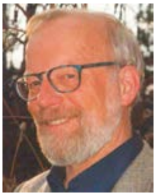
# A Knowledge-Based Optical 3D Measurement and Analysis System for Quality Control



*Alexander Reiterer, Martin Lehmann, Johannes Fabiankowitsch and Heribert Kahmen*

**Abstract**

In the FWF project P18286 *"Multi-Sensor Deformation Measurement System Supported by Knowledge Based and Cognitive Vision Techniques"* a new kind of image-based measurement system is under development. This system is able to detect un-signalised object points by means of appropriate algorithms – the procedure is divided into three main steps: image pre-processing, automated point detection and interactive point filtering. The system is based on new techniques (originally developed in the area of Artificial Intelligence) which shall be used for the task of deformation measurement, analysis and interpretation. Examples for such techniques are knowledge-based systems, cognitive vision and image understanding methods and case-based reasoning.

**Kurzfassung**

Derzeit wird im Zuge des FWF Projektes P18286 *"Multi-Sensor Deformation Measurement System Supported by Knowledge Based and Cognitive Vision Techniques"* ein neues bild-basiertes Messsystem entwickelt. Dieses System ist fähig nicht-signalisierte Punkte mit Hilfe geeigneter Algorithmen zu detektieren – die Prozedur ist in drei Teilschritte unterteilt: Bildaufbereitung, automatische Punkterfassung und Punktfilterung. Das System basiert auf neuen Techniken (ursprünglich im Fachgebiet der Künstlichen Intelligenz entwickelt), welche für die Teilschritte der Deformationsmessung, -analyse und -interpretation genutzt werden sollen. Beispiele solcher Techniken sind wissensbasierte Systeme, Cognitive Vision, Bildverstehen und Fallbasiertes Schließen.

## 1. Introduction

In science and industry (e.g. in architecture, medicine, or construction), highly accurate 3D representations and/or monitoring of objects are required. A great variety of optical 3D measurement techniques like laser scanners, photogrammetric systems, or image-based measurement systems is available to achieve this need.

In comparison with laser scanners, image-based systems measure objects with higher accuracy; compared with photogrammetric systems, they can be used more easily for on-line measurement processes. This will especially be the case, if the measurements can be performed with a high degree of automation.

During the last years, research in the area of image assisted measurement systems has gained an increasing interest. Most systems are working on the basis of user-interaction. Notable are the systems developed by *Leica Geosystems* [18, 19], by *Technische Universität München* [20], by *Ruhr University Bochum* [16] and by *Topcon* [17] (see Figure 1).

The central topic of all image-based measurement systems is the calculation of 3D object coordinates from 2D image coordinates for subsequent processing steps. As mentioned above the concept of these systems is based on a permanent interaction between user and system.

One of the main goals of the research work done at the *Institute of Geodesy and Geophysics* of *Vienna University of Technology* is to automate such image-based measurement systems. *Fabiankowitsch* [6] was the first researcher who experimented with a new measurement system on the basis of the *Leica TM3000* videotheodolite. His work resulted in special measurement methods (filtering techniques) for active targets. In 1994, the research project *"Stereovideometry and Spatial Object Recognition"* commenced. One of the milestones of this project was the work done by *Roic* [14]. The aim of his work was to prepare images of unsignalized targets by using image processing methods, in order to make interactive and automatic spatial surface measurement possible. A few years later *Mischke* [11] developed a powerful measurement system based on two videotheodolites. The system was able to measure active or passive targets and non-signalized points, like intersections of edges or lines. *Mischke* has implemented the *"Förstner Interest Operator"* to select all remarkable but non-signalized points. *Interest operators* (IOPs) were well-known for offline applications in photogrammetry, but had not been used for videotheodolites before.

The disadvantage of all these measurement systems is the requirement for a well-trained "measurement expert" who has to have certain skills and experience to properly handle the complex system. From sensor orientation, data capturing to the detection and tracking of points of interest, a series of actions and decisions have to be performed. In two research projects at the *Institute of Geodesy and Geophysics* of *Vienna University of Technology (1:2001-2005 - "Theodolite-based and Knowledge-based Multi-Sensor-System"; 2: 2006-2008 - "Multi-Sensor Deformation Measurement System Supported by Knowledge-Based and Cognitive Vision Techniques"*) a new kind of measurement system is under development [13]. This system is based on new techniques (originally developed in the area of Artificial Intelligence) which shall be used for the task of *decision making* and *quality control* (deformation measurement, analysis and interpretation). We report on the state-of-the-art of such a new measurement system, its functionality and development stage.

## 2. Concept for a new kind of measurement system

An image-based measurement system is a combination of different components:

- image sensors (our system is based on the Leica IATS – see Figure 1c),
- a computer system,
- software (e.g. control system, decision-making system, image processing, etc.),
- accessories.

IATS and videotheodolites 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.

An *optical system* for such a system (see Figure 2) was developed by *Leica Geosystems* [19]. It is reduced to a two-lens system consisting of the front and the focus lens. Instead of an eyepiece 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. In an optical system with a focus lens the camera constant, however, changes with the distance of the object.

(a) (b) (c)

***Figure 1:*** *Examples of image-based measurement systems developed by (a) Topcon, by (b) the University of Bochum, and (c) by Leica Geosystems..*

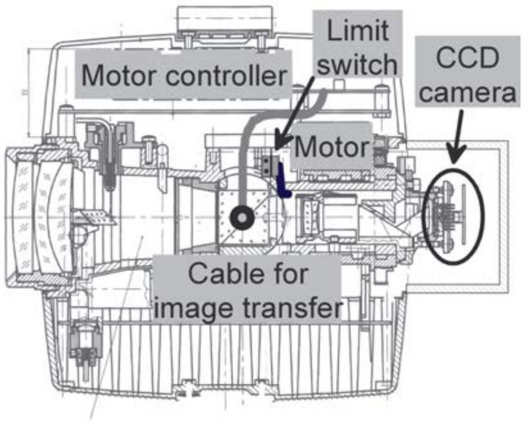



*Figure 2: Cross section of the telescope developed by Leica Geosystems [19].*

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. Now the optical mapping model includes not only the theodolites axis errors and the vertical index error, but also errors resulting from a displacement of the projection centre from the intersection of the theodolites axes and from the optical distortions for field points. Consequently calibration of an image-based theodolite has to comprise all these errors.

As mentioned, our new system is based on a combination of the IATS prototype developed by *Leica Geosystems* and a terrestrial Laser Scanner (TLS). The data of the different sensors have to be merged by a special data fusion process, which is designed as a knowledge-based approach (the implementation will be done in the near future). Such a system provides an immense number of 3D data, both from the IATS system and from the laser scanner. This point cloud may be reduced by filtering, even if not very effective. Our approach builds on *cognitive vision techniques*. These methods can be used as well for finding regions of interest as for point detection. A combined system of this kind will be a great challenge in the future (details about data fusion and interpretation are currently in publication/review).

The basic concept of our new measurement system / procedure can be formulated as follows:

- IATS and TLS are used in a common way for data capturing. Roughly speaking the point-oriented method of the image assisted theodolite is capable to capturing structured regions (e.g. edges and corners) of an object with high accuracy while the area-oriented method of the laser scanner is able to survey the unstructured regions. The data of the different sensors have to be merged by a suitable data fusion process (as mentioned above). In the long term the combination of image assisted theodolites and laser scanners should yield optimal results for most fields of application.
- The captured data (images and laser scanner data) are used by an *data interpretation tool* (which is working on the basis of *image understanding* and/or *cognitive vision techniques*) to produce a description of the scene/object. This can be done by recognizing different objects and assigning them to proper categories together with information about the object and relevant parameters. This process results in a special kind of "*object information system*".
- The information yielded is used as input for a decision system, to produce a list of actions (e.g. ranking of suitable point detection algorithms or the context between different object parts and suitable sensors).
- Furthermore, on the basis of the generated scene description, regions of interest (ROI) are selected. One ROI is the smallest measurement area in the current framework. For provision of a suitable data base the order of measurements can be predefined either as individual measurements, as repetitive measurements (each hour at same minute, each day at same hour, each month at same day) or can be created automatically.
- On the basis of the captured measurements a new kind of deformation analysis will be processed – we will call this process in the following as *deformation assessment*. This step results in an appropriate report.

The abstract, simplified measurement and analysis procedure is shown in Figure 3.

The process of *measurement* consists of several steps, including image capturing, image pre-processing, point detection, calculation of 3D point coordinates, etc.

The part of point detection by means of the image-based measurement system can be divided into two main steps: detection of points in the image(s) and measurement of these points in the object space. To process such a procedure, image points have to be transformed into the coordinate system of the measurement system. This is done by a complex mapping function (using the pinhole camera model) developed by *Walser* [18]. The underlying object measurement is realized on the basis of conventional tacheometric measurement elements – each detected image point is measured in the object space by horizontal and vertical angles and distance.

The integration of a laser scanner device into the measurement procedure is currently only realized by prototypical implementation (as shown in Figure 3 data are used as an overview – data processing and orientation is done in a manual way). A fully integrated system is planned for the near future and could be based on techniques developed by *Jäger* [8].

Image pre-processing and image-point detection algorithms are selected on the basis of extracted image features (e.g. *histogram features*, *Haralick moments*, etc.). The selection and combination of suitable algorithms is done in an automatic way, by a *knowledge-based decision system*. The knowledge which was required to be included was obtained in different ways: from technical literature, e.g. [2, 4], previous projects [6, 11, 13, 14] and from experiments. This knowledge was converted into "*If-Then-Statements*" (rules) followed by coding them for the used development tool. The knowledge-based system has been carried out in *Clips*, a productive tool which provides a complete environment for the construction of rule- and object-based systems [3]. More details about this part can be found in [13].

After having detected points of interest in more than one time epoch, *deformation assessment* can be done (see Figure 3).

## 3. Deformation assessment for quality control

The main goal of the developed *deformation assessment* is to classify relevant deformations on an unstructured point cloud. This process can be divided indo several steps. As a first step a *classical deformation analysis* (as the absolute deformation network type according to [12]) on the basis of the measured point coordinates can be done (deformation analysis by means of laser scanner data is one of the main goal of the actual development done by [7, 8]).

Coupled to this procedure can be a process, which sets up a description of the movements and distortions of the object. An assessment of the deformation can follow. This "deformation classification" must be outlined in a framework of *local-to-global information integration*, by grouping locally measured deformation into a more informative *deformation pattern*. The identification of *prototypical* discriminative deformation patterns will enable to derive a codebook of deformation characteristics to achieve a vocabulary of prototypical patterns for future reference. Early identification of critical prototypical deformation patterns may initiate focus of attention thereon, requiring a more precise and possibly time consuming analytical process that might even involve human intervention.

We have tested several methods for the task of "*deformation clustering*" (e.g. strain analysis, k-means, hierarchical clustering, etc); for an on-line characterisation of deformations it needs a simple and runtime optimised solution – the development of a compact algorithm is necessary.

The new developed procedure can be divided into several steps. First of all the surface of the object is subdivided into regions which might have deformed in the same way (this step will be processed by means of a new developed knowledge-based image understanding tool or in close collaboration with experts from civil engineering domain). This sub-division into

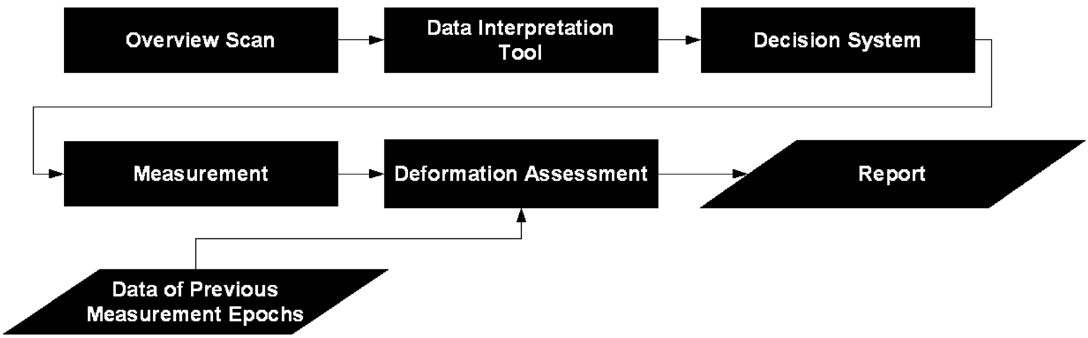



*Figure 3: Abstract, simplified measurement and analysis procedure.*

$$\begin{pmatrix} x' \\ y' \\ z' \\ 1 \end{pmatrix} = \begin{pmatrix} \cos\beta\cos\gamma & \cos\beta\sin\gamma & \sin\beta & t_x \\ \sin\alpha\sin\beta\cos\gamma + \cos\alpha\sin\gamma & -\sin\alpha\sin\beta\sin\gamma + \cos\alpha\cos\gamma & -\sin\alpha\cos\beta & t_y \\ -\cos\alpha\sin\beta\cos\gamma + \sin\alpha\sin\gamma & \cos\alpha\sin\beta\sin\gamma + \sin\alpha\cos\gamma & \cos\alpha\cos\beta & t_z \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix}$$

*Formula 1: Motion of a point described by similarity transformation*

regions of interest is founded in the local-to-global information integration as mentioned above. The following calculations and methods are only applied to the single ROIs (due to each ROI can only be modeled as rigid-body motion). In a later step the results of the investigation of these bounded areas are combined to formulate a deformation model for the whole object (rigid-body motion and inner geometry changes).

Inside the ROIs points are detected by means of image processing techniques (so-called *interest operators*). After having measured the points in different time epochs, a classical geodetic deformation analysis is used to find significant motions (this part is based on GOCA) [7]. The determined deformation has to be split into basic motions. Currently, the developed method analyses only *translations* along the coordinate axes and *rotations* around these axes – an extension to other movements/ distortions is planned for the near future. The motion of a point $(x, y, z \rightarrow x', y', z')$ is described by an *similarity transformation* [4] (in terms of homogeneous coordinates, modeled with 6 parameters) see Formula 1.

To calculate the parameters (for the rotations around the axes: $\alpha$, $\beta$, $\gamma$ and for the translation along the axes: $t_x$, $t_y$, $t_z$) inclusive their standard deviation a *Gauss-Helmert* equalization is used. To use this method a minimal number of three points is necessary (the distribution of these points in the considered region is (nearly) irrelevant).

With an artificial testobject, shown in Figure 4, we have done some tests, to proof the accuracy of the algorithm.

As mentioned, the calculated parameters only describe the deformation of the individual region – to make a conclusion about the deformation of the whole object, it is necessary to group these regions by their specific parameters (this combination can be done by statistical clustering methods).

On the basis of well known prototypical "*deformation cases*" a special kind of codebook of deformation characteristics will be implemented. The matching between cases in the database (codebook) and a new (unknown) one will be processed by means of *case-based reasoning* (CBR) (see Figure 5) [1].

## 4. Conclusion

In this paper, first steps of the development of an optical 3D measurement and analysis system for quality control have been described. The main task of this development has been the automation of different decision makings in the course of the measurement and analysis process. The analysis process is based on a combination between a conventional deformation analysis and *case-based reasoning* techniques. For an on-line system a fast execution of all algorithms and processes is necessary.

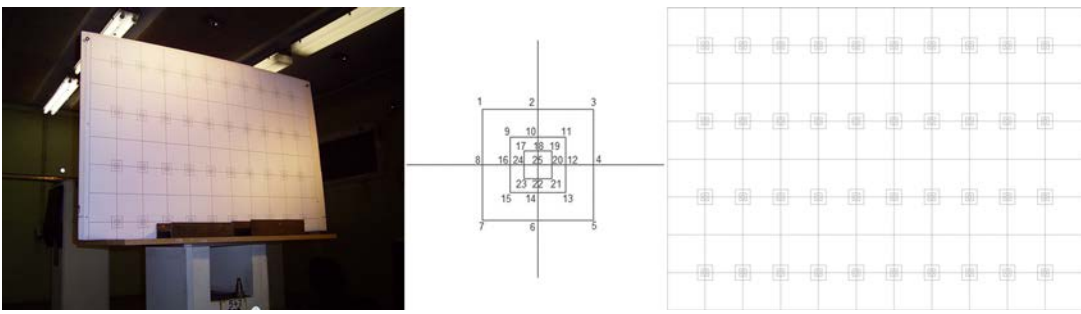


*Figure 4: (a) Testobject, (b) gridsector with pointnumbering, (c) grid.*

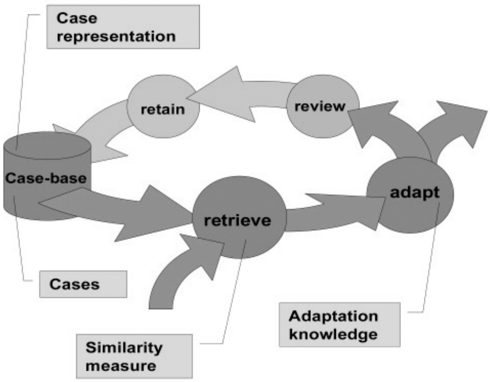



*Figure 5: Case-based reasoning cycle [1].*

The vision for the next years is the development of a fully integrated and automated measurement system, supported by image-based measurement techniques and laser scanning techniques. Also the fusion with other sensors (GNSS, PMD, etc.) will be a challenging task.

Such a integrated system represents an approach for an automated on-line working 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.

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## Contact

**Dr. Alexander Reiterer,** Institute of Geodesy and Geophysics, Vienna University of Technology, Gusshausstr. 27-29, 1040 Vienna, Austria.
E-Mail: alexander.reiterer@tuwien.ac.at

**Dipl.-Ing. Martin Lehmann,** Institute of Geodesy and Geophysics, Vienna University of Technology, Gusshausstr. 27-29, 1040 Vienna, Austria.
E-Mail: martin.lehmann@tuwien.ac.at

**Dr. Johannes Fabiankowitsch,** Institute of Geodesy and Geophysics, Vienna University of Technology, Gusshausstr. 27-29, 1040 Vienna, Austria.
E-Mail: jfabian@pop.tuwien.ac.at

**Prof. Dr.-Ing. Heribert Kahmen,** Institute of Geodesy and Geophysics, Vienna University of Technology, Gusshausstr. 27-29, 1040 Vienna, Austria.
E-Mail: Heribert.Kahmen@tuwien.ac.at

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