EFFICIENT INTEGRATION OF AERIAL AND TERRESTRIAL LASER DATA FOR VIRTUAL CITY MODELING USING LASERMAPS

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ABSTRACT

One of the first steps during evaluation of terrestrial LIDAR measurement is the co-registration of the data sets, which are collected from different stations and their transformation to a suitable reference coordinate system. As it is demonstrated within the paper, this can be achieved automatically, if low-cost components are used for direct georeferencing parallel to LIDAR measurement. By these means the position and orientation of the laser scanner can be determined. Further refinement is feasible, if the terrestrial scans are aligned to a DEM from airborne LIDAR or existing 3D building models. Frequently, terrestrial lasers scanning (TLS) is used to collect building facades at a large amount of geometric detail. For this type of application, the integration of existing 3D building models from airborne data collection as complimentary data source is especially suitable for the modeling step. Due to viewpoint restrictions of airborne data collection, the amount of detail, which is available for the building facades, is very limited. Thus, after alignment, the terrestrial scans are ideally suited to refine these models. However, as it is demonstrated in the second part of the paper, the large effort required for explicit modeling can be avoided if so-called LASERMAPs are extracted from TLS and mapped against the coarse 3D building model.

1. INTRODUCTION

The complete coverage of spatially complex objects by terrestrial laser scanning (TLS) can only be guaranteed, if data collection is done from different viewpoints. The automatic registration of these different scans is one of the first processing steps during data evaluation. Frequently, this is done by semi-automatic tie point measurements using specially designed targets. Within the semi-automatic process the tie-point is identified manually while a refined measurement at the signalized points is performed automatically. Sufficiently overlapping scans can alternatively be matched against each other using processes like the iterative closest point algorithm introduced by (Besl & McKay 1992). Since these types of algorithms are based on a coarse alignment of the different scans, manual interaction is also necessary to provide the required approximate registration.

In principle this alignment process can be carried out in a local coordinate system. However, if the 3D point cloud from terrestrial laser scanning is combined with additional data like existing plans, ortho-images or DTM, a transformation to a global reference system is indispensable. For this purpose the coordinates of the signalized targets are determined in the selected reference frame and used as control point information. Especially for high accuracy demands, this is usually done by standard surveying using a total station. By these means the horizontal and vertical reference coordinates as they are available at survey markers and leveling bolts are transferred to the signalized targets.

All these steps imply a considerable manual effort during standard georeferencing of terrestrial LIDAR. In contrast, much more automation is feasible for data collection from airborne platforms, which are usually equipped with GPS/INS components for accurate direct georeferencing. As it has been demonstrated for vehicle based mobile mapping systems direct georeferencing of laser data is also feasible for terrestrial platforms

However, for standard applications of TLS, especially the large expenses of inertial measurement units will usually prevent the use of such high-end systems. In contrast, direct georeferencing will be profitable for most users, if it is realized by low-cost components. This potential of integrating such components as low-cost GPS or digital compass to simplify the georeferencing process will be discussed in the first part of the paper.

Frequently, TLS is applied for the generation of highly detailed 3D city models from ground based views. In the context of such applications, large scale city models at a limited level of detail are already available for many cities. Usually they have been created from aerial images using stereo measurement or they are extracted from DEM collected by airborne LIDAR. Since these DEMs already provide a geocoded reference surface, the georeferencing of the terrestrial scans can be achieved when they are mapped against the airborne DEM. This automatic registration of facade surfaces collected by a laser scanner from a moving platform has for example been demonstrated by (Früh & Zakhor 2003). In addition to airborne DEM, geocoded reference surfaces are also directly provided by the virtual city models. Hence, geocoding can be realized alternatively by registration of the point clouds from TLS against the corresponding faces of a given 3D building model.

As already discussed, these automatic algorithms for surface registration require a coarse alignment of the scans from TLS. However, this can be provided from direct georeferencing, even if low-cost components are applied. Thus, the presented workflow is as follows: during laser data collection, the position and orientation of the scanner is determined by GPS and digital compass, respectively. For comparison GPS measurement is realized both by a low-cost and a high-end system. The coarse georeferencing of the laser point cloud is then improved by alignment to the airborne DEM and a 3D city model, respectively. The accuracy of the different steps and sensor configurations are determined by comparison to standard referencing using signalized targets. These accuracy investigations are discussed in section 3, while in section 2 the different sensor

components and configurations used for direct georeferencing as well as the properties of the airborne DEM and the 3D city model, which are used as reference surfaces during co-registration of the terrestrial scans are presented.

Existing 3D city models, which are usually collected from airborne views, can additionally be used to support the further processing of data from TLS. Obviously, the airborne acquisition of 3D building models does not provide detailed geometry for the facades of the building. Consequently, this information, which is for example required to generate virtual views from pedestrian perspectives, has to be captured by ground-based approaches like TLS. However, a complete 3D model, containing facades as well as building tops can only be created, if data from airborne and terrestrial views are merged. One option especially suitable for visualization applications is the use of TLS to refine the geometry of relatively coarse building models as they are collected from airborne data by so-called displacement maps. This will be discussed in section 0.

2. AVAILABLE DATA SOURCES

Within our investigations the Leica HDS 3000 was used for LIDAR measurements. This system is based on a pulsed laser scanner operating at a wavelength of 532 nm. It is able to acquire a scene with a field of view of up to 360° horizontal und 270° vertical in a single scan. The typical standoff distance is 50 to 100 meters, but measurements of more than 200 meters are possible. The accuracy of a single point measurement is specified with 6 mm. However, the coordinates of specially designed targets can be captured at an internal accuracy below 1 mm. In standard measurement configurations, these targets are used to provide tie and control point information. For our investigations, these signals were also used as check point. By these means the accuracy of different data collection and processing configurations of TLS could be determined.

2.1 Sensor configuration for direct georeferencing

For direct georeferencing of the terrestrial scans, a low-cost GPS and a digital compass were additionally mounted on top of the HDS 3000 laser scanner. This sensor configuration is depicted Figure 1. Digital compasses such as the applied TCMVR-50 can in principle provide the azimuth at standard deviation below 1°. However, these systems are vulnerable to distortion. Especially in build-up areas the Earth's magnetic field can be influenced by cars or electrical installations. These disturbances usually reduce the accuracy of digital compasses to approximately 6° (Hoff and Azuma, 2000).

Figure 1. Laserscanner with low-cost GPS and digital compass

The low cost GPS receiver mounted on top of the digital compass is based on the SIRF II chip. Thus, if operated in differential mode, the EGNOS (European Geostationary Navigation Overlay Service) correction signal is used. Similar systems, which provide a correction signal generated from information of different ground stations by geostationary satellites are the American WAAS and the Japanese MSAS system. Such satellite-based augmentation systems allow for the real-time differential processing of pseudorange measurements. By these means the accuracy of GPS positioning can be improved from 5-25m to approximately 2m. The vertical component of the low-cost GPS measurement can be discarded and substituted by height values from a Digital Terrain Model, when the accuracy of the GPS measured height is insufficient.

The position of the laser scanner station can be provided alternatively at accuracies of 1cm, if differential phase measurements are available. For this reason a Trimble 4700 GPS receiver was additionally used. Since the GPS antenna and the laser scanner are equipped with the same tribrach, both systems can be mounted at the same position. Data collection by TLS and GPS total station can be realized in parallel, if at least two tripods and centering bases are used. However, while the theoretical accuracy of this differential GPS measurement is very high, there are a number of practical limitations when it is applied in built-up areas. Shadowing from high buildings can result in poor satellite configurations; in the worst case the signal is lost completely. Additionally, signal reflections from buildings nearby can give rise to multipath effects, which are further reducing the accuracy of GPS measurement. However, to demonstrate the optimal benefit of high quality GPS measurements in our investigations, these effects were avoided realizing data collection in the environment of a solitary building.

Our test measurements were performed at Schloss Rosenstein, a palace built from 1822 to 1830. The castle is located on a small hill in a park just outside the city center of Stuttgart and gives a beautiful view over the Neckar valley. The main goal was to acquire dense range data of the facades on all sides of the palace. Five stations were selected around the palace, which has a length of about 80 meters on one side.

2.2 Airborne LIDAR

The DEM from airborne LIDAR used for our investigations was collected as part of a project, which will provide a Digital Terrain Model for the federal state of Baden-Württemberg (Schleyer, 2001). The LIDAR measurements were carried out by the company TopScan using an OPTECH ALTM 1225 scanner. The data was collected at flying heights of 900m and a scan angle of 20°. This resulted in a mean point density of 1.5 points per square meter and a standard deviation of the single point measurements specified to 15cm. The collected data is further processed by the state survey department of Baden-Württemberg to derive a high quality DTM of 5m grid width. Our investigations are based on the original point clouds, which were available in the ETRS89/UTM reference frame with ellipsoidal heights.

2.3 3D city model

Similar to airborne LIDAR, 3D city models have become a standard product of photogrammetric data processing. While airborne LIDAR is available at homogenous qualities, since it is usually collected under contract of a national mapping agency, the situation is more complex for 3D city models. Despite of current attempts aiming on the definition of standards for mod-

eling and representing 3D city models at different levels of detail (Kolbe & Gröger 2003), problems may arise when integrating the models with standard processing due their alternating quality and limited availability.

The 3D city model used in our investigations was collected on behalf of the City Surveying Office of Stuttgart. The roof faces were collected semi-automatically by photogrammetric stereo measurement from images at 1:10000 scale (Wolf 1999). Additionally the outlines of the buildings as provided from the public Automated Real Estate Map (ALK) were used during modeling. Since these building outlines were collected by terrestrial surveying for applications in a map scale of 1:500, a horizontal accuracy of the final building model in the centimeter level was achieved, while the vertical accuracy of the single point measurements used to determine the roof shape was specified to 20cm. Currently, the complete 3D city model covers approximately 110.000 buildings.

3. INTEGRATED GEOREFERENCING OF TERRESTRIAL LASER SCANS

Combining the low-cost GPS and the digital compass measurements gives a global orientation of the scanner head in the selected reference frame. Thereby the laserscanner data is directly georeferenced instantaneous to the measurement itself and the data can immediately be super-imposed with other geodata. Since the HDS 3000 has to be leveled for operation, the tilt measurements of the compass are ignored for these experiments. To be able to asses the accuracy of our approach to georeferencing geodetic GPS measurements were made using a high-end GPS receiver in addition to the low-cost GPS measurements.

Comparing the low-cost to the high-end GPS measurements over the five stations, the mean absolute error is about 1 meter in position and 2 meters in height. The mean absolute errors in on signalized control points, which were established transferring the geodetic GPS measurements onto targets, is about 3 meters in position and 2 meters in height for full georeferencing. It is obvious, that the errors in position are larger than the deviations of the low-cost GPS alone, since compass errors are added with a lever of about 50 meters, whereas the height is not influenced by compass measurements.

This approximate solution is further refined using the iterative closest point (ICP) algorithm introduced by (Besl & McKay 1992). The result of the direct georeferencing is used as an initial value for the iterative registration of the laser scans. Once the registration of the TLS data has converged, it is kept fixed. Then the complete dataset is registered with the city model or airborne LIDAR using the same algorithm. Since the initial approximation of the direct georeferencing is within the convergence radius of the ICP algorithm this approach allows for an automated georeferencing of TLS data.

Figure 2 depicts the super-imposition of the terrestrial laserscanner data, which was directly georeferenced by the low-cost components to the DEM from airborne LIDAR and the available 3D building model, respectively. Based on this information, the further alignment could be computed, which is depicted in the bottom of Figure 2. Some detail of the alignment at a corner of the building where four scans meet is depicted in Figure 3. One general problem during alignment of airborne and terrestrial laser data is the required overlap between the measured surfaces, since terrestrial data collection aims on the collection of the building facades, which are only poorly defined in airborne views. However, as it is shown in Table 1,

absolute georeferenceing accuracies of a few decimeters could be realized. The error using the virtual city model is caused by a systematic height offset of the model. More details of our approach on automated georeferencing are published in (Schuhmacher & Böhm 2005).
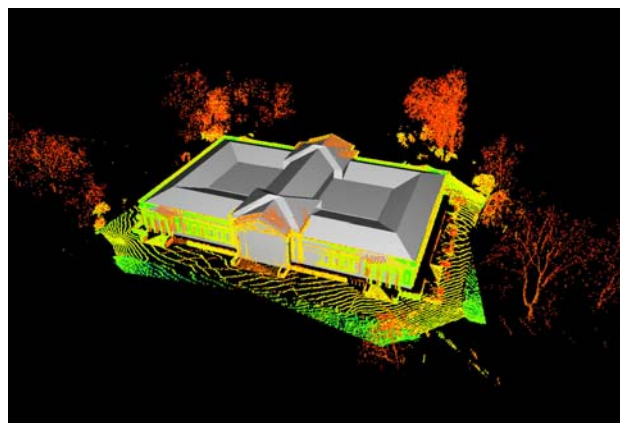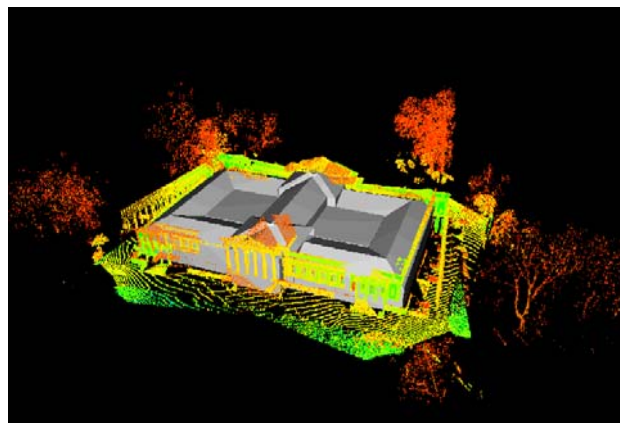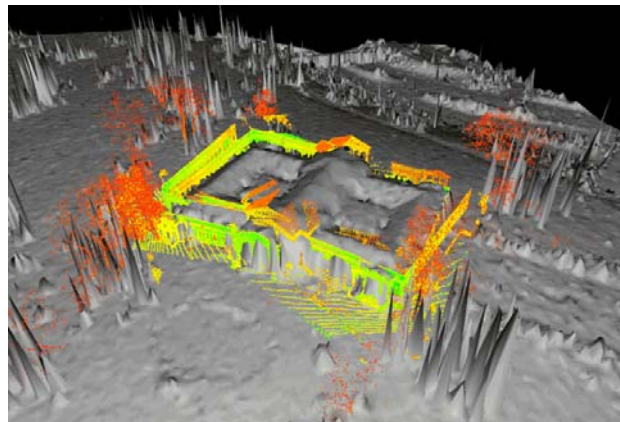

Figure 2: Super-imposition of directly georeferenced terrestrial laserscanner data and aerial LIDAR (top) and virtual city model (middle) with result after alignment (bottom).

method	total accuracy
low-cost GPS and digital compass	4.7 m
refinement using virtual city model	0.80 m
refinement using virtual city model (position only)	0.24 m
refinement using aerial LIDAR	0.27 m

Table 1: Total georeferencing accuracies at signalized control points for different methods.
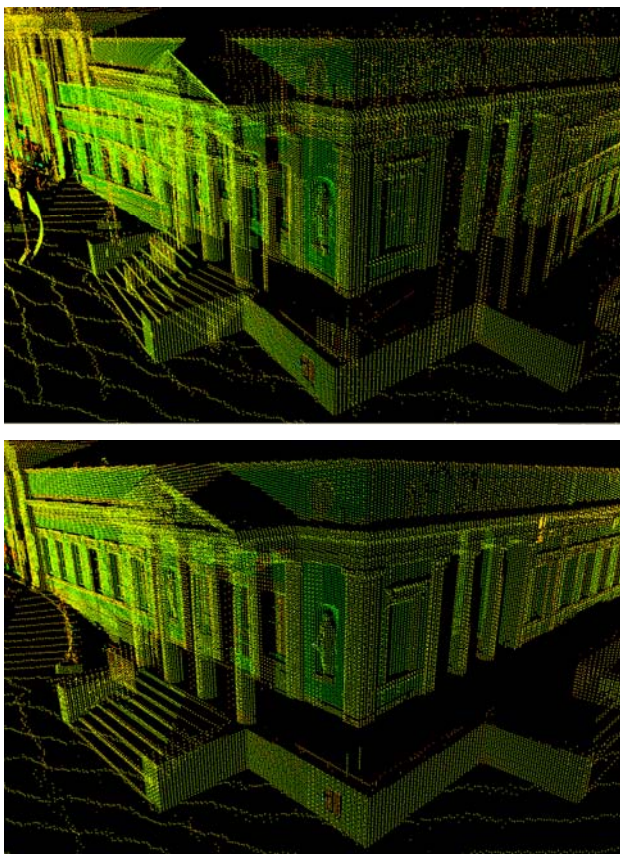
Figure 3. Detail of the aligned datasets. Top: The alignment after integrated georeferencing. Bottom: The alignment after iterative refinement.

4. LASERMAPS FOR REFINEMENT OF 3D BUILDING MODELS

Recent progress in the development of terrestrial laserscanners allows us to acquire densely sampled point clouds of architectural objects consisting of several million points. Using state-of-the-art meshing techniques, though not without problems, these point clouds can be converted to polygonal meshes, immediately suited for graphic rendering. While dense polygon meshes might be a suitable representation for applications in computer graphics, in the world of geomatics this representation lacks desirable features. Let alone the size of the data makes it unrealistic to derive such a representation for even a part of a city. Furthermore a dense polygon mesh is not grouped into meaningful entities, such as different architectural structures, for example wall, roof, and so on.

Deriving such a grouping leads to the task of modeling, where geometric primitives are fit to segmented portions of the data. For TLS data this is typically an interactive process, involving the manual segmentation of the point cloud and the selection of appropriate primitives. This approach is currently applied for the representation of industrial scenes, where objects can be described with a reduced set of geometric primitives and graphical realism is of little interest. For the representation of general architectural scenes this approach of modeling does not seem suitable. For one the work load of manual interaction limits the approach to very small scenes or even single buildings. Secondly most modeling environments for TLS data are limited to simple surfaces types such as ruled surfaces, seldom higher order curved surfaces are used. This set of geometric primitives is not suitable for the representation of

highly detailed ornaments of historical buildings, which are of particular interest in any city model. This discrepancy in the ability to capture fine detail and the representation of surfaces in a model has long been noted in computer graphics. A solution which is often chosen is to separate the representation of coarse geometry from the representation of fine surface detail as shown in Figure 4 (a) to (b).

One of the very first works in this direction has been presented by (Catmull 1974). He proposed to use a mapping of intensity values to the surface representation in order to suggest a higher level of detail to the user. Texture mapping today has become one of the primary tools in virtual city modeling to increase the level of realism for viewers. As well known as the method itself are its shortcomings. Since texture maps only change the intensity values of the surface, the geometric appearance is still given by the underlying coarse geometry. For virtual city modeling this means that the facades are still planar surfaces. While this fact can be ignored when the surface is rendered in an orthogonal view, it becomes more evident the lower the angle of view is to the surface. A second shortcoming of texture maps are related to the illumination of the object. Textures acquired by real images capture the objects intensity properties at the moment the image is taken. Therefore texture maps are bound to the lighting conditions encountered at the moment of the acquisition. At the rendering stage artificial light sources can be introduced at arbitrary locations. If these locations do not correspond with the original image the textures appear unrealistic. Furthermore, any illumination effects in the texture map, that were caused by the interaction of the direction of the light source and the surface orientation, will appear unrealistic when the model's orientation is changed with respect to the light source.
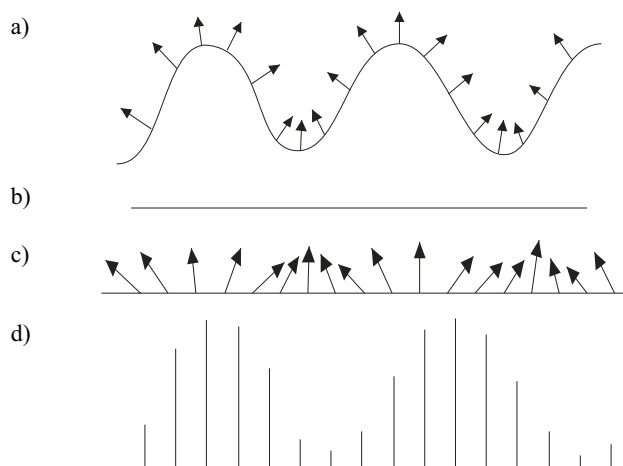

Figure 4. The true geometry of a surface (a) is separated into it's coarse geometry (b), the normal map (c) and the displacement map (d) which contains the difference of (b) to (a).

An important idea in the field of computer graphics addressing this issue was introduced by (Blinn 1978). He observed that the effect of fine surface details on the perceived intensity is "primarily due to their effect on the direction of the surface normal … rather than their effect on the position of the surface". This idea is a first step in separating the coarse and fine geometry of a surface. While the fine details are not modeled as explicit geometry, their perturbation on the direction of the surface normal is recorded as shown in Figure 4

(c) and introduced to the computation of surface intensity. This idea of generating normal maps to enhance the realism of computer generated surfaces is known as bump mapping and has become a standard in computer graphics. On nearly all up-to-date computer graphics card this feature is implemented in hardware on so called graphics processor units (see for example (Kilgard 2000), and therefore ideally suited for high performance rendering and real-time animation.

In order to capture the true geometry of the surface on top of the coarse geometry, displacement mapping introduced by Cook (1984) can be used. For this modeling method the difference of the true geometry to the simplified representation is stored in a separate displacement map (see Figure 4 (d)). In the form of a height field the displacement map can be handled like a color texture image. This approach has been particularly successful in applications were a representation based on NURBs is desired (Krishnamurthy & Levoy 1996) and in applications where automated mesh simplification is performed but geometric detail shall be preserved (Cignoni et al 1999).
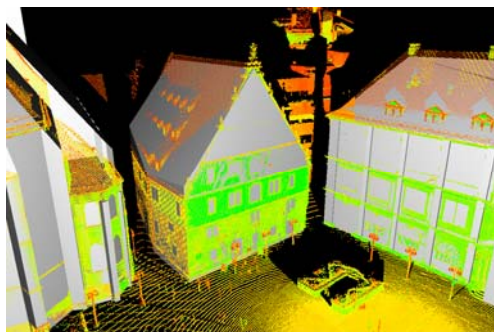

Figure 5. Top: Multiple georeferenced point clouds aligned with a virtual city model. Bottom: The LASERMAP of a single facade extracted from the data.

In the case of adding detail to a virtual city model, the coarse geometry is already given by the model extracted from aerial LIDAR data or photogrammetry. The coarse geometry is represented by the planar polygons of the boundary representation of a building. The task is to use the terrestrial laser data to add the detail. Since terrestrial laser scanners capture mainly the vertical structures, we concentrate on the facades of buildings. Following the approach described above, we aim to extract the displacement map of the CAD model surfaces to the terrestrial point cloud. In order to be able to bring the terrestrial laser data into relationship to the city model, the laser data has to be georeferenced as already described. An additional example is depicted in Figure 5 (top).
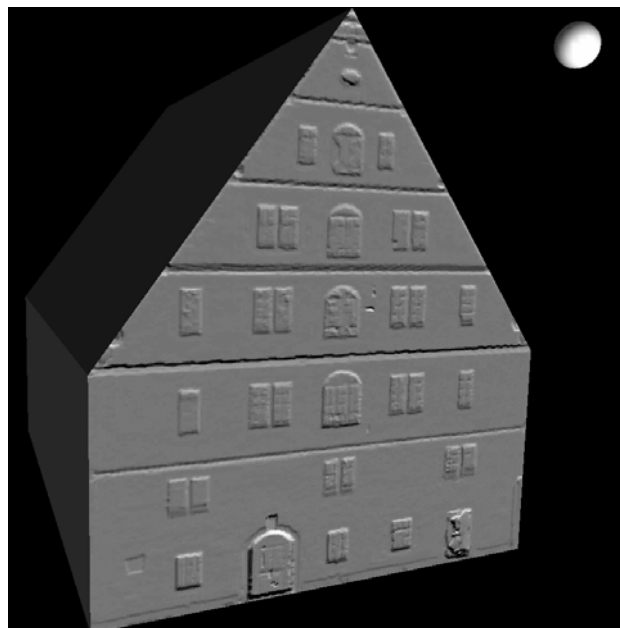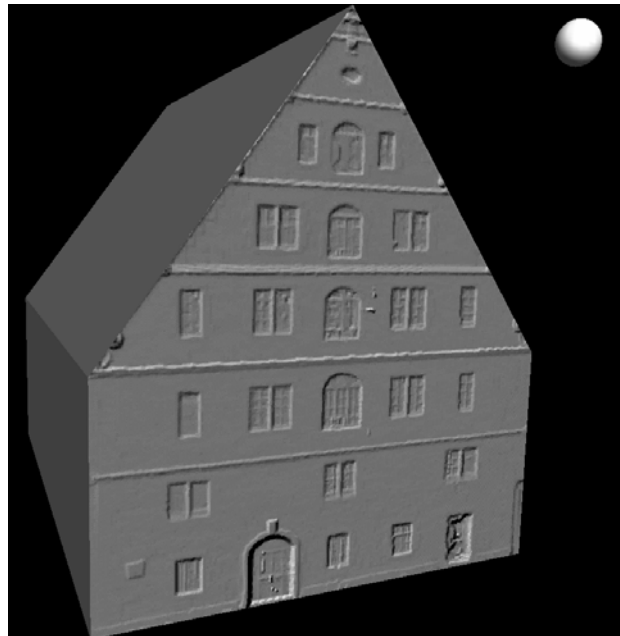

Figure 6. The LASERMAP applied as a bump map to the CAD model of the building.

Once the data is brought into a common geometric reference frame, the difference of the point cloud to a planar facade can be computed easily. Since we assume a multi station configuration for the acquisition of terrestrial data, we can not restrict ourselves to ordered point clouds. Rather we have to work with an unordered point cloud where no neighborhood relation is available. We therefore re-interpolate the portion of the point cloud within a facade's buffer region to a regular raster centered on the plane of that facade. An example of such a re-interpolated displacement map is given in Figure 5 (bottom).

The advantage of the re-interpolation mechanism is that we do not have to establish the neighborhood relation within the point cloud for example by triangulating the point cloud, which can be a complicated process. The disadvantage is that we are restricted to 2½ D structures. However it is common to assume, that facades can be sufficiently described by a relief.

We call such a re-interpolated laser point cloud a LASERMAP. The term is composed from two terms describing the source of the data, a laser scanner, and the use of the data, as a displacement or bump map. The LASERMAP map can either be directly used as a displacement map, when a suitable rendering engine is available or a bump map can be computed using simple normal vector computation from a height field. The application of the LASERMAP as a bump map for the CAD model is shown in Figure 6. This demonstrates the change in the shading of the surface due to the different direction of the light, which is also visible on the sphere added in the upper right corner.

5. CONCLUSION

Within the paper the georeferencing of TLS data based on low-cost components for direct georeferencing has been discussed. Based on this information an automatic alignment of the terrestrial scans against reference surfaces is feasible. These surfaces can either be provided by a dense DEM from airborne LIDAR or a 3D building representation from a virtual city model. Following this approach accuracies can be achieved, which are for example sufficient for model refinement in the context of visualization applications. As it is depicted in the workflow diagram of our algorithm in Figure 7, the coarse CAD model of the building can additionally be used in the modeling step.
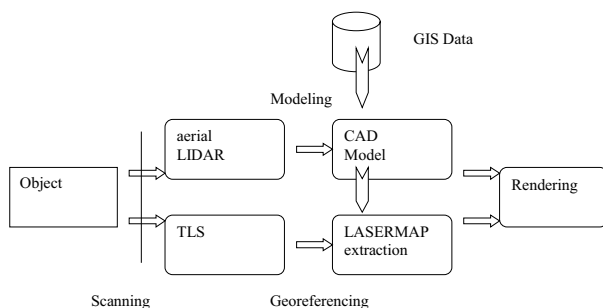

Figure 7 Integration of aerial and terrestrial laser data for virtual city modeling.

Usually, 3D city models are provided at different levels of detail. For example, a municipality may have a complete small scaled, coarse 3D city model on the one hand and detailed representations of selected buildings on the other hand. In the coarsest level of detail, sometimes referred as Level of Detail LoD1 (Kolbe & Gröger 2003) buildings have a representation as a simple block

In LoD2 a building is represented as a (textured) object with a simple roof, while LoD3 provides highly detailed objects with complex roof shape, detailed windows, entrances and ledges. While LoD1 and LoD2 buildings can be captured for wide areas based on airborne data, terrestrial approaches like TLS have to be applied to collect LoD3 buildings. Obviously, the required model generation based on TLS data can be simplified considerably by a coarse to fine strategy based on the 3D models from airborne data collection as initial reconstruction. As it was demonstrated, the huge work load of this explicit

modeling is reduced by the application of displacement maps. This approach, which is frequently used for visualization applications, requires only a suitable interpolation and mapping of the terrestrial data against the planar facades of the coarse building model in order to present the geometric details as they are available from TLS.

6. REFERENCES

Besl, P. J. & McKay, N. [1992] A method for Registration of 3-D Shapes. IEEE Trans. on Pattern Anal. & Machine Intell. 14[2], pp. 239-256

Blinn, J.F. [1978]. Simulation of wrinkled surfaces. *ACM SIGGRAPH Computer Graphics* **12**(3), pp. 286-292.

Catmull, Ed. A. [1974] Subdivision Algorithm for Computer Display of Curved Surfaces. PhD thesis, Computer Science Department, University of Utah, Salt Lake City, UT, Report UTEC-CSc-74-133.

Cignoni, P., Montani, C., Rocchini, C., Scopigno, R. & Tarini, M. [1999]. Preserving attribute values on simplified meshes by resampling detail textures. *The Visual Computer* **15**(10), pp. 519–539.

Cook, Robert L. [1984]. Shade trees. In Computer Graphics (Proceedings of SIGGRAPH 84), volume 18, pp. 223--231, Minneapolis, Minnesota, July.

Früh, C. & Zakhor, A. [2003]. Constructing 3D City Models by Merging Ground-Based and Airborne Views. *IEEE Computer Graphics and Applications,* Special Issue Nov/Dec

Hoff, B. & Azuma, R. [2000]. Autocalibration of an Electronic Compass in an Outdoor Augmented Reality System. Proceedings of International Symposium on Augmented Reality, pp.159-164.

Kilgard, M. [2000] A Practical and Robust Bump-mapping Technique for Today's GPUs. GDC 2000: Advanced OpenGL Game Development.

Kolbe, T. H. & Gröger, G. [2003]. Towards unified 3D city models. ISPRS Comm. IV Joint Workshop on Challenges in Geospatial Analysis, Integration and Visualization II.

Krishnamurthy, V. & Levoy, M. [1996]. Fitting smooth surfaces to dense polygon meshes. SIGGRAPH 1996, pp. 313-324.

Schleyer, A. [2001]. Das Laserscan-DGM von Baden-Württemberg. Photogrammetric Week '01, pp. 217-226.

Schuhmacher, S. & Böhm, J. [2005]. Georeferencing of terrestrial laserscanner data for applications in architectural modeling . To appear in 3D Arch, Venice Italy.

Wolf, M. [1999]. Photogrammetric Data Capture and Calculation for 3D City Models. Photogrammetric Week '99, pp. 305-312.