3D SCANNING INSTRUMENTS

Wolfgang BOEHLER, Andreas MARBS

i3mainz, Institute for Spatial Information and Surveying Technology, FH Mainz, University of Applied Sciences,
Holzstrasse 36, 55116 Mainz, Germany,
i3mainz@geoinform.fh-mainz.de

KEY WORDS: 3D, scanner, close range, cultural heritage.

ABSTRACT:

All instruments collecting 3D coordinates of a given region of an object surface automatically and in a systematic pattern at high rates and achieving these results in near real time are considered as 3D scanning instruments in this article. For cultural heritage documentation, mobile systems for close- and mid-range applications are applicable. Different technical solutions have been developed to obtain the necessary measurements for the derivation of the 3D point coordinates on a reflecting surface. Ranging scanners measure horizontal and vertical angles and compute the distance either by the time-of-flight method or by comparing the phases of the transmitted and received wave form of a modulated signal. Triangulation type instruments include a base. They analyze the location of a projected laser spot or other pattern using one or two CCD cameras. The different principles lead to a different accuracy behavior of the distance measurement. Since noisy measurements are difficult to process, a high accuracy of the scanner is desirable. This leads to the conclusion that no single scanner can fulfil all demands in different cultural heritage recording projects.

Besides accuracy considerations, other characteristics are important for the selection of the most suitable instrument for a certain task. Among these are scanning speed and resolution, range limits, influence of interfering radiation, possible field of view, inclusion of imaging cameras, ease of transportation, type of power supply, and the quality of the scanning software.

A list of presently available 3D scanners completes the overview given in this article.

1. DEFINITION

To the knowledge of the authors there is no generally accepted definition concerning instruments which are considered to be 3D scanners. Since different technical principles are used to measure the elements needed to compute 3D coordinates, some technicians have tried to delimitate 3D scanners from other instruments based on their technical way of operation. Among other drawbacks, this has also led to a superfluous discussion whether 3D scanning 'belongs' to geodetic surveying or to photogrammetry.

For the user, however, it is the result only that counts, regardless of the method used to achieve it. From a user's point of view, a 3D scanner is any device that collects 3D coordinates of a given region of an object surface

- automatically and in a systematic pattern
- at a high rate (hundreds or thousands of points per second)
- achieving the results (i.e. 3D coordinates) in (near) real time.

The scanner may or may not deliver reflectivity values for the scanned surface elements in addition to the 3D coordinates.

3D scanners are used

- stationary in a fixed position (e.g. in production lines for quality control)
- as mobile systems on tripods or similar stands for close and mid-range applications
- as airborne systems for topographic applications.

2. USE IN CULTURAL HERITAGE DOCUMENTATION

Metric cultural heritage documentation tasks usually comprise close range recording applications. Objects range from small artifacts over sculptures to buildings. Irregular shapes and surfaces are encountered frequently. Often, the time available for the measurements is limited. In the past, close range photogrammetry was the only method to meet these demands.

3. PRINCIPLES OF OPERATION

3.1 Ranging scanners

Time of flight of a laser pulse. A laser pulse is sent to the object and the distance between transmitter and reflecting surface is computed from the travel time between signal transmission and reception (fig.1). This principle is well known from electronic tacheometers. In fact, a tacheometer with motor-driven axes could be programmed to work as a scanning device. Measuring rates would be very low, however, since - due to the mass of the instrument - the incremental rotation steps around the axes cannot be performed fast enough, signal processing usually takes too long and angular values have to be read troublesome from coded circles. Scanners use small rotating devices for the angular deflection of the laser beam (at least for one of the two angles) and use simpler algorithms for range computation which may lead to poorer accuracy values. Typical standard deviations of range measurements by time-of-flight scanners are in the order of some millimeters. Since ranges are relatively short, this accuracy is nearly the same for the whole object space. The 3D accuracy is also influenced by the accuracy of the angular pointing of the beam. Few investigations concerning this matter have been made public yet.

Phase comparison method. This method is also well known from tacheometric instruments. In this case, the transmitted beam is modulated by a harmonic wave and the distance is calculated using the phase difference between transmitted and received wave. From the users point of view, the method is not very different from the time-of-flight method. Due to the more complicated signal analysis, the results may be more accurate (at the expense of the measuring rate). Since a well defined returning signal is needed, scanners using the phase comparison method may also have a reduced range and tend to produce more wrong or dropped points.

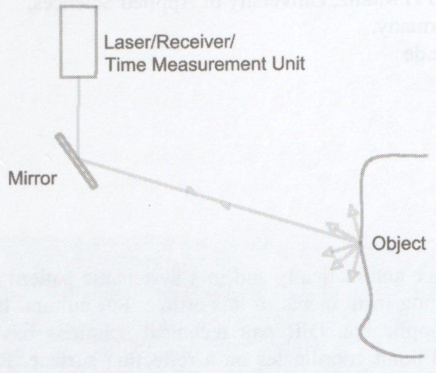

Figure 1. Time of flight principle

3.2 Triangulation scanners

Single camera solution. This type of scanner consists of a transmitting device, sending a laser beam at a defined, incrementally changed angle from one end of a mechanical base onto the object, and a CCD camera at the other end of this base which detects the laser spot (or line) on the object. The 3D position of the reflecting surface element can be derived from the resulting triangle (cf. fig. 2). This principle, too, has predecessors in surveying where range finders with constant bases have been used. From there, it is also well known that the accuracy of the distance between instrument and object decreases with the square of this distance. Obviously, for practical reasons, the base length cannot be increased at will. Nevertheless, these instruments play an important role for short distances and small objects where they are much more accurate than ranging scanners (cf. fig. 4).

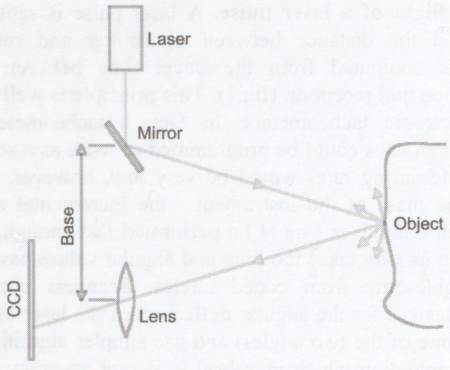

Figure 2. Triangulation principle: single camera solution

Double camera solution. A variation of the triangulation principle is the use of two CCD cameras, each one at another end of the base. The spot or pattern which is to be detected is generated by a separate light projector which does not have any measuring function (cf. fig. 3). A large variety of solutions can be found. The projection may consist of a moving light spot or line, of moving stripe patterns, or of a static arbitrary pattern. The geometric solution is the same as with the one camera principle, thus resulting in the same accuracy characteristics. Not all devices using two cameras offer high point rates and not all of them produce 3D coordinates in real time. If high point rates and real time processing are provided, however, these instruments are an alternative to the scanning devices specified above and may under practical requirements be considered as 3D scanners as well.

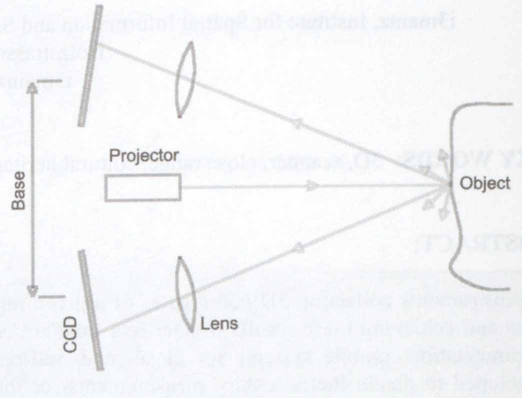

Figure 3. Triangulation principle: double camera solution

4. ACCURACY CONSIDERATIONS

Accuracy is not always the predominant demand in cultural heritage documentation. A standard deviation of a few millimeters for a single scanned surface point is not of much evidence if this point is part of an element possessing a regular geometry (plane, cylinder or the like) and is just used to find the parameters describing this element in a CAD representation. If irregular surfaces have to be modeled (usually by a mesh representation), noisy point clouds can be a rather nuisance in processing, especially when the presence of edges does not allow overall smoothing operations. Therefore, the scanning procedure should be carried out with the most accurate scanner available for the size and range of the particular object.

Since objects of many different sizes occur in cultural heritage documentation, no single scanner can really be recommended for all tasks. Instead, a selection of three different scanners covering roughly the ranges 0.1 to 1 m, 1 to 10 m, and 10 to 100 m is desirable. A large selection of scanners for ranges below 1 m is available (tab.1); a single point accuracy of 0.1 mm and below can be expected. For the mid range from about 1 to 10 m, the MENSI S10 and S25 (former names: SOISIC SD and LD) triangulation scanners are presently the optimal choice (0.5 mm at 2 m, 2 mm at 10 m, for the S25). For larger distances, again a good choice of instruments can be found (table 1), yielding an accuracy of a few millimeters to some centimeters depending to some extent on their possible maximum range.

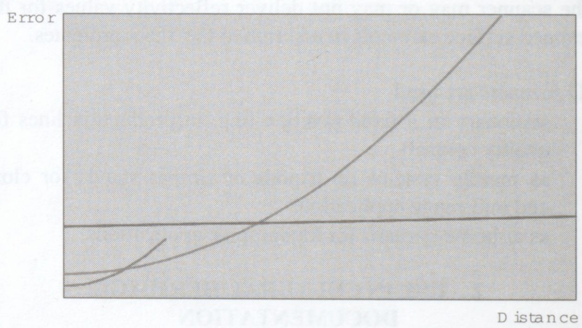

Figure 4. Scanner accuracy (Small parabola: triangulation scanner with short base. Large parabola: triangulation scanner with long base. Straight line: Ranging scanner)

5. FURTHER CONSIDERATIONS

5.1 General

Although surveyors tend to see accuracy as a predominant consideration when comparing measuring equipment, for the practical use there are numerous other characteristics which may be decisive under certain project pre-conditions. This also applies to the suitability of 3D scanning equipment for cultural heritage recording projects.

5.2 Speed

In spite of high data acquisition rates, scanning can become a time-consuming process when high point densities are needed for high object resolution. 100 points per second can still be considered as a slow rate. A rate of about 1000 points per second is satisfactory in many cases. It should not be deducted, however, that this will complete the same project 10 times faster since the additional time needed (e.g. for transportation to and between different observation points, for setting up the scanning process, for control point measurements, etc.) cannot be accelerated and will thus comprise an increasing percentage of the whole working time. For the same reason, a boost to tens of thousands of measurements each second does not really mean a great improvement.

5.3 Resolution and spot size

Object resolution is theoretically a function of the size of the angular increments the measuring beam can be moved. Of more practical evidence is the size of the reflecting area (spot size), since this will limit the local resolution. If high resolution is needed (which is often the case), it should be carefully checked how well the beam is focussed and if an automatic focussing procedure is provided for varying ranges.

5.4 Range limits and influence of interfering radiation

Range specifications should always be doubted. Possible ranges depend highly on the reflectivity of the material itself, on the cleanness of the atmosphere and on the additional radiation caused by reflected sun or artificial radiation on the object or interfering sources near the object. In general, time-of flight instruments are relatively robust, whereas phase measurements and signal detection on the CCDs of triangulation instruments are more sensitive and may demand night-time measurements.

5.5 Field of view

Fixed scanners without motorized axes for rotation (camera view scanners) have a limited field of view. Typically they can scan an area of about 40° by 40°, which amounts to about 0.5 steradiant (a full sphere amounts to 4π or about 12.6 steradiant). Scanners with one axis, like the MENSI SOISIC cover about 45° by 320° or 4.5 steradiant, whereas instruments with two axes (panorama view scanners) can scan anywhere except a conical area of about 30° around the nadir, leaving a field of view of about 11.7 steradiant. Large fields of view can be of great significance in closed rooms where scanners can collect large amounts of data from a single observation point without any attention by personnel (e.g. over night).

5.6 Registration devices

If partial scans from different observation stations have to be combined and/or transformed to a common coordinate system (registration), it is desirable to have special targets in the object space, which can be easily detected by the scanning software. Some producers supply special targets (spheres, plane targets with high reflectivity) which are adapted to their hard- and software. These targets should also be suitable as targets for tacheometers and for photogrammetric imaging.

5.7 Imaging cameras

Many applications demand for object texture information in addition to the geometric definition of the object. If these textures are mapped onto the 3D model, a photo-realistic view can be achieved. Some scanners record intensity values for the returning signal. Usually, this is not sufficient to supply a texture information good enough for texture mapping. The same applies to the cameras of the triangulation scanners which are optimized for spot detection but not for imaging. Some users demand the inclusion of high quality (color) cameras into the scanning equipment where others would not be ready to pay for this extra feature. Adapters to fit a camera to the scanner might be a solution. In this case, the relative positions of scanner and camera could be calibrated which would facilitate the co-location of scanning results and images.

5.8 Ease of transportation

Ideally, the scanning equipment should be small and lightweight. Most mid- and long-range scanners are still relatively bulky. So, for instance, it is not possible to carry them as cabin baggage on commercial flights. Especially in cultural heritage documentation, where remote locations are common, great attention should be paid to the ruggedness of the equipment and to the quality of the carrying cases supplied with it.

5.9 Power supply

Scanners which can be operated by batteries are more versatile to use than those needing a power line supply. Portable generators may help in the latter case, but it can be necessary to run long power cables when working in interiors or caves. Also, generators and cables add to the equipment load to be transported.

5.10 Scanning software

The software needed on site should offer fast and simple interfaces for defining scan windows and resolution values. A possibility to observe the scanning progress and to estimate the remaining scanning time should be available. More sophisticated features such as automatic target detection for artificial tie and control points and dynamic adjustment of resolution are desirable. If large objects are recorded, it should be possible to accomplish at least a rough registration of point clouds taken from different points of observation in order to check the completeness of the scan.

6. LIST OF AVAILABLE INSTRUMENTS

A list of available 3D scanners is included in table 2. Some companies are known to be in the process of developing new instruments, presently. A list which is frequently updated and includes web links to producers can be found under http://scanning.fh-mainz.de.

	Producer	Type	Range	Princ.
Mid Range	Optech	ILRIS-3D	800	tof
	Riegl Laser Measurement Systems	LMS-Zxxx	450	tof
	Mensi	GS 100	100	tof
	Callidus Precision Systems	Callidus	80	tof
	MetricVision	MV 200	60	tof
	Zoller+Froehlich GmbH	IMAGER 5003	55	tof
	Cyra Technologies	Cyrax 2500	50	tof
	Mensi	S10, S25	25	tri
	3rdTech	DeltaSphere	12	tof

	Producer	Type	Range	Princ.
Close Range	Arius3D	Arius3D	6	tri
	Breuckmann	optoTOP	5	tri
	Digibotics	Digibot	1.8	tri
	GOM mbH	ATOS	1.6	tri
	ABW GmbH	Kombi-640	1.5	tri
	MEL Mikroelektronik GmbH	M2D	1.2	tri
	Minolta	VI	1.2	tri
	3D Digital Corporation	Model 100, 200, 300	1	tri
	Cyber F/X	various	ca. 1	tri
	Cyberware	various	ca. 1	tri
	Intelligent Automation	4DI	ca. 1	tri
	Laser Design	DS, RE, PS	1	tri
	Vitronic	Vitus	ca. 1	tri
	micromeasure GmbH	various	0.8	tri
	Polhemus	FastScan	0.8	tri
	Steinbichler Optotechnik	various	0.8	tri
	TC2	Body Scanner	0.8	tri
	Genex	Rainbow 3D	0.7	tri
	Shape Grabber	various	0.7	tri
	SCAN technology	various	0.6	tri
	DLR German Aerospace Center	Laser Range Scanner	0.3	tri
	INO	3D Laser Profiling Sensor	0.3	tri
	INTECU	Cylan	0.3	tri
	Nextec	Hawk	0.3	tri
	Roland	Picza	0.3	tri
	3D Scanners, Nvision	ModelMaker	0.2	tri
	Kréon	KLS	0.2	tri
	Metris	LC 50, LC 100	0.2	tri
	3DMetrics	3DFlash!	0.1	tri
	Hymarc	Hyscan 45c	0.1	tri
	Perceptron	Contour Probe Sensor	0.1	tri

Table 1. Overview of available scanners sorted by range (tof = time of flight, tri = triangulation). From WWW, 2002.

7. REFERENCES

Boehler, W., Heinz, G., Marbs, A., 2001: The potential of non-contact close range laser scanners for cultural heritage recording, XVIII. CIPA Symposium, Potsdam, Germany, Proceedings. In print.
(Also available at http://www.i3mainz.fh-mainz.de)

WWW 2002: http://scanning.fh-mainz.de