PHOTO-TACHEOMETRY AND INTELLIGENT SCANNING. AN ALTERNATIVE TO 3D-LASER SCANNING

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ABSTRACT

The method of photo-tacheometry is based on tacheometry as well as on elements of photogrammetry. Its basic hardware components are an intelligent tacheometer and a digital camera. An intelligent tacheometer is a motor-driven total station capable of reflectorless measuring, which is controlled and directed via a computer-notebook. This combination enables the development of control circuits and other "intelligent" control mechanisms that are based on the process of setting out.
Intelligent tacheometry has several major advantages over traditional manually controlled electronic tacheometry. In combination with an image from the digital camera there are some more benefits concerning
a) the field of documentation (i.e. by online superpositioning an image with other graphic information),
b) the control of the instrument and
c) the use of a photo for visualization purposes on site - detailed recording and control are possible as well as quick construction of photorealistic models.
The most important functions of photo-tacheometry are explained, the advantages are shown and the differences between traditional tacheometry, intelligent tacheometry and laser scanning are discussed in detail. The user may decide if and where photo-tacheometry offers an actual advantage over laser scanning.

1. SOME NECESSARY DEFINITIONS

Photo-tacheometry, intelligent scanning, intelligent tacheometry are keywords that arose in the course of the last two years. Their common basis is the well known tacheometric polar measuring technique. First of all, a distinction will be drawn between the terms traditional tacheometry, intelligent tacheometry, intelligent scanning, photo-tacheometry and laser scanning.

• Traditional tacheometry

Fundamental differences between intelligent tacheometry and traditional tacheometry (one could also say conventional tacheometry) have to be considered. Traditional tacheometry in this case stands for the use of the widespread reflectorless measurement method, utilizing a laser beam which is directed to the object manually. As far as hardware costs are concerned, intelligent tacheometry in comparison to conventional tacheometry adds a - rather negligible – 20%. The benefits outweigh the unique extra costs several times.

• Intelligent scanning and intelligent tacheometry

Intelligent scanning means scanning of predefined profiles, e.g. to determine the intersection between a plane with a building or, as it is done via laser scanning, to measure point arrays. To do this, there has to be feedback between the instrument and the object, which is provided by the controlling software. All tacheometric techniques focus on single points, whereas laser scanning initially delivers an unoriented point cloud, which is hardly adaptable to special circumstances. There is no feedback between object and measurement, i.e. no possibility to directly measure **precisely** defined profiles. The most important differences between intelligent scanning and laser scanning are point selectivity on site in intelligent tacheometry, and the high measuring speed in laser scanning. The costs for recording an object via intelligent tacheometry or laser scanning may also vary considerably.
Intelligent scanning is part of intelligent tacheometry. Various surveying technologies, based on control circuit mechanisms, have been developed for the intelligent tacheometer: The ability to traverse feedbacks distinguishes the active, object-oriented intelligent totalstation fundamentally from the passive, not object-oriented laser scanner. Tacheometric methods are point-oriented; laser scanning is surface-oriented.

• Photo-tacheometry

Photo-tacheometry is a combination of intelligent tacheometry with high-quality photos. The image in this case does serve entirely different purposes than in photogrammetry and it has additional control functions. The possibility of linking coordinate-information with image-information is used consistently.
In the next two chapters intelligent tacheometry and photo-tacheometry will be explained in detail. Figure 1 shows a comparison between intelligent tacheometry (photo-tacheometry included), conventional tacheometry and laser scanning. The numbers in figure 1 refer to these explanations.

2. TOOLS OF INTELLIGENT TACHEOMETRY

• (1) Scanning of arrays

This tool is the one operating in a way closest to laser scanning, as the results are point-clouds as well. The data handling is the same as with laser scanning. Of course, recording of well defined regions as in figure 2 or of small artefacts like in figure 3 takes much longer than with laser scanning. However, as the workflow proceeds completely automatic, assistance is not necessary, thus the tacheometer may work automatically. Figure 2 shows the recording of a rather large region at one edge of Basilica de Massenzio, Rome. This recording combined with scanned profiles taken inside of the building was allowing a structural analysis for measures of repare.

Increase in value of intelligent tacheometry **All results are obtained on site !**			intelligent tacheometry	traditional tacheometry	laser scanning
geometry	recording	(3) - corners, edges	√	relative high expenditure	relative high expenditure
		(2) - intersection-profiles (horizontal, vertikal, arbitrary)	√	impossible i.g.	extraction later
		(1) - modeling of non mathematical surfaces	high expenditure	very high expenditure	√√
		(1a) - 3D-objects	√		√
		- monitoring by automatically repeated algorithms	ideal	very high expenditure	not possible precisely
		(1b) - smaller 3D-objects	precise	-	√ low accuracy
		(4) - hidden points	√	√	i.g. not possible
		(5) - directing automatically to predefined points	√	-	-
	setting out	- intersection lines (i.e. plane and object)	√	very high expenditure	not possible
		- engeneering surveying 2D- profiles	√		
		- setting out i.g. 3D- profiles	√		
visualization (external photo)	rectification	- plane / cylindric surface	√ point identification not necessary, partly automatic	high expenditure for referencing of object- and imagecoordinates	√
	orthophoto	(6) - projective or parametric projection	√		√ partly automatically
	3D- model	(7) - sequential structuring based on parametric rectification	√		-
	practical work	(8) - monitoring without targets	√		not possible
		(9) - connection between different instrument setups via natural points	√	-	
		(10) - dynamic visual measurement protocol	√	-	-
work with remote control (bluetooth)		(11) - identification face to the object simple and safe	√ portraying way to work	-	-
		(12) - steering of the instrument via grafic / image / touchpad	√		

Fig. 1 Comparison between traditional tacheometry, intelligent tacheometry and laser scanning

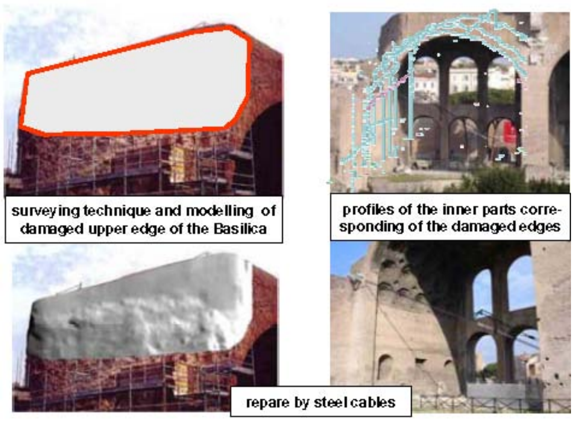

Figure 2: Recording of arrays and profiles

Figure 3 shows a small sculpture – the recording was taken with millimeter-precision. To achieve this, tacheometric distance measurement requiring rather high precision was necessary, as well as minimization of the the diameter of the measuring point itself. This was accomplished by inserting a diaphragm into the outgoing distance measuring laserbeam, resulting in a resolution better than 1mm.

• **(2) Scanning profiles**

Horizontal or vertical intersections often are of high interest. They are measured completely automatic. The instrument must not be positioned in the plane itself. The profile is continued automatically as the instrument is positioned at a new location, i.e. measurements at the front side and the back side of a wall. Results of some profiles taken at Basilica di Massenzio are to be seen in figure 2 and figure 4. For this kind of measurement one must insert some initial data into the system: the position of the profile (horizontal or vertical) indicated with the laser pointer,

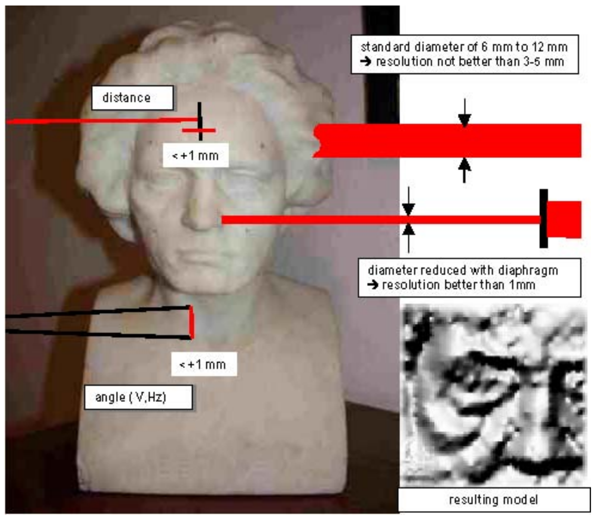

Figure 3: Resolution depending on standard deviation and diameter of the footprint

the maximum thickness of the "profile-disc" allowed in which the points have to be measured and the distance of the points in the profile on the wall itself.

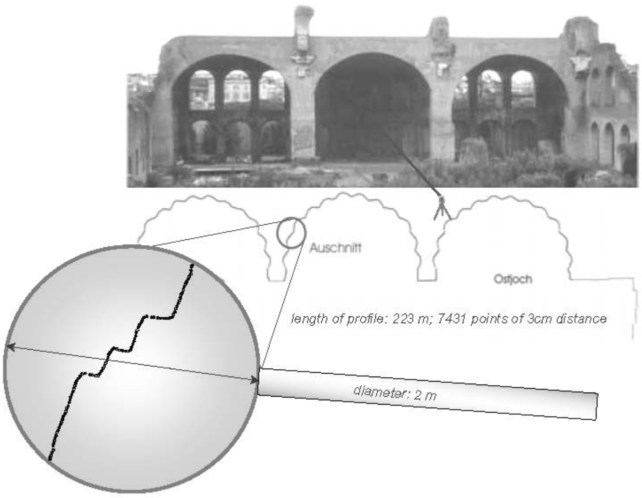

Figure 4: Precise intelligent scanning

• (3) Detection of edges

Due to the fact that the diameter of the footprint of the laser beam measures nearly as much as one centimetre, edges i.g. cannot be determined in a simple way with high precision. However an automatic, intelligent process may run like indicated in figure 5.

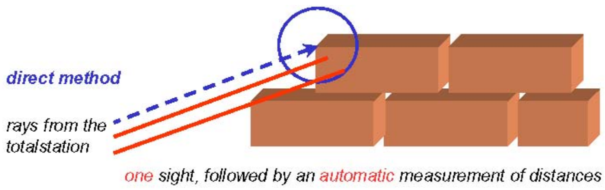

Figure 5: Exact detection of edges

• (4) Hidden Points

Another tool is a specially coded extrapolation-rod which is used to measure hidden points quickly, precisely and widely automatic (fig. 6).

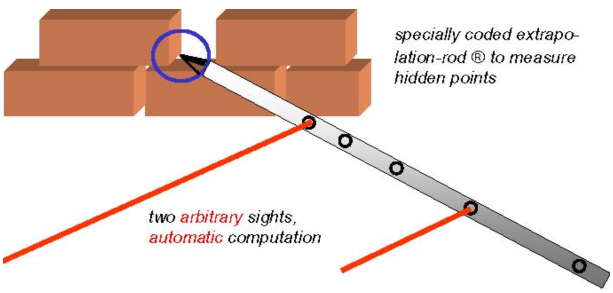

Figure 6: Coded extrapolation-rod for indirect measurement

• (5) Tools supporting the measurement in networks (free stationery)

After the instrument's position has been defined by two points, any other already coordinated points are than simply found automatically. The instrument turns to these points; they may be measured again and contribute to the stability of the network in the adjustment. Thus, though working fast, a rather complicated network of about 120 natural points, spread over four stories, could be measured with ± 2mm point accuracy.

3. PHOTO-TACHEOMETRY

As far as the recording of geometry is concerned, photo-tacheometry is based on intelligent tacheometry. Additional photos may be either photogrammetric images, and/or images taken with cameras that are integrated into the intelligent tacheometer itself. Both options are described in more detail:

1. The camera is built into the instrument (see fig. 7). The orientation of the image is then always known automatically, since it comes from the instrument itself. For practical reasons there are three cameras: two wide angle cameras and one camera replacing the eyepiece. A click into the photo on the notebook's screen makes the instrument turn to the point of the object, corresponding to the pixel clicked on in the image.

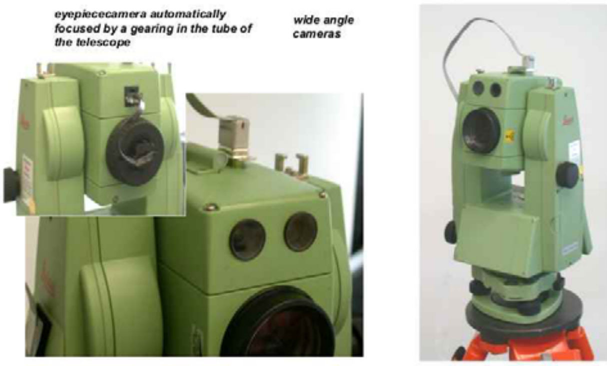

Figure 7: Reflectorless measuring tacheometer with integrated cameras

2. If an external high-quality photo is used, the connection to the coordinate system of the tacheometer has to be made first (the so called parametric orientation). This is done online on site by measuring four points of the object with the tacheometer that correspond to adjacent points in the image; the position and orientation of the camera in the coordinate system of the tacheometer are calculated (see picture A in fig. 8).). Thus, the orientation-parameters are in the database whenever the photo is used later (also to be understood as step 1 followed by many others described later).
In the following chapters some examples on the functionality of photo-tacheometry are given, the numbers of the headlines again referring to figure 1.

• (6) Interactive rectification and construction of ortho-photos

Photo-tacheometry makes possible very fast rectification and recording of ortho-photos, since coordinate-measurement, identification and pixel-assignment of the photo are made in one step, on site and not separately - referencing is no longer needed. Basis for rectification may either be a projective or a parametric projection (see fig. 8, A or B).

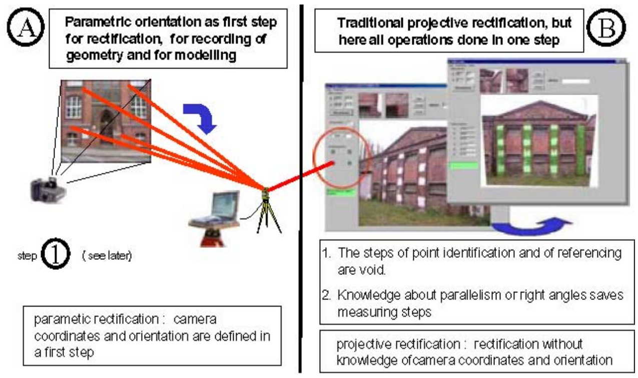

Figure 8: Different concepts of rectification

• (7) Directing the instrument via photo

Knowing the orientation of the photo also makes it possible to direct the instrument by simply clicking into the image (picture 2 in fig. 9). If a point in the image is marked, the corresponding distance measuring spot on the real object is found automatically in a few steps. This is done with a fast iteration process that allows comfortable measurements to the object.

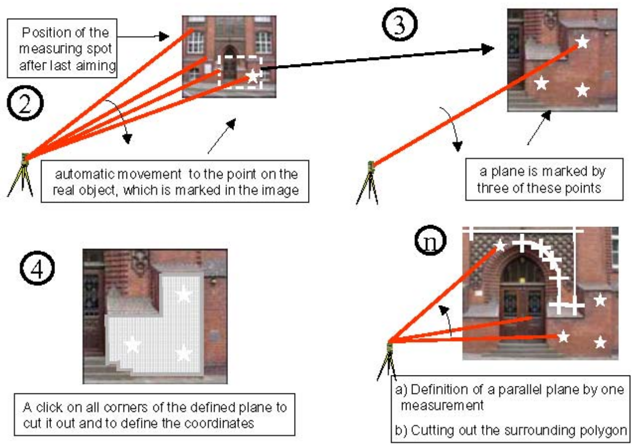

Figure 9: Example for visualization and coordinate measurement after parametric orientation

• (7) Special visualisation techniques

- Geometry and segments of the photo for rendering can be obtained in an integrated step shown in an example: In the picture (see number 3 in fig. 9) one may click on three different points of a plane. The instrument will then be directed automatically to these three points, one after the other, and coordinates are automatically measured. Thus the plane is defined. The following step then takes place exclusively in the picture (number 4). The corners of the plane to be cut out for the rendering are marked with the cursor. At the same time the geometry of these edges is determined by intersecting the plane with the beams from the camera-position (obtained by step 1, fig. 8) to the indicated edges. In this way, coordinates are found that fit to the model with sufficient accuracy.
- A plane parallel to others already used may be defined by one single click into the photo. The distance measuring spot of the tacheometer will move to this object-point by itself. Thus the plane is defined and in the next step cutting out and calculating of the coordinates of the edges run as already described above.
- Rectangular planes may be defined in a way similar to parallel planes. The connection between coordinates and parts of the image for rendering is done following the same method.
- Planes do not necessarily have to be determined this way, of course; the direct measuring of corners using the tools of intelligent tacheometry may be more reasonable sometimes. Irregular objects may be modelled in the same way, by using triangles on the object surface, the procedure with the triangulation of point clouds in laser scanning.

4. WORKING WITH PHOTO-TACHEOMETRY

• (10) Dynamic visual measurement protocol

The close link between the coordinate system and the image allows to overlay the image with positioning attributes. Points of interest, lines and alphanumeric information may be written

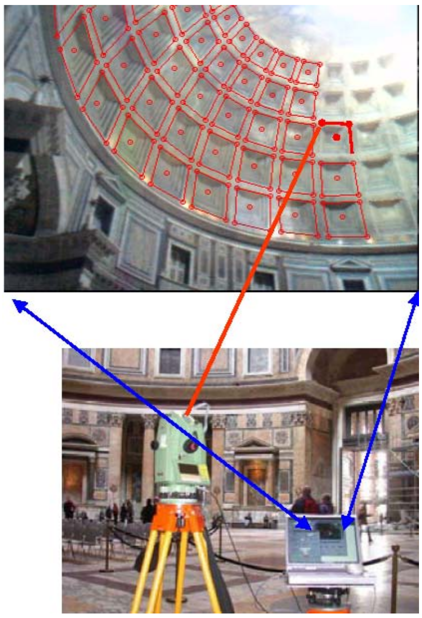

Figure 10: Continuous documentation of the measuring progress

to the adjacent points (see fig. 10). In this way a graphical measurement protocol may be generated continuously.

A protocol is also shown in picture 1 of figure 11. Here three different pictures with different magnification are stored as documentation of natural points in the form of an album (see Nr. 10 in fig. 1) with additional vector graphics and information.
This attributive image is connected to the graphic presentation of the coordinate system in picture 2 fig. 11. A click on either a coordinate in picture 2 or on the attributive image in picture 1 makes the instrument turn to this point. This is a very useful tool for measurement and control. Also the work with such an album of natural solid points is helpful for monitoring at any time. Picture 3, fig. 11 shows a possibility of steering the instrument by clicking into pictures, that may either be pictures from the build-in-cameras (see fig. 7), or from the external image. If the direct view through the telescope is given there is no parallax between camera and telescope axis. In addition to the eyepiece-view, the right picture gives an overview that was taken by one of the built-in wide-angle-cameras. Clicking into picture 2 or on a coordinate indicated in picture 1 will lead to the direct sight image given in picture 3. The interaction between all these components makes work with natural points very simple.

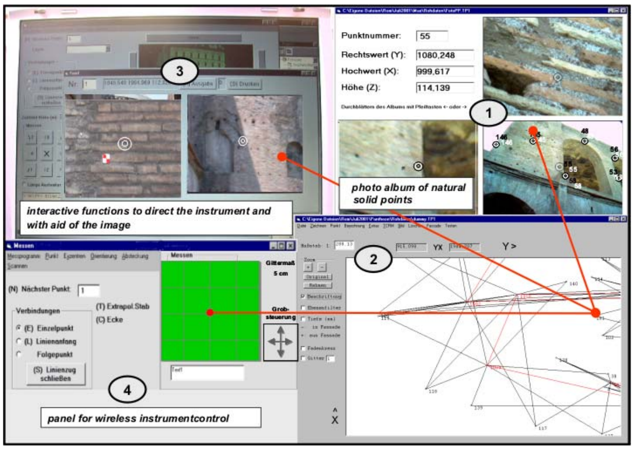

Figure 11: Interaction between different tools controlling the measurement process

• (9, 10) Monitoring with natural points

This should be a point of high interest for everybody engaged in monitoring cultural heritage. Targets are not necessary any longer, neither on floors nor on the walls. Number 9 in figure 1 indicates that the practical work is supported by the possibility of connecting different instrument setups using only natural points, which is of highest importance concerning a buildings coordinate system that is supposed to be used for decades.

• (12) Portraying work

A helpful tool directly connected to the others is a panel for wireless instrument control (see number 4 in figure 11). It allows to work on site and close to the building: The tacheometer is set up, the user himself stands in front of the building or archeological site with his notebook. If an oriented photo is not available yet (see no. 7), the distance measuring laser point may be directed by clicking into the panel, which is scaled automatically according to the distance. This allows the user to move the laser point along the object similar to the work with a photo shown in picture 3, fig. 11.

5. CONCLUSIONS

In figure 1 the possibilities of the three methods, traditional, intelligent and laser scanning are compared. The differences between intelligent scanning- respectively photo-tacheometry - to traditional tacheometry are very great. With traditional tacheometry only a very poor spectrum can be covered. The comparison of intelligent tacheometry and laser scanning reveals interesting differences as well: One has to consider that intelligent tacheometry has above all the advantages that it is low cost and one can get the result on site, in a portraying way. That is of highest importance for architectural users and some fields of cultural heritage documentation.

Methods of intelligent tacheometry and photo-tacheometry are also preferable if high density of the measured points is not required, or if the object may be defined by a lower number of points with high precision. For additional manual measurement the picture album as shown in figure 11, picture 1, can be used outside later, working either on paper print or with the notebook.

It could be demonstrated that the linkage of images with geometry taken by an intelligent tacheometer may be used successfully with respect to all results of recording: i.e. profiles, facades, visualization. The user himself has to decide whether he uses traditional tacheometry, intelligent tacheometry, photo-tacheometry or laser scanning. The decision should depend on the sort of building, on the task itself, on the presentation demanded and also on the budget available.

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