The Riegl Laser Scanner for the Survey of the Interiors of Schönbrunn Palace

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Abstract: Laser scanners are being used more and more in surveying. High speed of measurement and a high point density distinguish those devices. Spatial similarity transformations are used to provide the data of all positions in one co-ordinate system. For modelling purposes a filtering of the data can be necessary, depending on the accuracy of the scanner. In this paper the applicability for measuring interiors is verified, followed by an accuracy investigations of the Riegl LMS-Z210 laser scanner, finally some modelling approaches are presented.

Keywords: terrestrial laser scanning, accuracy analysis, modelling techniques, registration

1 Introduction

In the last few years laser scanners have been utilised increasingly in all fields of surveying. With laser scanners the distances to points are measured without corner-reflectors and the measurement is not performed for specific points, but a whole area is being scanned automatically. Airborne laser scanners were introduced around 1996 (in Europe) and in the meantime they are a well-known, often applied technique (with GPS and INS support) for capturing elevation data from the terrain. The range measurement can be performed over more than 2km (double way) with a precision of a few cm (e.g. [1]), and most scanners also register the intensity of the return signal (in case of multiple reflections: the runtimes and intensities of the returning signals).

For terrestrial surveying purposes laser scanners have mainly been used in the field of construction, but the range of applications widens. By different methods (rotating mirrors, ...) the laser beam is deflected into different directions, the distance is either measured by the runtime principle but some scanners apply the principle of phase difference measurement[1]. The laser scanners available differ strongly in terms of accuracy, measurement speed, and angular and distance measurement range.

The laser scanner which was used for this work is the Riegl LMS-Z210. Its main features will be presented in section 2, more details can be found in [2] and at [3]. The room which was

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[1] This principle is applies for example by the Zoller+Froehlich laser scanners (www.zofre.de), for airborne scanners it is utilised in ScaLARS [A. Wehr. ScaLARS, Operational Production of DEMs Using ScaLARS. OEEPE workshop on Airborne Laserscanning and Interferometric SAR for Detailed Digital Elevation Models. Stockholm, Sweden, 2001].

chosen for the test of fitness of laser scanners for interiors is the so-called “Kleine Galerie” of Schönbrunn Castle, Vienna. It has a size of $18 \times 9m^2$ and a height of 8m. The measurements which have been carried out there will be described in section 3. In section 4 the registration of the laser scanner data is described and in section 5 some modelling techniques will be presented. A few comparisons to “classical” photogrammetry and tacheometry will be presented.

2 Laser scanner LMS-Z210

As mentioned above, the scanner used is the Riegl LMS-Z210. It is an imaging laser sensor which provides not only the ranges but also the intensities of the return signals (active measurement). In the meantime laser scanners are available too, which also provide colour information from the observed surface. This can either be achieved by an active measurement (using 3 lasers: a red one, a blue one, a green one [4]) or passively with a one pixel digital camera [8] with (more or less) the same instantaneous field of view (orientation and divergence) as the laser beam. In the second case the light (energy) comes from the sun or an artificial light source.

The laser range finder (LRF) of the LMS-Z210 measures the distances (range r) by the runtime principle in a range of 2m-350m with an accuracy of ±25mm under normal conditions. The ‘fast scan’ (angle θ) is realised by a rotating polygonal mirror, which allows a range of up to $\pm 44^g$ with a nominal accuracy of $\pm 0.04^g$. The ‘slow scan’ (angle φ) is realised by rotating the first deflection unit and parts of the LRF. This is possible in a range of 0^g-370^g with a nominal accuracy of $\pm 0.02^g$. The minimum step width for both angles is 0.08^g. The data are organised in a matrix of independent measurements, each element containing four measurements: 2 angles in the sensor polar co-ordinate system, the range, and the intensity of the received echo impulse.

There are a number of *simple* ways to visualise the data of one position (not specific to Riegl laser scanners). The matrix mentioned above can be interpreted as a digital image, and the intensity of the return signal is the pixel value (fig. 1). Analogously the range can be seen as the pixel value, leading to so-called range images. Another possibility is to export the 3d point cloud (optionally with the intensity) and view it interactively in a CAD system or with VR tools, like VRML (virtual reality modelling language).

3 Data capturing with the scanner

As mentioned in the introduction the “Kleine Galerie” was surveyed with the laser scanner. For preparation a laptop has to be linked to the scanner. An angle step width of 0.2^g was chosen and the complete field of view was scanned. This resulted in a measurement time of 2 minutes per position. The room has many niches and therefore 15 positions of the laser scanner were necessary to scan the whole room. This was performed within half a day. With terrestrial photogrammetry 13 positions with a P31 (analogous photogrammetric camera) were required which took one day. Altogether 23 retroreflective targets with a diameter of 3cm were attached to pillars on the walls, close to the floor and in a height of 3m. These points can be used as tie points in the step of data registration. For the following work 5 (of the 15) positions were chosen. For these the scanner was mounted on the tri-pod in horizontal positions, scanning the ceiling, 2 walls and parts of the floor (schematically see right scanner of fig. 2). The measurements of two different horizontal positions can be seen in fig. 1.

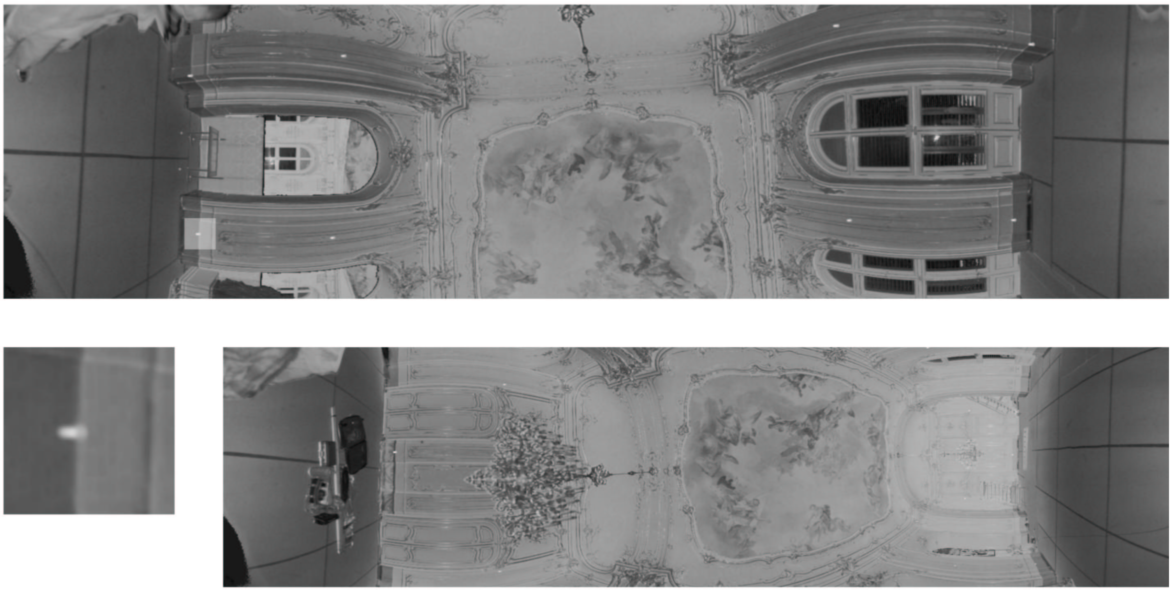

Fig. 1: The upper image shows a measurement across the longer axis of the room, the lower right image shows a measurement along it (each 1800×444 single measurements). The lower left image depicts an enlargement of the marked area in the upper image. It shows an area of 40×40 single measurements, conforming to an object size of $60\times60\,cm^2$. (This projection is the Equirectangular projection by Marinus.)

The "Kleine Galerie" is decorated with artistic plaster ornamentation, and therefore only a few number of well-defined corners (most of them close to the floor) can be found in this room. A painting with animals and figures can be found on the ceiling.

4 Data transformations

For each position the scanner yields a point cloud in the sensor co-ordinate system $(x,y,z)^T$. The data sets of all the positions have to be orientated relatively to each other (registered, fig. 2) so that homologous points have the same co-ordinates. If co-ordinates of some object points are known, an absolute orientation can be performed too, otherwise the result is obtained in some arbitrary system $(X,Y,Z)^T$. In the second case the rotations are usually set in a way that the Z-axis of the local system is coincident with the direction of gravity and the centre of gravity of the points is close to $(0,0,0)^T$. In this case the datum is either defined by a free net adjustment or by preferring on position to the others and set its orientation parameters to fixed values [5]. For the LMS-Z210 the z-axis is the length axis of the scanner itself, but of course the scanning can be performed with any orientation of the scanner. The zero-direction of θ is orthogonal to the scanner's z-axis, and the zero-direction of φ is defined within the scanner and has no specific meaning.

4.1 Tie point measurement

In a first step the 23 signalised points (tie points) were measured. Such a signal can be seen in the lower left part of fig. 1. They were identified in the intensity images using the software ORPHEUS [6] which is a multi image mono comperator, developed for photogrammetric purposes. However, it makes no difference whether the image comes from an area based camera or a laser scanner, only the geometry of the images is different. The identification of the points was very easy, because the echos of the retro-reflective targets have much higher intensities than the surrounding area. Depending on the distance from the scanner to the

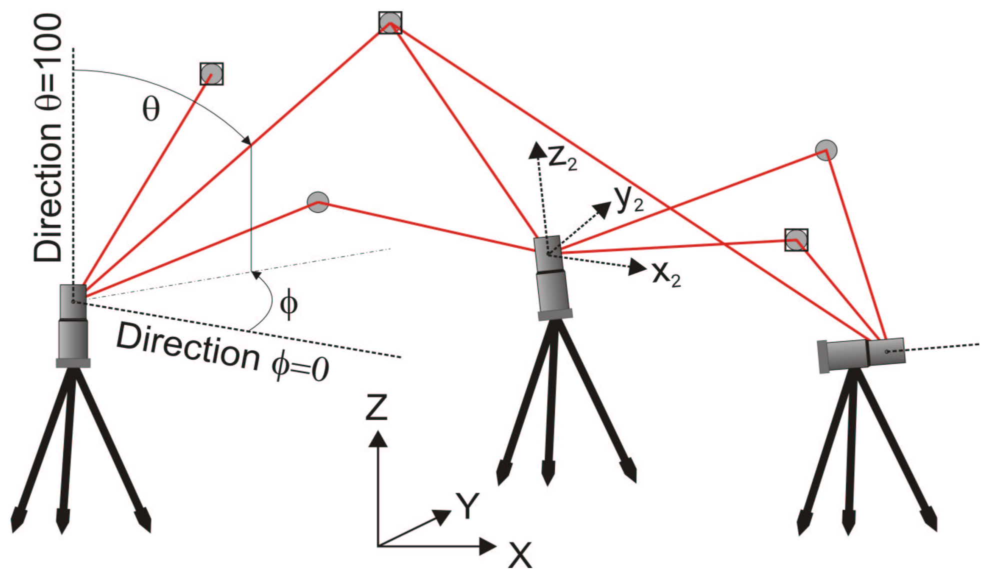

Fig. 2: Different positions of the laser scanner have to be oriented to each other. The laser scanner can be mounted on the tri-pod horizontally or vertically, or – theoretically – in any orientation.

target (signalised point) the signal was from less than 1 to about 4 pixels in diameter in the intensity images. This point measurement (identification) can be performed with sub-pixel-accuracy, the result are two real-valued indices. The index-pair is used to get the angle and distance values from the matrix of the scanner's measurements. For this step bi-linear interpolation (resampling) of the original data is appropriate, especially if the point is not situated directly on the edge between two or more surfaces[2]. The result of this step were 165 observations (3 per identified point in one laser data set).

In a second step 19 unsignalised points were measured on or close to the ceiling. Most of these points were situated on the painting (fig. 1, e.g. tips of the wings of birds, ...), but some were also characteristic parts of the ornamentation. The point identification was harder than for the first group, because the grey value differences at the tie points were smaller. Additionally the "targets" are not symmetric which also complicates the measurement. The result of this step were 213 observations.

4.2 Orientation of the scanner positions

The scanner positions (location and orientation) were determined with the first group of points. Of the 23 points one was not used, because is was only visible from one of the 5 positions. Least squares adjustment was used to determine the elements of outer orientation (location and rotation) of the scanner positions. The accuracy of the observations a-priori was the one specified by the manufacturer ($\pm 0.04^g$, $\pm 0.02^g$, ±25mm) for (θ, φ, r). A free net (over the tie points) was computed and a variance component analysis applied with the software ORIENT [7]. This resulted in an improved stochastic model with an accuracy of ($\pm 0.04^g$, $\pm 0.04^g$, ±22mm) for the observations. The accuracy after the adjustment was ±6mm for the positions of the scanner and ±13mm for the tie points ($(m_x^2 + m_y^2 + m_z^2)^{0.5}$). The longest axis

[2] For the distances gaussian resampling could be used too, which uses more than 4 distance observations but gives more weight to the centre pixels (measurements).

of the error ellipsoids of the tie points are directed towards the scanner positions (centre of the room). The rotations could be determined with an average accuracy of $\pm0.05^g$.

Next the not-signalised points were included in the adjustment, and the same computations as before were performed. The observations of the "natural" targets were put into an own category for the variance component analysis. The various accuracy measures were the same as in the first run, only the angle accuracy for the second point group was ($\pm0.12^g$, $\pm0.07^g$) for (θ, φ). The accuracy in Z (height of the room) of the tie points of the second group is worse than the one of the first group (±8mm vs. ±4mm).

This is, however, more a test of "measure-ability" of the not-signalised points, and not so much of the angle and distance accuracy of the laser scanner as it is the case for the first group of points. Anyway, it shows that data registration is possible without signalised targets, too. The nominal accuracy given by Riegl is – more or less – correct.

5 Modelling

After the data has been transformed into one superordinate co-ordinate system, the measurements are only a cloud of points (with intensities). There is a high number of measurements, but no attribute information is attached to the points. The terrestrial laser scanners excel in measurement quantity and speed. In comparison tacheometric measurement provide a structured point cloud with attributes for each point (e.g. corner of a house, ...), but the point number is rather low. Tacheometry excels in measurement quality.

The unstructured point cloud itself is not usable. Some modelling techniques have to be applied to generate a model of the surface (the room, ...) which has been captured by the laser scanner. CAD-models, topographic models or triangulations are possible. These models can be visualised or animated, intersected with planes to generate profiles or contour lines, it is possible to calculate volumes and many other applications are sensible. Here, two modelling approaches will be described. One is the generation of contour lines of the ceiling of the "Kleine Galerie" and the other is the production of an ortho image of the painting on the ceiling.

5.1 Geometric model

To generate a model of the ceiling two of the horizontal positionings of the scanner were used (one can be seen in the upper part of fig. 1). They overlap in the middle, but non of the signalised points is visible from both positions. These two models were chosen because remaining orientation errors can be detected easily, especially in the contour lines because the surface is rather flat.

To reduce the data only every 2nd point in each angular direction was used (reduction to 25%). The result can be seen in fig. 3. The elevations were interpolated with linear prediction. The superordinate co-ordinate system is tilted about 0.8^g from a horizontal one. A discussion will follow in section 5.3.

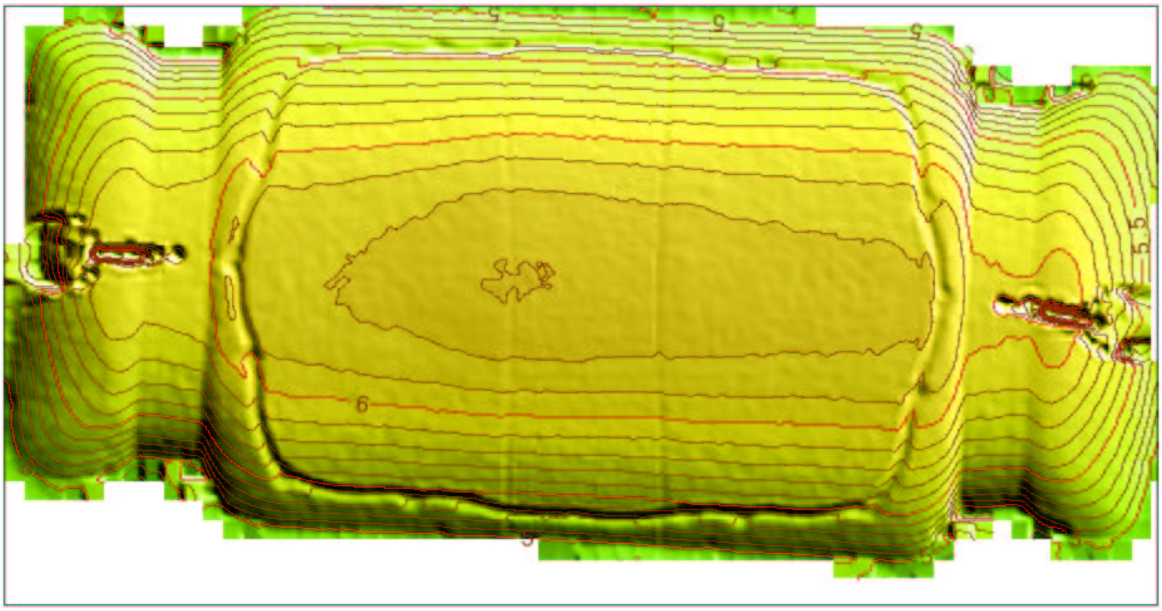

Fig. 3: Contour lines (10cm interval), together with a shading and a z-coding. The random noise in the distances has not been filtered completely and is about 1cm in this example. The overlapping zone can be detected in the (vertical) middle of the image. The elevations range from about 5m to 6.2m.

5.2 Ortho image

Ortho photos are well known products in photogrammetry, they can be extended to photo realistic models, where the texture of an image is draped over a CAD model [9]. If however, an object point and its grey value (or colour value or intensity i) are measured simultaneously, as it is the case for an imaging laser scanner, there is an easier way to generate an ortho image. The laser measurements are (θ,φ,r,i), the angles and the range can be mapped to any desired bivariate system (parameter domain s,t), e.g. a plane or a zylinder surface. These parameters can be considered to lie in the plane of a (digital) image, and the intensities are simply adopted: $(\theta,\varphi,r,i) \rightarrow (s,t,i)$. Over the (s,t) domain the intensities are interpolated, the interpolation function is evaluated in a regular grid, which is the ortho image itself.

This process has been carried out with the same two positions of the scanner as in the previous section. The angles and the range were mapped to a horizontal plane and the intensities interpolated with linear prediction. The result can be seen in fig. 4. The models (images) have been interpolated independently, the seam line was set arbitrarily.

5.3 Discussion

The elevations in the overlapping zone (fig. 3), which is 2m wide, show discrepancies at the left and the right border of the zone, about 25mm in height. (Remember: 25mm was the distance measurement accuracy.) If this was due to an orientation error, than this error would have a size of 0.7^g. This is not probable, because the accuracy of the rotation parameters is one order better and the redundancy in the adjustment is very high. Additionally the discrepancies show up only on the borders of the overlapping zone, but not in the middle of it. What is more likely, is the existence of systematic errors. After a closer inspection of the data in the overlapping zone it turned out, that the data next to the measurement borders is not

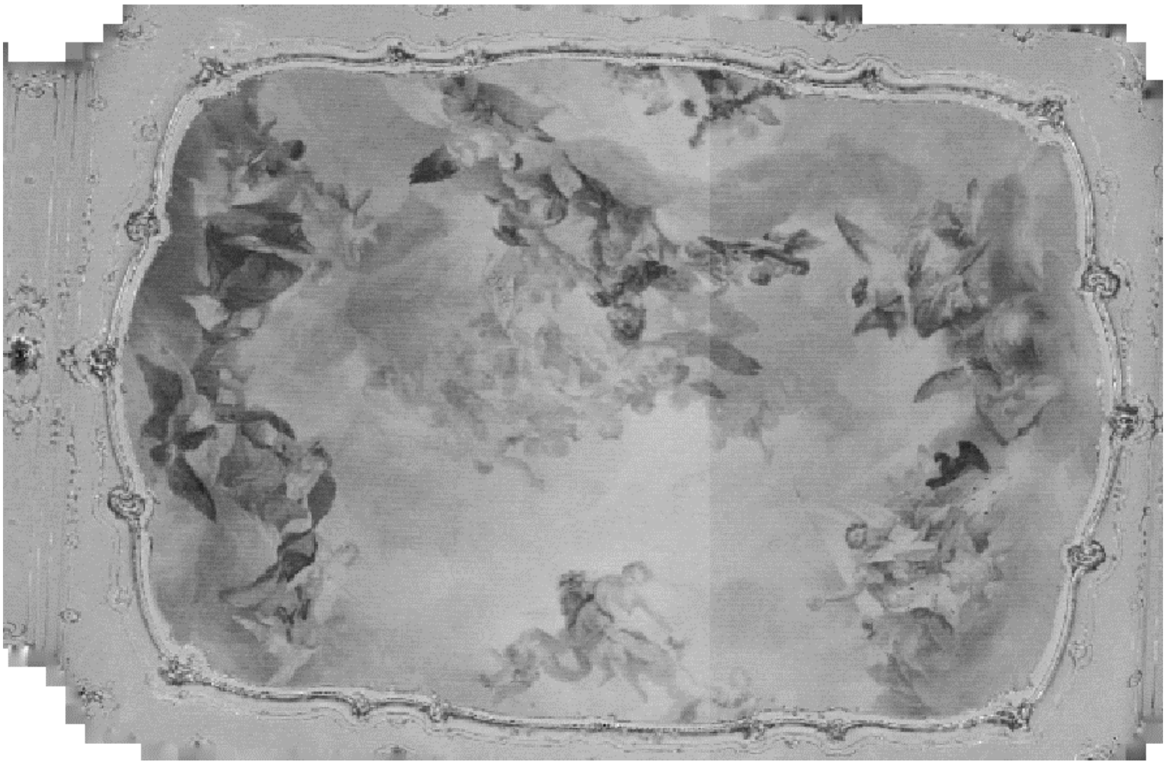

Fig 4: Ortho image of the ceiling produced from 2 different positions.

as reliable as the inner measurements. Only the measurement for θ in the range of $\pm 42^g$ (of $\pm 44^g$) should be used in this example. This systematic error could either be an error within the scanner, or a result of the measurement process (e.g. beam profile, ...). The (preliminary) conclusion is, that approximately 7 scan lines (1.4^g) should be left out of consideration for measuring of tie points or modelling purposes. A similar effect is known in photogrammetry where no points should be measured close to the image borders.

Looking at the left and the right part of fig. 3 still indicates, that there might be some errors, the contour lines appear to have a sharp bend next to the border of the right model. A comparison with a model which was computed from one position only, which covers the whole ceiling, showed the same contour line pattern. Obviously, the ceiling has this sharp bend itself.

The horizontal position of the contour lines, as well as the fit along the seam line of the ortho image (fig. 4) indicate, that the horizontal location, as well as the corresponding rotation were determined accurately in the adjustment process. Thus, the accuracy for these values is probable and no systematic errors are visible in the result.

The intensity values along the seam line of the ortho image show a jump in magnitude. The lines across the seam line are steady, as mentioned above. A more elaborated mosaiking approach would be necessary to compensate this effect.

It should be noted here, that registration via tie points is not the only method for laser scanner data. The orientation procedure is also possible with homologous edges or planes. Even curved patches could be used as tie elements. The parameters of these tie patches could either be unknowns in the adjustment or determined before. The high point density makes this approach feasible.

6 Conclusion

This test showed that laser scanning is applicable for the measurement of interiors. The accuracy reached with the Riegl LMS-Z210 is in the range of better than 2cm. The measurement process is fast and highly automated. The process of the data registration is operational, but fitting of surface patches will be investigated. The semi-automatic extraction of edges (not touched in this paper) is possible, but it is a long way to go until a fully automated process will generate a CAD model. Concluding it can be said that laser scanners in general as well as the one we used, are fit for the surveying of interiors.

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