Application of Laser Scanners to Determine the Geometry of Buildings

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Abstract. Laser scanners provide a new economically measuring method to determine the geometry of object surfaces in a time-saving way, which have a large filed of use. Some special demands and restrictions on the use of laser scanners in determination of building geometry will be outlined, which have to be regarded for getting reliable results.

Key words: laser scanner, building geometry

1 Introduction

In recent years laser scanners became a powerful tool for determination of object surfaces of different kind. The wide range of laser scanner applications includes for example the airborne determination of earth surface, the terrestrial determination of visible geotechnical structures like rocks and slopes, fade surveying of buildings, the determination of interior building structures, cavern measurements, the reengineering of designed models. The further comments will be focused on the use of laser scanners to determine the geometry of interior building structures. The pro and cons and also some restrictions on this new measurement method shall be outlined.

2 Demands on determination of the geometry of buildings

The as-build-documentation has grown in interest during the last two decades, because an economical estate management demands the knowledge of an exact geometry for planning and utilization processes of buildings. Today nearly 60 percent of building operations are done in stock. But only for a few buildings up-to-date information about the interior geometrical structure are available. Therefore applications for geometry determination are demanded, which has the potential of

- surveying the interior of buildings in a time-saving and economical way
- easy feasibility
- generating 3D models of the building environment even of complex geometric structures
- interfacing CAD- or CAFM-Systems

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Depending on the later application of the building model the demands on accuracy of the geometry are varying (Tab. 1). In this sense the accuracy has to be interpreted as relative accuracy between 2 points on the surfaces of the building structure.

Application	accuracy
Space planning and area management	5 – 20 cm
Building operations on architectural fabric	1 – 2 cm
Plant management (Planning and operations)	0.1 – 2 cm
Reconstruction of historical building details	0.1 – 1 cm
Prototyping / reverse engineering	< 0.1 cm

Tab. 1 accuracy demands on building geometry

Not only the accuracy has to be considered but also the resolution of the measuring method. Especially the reconstruction of historical buildings demands a detailed geometrical description of fine structures of the object geometry.
The advantages of applying laser scanners in building measurements are the high speed determination of the surface geometry of all objects in the field of view of the scanner and the ease of operation. In contrast to photogrammetric measuring methods in laser scanning illuminated and constrasty object surfaces are not demanded. Laser scanners can be handled by a single person and they are cost-effective.

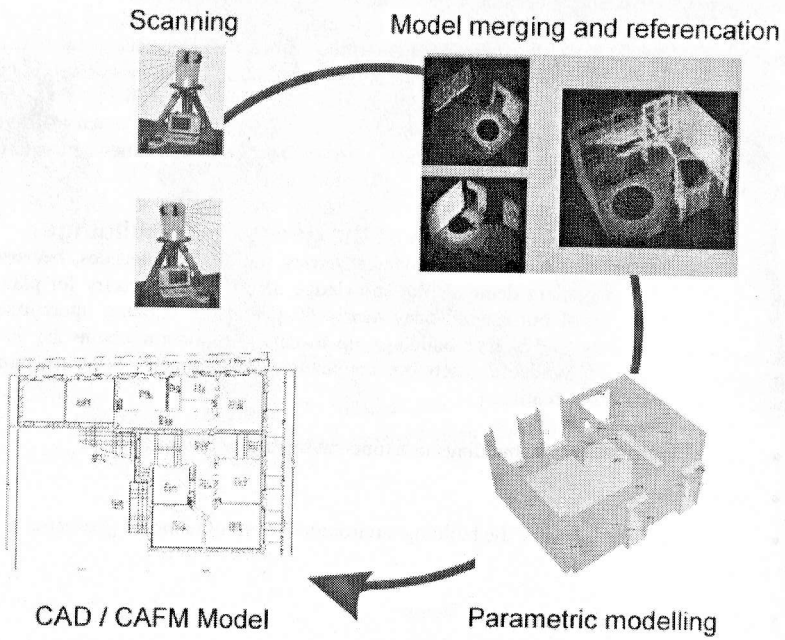

Fig. 1 Laser scanning process model
(Photos by courtesy of Callidus Precision Systems GmbH)

3 Measuring and evaluation processes with laser scanners

The result of a scan initially is an unreferenced point cloud. Normally for registration of the whole object many scans form different stations are needed, which have to be combined to a complete object point model. As optional step the referencing to a given coordinate system can be necessary.

The merged and possibly referenced point cloud can afterwards be used for three-dimensional visualization of the building. But normally the results of geometry determination have to be transformed to a CAD or CAFM models. Therefore a parametric object model has to be derived form the point cloud.

3.1 Model merging and referencing

The model merging process is comparable to the bundle block adjustment in photogrammetric data processing. The point cloud will be scanned so that there are overlapping areas in the scans. For the correlation of the scans homologous points, lines or surfaces can be used to merge the scans by spatial transformation techniques. When specific points are also referenced to a three dimensional coordinate system the referencing can be done by the way.

For merging scans by use of homologous points either artificial targets will be positioned in the object space or natural points on the objects has to be identified in the different point clouds. As artificial targets retroreflective targets (*Fig. 2*) can be used, when the scanner also registers the reflectance beside the coordinates of the measured point, or spherical targets (Fig. 3), which midpoint can be computed by shape recognition algorithms from the measured surface points of the sphere. Different radii of the spheres provide a coding system, so that the target points can be unambiguously identified by image processing algorithms.

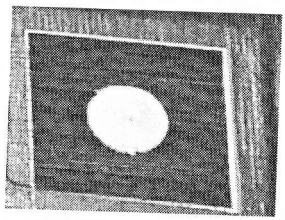

Fig. 2 retro reflective target

Fig. 3 spherical target

The required target size depends on the angular stepwidth, the divergence of the laser beam and the range between the scanner and the target. To get reliable results for example on a spherical target 9 points should be measured theoretically for the determination of the parameters of the sphere. This means that 3 horizontal and vertical scan lines each have to hit the sphere. With an angular stepwidth of 0,25 deg, which is used as minimal stepwidth of some scanners, at a range of 25 m the diameter must exceed 22 cm. In practice the diameter of the sphere has widely be enlarged, because the spherical parameters are only determinated form a small part of the surface and outliers, which often occurs at the boundary of the spheres caused by multipath effects, can better be detected with high redundancy.

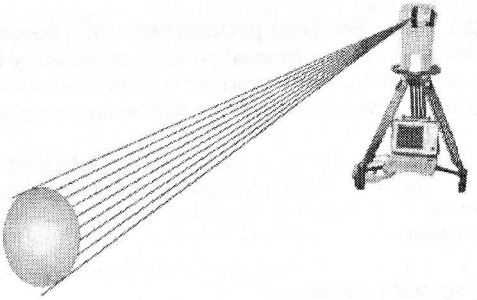

Fig. 4 measurement of spheres

The use of plane retroreflective targets requires a high angular resolution of the scanner, because the boundary of the reflectance area has to be determined from which the midpoint of the target will be derived. Therefore the reflectance and the measured coordinates have to be combined unambiguously. Not all today's scanner are able to register the reflectance, so that this merging method cannot be used with all scanners.

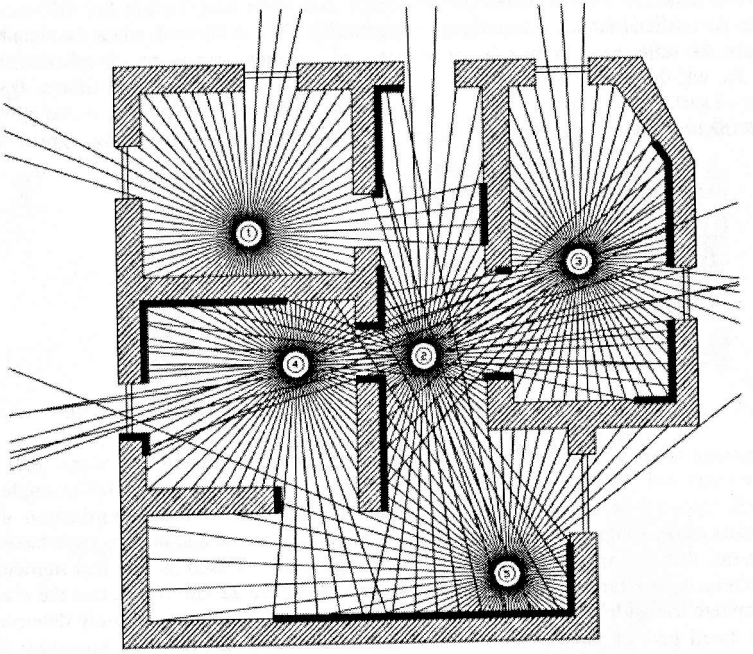

Fig. 5 merging with corresponding surfaces

Another way of merging scans is the use of corresponding surfaces. For that the different point clouds are clustered into sections from which geometrical primitives are computed by adjustment techniques. From corresponding surfaces which are at least determined form two

stations transformation parameters can be computed and the point clouds can be merged together. In minimum three corresponding surfaces are needed for an unambiguously merging of two point clouds.
Instead of using corresponding surfaces the intersections of these can also be computed, so that the derived intersection lines or intersection points can be used for merging. All merging techniques with derived objects (surfaces, lines, points) are critical in point of error theoretical view. Especially in determination interior building geometry the corresponding objects are positioned in small corridors of view, e.g. through doors or other openings in building structure. The determinations of the corresponding surfaces from different stations are normally not based on the same surface sections, because it is difficult to decide which parts of the point clouds are corresponding and. this process has to be done interactively. Even small differences in parameter determination of the corresponding surfaces causes difference in the transformation parameters, so that these errors will propagate over the other stations and larger differences have to be expected.
With demands on high accuracy its therefore advised to use artificial targets, which coordinates are probably determined by other measurement techniques. Further the accuracy can be increased by redundant measurements, e.g. to combine the scans to a network as like done in tacheometric measurements.

3.2 Parametric modelling

The result of the merging and referencing process is one point cloud with a unique reference. Because point clouds can not directly be used for deriving geometrical dimensions of the measured objects and the handling of point clouds in CAD or CAFM systems are not very user friendly, as next step of the evaluation process in laser scanning a parametric modelling of the objects has to be done. Therefore the manufacturers of laser scanners provide their own modelling systems.
Basis of the modelling process are adjustment programs, which compute from the three dimensional points parametric representations of the object shape. Because in the field of view of a scan are normally many different objects, the point cloud has to be segmented into point clusters, which particular represent the shape of a single surface. The clustering will be done interactively by the user. E.g. the user has to decide which part of the point cloud belongs to a single surface. For this purpose the modelling programs provide visual help by range dependend colouring the points or by reflectance pictures, where the points are coloured depending on the measured reflectance.
The geometry of modern buildings is normally composed of simple structured elements like planes, spheres, cylinders or cones. Also other second order surfaces will be used to approximate the geometry. Especially in historical buildings the surfaces can't be approximated by regular surfaces. Therefore spline surfaces as nurbs or polygonal meshes will be used for approximation of irregular surfaces.

4 Dependencies on determination of building geometry

4.1 Field of view

Laser scanners can be classified respectively to their filed of view (FOV) into:

- panoramic scanners and
- cameralike scanners.

While panoramic scanners are able to scan around the whole horizon cameralike scanners have only a limited field of view in horizontal as well as in vertical direction. The field of view in vertical direction of panoramic scanners varies from ±30 deg up to 180 deg.
With respect to determination interior building geometry panoramic scanners have an advantage over cameralike scanners. Because the limited filed of view of cameralike scanners (Fig. 7) many stations are required for the determination of whole geometry of a room. By contrast panoramic scanners (
Fig. *6*) only need few station provided that the geometry is not masked by furniture or other obstacles. For the reason that the time for measurement and evaluation increases with the number of stations panoramic scanners are more economically in determination of room with small volumes. But the use of all scanner types is also limited respectively to the lower limit of range measurements, which varies from 0.6 m up to 2 m. Because of that very small rooms like boxrooms or toilets can't be measured by laser scanners.

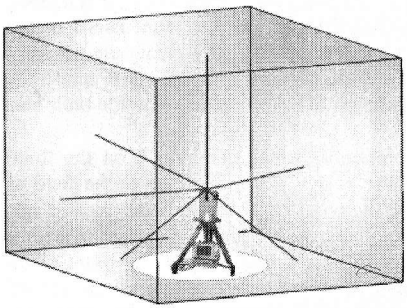

Fig. 6 Field of view of panoramic scanners

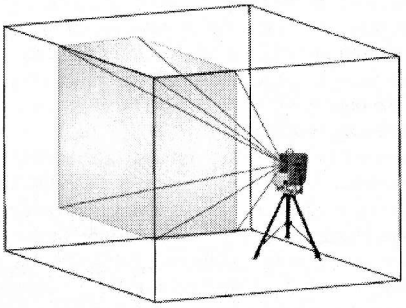

Fig. 7 Field of view of cameralike scanners

The advantages of cameralike scanners are in determination of surfaces which are located in nearly one direction like fades, because this scanner type can be directed straight to the object. By contrast panoramic scanners are often only able to scan a whole panorama, so that many object have to be recorded which are not point of interest.

4.2 Determination of corners and edges

Respectively to the divergence of the laser beam the spot diameter increases with the range form the scanner to the object. At a range of 50 m the spot diameters of today's laser scanner vary form 6 mm to 250 mm. Especially measurements to corners and edges are affected by this circumstance.
A laser beam with high divergence causes a large reflection area on the object surface. Respectively to the reflectance and the angle of incidence the laser impulse will be remitted in various ways. Normally the receiver of a laser scanner measures the range, when the intensity of the reflected impulse exceeds an internal limit. While measuring to corners or edges this results in either shorter (*Fig. 8* or longer *Fig. 9*) ranges. Therefore the edges and

corners seems to be rounded. This error can be greater than 2 cm, so that the demands on accuracy can be exceeded.

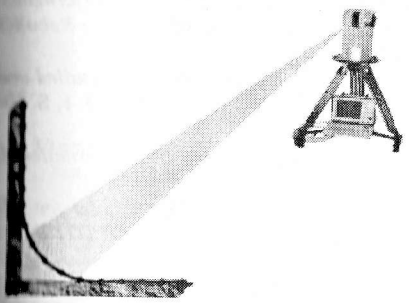

Fig. 8 corner measurement

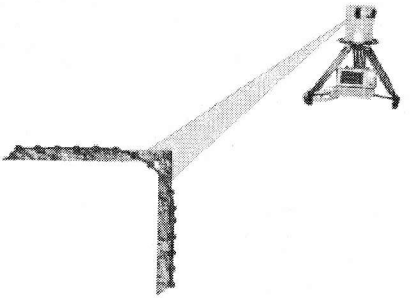

Fig. 9 edge measurement

Another effect especially in corners which causes ambiguous range measurements is the multi-path of the laser beam. It also depends on reflectance and angle of incidence. The impact on the range measurements is not systematically, so that the ranges can be measured either to short or to long.

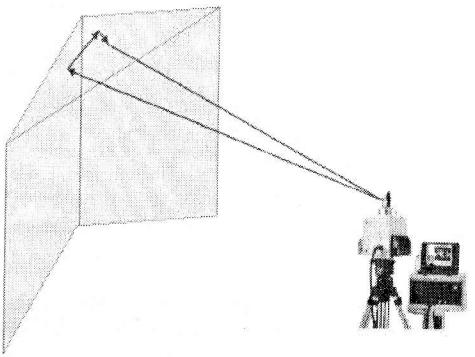

Fig. 10 multi-path effects

5 Conclusions

With laser scanning in the last decade a powerful measurement method has be developed, which provide an economical and easy to use way for determining the geometry of buildings. Considering possible effects onto the results high- accuracies can be achieved. The gap between tacheometric and photogrammetric measurements will be closed by laser scanning, so that the scanning technology will be the measurement technique of the future.

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