Testing and Verification of the Accuracy of 3D Laser Scanning Data

Chris Tucker
The Focus Corporation Ltd. Calgary, Canada

ABSTRACT

Accurate representation of existing facilities with ornate or elaborate fixtures is limited by the amount of labour required in conventional surveying data collection techniques. Three dimensional laser scanning may replace the use of conventional surveying practices by faster and more complete data collection in some instances. The completeness of the data coupled with the reduced time in the field can revolutionize survey data collection and rendering in many areas such as deformation analysis, as builts, volume determinations and architectural and heritage recordings.

A laser scanner is a pulsed laser ranging system coupled with mirrors to facilitate beam deflection. Cyrax 2500 laser scanners were tested within The Focus Corporation to investigate the accuracy of the system. Cyrax performance will be tested in a close range application to verify the accuracy at extremes of mirror deflection as well as range data collection within specifications. The data compared will be the coordinates of survey control to the coordinates of targets determined by Cyra's Cyclone software. Cyra Technologies Inc. produces the laser scanner, which is a wholly owned subsidiary of Leica Geosystems.

Key Words: Cyrax 2500, accuracy, Cyclone

1. INTRODUCTION

Terrestrial three dimensional laser scanners show great potential in may areas including industrial metrology, deformation analysis and heritage recording. When compared to conventional survey techniques, unprecedented amounts of positional data can be collected to aid photogrammetrists, engineers and surveyors. The Focus Corporation is a Canadian based consulting firm providing engineering, geomatics and related services to clients involved in resource, infrastructure, environmental and land development projects worldwide. As a result, laser scanning has provided Focus with a new and more complete technique of data collection. With that in mind, Focus wished to test the Cyrax scanner to verify the accuracy claims of Cyra Technologies. The claim is, by Cyra, the positional accuracy of a single point is ±6mm at 1.5 to 50 metre range.(1σ) Distance accuracy is reported to be ±4mm over the same range.(1σ) (For clarification, Cyra is the company and Cyrax is the scanner model.)

Focus tested the Cyrax 2500 in two different experiments. The first experiment was at close range (3-5m) with circular Cyra targets located on a wall. The intended purpose of this experiment was to confirm the accuracy of the scanner at the extremes of the data collection field of view. The second experiment was to test the accuracy of the scanner at almost the entire distance of Cyra specifications. In this experiment, the scanner was tested at ranges from 9 to 43 metres. Ten targets were used in both experiments.

The Cyra targets are approximately 15cm in diameter and at the centre of the target is an extremely reflective material approximately 2mm in diameter. These targets are designed specifically for use with the Cyrax system. During data collection and after manual location of the targets in the scan data, the firmware will determine the reflective centre area of the target and collect high density scans to create the vertex of the target for bundling the scans together. The term used by Cyra for the bundling is Registration.

Prior to the scanning of the targets, surveys were conducted using a Leica TCR-305 reflectorless total station to determine the coordinates of the targets in both experiments. In addition, a prism constant was determined for the total station when shooting Cyra's targets.

2. Cyrax Scanner

The scanner unit consists of a enclosed case 40cm x34cm x 43cm and weighs approximately 20.5 kilograms. It may be tripod mounted or stand alone base mount during operation. The system may be single person operated but is certainly a great deal less strenuous when operated by a two person crew.

The radiation is an eye safe, green light, pulsed laser with a 40° by 40° field of view. Two mirrors in the case manage the horizontal and vertical movement of the laser light. The collected data is presented in real time to a laptop via a network cross over cable. A digital video image of the scan area is collected prior to the scan and upon this image the operator can select a scanning window of any rectangular size. The operator can also determine the spot density of the laser at a given distance.

3. Determination of "Prism Constant" for Cyra Targets

Prior to the control survey, a prism constant for distance measurement of the total station to the Cyra targets was calculated. The constant was determined with 3 stations set in line at the same level. The distances were shot from all stations using the Cyra targets and Leica prisms. Measurements to the Cyra targets were shot twice. During the first set of measurements the Cyra target prism constant was set to 0mm. The Leica prisms have a known constant of 0mm. The measured distances are shown in Table 1.

Table 1 Determination of Prism Constant

Distance (station to station)	Leica Prism (m)	Cyra Target (m)
1 – 2	15.599	15.570
2 - 3	12.139	12.109
1 - 3	27.737	27.705
Sum of two distances	27.738	27.679

When measuring with the Leica prism, the sum of the two distances (1-2 and 2-3) is within 1mm of the distance measured from station 1 to 3. The difference of the distances from stations 1-3, shot with the targets and shot with the Leica prism, should show the prism constant. This distance differs by 32mm. By setting the instrument at the centre station (station 2) and measuring to stations 1 and 3, the sum of the measurements using the Cyra targets should show twice the prism constant. The difference is 59mm and when divided by two, the accepted offset in this configuration to be 30mm. The initial single measurement determined an offset of 32mm. The average of 31mm was used for the prism constant during the experiments when measuring distance to the Cyra targets. The distances were than shot again to confirm the calculated prism constant. The final distance shot from station 1 to station 3 using Cyra targets and a prism constant of 31 mm was precise to the millimetre when compared to the distance originally shot with Leica prisms.

4. Methodology

The two experiments were each completed in two phases. The first phase was the survey of the target locations. Three stations were set up to survey the location for each experiment. At each of these stations, when not occupied by the instrument, a Leica prism was set up and the location of the control station was surveyed as well. All the target locations were measured from each station with the final coordinates and error ellipses determined for each target. Data was collected to a Topcon Ranger and the data collection software was rtSeek created by Grove Custom Solutions Inc. All tests took place inside an office building so there would have been no wind and a constant temperature of 21°C.

Phase two of the experiment is to scan the targets and incorporate the scan data with the control data. During scan data collection, a coarse scan is taken of the field of interest to determine if the field of view of the scanner is sufficient. If some of the selected area is not in the scan data, the operator then adjusts the equipment to capture the desired area and collects another coarse scan. On a couple of occasions the coarse scan revealed that some of the targets did not make it into the scan data. This is why the scans are not numbered in order on the test data. Each of the experiments entailed scanning of all the targets from three locations. The only exception to this is Target 1 was missed on one scan on the close range wall test. After the scan data was collected it was bundled together or registered. The final step was to import the final coordinates from the surveyed control into Cyclone 3.1 software.

Cyclone is Cyra's software that allows for data collection, registration, modelling and rendering, as well as export functions. By importing the control coordinates we can transform the Cyra targets into the control coordinate system. All constraints were default to unity and no weighting took place in any registration. The target recognition and vertex location was completed automatically in Cyclone software. There was no manual manipulation of any data so all comparisons are based solely on the solutions determined from Cyclone.

5. Field of View Survey "The Wall"

The first test was to set up the scanner in ranges from 3.2 to 5.8 metres from a wall with ten targets placed on the wall from ceiling to floor. Three scans were collected, one on each side or the array of targets at oblique angles and one scan was set straight on the array. Three control points were also created to survey the locations of the targets and create a strong network to determine the target locations. The scanner collection points were not the same point as the control points. A photo of the set up of the scanner, control points and target locations is seen in Figure 1.

Figure 1: Set-up for Scans of the Wall

After the survey of the control targets the data was processed using proprietary software. Error ellipses were created to display the quality of the survey solution. The coordinates and error ellipses information (95% confidence) for each point is tabulated below. Observations for adjustment included directions, zenith angles and slope distances producing 99 observations with 33 unknowns. The variance factor from the adjustment was 1.01. During the adjustment Target 1 on the wall and Pt. 13, a control point, were constrained.

Table 2: Control Coordinates and Error Ellipse Parameters

Station	Northing (m)	Easting (m)	Elevation (m)	Semi-Major (mm)	Semi-Minor (mm)	Azimuth Semi-Major (GON)	Height Error (mm)
1	500.000	804.986	11.142	Fixed	Fixed		
2	500.927	804.023	11.149	0.70	0.51	80	0.43
3	502.045	802.865	11.158	0.59	0.43	82	0.36
4	500.005	804.985	10.391	0.66	0.42	94	0.34
5	502.054	802.859	10.447	0.60	0.42	94	0.34
6	500.010	804.980	9.733	0.66	0.42	305	0.34
7	502.064	802.851	9.811	0.60	0.42	303	0.34
8	499.950	805.039	8.528	0.66	0.43	324	0.37
9	500.900	804.058	8.528	0.62	0.43	325	0.37
10	502.058	802.858	8.530	0.59	0.44	325	0.37

It is readily apparent the internal accuracy of the control survey is satisfactory to compare the coordinates of the targets determined by the scanner to the coordinates determined from the conventional survey.

During the three scans, the maximum amount of travel in the mirrors to acquire data from the targets was 43.04° horizontally and 37.32° vertically. It seems operations can occur outside of the product specification of 40° by 40° field of view by setting the targets at the extremities of the field of view. When the fine scan data is collected to define the position of the target for registration, the Cyrax will take the operators input position and scan an enlarged area around the input point. The two targets that were scanned at 43.04° horizontally separated are Targets 8 and 10, Scan 3. Table 3 shows all misclosures of the Cyclone derived targets compared to the control targets.

Table 3: Misclosure of Cyclone created Target Coordinates to Control

TargetID	Scan #	Misclosure (m)	TargetID	Scan #	Misclosure (m)
1	2	0.001	6	2	0.001
1	5	0.001	6	3	0.001
2	2	0.002	6	5	0.001
2	3	0.001	7	2	0.001
2	5	0.001	7	3	0.001
3	2	0.001	7	5	0.000
3	3	0.001	8	2	0.001
3	5	0.001	8	3	0.001
4	2	0.001	8	5	0.001
4	3	0.001	9	2	0.001
4	5	0.001	9	3	0.002
5	2	0.001	9	5	0.001
5	3	0.000	10	2	0.002
5	5	0.001	10	3	0.001
			10	5	0.001

Five scans were acquired with only three scans used in the final analysis. Scans 1 and 4 missed some of the targets so were not used. The final stage was to insert the control coordinates into the Cyclone software to compare the misclosure of all the targets to control from three individual scans. The Cyclone software is reported not to create a scale factor during any transformations or registrations. The completed exercise shows the operation of the scanner is capable of keeping accurate coordinates of collected data outside the specified field of view but also provides insight into the repeatability of the scan data from different set ups at short ranges. The RMS of the misclosures to all targets is 1.1mm.

6. Range Survey

The second experiment consisted of setting up the scanner at one end of an empty office space and scanning the entire length of the open area. The maximum distance from measured from scanner to target was 42.9 metres, which is less than the specified maximum range of 50 metres.

Again the control targets were surveyed prior to scan data being collected. The survey observations consisted direction, zenith angle and slope distance for a total of 102 observations and 33 unknowns. The variance factor after adjustment was 0.722. Target 3 was held this time in the adjustment and the parameters of the error ellipses are shown at the 95% confidence interval in Table 4.

Table 4: Control Coordinates and Error Ellipse Parameters

Station	Northing (m)	Easting (m)	Elevation (m)	Semi-Major (mm)	Semi-Minor (mm)	Azimuth Semi-Major (GON)	Height Error (mm)
1	500.000	806.536	9.875	0.99	0.59	30	0.43
2	513.940	823.538	10.287	0.97	0.61	17	0.45
3	519.633	826.655	10.430	Fixed	Fixed		
4	520.490	825.828	10.398	1.00	0.73	47	0.51
5	521.378	824.970	10.429	1.00	0.73	54	0.51
6	522.157	824.224	10.443	0.99	0.73	59	0.51
7	520.681	820.508	10.384	0.98	0.66	73	0.48
8	520.692	820.501	9.723	0.98	0.66	74	0.48
9	518.068	820.032	8.447	0.95	0.60	68	0.47
10	503.765	802.918	9.809	1.06	0.61	90	0.43

The targets were at ranges from 9 to about 43 metres from the scanner. Targets 1 and 10 were closest to the scanner with the longest range from the scanner to targets being to Targets 3 through 6. For the comparison of distances, the surveyed control distances from Targets 1 and 10 to Targets 2,3,4,5,6 and 9 are compared to the distances determined by the scanner. Targets 7&8 are at mid range and are not included in the comparison. In hindsight, a few targets should have been placed near the scanners minimum range and have a few targets at the scanners maximum range to verify the range accuracy over the complete product specification.

Table 5: Range Comparison of Control and Scans

From Target	To Target	Control Range (m)	Scan 2 (m)	Scan 3 (m)	Scan 4 (m)	RMS (m)
1	2	21.989	21.990	21.990	21.989	
			-0.001	-0.001	0.000	0.001
1	3	28.116	28.120	28.118	28.120	
			-0.004	-0.002	-0.004	0.004
1	4	28.147	28.152	28.150	28.152	
			-0.005	-0.003	-0.005	0.004
1	5	28.233	28.237	28.235	28.237	
			-0.004	-0.002	-0.004	0.003
1	6	28.357	28.360	28.359	28.360	
			-0.003	-0.002	-0.003	0.003
1	9	22.597	22.598	22.595	22.599	
			-0.001	0.002	-0.002	0.002
10	2	22.998	23.001	23.000	22.999	
			-0.003	-0.002	-0.001	0.002
10	3	28.559	28.564	28.561	28.563	
			-0.005	-0.002	-0.004	0.004
10	4	28.371	28.376	28.374	28.377	
			-0.005	-0.003	-0.006	0.004
10	5	28.229	28.234	28.231	28.234	
			-0.005	-0.002	-0.005	0.004
10	6	28.153	28.158	28.156	28.157	
			-0.005	-0.003	-0.004	0.004
10	9	22.345	22.347	22.344	22.349	
			-0.002	0.001	-0.004	0.003
		RMS (m)	0.004	0.002	0.004	

The RMS is shown with respect to the measurements from each scan and measurements to the selected targets from the three scans. (i.e. target-wise and scan-wise) If one looks at the RMS scan-wise(the lowest line in the table), Scan 3 has a slightly better RMS than Scans 2 and 4. One possible explanation for this is Scans 2 and 4 are more oblique to the targets than scan 3. This may have given rise to some error in the target analysis during the scanning.

Also we see the RMS smaller on the two shorter ranges. (Targets 1 and 10 to Targets 2 and 9) Keeping in mind error ellipses of about a millimetre, one cannot say if the range falls in or out of product specification on some measurements. The product specifications for the Cyrax 2500 in distance measurements are ±4mm.

7. Conclusions

The two tests gave little concern about the stated accuracy of the Cyrax 2500 scanning system and Cyclone software. The first test to measure the accuracy of the scanner at the extremes of mirror movement found the system to perform much better that the Cyra performance specifications. Cyra states accuracy of ±6mm at 1.5 to 50 metre range.(1σ) The RMS for the survey of 29 targets at ranges of about 3 to 6 metres, in three separate scans with mirror rotations by as much as 7.6% beyond performance specifications was 1.1mm.

The second test was to compare the distance measurements of the scanner to those of known control. The error ellipses determined form the control data showed uncertainties up to one millimetre. The RMS of some measurements determined from scan data was four millimetres, which is product specified performance. Statistically, it is difficult to determine if the distance measurements are within performance specifications. However, it is not an over simplification to state the system is very close. Other sources of error may be an improper determination for the prism constant when using the Cyra targets with a reflectorless total station.

Operations of the system are purported to be a one person crew. The weight of the scanner and power supply coupled with the large cases for protection of the system while being transported, would make it difficult for one person to do all tasks required in this type of survey. On large scale surveys, such as processing plants or large earth works, it is time consuming for one person to confirm intervisibility from targets to scanner and ensure enough targets are in view from all pre-planned scan positions. Also, if the scans were required to be tied to a control grid, it would not be cost effective to have the scanner sitting while survey control is brought in. Experience has already shown that for most applications laser scanning data collection is not a single operator task.

The Cyrax 2500 used for these tests is a demonstration unit and was not “right off the line”. Prior to the last calibration the authors are aware of this system flying twice across Canada and riding in the back of a truck from Edmonton to Calgary, return, in –30° C weather.

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