Advantages of the Integration of Image Processing and Direct Coordinate Measurement for Architectural Surveying - Development of the System TOTAL –

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ABSTRACT

First, a short comparison of different types of edifices, different types of recording, different instruments and different surveying methods is given. Four surveying methods are taken into account: manual measurement, photogrammetry, tacheometry and scanning. Two of these methods will be described in greater detail, due to the fact that they are less common: scanning and tacheometry with a totalstation controlled via notebook.

On the one hand the methods compete up to a certain amount, on the other particular surveying methods are suited more or less well to detect special qualities of a building or a monument. In reality a certain method is not always used how it fits best for the problem. Which one is chosen depends on the experience of the surveyor or of the equipment available. Quite often there is no single method which alone is a perfect solution, it is rather a combination of different methods that would produce the best results or allow the most rational way of working. In consequence, the question arose whether it would be more effective, cost-reducing and time-saving not only to more often use different surveying methods side by side, but also to achieve a synthesis of different methods and to integrate these methods into one system.

The investigation was extended now to find out which of the special characteristics of the methods should be combined. As a result, a new measuring system was designed. It consists of several different elements of modern tacheometry, photogrammetry and scanning. It was named TOTAL, which means **T**acheometric **O**bject-oriented Partly (**T**eil-) **A**utomated **L**asersurveying. It is based on reflectorless measuring by a totalstation that is equipped with servo-drives, and controlled by a notebook. Several cameras are implemented in addition, two of them fixed to the totalstation, as well as one external camera.

TOTAL allows fast and precise capturing of geometry, and of visual aspects of buildings and monuments in a single move. Several new possibilities make it possible to record geometry quite accurate. Control points allow fast production of ortho-images derived from rectification on-site. Another important function of the cameras is their ability to precisely point and control. The images may also serve as an archive, and may then be accomplished with numbers and coordinates and serve as a basis of an MIS, a Monument Information System. A very interesting tool is the automated profile-measurement, which offers the

possibility to continue profiles automatically even without direct sights. The system was used with great succes at monuments in Germany and Italy, e. g. at the Basilica of Maxentius on the Forum Romanum, Rome.
Several examples show, that considerable benefit derives from a close combination of certain elements of the methods mentioned above in a single instrument.

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1. ARCHITECTURAL SURVEYING – AN OVERVIEW

Architectural surveying affects different types of areas:

a) Different disciplines, like the preservation of buildings and monuments, facility management, architectural analysis of buildings, archeology and as built documentation for reconstruction
b) Different types of results and presentation and
c) Different technical methods of surveying.

Table 1 shows interactions between disciplines, typical accuracies and some characteristics on clients and the role of visualization for the disciplines.

Precision is the most important factor when choosing a measuring method. Thus it was chosen as the background for the classification. It reaches from high precision needed for the analysis of buildings via recording in preservation of historic buildings and monuments,

Different types of monuments and of recording	documentation for analysis of buildings, surveying artefacts	Preservation of historic buildings and monuments, archeology	Architectural surveying, as built documentation	facility management
magnitude of demanded accuracy	3 mm ... 1 cm	1 cm ... 2 cm	2 cm ... 5 cm	3 cm ... 10 cm
geometrical accuracy	→			
Characteristical Catchwords	on-site, portraying, analytical recording	giving a precise model of shape	Presentation fit for architectural means, rather schematic graph	determining areas, rough positioning of attributes
importance and clients	special scientific interest	public general interest	private client	geometrical back-ground, private interest
demand for visualization	detailed, but only for parts of the object	rarely public, mostly for education and tourism	planning, background for decisions	commercial/ estate agent

Table 1: Types of recording concerning geometry visualization and accuracy

via architectural surveying down to low accuracy in facility management. The transitions shown above are not very distinct, but the direction of the gradation is obvious.

Also, knowledge about the variety of possibilities for presenting results is important, no matter whether the surveyor carries out the presentation himself or not. There are traditional as well as modern types of presentation (table 2): conventional presentation of the highest accuracy on one side, rough visualization for popular purposes on the other as well as numerical presentation, drawn plans and more or less photorealistic visualization with animation. Obviously, the form of presentation chosen influences the surveying-method, especially when visual information has to be recorded alongside the geometry.

<table>
<tr><td>numerical presentation</td><td colspan="2">Visualization</td></tr>
<tr><td rowspan="2">numerical data:
coordinates, measurements, surfaces</td><td>drawing</td><td>photorealistic model,
surface</td></tr>
<tr><td rowspan="2">alphanumerical data:
list of attributes and objects</td><td rowspan="2">horizontal profile and vertical profile, projection, elevation drawing, precise plan of quarrystones, gridmodel, e.g. as network of triangles</td><td rowspan="2">panorama,
rectification/ortho-image,
3 D-model with texture/rendering,
photorealistic walkbys,
precalculated or free</td></tr>
</table>

Table 2: Forms to present results

2. TODAY'S SURVEYING METHODS – THEIR ADVANTAGES AND DISADVANTAGES

Table 3 contains the most important surveying methods and characteristics as far as their actual instrumentation and the disciplines where these methods are concerned. Here, the diversification into two groups of methods is of exceeding importance: there are those methods generally extracting information on-site and those collecting spatial information, but filtering and mapping the recorded data with time delay. Manual measurement and tacheometry belong to the first category. Characteristic points of a building are extracted on-site here. But photogrammetry and scanning gather the object as a whole, point by point; the extraction of characteristic data is carried out later on. Manual measurement and photogrammetry are well known. A brief characteristic of the other two surveying methods – scanning and modern tacheometry – will be given now. Especially modern tacheometry is still hardly known.

Scanning is characterized by the ability to sample an object very fast. E.g. 1000 points may be captured per second. In the cruising radius of the instrument, the environment is measured point by point thus producing a sort of „distance-image“ or “coordinate - picture”.

The coordinate cloud produced by scanning may be used in different ways:

a) In order to model an irregular surface, a dense network may be derived from the point-cloud directly, especially to model shapes like statues and reliefs. The triangles forming the net are often used as background for a rendering for visualization.

actual application	Instrumentation	filtering/extraction of the points of interest: on-site, before measuring	filtering/extraction of the points of interest: later on, in course of mapping	Instrumentation	actual application
supplementary and control measurements, facility management	handheld notebook controlled distancemeter, telescope rod, plumb	manual measurement	Photogrammetry	digital camera, bundle-adjustment, matching	preservation of historical buildings, architectural surveying, mapping of facades, visualization
architectural documentation, preservation and conservation of historic buildings, archeology, facades	totalstation for reflectorless survey with servo-drives, controlled by notebook	tacheometry	Scanning	fast destination of polar elements, triangulation principle, cloud of points	*polar:* industrial plants, architectural surveying, facility management
					triangulation sculptures, reliefs, architectural details

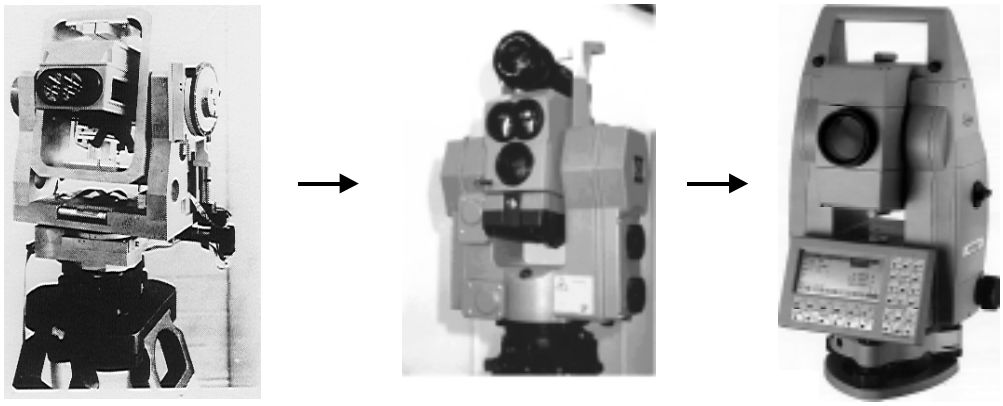
Table 3: The four most important surveying methods, state of the art

b) Regular objects may be modelled by the use of simple geometrical forms like mostly a plane or a cylinder. They are then fitted into the cloud of points. Modelling of surfaces succeeds rather well, due to the large number of points, although the single point accuracy might be moderate (up to some cm).
c) Characteristical single points of a building may - mostly - derive from intersections of planes, modelled according to b). This needs much manual supply.

Different operational areas need different types of scanners. Here a classification into three types is made:

1. The so called laserscanners. Angle measurement and distance measurement serve as a basis to achieve polar coordinates. They work from short ranges (meter distance) up to medium distances (e.g. 100 m) with accuracies of 5 mm to 3 cm. Contrast and illumination of the enhancement of the object cause no difficulties. But these instruments are rather big and expensive, some of them working only in a limited spatial sector, offering no possibility of single point acquisition.
2. Scanners of high resolution (0.2 mm at 1 m distance up to 2 cm at a range of 30 m), based on the triangulation principle. Disadvantages are the decrease of accuracy with growing distance, the considerable weight, great volume and high costs. The receiver, the CCD-array, needs sufficient return signal. So working at night is often necessary.
3. Scanners of highest resolution, making it possible to do freehand-scanning with an accuracy of millimeter to submillimeter. They may be used for sculptures, reliefs, architectural and archeological details. Disadvantages may be the rather limited cruising radius, problems with magnetical orientation or problems to fit different areas together and high costs.

Modern tacheometry uses a totalstation as hardware which is equipped with servodrives, directed by a notebook and measuring ranges reflectorless. The first instrument was developed and constructed in 1994 in our laboratory (figure 1).



1st generation:
Special mounting with an Ibeo -Pulsar for distance measurement

2 nd generation:
Modified Geodimeter DR 486 with mounted CCD-Camera

3 rd generation:
Totalstation Leica TCRM / TCRA

common qualities of modern tacheometers: servo drives controlled and directed by notebook, distance measured without reflector

Figure 1: Development of the hardware

Meanwhile, important manufacturers of surveying instruments began producing this type of instrument. We continued to develop special software with regard to the survey of architectural sites and monuments. Thus this class of totalstations may be used in an optimal way. A very central principle of the developments was the idea to control each result on-site. The whole system is named TOTAL - Tacheometric Object-oriented Partly (Teil-) Automated Lasersurveying – and it runs on a notebook. The software provides a large spectrum of automatic and half-automatic measuring possibilities. It is, for example possible, to detect edges and corners with very high precision. Due to the fact that the diameter of the footprint of the laser beam measures several centimeters, they cannot be otherwise determined with high precision. Another tool is a specially coded extrapolation-rod which is used to measure hidden points quickly, precisely and widely automatic.

When documenting monuments, the profile-measuring function proved a very powerful tool. Horizontal and vertical profiles can be taken completely independent from the local position where the instrument is stationed. An example is given in figure 2, showing rough data of a survey of the Basilica di Massenzio, Forum Romanum, Rome, Italy. The software provides the ability to automatically continue profiles everywhere in the monument e.g. on both sides of a wall.

Further useful tools, like initiating measurements out of the graph shown on the screen of the notebook make sure that work is fast and effective (Juretzko 2001). Using the totalstation in this modern way may be characterized as a continuation of the classical "painting a

portrait “. Documenting and analyzing face to the building is called like this in architectural analysis .

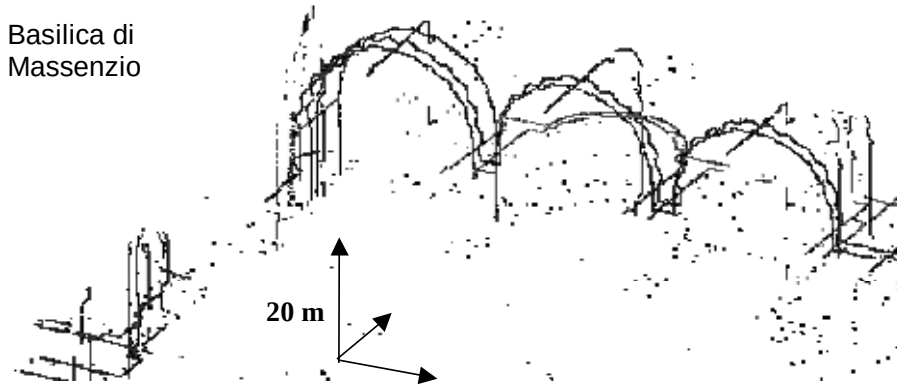


Figure 2: Horizontal and vertical profiles

Comparing the four principal surveying methods discussed in this chapter, that is manual measurement, photogrammetry, scanning and tacheometry, it can be seen that each one has its advantages and disadvantages (more detailed in (Scherer 2001, a)). Obviously, to get a perfect record several methods need to be used parallelly at least. With regard to a synthesis of parts of them, it had to be analyzed which characteristics should be chosen and combined.

3. TOWARDS A SYNTHESIS OF DIFFERENT SURVEYING METHODS

Those qualities of each method have to be picked up, which are unique and/or supplemental. In a first step the importance of each method for different tasks had to be investigated.

method	architectural analysis and documentation	as built docu-mentation for architectural reconstruction	preservation of historic buildings and monuments	Facade s	Arche-ology	facility manage-ment	industrial plants
manual measurement	3 – 1*	1	1	1	2	2	0
photogrammetry	2	0	2	3	2	0	3
scanning	1	2	1	2	1	2*	3
tacheometry	2	3	2	3	3	1	1

1 = occasinally used 2 = medium 3 = preferred 0 = without importance
* = strongly depending on type of recording

Table 4: The actual role of the surveying methods in different disciplines of architectural surveying

Table 4 gives an impression of the importance of each method for different tasks. The numbers marked in the table are strongly dependant on individual experiences. Photogrammetry and tacheometry seem to be the most important tools for architectural surveying. It is a positive aspect, that they each belong to one of the two very different categories mentioned above (see table 3): methods measuring discrete points (manual measurement and tacheometry) on one side, and the data gathering methods (photogrammetry und scanning) that work more globally on the other side. At least one method of each

category should be taken into account for a synthesis: The characteristics of these methods offer a broader number of complementing qualities.
Another way to compare the importance of the surveying methods in a more deatailed way is to look at job steps in the survey itself. Table 5 gives an overview about useful qualities and specifications of the methods. Manual measurement is no longer taken into account here, because of the difficulties introducing the results into a consistent coordinate system.

step / method	single point	corner, edge	irregular surface	control point	Rectification		profile	accuracy	results on-site
					image	coordinates			
photo-grammetry	X	X	X	0	X	indirect	X	corres-ponding	image process-ing possible
tacheo-metry	X	X	(X)	X	0	X	X		
scanning	0	indirect	X	0	0	0	X	0/X	

X = existing / possible 0 = unfavorable / impossible / difficult

Table 5: Corresponding characteristics chosen for a synthesis

Tacheometry and photogrammetry each offer more tools than scanning. So elements of these methods were selected for the synthesis. Because of photogrammetry and tacheometry being very different, photogrammetry gathering point clouds and extracting characteristic points with time delay, and tacheometry selecting before measurement. we combined tacheometry with elements from photogrammetry, hardware as well as software. Those functions marked in grey in table 5 were selected of each method. Obviously, all important functions can be gathered by means of photogrammetry and by means of tacheometry based on the experience with the notebook-controlled total station. The only thing not possible is to scan surfaces quickly. As a compensation, an option to scan a raster within a polygonally enclosed area has been developed. Based on this analysis the new system was designed.

4. TOTAL – INTEGRATION OF GEOMETRICAL AND VISUAL FUNCTIONALITIES

The core of this system is the totalstation, measuring polar coordinates without using a reflector. The instrument itself is directed and controlled by a notebook and equipped with three cameras. Two of them are fixed to the totalstation: a wide-angle camera giving an overview as well as an eyepiece-camera delivering a view through the telescope(figure 3). A

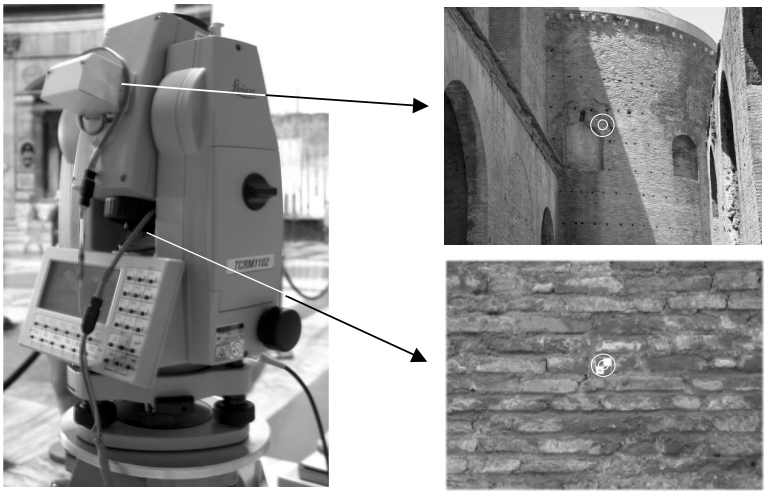


Figure 3: Totalstation with adapted cameras and corresponding screenshot

third, supplementary external camera may be of higher quality. The integrated cameras have three very different roles:

(1) Archieving

Points of interest are marked in the image and documented precisely together with the coordinates, point numbers and other descriptions. This is an excellent help establishing a monitoring system (MIS = Monument Information System) and for the identification of photogrammetric control points (see fig. 4).

Figure 4: Screenshot showing the software-integration of geometrical and image processing

(2) Targeting and Calibration.

Targeting is done using the images provided by the cameras. The redundant information of

the images and of the polar measurements may be used for automated detection of corners (fig. 5) and to control some tools of the system itself.

Figure 5: Three-dimensional target for calibration, sensitive towards distance-change and differences in contrast

(3) Visualization and modelling, generation of ortho-image.
For this purpose it is a great advantage that coordinates may be measured quasi-simultaneously to the capturing of the image within the photo-array. Overlapping photos serving for coordinate determination by bundle adjustment are hardly necessary (fig. 6).

Figure 6: Orthophoto for restauration purposes

Especially for architectural and archeological analysis it may be of a high advantage to model precisely on-site (fig. 7).

Figure 7: Detailed 3D-model of antique artefact for special architectural analysis

5. FUTURE DEVELOPMENTS – GENERAL VIEW AND OUR PLANS

Visualization is going to be an area of rapid expansion. This affects scientific and public purposes as well as commercial ones. The integration of tacheometry and photogrammetry enables automated modelling within areas of different precision, controlled on-site. Using the redundant information realized by tacheometric measurement and given by the variation of intensity in the picture will have another strong impact towards automation. Actually, we are working on both, the integration of visualization as well as the automated recognition of edges and corners.

Looking at the advantages of the integration of tacheometry and photogrammetry, scanning should be added soon. Modern instruments for architectural surveying will consist of a synthesis of tacheometry, photogrammetry and scanning. I think it is right to approach this aim from the side of very precise determination of single points as the core of the system, while other methods are added and grouped around and integrated.

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