseline. Only image pairs with a limited convergence, acquired straight in front of the facade with a base–distance relation between 0.1 and 1, are well suited for the restitution. Other arrangements obstruct the stereo view and the restitution. This arrangement is a limitation factor in many situations.

Another shortcoming of this approach is the requirement for expensive hardware like analytical plotters. So far no low-cost and reliable hard- and software is available for a digital stereophotogrammetric restitution for architectural purposes. Beside these shortcomings, stereophotogrammetry delivers precise and reliable results. If a large amount of data is required the expenditures are justified (DALLAS, 1995).

The other widely used approach is the restitution based on bundle adjustment. A lot of low-cost systems have been developed for these purposes (FELLBAUM, 1992). Whereas in older systems usually digitizer have been used for the measurement of image coordinates, today the common technique is the measurement on the screen in the scanned images. The main shortcoming of the bundle oriented systems for orientation and for rectification is the necessity to measure points sequentially in the different images. Therefore only clearly identifiable points can be used.

In some systems epipolar lines are displayed in the images after the orientation process. This provides the operator with the opportunity to measure points on edges intersected by the epipolar lines. Until now, the operator has to switch between the images and to re-identify the points. This procedure is time consuming and produces a lot of blunders. This blunders are difficult to detect and to solve, because of the separation of measurement and calculation.

With modern computers and software concepts like multi-threading it should be possible to execute real time orientation calculations in the background during the interactive measurement, even on PCs. This would inform the operator directly after the measurement about the influence of the new measurement on the whole orientation. But the main emphasis of this paper is put on the restitution process, which requires an enormous amount of interactive work.

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.

So far in many software packages the measurement of reseau crosses is the only task, where digital image processing is used for automation. But the wide varieties of features at building prevent that full automatic image analysis techniques can be used in architectural photogrammetry. Therefore, we decided to follow two independent developments to avoid these problems. The first is to use semi-automatic techniques, which support

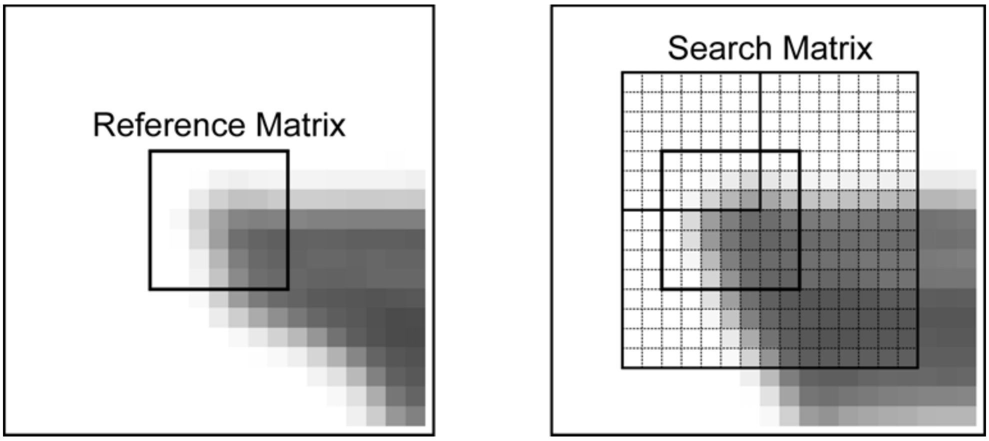

Figure 1: Classical matching approach, as used for measurement of tie points

the operator – but leave the decision for each feature to extract in the hand of the operator. This requires not notably more work than automatic processes followed by interactive control. The second approach is to confine oneself to a few but frequent features.

2. SEMI-AUTOMATIC MEASUREMENT

Special attention is put on the possibilities to support the interactive point measurements by digital image processing techniques, like matching. 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 that are provided by various geometric constraints.

2.1. Measurement of Tie Points for the Orientation

For relative orientation and bundle adjustment a large amount of tie points is required. The more and better distributed tie points are available 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 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 the correlation coefficient is calculated within the search area. The corresponding point is anticipated at the position with the maximum correlation coefficient. There are further techniques available for the measurement of tie points, like least-squares matching (WEWEL, 1996) or feature based matching (FÖRSTNER & GÜLCH, 1987). We examine these 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. 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.

2.2. Measurement for the Restitution

If orientation data are available, it is possible to reduce the search area of a correlation process. The *Vertical Line Locus* (*VLL*) technique reduces the search area of matching 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 acquire 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. 2). 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 problems in architectural photogrammetry result from a confusion of similar looking object points. The eyes of the operator stay on the master image if the

Number of already measured points	Prediction technique
0	Interactive
1	Two translations
2	Similarity transformation
3	Affine transformation
4	Projective transformation
≥ 5	Relative Orientation and calculation of a medium distance

Table 2: Prediction of the position of corresponding points

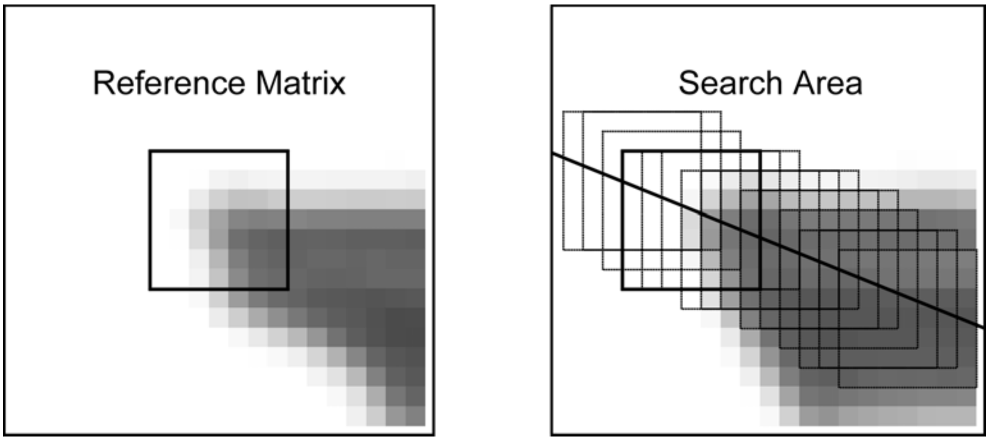

Figure 3: Matching along the epipolar line in the restitution process

matching result is acoustically announced. Using the semi-automatic point measurement during the restitution process the task of the operator is reduced to mono-plotting. But even mono-plotting is tedious if many data have to be acquired. Experiences show, that a large part of this work is the exact positioning of the floating mark on edges. Therefore a technique has been developed to support the measurement of edges. The first point of the edge has to be measured interactively. As in other systems a rubber line is drawn from the initial point to the cursor position. In our system a search line through the cursor position and rectangled to the connection line between the initial point and the cursor positions is defined.

The gray value gradient is calculated along this search line. A weight factor is introduced, reducing the weight of the gradient with a growing distance from the cursor position. The product of the weight factor and the gradient is defined as likelihood of edge intersection. If a point within a maximum distance from the cursor position has a significant higher edge probability, the maximum likelihood of an edge intersection is calculated on the search line in sub-pixel accuracy. A line is drawn from the initial point to this proposed edge point. If the cursor is moved into the surroundings of an edge, the end of the line jumps from the cursor to the proposed edge point. This approach relieves the operator from an exact positioning of the cursor on the edge and is well suited for the measurement along straight edges. For curved edges a technique is under development to fit the drawn rubber line to an edge in the surroundings of the straight connection of initial point and a proposed edge point. An approach is used, comparable to active contours or snakes (see section 3.2). The target function is to minimize the necessary energy for the connection between the initial point and the proposed edge point. The desire to minimize the absolute sum of the inverted gradients leads to a high frequent curved line. The minimizing of the curvature and the sum of changes of the curvature the rubber line would lead to a straight line.

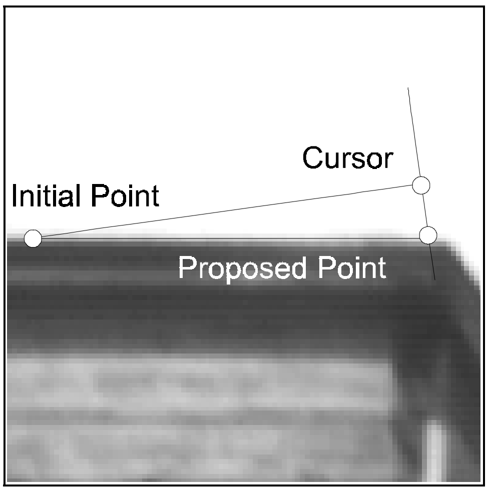

Figure 4: Semi-automatic measurement of edges during the restitution process

A compromise has to be found to deliver a well fitting and short connection. After determine the path of the rubber line a further algorithm reduces the number of vertexes by eliminating nodes, without a significant influence on the shape of the curve. This is done by calculating the distance of the vertex from the connection between the preceding and following point. As the derived rubber line is displayed on the screen, the operator can change the form of the line by moving the cursor.

3. DIGITAL IMAGE ANALYSIS

For many purposes a detailed restitution result is required. To provide a two-dimensional facade plan containing every brick or stone, an enormous amount of interactive work is necessary. Utilizing digitized images for the acquisition of geometric information, the human operator can be assisted by some image processing tools. The use of digital image analysis in architectural photogrammetry allows the automation of various low-level tasks and supports the interpretation of facades. The focus of the described work is the computer assisted mapping of joint contours in architectural gray-level images.

Classical image processing techniques like edge or line detection filters are very sensitive to noise and not suitable for historical objects, where the analysis task is complicated by weathering. Therefore, a new image segmentation technique has been developed using *digital watersheds*.

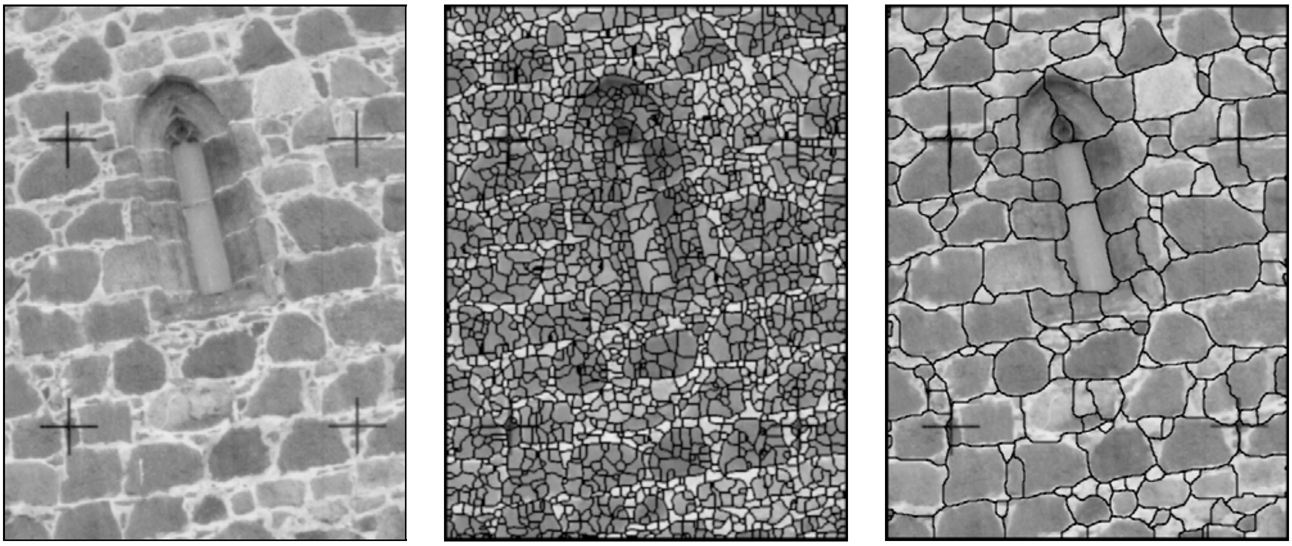

Figure 5: a) Digital gray-level image (*left*), **b)** Over-segmented result of the watershed transform (*center*), **c)** The result of the watershed transform with a smoothed gradient image (*right*)

3.1. Segmentation of Stones Using the Watershed Transform

The watershed transform is an image segmentation approach based on mathematical morphology that divides an image due to the topology of the gray-levels. In contrast to a classical area based segmentation, the watershed transform is executed on the gradient image. The *gradient* defines the first partial derivate of an image and contains a measurement for the change of gray-levels. We obtain the gradient information using the algorithm proposed by DERICHE (1987). To illustrate this technique, the amplitude of the gradient can be interpreted as relative altitude.

The aim of the watershed transform is to search for regions of high intensity gradients (*watersheds*) that divide neighbored local minima (*basins*). A digital watershed is defined as a small region that can not assigned unique to an influence zone of local minima in the gradient image. For applying the watershed transform an advanced algorithm proposed by VINCENT (1991) was implemented. The intensity values are sorted and stored in a table to achieve an efficient execution. The transform can be calculated without the gradient image using a table and neighborhood relations. The result obtained from the watershed transform is shown in Fig. 5b.

Watershed Transform Using a Smoothed Gradient

It is evident that the segment sizes are very small and that uniform areas are separated. The reason for the so-called *over-segmentation* is the sensibility of the gradient to noise. 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. A segmentation result of the watershed transform using a smoothed gradient for the stones is shown in Fig. 5c. A problem introduced by the smoothing process are the shifted positions of the contours. The correction of the object contours with an arbitrary shape is difficult (see section 3.2).

Merging of Watershed Regions

Another approach to prevent the over-segmentation is the merging of small segments using a *fusion criterion*. By merging of neighbored segments, erroneous watersheds are eliminated. After applying the classical watershed transform, this criterion is calculated for every region. The numbers are normalized to the maximum gray-level and the regions are filled with these values. The resulting *mosaic image* (see Fig. 6a) can be used for another watershed transform as input during an iterative process. The merging criterion is based on region properties (i.e. texture features) and the gradient amplitude between the regions. Using the region mean value, the quality is comparable with the results obtained by a classical area-based segmentation approach (e.g. *region-growing*). Utilizing high-level texture features as criterion (i.e. *Gabor energy filter* or *Markov random fields*) this technique is able to increase the quality of the segmentation process.

Combination of the Watershed Algorithms

Using the watershed transform with a smoothed gradient image, most of the stones can be separated but with shifted segment contours (see Fig. 5c). The mosaic image of the watershed merging process contains the correct contours but several objects are joined erroneously (see Fig. 6a). The new segmentation technique is a combination of these approaches and is well suited to separate objects from a background.

First, both algorithms have to be applied to the input image separately. Using a logical operation the erroneous joined results of the watershed merging are isolated by the result of the watershed smoothing. A superposition of the joined segments with the shifted watersheds is shown in Fig. 6b. After the separation of the stones a postprocessing stage is necessary. The elimination of remains may be done by a *morphological opening*, which is defined as an erosion followed by a dilation. The final result of the *combined watershed algorithm* applied to irregular stones is shown in Fig. 6c.

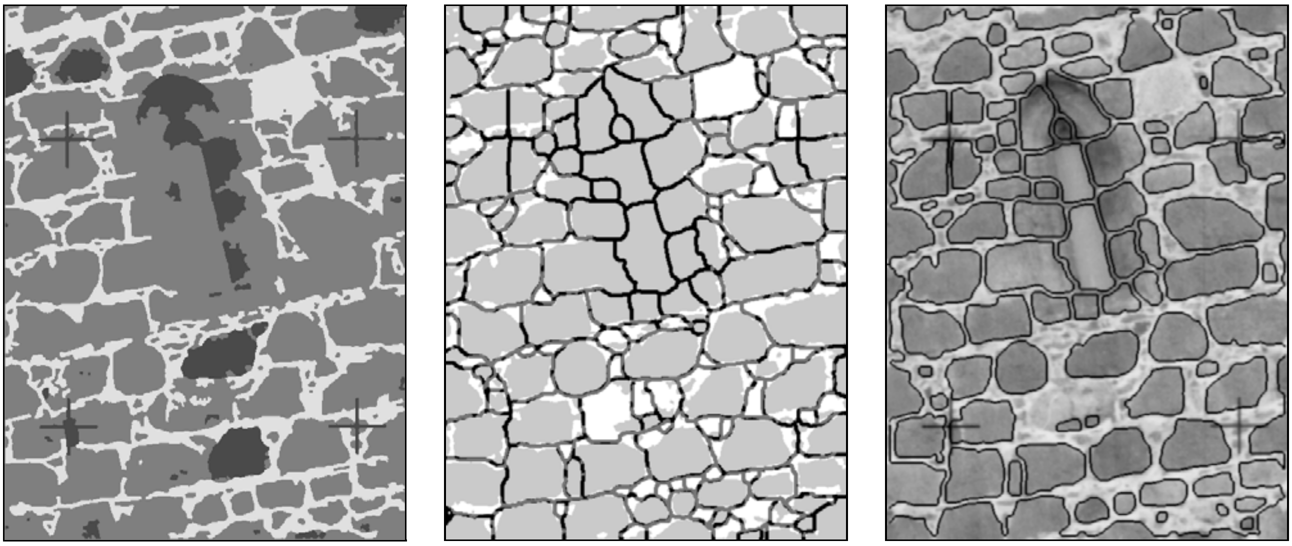

Figure 6: a) Merged watershed regions using the mean value (*left*), **b)** Superposition of the watersheds with the merged segments (*center*), **c)** Result of the combined watershed algorithm (*right*)

3.2. Shape Analysis 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 watershed algorithm that also defines an outer boundary (see Fig. 8b). The optimization will minimize the contour's energy based on an energy function. The internal energy consists of one term, which affects the rigidity of the active contour and the maximum change in the tangent vectors of the curve. Additionally, another term minimizes the distance between contour points and favors the shortest contour length. 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. The image energy describes how the contour conforms to the gray-level gradient within the image. Details concerning active contours can be found by KASS (1988). The result obtained by the energy minimization using a dynamic programming technique is shown in Fig. 8b. A major advantage of the active contour model is the retention of the viscosity feature of the watersheds. On the other hand, it is not easy to find appropriate parameters for different contours automatically and the optimization process is not very robust. For now, the human operator has to verify the results obtained with active contours and to adjust the parameters.

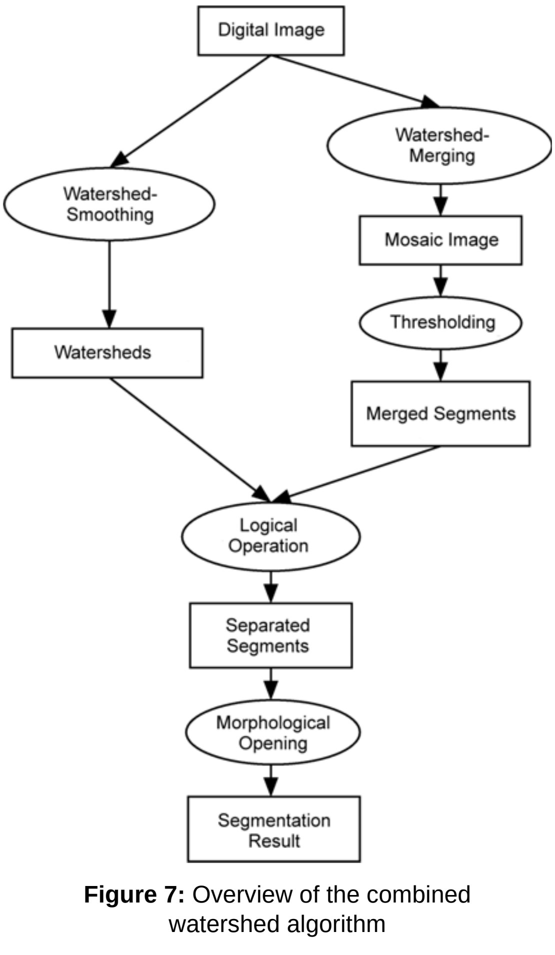

Figure 7: Overview of the combined watershed algorithm

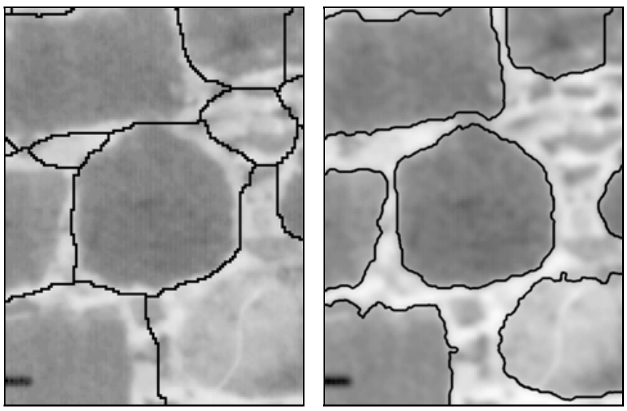

Figure 8: a) Shifted contours of the watershed transform using a smoothed gradient (*left*), **b)** The result of the optimization process using Active Contours (*right*)

4. CONCLUSIONS

Due to the complexity of architectural imagery an automatic photogrammetric restitution cannot be expected in the near future, but there are a lot of investigations towards a computer assisted restitution for the next years. The first semi-automatic approach supports the photogrammetric operator interactively during his work, the other tries to automate monotonous low-level tasks using digital image analysis.

We presented different approaches to support the construction of a facade map by using digital image processing. We can summarize, that the watershed transformation is well suited for the segmentation of facades. The proposed combination of the watershed algorithms is able to separate objects from a background and is well suited for the segmentation of irregular stones.

The active contour model was introduced to raise the precision of the measurement. Exemplary, this approach can produce satisfying results, but the optimization process is not very robust and needs more investigations for practical use. Overall, we should like to emphasize, that the presented techniques towards an automation in architectural photogrammetry using digital image processing will assist and accelerate the human restitution process.

5. ACKNOWLEDGMENT

This work has been supported in part by the German Research Foundation (*DFG*).

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