Terrestrial Laser-Scanning – Universal Method or a Specialist's Tool ?

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SUMMARY

The methodology of laser scanning is in transition very fast. Coming in from other fields of metrology, like machine construction or medicine applications, the impact on classical surveying methodology is tremendous. Currently the manufacturers of instruments are on the way to develop the market. From the applicants point of view, the easy to use data post-processing capability is as, or maybe more important, than the scanning device itself. Effective data processing of huge amount of data points is the true challenge in this discipline. It is essential to define a workflow from data acquisition of 3D point clouds in combination with color from CCD cameras to deliverables which are able to fulfill the customers demands. A set of examples is used to show several workflow characteristics, optimized for specific requirements.

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1. INTRODUCTION

The methodology of laser scanning is under most rapid development in surveying in the past decade. As well as in airborne laser scanning also terrestrial devices were introduced in the market and permanently improved from each month to the next. This development was indicated by several authors since around 1995 with strong focus on instrument developments. The processing perspective was characterized by Prof. Kraus (Kraus, 2001) as change of paradigm. His argument was that methodologies form surveying and photogrammetry are soldered in sensors combining laser scanned geometry and color information. He also claimed new, or better to say adapted processing routines. Several groups elaborate such modified processing systems on universities and also in corporation with private companies (Ullrich, et. al. 2003).

Today several firms focus on the production and maintenance of such instruments. The origin of these firms is either manufacturing classic surveying instruments or industrial metrology. The outcome of such instruments is more or less similar to describe as a 3D point cloud. Core question is, how to process such typically huge volumes of points in an applicable way to final products as planes, 3D models, etc.

Looking on competitors in the product field of 3D Laser scanner devices underlines the estimated market potential of this technology segment. Currently some prominent companies are on the way to enter the market through acquisition of small technology firms. The two key players in the market of surveying instruments realized this potential to improve their product portfolio. Leica Geosystems (Leica, 2004) invested in the acquisition of Cyra Technologies in 2001 and Trimble Inc. (Trimble, 2004) acquired the French MENSI (Mensi, 2004) in September 2003.

The impressive position of the Austrian Company RIEGL Laser Measurement Systems in this market segment of terrestrial 3D laser scanners is about 24% (forecast 2003 with a total of $29.8 million)(SparView, 2003).

For post processing, a number of software products in the market promise fine results in particular application fields. Typically this developments tends to combine the scanning device and the post processing environment. Reasons to do so are to enable optimized data structures and information flows between the two components, but also to keep consumer on track with one product line from marketing perspective.

Typically real project definitions differ more or less from one sensor or software's specification. Interfaces between different sensor types and post processing software's are often enough either not implemented or of poor quality or performance.

When you are looking at the colorful product folders it sounds so easy to perform data processing, but in manifold projects it ends in frustrating number crunching with poor outcome. Main reasons for that are:

- data volume exceeds physical or practical limits,
- the chosen processing environment is suboptimal,
- data flow from scanner instrument to processing software is too complex and
- the poor compatibility of software tools used.

The workflow has to be seen as relevant for the complete production chain. From the planning and realization of data acquisition the preprocessing including geo-referencing of individual scan positions, the combining and integration of color information, up to processing and derivation of the final product the chain has to be designed slim. The optimized data processing and organization is essential for the further products and for the over all economic aspect.

It is not the aim, to be negative, but the assessment of laser scanning potential in the market has to be realistic. The potential for application of laser scanning is broad. Documentation of terrestrial areas, buildings, up to single objects with high value in money or cultural importance must be seen in this interrelation. The precise and complete documentation of areas and forms causes the high level of evidence of laser scanning. Synchronously acquired picture information, as a supplementary information to the geometry derived from the 3D point cloud rises the level of documentation quality. The relevance of optimized and integrated processing was mentioned above. In the examples presentation part, a selection of projects, including information for the data acquisition and processing and finally some derived products and forms of presentation, will be given.

Finally, laser scanning is recognized as an high efficient method of metrology. Its application has to be planned very carefully for the complete workflow with respect to the parameters of the individual project. Following this principle, impressive and competitive results in the meaning of precision, resolution, completeness and economics can be achieved.

2. GENERAL WORKFLOW CHARACTERISTICS

First reflectors are attached to well-conceived, regular distributed and from all sides well visibly positions. Only a optimal distribution of the tiepoints guarantees a high quality of the georeferenciation. After measuring the reflectors with classical measurement the object is scanned with single scans or using scan sequeces. The number of scans per sequence depends on the aimed accuracy. Usually the acquired 3D-scans are immediately transformed in the national or an other common coordinate system. For coverage control the point clouds of the single scans are combined to a pointcloud. This helps to detect scan shadows and is used to position outstanding scans. (Riegl, 2004).

In the course of post processing the rough refereciation that was calculated in the the field is controlled and corrected, if necessary. The single scans are combined to a common pointcloud and resampled to the aim point density.

The further workflow differs, depending on the specifications of the project. (Stanek, 2004) To extract Digital Terrain Models for example the original point cloud is reduced from 3D to 2.5D using only the lowest point per aimed grid width. The following segmentation of points in ground and vegetation and building points is operated by classical software for computation and utilization of Digital Terrain Models.

3. COMBINATION OF 3D VECTOR DATA AND RGB VALUES

In this paragraph the technique and type of sensors, used in the projects of following sections, is introduced.

For RGB data capturing we use a high-resolution digital camera Nikon D 100 with a CCD array with 3008 x 2000 elements (6 million pixels). According to the object distance we use lenses with focal distances of 20mm for short and 85mm for longer distances. The digital camera is mounted on top of the laser sensor.

After acquisition of the scan data, the camera takes a series of photos covering the field of view of the scan data. On the basis of a precise camera-calibration and the relative orientation and mounting position of the camera according to the scanner the image data are used to assign a colour value to every scanned 3D-point. These very complicated data processing functions are managed by RiSCAN PRO. RiSCAN PRO is a project orientated hybride Software from RIEGL Laser Measurement Systems GmbH, that offers functionality for the entire data acquisition during a measurement campaign, project structure for organized data storage and for postprocessing data.

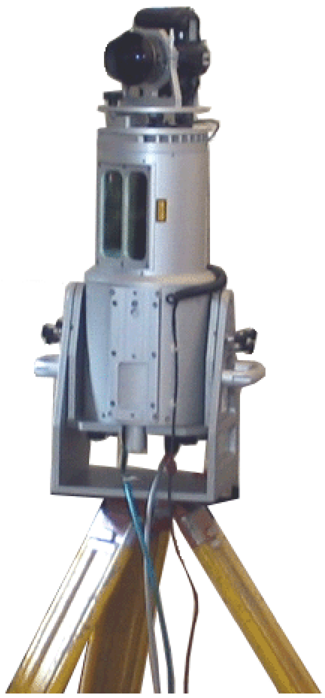

Figure 1: Nikon D 100 mounted on top of LMS-Z420i

A notebook is used to control the scanning instrument and the digital camera. This device is also used for data storage and quality control maintained directly in the field during the acquisition process. If the coordinates of reference points are available at this time, the registration of every scan may be done immediately after finishing the data acquisition. Following this strategy, a high level of quality control reduces any risk of fault data recognition for following processing steps.

This equipment is used in similar configuration for very different applications. In the range between documentation of open pit mines up to the precise surveying of very sensitive objects the method may be applied. For the data acquisition just the density and the precision – chosen by the number of scan sequences for every single scan – may be optimized for time reasons. Also the number of reference points, used for registering the single scans to one well fitting 3D point cloud is a matter of quality.

On the other hand, the further way of processing of the 3D point cloud differs significantly depending on the demanded final products.

4. EXAMPLES OF BEST PRACTICES

The following three examples will show the background, specific aspects and the out coming results. This examples were chosen, because the complete workflow can be described in short words, but also the outcome was positively evaluated by customers. From the economic point of view for each application the ratio of time used for data acquisition and post processing is given. The aim of picking up these specific three examples was also to illustrate the broad bandwidth of laser scanning applications, but also the necessary steps of refinement in project definition and demanding optimizations of processing strategies.

4.1 Concrete Factory Volume Determination

The aim of the project was to measure a 3 ha large pit in order to determine the volume of 13 heaps of crushed stone of different grain size for the annual inventory of the factory. The whole measurement has to be done in a very short time period under real working circumstances including a lot of lorry traffic, loading activities and dust. Non contact measurement was a key issue in this project, because direct, on surface measurements were strictly forbidden, because of risky environment.

From 24 scanner positions about 7,4 million points were measured with a LMS-Z420i 3D-laserscanner from RIEGL Laser Measurement Systems GmbH. The distance of surface points ranges from 10 to 180 m. The heaps holds volumes between 356 m³ and 3.800 m³.
A set of 29 reference points was measured with GPS in direct connection with the national Austrian coordinate system. In the referencing procedure, the 24 individual point clouds corresponding with single scans, were transformed in the national coordinate system. The Volume of each heap was calculated as the difference of the digital terrain model of the actual epoch and the prior surface, which was derived from a CAD plan documentation. Beside the determination of precise volume information, also a value added product - a shading image was derived from the data set. This information was combined with cadastral and other attribute information in the client's GIS

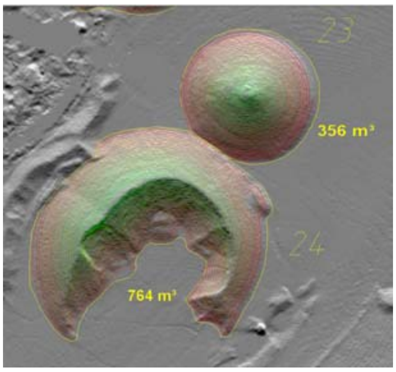

Figure 2: ISO-lines with a shading of the DSM

The time ratio between data acquisition process and post processing was 1 : 2.8 for this work. One interesting aspect during the final presentation was, that after explaining the techniques there was no further discussion about accuracy of volume determination.

4.2 Main Railway Station St. Pölten (Lower Austria)

The aim of the project was to generate true ortho-images of the facades of the about 150 meters on both sides of main railway station St. Pölten. The work was ordered to achive an adequate bases for planning activities for architects and for CAD construction of facade components. Beside the precise geometry, also colour information was to be acquired in one cost saving process.

From 9 scanner positions on the north side of the station about 11.3 million points and 7 scanner positions on the south side about 8 million points were measured with a LMS-Z420i 3D-laserscanner from RIEGL Laser Measurement Systems GmbH.

Using a high-resolution digital camera Nikon D 100 with focal distances of 20mm for short distances and 85 mm for the longer distances about 60 photos for colouring the 3D-points were taken.

Based on 180 tacheometric measured reference points the group of 16 individual point clouds were transformed in one homogenous coordinate system.

Caused by the high frequencies of coming, going and passing trains on the north side some scans partially had to be repeated or combined of several scans. This scalability of the data acquisition process was very important to finish this work.

In post processing, hindrances, like parking cars and advertises and steel structure elements in front of both facades must be eliminated. Using segmentation routines this task was done analytically.

It was very important for the client to deliver the final data set in an easy to use format ready for the usage by architects and planners. So the point cloud was customized and transformed in a digital TIFF file for each façade. Additionally, for the south facade a CAD plan was derived from the point cloud and prepared as vector overlay for the ortho-image.

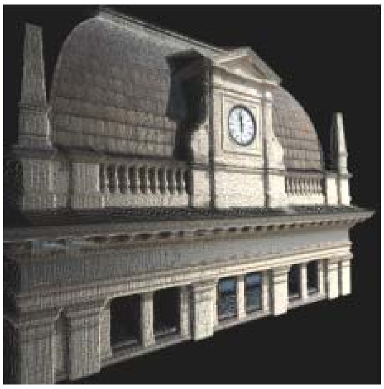

Figure 3: colored point cloud **Figure 4**: true ortho-image

The overall ratio between data acquisition process and post processing was 1 : 6 in this project. One point high valued by the client was that the complete set of plans and images was delivered just two weeks after data acquisition was finished.

4.3 Royal Coach Nr. 018 of Schönbrunn Castle - "Kunsthistorisches Museum" – KHM Vienna

This carriage was constructed for the emperor of Austria Franz Joseph I. around 1965 by the company Carl Marius in Vienna.. One exceptional detail is the construction of suspension based on eight springs. Today historians have strong scientific interest in the detailed construction of this coach and have demand on precise documentation.

The aim of the work was to aquire a complete 3D pointcloud, including colour information of the coach for further computation, visualisation and CAD-construction. For the measurement-work the LMS-Z420i (High-Accuracy & Long-Range 3D Imaging Sensor) from the RIEGL Laser Measurement Systems GmbH was used.

From 32 Scanner-Positions on 5 different height levels (0.3, 0.5, 1.4, 2.0 and 3.0m) all around, and inside the object was scanned. To increase the accuracy of the point-coordinates 4 scan-sequences were measured on each position. The scanning resolution on object-distance was set to 3mm. By resampling the scansequences the original amount of more than 35 Million of measured 3D-points could be reduced to about 6 Mio. points and the precision of the scanned points could be improved. From each scannerposition photographs with a high-resolution digital camera (Nikon D 100) were taken synchronously.

Using 29 terrestrial measured reference points, the 32 individual pointclouds were transformed in an unique coordinate system.

On the basis of a precise camera-calibration and the mounting calibration a RGB value was assigned to every scanned 3D-point.

Figure 5: colored pointcloud

Figure 6: true ortho image

Due to the partly short differences between the objects surface and the scanning device difficulties in data handling have to be solved. Especially the positions from below suffer from dispersion, refraction and overreaction of the lasersignal.
Another challenge was to consider the different light conditions on the object during data aquisition. Although using floodlight and diffusors, it was necessary to match the pictures with each other before coloring the point clouds.

After processing the acquired data sets in finally one homogeneous point cloud in several products was derived. It is important to remark, that the definition of this deliverables was done mainly after the data acquisition in discussion with the client's representative. So, as a service provider one has to be somehow illusionary but also permanently realistic due economic reasons. In this project finally, a complete set of CAD plans of profiles and cuts were derived. For the practical use, the point cloud was segmented in logical portions to generate the demanded plans in all details. The ability to perform such segmentation was recognized as a basic part of the complete work flow in post processing. For interactive visualization the data set was adopted. The time ratio between data acquisition process and post processing was 1 : 12 for the basic elaboration.

Latest, one subset of the point cloud was used to produce a new form of souvenir. The multi usage of the acquired data set is one key argument, beside precision and density of documentation, for introducing laser scanner methodology. It is a chance to develop such value added products to finance such kind of projects.

5. CONCLUSION

Applications of lasers scanners are successful in wide areas of documentation of surfaces and objects. Almost, the general principle of data acquisition must be optimized in specific ways. For the data acquisition the demanded precision and density, but also the number and distribution of reference points may vary. Optimizing the post processing work flow has major impact on the total project. It is essential to define selection and combination, but also the flow of up to 12 different working steps, maintained based on almost different software products.

Also the aspect of separating the accurate and detailed data acquisition (3D point cloud) from customized post processing is relevant for the economic standpoint. Synchronously acquired picture information, as a supplementary information to the geometry derived from the 3D point cloud rises the level of documentation quality.

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