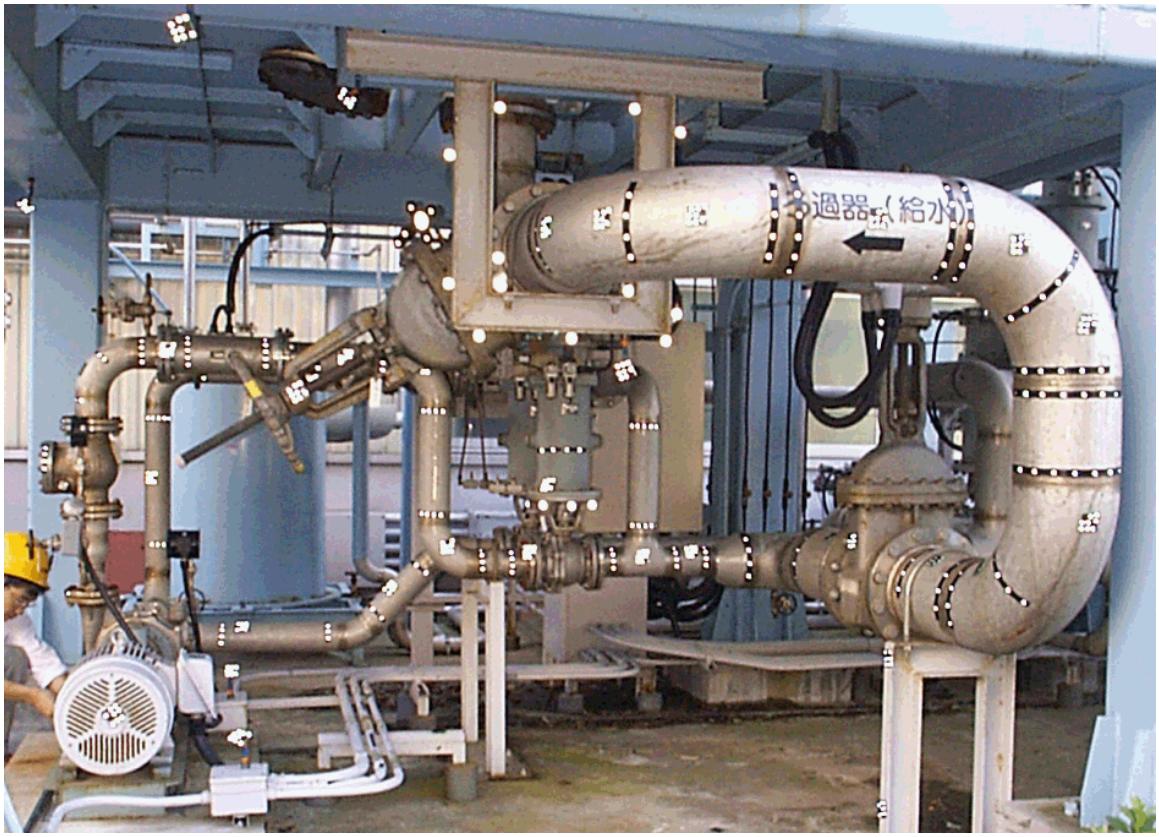
Geodetic Services Inc.

Report of Suitability of V-STARS for Pipe Measurement.

Introduction:

The following report is a summary of the V-STARS work carried out at the XXXX facility in XXXX. The objective was to measure the location and size of various pipes in an enclosed volume. This was done as part of an evaluation study on the suitability of V-STARS for use in pipe location and dimensional control. The volume in question had approximate dimensions of (3 x 3 x 2.5m). An image of the pipe volume is shown below:-



Primary Requirements:

- To trace the centerline position of the pipes contained within the defined volume.
- To determine the location of other features such as pipe supports.
- To determine the height of a key feature. (Feature shown in adjacent image)

Documentation:

The following documentation is included in this report.

- A report outlining methodology and results.
- The XYZ coordinates of the determined centre points for each of the pipe sections.
- The height of the key feature.
- Images showing target labels and positions.
- Pipe trace diagrams.
- Background information on the V-STARS system (Also refer to Appendix 3)

Itinerary:

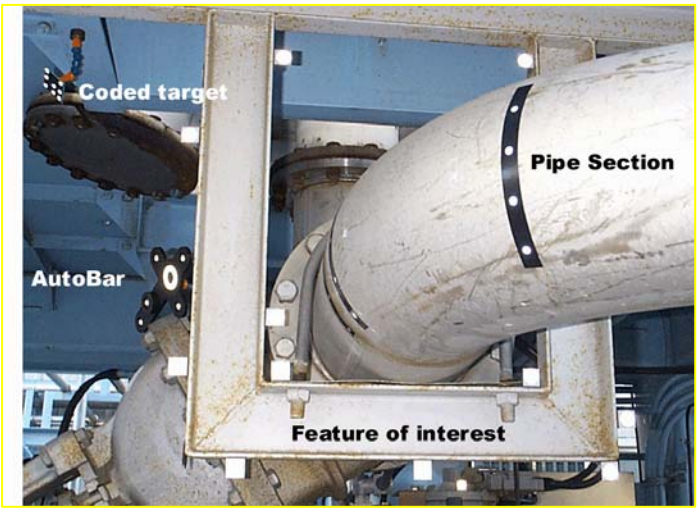
The itinerary undertaken was as follows: -

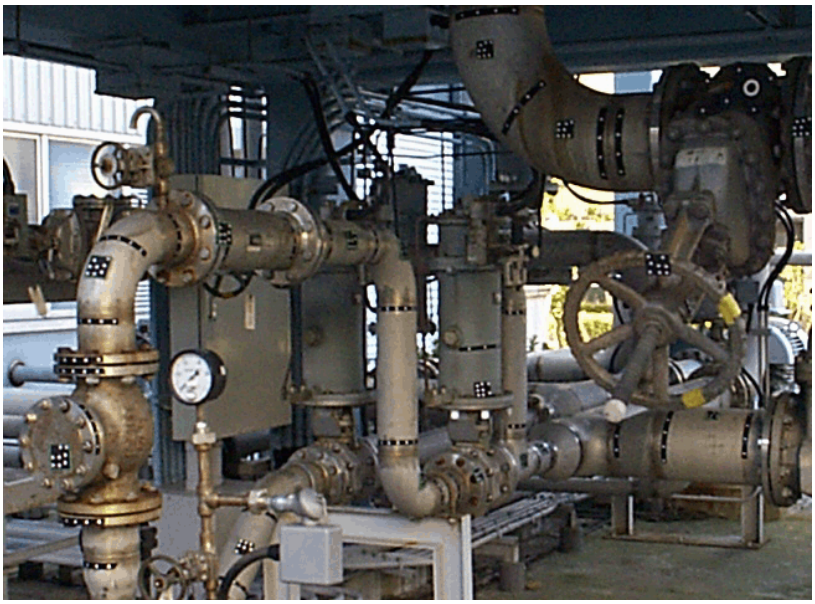
Wednesday	*9th September*
Afternoon	Introduction to V-STARS system.
Afternoon	Measurement of pipe volume (Targeting, photography and processing)
Mid-Afternoon	Measurement discussion

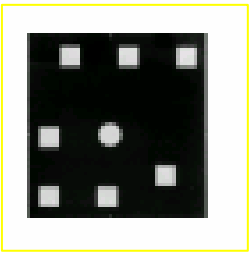
Measurement Procedure:

Targeting.

The key objective of this test measurement was to the trace the path of a number of pipes in the defined volume. To complete this objective it was necessary to place strip tape targets along cross sectional areas of the pipe. This information would then be used to compute a best fit circle and hence a centre point. One of these areas is shown in the adjacent diagram. The diagram also shows one of the key features, a coded target and the AutoBar. Targeting of the pipes and other areas of interest consumed approximately 30 minutes.

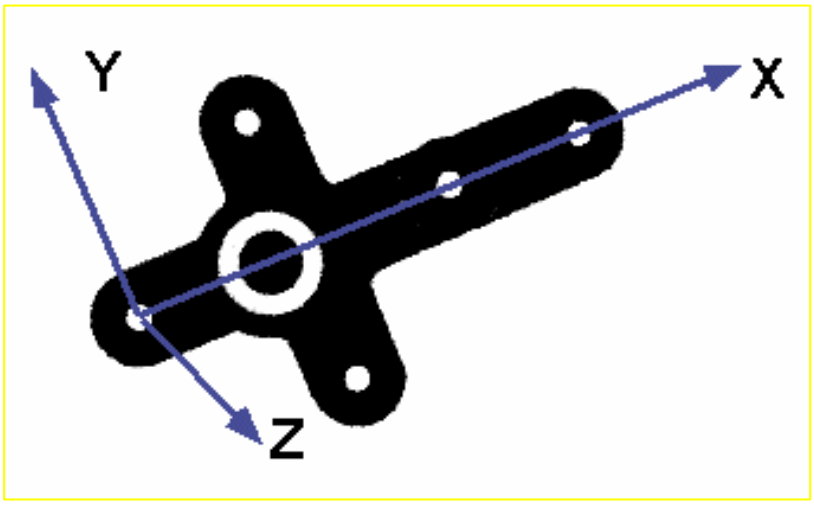






To automate the measurement process it was necessary to add “coded” targets to the pipes and surrounding volume. These targets are automatically detected and help the software determine the location and orientation of the camera at the time the photo was taken. They also help tie the entire object into a uniform coordinate system. The codes were placed in sequential order along the length of the pipes to make it easier to determine an approximate path.

The initial coordinates system and scale is determined via the AutoBar. The AutoBar used by the V-STARS system is a fixture with five targets arranged in the form of a cross. The target's known coordinates are used by the AutoMatch procedure to determine the camera's orientation relative to the AutoBar. The AutoBar is securely attached on or near the measured object, preferably in a highly visible location. The AutoBar's default coordinate system has its origin at Target 1 at the bottom of the AutoBar. The positive Y-axis goes through Target 3 at the top of the bar. The positive Z-axis is up out of the AutoBar. The diagram on the left shows both the AutoBar and its coordinate system



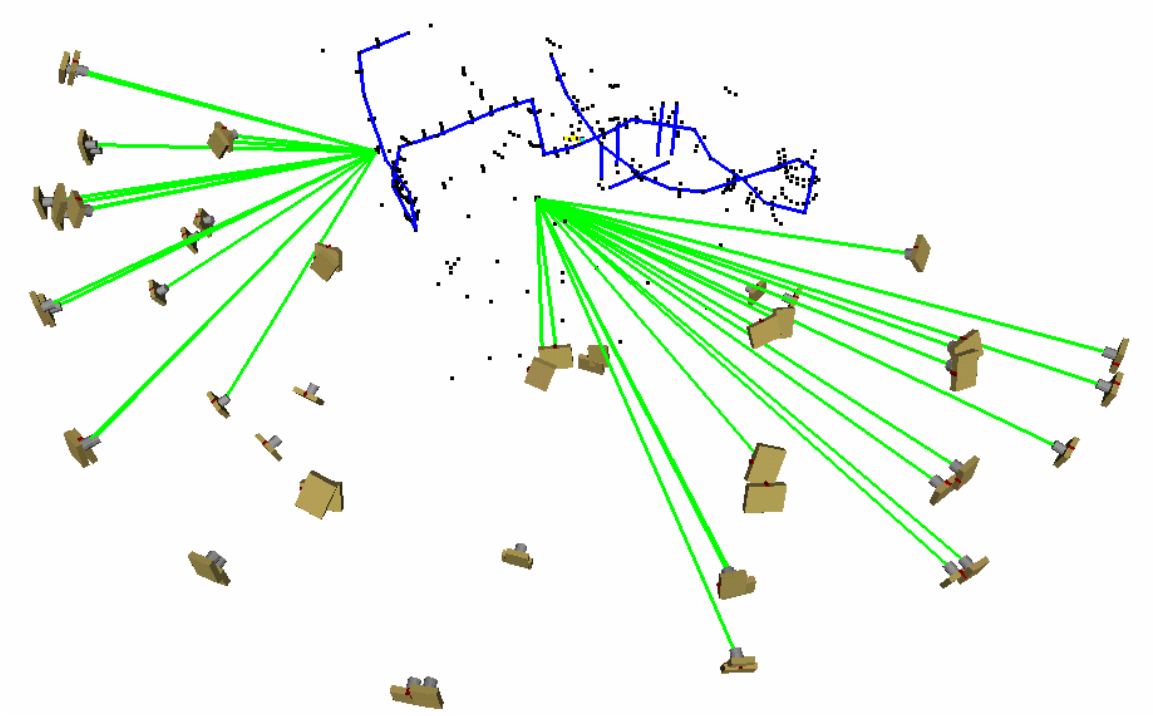
Photogrammetric measurements are initially dimensionless. An example of this is shown below. The picture of the first car could be a picture of a full-size car or of a match box model; there is no way to tell. However, if we know the size of something that is also in the picture, we can now say something about the size of the car.

To scale a photogrammetric measurement, there must be at least one known distance. Two scale distances were used in the pipe measurement. These distances came from a calibrated scale bar.

Photography

Once the object targeting was completed the object was photographed. Put simply, the aim of the photography is to record each of the targeted points in as many images as possible from as wide a range of angles as possible.

To improve the accuracy of the survey photos were taken both close to the ground and from a stepladder. The photography was completed in approximately 5 minutes. The camera station locations for the measurement are shown in the diagram below. Also shown are some sample intersection angles to points of interest.

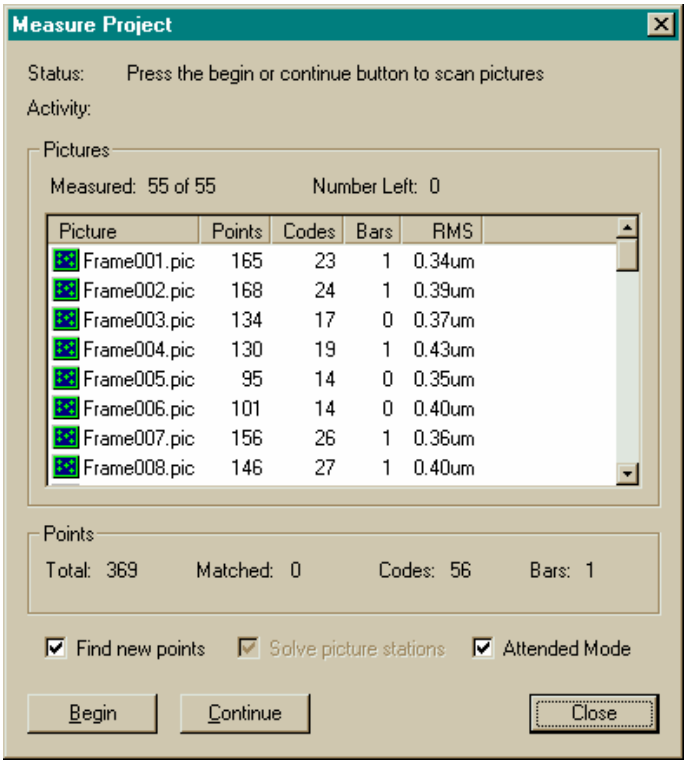


Approximately 55 photographs were taken of the work volume. With planning this number can be reduced to approximately 40 depending on the complexity of the measurement and accuracy requirements.

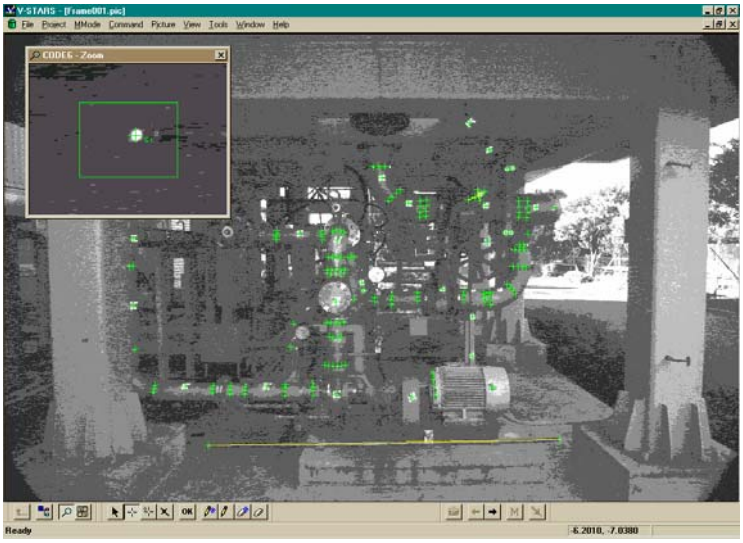
Processing

Once the photography was completed the images were transferred to the system laptop. The images are stored on a PCMCIA hard drive and V-STARS accesses these images directly from the drive.

Almost all of the measurement process is automated. The images are processed and the coordinates extracted by the "AutoMeasure" command. The AutoMeasure dialog box is shown on the right. The AutoMeasure command will open each of the images, determine the camera location, find new target points and finally adjust all the measurements in the "Bundle Adjustment". At the conclusion the user is left with the XYZ coordinates for all the target points in the network. The AutoMeasure procedure is very powerful as it allows the user to continue working while it processes the data. It also means that relatively unskilled workers can be used to process the data.

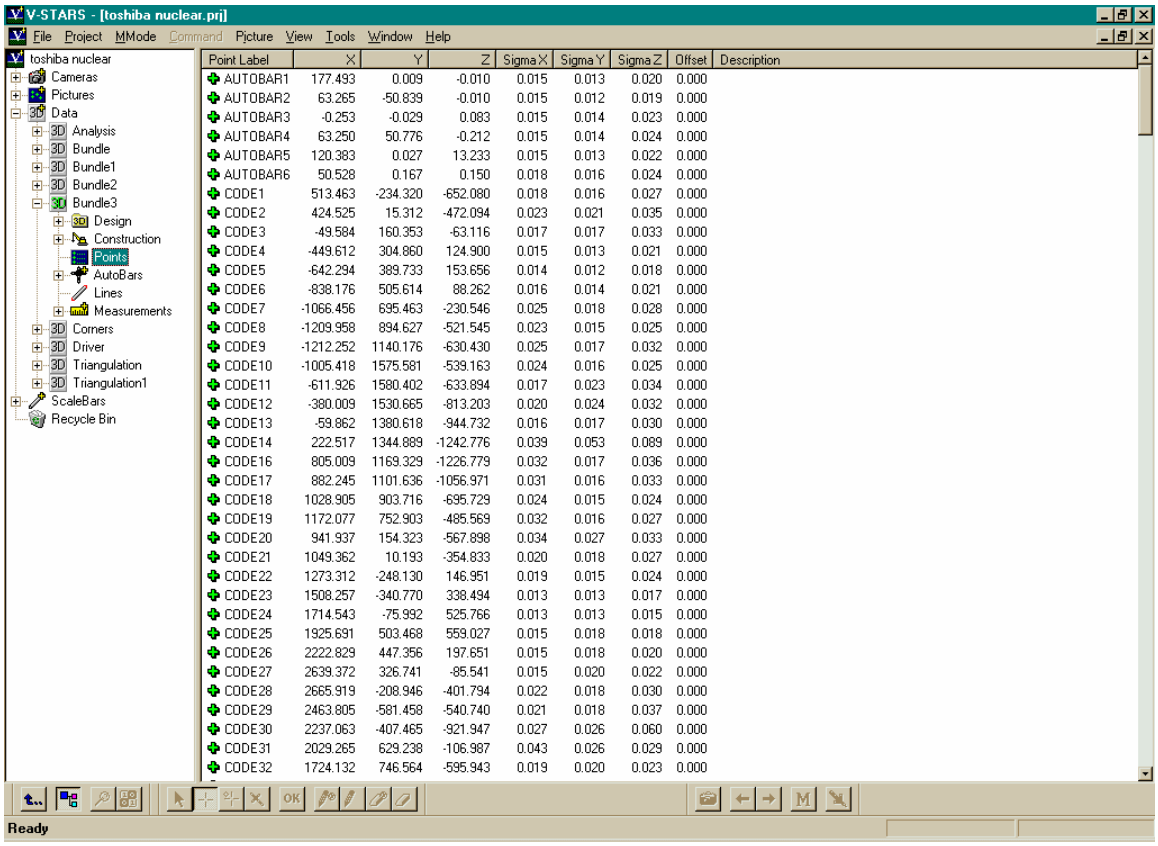


Seen below is an image taken as part of the pipe measurement.



The green text represents points that have been located in this particular image. Note that the image appears very dark and difficult to see. This is intentional as the best photogrammetric measurements are made on images that have dark backgrounds and bright targets. One of these targets is shown in the zoom window in the top left-hand corner.

Finally, the points can be listed. A typical point listing is shown below.



Point Label	X	Y	Z	Sigma X	Sigma Y	Sigma Z	Offset	Description
AUTOBAR1	177.493	0.009	-0.010	0.015	0.013	0.020	0.000	
AUTOBAR2	63.265	-50.839	-0.010	0.015	0.012	0.019	0.000	
AUTOBAR3	-0.253	-0.029	0.083	0.015	0.014	0.023	0.000	
AUTOBAR4	63.250	50.776	-0.212	0.015	0.014	0.024	0.000	
AUTOBAR5	120.383	0.027	13.233	0.015	0.013	0.022	0.000	
AUTOBAR6	50.528	0.167	0.150	0.018	0.016	0.024	0.000	
CODE1	513.463	-234.320	-652.080	0.018	0.016	0.027	0.000	
CODE2	424.525	15.312	-472.094	0.023	0.021	0.035	0.000	
CODE3	-49.584	160.353	-63.116	0.017	0.017	0.033	0.000	
CODE4	-449.612	304.860	124.900	0.015	0.013	0.021	0.000	
CODE5	-642.294	389.733	153.656	0.014	0.012	0.018	0.000	
CODE6	-838.176	505.614	88.262	0.016	0.014	0.021	0.000	
CODE7	-1066.456	695.463	-230.546	0.025	0.018	0.028	0.000	
CODE8	-1209.958	894.627	-521.545	0.023	0.015	0.025	0.000	
CODE9	-1212.252	1140.176	-630.430	0.025	0.017	0.032	0.000	
CODE10	-1005.418	1575.581	-539.163	0.024	0.016	0.025	0.000	
CODE11	-611.926	1580.402	-633.894	0.017	0.023	0.034	0.000	
CODE12	-380.009	1530.665	-813.203	0.020	0.024	0.032	0.000	
CODE13	-59.862	1380.618	-944.732	0.016	0.017	0.030	0.000	
CODE14	222.517	1344.889	-1242.776	0.039	0.053	0.089	0.000	
CODE16	805.009	1169.329	-1226.779	0.032	0.017	0.036	0.000	
CODE17	882.245	1101.636	-1056.971	0.031	0.016	0.033	0.000	
CODE18	1028.905	903.716	-695.729	0.024	0.015	0.024	0.000	
CODE19	1172.077	752.903	-485.569	0.032	0.016	0.027	0.000	
CODE20	941.937	154.323	-567.898	0.034	0.027	0.033	0.000	
CODE21	1049.362	10.193	-354.833	0.020	0.018	0.027	0.000	
CODE22	1273.312	-248.130	146.951	0.019	0.015	0.024	0.000	
CODE23	1508.257	-340.770	338.494	0.013	0.013	0.017	0.000	
CODE24	1714.543	-75.992	525.766	0.013	0.013	0.015	0.000	
CODE25	1925.691	503.468	559.027	0.015	0.018	0.018	0.000	
CODE26	2222.829	447.356	197.651	0.015	0.018	0.020	0.000	
CODE27	2639.372	326.741	-85.541	0.015	0.020	0.022	0.000	
CODE28	2665.919	-208.946	-401.794	0.022	0.018	0.030	0.000	
CODE29	2463.805	-581.458	-540.740	0.021	0.018	0.037	0.000	
CODE30	2237.063	-407.465	-921.947	0.027	0.026	0.060	0.000	
CODE31	2029.265	629.238	-106.987	0.043	0.026	0.029	0.000	
CODE32	1724.132	746.564	-595.943	0.019	0.020	0.023	0.000	

This point data can be analysed within the V-STARS' Solids module, easily exported to almost any CAD platform or pipe fitting program. The entire project was completed in under an hour.

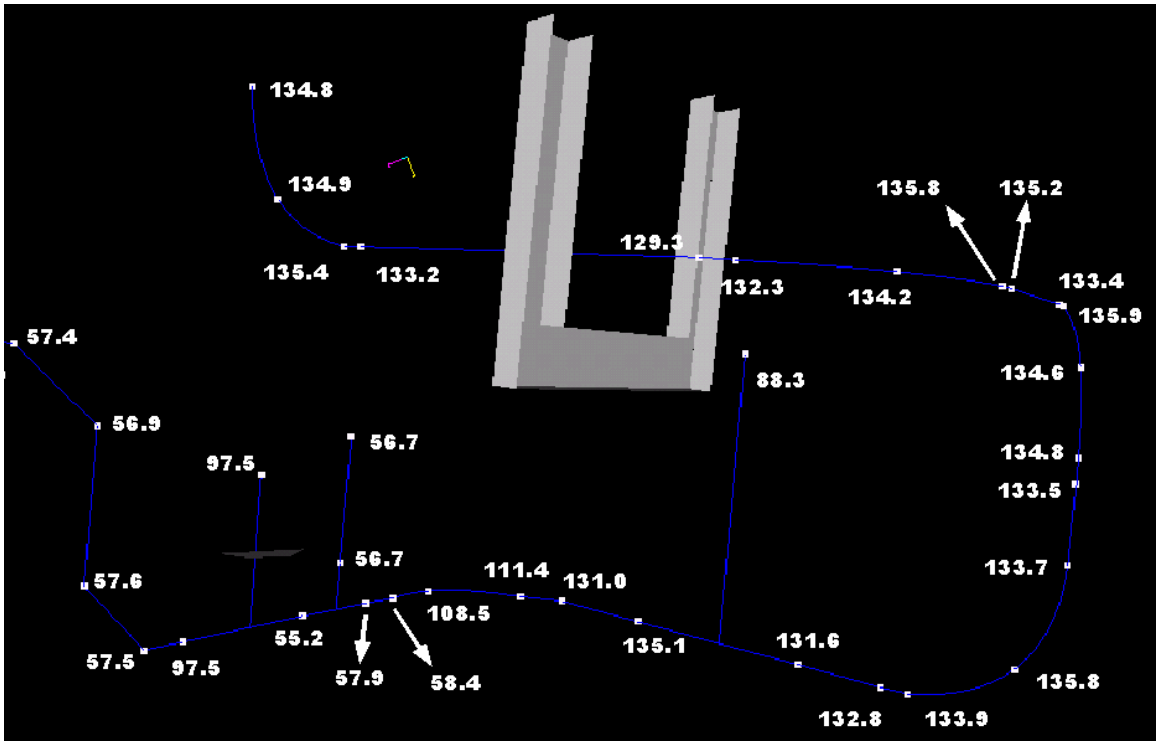
Results:

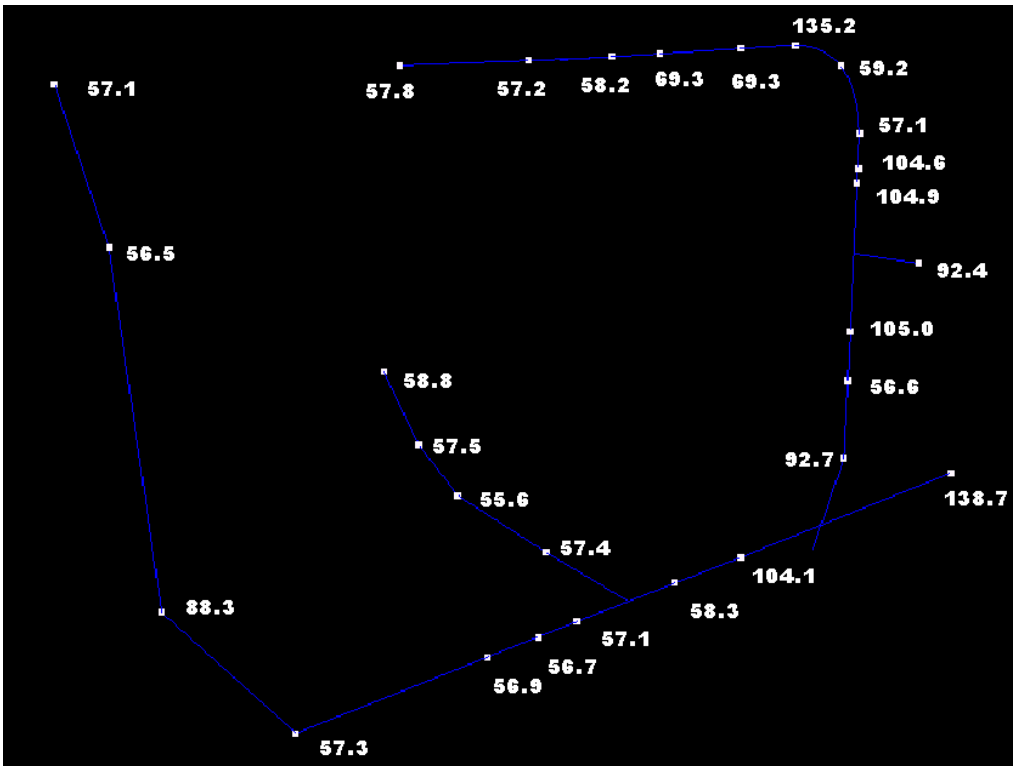
The following is a summary of the measurement statistics from the measurement of the pipe volume.

No of photos	55		
No of points	369		
No of scales	2		
Scale Agreement	0.02mm		
RMS(mm) X,Y,Z		X	0.03
		Y	0.02
		Z	0.03

A full listing of V-STARS coordinates for each pipe point can be found in Appendix 1

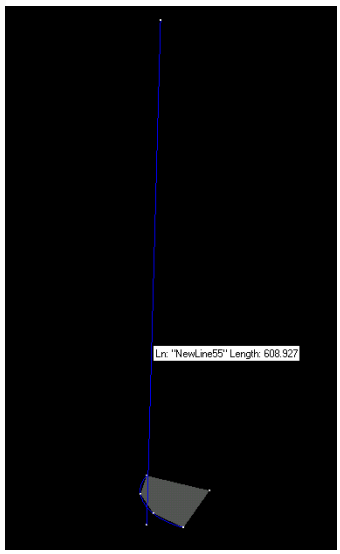
Based on the points determined on the pipe surface it is possible to compute best-fit circles, radii and fit centre points. These center points can be joined together to form a pipe centreline trace. The following diagrams show the pipe trace and the corresponding radii at the computed cross section.





The full results of the best fit circles can be found in Appendix 2

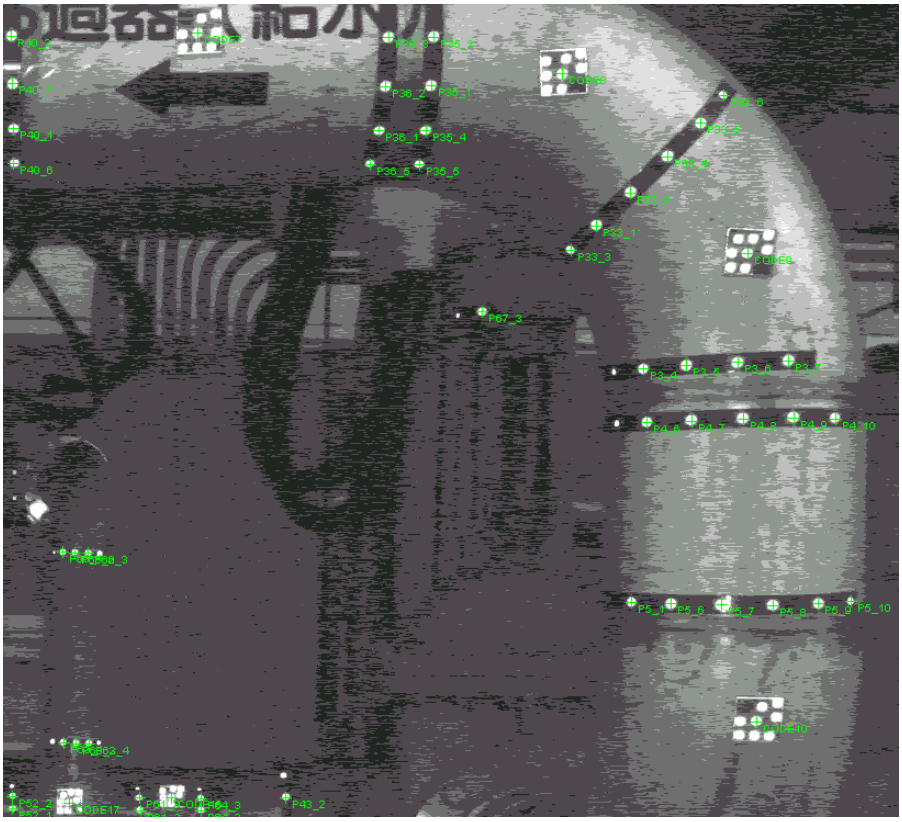
One other requirement was to determine the height of a certain feature. An image of this feature is shown below . The true height of the feature was determined by fitting a plane to the bottom surface and then computing the perpendicular distance to a point on the top surface. This construction is shown below. As offset targets were used it was necessary to subtract the appropriate offsets from the final distance.

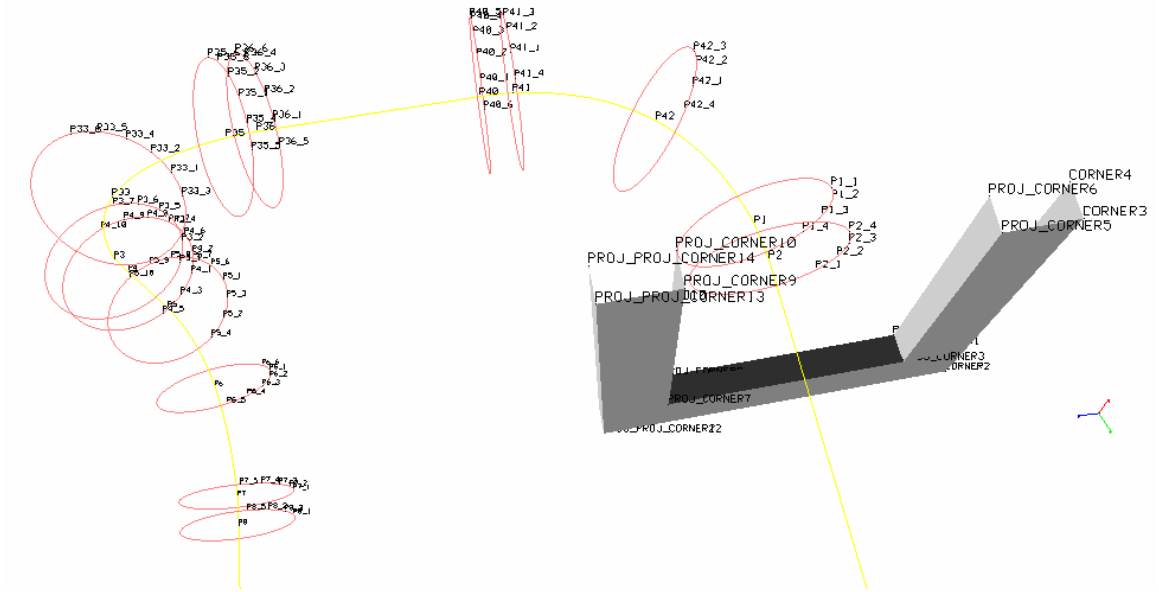


Height of feature = 608.9 –31 = ***577.9mm***

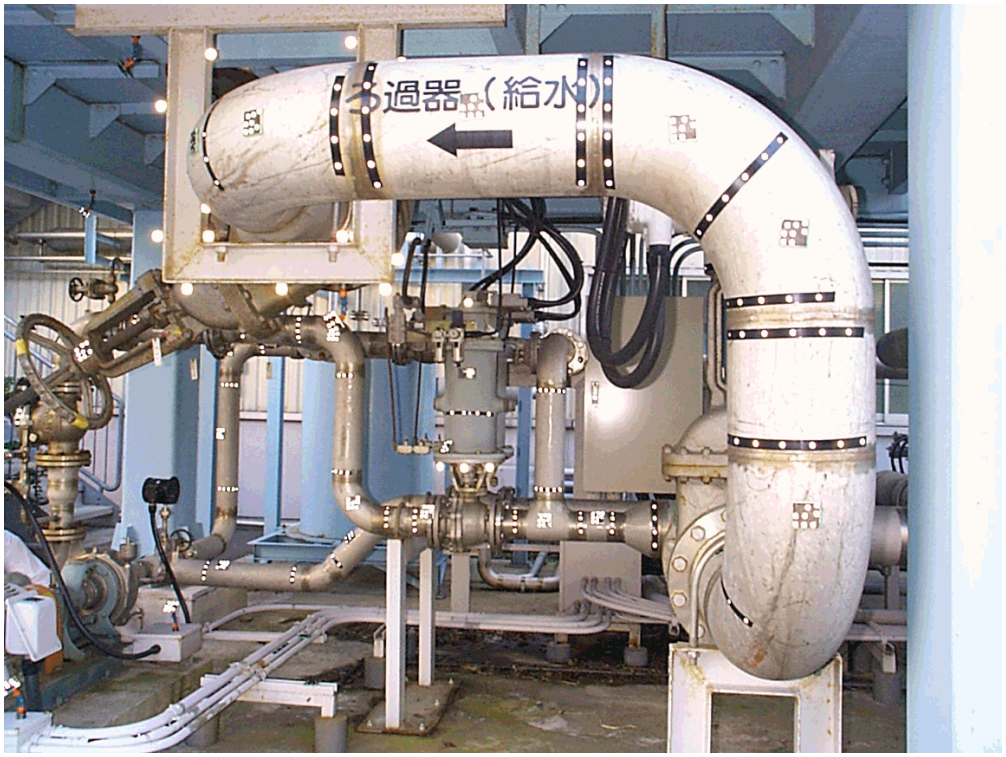
Graphical Results:

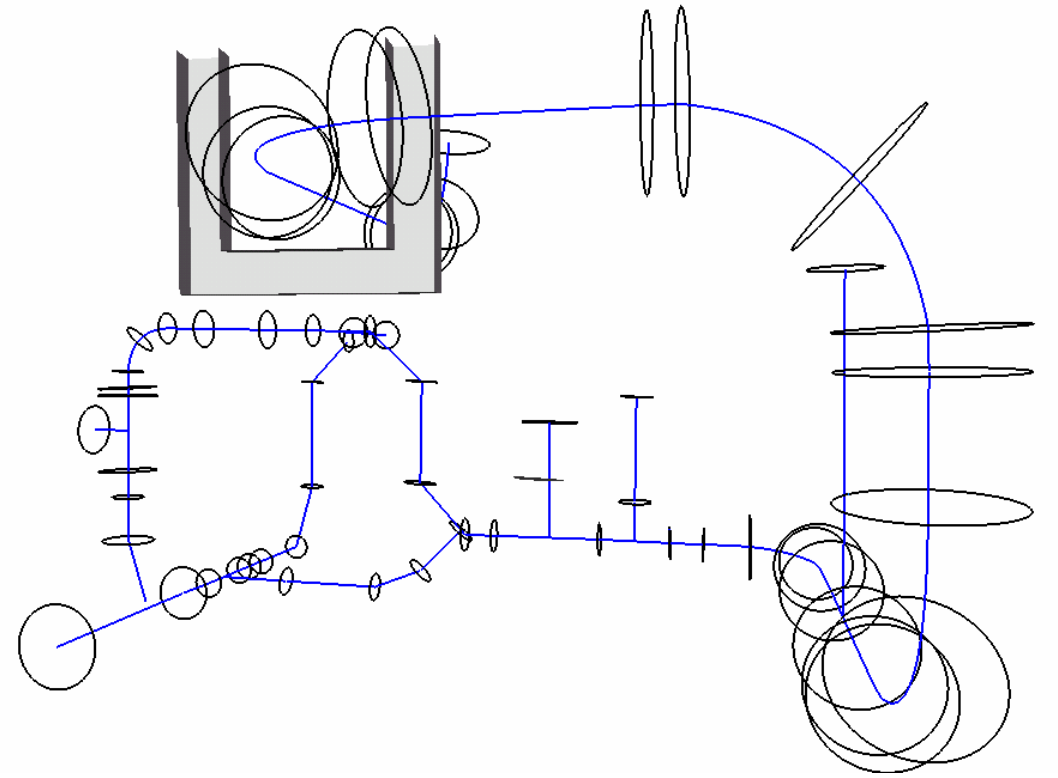
The images below are samples of the numbering documentation the software is capable of. The first image is taken directly from the measurement images. The second comes from the 3D graphical view.

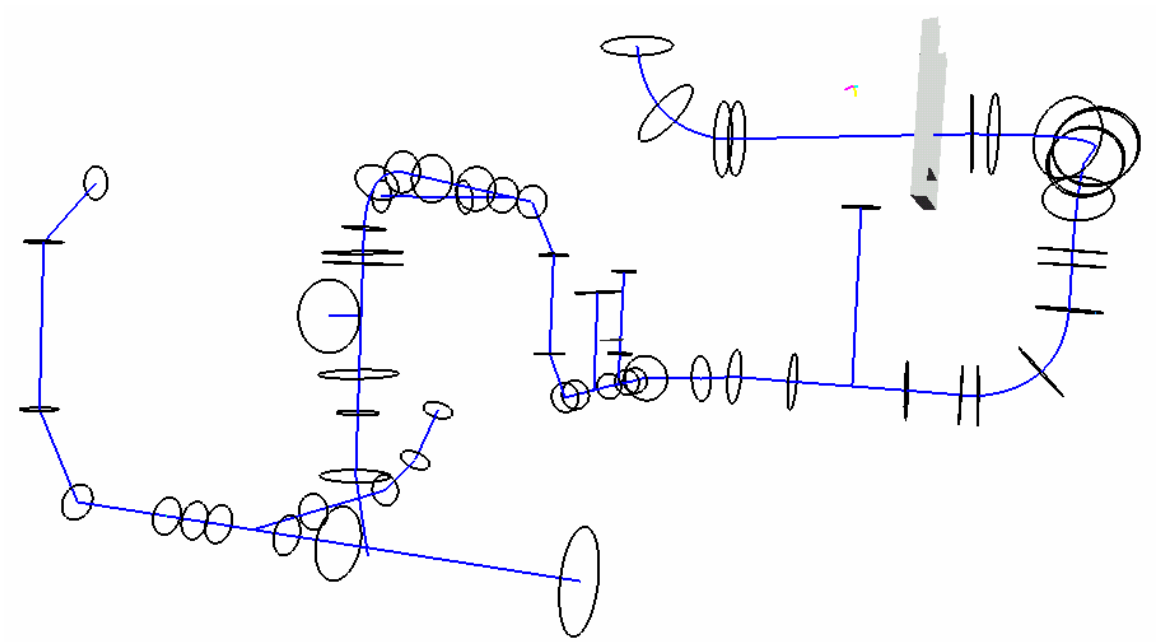


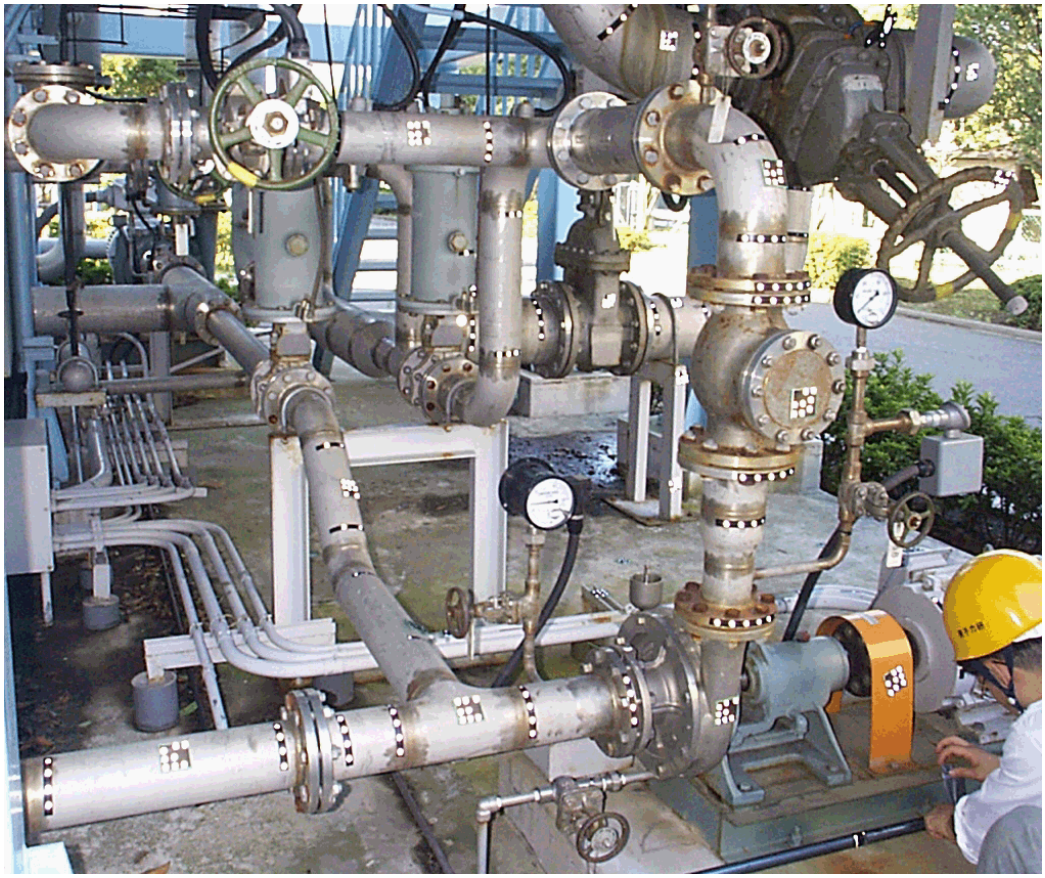


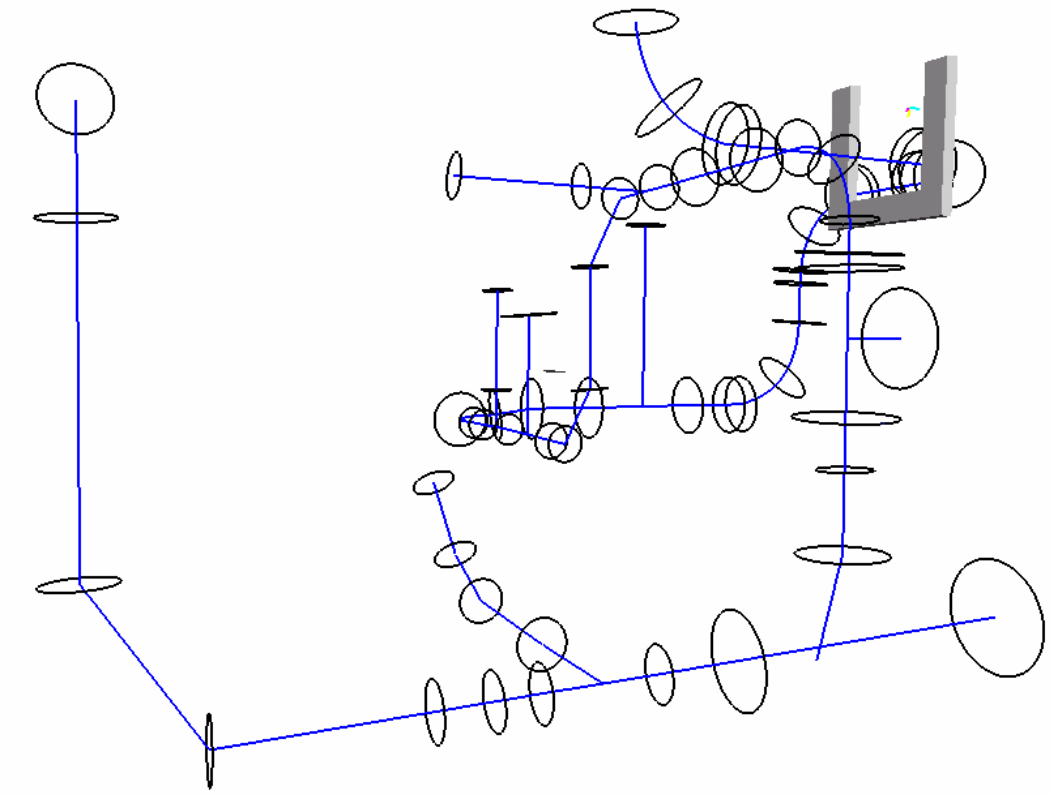
The following pairs of images show a comparison between the actual pipes and the measured pipes.











Concluding Remarks:

This pipe measurement demonstration has clearly shown that V-STARS is potentially a very powerful measurement tool in the determining the size, position and orientation of pipes and other features. The results of the measurement are very accurate and more importantly were produced quickly. The time taken to complete the measurement can be significantly improved via the used of special targets and through adequate planning. The benefits of such timesavings are obvious.

GSI and Leica would like to thank XXXX for welcoming us into your facility and for the opportunity to present our system to you. We will be happy to discuss the results of this report or any other aspect of the technology presented.

Appendix 1 – Coordinate Data

V-STARS Coordinates (mm)

	Coordinate			Accuracy Estimate		
Point	X	Y	Z	SX	SY	SZ
CORNER1	-55.2	366.2	182.8	0.02	0.02	0.02
CORNER2	-18.1	354.6	156.6	0.02	0.02	0.03
CORNER3	-253.4	-118.0	33.2	0.02	0.02	0.03
CORNER4	-294.7	-112.7	58.5	0.02	0.02	0.03
P10_1	169.2	1414.1	-1108.5	0.02	0.03	0.05
P10_2	194.9	1453.5	-1089.9	0.02	0.03	0.05
P10_3	139.6	1388.6	-1140.2	0.02	0.03	0.06
P10_5	109.9	1379.4	-1179.7	0.05	0.10	0.17
P11_1	393.1	1339.6	-1270.9	0.02	0.02	0.04
P11_2	420.3	1376.9	-1250.7	0.02	0.03	0.04
P11_3	439.1	1423.4	-1245.5	0.02	0.03	0.05
P11_5	361.9	1316.8	-1303.2	0.03	0.03	0.05
P12_1	565.7	1365.4	-1366.4	0.02	0.03	0.07
P12_2	542.4	1328.4	-1391.0	0.03	0.04	0.08
P12_3	512.1	1310.0	-1425.9	0.04	0.08	0.13
P13_1	285.7	31.0	-409.6	0.03	0.02	0.04
P13_2	312.7	67.6	-387.8	0.03	0.02	0.04
P13_3	332.7	113.3	-380.4	0.03	0.02	0.04
P13_4	342.0	162.2	-389.4	0.03	0.03	0.04
P14_1	329.5	23.2	-433.9	0.03	0.02	0.04
P14_2	355.7	61.3	-414.0	0.03	0.02	0.04
P14_3	374.8	107.7	-408.6	0.03	0.02	0.04
P14_4	383.3	156.3	-419.5	0.03	0.02	0.04
P15_1	419.2	-101.0	-565.1	0.02	0.02	0.03
P15_2	467.3	-87.8	-557.1	0.02	0.02	0.03
P15_3	511.5	-64.7	-564.9	0.02	0.02	0.03
P15_4	545.6	-34.8	-587.0	0.03	0.03	0.04
P16_1	522.4	-333.7	-723.9	0.03	0.02	0.05
P16_2	485.2	-327.9	-690.3	0.02	0.02	0.03
P16_3	440.3	-314.3	-671.7	0.02	0.02	0.03
P16_7	394.1	-294.2	-671.1	0.02	0.02	0.03
P17_1	1383.6	621.9	798.1	0.01	0.02	0.02
P17_2	1412.6	643.2	833.7	0.02	0.02	0.02
P17_3	1438.2	679.3	858.4	0.02	0.02	0.02
P17_4	1355.2	617.8	756.5	0.02	0.04	0.03
P18_1	1987.1	475.0	383.1	0.02	0.02	0.03
P18_2	2002.1	484.7	401.2	0.02	0.02	0.02
P18_3	2016.2	499.7	416.2	0.02	0.02	0.02
P18_4	2028.3	519.0	427.2	0.02	0.02	0.02
P19_1	2134.5	478.9	268.5	0.02	0.02	0.02
P19_2	2149.4	491.8	284.2	0.02	0.02	0.02
P19_3	2119.3	476.1	248.5	0.02	0.03	0.03
P19_4	2161.3	512.3	292.8	0.02	0.02	0.02

	Coordinate			Accuracy Estimate		
Point	X	Y	Z	SX	SY	SZ
P1_1	-415.7	241.2	70.7	0.02	0.02	0.03
P1_2	-391.8	279.1	93.8	0.02	0.01	0.02
P1_3	-373.5	325.6	100.8	0.02	0.02	0.02
P1_4	-363.4	374.1	90.4	0.02	0.02	0.03
P20_1	2347.0	428.3	141.4	0.02	0.02	0.02
P20_2	2360.0	447.2	152.1	0.02	0.02	0.02
P20_3	2332.0	418.1	124.0	0.02	0.02	0.02
P20_6	2317.6	418.5	103.2	0.02	0.04	0.03
P21_1	2419.5	405.4	88.1	0.02	0.02	0.02
P21_2	2432.1	423.6	100.4	0.02	0.02	0.02
P21_6	2405.2	396.3	69.6	0.02	0.03	0.03
P21_7	2392.0	398.0	48.1	0.02	0.04	0.03
P22_1	2491.2	370.2	4.0	0.02	0.04	0.04
P22_2	2519.9	393.7	36.2	0.02	0.03	0.03
P22_3	2506.2	377.2	23.0	0.02	0.03	0.03
P23_5	2823.1	304.5	-169.1	0.02	0.03	0.03
P23_6	2808.5	288.1	-181.8	0.02	0.03	0.03
P23_7	2792.7	281.2	-200.1	0.02	0.03	0.03
P23_8	2778.7	285.0	-220.5	0.03	0.05	0.05
P24_1	1813.6	323.6	577.9	0.02	0.02	0.02
P24_2	1836.5	312.8	575.8	0.01	0.02	0.02
P24_3	1858.7	304.1	567.2	0.01	0.02	0.02
P24_4	1878.7	298.5	552.6	0.02	0.02	0.02
P24_5	1895.1	296.1	533.3	0.02	0.02	0.02
P24_6	1906.3	297.2	510.5	0.03	0.03	0.03
P25_1	1750.5	181.0	503.3	0.02	0.02	0.02
P25_2	1792.4	166.6	482.1	0.02	0.02	0.02
P25_3	1804.6	167.3	460.0	0.02	0.03	0.02
P25_4	1773.2	171.4	497.6	0.01	0.02	0.02
P26_1	1713.3	78.2	525.7	0.01	0.01	0.02
P26_2	1736.4	69.4	520.3	0.01	0.01	0.02
P26_3	1758.3	62.7	509.2	0.01	0.01	0.02
P26_4	1777.5	58.3	493.1	0.02	0.02	0.02
P26_5	1792.9	56.7	473.0	0.02	0.02	0.02
P27_1	1583.8	-178.1	455.4	0.01	0.01	0.02
P27_2	1606.8	-187.9	450.6	0.01	0.01	0.02
P27_3	1628.7	-195.5	440.2	0.01	0.01	0.02
P27_4	1648.1	-200.6	424.7	0.02	0.02	0.02
P27_5	1664.0	-202.8	405.0	0.02	0.02	0.02
P28_1	1571.1	-197.0	449.6	0.01	0.01	0.02
P28_2	1616.7	-213.4	435.9	0.01	0.01	0.02
P28_3	1652.8	-221.3	401.5	0.02	0.02	0.02
P28_4	1594.5	-205.8	445.7	0.01	0.01	0.02
P28_5	1636.5	-218.7	420.8	0.02	0.02	0.02
P29_1	1543.6	-248.3	386.1	0.01	0.01	0.02
P29_2	1565.9	-257.9	379.2	0.01	0.01	0.02
P29_3	1584.6	-262.6	363.0	0.02	0.02	0.02
P29_4	1596.2	-261.8	340.5	0.03	0.02	0.02

	Coordinate			Accuracy Estimate		
Point	X	Y	Z	SX	SY	SZ
P29_5	1522.1	-235.7	382.1	0.02	0.01	0.02
P2_1	-304.6	357.0	49.7	0.02	0.02	0.03
P2_2	-310.3	307.8	59.6	0.02	0.02	0.03
P2_3	-326.3	260.4	53.0	0.02	0.02	0.03
P2_4	-349.7	222.0	30.3	0.02	0.02	0.03
P30_1	1450.4	-365.2	291.6	0.02	0.02	0.03
P30_2	1471.7	-375.0	282.2	0.02	0.02	0.02
P30_3	1493.2	-374.7	269.1	0.03	0.03	0.03
P30_4	1433.1	-347.2	295.5	0.02	0.01	0.03
P30_7	1422.8	-324.4	292.3	0.02	0.01	0.03
P31_1	1276.0	-84.8	-442.3	0.03	0.03	0.04
P31_2	1263.3	-100.8	-457.1	0.04	0.04	0.06
P31_3	1285.0	-62.2	-435.5	0.04	0.03	0.05
P31_4	1288.2	-37.3	-438.1	0.04	0.03	0.05
P32_1	1558.5	-146.8	-631.6	0.02	0.03	0.04
P32_2	1546.2	-168.0	-637.6	0.02	0.03	0.04
P32_3	1530.4	-182.1	-651.1	0.02	0.03	0.05
P32_4	1565.2	-122.6	-634.7	0.02	0.02	0.04
P33_1	-1127.5	1036.1	-555.8	0.02	0.01	0.02
P33_2	-1176.6	1029.1	-565.0	0.02	0.01	0.02
P33_3	-1077.7	1036.4	-563.9	0.02	0.02	0.03
P33_4	-1218.1	1016.2	-590.5	0.02	0.01	0.03
P33_5	-1246.0	998.1	-628.6	0.03	0.02	0.03
P33_6	-1256.5	975.5	-672.4	0.04	0.02	0.04
P35_1	-1139.1	843.8	-421.1	0.02	0.02	0.03
P35_2	-1168.4	803.2	-426.9	0.02	0.02	0.03
P35_4	-1099.4	874.1	-427.4	0.02	0.02	0.02
P35_5	-1055.3	890.1	-445.5	0.03	0.02	0.03
P35_6	-1181.9	713.8	-467.4	0.03	0.02	0.04
P35_8	-1183.8	757.9	-443.0	0.02	0.02	0.03
P36_1	-1077.5	853.3	-389.1	0.02	0.02	0.02
P36_2	-1118.1	824.0	-383.7	0.02	0.02	0.03
P36_3	-1148.1	783.8	-389.2	0.02	0.02	0.03
P36_4	-1163.7	738.5	-405.2	0.02	0.02	0.03
P36_5	-1031.7	866.7	-405.2	0.03	0.03	0.04
P36_6	-1161.6	694.8	-430.0	0.04	0.02	0.04
P3_1	-990.3	1153.4	-619.9	0.02	0.02	0.05
P3_2	-1028.1	1168.0	-589.9	0.02	0.02	0.04
P3_4	-1072.5	1187.8	-576.4	0.02	0.02	0.03
P3_5	-1117.2	1210.8	-581.2	0.02	0.01	0.02
P3_6	-1155.2	1234.7	-604.3	0.02	0.01	0.02
P3_7	-1181.7	1255.3	-641.8	0.03	0.02	0.03
P40_1	-914.2	686.8	-76.1	0.02	0.02	0.03
P40_2	-951.9	654.2	-69.9	0.02	0.02	0.03
P40_3	-979.2	612.1	-75.2	0.02	0.02	0.03
P40_4	-992.1	566.1	-91.5	0.03	0.02	0.03
P40_5	-987.5	522.6	-116.7	0.04	0.02	0.04
P40_6	-870.3	704.7	-93.4	0.03	0.02	0.03

	Coordinate			Accuracy Estimate		
Point	X	Y	Z	SX	SY	SZ
P41_1	-922.8	628.3	-21.1	0.02	0.02	0.03
P41_2	-951.3	587.2	-28.3	0.02	0.02	0.03
P41_3	-965.3	542.5	-47.0	0.03	0.02	0.03
P41_4	-883.8	660.0	-26.1	0.02	0.02	0.03
P42_1	-677.2	460.5	148.5	0.02	0.01	0.02
P42_2	-701.5	416.6	142.9	0.02	0.01	0.03
P42_3	-720.3	375.9	119.6	0.02	0.02	0.03
P42_4	-650.5	501.3	135.3	0.02	0.01	0.02
P43_1	682.0	1307.9	-1351.2	0.04	0.02	0.05
P43_2	670.9	1262.0	-1368.8	0.04	0.02	0.05
P43_3	711.7	1348.2	-1346.4	0.04	0.02	0.05
P43_4	680.8	1220.6	-1395.9	0.06	0.03	0.07
P44_1	1102.7	915.6	-661.7	0.03	0.02	0.03
P44_2	1096.3	892.7	-670.0	0.03	0.02	0.03
P44_3	1117.8	935.6	-659.4	0.04	0.02	0.03
P44_4	1100.1	871.0	-682.4	0.04	0.03	0.04
P45_1	1154.5	877.9	-572.2	0.03	0.02	0.03
P45_2	1144.7	855.3	-578.0	0.03	0.02	0.03
P45_3	1144.5	832.7	-589.1	0.03	0.02	0.03
P45_4	1154.0	814.4	-603.5	0.04	0.03	0.04
P46_1	1184.4	605.0	-459.7	0.02	0.02	0.02
P46_2	1226.1	594.2	-483.1	0.02	0.03	0.04
P46_3	1207.2	596.9	-466.7	0.02	0.03	0.03
P46_4	1136.1	642.1	-495.7	0.03	0.02	0.03
P46_5	1145.3	630.3	-475.6	0.02	0.02	0.02
P46_6	1162.4	617.0	-462.6	0.02	0.02	0.03
P47_1	1271.4	-255.2	62.0	0.03	0.02	0.03
P47_2	1274.3	-232.2	72.1	0.04	0.02	0.03
P47_3	1284.9	-210.0	77.5	0.03	0.02	0.03
P47_4	1302.1	-191.3	77.0	0.02	0.02	0.02
P47_5	1276.7	-276.0	48.7	0.03	0.02	0.04
P48_1	1184.6	-77.5	-130.0	0.03	0.02	0.03
P48_2	1158.5	-119.1	-137.5	0.02	0.02	0.03
P48_3	1168.1	-96.7	-131.0	0.02	0.02	0.03
P48_4	1157.0	-142.0	-148.3	0.03	0.02	0.05
P48_5	1163.9	-162.2	-161.9	0.04	0.03	0.05
P49_1	1351.0	-308.5	184.5	0.03	0.02	0.04
P49_2	1376.6	-266.9	191.1	0.02	0.02	0.03
P49_3	1359.8	-285.8	191.2	0.02	0.02	0.02
P49_4	1352.0	-330.8	172.7	0.03	0.02	0.04
P4_1	-969.3	1206.9	-605.7	0.02	0.02	0.04
P4_2	-1007.8	1221.0	-576.2	0.02	0.02	0.03
P4_3	-941.7	1202.3	-647.6	0.04	0.04	0.06
P4_5	-929.3	1208.0	-696.2	0.10	0.07	0.08
P4_6	-1052.2	1241.5	-563.4	0.02	0.01	0.02
P4_7	-1096.3	1265.3	-569.9	0.02	0.01	0.02
P4_8	-1133.1	1289.2	-594.8	0.02	0.01	0.02
P4_9	-1158.4	1310.4	-632.9	0.03	0.02	0.03

	Coordinate			Accuracy Estimate		
Point	X	Y	Z	SX	SY	SZ
P4_10	-1168.0	1326.3	-679.9	0.04	0.02	0.04
P50_1	1001.5	81.4	-458.4	0.03	0.02	0.03
P50_2	1019.5	99.2	-458.5	0.03	0.02	0.03
P50_3	991.2	36.7	-476.3	0.10	0.03	0.13
P50_4	991.5	59.2	-464.8	0.03	0.03	0.03
P51_1	1117.3	-0.1	-279.3	0.03	0.03	0.03
P51_2	1099.4	-17.7	-279.2	0.03	0.02	0.03
P51_3	1089.2	-39.9	-285.7	0.03	0.02	0.03
P51_4	1088.2	-62.1	-297.7	0.03	0.02	0.05
P52_1	937.2	1067.4	-968.8	0.03	0.02	0.03
P52_2	934.3	1044.3	-978.7	0.04	0.02	0.03
P52_3	949.8	1088.8	-964.8	0.04	0.02	0.04
P52_4	942.1	1024.4	-992.2	0.11	0.04	0.08
P53_1	797.5	655.8	-935.3	0.04	0.02	0.03
P53_2	811.3	636.2	-890.9	0.03	0.02	0.03
P53_3	845.5	613.2	-862.2	0.02	0.02	0.03
P53_4	891.4	593.3	-856.5	0.02	0.02	0.03
P55_1	2570.2	-448.3	-459.4	0.02	0.02	0.05
P55_2	2550.4	-436.2	-469.1	0.02	0.02	0.03
P55_3	2537.8	-424.3	-487.4	0.03	0.02	0.04
P56_1	2369.9	-519.0	-688.3	0.02	0.02	0.05
P56_2	2360.7	-541.6	-694.4	0.02	0.02	0.04
P56_3	2387.1	-500.5	-689.0	0.04	0.03	0.06
P56_4	2360.7	-563.6	-706.3	0.03	0.03	0.07
P57_1	2060.3	609.2	-38.8	0.09	0.03	0.04
P57_2	2061.6	630.6	-25.7	0.08	0.03	0.04
P57_3	2072.6	651.9	-17.8	0.09	0.03	0.04
P58_1	1888.6	816.2	-340.7	0.04	0.02	0.03
P58_2	1883.8	793.5	-350.5	0.04	0.02	0.03
P58_3	1889.2	773.4	-364.8	0.03	0.03	0.03
P59_1	1819.7	767.7	-531.1	0.02	0.04	0.04
P59_2	1767.9	839.9	-523.3	0.06	0.02	0.04
P59_3	1781.2	793.1	-513.8	0.02	0.03	0.03
P5_1	-953.7	1403.3	-521.3	0.02	0.02	0.03
P5_2	-875.9	1374.4	-575.7	0.03	0.03	0.04
P5_3	-911.1	1384.6	-541.1	0.02	0.02	0.04
P5_4	-853.2	1374.6	-620.9	0.04	0.03	0.05
P5_6	-998.4	1426.6	-520.6	0.02	0.01	0.02
P5_7	-1038.1	1451.6	-539.3	0.02	0.01	0.02
P5_8	-1068.5	1474.7	-572.4	0.03	0.02	0.03
P5_9	-1084.6	1491.7	-617.1	0.04	0.02	0.03
P5_10	-1084.0	1500.8	-666.8	0.08	0.04	0.06
P60_2	1639.5	716.1	-693.3	0.02	0.02	0.03
P60_3	1679.4	690.2	-706.1	0.02	0.03	0.04
P60_4	1624.5	760.8	-707.7	0.09	0.03	0.11
P61_1	843.5	1191.0	-1161.8	0.04	0.02	0.04
P61_2	833.2	1168.4	-1166.8	0.04	0.02	0.04
P61_3	832.4	1145.4	-1177.2	0.04	0.02	0.04

	Coordinate			Accuracy Estimate		
Point	X	Y	Z	SX	SY	SZ
P61_4	841.5	1126.3	-1190.6	0.10	0.04	0.09
P63_1	845.5	993.1	-1079.4	0.02	0.02	0.03
P63_2	830.0	1005.3	-1095.2	0.03	0.02	0.04
P63_3	866.7	980.8	-1073.1	0.03	0.02	0.04
P63_4	823.4	1014.8	-1117.7	0.05	0.03	0.04
P64_1	792.9	1237.5	-1253.4	0.04	0.02	0.04
P64_2	783.1	1215.4	-1261.2	0.04	0.02	0.04
P64_3	783.3	1193.5	-1273.5	0.04	0.02	0.04
P65_1	934.1	775.1	-774.2	0.02	0.02	0.02
P65_2	861.6	825.7	-830.0	0.03	0.02	0.03
P65_3	860.2	851.8	-926.0	0.03	0.02	0.04
P65_4	1016.1	739.0	-787.9	0.02	0.02	0.03
P66_1	694.9	666.1	-1162.9	0.02	0.02	0.03
P66_2	676.4	678.6	-1174.8	0.03	0.02	0.04
P66_3	665.6	690.0	-1194.5	0.04	0.03	0.04
P66_4	717.5	654.8	-1161.7	0.03	0.02	0.05
P67_1	-409.9	812.9	-1155.0	0.03	0.02	0.07
P67_2	-371.3	801.4	-1184.8	0.03	0.03	0.06
P67_3	-455.3	833.7	-1151.2	0.02	0.02	0.05
P69_1	2790.2	46.2	-335.5	0.03	0.02	0.04
P69_2	2776.7	58.5	-353.0	0.03	0.02	0.03
P69_3	2772.3	68.0	-375.9	0.05	0.03	0.05
P6_1	-731.2	1651.0	-511.4	0.02	0.02	0.03
P6_2	-714.4	1606.9	-529.1	0.02	0.02	0.03
P6_3	-706.4	1569.7	-562.3	0.02	0.02	0.03
P6_4	-707.2	1544.9	-606.2	0.03	0.03	0.05
P6_5	-716.6	1535.9	-655.0	0.15	0.19	0.17
P6_6	-754.2	1695.9	-511.0	0.02	0.02	0.03
P71_1	1631.6	-70.9	554.5	0.02	0.02	0.02
P71_2	1623.4	-93.6	546.5	0.02	0.02	0.02
P71_3	1621.4	-116.2	535.1	0.03	0.02	0.03
P71_4	1625.7	-137.2	521.4	0.03	0.02	0.03
P7_1	-446.4	1691.9	-631.2	0.02	0.02	0.04
P7_2	-462.4	1644.6	-638.5	0.02	0.02	0.03
P7_3	-486.1	1605.9	-660.4	0.02	0.02	0.03
P7_4	-514.5	1581.2	-694.2	0.02	0.02	0.03
P7_5	-543.4	1574.7	-734.9	0.03	0.03	0.05
P80_1	1050.7	277.1	-558.4	0.02	0.02	0.04
P80_2	1027.8	285.2	-551.2	0.02	0.02	0.03
P80_3	1069.4	274.2	-575.2	0.03	0.03	0.04
P80_4	978.9	320.2	-588.7	0.04	0.03	0.03
P80_5	1005.7	296.8	-554.6	0.02	0.02	0.03
P80_6	988.4	309.3	-568.0	0.02	0.02	0.03
P8_1	-401.6	1642.7	-670.8	0.02	0.02	0.03
P8_2	-454.6	1572.9	-716.9	0.02	0.02	0.03
P8_3	-425.6	1601.6	-687.3	0.02	0.02	0.03
P8_5	-484.1	1561.2	-756.2	0.03	0.03	0.04
P9_1	-252.1	1527.6	-831.9	0.02	0.02	0.03

	Coordinate			Accuracy Estimate		
Point	X	Y	Z	SX	SY	SZ
P9_2	-226.3	1563.5	-807.5	0.02	0.02	0.03
P9_3	-281.3	1507.1	-867.7	0.02	0.02	0.03
P9_4	-309.0	1504.7	-909.6	0.04	0.04	0.07
TOP	613.0	291.5	-985.2	0.05	0.04	0.05

Appendix 2 – Best Fit Circle Results

Circle centre points and radii(mm)

Point	X	Y	Z	Radius
P1	-430.6	338.4	-17.9	132.3
P2	-376.5	319.0	-50.8	129.3
P3	-1073.1	1212.1	-708.8	134.8
P4	-1048.2	1267.9	-694.5	133.5
P5	-966.7	1437.9	-650.4	133.7
P6	-773.8	1658.3	-640.0	135.8
P7	-518.3	1705.8	-743.4	133.9
P8	-459.4	1689.3	-780.9	132.8
P9	-273.7	1631.6	-909.8	131.6
P10	140.0	1509.6	-1199.7	135.1
P11	364.7	1438.2	-1352.3	131.0
P12	506.4	1419.9	-1443.4	111.4
P13	261.5	133.3	-491.4	133.2
P14	301.7	122.3	-521.9	135.4
P15	439.4	-16.4	-668.1	134.9
P16	430.1	-269.8	-798.6	134.8
P17	1387.3	752.7	752.3	138.7
P18	1985.7	573.5	349.4	104.1
P19	2133.0	532.7	246.0	58.3
P20	2336.0	472.4	106.8	57.1
P21	2410.7	450.9	55.6	56.7
P22	2499.9	425.5	-6.6	56.9
P23	2801.6	336.7	-211.4	57.3
P24	1828.6	342.8	488.5	92.7
P25	1756.4	194.8	448.8	56.6
P26	1713.1	104.0	423.9	105.0
P27	1587.8	-151.9	353.9	104.9
P28	1575.1	-177.4	346.9	104.6
P29	1547.5	-233.3	331.0	57.1
P30	1472.2	-320.1	260.1	59.2
P31	1256.0	-50.5	-483.4	57.2
P32	1528.5	-131.2	-678.6	57.8
P33	-1122.2	980.9	-678.3	134.6
P35	-1064.1	769.2	-506.6	135.9
P36	-1043.4	747.1	-462.9	133.4
P37	1333.3	-237.7	35.9	69.5
P40	-873.4	584.1	-154.3	135.2
P41	-846.5	560.2	-110.3	135.8
P42	-661.3	439.1	16.9	134.2
P43	768.5	1282.6	-1411.6	108.5
P44	1149.2	899.8	-692.3	57.8
P45	1194.8	854.8	-606.1	57.5
P46	1187.9	624.3	-513.8	57.6
P48	1219.5	-121.8	-170.2	69.3
P49	1401.6	-306.1	157.3	57.5

Point	X	Y	Z	Radius
P50	1042.2	58.2	-491.6	57.4
P51	1139.7	-40.6	-314.6	58.2
P52	984.4	1059.5	-996.2	55.2
P54	888.6	624.1	-949.0	97.5
P55	2586.7	-437.6	-512.3	56.5
P56	2409.4	-539.7	-724.0	57.1
P57	2112.0	629.7	-53.1	57.4
P58	1933.6	806.0	-371.7	55.6
P59	1815.4	821.8	-550.0	57.5
P60	1674.9	742.7	-732.0	58.8
P61	883.9	1165.4	-1194.5	57.9
P63	874.4	992.3	-1128.1	56.7
P64	836.1	1215.3	-1286.0	58.4
P66	715.4	672.7	-1215.4	56.7
P67	-431.0	841.9	-1235.7	88.3
P69	2824.1	43.8	-381.8	57.4
P71	1705.3	-93.6	503.6	92.4
P80	1030.4	302.2	-605.5	56.9

Appendix 3 - Additional Background Information

A brief description of the V-STARS systems is provided in this section. For a more complete description, please see the product literature available from GSI.

The V-STARS systems are photogrammetric coordinate measurement systems that use single or multiple digital cameras to obtain images, which are subsequently processed to obtain spatial three-dimensional coordinates. V-STARS has been very successful with over 80 cameras sold since its introduction in 1994. The latest generation of camera known as INCA (**IN**telligent **CA**mera) was introduced for use with V-STARS in 1996. It has also been very successful with over 50 sold including over 20 to Boeing.

V-STARS/S

The V-STARS/S system is an intelligent single camera 3-dimensional coordinate measurement system based on photogrammetry. The S model consists of a notebook computer, a single high-resolution intelligent digital camera (INCA), a V-STARS/S single-camera software license, and some accessories.

The INCA camera provided with the S model incorporates a high-resolution digital camera, and an Industrial PC with a built-in PCMCIA interface. The system can be operated in off-line mode or in on-line mode. In off-line mode, images are stored on a removable disk storage card for subsequent processing. In on-line mode, the camera is connected directly to the computer (via the optional Ethernet network kit) so images can be immediately processed. The achievable accuracy with the system is typically better than 10 ppm (parts per million).

In operation, the single camera system is used to take pictures of the measured object from several different locations. The different camera locations are needed to ensure all points on the object are seen from enough geometrically diverse locations to get good intersection angles for triangulation. The V-STARS/S system measures retro-reflective target points. High contrast retro-targets make measurement fast, reliable, and for the most part automated.

V-STARS/S Camera in typical operation

The single camera system is extremely portable. The entire system (including notebook, camera and accessories) fits into two small cases that can be hand carried aboard an airplane. So the system can go with you anywhere in the world, and be immediately available for work.