

Terrestrial Laser Scanners – an Important Step towards Construction Information

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SUMMARY

A completely new geodetic instrument and surveying method is on its way to revolutionize expensive current surveying procedures for precise building documentations and facility inventories. Former single points defining object shape are now replaced by a hundred of thousands of grid points, gained within minutes by terrestrial laser scanning, an efficient laser vector sensing technique. The resulting spatial point cloud may be immediately viewed and treated. A couple of adjacent point clouds can be merged and transformed into a defined coordinate system. The joint survey result's primary potential is based on the straightforward modelling and object creation possibilities for CAD.

Very promising applications turn up in monitoring construction progress, preparation of reconditioning works and creating product models for building adaptation planning, as there is a growing demand for related information systems. Terrestrial Laser Scanning, well combined with prismless tacheometry and handheld laser devices, delivers the ideal basic data sets for this kind of information systems.

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1. CATCHING THE COMPLEX GEOMETRY OF REALITY

If our mission is to determine the complex geometry of an impressive architectural structure, of a challenging engineering construction or of a sophisticated industrial pipeline facility, we should contact an experienced professional surveyor. His suggestion will be either a geodetic or a photogrammetric concept of survey. The geodetic strategy aims at the polar survey of a minimum number of characteristic points by means of a prismless total station., sufficient to define all line and surface elements. The relation to the co-ordinate system desired will be generated by the predetermined instrument station and the respective orientation of the servo tacheometre. The survey demands an expert, familiar with the type of object and the final aim of the ordered survey; in general, the fieldwork is time consuming. One of the reasons is that the simultaneous preparation of a thorough field sketch is indispensable. Supported by this manual sketch the processing and geometric construction is done in the office. As a rule, this part of the work will be finished rather quickly, in particular, when the target are two-dimensional plans. For the photogrammetric strategy things behave just the other way round: recording the pictures with a digital metrical camera from at least two different stations does not take much time. The effort needed appears when it comes to model orientation and stereo analysis by a skilled operator. For relative orientation the perspective bundles, determined by the pictures and the camera parameters, have to be adjusted by a least squares procedure. Each pair of corresponding rays has to intersect in an optimum way at the respective target. Following, absolute orientation is reached by three control points with known co-ordinates, which are sufficient to determine the spatial transformation to a desired co-ordinate system. Stereo-photogrammetry's main advantage lies in the complete documentation of the object, so that parts, which might be of interest somewhat later, still can be observed and evaluated. Drawbacks of the method are the condition of good, homogenous illumination and the problem of hidden spaces, contained in a single picture only.

2. THREE DIMENSTIONS IN ONE STRIKE

What the expert surveyor would prefer to offer, were a method, combining the advantages of the two concepts mentioned above, without being obliged to accept the drawbacks; i.e. a quick, spatial survey of the entire information. Since 2000 this has become possible with the revolutionary technique of 3d laser scanning. Although the purchase price of such instruments is rather exclusive at the moment, the method's potential is so promising, that the author has no doubt about its triumph during the next decade (Wunderlich, 2001). When the instruments start to spread more widely, effects known from the beginnings of GPS will repeat and the prices will lower. In ten years terrestrial laser scanners will have become standard in every bigger surveyor's office or construction enterprise!

A 3d laser scanner scans an object according to a grid of selectable density by means of a visible laser beam. For each particular orientation of the ray its spatial direction (referring to the instrument's system) will be recorded as horizontal and vertical angle together with the slope distance to the target point. Within minutes thousands of 3d vectors are created, which originate from a fictitious centre and whose terminal points reproduce the scanned object in form of a fine grid of 3d co-ordinates. This the reason why a 3d laser scanner often is called a spatial '1:1 digitizer'.

The scanning result is a spatial cloud of points, visualized simultaneously on the computer screen, so that we can watch the object's representation building up. Depending on the type of instrument, the point cloud may be colour coded according to the point distance or to the reflected intensity. But it is not only a intuitive, axonometric visualization, moreover we can directly treat the co-ordinates of any point or point group without any delay. The possibilities to use the point cloud are immense, although (yet) unfamiliar:

- The point cloud may be arbitrarily rotated during the scanning process and viewed from different perspectives and distances
- Disturbing and non-welcome points can be easily eliminated
- Measurements can be performed between different points of the cloud; in this way in-situ quality control is possible at once.
- By means of best-fitting surfaces CAD objects can be created from corresponding segments of the point cloud

As a matter of fact, the last option represents the highlight of the new method; it opens the door to reverse engineering for entire structures. By consequent modelling a complete transition of the scan to a CAD system becomes possible. So, finally, an economic way of input has been found to bring structural information or facility inventories into a CAD system. From there on planning of reconstructions or difficult inventories can be realized digitally. Especially for the purpose of modernization of old buildings the new method will be accepted quickly, the more when it is well combined with other laser supported strategies (hand lasermeter, prismless servo techeometres). There is also great interest from the field of facility management.

3. HOW TO FIND THE MOST USEFUL SCANNER

Regarding the short time since terrestrial laser scanners came to the market (airborne ones started operation earlier), a surprising diversity of such instruments can be noticed. Even if we do not consider table scanners (for rather small objects) and long-distance scanners (to monitor e.g. avalanche areas), a good half of a dozen current products remain. Among them are Callidus (D), Cyra/Leica (USA,CH), MDL (UK), Mensi (F), Optech (CAN), Riegl (A) and Zoller&Fröhlich (D). Detailed information is offered at the manufacturers' web pages, which are given in the references.

Enclosing essential constructive differences, there are mainly five items to differentiate:

- Cameralike scanner or panoramic scanner

- Distance spectrum (between 1-2 m in minimum and 25-800 m in maximum)
- Accuracy (reaches from $< \pm 6$ mm to ± 25 mm)
- Extra information available ? (e.g. radiometric information)
- Efficiency of delivered software for computation and modelling

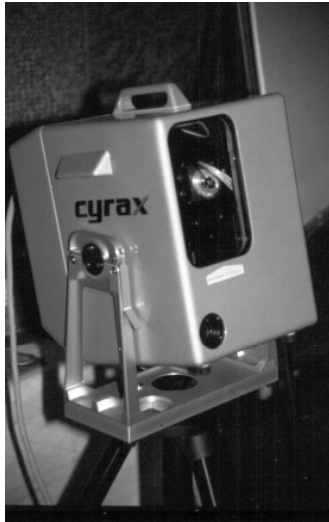


Figure 1 LEICA CyraX2500 (camera view)



Figure 2 RIEGL LMS-Z360 (panoramic view)

A cameralike scanner (Fig.1) scans within a predetermined and oriented angular region and therefore uses a simple video camera as finder and to document the scan area. A panoramic scanner (Fig.2) sequentially turns around its vertical axis while recording vertical profiles. It might use a better camera to gain visual information to be used for texturing the model naturally. Here we have to emphasize, that an enormous strategic advantage of laser scanning lies in its ability to operate in complete darkness! This, evidently, is not possible for the additional camera information, which depends of the surrounding light.

Some scanners derive their distance data from runtime measurements of impulses, others observe the phase shift of modulated waves. Both approaches must accept a certain distance limit; for the first method, the front, deformed by travelling through the atmosphere, must still be exactly detectable. For the second method, the distance limit is defined by the modulation wavelength. Instruments of the latter type are commonly delivered for single or double nominal maximum distance; as the accuracy of phase determination remains constant, the double distance capacity naturally also doubles the standard deviation for distances. The third principle, triangulation, will not be considered here, as it only works for short distances.

The accuracy of a scanned point's spatial position also depends of the angle measurements' quality, which has physical limits. Where the laser beam is guided by rotating mirrors or polyhedrons with reflecting surfaces, it is the flatness of these optical parts that represents one parameter for accuracy. The other one relates to the quality of the angular encoders which determine the rotational position of the mirrors. Precision scanners dispose of an optimally designed relation between angle and distance accuracy; they are able to give 3d

point position with ± 6 mm on a distance of 50 m. Due to this, the accuracy of a best-fitting surface improves to $\pm 2-3$ mm.

For some missions it might prove advantageous, if radiometric information comes with the geometric one. In future this may be used to support automatic object extraction to improve modelling time. Today, basically, the aim is simple: to gain texture which can be stuck on the geometric model to increase a natural impression.

Ultimate attention should be focussed on the accompanying software package for the processing. In particular the abilities concerning object generation and modelling as well as the potential to transfer the model to a common CAD system should be scrutinized.

4. THE INDIRECT WAY TO THE TARGET CO-ORDINATE SYSTEM

Some products have been designed for tasks in which the focus laid on determination of the pure object geometry – without any ties to any superior site- or national co-ordinate system. An example for application can be found in recording natural sceneries to be used combined with virtual realities for comic or science fiction movies. Another one aims at exposing surface damages on heavy traffic highways for reconstruction purposes. Two consecutive scans can be linked by three natural or artificially signalled tie points, which can be identified in both point clouds. This familiar strategy, commonly used in photogrammetry and in industrial measurement systems, of course can be repeated and thus manages to assemble a coherent survey unit. All scan results hence lie in a unique co-ordinate system, e.g. the first scan's one, and allow joint and uniform treatment. Recently, constraint solutions turned up (Leica, 2003), which automatically combine overlapping scans by minimizing the sum of squared distances between identical surface parts within the two or more point clouds. This means an important reduction of evaluation time.

Structures and industrial facilities however demand a superior, officially specified co-ordinate system, eventually given from the planning phase. If such a system does not or not longer exist, we best choose the national system. Anyway, single scans now can be transformed scan by scan independently, or as a complete unit, directly to the superior system. On behalf of this the tie points are determined by geodetic means in this system. In exceptional cases, when the tie points' configuration is unfavourable, special transformation points (mostly of spherical shape) will be installed, included in the scan and surveyed using a total station. The survey procedure is easily synchronized to the scan phases and leads to an optimum employment of personal capacity in the field.

One example to illustrate the potential: a point cloud transformed to the system of layout and setting-out would be suited for immediate control of completion by superimposing it on the digital (3d) design. In a second step we even can imagine quality control.

5. A MILLION POINTS ASSAULT A CAD SYSTEM

The result of one single scan with dense grid (< 1 mm on 50 m) on average numbers one million points. To feed them directly into a CAD system overcharges any such system.

Therefore at least one of the manufacturers supplies a specific software to enable the loading of the complete point cloud as background of the CAD content. Based on this feature, requested constructions or comparisons can now easily be put into reality.

However, frequently the main target will be to model as many regions of the point cloud as possible with the processing and modelling software itself. A series of best-fitting surfaces resp. geometric simplexes is in stall to generate components as CAD objects. The plane, surfaces of 2nd order (e.g. sphere, cylinder) or 4th order (e.g. torus) as well as prismatic beams and girders with I- or T-profile belong to these. After generation of each object the points selected for the best-fit adjustment can be dropped. At the moment the workflow has to be managed interactively; at least semi-automatic recognition and extraction procedures (Niemeier and Kern, 2000) are currently under development.

It is not always necessary to model the point cloud at once, as it is in quality or layout control. Just when the task is to ensure later reconditioning or reconstruction, it might turn out sufficient to establish a scan archive as a precaution and to wait with processing the required parts until an occasion makes it unavoidable.

Obviously, arbitrary plane sections can be created and used for two-dimensional views like plans and profiles. It is here, the main advantage compared to conventional polar survey with total stations becomes evident: the decision, where a section is needed, may now be taken even after the survey, because the entire 3d information is contained in the scan or scan unit!

Where architectural or constructive details are of interest (which can be recorded with increased grid density) or where a randomly shaped object shall be caught, an automatic triangular mesh routine will provide the surface visualization (e.g. determination of rock masses in quarries, in earthworks or in tunnelling).

Using precision scanners, there are even investigations concerning deformation measurements (within the accuracy currently available) at bridges (Gordon, Lichti and Stewart, 2001).

6. WE GIVE A CONVINCING EXAMPLE

It proves best to demonstrate scanner application and point cloud modelling until the final product guided by a practical example. We here describe a project proposed by the Bavarian Board of Civil Engineers to the Chair of Geodesy at the Technical University Munich. It has been executed with a 3d laser scanner of our own within the scope of a diploma thesis. The task was to survey the complete roofing of a famous historical church, the 'Frauenkirche' at Günzburg/Bavaria, in all three dimensions, to model it for CAD use and, finally, to visualize it by means of spectacular animations.

On the occasion we should direct attention to the reconditioning actions taken by the planning office Dr.Bergmann (Bergmann, 2002). It was the board's wish to establish a convincing and instructive example both of a successful reconditioning and of the new survey method of 3d laser scanning.

The roof's construction encloses three floors and a total volume of 4.700 m³, which lies in complete darkness. After a careful inspection a survey concept was set up, comprising 95 scan stations and 168 tie-points to link the scans and transform them into the structures coordinate system. It took 10 days and 2 persons to perform the scanning work and the determination of the transformation points from an accompanying traverse. The average grid density of 2 cm lead to a number of 10,8 million space points, which equals a data amount of considerable 365 MB. Our scanner is a LEICA-Cyrax2500, a precision instrument, measuring distances by pulse time of flight and guiding the green laser beam along vertical profiles by two incrementally rotating mirrors.

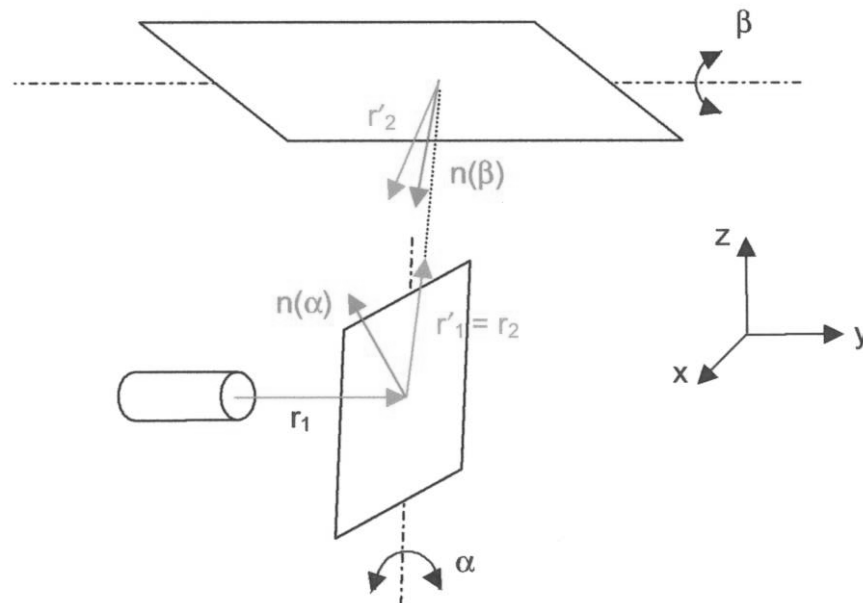


Figure 3 Laser beam guidance in principle for LEICA CYRAX2500

The beam steering principle can easily be taken from Fig.3; the usable angle sectors of this cameralike scanner amounts to 40 x 40 degrees. Scanning a column with constant 1.000 steps affords one second of time, independent of the grid width; i.e. the total time for a single scan is subject to density of the columns themselves. According to the distances to be covered, we worked at Günzburg with 240 to 600 columns; this corresponds to 4 to 10 minutes for a single scan. Figures 4 and 5 show a typical survey situation – left the scenery as snap-shot of the built -in video camera and right the recorded point cloud. In both pictures the artificial tie-points and the spherical transformation points clearly can be identified; the original representations in full colour are of much better quality than the black and white copies reproduced here.



Figure 4 Videoshot of the survey scenery

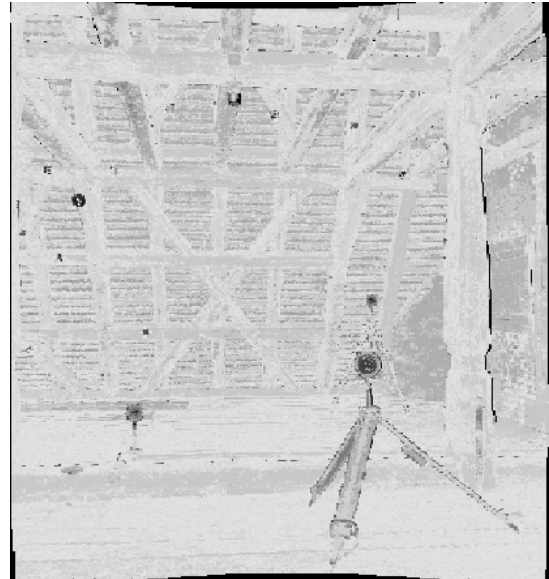


Figure 5 Point cloud of the same scenery

During the processing phase the diploma candidate consecutively generated CAD objects from segmented regions of the assembled total point cloud; mainly it concerned best-fit adjustments of construction elements by prismatic beams. The principle is shown in Figures 6 and 7: at first a region on the screen is selected, then a triplet of points must be marked and at last the modelling is performed by choosing the requested function. The modelled region can subsequently be extended with a region growing function and clipped at the penetration areas with adjoining elements. For in-situ control purposes isolated models are created directly after the scan. Their cross-section dimensions can immediately be compared with a folding-rule.

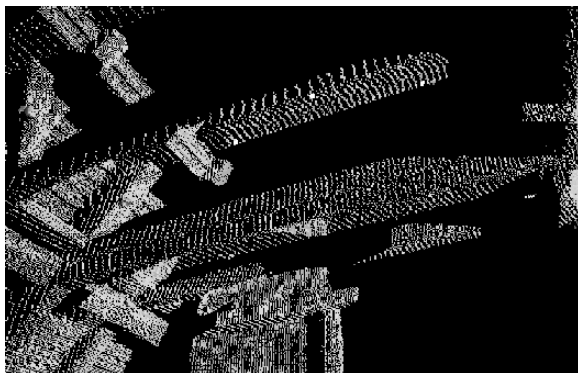


Figure 6 Marking 3 points

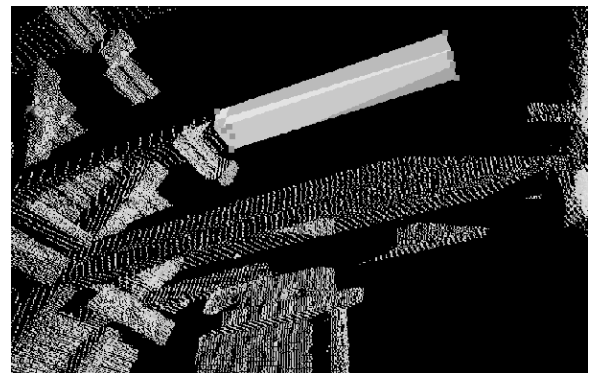


Figure 7 Generation of a CAD-object

The complete modelling of the roofing plus the dimensional visualization took 30 days, including the accommodation work to the software 'Cyclone' going with the instrument used. The relation 3:1 for modelling to survey effort presents itself very good for this project, because of the geometric primitives provided. When complicated architectonic details have to

be processed the relation may even reach 10:1, as modelling will become rather laborious. In such cases it would be advantageous to feed the point cloud directly into a CAD system like 'AutoCAD' or 'Microstation' via the additional Cyra software 'Cloudworx'. Then all familiar tools are available and the geometric construction will be accomplished easier. Fig. 8 shows the final product, the digital 3d model of the Günzburg church's roofing, based only on processing with 'Cyclone' (Peschl, 2002; Weber, 2002). Fig. 9 gives details of the reconditioning construction parts.

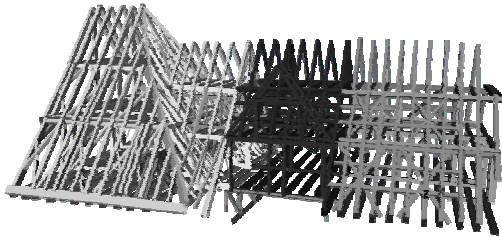


Figure 8 CAD-model of roofwork

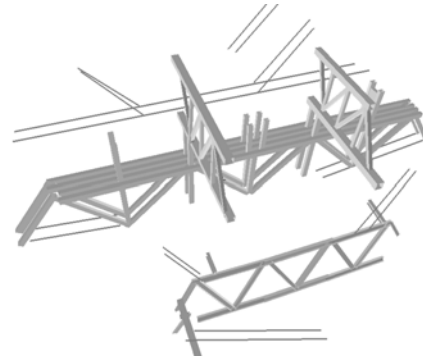


Figure 9 Reconditioning elements

In future the digital models created by laser scanning (may be in optimum combination with laser servo tacheometres and hand laserimeters), will grant distinct economic and technical benefits. However, to completely comprehend the potential of laser scanning we must not stop at catching the pure geometric reality – this geometric model very soon could only serve as basic platform for an extensive structure related information system!

7. PRODUCT MODELS AND CONSTRUCTION INFORMATION

When we introduce the geometric model, e.g. as a boundary representation model into a capable CAD system, we might add characteristic object parameters as material, heat conductivity, bearing capacity or more. Thus, people from structural informatics are able to create a product model as basis for building adaptation planning. It would be a decisive step to enable digital 3d planning methods for existing buildings, not only for new constructions. The final target is a construction information system that supports any computation from statics to energy balance.

It is our, the surveyor's part, to find out the quickest, most efficient and economic approach of providing the digital geometry for the civil engineers and architects. This has to be done by an optimum use of simple and sophisticated instruments, from laser tape over prismless tacheometres to laser scanning – dependent on the complexity of the building.

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