Architectural Surveying and Visualization Using "Photo-Tacheometry"

Michael SCHERER, Germany

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SUMMARY

In architectural surveying it is much more effective to closely integrate different surveying methods than to use them side by side. Based on this experience, new hardware and software as well as corresponding new measuring tools were developed. The hardware is based on a computer-notebook-directed robot-tacheometer capable of reflectorless measuring. It is a so-called intelligent tacheometer, enabling the device to run several new and innovative measuring functions. In combination with an additional digital camera the instrument may be used in many more possible ways. This working-mode is called "photo-tacheometry".

It, for example, offers the possibility to direct the instruments telescope by mouse-clicking on a photo being displayed on a computer notebook's screen, and thus to exactly measure the coordinates of the point indicated by the cursor. In this operation-mode, the image may be taken from an arbitrary position or a camera integrated into the total station. This technique makes it quite easy to do online rendering or to establish a virtual model.

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1. FROM CONVENTIONAL MEASURING METHODS TO PHOTO-TACHEOMETRY

It should be stressed that photo-tacheometry, the surveying method mentioned in the title, is not an exotic method at all. Every tacheometer and each motor-driven total station capable of reflectorless measuring may be operated by means of photo-tacheometry. In Germany alone several hundreds of surveying offices and architectural agencies make use of these devices on a daily basis. It is a pity however, that even surveying engineers are not fully aware of the enormous potential these tools really offer. The ability of linking them to simple digital consumer cameras – there are no expensive photogrammetric cameras needed - opens up an entire range of completely new, low-personnel, resource-saving fields of deployment.

Figure 1 shows the development of total stations in the field of architectural surveying.

≈1970	electronic tacheometer measuring to a reflector = total-station
≈1990	first total station without reflector = here called traditional or conventional tacheometer or total-station
1994	prototype of intelligent total station; constructed by Ruhr-University Bochum
1997	photo-tacheometry with external camera
1999 2001	first commercial intelligent total station: Leica TCR first equivalent instrument by Zeiss/Trimble prototype of first photo-total station (developed at RUB)
2001	first "video-total station" (RUB)
2003	total station with diaphragm for high-resolution-scan (RUB)
2004	first commercial reflectorless measuring video-total station with integrated cameras: Topcon

Fig. 1: From traditional tacheometer to photo-tacheometer

Development advanced from the traditional electronic measuring tacheometer using retroreflector to the reflectorless measuring mode [Scherer 1995, 2001]. In 1994 the intelligent tacheometer followed. At the present time we observe the surfacing of photo-tacheometry.

What is intelligent tacheometry?

Intelligent tacheometry is known as the process of recording three-dimensional polar coordinates of typically the object-describing points that are mostly based on control circuit mechanisms and iteration processes. This requires servodrives and distance measurement without reflector. Special techniques to determine single points, points on spatial curves and points on surfaces are used. The first reflectorless measuring instrument of this kind was developed at the Ruhr- University Bochum, Germany, in 1994; now the companies of Leica and Trimble sell such devices with varying specifications. The ability to traverse feedbacks fundamentally distinguishes the active, object-oriented robot-total station from the passive, non object-oriented laser scanner, which records millions of points while individual points are of no importance at all. Laser scanning does not take the object into immediate account. These instruments are still very expensive, and on-site-off-site time relations fluctuate between 1:5 to 1:30. Often an additional tacheometer is needed to establish a coordinate network. It has also to be taken into account that the tacheometer is the most universal surveying instrument there is, applicable to many different tasks. Unlike the laserscanner it is a specialized construction.

In order to compare the efficiency of laser scanning and tacheometry, it has to be referred to the present methods of intelligent tacheometry and laser scanning, as opposed to the traditional and nowadays outdated method of reflectorless tacheometry. Figure 2 indicates a connection between laser scanning and photogrammetry, as well as a link between intelligent tacheometry and photo-tacheometry - but not, however, between laser scanning and intelligent tacheometry (more on this later).

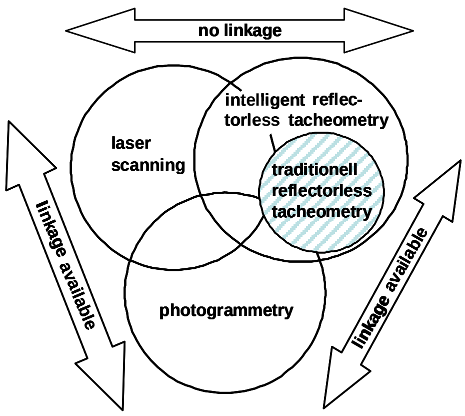


Fig. 2: Cooperation of laser scanning, photogrammetry and intelligent tacheometry

Intelligent tacheometry and photo-tacheometry rely for the most part on the “TOTAL”-software, which was developed at the Ruhr-University at Bochum, Germany. Currently the software is being reorganized to operate within AutoCAD.

The following chapters introduce the technique of “collecting geometry" by means of intelligent tacheometry and separately the ”visualization" by photo-tacheometric procedures. This distinction is necessary, because frequently data regarding the geometry of an object is needed, while visualization is commonly only regarded as an additional feature. Thus, recording of the geometry can take place effectively all the time, with out any use of pictures. A special quality of the photo-tacheometric method is the ability to carry out the step-by-step collection of geometry and the following construction of the photo-realistic model on site in a single processing step.

2. LOW-COST-RECORDING OF GEOMETRY WITH THE INTELLIGENT TACHEOMETER

The term “intelligent scanning”, as opposed to ‘not intelligent’ laser scanning as well as ‘not intelligent’ tacheometry refers to the fact that in this case hardware and software are not linked, and recording is not controlled automatically by the object’s geometry. With laser scanning there is at first no connection to the recorded building, whereas in the case of conventional tacheometry this connection is only made manually.

Intelligent tacheometry contains all elements and includes the whole potential of conventional tacheometry; it is, as far as hardware and software are concerned, only insignificantly more expensive. However, due to its economical operation routine it can actually save an enormous amount of resources.

Figure 3 shows the substantial abilities of intelligent tacheometry and advantages: point-oriented admission of geometry, mapping quality and the resulting links to the photo.

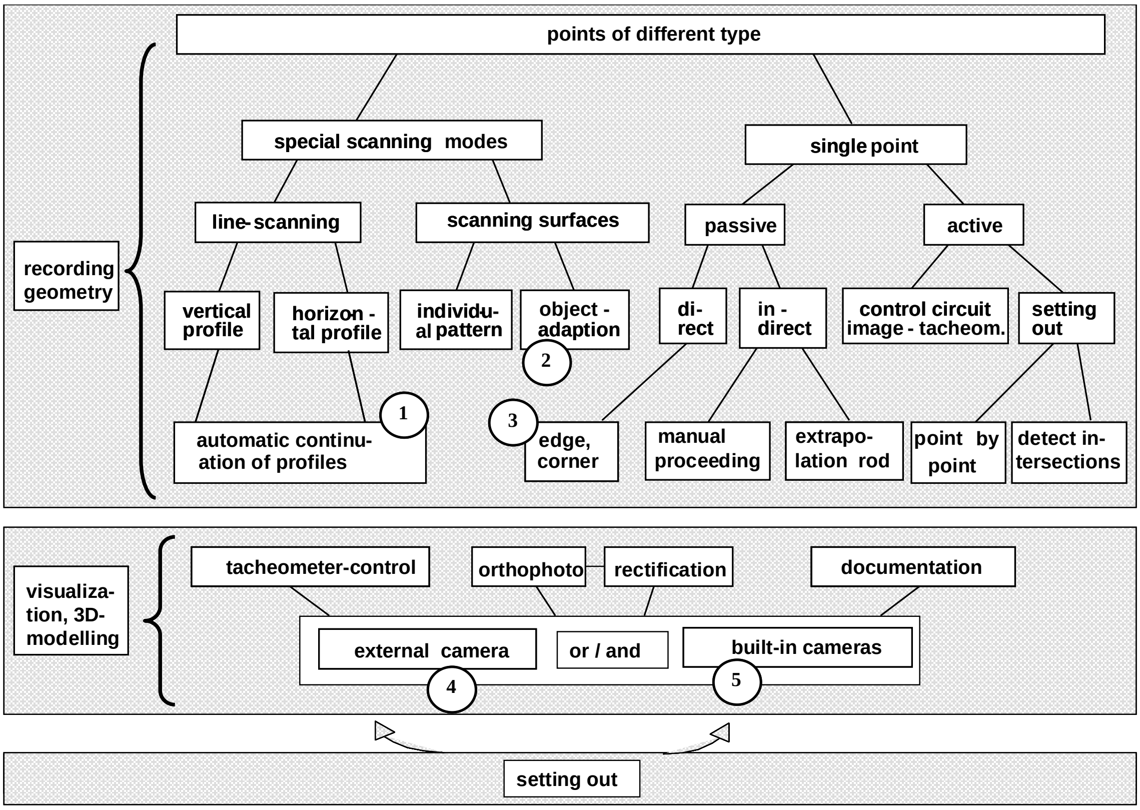
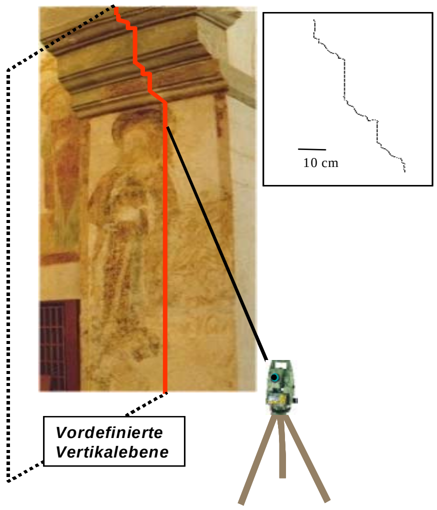


Fig. 3: Intelligent tacheometry and photo-tacheometry

The following section takes a more detailed look at some of the software tools used to record geometry. It is always to be noted that, as far as intelligent tacheometry is concerned, the setting out plays a central role - also during recording. Important is the control circuit, consisting of computation, i.e. prediction of a position - measurement of the position adjusted at the very moment - calculation of the difference between a precalculated point and one measured by the total station - the redirecting i.e. setting out of the precalculated position until the indicated position is reached. The following examples are marked in the diagram figure 3 by a number in a circle.

1 Intelligent scanning

Intelligent scanning is a good example to demonstrate how an intelligent control operates. In accordance to figure 4 a vertical profile is to be recorded point by point while the equipment is placed at an arbitrary position out of the profile plane. At the surface of the capital the distance of the subsequent points may be selected freely, i.e. 5mm. This distance on the object surface as well as the placing of the vertical profile and the starting point, i.e. above it, will be entered. The software then computes the next point, taking into account that it is vertically positioned below the first point. Then the distance measuring spot is directed to this point. Hence always the next position in the vertical cut is computed. If a displacement happens –i.e. at an edge- , the measuring spot will not touch the vertical plane, since the tacheometer in general is not placed within the vertical plane itself, but is rather set up at a different, arbitrary position.



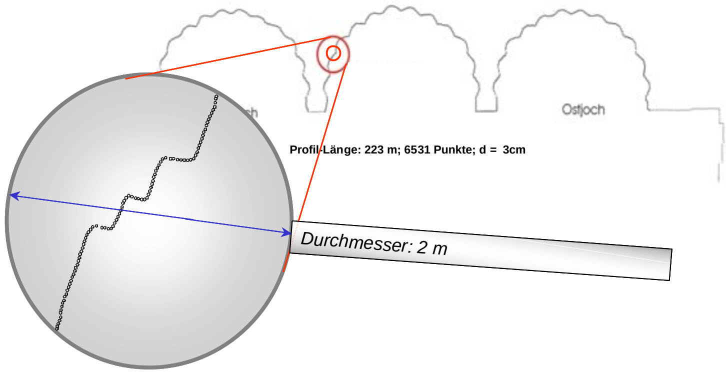


Fig. 4: Vertical profile

Profile taken up by numerous different points of view outside of the profile

2 Recording of surfaces

As far as this operation mode is concerned, the total station and the laser scanner have the most similarities: there is no differentiated selection of the measured points, but merely a polygonal separation of the measurement area with subsequent automated measuring of the matrix points (see figure 5). The procedure of this operation is to be carried out as follows: First, the area has to be defined by surrounding it with the laser point, then the grid density is to be determined; now the point positions to be measured are computed, and the coordinates are measured automatically.

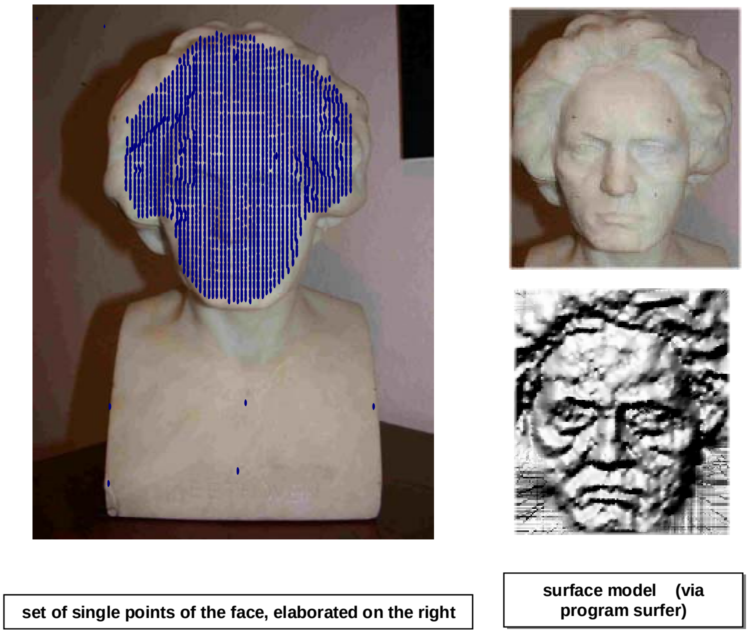
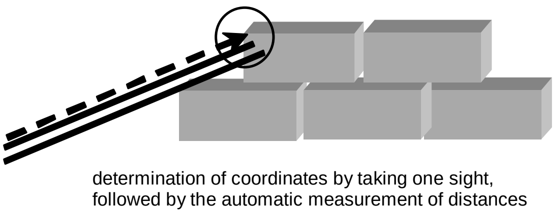


Fig. 5: Highly soluble 3D-recording

Using the Leica TCRM instrument, distance and angle accuracy yield an expected coordinate accuracy of about ± 1mm. Apart from general measurement accuracy, the diameter of the distance measuring ray is crucial for the recording of details. A standard spot diameter of 6 mm – 12mm limits the resolution to 3mm – 5mm at the most. Therefore steps to increase the resolution had to be taken before use of the actual accuracy of measurement could be made. To achieve this, a diaphragm was inserted into the ray path.

3 Precise and fast determination of edges and corners

Due to the fact that the diameter of the footprint of the laser beam measures nearly as much as one centimeter, edges i.g. cannot be determined in a simple way with high precision. However an automatic, intelligent process may run like indicated in figure 6a.



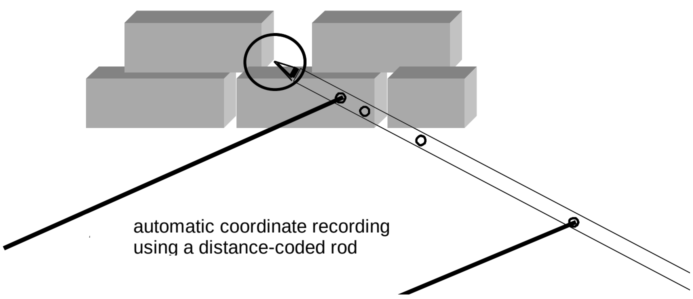


Fig 6a: Precise determination of edges

Fig. 6b: Measuring hidden points

All the functionalities of the intelligent tacheometry are enhanced in their practical handling by the use of images. Some special, even more advanced applications are shown in the following chapter.

3. PHOTO-TACHEOMETRY

The term ”photo-tacheometry” stands for the close connection (which may even be called fusion) of intelligent tacheometry and photogrammetric operations. A picture’s allocation to the total station can thus be realized in two entirely different ways:

1. The picture is taken by a so-called external camera, meaning a camera which is located at any given shooting location.
2. The picture (the pictures) is (are) taken at the location of the total station - special cameras were integrated into the total station - which thus became the ”video total station” (see figure 1 and figure 7).

Those functionalities and possibilities, gained from such a close connection of picture and tacheometer, are to be attained only via intelligent tacheometry.

Figure 7 and 8 show the two different modes of photo-tacheometry, resp. video-tacheometry.

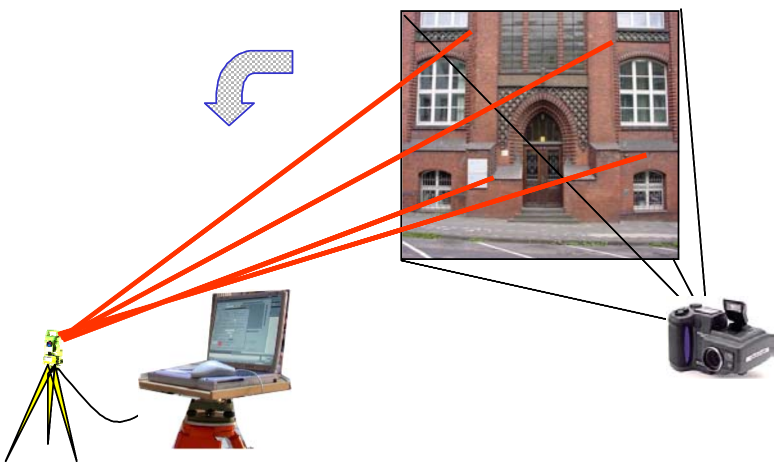


Fig. 7: Photo-tacheometry: External camera, connected by identical points with the total station

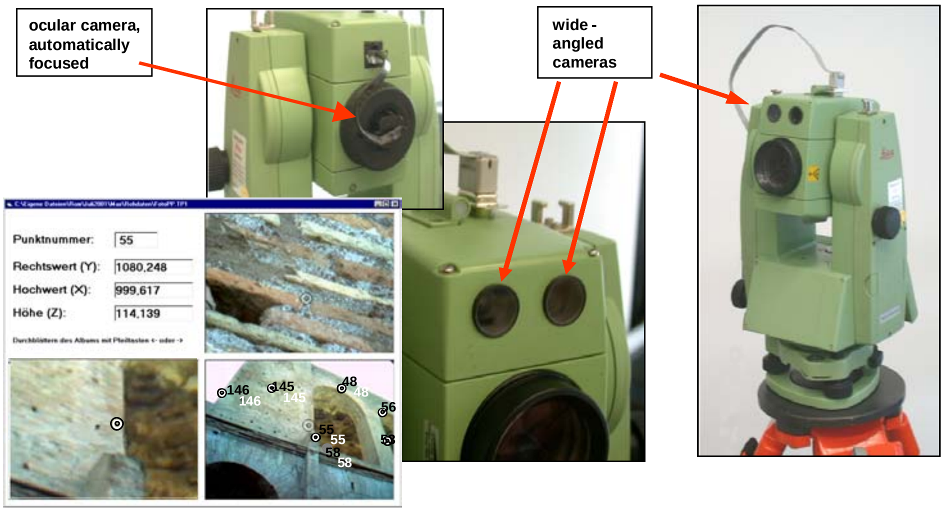


Fig. 8: "Video-Total station" = Total station with three integrated cameras (one eyepiece-camera, automatically focused and a set of photos of a natural point, ideal for monitoring purposes and for hand measurement)

Photo-tacheometry, consisting of intelligent tacheometry in conjunction with an external camera, can be operated instantaneously by virtually anyone; however, the measuring mode with integrated camera can only be used after certain reconstructions of the equipment have been performed. In 1997 the world's first linkage of intelligent tacheometer and telescope camera had already been shown by the Ruhr University Bochum [Juretzko 2001]. The use of a picture to control a device and to operate visualization on the screen of a computer notebook has been exercised since 2001.

In autumn 2004, a commercial reflectorless measuring servo-driven tacheometer with a camera installed into the telescope-tube was introduced for the first time (on the occasion of the INTERGEO fair at Stuttgart by the Topcon company, announced as "world novelty"). In contrast to the possibilities of device control, archiving of picture, geometry and attributes - as described later – which has already been available for years at Ruhr-University Bochum, the commercial instrument is equipped with a camera of (relatively) low resolution. It also does only offer basic visualization functionality.

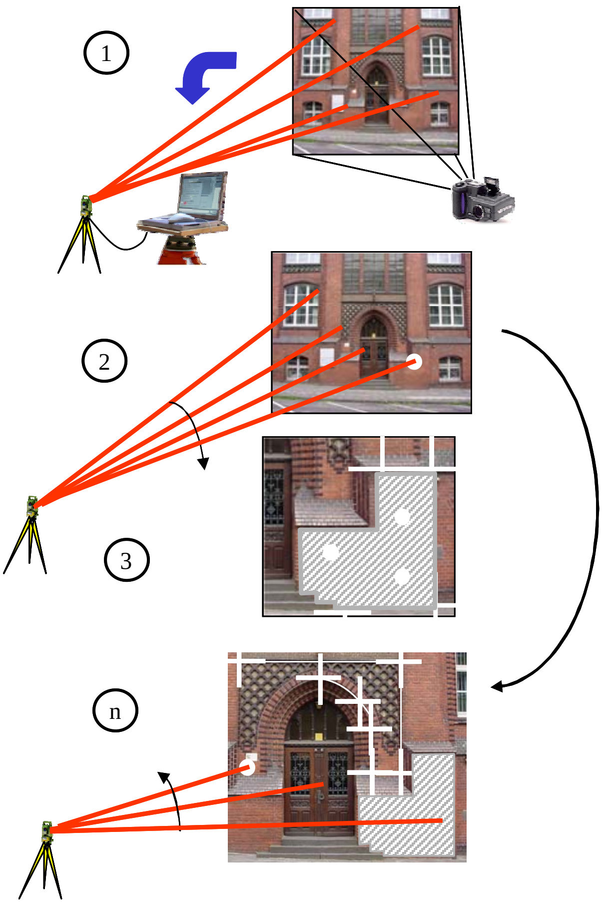
Since a high-quality picture is crucial for visualization and photo-realistic 3D-modeling, an external camera (see below) is to be preferred over an integrated camera of lower resolution. On the field of device control, however, this type of camera is better suited than the external one, as the description of the prototype of Ruhr-University Bochum further down indicates. Still, device control from within the picture cannot be performed by the Topcon device.

4 Examples for the use of the external camera (see figure 3)

The external camera delivers a high quality picture and offers the flexibility of conventional photogrammetry (arbitrary camera location) in combination with the advantages of intelligent tacheometry. This enables high-speed operation and saves time by reducing the number of measuring procedures (particularly when the knowledge about parallelism and rectangularity is used), as the following examples show:

- Visualization

This procedure allows a particularly fast on-site generation of ortho-images and 3D visualization. It may consist of the following steps (see figure 9). However, various other procedures are possible:



Working Steps

1. Make the photo, save it to a laptop and orientate the image by using control points that are to be measured during the process. This delivers the position as well as the direction of the camera at the time of recording (parametric orientation).

2. Click on an arbitrary point of a surface on the edifice in the photo; automatic steering of the distance measuring laser dot to the corresponding point on the object takes place. The real coordinates of the clicked point are automatically measured. Thus the area (plane) may be defined by three points.

3. Click on the corners of the surface in the image, connect them, and cut out image planes resp. triangles for the visualization software.

n. Select another (e.g. parallel) plane, click on the parallelity-function and also click on a point in the image; again, automatic steering of the measuring spot is carried out followed by the computing of the plane and the cutting out.

Fig. 9: Intelligent control by external images

- Dynamic visual measurement protocol

A continuously growing graphical measurement protocol is generated through the parametric link between the coordinate system and the image. Additionally, single points and connecting lines are faded in automatically into an oriented image (figure 10).

Point numbers can be registered for future applications, e.g. for monitoring or for densification of the network, or for referencing them for photogrammetric purposes. The link between the images and the coordinates is permanent. Therefore, the total station also can be directed at any time by clicking on the points in the image.

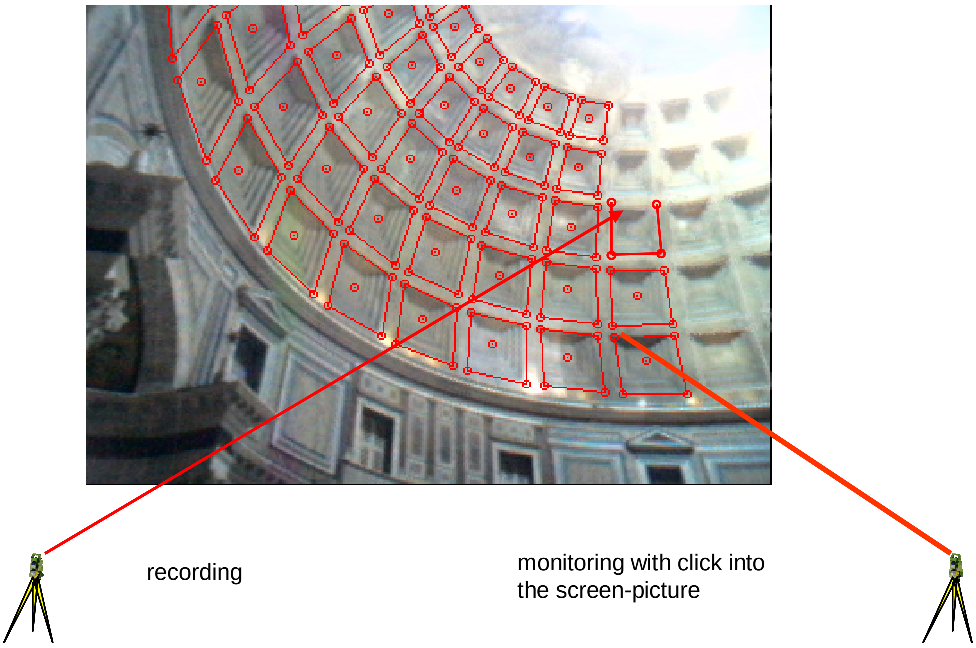


Fig. 10: Dynamically visualized measurement protocol and later use in monitoring

5 Work with integrated cameras

When using cameras installed into the telescope-tube instead of high-quality pictures of an external camera there is no need for parametric orientation [Scherer 2004]. Pictures of lower quality are less suitable for visualization purposes and rectification. They are, however, excellent for the controlling of the total station, while the screen of a computer notebook is used.

Figure 8 shows the photographs of the three cameras built into the telescope tube. The measured geometry has been added transparently to the background of the pictures for purposes of documentation, as well as to enable quick relocation of the points for monitoring.

Since the pictures, the graphical representation of the recording and the coordination data are interconnected permanently, the total station may be controlled by three different types of media: picture, diagram and data file.

This "picture album" can also be carried around for manual measurement or for the entry of findings, be it on paper or on a notebook computer's hard disk on the building site.

4. SUMMARY AND A GLANCE INTO THE FUTURE

Apart from the long-proven manual measurement, three more procedures for the recording of geometry are available in architecture, care of monuments and building research: photogrammetry, laser scanning and intelligent tacheometry and/or as extension the photo-tacheometry.

Photogrammetry and laser scanning are sufficiently well-known. In the meantime it has also become evident, that a "photogrammetric" – single-image does indeed fit ideally with the point cloud, which is a unique product of laser scanning. It could be demonstrated here that linkage of the picture with the point-net data acquired via tacheometry is successfully usable as well, and that the "intelligence" of photo-tacheometry brings even more advantages.

Figure 11 shows a comparison of characteristics of the two recording methods of laser scanning and photo-tacheometry and/or intelligent tacheometry. It is evident that it is worthwhile indeed to give more attention to the inexpensive surveying methods of intelligent tacheometry and photo-tacheometry. Laser scanning, however, should not be regarded as opposed to tacheometry: The two different procedures have the potential to complement each other favorably, though today most of the investigations on this matter are still pending.

	photo-tacheometry	laserscanning
surveying of geometry		
single point	method ideal for this purpose	not directly possible
connection between different instrument setups	use of natural points; no targeting necessary	special targets or link using surfaces
point-accuracy	high resolution (i.e. distance measurement between inner and outer pass of light)	comparatively low
hidden prints	special extrapolation rod	no detection
modeling of mathematical surfaces particularly at industrial sites	under restrained conditions with extrapolation rod	partly automatically extraction of primitives
modeling of non mathematical surfaces	slow, but higher accuracy possible, method of choice if no large point-cloud is demanded	ideal for this purpose and for modeling large non mathematical shapes
visualization/3D-modelling		
rectification	real time, fast	lengthy
orthophoto	fast, on site	relative high expenditure
photorealistic rendering of simple mathematical surfaces	real time possible, only few points necessary	i.g. the ideal procedure
non mathematical surfaces	very slow, but automatic procedure, appropriate if maximum point density is not necessary	ideal method
recording of additional attributes		
i.e. restoration, conservation tear,... building documentation special structure, .. facility management plug sockets,	real time marking and georeferencing, possibly to have documentation in the image at the same time	only required for later revision
controlling off-line (blue tooth), the field notebook can be kept separate from the place where the instrument is set up	makes possible personal saving and portraying work face to the object	not intended; not applicable

Fig. 11: Special abilities of intelligent tacheometry and/or photo-tacheometry in comparison to laser scanning

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BIOGRAPHICAL NOTES

Born in 1945; studies at Bonn and Berlin, degree diploma; graduate civil servant; graduation in the sector of satellite geodesy: postdoctoral lecture qualification in the field of geodetic measuring methods, professor at university of Bonn, since 1988 at Bochum University; currently working on the development of surveying methods in architecture and cultural heritage.

CONTACTS

Prof. Dr.-Ing. Michael Scherer
Ruhr-Universität Bochum
Arbeitsgruppe Geodäsie
Universitätsstrasse 150; IA 4/49
44780 Bochum
GERMANY
Tel. +49 (0)234 32-26070
Fax +49 (0)234 32-14373
Email: michael.scherer@rub.de
Web site: www.ruhr-uni-bochum.de/geodaesie