# VIDEOTHEODOLITE MEASUREMENT SYSTEMS – STATE OF THE ART

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**KEY WORDS:** Videotheodolite Measurement System, Image Assisted Total Station, Measurement Robot, Interest Operator, Knowledge-Based System.

## ABSTRACT

Engineering geodesy has undergone significant changes in recent years. Most obvious is the transition from analog to digital operating modes. Automation of surveying instruments is indeed in high demand. The automation in the area of tacheometer measurement systems has began years ago with automatic target recognition (ATR) and tracking features. Image processing has become a powerful tool of science and industry and is therefore an ideal enhancement for traditional tacheometers. The vision for the next year is to replace/assist the measurement expert in a best way. We report on the state of the art of such image-based measurement systems their functionality and development stage.

## 1 INTRODUCTION

In science and industry increasingly 3-D representations 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 (Grün et al., 2005). Compared to 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.

Today's theodolites measure directions automatically with electronic sensors. The axes are driven by motors controlled by a computer, automatic pointing is possible if especial cooperative targets or active targets are used, and data can be captured, stored, and evaluated without human interaction. A higher degree of flexibility and automation, however, will be possible, if no longer special targets must be fixed on the objects to be monitored.

This will be possible, if the images of the telescopes visual field is used in a more flexible way.

For the development of such a system it exists three development stages:

- a image-based theodolite measurement system for manual pointing;

- a semi-automatic image-based theodolite measurement system;

- an automatic image-based theodolite measurement which works with user-interaction.

We report on the architecture and functionality of such videotheodolite measurement systems and their development stage. Due to lack of space we will give only an overview of the more important developments. A detail description of the respective systems can be found in literature.

Before we describe in detail the three development stages we will give some information about the architecture of such a measurement system.

## 2 SYSTEM ARCHITECTURE

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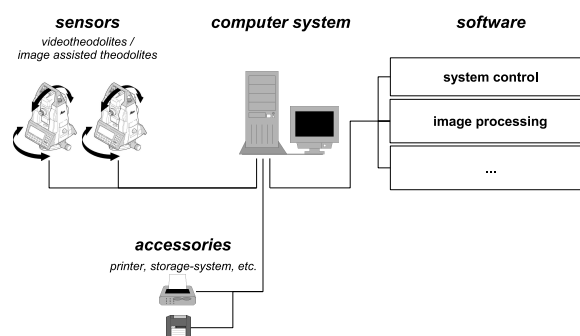


Figure 1. Abstracted architecture of a videotheodolite measurement system.

Videotheodolites have a CCD camera in its optical path. The images of the telescopes visual field are projected onto the cameras 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.

In such a system viewing angles must be addressed to CCD pixels inside the optical field of view. That means, especial calibration methods have to be used for the theodolites, 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 (Walser et al., 2003; Walser, 2004). 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. In an optical system with a focus lens the camera constant, however, changes with the distance of the object.
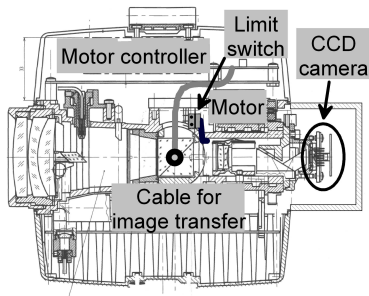


Figure 2. Cross section of the telescope (Walser, 2004).

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 center 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 (Walser et al., 2003).

A traditional videotheodolite works without integrated distance measuring. Therefore for the measurement and calculation of 3D point coordinates two or more theodolites are used (master / slave mode); one (master) scans the object while the other one (slave) tracks it. New developments combine the image-based measurement system with an integrate distance measurement unit. The system can be compared with a traditional tacheometer (total station) supported by image-based measuring – Leica has created the expression "Image Assisted Total Station (IATS)" (Walser et al., 2003; Walser, 2004).

The type and scaling of the *software components* for such a systems depend on the level of automation. From simple image processing to integrated complex decision support systems all variants are possible.

For the future the fusion of sensors, computer system and software in one measurement system is obvious.

## 3 A IMAGE ASSISTED THEODOLITE MEASUREMENT SYSTEM FOR VISUAL POINTING

The main idea of an image assisted theodolite measurement system for visual pointing is to support the operator to identify "natural targets" on the surface, which he can intuitively reduce to features of simple geometrical forms. The measurements has to find points of interest with such a distribution and density that the geometrical interpretation of the objects surface is possible.

The work-flow of such a vision software is shown in Figure 3. The main steps are image formation, image preprocessing, iconical image processing, image feature extraction, image interpretation, and image analysis (Roic, 1996).

Image formation involves the light source and the object reflecting the light. The real scene is transformed into a two dimensional function of the object and stored as a matrix of grey values. The hardware contains amplifiers, A/D converters, frame

grabbers, and additional devices. The preprocessing software enables improvement of the radiometric quality of the images and enhancement. The radiometric quality is influenced by different handling of the grey value diagrams and enhancement includes improvement of the geometric quality of the image and data reduction by applying digital filtering. The result is an iconical image which is now more suitable for feature extraction and detection of interest points.

Iconical image processing is used to create new images, finally resulting in sets, containing the desired information. Image feature extraction (segmentation) comprises searching the objects of interest from the rest of the scene with the aim of partitioning the image into various clusters; thresholding is a special method for that. Figure 4 shows a result, taken from a facade. Finally the operator has to extract feature information from the enhanced and segmented images and analyze whether it can be identified targets.
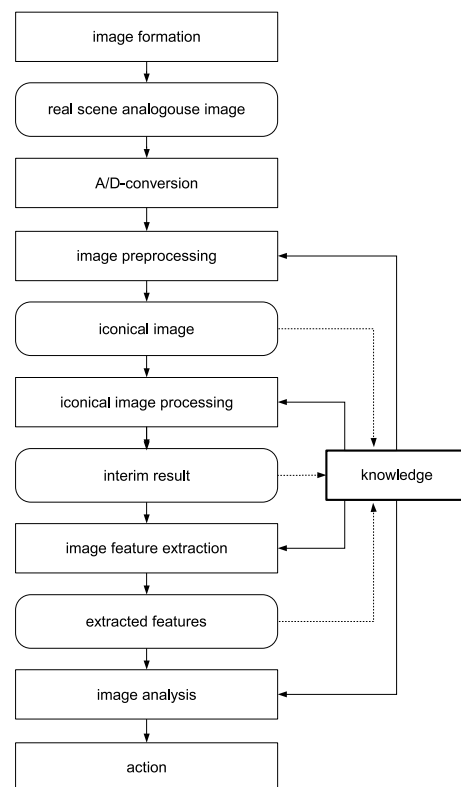


Figure 3. Work-flow of a theodolites vision software developed by Roic (1996).

Such a system was developed at the Vienna University of Technology by Roic (1996). To test the measurement system, a facade was monitored – about twenty selected edges were monitored. To enhance the edges a Sobel operator was used with histogram equalization and thresholding (Figure 4). Finally the edges could be measured with an accuracy of $2mm$ ($s$). The accuracy was only limited by the roughness of the surface. In addition very accurately defined industrial objects were measured. It could be shown that accuracies of about $0.1mm$ ($s$) are possible (Roic, 1996).

An image assisted theodolite measurement system for visual pointing allows a precise acquisition of object points. The advantages in comparison with a traditional tacheometer are an easier identification of suitable object points and therefore a faster measurement process. The disadvantage of such a system is the low-level
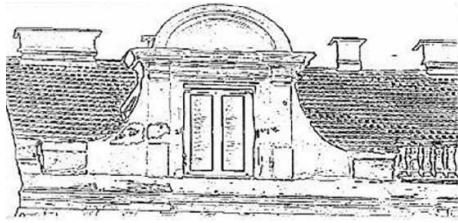
Figure 4. A building facade after histogram equalization, edge detection and thresholding was applied (Roic, 1996) .

of automation – the selection of suitable points and the process of pointing are manual tasks.

## 4  A SEMI-AUTOMATIC 3-D POINT DETECTION SYSTEM

The main goal of a semi-automatic system is, to detect points of interest on the surface of the objects with a minimum of human interaction. This process can be seen as a special kind of *scanning* – points of interest have to be detected to describe the 3D surface of the object. This procedure (for a system which works in a master/slave mode – see Section 2) is described in Figure 5. While the master theodolite is scanning the object, the slave has to track it in order to find homologous regions and finally, homologous points.
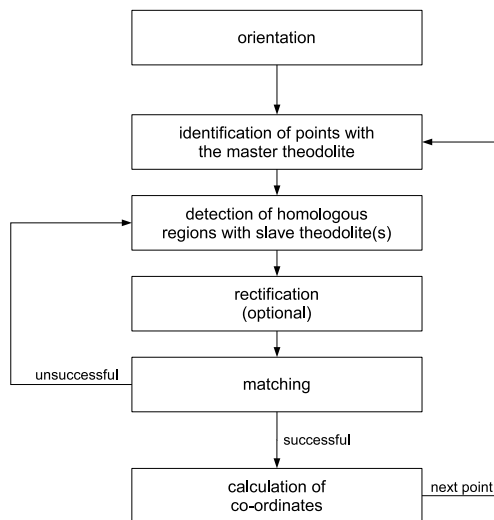


Figure 5. Work-flow of the semi-automatic measurement system developed by Mischke et al. (1997).

A fast tracking algorithm has been developed by making use of the epipolar line geometry. An epipolar line is given by the intersection of two plains. One plane is defined by the collimation axes of the two theodolites when pointing at a point of interest, given by approximate coordinates. The other plain is given by the CCD array of the slave. Approximate coordinates of the interest point we get from measurements of the master while scanning the object: horizontal and vertical angles from the encoders and an approximate distance from an autofocus system (Mischke et al., 1997).

After the coordinates of the intersections are determined with respect to the theodolite coordinate system correction angles can be calculated by which the collimation axis of the slave can be moved along the epipolar line. Simultaneous with this tracking

procedure, a matching algorithm is used to detect homologous regions and points with respect to the master theodolite.

Points of interest are identified with interest operators (IOPs) (e.g. Förstner operator (Förstner et al., 1987) or Harris operator (Harris et al., 1988)). 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.

The first semi-automatic image-based theodolite system on the market is the Topcon Imaging Total Station GPT-7000i (Topcon, 2006). The system has two integrated CCD cameras: one can be used for finder view and one for wide view. The display of the measurement system can be used as monitor for the "live-image" and for the overlapping of several image respectively point features. Thus the user can be supported with several visualization utilities, e.g. surveyed points, line and edge extraction to quickly and precisely define corner position or digital images to show recorded positions. This system uses the captured images mainly as user-support – processing on the basis of them is not intended. Also the use of the system in an automatic way is not possible because the axes are not driven by motors (cp. Section 2). Although, the Topcon-system is trend-setting for a new kind of tacheometers which will be used in the next years.

A combination of imaging system and tacheometer was developed by Scherer (2006) and named TOTAL for Tacheometric Object-Oriented Partly ("Teil-") Automated Lasersurveying (Figure 6). A result of this research is a prototype including tacheometric, photogrammetric and scanning elements. The system is based on a conventional tacheometer extended by three cameras (two wide-angled cameras with different focal lengths and one camera located in the plane of reticule). The ocular camera is automatically focused by a gearing in the tube of the telescope. The system use the capture image(s) for three different areas: for



Figure 6. Combination of imaging system and tacheometer developed by Scherer (2006).

documentation and archiving, for targeting, and for visualization and modelling. The measurement system provides two different point detection methods: (1) single point detection and (2) special scanning. The special scanning procedure includes several measurement modes, e.g. horizontal and vertical profiling and recording of surfaces (no differentiated selection of the measured points).

A prototype of a semi-automatic image-based measurement system has been developed by Leica Geosystems (Walser et al., 2003; Walser, 2004). The measurement process is based on a permanent interaction between user and instrument; the user supervises the measurement sequence while the system executes the measurements. The optical system of this system was described in Section 2. The measurement process is organized as follows: The

user aims at the target and focuses coarsely – a suitable template from a database has to be selected. Following the system performs exact focusing, target identification by template matching, fine pointing and finally the determination of polar coordinates. This process is automatically repeated for all relevant points of the selected template. As mentioned above not full automation is the aim of this prototype, but rather meaningful interaction between instrument and user. The user contributes his expert knowledge to increase overall effectiveness while the system is operated at a higher level of efficiency.

A further semi-automatic system was developed at the *Technical University of Munich*. It can measure horizontal directions without human interaction if the targets are symmetrical figures, like church towers or flag staffs (Wasmeier, 2003).

At the Vienna University of Technology a measurement method was developed that furnishes an approach to copy human visual perceptivity – individual objects are extracted and their deformation analyzed. Different colours represent the starting point for distinction of objects in the captured image. A semantic statement about the occurrence of deformation is the result (Niessner, 2002).

Comparing the semi-automatic system method with the traditional one or with image assisted theodolite measurement systems for visual pointing, the accuracy for point measuring depends on the power of the image processing algorithms but not on the human surveyor. Up to now the pointing accuracy depends on the interpretation capability of the human visual system. The new modes, allow to determine the exact object/point position by algorithmic treatment.

## 5 AN AUTOMATIC MEASUREMENT SYSTEM

In complex measurement systems, as described above, with many algorithms (e.g. for image processing or for point detection), the selection of suitable algorithms, their order of application, and the choice of necessary input parameters is a highly non-trivial task. To automate this selection a suitable decision support system has to be integrated.

A decision systems is a specific class of a computerized information system that supports engineering, business or organizational decision-making activities. A properly designed decision systems is an interactive software-based system intended to help decision makers to solve problems and to make decisions. Such a system consists in its plainest form of three main components: an input component, decision algorithm(s) and an output component (Figure 7).
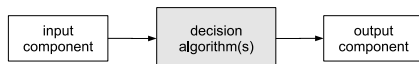


Figure 7. Simplified architecture of a decision system.

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[1]. For this reason appropriate values as input for the decision system have to be used.

Extensive experimentation (Reiterer, 2006) showed that the algorithms for image preprocessing and interest operators can be chosen on the basis of parameters extracted from the image (low-level feature extraction). This can be done by calculating several

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[1] Additional parameter can be collected by user-interaction.

types of image features, e.g. histogram features and/or Haralick features. More detail about these features can be found in (Haralick et al., 1993).

In an interdisciplinary research project (FWF-project: "Knowledge-based Multi-Sensor System") at the Vienna University of Technology a knowledge-based approach has been chosen for representing the knowledge necessary for decision-making, allowing for a declarative and modular representation of a decision policy together with easy extendibility. Knowledge-based systems (KBS) emulate human expertise in well defined problem domain (Stefik, 1998). They are the results of research in the area of artificial intelligence. The availability of knowledge-based system tools, such as CLIPS (Clips, 2006) or ILOG (ILOG, 2006), has simplified the development of knowledge-based systems.
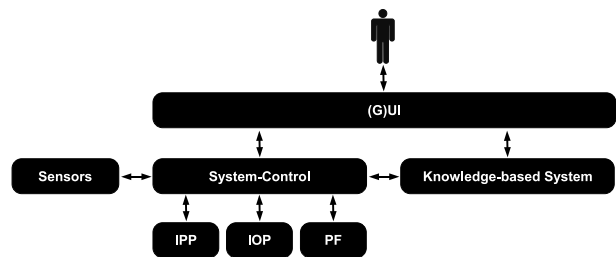


Figure 8. Simplified architecture of measurement system.

There exist various schemes for knowledge representation, e.g. rules, frames, semantic nets and others. Each has its peculiar strengths and weaknesses. The structure of a rule-based approach is very similar to the way how people solve problems. Human experts find it convenient to express their knowledge in form of rules (situation-action pairs). Further rules are a way to represent knowledge without complex programming constructs. For these reasons a rule-based approach should be used to implement the relevant knowledge.

The development carried out at the Vienna University of Technology supports the operator when making the following decisions: (1) selection of suitable image preprocessing algorithms, (2) selection of suitable interest operators, (3) selection of points which are convenient for deformation analysis / object reconstruction. Corresponding to this process steps, the system consists of several main components: sensor(s), system control component, (graphical) user interace (GUI), knowledge-based system, image preprocessing (IPP), interest operators (IOP) and point filtering (PF). A simplified architecture of measurement system is shown in Figure 8.

The whole functionality of this system will be described in a separated publication (Reiterer, 2006).

## 6 FUTURE

For the future there are still many possibilities to improve the operability of image assisted theodolite measurement systems; beside the improvement of existing system components, the degree of automation for the whole system should be increased by integrating other sensors in the measurement process (e.g. 3D laser scanners).

Such a system provides an immense number of 3D data, both from the theodolite system and from the laser scanner. This point cloud can not be reduced very effectively by filtering. A new approach could be based on cognitive vision and work in a two step mode:

- The captured data (image and laser scanner data) must be used to produce a description of the image. This can be done by recognizing and assigning different objects to proper categories together with information about the object and relevant parameters. This process results in a special kind of information system.

- The yield information is then used to produce actions into the physical world, like measuring only a special part of the object.

The features extracted from the image and the scene description generated by the cognitive vision system are used as input for a (knowledge-based) decision system. Due to the integration of the cognitive vision and the knowledge-based system a highly automated measurement system should be possible.

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