OBJECT MONITORING/RECONSTRUCTION WITH AUTOMATED IMAGE-BASED MEASUREMENT SYSTEMS

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Abstract: The increasing number of objects involved in deformation processes in highly populated areas has increased the demand for rapidly working and easily usable deformation and measurement systems. This demand is associated with a higher degree of automation of monitoring, analysis and interpretation. There are various different sensor systems on the market that can be used for object monitoring. During the last years, research in the area of image-based measurement systems has gained an increasing interest. Unfortunately, most of such systems required artificial targets defining object points. To overcome this restriction the texture on the surface of the object can be used to find interesting points. However, well-trained "measurement experts" are required to operate such a system. In a complex image-based measurement system, the selection of suitable sensor units or suitable measurement modes is a highly non-trivial task. To make the measurement system easily applicable even for non-experts, it can be extended by a suitable decision support system. The following paper presents such a automated image-based measurement system currently under development.

1. Introduction

In science and industry increasingly 3-D representations and monitoring of objects in the built environment are needed with high accuracy. Meanwhile a greater number of optical 3-D measurement techniques is available: laser scanners, photogrammetric systems, measurement robots, theodolite measurement systems [6]. In comparison with laser scanners and measurement robots theodolite measurement systems measure objects with higher accuracy, compared with photogrammetric systems in many cases they can easier be used for on-line measurement processes. This will especially be the case, if the theodolite measurements can be performed with a high degree of automation. This will be possible, if the images of the telescope's visual field is used in a more flexible way.

Such a image-based measurement system should be capable of applying knowledge within a visual input to discriminate decisive from irrelevant information, to find out what needs to be attended to, and when, and what to do in a meaningful sequence, in correspondence with visual feedback. Therefore, successful visual interpretation includes fusion of visual features, applies reasoning and inference for prediction and verification, and requires context recognition to focus attention on promising information.

We report on the architecture and functionality of the such a image-based measurement system, especially on the potentiality of automation – the concept of a knowledge-based decision system, its development stage and the promising results obtained in experimentation.

2. Image-based measurement system

A image-based measurement system (Figure 1) is a combination of different components: image sensors (image-based tacheometers or videotheodolites), a computer system, software (e.g. control system, image processing, etc.), and accessories.

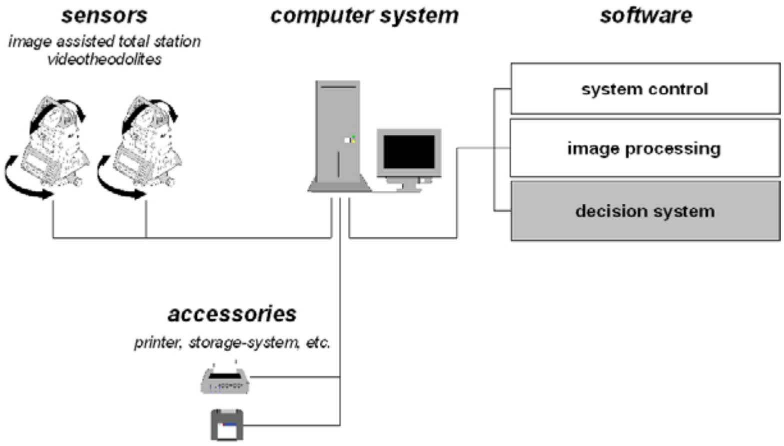


Figure 1: Abstracted architecture of a image-based measurement system.

Recently, research interest in the area of image-based measurement systems has been increased. Most notably the works done by Walser [21, 22], Wasmeier [23] and Topcon [20]. The central topic of all these image-based measurement systems is the calculation of 3D object coordinates from 2D image coordinates for subsequent processing steps.

Image-based tacheometers/videotheodoites have a CCD camera in its optical path. The images of the telescope's visual field are projected onto the camera's CCD chip. The camera is capable of capturing mosaic panoramic images through camera rotation, if the axes of the theodolite are driven by computer controlled motors. With appropriate calibration these images are accurately georeferenced and oriented as the horizontal and vertical angles of rotation are continuously measured and fed into the computer. The oriented images can then directly be used for direction measurements with no need for object control points or photogrammetric orientation processes.

In such a system viewing angles must be addressed to CCD pixels inside the optical field of view. That means, especial calibration methodes have to be used, an autofocus unit has to be added to the optical path, and special digital image processing procedures have to be integrated.

An optical system for such a system was developed by Leica Geosystems [21, 22]. It is reduced to a two-lens system consisting of the front and the focus lens. Instead of an eyepice a CCD sensor is placed in the intermediate focus plane of the objective lens. The image data from the CCD sensor are fed into a computer using a synchronized frame grabber. For the transformation of the measured image points into the object space the camera constant must be known[1].

[1] In an optical system with a focus lens the camera constant, however, changes with the distance of the object. The camera constant can be derived from the focal length. This can be performed automatically if an encoder measures the focus lens position relative to an origin, which is chosen when focusing to infinity.

Points of interest can be identified with interest operators (IOPs) (e.g. Förstner operator [4] or Harris operator [8]). Interest operators permit the location of a wide field of different points with subpixel accuracy: points on lines or edges, centres of symmetrical figures, intersections of lines, edges, etc.

In a complex measurement system with many algorithms for image processing and interest operators, the selection of suitable algorithms, their order of application, and the choice of input parameters is a non-trivial task. To provide automated support, a suitable decision support system has to be integrated in the system (see Figure 1).

A decision (support) systems is a specific class of a computerized information system that supports engineering, business or organizational decision-making activities. Such a system consists in its plainest form of three main components, namely an input component, decision algorithm(s) and an output component.

There exist various approaches for the implementation of decision support algorithms (module-oriented systems, object-oriented systems, knowledge-based systems, neural networks, software agents, and others). One of the most suitable and common used approaches for (automatic) decision making are knowledge-based systems (rule-based). This technique has been developed more than thirty years ago and has some exceptional advantages in comparison with conventional approaches.

Gonzalez et al. [5] have formulated three fundamental concepts which distinguish knowledge-based systems from conventional algorithmic programs and from general search-based programs: (1) the separation of the knowledge from how it is used, (2) the use of highly specific knowledge, and (3) the heuristic rather than algorithmic nature of the knowledge employed.

The first underlying idea is the most important and leads to one of the biggest advantages of knowledge-based systems compared to conventional software. The fundamental concept of the separation of domain-knowledge from reasoning mechanism makes it easy to modify or extend the knowledge. In modern information technology changes occur frequently and knowledge has to be updated; ease of modification is a very important feature in these situations.

Knowledge-based systems (KBS) are complex computer software products that can be viewed from the perspective of an end user or from the perspective of a knowledge engineer. From the point of view of the user a knowledge-based system consists of an intelligent program, a user interface and problem-specific database. The system is a black box that operates based on unknown algorithms. From the developer’s (knowledge engineer) view the system consists of two components: an intelligent program and the development shell. The development shell is a set of tools that assist the implementation of relevant knowledge.

In image-based measurement systems all decisions have to be done on the basis of the captured image or on values which represent this image. Using the whole image as input is, because of processing time, not suited for an on-line measurement system. For this reason appropriate values which represent the captured image should be used (image analysis).

3. Processing chain

The central topic of all image-based measurement systems is the calculation of 3D object coordinates from 2D image coordinates for subsequent processing steps, like deformation analysis or object reconstruction. A system which works on-line has the additional task to provide all results nearly in real-time ("pseudo real-time"). For such a system several procedures can be developed – Reiterer [15] has developed the following processing sequence (Figure 2):

- image(s) capturing,
- image analysis,
- image preprocessing and image enhancement[2],
- image analysis,
- point detection,
- point filtering.

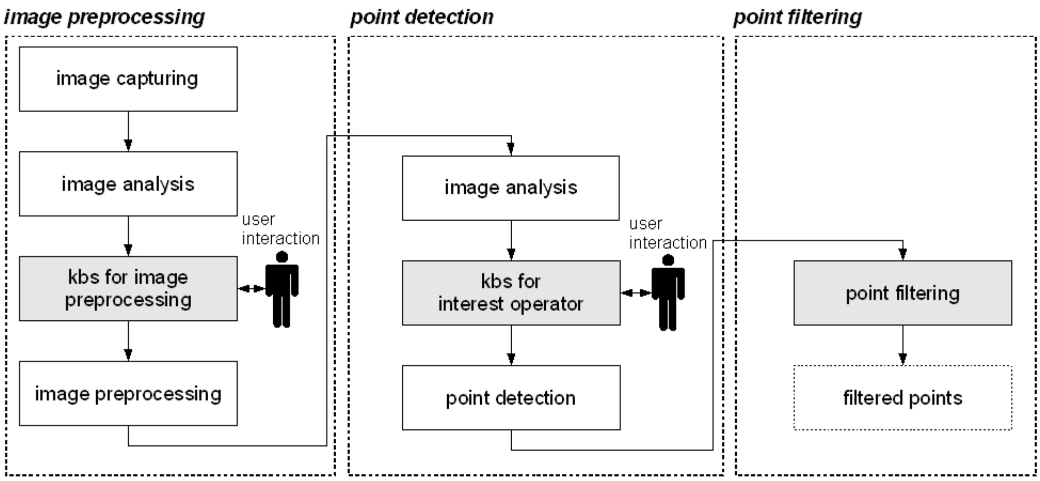


Figure 2: Processing sequence and data flow [15].

This procedure is based on point detection by means of interest operators and subsequent point filtering. This means that the point detection is not strongly application-oriented (point reduction to relevant points for subsequent processing steps is done by special filtering).

A more intuitive procedure could be based on "application-oriented point detection". The main goal of such a sequence is to use knowledge about the object (so-called "*model-knowledge*") and about the intended subsequent processes. From this viewpoint, a processing sequence could be sketched as follows: the master sensor (in a multisensor system one of the image-based theodolites) "scans" the object; on the basis of these captured data a *image understanding sytem* (or a *cognitive vision system*)[3] analyses the whole scene. The resulting description of the object is used by a knowledge-based system for several decision-makings like the choice of regions of interest or the choice of suitable object points for subsequent processing steps (e.g. deformation analysis). Additional features extracted by image analysis and by user-questions can influence this process. The development of such a measurement

[2] Experiments [16] have shown that a necessary precondition for the successful application of algorithms for finding interesting points is the "quality" of the image. It is often required to improve the visual appearance of an image. This can be done by image preprocessing and enhancement processes. Furthermore, flexible image processing makes the measurement system more independent of variable illumination during image capturing.

[3] *Image understanding* and *cognitive vision systems* perform information processing on multiple levels of abstraction, such as in low-level feature extraction, feature grouping, object and scene recognition.

system (which works on the basis of *cognitive vision*) is content of a new research project on the Vienna University of Technology, Institute of Geodesy and Geophysics (FWF-Project P18286: *Multi-Sensor Deformation Measurement System Supported by Knowledge Based and Cognitive Vision Techniques*).

Independent from the chosen startegy image preprocessing has to be done. In the following we will give some information about the processing procedure (inclusive point detection and point filtering) shown in Figure 2.

3.1. Automated image preprocessing:

Necessary processing steps can be selected on the basis of extracted image features (image analysis). Such a knowledge-based image preprocessing system was described in [16]. The decision process can be divided into three sub-processes: (1) choice of suitable algorithms for image preprocessing and enhancement, (2) definition of their execution order, and (3) predefinition of necessary parameters.

As mentioned above, the decision process can be executed on the basis of parameters extracted from the image. Examples for such image features are the histogram features or the Haralick features [7, 14].

Reiterer et al. [16] have shown that adequate image preprocesssing is possible with the following algorithms: histogram equalization, gray-level scaling (image brightening / darkening), median and gauss filtering, edge detection (Sobel-, Prewitt-, Laplace operator) and thresholding.

The knowledge aboute the coherences between image features and image preprocessing algorithms can be implemented by means of rules[4]. As an example, we list in the following the relevant rule for the detection of necessity of *edge detection*. The rule has the following syntax (*Clips syntax*[5]), and should be self-explanatory ("|" means "or"):

```
(defrule edge
  (Stat_Moments (M1_f very_low))
  (Stat_Moments (M2_f very_low))
  (Stat_Moments (M3_f middle_negative | high_negative | very_high_negative
                   | middle_positive | high_positive |very_high_positive))
=>
  (assert (condition (edge yes))))
```

3.2. Automated point detection:

Automated point detection in images can be done by means of *interest operators* (IOPs). They highlight points which can be found using correlation methods. There exist many IOPs [4, 8, 12, 14]; however, no IOP is suitable to find all desired points. For this reason, a measurement system should have included different IOP algorithms (e.g. Förstner operator, Harris operator, Hierarchical Feature Vector Matching operator, etc.). The choice of one or

[4] To make the image features more suitable for the knowledge-based decision system, a classification procedure should be used. This procedure translates the input values (image features) into linguistic concepts. The use of these concepts permits to write rules in terms of easily-understood word descriptors, rather than in terms of numerical values (fuzzy rules).

[5] For our example the knowledge-based system has been carried out in *Clips*, a productive development tool which provides a complete environment for the construction of *rule- and object-based systems* [3].

more suitable algorithm(s), their combination and parameter(s) can be done, on the basis of extracted image features, by a decision system (e.g. KBS).

The knowledge to be included in this part of the knowledge base can be obtained by theoretical considerations and extensive experiments. Only few evaluation methods for point detection (resp. description) algorithms can be found in the literature, cf. [1, 2, 10, 19], among which the work by Schmid et al. [19] on interest operators (IOPs) is of particular importance for image-based measurement systems. The prevailing methods for evaluation are largely based on subjective evaluation (visual inspection and ground-truth verification), as well as on objective criteria such as repeatability of information content for images. A drawback of these methods is that they neither account for the formation of the point cloud detected by a point detection algorithm, nor for its localization accuracy. In order to overcome this, Reiterer et al. [17] have introduced a novel criterion which is based on distances between sets of points and can be used as a complementary technique to the existing evaluation methods. This criterion allows to compare point detection algorithms very easily and, moreover, in an objective but strongly application-oriented way. Indeed, one aim of this new method is to move the evaluation process from an intuitive, informal one to a *measurable and computational* criterion. More details about the new evaluation method can be found in [17].

3.3. Automated point filtering:

The disadvantage of the shown processing sequence is that in spite of choosing suitable image preprocessing algorithms and suitable interest operators, the number of detected points is often too high. Point reduction can be done by adequate filtering.

In most cases, the elementary object structure can be represented by simple line geometry. Points detected apart from this line structure are undesirable and not useful for subsequent process steps, like object reconstruction or deformation analysis. The point reduction should be not a removing process of undesirable points (all detected points should be preserved such that no information is lost), but sould be based on the weighting of each point.

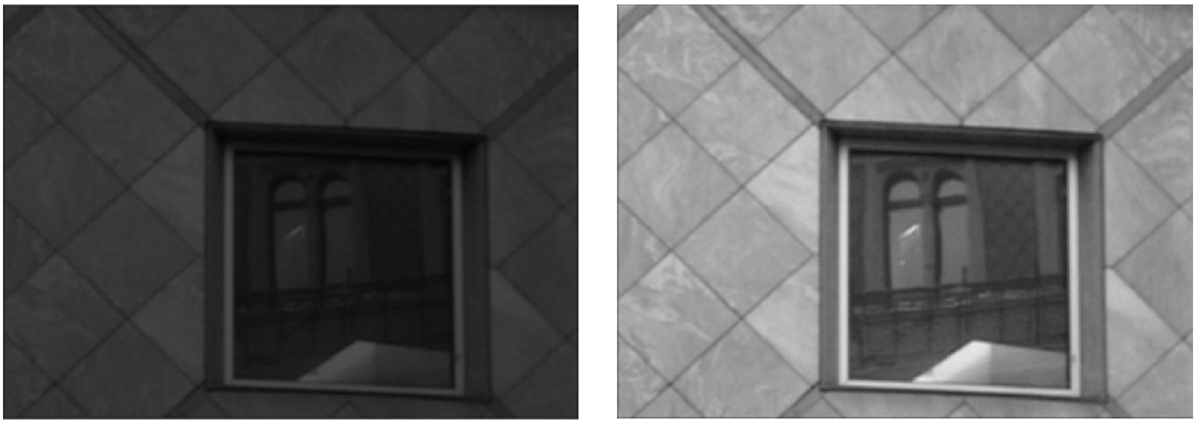
The filtering process can be done by means of two methods: (1) on basis of defined rules (knowledge-based), and interactive (user-based). For the first method, several criterions can be used to weighten each point, e.g. *"how many interest operators detect the (same) point"*, or *"which 'property-parameters', obtained from the interest operator(s), the point has"*. The second method can be realized by means of a simple user interface. The user has the possibility to remove single points or point groups.

Such a point filtering is a very simple method to reduce the number of points. To a certain degree of object complexity this methods yields good results. If object and desired point cloud are highly complex other methods are required (see argumentation in Section 3).

4. Experiments:

In this section we will present the complete functionality of such a image-based measurement system developed on the Vienna University of Technology, Institute of Geodesy and Geophysics (FWF-Project P14664: *Theodolite-based and Knowledge-based Multi-Sensor-System*) by an example.

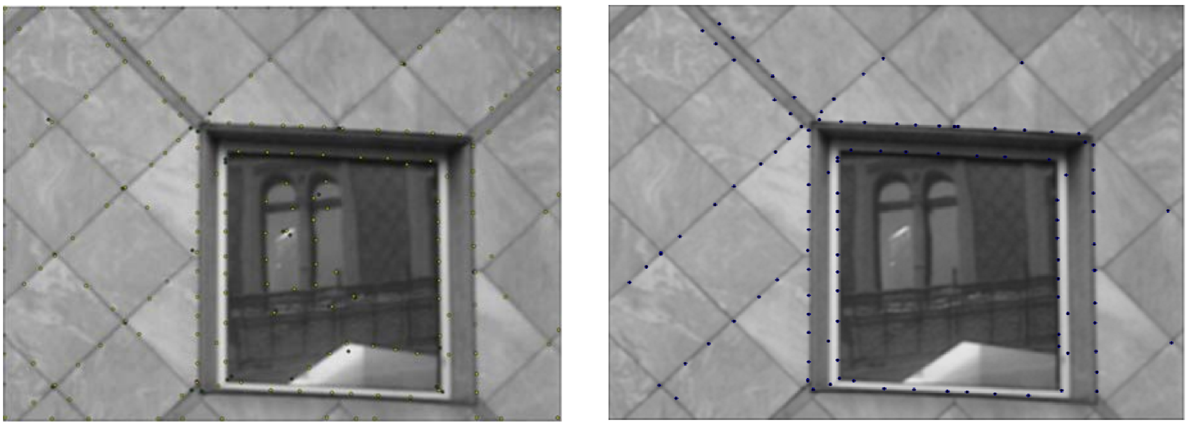
The picture in Figure 3a shows a noisy underexposed image; relevant details (like corner points) may not (or not easily) be visible. In order to improve the visibility of relevant details, suitable image processing and enhancement algorithms have to be used, which are selected by the KBS.



(a) (b)

Figure 3: (a) Noisy underexposed image; (b) image after *image brightening* and a 3×3 *median filtering*.

In this example, the system chooses the following algorithms on the basis of the extracted image features: *image brightening*, *gauss filtering*, *edge detection* and *thresholding*. Now, the KBS gives the user the possibility to overrule this decision. If the user deletes edge detection from the list (for our example we assume that), then only *image brightening* and *median filtering* (which replace the *gauss filtering*) remain. The processed image is shown in Figure 2b.



(a) (b)

Figure 4: (a) Interest points detected with combined Förstner and Harris operator; (b) final result after image preprocessing, application of interest operators and point filtering.

After preprocessing the image, its features will be recalculated. Furthermore, additional features are collected by user-queries. Based on these features, a combination of IOPs, including their parameters, has been selected by the KBS: (1) the Förstner and (2) the Harris operator. The detected points are shown in Figure 4a.

It can be seen that interest points are generally detected on the regular structure of the object. Only a small number of isolated single points are detected inside these “structure lines”. These points result from local grey-level differences, like “fault-pixels”. A more problematic area is the glass window, where many interest points are emerged by reflections.

Changes of parameter values (of the interest operators) would remove the undesirable points on the glass windows, but the desired interest points, too (the grey-level differences in this area are the same as those of the “structure lines” of the facade). Undesirable points can only be suppressed by a suitable point filtering technique as described above.

The resulting interest points are shown in Figure 4b. Most of the undesirable points have been filtered by the rule-based filtering sequence; only a small number of points (inside the glass window) by user interaction. It can be seen that the point cloud after filtering is more “structured” and therefore more suitable for subsequent processing steps, like deformation analysis or object reconstruction. Nevertheless, in the feature the filtering process should be improved; for example by integrating “*model-knowledge*” into the decision procedure.

Accuracy:

For testing and investigation of such a measurement system[6] different apllications have been carried out. Roic [18] has tested how accurate a object (facade) can be monitored by *interactive pointing* for deformation analysis. To enhance the image (the edges) preprocessing algorithms were used. The distance between object and measurement system was about 33m. The accuracy *s* of the determined edges was only limited by the roughness of the object surface and was ± 2mm. When the observation was performed without image preprocessing *s* increased to ± 5mm.

Mischke et al. [11] have tested the measurement system for *automated point detection by means of interest operators*. According to an object distance of about 3.5m (industrial object) the average accuracy for the components of the co-oordinates was: $s_x = \pm$ 0.10mm; $s_y = \pm$ 0.03mm; $s_z = \pm$ 0.06mm and therefore s= ± 0.12mm.

Runtime:

We will conclude this section with some information about the runtime of the developed system. For an image with 8 bits-per-pixel (bpp) and 640×480 pixels the following runtime values[7] results:

- 1 sec. for image analysis;
- 1 sec. for image processing;
- 5-30 sec. for point detection (5 sec. for the Förstner operator, 14 sec. for the Harris operator, and 30 sec. for the HFVM operator);
- 1 sec. for the knowledge-based point filtering.

The runtime is correlated with image size and detected points; all listed values are mean values (deviations from the mean value are under 1 sec.) from more than 100 images.

[6] The used measurement system is based on two Leica TM3000V video-theodolites.
[7] Calculated on a Personal Computer – Intel Pentium 4 with 3 GHz and 512MB Ram.

5. Conclusion:

In this paper, a new knowledge-based decision system for a image-based measurement system has been described. The main task of this development has been the automation of different decision makings in the course of the measurement process. The decision process is based on image features which represent the decisive image properties. For an on-line system a fast execution of such a feature extraction (image analysis) is necessary. This can be done by statistical feature extraction techniques.

Such a system presents a basic approach for an automated on-line image-based measurement system. The degree of automation can be very high, whereas by decision-making, human interaction remains an important part of the workflow even though the amount of decisions done by the user can be reduced considerably to a minimum.

There are still many possibilities to improve the operability of the system, e.g. integration of more algorithms of image preprocessing and point detection.

Beside the improvement of the system, the degree of automation for the whole system should be increased by integrating other sensors in the measurement process. A suggestive extension could be the integration of 3D laser scanners. The data of the different sensors have to be merged by a special data fusion process, which could be knowledge-based. Such a system provides an immense number of 3D data, both from the videotheodolite system and from the laser scanner. This point cloud may be reduced by filtering, even if not very effective. A new approach could build on cognitive vision.

References:

[1] Baker, S. / Nayar, S.K.: Global measures of coherence for edge detector evaluation. Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition, Colorado, 1999.

[2] Bowyer, K. / Kranenburg, C. / Dougherty, S.: Edge detector evaluation using empirical ROC curves. Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition, Colorado, 1999.

[3] CLIPS-Project-Page: http://www.ghg.net/clips/CLIPS.html, (as 03.2006).

[4] Förstner, W.: Statistische Verfahren für die automatische Bildanalyse und ihre Bewertung bei der Objekterkennung und -vermessung. DGK, vol. C, no. 370, München, 1991.

[5] Gonzalez, A.J. / Dankel, D.D.: The Engineering of Knowledge-based Systems. 1st Edition, Prentice-Hall Inc., 1993.

[6] Grün, A. / Kahmen, H.: Optical 3-D Measurement Techniques VII, Volume I and II, Vienna, 2005.

[7] Haralick, R.M. / Shapiro, L.G.: Computer and Robot Vision. 1st Edition, Addison-Wesley Verlag, New York, 1993.

[8] Harris, C. / Stephens, M.: A combined corner and edge detector. In: Proceedings of the 4th ALVEY vision conference, Matthews (ed.), University of Manchester, 1988.

[9] Kahmen, H. / Niessner, A. / De Seixas, A.: 3D Object Sensing Using Rotating CCD Cameras. In: Kropatsch / Bischof (eds.), Digital Image Analysis, 1st Edition, Springer, Berlin/Heidelberg/New York, 2001.

[10] Mikolajczyk, K. / Tuytelaars, T. / Schmid, C. / Zisserman, R. / Matas, J. / Schaffalitzky, F. / Kadir, T. / Van Gool, L.: A Comparison of Affine Region Detectors. International Journal of Computer Vision, 2004.

[11] Mischke, A. / Kahmen, H.: A New Kind of Measurement Robot System for Surveying of non Signalized Targets. In: Optical 3-D Measurement Techniques IV, Grün and Kahmen (eds.), Herbert Wichmann, Karlsruhe, 1997.

[12] Paar, G. / Rottensteiner, F. / Pötzleitner, W.: Image Matching Strategies. In: Kropatsch / Bischof (eds.), Digital Image Analysis, 1st Edition, Springer Verlag, Berlin/Heidelberg/New York, 2001.

[13] Perner, P.: Why Case-Based Reasoning is Attractive for Image Interpretation. In: Aha / Watson (eds.), Case-Bases Reasoning Research and Developments, Springer Verlag, 2001.

[14] Pratt, W.K.: Digital Image Processing. 1st Edition, John Wiley and Sons, New York/Chichester/Brisbane/Toronto, 1978.

[15] Reiterer, A.: A Knowledge-Based Decision System for an On-Line Videotheodolite-Based Multisensor System. PhD thesis, Vienna University of Technology, 2004.

[16] Reiterer, A. / Kahmen, H. / Egly, U. / Eiter, T.: Knowledge-Based Image Preprocessing for a Theodolit Measurement System. In: Optical 3-D Measurement Techniques VI/I, pp. 183-190, Grün and Kahmen (eds.), Privately published, Zurich, 2003.

[17] Reiterer, A. / Eiter T.: A Distance-Based Method for the Evaluation of Interest Point Detection Algorithms. IPIC2006, in review.

[18] Roic, M.: Erfassung von nicht signalisierten 3D-Strukturen mit Videotheodoliten. PhD thesis, Vienna University of Technology, 1996.

[19] Schmid, C. / Mohr, R. / Bauckhage, C.: Evaluation of interest point detectors. In: International Journal of Computer Vision - Volume 37/2, pp. 151-172, 2000.

[20] Topcon-Webpage: The GPT-7000i, (as 03.2006).

[20] Walser, B.:Development and Calibration of an Image Assisted Total Station. PhD thesis, ETH-Zurich, 2004.

[21] Walser, B. / Braunecker, B.: Automation of Surveying Systems through Integration of Image Analysis Methods. In: Optical 3-D Measurement Techniques VI/I, pp. 191-198, Grün and Kahmen (eds.), Privately published, Zurich, 2003.

[22] Wasmeier, P.: The Potential of Object Recognition Using a Servo-tacheometer TCA2003. In: Optical 3-D Measurement Techniques VI/II, pp. 48-54, Grün and Kahmen (eds.), Privately published, Zurich, 2003.