

Detailed and Accurate 3D Object Models from Laser 3D Close-range Laser Mapping Syst

The measurement of distances by means of laser has for more than three decades been operational in everyday surveying. Today, advancements in computer technology enable the automatic collection and processing of large volumes of laser range data. The resulting 3D Close-Range Laser Mapping Systems are able, within short time spans, to create highly detailed and accurate computer models of a wide variety of objects, including construction works, industrial plants, works of art and buildings. The authors treat, illuminated by practical examples, the working and possibilities of 3D close-range laser mapping systems. They also compare the pros and cons of the technique with those of photogrammetry

By dr. ir. Mathias J.P.M. Lemmens and ir. Frank A. van den Heuvel, Department of Geodesy, Delft University of Technology

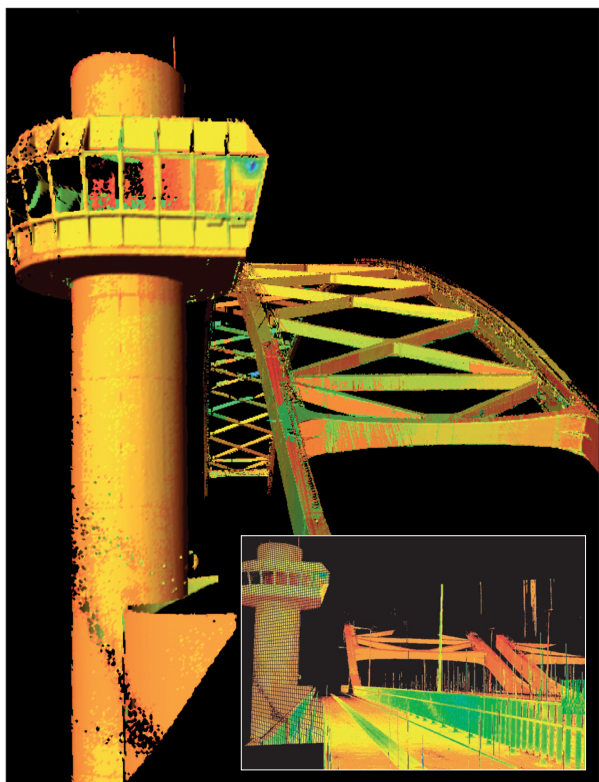


Figure 1, 3D Close-Range Laser Mapping of de 'van Brienenoordbrug', a large bridge over the river Maas in Rotterdam. Inset: In the raw data moving objects, like trucks, show up as spikes in the scan.
(Photocourtesy: Delfttech)

Active remote sensing systems, in particular radar and laser systems, are becoming increasingly important in the creation of 3D computer models of real world objects. In this context, 'active' means that the sensors themselves emit the necessary electromagnetic energy. Next, the energy scattered back from the surface is recorded. Laser distance measurements have for more than three decades been operational in everyday surveying. Advancements in automatic collection and processing of large volumes of range data have, over the past decade, resulted in operational 3D close-range Laser Mapping Systems (3D-LMS). These are able to create detailed and accurate computer models of a wide variety of objects, like construction works (Figure 1).

Principles

The basis of the 3D-LMS technology is a scanning laser range-finder. The distance from sensor to arbitrary points on the object surface is calculated from the

pulse travel time. Scanning with this principle results in a fan-shaped set of laser pulses (Figure 2). Thousands of points are scanned per second. The 3D fan is created by rotating mirrors. Also, the intensity of the reflected laser pulse is often recorded. This provides an indication of the reflection characteristics of the surface, enabling the creation of quasi images (Figure 3a). When large and complex objects are recorded, many scans taken from different station positions will be necessary. The resulting different scans need to be tied together by special software in a preprocessing stage.

Reflectorless

Contrary to everyday surveying work, no use is made of reflectors. It is thus the type of material hit by the pulses which determines the intensity of the returning signal. For example, marble will cause subsurface scattering because it is translucent, resulting in a degradation of the quality of the range data. It may even happen that no signal at all will be returned. This can happen when the surface behaves as a mirror. The wavelength of the laser lies in, or just above, the visual range of the electromagnetic spectrum. This roughly speaking means that what a human being can see, the laser ranger also 'sees'. The laser can measure through glass and clear water. Rain causes, at most, few problems. Snow, however, will cause a rapid reduction in visibility. The operation of laser is independent of the presence of daylight; the scanner can operate in complete darkness.

CAD Modelling

Once tuning parameters have been set, like horizontal and ver-

ems

tical range and angular step increments, the creation of the initial point cloud of 3D data (intensity as a function of x, y, z , coordinates) is done automatically. However, to convert the point cloud into meaningful 3D CAD models, the set of points needs to be imported into a powerful PC equipped with advanced CAD modelling and fitting algorithms (Figure 3b). Through a set of neighbouring points, which together build up into an object or a part of it, geometrical shapes have to be fitted. This interpretation process of converting the set of x, y, z coordinates into a restricted set of shapes, like I-beams, C-beams or pipes, is a highly demanding manual process. Even when auto-segmentation tools are used, much manual processing is still required. The operator guides the editing by outlining areas of interest and defining the type of object, e.g. a pipe. Next, software is used to fit the selected geometrical shape (e.g. cylinder) to the point cloud. Because so much data is available, only some of the points, say 60 per cent, need to fit the shape. The computer space needed to store the cylinder is just a fraction of the space necessary for storing the original 3D points.

Visualisation

Visualisation of objects which have not been decomposed into geometric shapes, requires structuring of the point-set by applying TIN-polygons. This is necessary, for example, when one wants to visualise 3D mappings of works of art, like statues and buildings. Let us take as an example 3D mappings of Michelangelo's David (Figure 4). In 1999 a team of thirty persons from Stanford University and the

University of Washington used 3D-LMS for the capturing of the shape and sizes of this historical statue in Florence, Italy. Besides laser scans, 7,000 digital colour photos were also taken. In order to recover every detail of the David, the targeted precision for range data was 0.25 mm, while the desired resolution was as dense as 1 mm; parts were even digitised with a resolution of 0.29 mm. The height of the David, excluding the pedestal, is 517cm; its surface area is 19 square metre, while its weight is 5,800 kg. A motorised gantry was customised in order to be able to reach the higher parts of the David. The final model of David consists of two billion polygons and 7,000 colour images. It took over 1,000 man hours to carry out the scanning, while 1.5 as much time was necessary to process the data. As a second example, Figure 5 shows the town hall of Delft, recorded by the company Delfttech, using a Cyrax 2400. This scanner, built by Cyra Technologies Inc. (Oakland California), (which company has been recently acquired by Leica Geosystems, see the December 2000 issue of GIM International, page 23), has a field of view in both horizontal and vertical directions of 40 degrees. The maximum range is 100m. The quasi colours are derived from the intensity of the returning pulses.

3D-LMS versus Photogrammetry

Much of the data that can be gathered by 3D-LMS can also be obtained by close-range photogrammetric means. The pros and cons of both methods can be

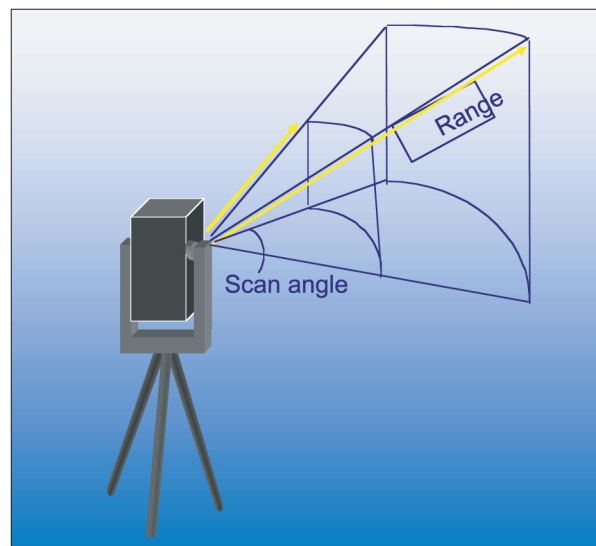


Figure 2, Recording principle of 3D LMS. Object space is scanned in both vertical and horizontal direction, enabled by rotating mirrors

summarised as follows:

1. On site recording by 3D-LMS is independent of the presence of texture on the object. Although this is also true for photogrammetry, when object edges and contours are being measured the creation of TIN models requires a matching step for which the presence of texture is essential
2. Light conditions are less critical for 3D-LMS
3. Photogrammetric recording is more flexible because photo cameras are more portable (less heavy) than laser scanners, while they also do not need tripods
4. High precision 3D-LMSs are presently more expensive, by a factor of ten, than photogrammetric systems with comparable precision
5. By using a set of cameras that

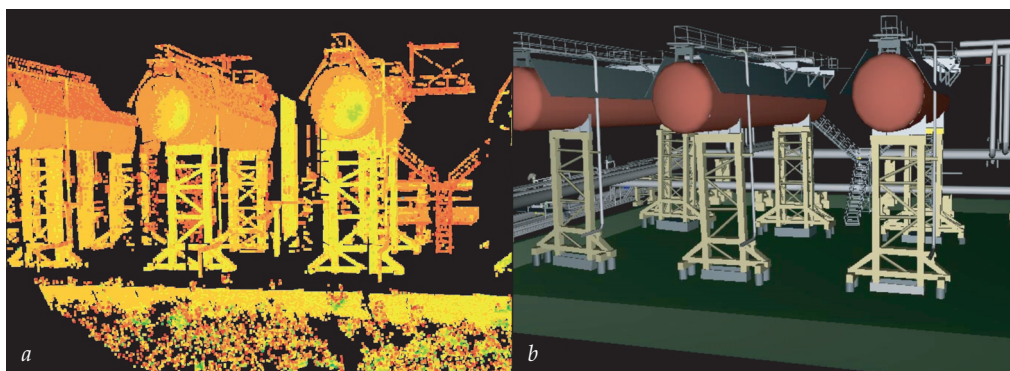


Figure 3, a) Quasi image of an Oil refinery, directly created from the raw data. b) 3D CAD Model created after a manual mapping process (Photocourtesy: Delfttech)

		3D-LMS	Photogrammetry
1.	Object Texture	Not necessary	Necessity depends on application
2.	Light Conditions	Largely insensitive to	Sensitive to
3.	Instrument weight	Heavy	Modest
4.	Instrument Costs	High	Low
5.	Recording	Sequential	Instantaneous
6.	Preprocessing	Linking scans together is straightforward	Orientation is complex
7.	TIN creation	Directly from the recorded 3D data	First a matching step with special software
8.	Rendering	Quasi image	Real image data
9.	Mapping	Labour-intensive, special software needed	Labour-intensive, special software needed

Table 1, Comparison of the pros and cons of 3D-LMS and close-range photogrammetry

- can be simultaneously exposed, photogrammetry enables instantaneous recording. Consequently, the recording of dynamic objects is possible. Notwithstanding that the scanning speed of 3D-LMS is very high, the surface is sensed sequentially, point by point. For example, a typical scan of the Cyrax 2400 takes 10 minutes. This means that dynamic objects, like human bodies, can not be recorded without distortions in the data
- Photogrammetry requires a relatively complex orientation stage before 3D data can be extracted from pairs or triplets of photographs. The different scans of 3D-LMS can be linked together in a straightforward manner
 - The creation of TIN models, necessary for visualisation and rendering purposes, amongst other things, can be

done directly and automatically from the recorded 3D-LMS data. Photogrammetric images first require a matching step in order to create a set of 3D points, for which specialised matching and editing software is needed

- The image created by a 3D-LMS is a quasi image, while photogrammetric images provide the ability to create a high quality visual database, well-suited for draping texture over 3D Models
- Depending on the application, a considerable amount of manual work is needed for both techniques in order to convert the data into suitable 3D CAD models. To arrive at a proper interpretation of sets of points acquired with 3D-LMS an operator may need visual support provided by video or photographs

The above comparison is summarised in Table 1.

Concluding Remarks

3D-laser mapping is able to gather directly, rapidly and accurately 3D point clouds of x,y,z coordinates. The process of transferring the sets of points into 3D CAD models is labour-intensive. Compared to photogrammetry, the method offers new possibilities to solve problems that earlier could not be tackled. The new technology is therefore likely to become co-existent with photogrammetry.

Further Reading

- Coburn-Price, S., 2000, Laser scanner provides as-built 3D data for refinery upgrade, Engineering Surveying Showcase, October 2000, pp. 18-20
- Levoy, M., et al., 2000, The digital Michelangelo project: 3D



Figure 5, Rendering of an automatically created TIN Model of the Town Hall in Delft. The surface is rendered with colours derived from the returned intensity values of the laser pulses. (Photocourtesy: Delfttech)

scanning of large statues, Proceedings of Siggraph 2000. (see also <http://graphics.stanford.edu/projects/mich/>)

- ◆ Greco, J., 2000, The Cyrax 3D laser scanning system, http://www.cadenceweb.com/features/mcad_future/greco.html, accessed 01/11/00◆



Figure 4, 3D computer mapping of Michelangelo's David. The scans and computer modelling for the Digital Michelangelo Project were carried out by Stanford University. (Photocourtesy: Stanford University)

Biography of the Authors



Dr. Mathias J.P.M. Lemmens

Dr. Mathias J.P.M. Lemmens is assistant professor GIS Technology at the Faculty of Civil Engineering and Geosciences, Department of Geodesy, Delft University of Technology. He is also editor, GIM International.



Ir. Frank A. van den Heuvel

Ir. Frank A. van den Heuvel is assistant professor Photogrammetry and Remote Sensing in the same Faculty, with a specialisation in close-range photogrammetry.

Delft University of Technology, Faculty of Civil Engineering and Geosciences, Department of Geodesy, Thijssseweg 11, 2629 JA Delft, The Netherlands, E-mail: m.j.p.m.lemmens@geo.tudelft.nl