

TERRESTRIAL LASER SCANNING SYSTEM MENSİ GS100/GS200 – ACCURACY TESTS, EXPERIENCES AND PROJECTS AT THE HAMBURG UNIVERSITY OF APPLIED SCIENCES

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ABSTRACT:

3D terrestrial laser scanning is well on the way to proving itself to be a 3D measurement technique that can complement or replace the established techniques of photogrammetry and tacheometry. For this reason investigations into accuracies and behavior are very important for the understanding and improvement of such measuring systems. The Department of Geomatics at Hamburg University of Applied Sciences has investigated the terrestrial 3D laser scanning system Mensi GS100/GS200 regarding the accuracy of distances measured and practical handling of the equipment in projects. It can be stated that distances measured with the laser scanner Mensi GS100 are systematically too long when compared to reference distances and that distances measured to spheres and targets placed on identical points are systematically different. In registration and geo-referencing of point clouds using Mensi spheres and targets in a 3D test field standard deviations of approx. 3mm could be achieved when compared to reference points. Investigations into the planarity of a stone slab showed measurement noise of some millimeters in the point cloud; which is within the range of the measuring accuracy. The laser scanners Mensi GS100 and GS200 have already been used in several projects at the HAW Hamburg and also in co-operation with a private engineering office. First experiences in data acquisition, registration and georeferencing will be reported in this paper using both systems.

1. INTRODUCTION

3D laser scanning systems are capable of generating millions of 3D points within a short period of time when scanning an object or a cutout with a laser beam. These systems are beginning to dominate the market in a range of applications such as in the mining industry, industrial as-built-documentation, archaeology, architecture, care of monuments, automobile and mechanical engineering. However, detailed investigations into accuracies and behaviour of such measuring systems must show whether these systems fulfil various project requirements and whether the technical specifications indicated by the system manufacturers are correct. Some authors (BOEHLER et al. 2003, LICHTI et al. 2003 and JOHANSSON 2003) have already reported first investigations into terrestrial laser scanners, while publications about experiences with laser scanners are summarized in the conference proceedings of the "Oldenburger 3D-Tage" (LUHMANN 2002, LUHMANN 2003, LUHMANN 2004) and the Optical 3D-Measurement Techniques V and VI (GRUEN and KAHMEN 2001, GRUEN and KAHMEN 2003).

The Department of Geomatics at Hamburg University of Applied Sciences (HAW Hamburg) purchased the terrestrial laser scanning system Mensi GS100 in September 2003 in order to use the new technology in teaching and practical research. Thus, know-how in this new technology can be built up at the university, and can be transferred by graduates of the university to private offices which want to invest in laser scanning technology.

2. THE TERRESTRIAL LASERSCANNING SYSTEM MENSİ GS100/GS200

The 3D laser scanning systems GS100 and GS200 are manufactured by Mensi S.A., France and consist of a laser scanner, accessories (Fig. 1) and appropriate software for data acquisition and post processing. The technical specifications of the two systems are summarized in MENSİ 2004. The most significant difference between GS100 and GS200 is in the optimal measuring distance and scanning range of 100 m for the GS100 as compared to 200 m for the GS200. The panoramic view scanner (field of view 360° horizontal, 60° vertically) offers an uninterrupted panoramic capture of a scene of 2m x 2m up to 200m x 200m x 60m indoors or outdoors. The resolution of the scanner is 0,002 gon (Hz/V). The laser point has a size of 3mm in 50m distance, whereby the standard deviation of a single distance measurement is 6mm. The distance measurements are performed by pulsed time-of-flight laser ranging using a green laser (532 nm, laser class II or III). The system is able to measure up to 5000 points per second.

Fig. 1 shows the 3D laser scanning system Mensi GS100 with accessories, consisting of a rugged flight case and a notebook for controlling the unit during data acquisition. The usage of an efficient power generator (e.g. Honda generator EU 10i, power output approx. 1 KW) is recommended for field work, when mains power cannot be obtained.



Fig. 1: The terrestrial 3D laser scanning system Mensi GS100 including transportation box, notebook and external Honda power supply at HAW Hamburg



Fig. 2: View into the scanner showing the digital camera and the laser mirror

A substantial component of the laser scanning system is the software. For data acquisition PointScape (version 1.2) is used as a so-called field service program, which controls the scanner via notebook. The post processing of the 3D point clouds is performed with Real Works Survey (V4.1) or with 3Dipsos (V2.5). Both programs offer registration and georeferencing of point clouds as well as multiple options for post processing. Real Works Survey is mainly used for meshing of point clouds, computation of volumes, derivation of contours as well as for matching of digital images with point clouds. The program 3Dipsos represents the engineering module, with which CAD constructions derived from the point clouds can be provided.

3. DATA ACQUISITION, REGISTRATION AND GEOREFERENCING

The substantial work procedures that must be completed before post processing 3D point clouds are data acquisition, registration (connection) and/or georeferencing of point clouds (obtained from different stations) into a superior coordinate system. Setting up and dismantling the system takes approximately 15 minutes at each station, while data acquisition per station takes approximately 1.5 hours (depending upon

number of requested details on the object). In order to connect point clouds from different stations automatically, white spheres with defined diameter and/or green targets have to be distributed in the object area. Each sphere/target requires a separate scan. The process of locating spheres and targets is called framing and is done in the image of the build-in video camera (Fig. 2). The recognition of the spheres/targets and the computation of the center coordinates in the local scanner coordinate system is performed in a semi-automatic process. The operator manually specifies the frame in the video image. In this frame the system recognizes and scans the sphere/target, computes the centre coordinates in the point clouds and finally shows the result in PointScape (Fig. 3 and 4). The pattern recognition algorithm does not always work reliably, depending upon background color/illumination in the video frame. Also, depending on the weather (e.g. strong sunshine) or distance to sphere/target, recognition problems may occur. A high-contrast background (e.g. using a field umbrella, Fig. 10) could help with this problem. Nevertheless it may happen that recognition gives incorrect results (Fig. 4 on the right).

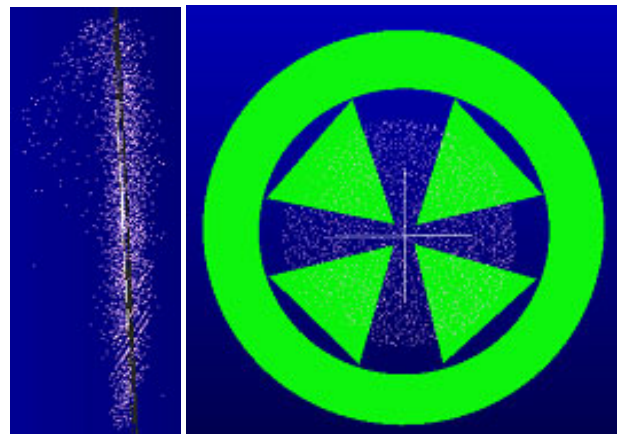


Fig. 3: Scanned (left) and automatically recognized target (right)

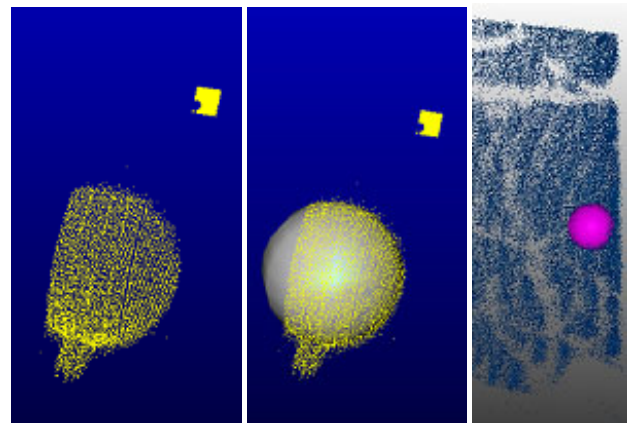


Fig. 4: Scanned (left) and automatically recognized sphere (middle), recognition error, sphere constructed into point cloud of a tree (right).

The object can be scanned as a cut-out or as a 360° scan with different resolutions (starting from 0,3mm at 10m distance), whereby the video framing supports the definition of the cut-out. The following registration of the point clouds can be performed automatically using spheres/targets or semiautomatically using selected spheres/targets or manually

using discrete points of the point clouds. If forced centering on tripods is used and if targets or spheres are measured geodetically in a superior coordinate system, the point clouds can be georeferenced using these points.

4. ACCURACY TESTS AT HAW HAMBURG

4.1 3D test field

In order to examine the accuracy of distance measurements, registration and georeferencing of the Mensi GS100 and GS200, a durable 3D test field was built in the hall of building D at the HAW campus (Fig. 5). The test field consists of 53 reference points which can be set up with spheres or targets. The points are distributed over 3 hall levels on the floor, on walls or on concrete pillars using M8 thread holes. The reference points were measured from nine stations with a Leica TDA 5005 total station. In a 3D net adjustment using PANDA the station coordinates were determined with a standard deviation of less than 0.5mm. The standard deviation of the coordinates of reference points is less than 1mm (local network). To set up the reference points special adapters were built in order to guarantee a precise, stable and repeatable set up of spheres or targets.



Fig. 5: GS100 in the 3D test field of HAW Hamburg



Fig. 6: Sphere (left) and target (right) with used adapter

The reference points and the 3D test field were scanned with the laser scanners Mensi GS100 and GS200. Since the GS200 was only available for one day, 26 reference points (max. distance 21m) were scanned with the GS200 from only two of the available station in the lower level of the test field. The GS200 was set up in a Leica tribrach. When compared to the GS200, the first GS100 scans (also set up in a Leica tribrach) in

the test field had some problems due to some play in horizontal and vertical direction because of the scanner's unstable attachment to the tribrach and because of the uncentred mass of the scanner. These problems lead to an orientation change of the scanner during scanning. It is generally advisable to repeat a scan to a well-known sphere at the end of the scanning campaign at a particular station to check the scanner stability. In a second campaign all reference points (max. distance 27 m) in the three levels of the hall were scanned from five different stations using the GS100 on a Mensi tripod. Thereby, 28 reference points were obtained with both spheres and targets.

The scans obtained with GS200 and GS100 were registered in Real Works Survey. For both systems the average and maximum distance to sphere and target centers were determined to within 2.4mm (max. 8.6mm) for the GS200 and to within 2.6mm (max. 4.8mm) for the GS100. The transformation result of GS100 measurements was more homogeneous in total due to the averaging of a higher number of points (spheres/targets). After the georeferencing of the point clouds in Real Works Survey using four well- distributed control points (Fig. 7) the coordinates of the spheres and targets could be transformed into the superior coordinate system. The comparison of the coordinates of the reference points with those obtained by the GS200 show a difference in the absolute average values of $dx = 2.6\text{mm}$, $dy = 2.5\text{mm}$ and $dz = 1.8\text{mm}$ with a maximum value of 9.6mm. Comparing the reference points with the results of the GS100 was slightly worse with $dx = 2.6\text{mm}$, $dy = 3.2\text{mm}$, $dz = 3.4\text{mm}$ and 16.9mm (max. value). In the comparison of 28 distances to reference points (max. distance 27m) which were equipped with spheres and targets in each case it could be stated that distances measured to spheres were systematically on average about 5mm longer than to those measured to targets.

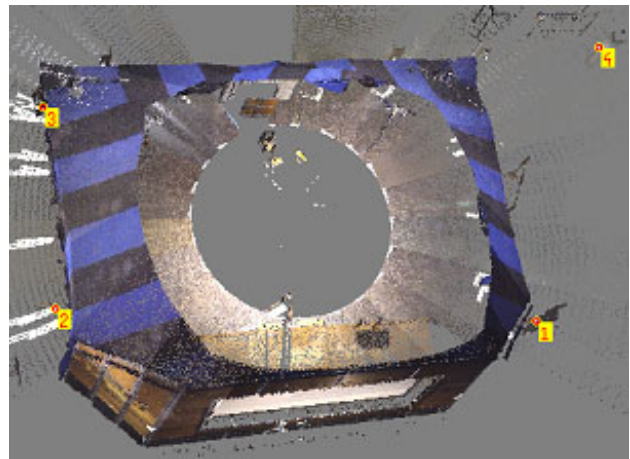


Fig. 7: RGB presentation of the point cloud of the test field including the four transformation points

4.2 Comparison of distances on a baseline

The result of systematically different distances measured to spheres and targets set up on identical reference points lead to a detailed investigation of GS100 distance measuring accuracy on the HAW baseline in Hamburg-Ohlsdorf (Fig. 8). In total up to eight distances between the baseline pillars, which were equipped with spheres and targets using a special adapter (Fig. 8), were measured as forward and backward measurements. Eight distances to the targets between 20m and 120m (80m and 120m each twice) were measured using automatic target recognition, while only six distances could be measured to the

spheres due to the failure of the automatic recognition to the 120m distance. Therefore the spheres were scanned as an object in forward and backward measurements to generate an additional data set with which the spheres could later be manually reconstructed from the point clouds in Real Works Survey. In total 55 scans were performed in four hours on seven different stations, whereby the pure scanning time was 141 minutes, which corresponds to a time of 2.5 minutes per scan. Within the four hours the scanner and/or the software crashed four times.



Fig. 8: Scanner on the baseline (above), sphere (left) and target (right) with the adapter used

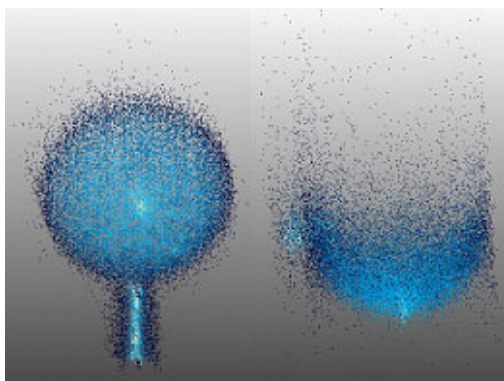


Fig. 9: Point cloud of sphere as front view (left) and as a view from above (right)

The results from the test field show that the derived horizontal distances to spheres and to targets on the baseline are systematically too long compared to the reference distances. The distances to the spheres are on average 8.3mm too long, while the distances to the targets are on average only 3.4mm too long. This result confirms the difference of 5mm between the distance to spheres/targets from the 3D test field. On the other

hand the distances to the manually constructed spheres, where the dispersion of points (noise in the measurements) was eliminated before the computational adjustment of the sphere in the point cloud, are on the average 3mm too short. Thus, it can be concluded that the centers of the spheres and targets are not always computed optimally in Real Works Survey due to the dispersion of points within the 3D the point cloud (Fig. 9).



Fig. 10: Background contrast for automatic detection of spheres in the video frame before scanning

4.3 Determination of the planarity of a stone slab

In order to obtain a better assessment of the measurement noise different scans were made of a planar stone slab placed 4m from the scanner (Fig. 11). The yellow sprayed stone slab (approx. 80cm x 80cm) was scanned from the front (0°) and with a 45° rotation with 7 scans each. Grid widths were 2mm, 25mm and 125mm. Various scanner settings (fixed focus on 4m, on 50m, with autofocus, grid quality as best quality or fast, and with 1 shot or 10 shots) have been used. The middle of Fig. 11 (bottom) shows a high resolution frontal scan with a hole in the center (dark-blue bordered), which is probably caused by filtering of a reflection of the laser beam that was too strong. In Fig. 11 (upper right) the same point cloud is illustrated in a side view with a scattering of approx. 4mm.

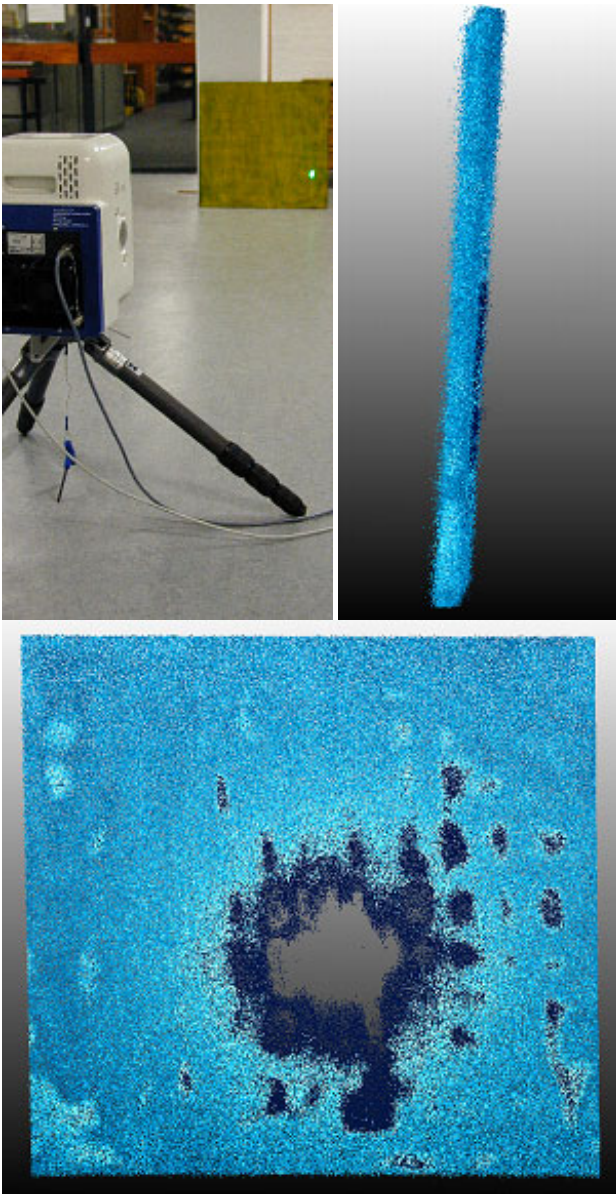


Fig. 11: Scanner in front of the stone slab (upper left), side view of the stone slab indicating the scattering of the points (upper right), high resolution frontal scan of the stone slab with a hole in the center (bottom)

The evaluation of the scans was conducted with 3Dipsos to check the planarity of the point cloud of the stone slab. The results of the scanned stone slab showed a significant difference between scans with a 0° and a 45° rotation. The data sets of the 45° scans were more homogeneous and more precise, i.e. after elimination of outliers a standard deviation of 5mm was achieved for the adjusted planarity of the stone slab. In comparison the 0° scan results varied between 3 and 7mm. For the 45° scans better results were also obtained with the grid option "best quality" in comparison to "fast". Scans with grid width 125mm were not processed due to the unusable quality. With 45° scans significant differences between the settings best quality/fast and 1 shot/10 shots could not be shown. A reduced number of points supplied an apparently better result, however an inclined planarity (approx. $0,1^{\circ}$ corresponds to approx. 2mm per 1m) was computed. In these investigations the standard deviation of 6mm for the single distance measurement indicated by the manufacturer was met, but no significant

improvement by using multiple measurements (10 shots) could be achieved.

5. PROJECTS

5.1 Overview

In addition to the scans in the 3D testfield and of the baseline with the terrestrial laser scanners Mensi G100 and GS200 some practical projects were carried out in the period from October 2003 until January 2004. The Torhaus in Hamburg-Wellingsbuettel was scanned for comparison with digital photogrammetry. The ring barrier plant in Willenscharen was scanned with the GS100 for the production of a topographic map 1:1000 (see in 5.2.) The church in Friedrichstadt was scanned for the derivation of different cuts and sketches. In cooperation with the engineering office RMK Vermessung, Celle the GS200 was used for one week in Hungary in the region of Budapest for data acquisition of various objects: approx. 1km double-sided embankments of the river Tisza at the village Tiszavárkony for production of a digital elevation model, various bridges (railway, motorway, Magareten bridge in Budapest) for CAD reconstruction, two building facades in Székesfehérvár for production of facades plans, a transformer station in Újpest and the medication works Chinion in Újpest (as-built-documentation), the cave Pál voelgyi bar-long in Pálvoelgy (documentation) and the statue at the square "1000 years Anniversary of Hungary" in Budapest (architecture). All Projects are still being processed. As two practical projects with an industrial plant (liquid gas plant Boie, Luebeck) and an architectural object (the historic building Holstentor in Luebeck) showed (JAHN et al. 2004), the ratio of approximately 1:9 between the time required for data acquisition and the time taken for data processing depends mainly on project requirements.



Fig. 12: Pre-historic Saxon ring barrier plant in Willenscharen, Schleswig-Holstein (view from south)

5.2 Topographical recording of a ring barrier plant Willenscharen

In December 2003 and January 2004 the pre-historic Saxon ring barrier plant in Willenscharen, Schleswig-Holstein (Fig. 12) was scanned on four days with the GS100 from six different stations, in order to derive a contour map 1: 1000 from the entire 3D point cloud and to compare the results with geodetic data acquisition regarding accuracy and efficiency. For the registration of the scans 16 spheres were scanned, whereby eight spheres were on geodetic points so that georeferencing of the registered point cloud could be completed. The registration of the individual point clouds was made using 3-7 spheres per station with an average and maximum distance to the sphere centers of 5.5mm and 11.9mm, which is more than sufficient for topographic data processing. The data processing of the registered point cloud (5.9 million points) is still ongoing and final results cannot currently be presented.

5.3 Embankments of the river Tisza

One of the major projects in Hungary using the GS200 was the scanning of approximately 1km of double-sided embankments of the river Tisza at the village Tiszavárkony (Fig. 13) for the production of a digital elevation model (DEM), which is the base data for flooding simulations. The river Tisza in the east of Hungary (Fig. 14) regularly causes heavy flooding in the village Tiszavárkony. Due to the steep slopes of the river bank several buildings are in severe danger of collapse. Simulation computations could help to establish suitable flood protection.



Fig. 13: Project area at river Tisza and village Tiszavárkony



Fig. 14: Scanner and equipment in use at the river Tisza



Fig. 15: Scanner in a warped embankment of the river Tisza

On three days the embankments of the Tisza were scanned from nine stations. A part of a point cloud is depicted in Fig. 17. For registration of the scans from the nine stations 17 spheres were used on tripods. Additionally center positions of these spheres where measured and determined geodetically by GPS for the georeferencing of the point clouds in the Hungarian national coordinate system. As a quality control for the DEM, which was derived from the georeferenced point cloud, profiles were measured every 50m by a total station. The average point density of the laser scans was 50mm and the scanning distances were on average in the range of up to 200m. However, objects at a distance of up to 330m were also scanned. To a large extent the laser scanning system worked without problems. However, it was realised that the combination of scanner weight (approx. 13 kg) and uncertain underground (warped embankments, Fig. 15) frequently caused the system to sink and thus slight changes in the orientation of the scanner during scanning of spheres and the river embankments. This sinkage yielded discrepancies in the georeferenced point cloud (Fig. 16). The spheres could not be automatically recognized when distances where longer than 100m, which meant that substantial additional post processing time was needed in order to reconstruct the spheres manually in the point cloud. For this project the registration of the point clouds was performed indirectly by georeferencing each point cloud separately. The average standard deviation after the transformation into the national Hungarian coordinate system was 33mm at all stations and 38mm at all spheres. The achieved result was sufficient with respect to the project requirements. Before generating the DEM from the georeferenced point cloud all points above ground must be removed by cutting options in Real Works Survey. Automatic filter algorithms did not work successfully to obtain a reliable result without eliminating too many points.

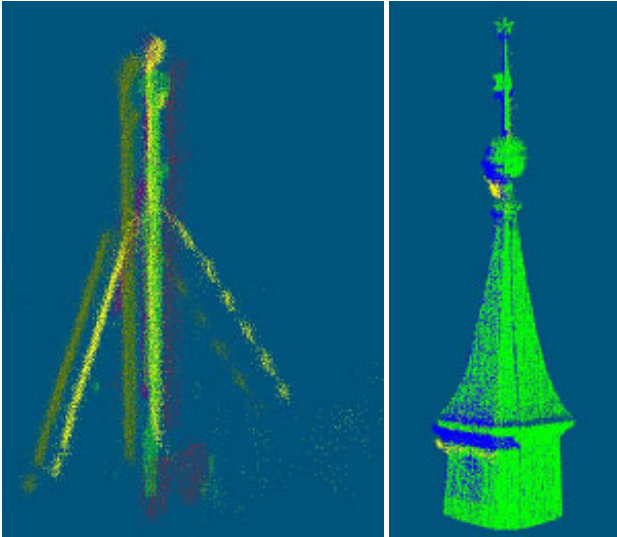


Fig. 16: Discrepancies in the georeferenced point cloud

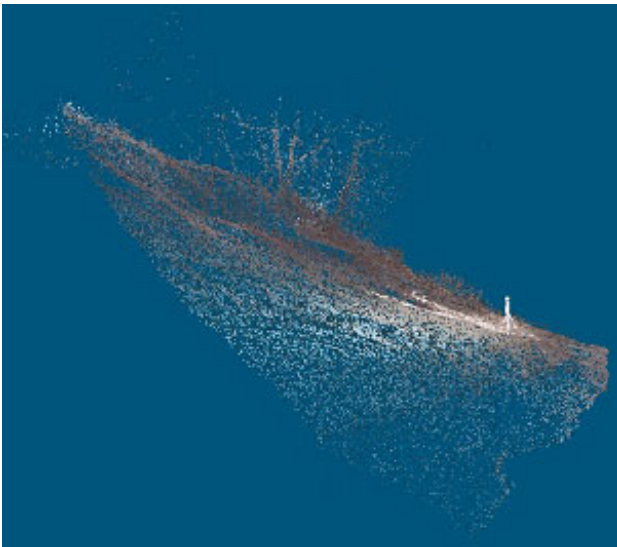


Fig. 17: Point cloud of a part of the embankment of river Tisza

5.4 Building facade and statue

In this chapter two other projects with the GS200 are presented. These projects were carried out in December 2003 in Hungary in co-operation with the engineering office RMK Vermessung from Celle. The facade of a church administration building in Székesfehérvár (Fig. 18) was scanned in approx. 4.5 hours from three stations, each with 10-15 scans for the production of facade plans. Some building parts were scanned with a resolution of 2-6mm in 10m, some individual details even with a resolution of 0.3mm in 10m which were used for the registration of the point clouds. The distances in object space ranged between 20 and 65m. The registration of the individual point clouds was conducted manually by constructing spheres from appropriate object elements (Fig. 19 left) so that a registration with 4-6 control points for each station could be achieved with a mean distance to the sphere centers of 4-5mm and with a maximum distance of 7.5mm. The registered 3D point clouds contain approx. 12 million points in total.



Fig. 18: RGB presentation of the point cloud of a building facade in Székesfehérvár (Hungary)

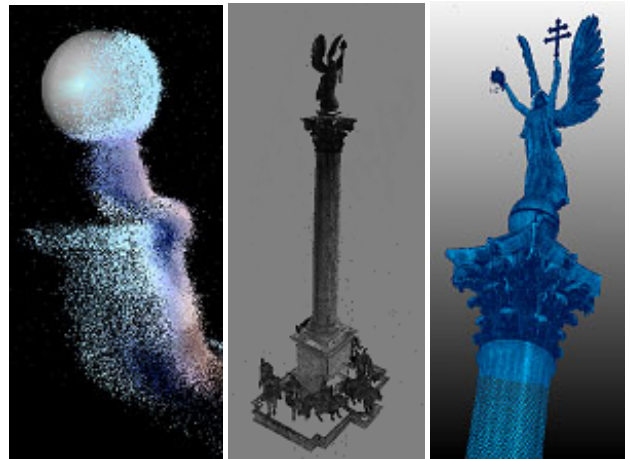


Fig. 19: Manually constructed sphere in a point cloud of a building facade (left) and scanned statue (middle, right)

A second example is the scanning of a statue on the square "1000 years Anniversary of Hungary" in Budapest. The statue was scanned with 17 scans in total from three stations with the GS200 in approx. 5 hours. The distances in object space ranged between 10 and 100m and scan resolution was 4m in 10m for the statue and 0.3mm in 10m for special details of the statue. Different to the building facade the point clouds were registered by 3-5 spheres for each scanning station, which yielded a total of 5.9 million points for this data set (Fig. 19 middle and right). For this project a similar result was achieved for registration as for the building facade: a mean distance to the sphere centers of 4-5mm and a maximum distance of 5.6mm. Thus, it could be demonstrated that registration of point clouds with manually constructed spheres from natural objects can give the same accuracy results as compared to registration using spheres. Georeferencing of registered point clouds was not demanded for these projects, which are still in process.

6. CONCLUSIONS AND FUTURE

The investigations at HAW Hamburg showed that distances measured with Mensi GS100 are systematically too long to spheres and targets compared to reference distances. Finally, it could not be clearly determined whether the above-mentioned differences are caused by scanning or by automatic determination of the sphere and/or target centers in the point cloud using Real Works Survey. However, it seems to be necessary to introduce an additional constant for the whole system (instrument and software). Furthermore, it could be confirmed that noise and/or dispersion in the order of magnitude of the manufacturer data specifications is contained in the point clouds. The terrestrial 3D laser scanning system Mensi GS100 and GS200 proved to be stable as far as possible and simple to use during the described projects. Registration and georeferencing of point clouds could be performed with deviations within the range of some millimeters in the completed projects. The system is suitable for use in teaching and practical research, so that co-operation with innovation-willing engineering offices represents a meaningful task in the form of know-how transfer. The data acquisition can be performed relatively simply and quickly, but post processing of large point clouds is very complex depending upon the project requirements. Experience in using the laser scanning system, which comes with an increased number of completed projects, is an important pre-condition for successful projects. However, it was obvious that communication between system manufacturers and universities is very important, so that the user can better understand the system afflicted with "teething troubles" and the manufacturers can solve problems efficiently.

In the future increased automation in data post processing will be necessary to achieve increased acceptance of this technology in the market. This will consequently lead to the use of laser scanning systems as efficient workhorses in surveying and geomatics. One can expect that laser scanning systems will be developed to multi sensor systems with a digital camera for the combination of point clouds and high resolution images and a GPS/INS for positioning and/or automatic georeferencing of the point clouds. In the future the system will become faster, more precise, more convenient and, hopefully, also less expensive. The investigations at universities as performed at the Department of Geomatics at HAW Hamburg will contribute to the improvement of the laser scanning systems in the future.

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