INVESTIGATING LASER SCANNER ACCURACY

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ABSTRACT:

Laser scanners have become very popular for cultural heritage documentation. A main advantage as compared to close range photogrammetry is the availability of near real time 3D coordinates for irregular surfaces. The striking capability of collecting hundreds or even thousands of points per second is praised by producers and operators. On the other hand, questions concerning the quality and accuracy of the recorded points receive little attention. Specifications stated by the producers are not comparable. In a research project, i3mainz has installed a number of different test targets that allow an investigation in the quality of points recorded by laser scanners and the geometric models derived from the point clouds. The standardized tests also allow a comparison between instruments of many different manufacturers for the first time. The test procedures include scans of plane surfaces of different reflectivity in different distances. When these point clouds are replaced by a best fitting plane, the same measurements can be used to get an indication of the noise of the range measurements. In a similar set-up, a test is performed to find out if different materials cause a systematic range offset. Several test fields using white spheres as targets have been installed to get information about the accuracy of distances in scanning direction and across. Short distances are verified using an interferometric comparator; the true values of longer distances rely on precision surveying methods. Due to different grid widths and spot sizes, not all 3D scanners have the same abilities to resolve small object details. They are also known to produce errors at edges. Both phenomena are tested with appropriate targets in order to find out how different instruments deal with these problems. The tests are still available and producers and users are invited to have their instruments examined.

1. INTRODUCTION

Surveying results must meet certain specifications in order to provide the necessary accuracy standards for a certain application. On the other hand, if instruments and methods are used which yield an accuracy far above the needed standard, this will result in unnecessary cost and expenditure. Therefore, any geometric surveying task comprises not only the derivation of the relative positions of points and objects but also an estimation of the accuracy of the results. Least squares adjustment based on overdetermination usually yields a reliable information concerning the accuracy of the results as well as the accuracy of the observations. If the number of observations is not sufficient for an adjustment, one may estimate the accuracy of the results by propagating the errors of the observation instruments to the results. In this case, the accuracy of the measurement device has to be known.

In the case of laser scanners, a large number of 3D coordinates on an object's surface is measured in a very short time. Important object features, such as corner points or edges, are not directly recorded; instead they have to be modeled from the point clouds in a separate process. While it is possible to record the same object several times from different observation points, it is impossible to record the very same points in these repeated surveys. Therefore, deviations can only be noticed after objects have been extracted from the point clouds and modeled. If the geometric properties of the object are known, however, the deviation of single points from the object's surface may be an indication for the accuracy. Using a plane surface would be the simplest case, but cylinders or spheres can also be considered.

2. ACCURACY OF LASER SCANNERS

2.1 General remarks

The accuracy specifications given by laser scanner producers in their publications and pamphlets are not comparable. Experience shows that sometimes these should not be trusted and that the accuracy of these instruments which are built in small series varies from instrument to instrument and depends on the individual calibration and the care that has been taken in handling the instrument since.

Every point cloud produced by a laser scanner contains a considerable number of points that show gross errors. If the point cloud is delivered as a result of surveying, a quality guarantee, as possible for other surveying instruments, methods, and results, cannot be given.

Many institutions have already published methods and results concerning accuracy tests with laser scanners (e.g. Balzani et. al. 2001, Johansson 2002, Kern 2003, Lichti et. al. 2000, 2002). Based on this knowledge a comprehensive test program was developed at i3mainz and as many different scanners as possible are compared using the same installations.

2.2 Angular accuracy

The laser pulse is deflected by a small rotating device (mirror, prism) and sent from there to the object. The second angle, perpendicular to the first, may be changed using a mechanical axis or another rotating optical device. The readings for these angles are used for the computation of the 3D point coordinates. Any deviations will result in errors perpendicular to the propagation path. Since the positions of single points are hard to be verified, few investigations of this problem are known. Errors can be detected by measuring short horizontal and vertical distances between objects (e.g. spheres) which are located at the same distance from the scanner and comparing those to measurements derived from more accurate surveying methods.

2.3 Range accuracy

In the case of ranging scanners, range is computed using the time of flight or a phase comparison between the outgoing and the returning signal. Ranging scanners for distances up to 100 m show about the same range accuracy for any range. Triangulation scanners solve the range determination in a triangle formed by the instrument's laser signal deflector, the reflection point on the object's surface and the projection center of a camera, mounted at a certain distance from the deflector. The camera is used to determine the direction of the returning signal. In contrast to the ranging scanners, the accuracy of ranges acquired with triangulation scanners diminishes with the square of the distance between scanner and object (Boehler, Marbs, 2002).

Ranging errors can be observed when known distances in range direction are measured with the scanner. If scanners are not equipped with a defined reference point (such as forced centering), it is only possible to measure range *differences* between targets. Plane, cylindrical or spherical targets may be used if their precise positions are surveyed with instruments and methods more accurate than the laser scanner.

Whereas a systematic scale error will be present in any spatial distance measured, a systematic constant (zero) error will be eliminated when distance differences in range direction are determined. The constant error will influence distances between two points which are located in different directions as seen from the scanner, however. If both points are located in the same distance from the scanner, the deviation of their distance will amount to the zero error when the direction difference is 60°; it will amount to twice the zero error when the direction difference is 180° (e.g. when scanning all walls with a panoramic scanner from one single observation point in the center of a room).

A very fast and easy check for the noise (accidental error) of range measurements can be achieved when a plane target perpendicular to the observation direction is scanned and the standard deviation of the range differences of the points from an intermediate plane through the point cloud is computed. As an additional result, this test also detects if range is internally only provided with a certain resolution (e.g. 1 cm) which is the case for some instruments (Kern, 2003).

2.4 Resolution

The term "resolution" is used in different context when the performance of laser scanners is discussed. From a user's point of view, resolution describes the ability to detect small objects or object parts in the point cloud. Technically, two different laser scanner specifications contribute to this ability, the smallest possible increment of the angle between two successive points and the size of the laser spot itself on the object. Most scanners allow manual settings of the increment by the user.

Since the combined effects of increments and spot size determine object resolution, a test object comprising small elements or small slots in front of a plane can serve to determine application related resolution information.

2.5 Edge effects

Even when well focused, the laser spot on the object will have a certain size. When the spot hits an object edge, only a part of it will be reflected there. The rest may be reflected from the adjacent surface, a different surface behind the edge, or not at all (when no further object is present within the possible range of the scanner). Both, ranging scanners and triangulation scanners produce a variety of wrong points in the vicinity of edges. The wrong points are usually to be found on the ray from the laser deflection point to the edge point, behind the edges (when looking from the scanner). The range error may vary from just a millimeter to values of several decimeters.

Obviously, wrong points are inevitable since the laser "spot" cannot be focused to point size. It can be assumed that well focused lasers will show better results. When using a standard target with different types of edges, the performance of different types of scanners can be compared.

A systematic effect can be observed when cylindrical and spherical targets are observed from a close distance (Lichti et. al. 2002). In this case, at the peripheral parts of the object, the center of the reflecting surface area is not identical with the center of the transmitted spot.

2.6 Influence of surface reflectivity

Laser scanners have to rely on a signal reflected back from the object surface to the receiving unit in case of ranging scanners and to the camera in case of triangulation scanners. In either case, the strength of the returning signal is influenced (among other facts such as distance, atmospheric conditions, incidence angle) by the reflective abilities of the surface (albedo). White surfaces will yield strong reflections whereas reflection is weak from black surfaces. The effects of colored surfaces depend on the spectral characteristics of the laser (green, red, near infrared). Shiny surfaces usually are not easy to record.

It has been observed that surfaces of different reflectivity result in systematic errors in range. For some materials these errors may reach amounts several times larger than the standard deviation of a single range measurement. Some scanners which provide some type of aperture adjustment show errors in the first points after the laser spot has reached an area of a reflectivity differing considerably from the previous area, and it can be observed that the correct range is achieved only after a few points have been measured. For objects consisting of different materials or differently painted or coated surfaces, one has always to expect serious errors. These can only be avoided if the object is temporarily coated with a unique material which, of course, is not applicable in most cases.

If the effect has to be examined and evaluated, one may use plane white targets and apply the material in question to the center part of the target. When the intermediate planes are computed for the coated center part only and then for the rest of the (white) target without using the center part, the difference between those planes will give an indication of this effect.

2.7 Environmental conditions

Temperature. Any scanner will only function properly when used in a certain temperature range. Even within this range, deviations may be observed, however, especially in the distance measurement. It should be noted that the temperature inside the scanner may be far above the temperature of the surrounding atmosphere due to internal heating or heating resulting from external radiation (sun).

Atmosphere. Since short distances only are measured, the change of the propagation speed of light due to temperature and pressure variations will not seriously affect the results. Many users report however that measurements in surroundings where dust or steam is present lead to effects similar to the edge effects described above.

Interfering radiation. Lasers operate in a very limited frequency band. Therefore filters can be applied in the receiving unit allowing only this frequency to reach the receiver resp. the camera. If the radiation of the illumination source (sunlight, lamps) is strong as compared to the signal, enough of this ambient radiation will pass the filter and influence the accuracy or prevent any measurements at all.

2.8 Specifications and considerations besides accuracy

This article concentrates on accuracy considerations. Of course, other scanner specifications influence their applicability as well (Boehler, Marbs, 2002). Among these are measuring speed, range limits, field of view, laser class, registration devices for the combination of several scans and the transformation to a control network, the availability of imaging cameras which can work in combination with the scanner, weight and ease of transportation, power supply (battery operation), ruggedness when operated in bad weather or hostile environments, availability and quality of software.

Besides, the quality of the user support and the guarantee conditions are not the same for all producers. These should be checked carefully in addition to the technical specifications before a decision is made to favor one product or another.

3. TESTING INSTALLATIONS AT i3mainz

3.1 General remarks

When the decision was made to start a research program with the aim to compare the accuracy and performance of different types of laser scanners, new testing installations had to be developed. In order to reduce measuring time and expenses, a set of targets was designed using standard materials, and all experiments were installed in two buildings of FH Mainz, University of Applied Sciences. Most experiments can be repeated at any other location provided the same type of targets and surface paints are used.

Since single points of scans cannot be analyzed and compared, ball type targets (white spheres with a diameter of 76.2 mm on a magnetic ground plate as produced by MENSI) are used for most distance determinations. Scanners proposed for a variety of different application tasks should be able to detect and model a sphere of this size. Plane boards are used for experiments concerning range noise and investigations concerning the behavior of surfaces with different reflectivities. Some additional special objects, described below, were constructed for further investigations.

It should be noted that these arrangements do not allow to find the mechanical, optical or electronic sources of errors in the instruments; instead they show the effects of such an error on a certain measurement under practical measurement conditions. When, for example, a short distance between two spheres which are at the same distance from the scanner, is derived after their center points have been modeled from the point clouds, this will give a general indication of the angular accuracy of the scanner but does not really tell everything about the accuracy of the angular position of a single point. Since the same procedures and targets were used for all instruments examined, this provides a reliable method to compare the performance of those instruments under practical application conditions.

On spheres, a point grid of 4 mm spacing was aimed at. If this was not possible, a value as close as possible was chosen. Accordingly, the grid spacing for planes was 5 mm or as close to this value as possible. Tests concerning resolution and edge effects were carried out with 1 mm grids, if possible. All objects were recorded once, using one measurement per point and recording tenths of millimeters (if possible).

Modeling points and spheres was accomplished using least squares adjustment. Known geometric object properties (planarity of planes, diameter of spheres) were introduced as fixed values. Mensi's 3Dipsos software was used after it was verified that it yields the same results for these tasks as other software.

When modeling intermediate planes, points near the edges were manually removed. When spheres were modeled for distance evaluations in range direction, points near the circumference were also removed manually (they were kept, however, when distances orthogonal to range direction were determined). All modeling and computation tasks were carried out by the same person.

3.2 Angular accuracy

Errors in the angles between two rays can be detected when a short distance between two spheres located at equal distances from the scanner is determined. Modeling the spheres will result in a low pass filtering. Therefore the results will not allow detecting small arbitrary angular variations.

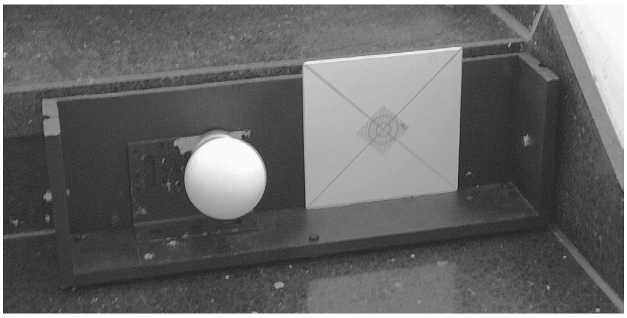

Fig. 1: Box for positioning spheres at defined locations on steps

A first test installation uses white spheres in a box that can be positioned at well defined points on a stone stairway at the end of a 60 m corridor. The box (fig. 1) allows repositioning the spheres within some tenths of millimeters with respect to the stone steps when the tips of six bolts protruding from the bottom and the sides are brought in contact with the stone faces of the steps. Thus, the precise position, acquired with geodetic methods can be re-established any time. The targets are used on either side of six steps at a distance of about 1 m (fig. 2). This allows the calculation of six independent short distances in horizontal and six in vertical direction.

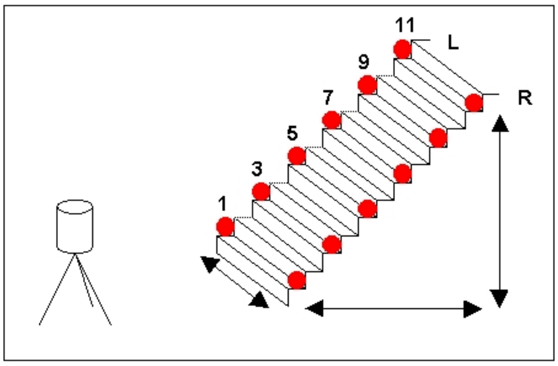

Fig. 2: Sphere positions on stairway

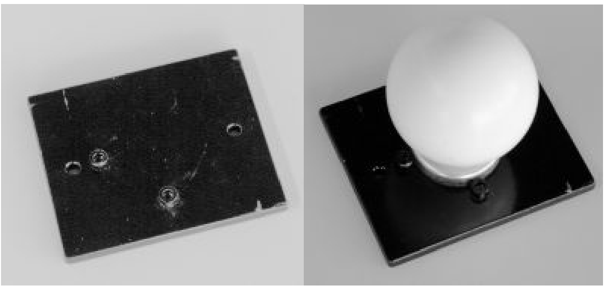

Fig. 3: Steel plate for positioning sphere at a wall

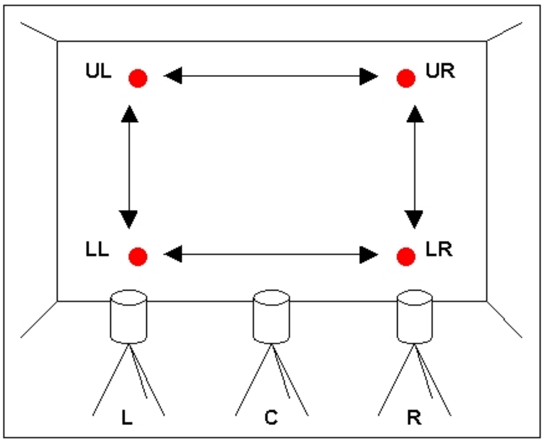

Fig. 4: Location of spheres at a wall and observation stations

In a different room, four spheres are installed at a vertical wall at the corners of a rectangle 3.5 m high and 5 m wide. Since special steel plates with two defined mechanical contacts for the magnetic ground plates of the spheres are used (fig. 3), the spheres can be re-positioned precisely to the original position which was determined by geodetic methods. This arrangement is scanned from a distance of up to 15 m from three observation points as indicated in figure 4. This again yields six independent distances in horizontal and six in vertical direction which can be compared to their calibrated values.

3.3 Range accuracy

Measuring noise. A very simple test to get an indication of the arbitrary deviations of the range measurements can be performed when a plane surface is scanned and modeled. The resulting deviations of the single points are a reliable source of information for the relative accuracy of range measurements. Three different surface paints are used: white, gray and black with reflectivities of about 80, 40 and 8 %.

Known range differences. Three different experiments are installed in order to compare known range differences with the ones measured by the scanners. Spheres were used in either case for the end points of the distances. In the set-up shown in figure 2, where small range differences can be measured from distances up to 60 m, the horizontal components in range direction are used to form six independent distances. In addition, the faces of steel lockers in this long corridor were used to place spheres at well defined known locations thus allowing the comparison of 4 range differences in mid-range. Finally, for close ranges between 3 and 8 m, a sphere is placed on an interferometric comparator and moved to six positions with 1 m spacing, thus providing another 3 independent range differences.

Since all these measurements concern differences in range direction, a systematic constant (zero) error would not be detected. This error will show up in the measurements of longer distances orthogonal to range direction, as the set-up shown in figure 4. Distance deviations in this case would be caused by both, an angular and a constant range error.

3.4 Resolution

Since values for increments and spot sizes in the manufacturer's specifications do not give much indication about the ability of a scanner to reach a certain resolution, a practical approach is chosen in order to achieve resolution information. A box about 300 mm x 300 mm was constructed (fig. 5). The front panel has slots which are about 30 mm wide at the outside becoming smaller towards the center. If a scanner has a high resolution (small angular increments and a small laser spot) there should be reflections not only from the front panel but also from the bottom of the box which is about 55 mm behind the front panel. If the resolution is very good, these reflections from the bottom should not only be present in the outer regions but also near the center. This target can be used to detect resolution information from different ranges.

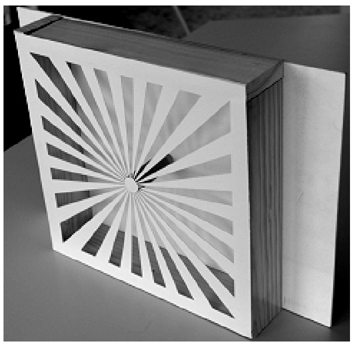

Fig. 5: Target with slots of varying widths for resolution tests.

3.5 Edge effects

Edges. A board (fig. 6) is used to get an indication how many points are recorded at wrong locations due to edge effects. The board is placed against a sky background when scanned. Thus, the measurement of the outer edges will not be influenced by objects behind the board whereas the front edges of the attached smaller board simulate the effect of reflections from two different objects. The evaluation is based on a plot of the resulting point cloud (see fig. 10).

Fig. 6: Board used to study edge effects

Cylinder. A vertical pipe with a diameter of 100 mm is scanned from a distance of 3 m. A cylinder is modeled from the point cloud and its diameter compared to the known value. Also, to visualize the effect, the resulting point cloud is plotted and compared graphically with the known diameter.

3.6 Influence of surface reflectivity

Boards showing a wide white frame and a square center part of different reflectivity (fig. 7) are scanned. Separate planes are modeled through the frame and the center part (excluding points at the edges). The range difference between the two planes indicates the error which has to be expected in similar cases. The following colors and materials are used:

- White dull spray paint, reflectivity 90%
- White dull spray paint, reflectivity 80%
- Gray dull spray paint, reflectivity 40%
- Black dull spray paint, reflectivity 8%
- Spray paint with metallic appearance
- Polished aluminum foil
- Blue retro foil, as used on CYRAX targets

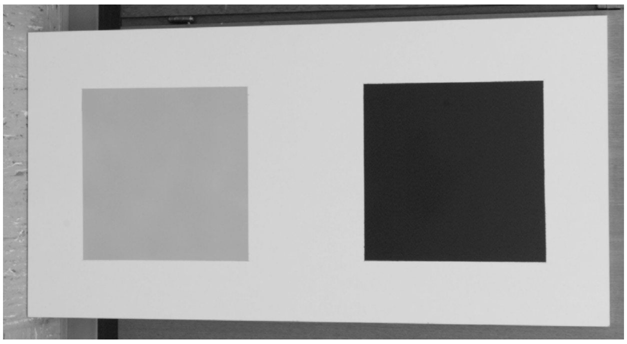

Fig. 7: Board with white frame and different surface coatings

Since large deviations were observed on a rubber traffic cone with orange and white stripes, this object (not a plane) was also added to the test procedure. Similar effects can be observed when range poles coated with “warning” color are scanned.

3.7 Environmental conditions

As mentioned above, there are further conditions that can influence the accuracy of laser scanner measurements. These have to be examined in further investigations.

4. RESULTS

4.1 Important preliminary remarks

Accuracy tests comparing different instruments have to be standardized in some way. We chose the approach to measure objects once with a defined grid spacing. (Alternatively, Considering the fact that some scanners record a much larger number of points in a certain time period, one could also use this time as a standard and allow a certain time period to achieve an object scan. Even more realistic, a relation between accuracy and cost could be used, considering different purchase and operating costs in addition.)

The following results were achieved solving certain tasks under certain preconditions as described above.

IF A SCANNER SHOWS “BETTER” RESULTS THAN ANOTHER ONE, THIS DOES NOT NECESSARILY MEAN THAT IT IS THE BETTER INSTRUMENT FOR A CERTAIN TASK DIFFERENT FROM THE ONES PERFORMED IN OUR TESTS.

For example, the fine grids of 4 resp. 5 mm could not be achieved with some instruments, therefore the results in our tests look poor, although these instruments would be perfectly suitable for certain other tasks (see also sections 2.8 and 4.8).

For the tests we selected all laser scanners (working either on the time-of-flight or triangulation principle) that are able to record points at a 10 m range and claim to be applicable for different scanning tasks. According to the list supplied by our web site (WWW, 2003) this comprises about one dozen different instruments. Manufacturers and users were asked to co-operate in the tests. We are very grateful that many gave us the opportunity to test their instruments and others promised to co-operate in the near future. The following list shows the instruments tested so far. Updates will be published on this WEB site.

Manufacturer	Type	already tested
Callidus Precision Systems	Callidus	2(u)
Cyra Technologies	Cyrax 2500[a]	1(o),1(m)
Mensi	S25	1(o)
Mensi	GS100	1(m)
Riegl	LMS-Z210	1(u)
Riegl	LMS-Z420i	1(m)
Zoller+Fröhlich	Imager 5003[b]	1(m)
Total Number		9

Table 1: Scanners in the tests (o = owned by i3mainz, m = instrument made available by manufacturer, u = by user)
[a] now referred to as Leica HDS 2500
[b] identical in construction: Leica HDS 4500

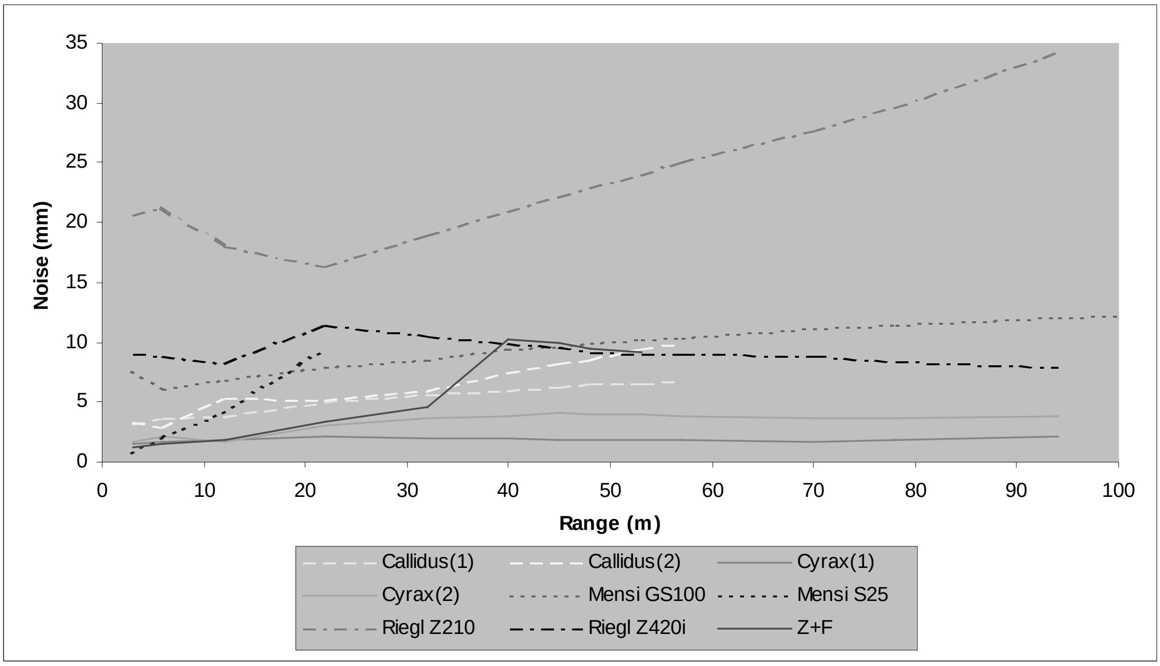

Fig. 8: Measuring noise in range direction (std. dev. for a single point) for different scanners on gray surface (40% reflectivity).

4.2 Distances orthogonal to range

Manufacturer	Type	vert. dist.	horiz. dist.	max. diff.
Callidus Precision Syst.	Callidus (1)	5.6[a]	4.3[a]	12,2[a]
Callidus Precision Syst.	Callidus (2)	9.9[a]	2.5[a]	18.3[a]
Cyra Technologies	Cyrax2500 (1)	0.8	0.8	1.6
Cyra Technologies	Cyrax2500 (2)	0.5	0.5	1.1
Mensi	S25	3.8[b]	3.4[b]	9.2[b]
Mensi	GS100	1.9	2.3	3.3
Riegl	LMS-Z210	10.2[a]	16.8[a]	27.1[a]
Riegl	LMS-Z420i	1.7	2.1	4.1
Zoller+Fröhlich	Imager 5003	2.9	7.5	11.1

Table 2: Standard deviations (mm) of at least 12 independent vertical and 12 independent horizontal distances (orthogonal to range) between two spheres.

[a] Because of coarse grid tested for short ranges only!

[b] Influenced by low range accuracy due to triangulation principle at far range. Much better for close ranges (e.g. 0.8 mm vert. and 0.2 mm horiz. at 4 m range)

4.3 Distances in range direction

Manufacturer	Type	close <10m	far 10-50m	max. diff.
Callidus Precision Syst.	Callidus (1)	1.5	- [a]	2.6
Callidus Precision Syst.	Callidus (2)	2.8	- [a]	5.9
Cyra Technologies	Cyrax2500 (1)	0.6	1.1	2.3
Cyra Technologies	Cyrax2500 (2)	0.4	0.5	0.9
Mensi	S25	1.4[b]	4.6[c]	7.7[c]
Mensi	GS 100	2.6	2.0	8.2
Riegl	LMS-Z210	19.7	- [a]	40.4
Riegl	LMS-Z420i	2.6	2.7[d]	5.9
Zoller+Fröhlich	Imager 5003	1.6	0.7[e]	12.3

Table 3: Difference between known and scanned distance differences in range direction. Std. dev. (mm) of at least 12 independent short distances between two spheres in close range and 14 independent short distances in far range.

[a] Modeling of spheres not possible for far ranges due to coarse grid .

[b] But 0.2 mm at 4 m range, 0.5 mm at 6 m range. [c] At 22m range

[d] only 4 measurements at far range [e] only 2 measurements

4.4 Resolution

Scanning results of the target shown in figure 5 give a good indication of the resolution that can be achieved. The resulting point clouds for different scanners are shown in figure 9.

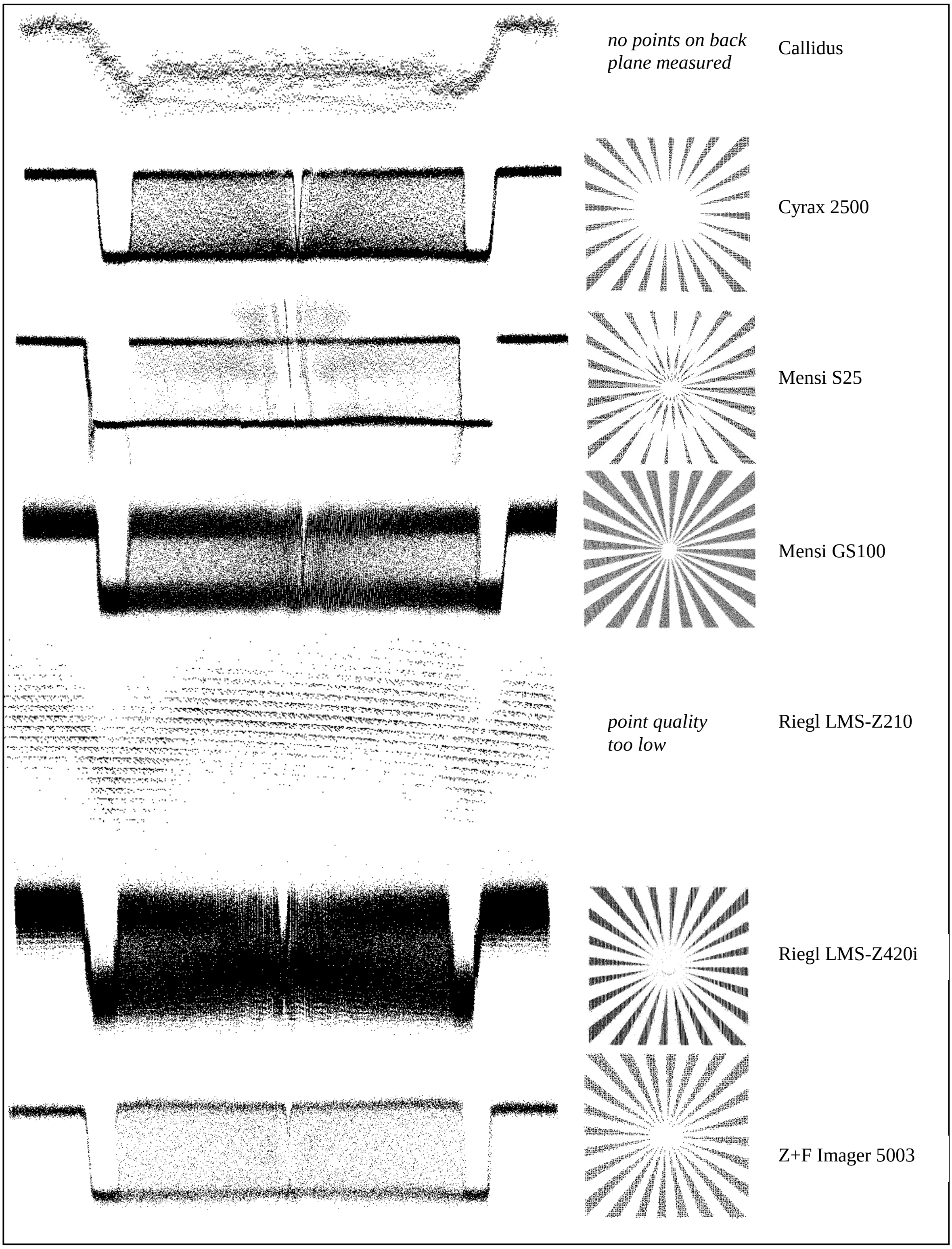

Figure 9a: Results of the resolution test using the target shown in figure 5. Scanned at 6m range. Left: Cross section of point cloud. Right: Points on back plane of target (in smaller scale).

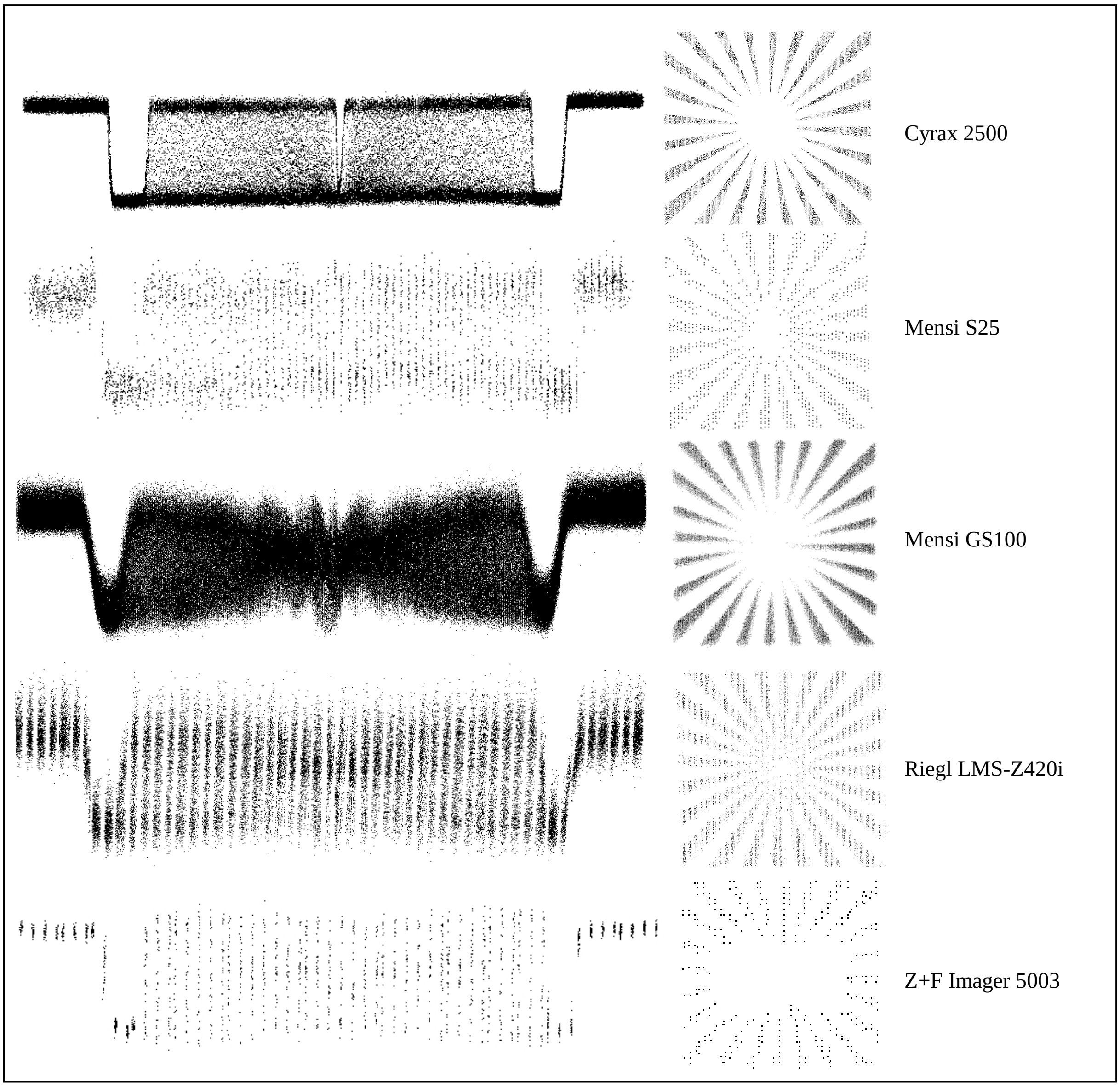

Figure 9b: Results of the resolution test using the target shown in figure 5. Scanned at 22m range.
Left: Cross section of point cloud. Right: Points on back plane of target (in smaller scale).
The point increments for the Callidus and the Riegl LMS-Z210 were too large to resolve the object at this distance.

4.5 Edge effects

Edges. Results for edge detection shown in table 4. Typical examples are shown below. Edge quality can also be judged from the results shown in figure 9.

Manufacturer	Type	Edge quality
Callidus Prec. Syst.	Callidus	low
Cyra Technologies	Cyrax2500	average
Mensi	S25	average
Mensi	GS 100	average
Riegl	LMS-Z210	low
Riegl	LMS-Z420i	average
Zoller+Fröhlich	Imager 5003	low

Table 4: Evaluation of edge quality.

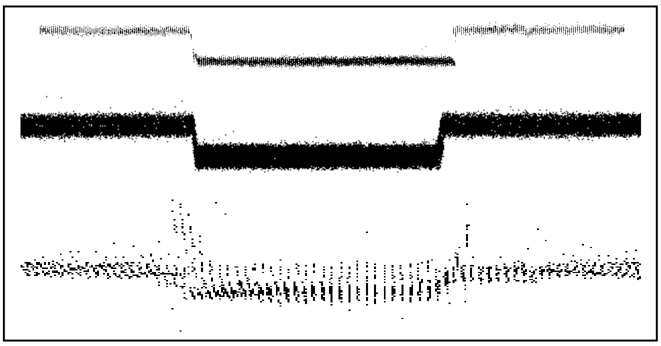

Fig. 10: Typical examples for edge quality (see fig. 6).
Upper: High quality (not achieved with any scanner).
Center: average quality. Lower: low quality.

4.6 Influence of surface reflectivity

The results of the experiments described in section 3.6 are shown in table 5.

Type	white 90%	white 80%	gray 40%	black 8%	metal paint	alu foil	blue foil	orange cone
Callidus(1)	0	0	0	0	0	0..-100	+7	-10
Callidus(2)	0	0	+4	+3	0..-10	0..-15	+5	-20
Cyrax (1)	0	0	0	0	0	0..+10	+22	-40
Cyrax (2)	0	0	0	0	0	0	+17	-70
S25	0	0	0	0	0	0	0	0
GS 100	0	0	0	+8	0	0	n.a.[a]	0
Riegl Z210	0	0	+13	+3	0..-100	0..-250	0	-100
Riegl Z420	0	0	0	0	0	0	0	-20
Z+F	0	0	0	0	0	0..+30	-18m	-20

Table 5: Distance correction in mm due to different surface materials. Positive sign = Distance is measured too short as compared to white surface.

[a] Scanner did not record any points on this surface

4.7 Environmental conditions

All tests were conducted under favorable conditions, predominantly inside of buildings.

4.8 Specifications and considerations besides accuracy

As pointed out in sections 2.8 and 4.1, accuracy is not the only fact that should be considered when choosing between different laser scanners. Selling prices are important, too, and may depend on different specifications. Support and warranty conditions differ considerably! It should be checked how often the instrument has to be calibrated, where this has to be accomplished, how long this will take and what kind of expenses (service contracts, transportation, fees) this will cause for the user.

The quality of the included scanning software has to be considered, and it should be decided if modeling software has to be purchased separately from other companies (Boehler, Heinz, Marbs, Siebold, 2002).

In the following tables the authors report some major advantages and disadvantages of scanners. This is based on many reports from users, experience and subjective impressions and not on systematic research.

Type	
Callidus	Very large field of view.
Cyrax2500	Good accuracy.
S25	Very high accuracy for short ranges.
GS100	Large field of view.
Riegl Z210	High ranges possible. Large field of view
Riegl Z420i	Very high ranges possible. Large field of view
Z+F	Very high scanning speed. Large field of view

Table 6. Major advantages of some laser scanners.

Type	
Callidus	Very coarse vertical resolution (0.25°)
Cyrax2500	Small scanning window (40° x 40°)
S25	Does not work in sunlight. Not suited for long ranges.
GS 100	Large noise.
Riegl Z210	Low accuracy.
Riegl Z420i	Large noise
Z+F	Low edge quality.Limited angular resolution (0.018°)

Table 7. Major disadvantages of some laser scanners.

5. CONCLUSIONS

Laser scanners show considerable errors under certain conditions. Even when accuracy is not of much importance in certain applications, the resulting strain between neighboring points can be cumbersome when surfaces have to be modeled or when small details have to be detected. The results of our tests may help the producers to compare the performance of their instruments to those of their competitors. For the users, this publication and the associated web site (WWW 2003) may help to select the appropriate instruments for their projects.

6. OUTLOOK

With the targets installed at FH Mainz, the authors are trying to test as many types of scanners as possible. Users and manufacturers are invited to have their instruments tested. Details about booking and fees can be found in the Internet (WWW, 2003).

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8. REFERENCES

Balzani, M., Pellegrinelli, A., Perfetti, N., Uccelli, F., 2001: A terrestrial 3D laser scanner: Accuracy tests. Proc. 18th Int. Symp. CIPA 2001, pp. 445-453.

Boehler, W., Heinz, G., Marbs, A., Siebold, M., 2002: 3D scanning software: an introduction. Proc. of the CIPA WG6 Int. Workshop on scanning for cultural heritage recording. http://www.isprs.org/commission5/workshop/

Boehler, W., Marbs, A., 2002: 3D Scanning instruments. Proc. of the CIPA WG6 Int. Workshop on scanning for cultural heritage recording. http://www.isprs.org/commission5/workshop/

Johansson, M., 2002: Explorations into the behavior of three different high-resolution ground-based laser scanners in the built environment. Proc. of the CIPA WG6 Int. Workshop on scanning for cultural heritage recording. http://www.isprs.org/commission5/workshop/

Kern, F., 2003: Automatisierte Modellierung von Bauwerksgeometrien aus 3D-Laserscannerdaten. Geodätische Schriftenreihe der Technischen Universität Braunschweig, Nr. 19, ISBN 3-926146-14-1

Lichti, D.D., Stewart, M.P., Tsakiri, M., Snow, A.J., 2000: Calibration and testing of a terrestrial laser scanner. Int. Arch. of Photogrammetry and Remote Sensing, Vol. XXXIII, Part B5, pp. 485-492.

Lichti, D.D., Gordon, S.J., Stewart, M.P., Franke, J., Tsakiri, M., 2002: Comparison of digital photogrammetry and laser scanning. Proc. of the CIPA WG6 Int. Workshop on scanning for cultural heritage recording. http://www.isprs.org/commission5/workshop/

VDI/VDE Guideline , 2002: Optical 3-D measuring systems /Optical systems based on area scanning. Beuth Verlag GmbH Berlin.

WWW, 2003: http://scanning.fh-mainz.de