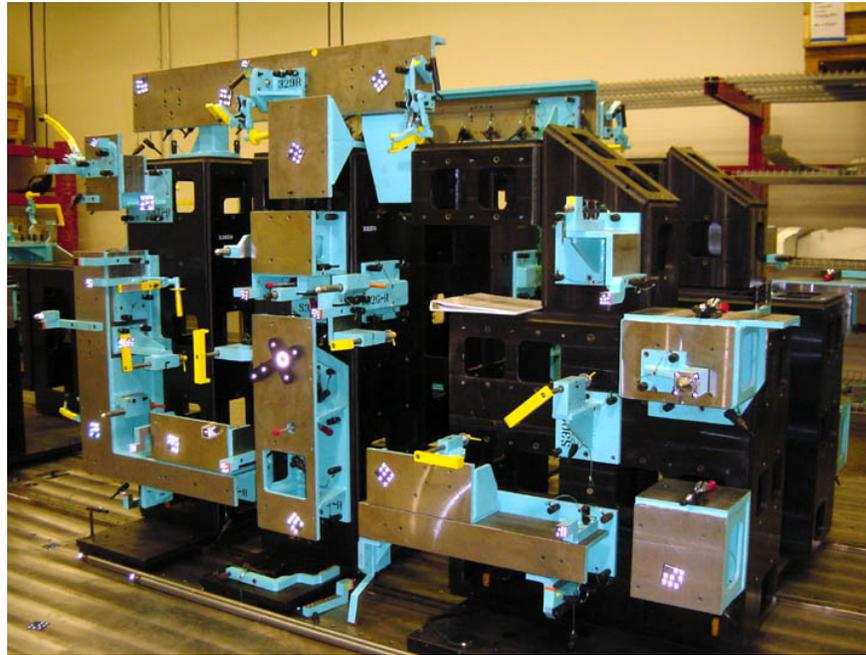


FORD Motor Company V-STARS Demonstration

EXECUTIVE SUMMARY



- The fixture was inspected in less than 20 minutes from start to finish.
- Coordinate data accuracy was typically better than (0.011, 0.015, 0.011)mm in XYZ.
- The speed of data collection ensures minimal disruption to the production line.
- System is portable and can be used to complete off site inspection and verification of fixturing.
- System is capable of working in environments with unstable floors.
- System is flexible enough to work in environments with challenging lines of sight.
- System is not susceptible to effects of temperature variation due to rapid acquisition time.
- Lower-cost E3X system could still easily met the accuracy and time requirements of the fixture measurement.

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Introduction

The following report is a summary of the V-STARS work carried out at the Ford Vehicle Operations facility in Dearborn, Michigan

One measurement was undertaken using the V-STARS metrology system.

The measurement involved the determination of the location of a number of pads and pins on a assembly fixture.



V-STARS with INCA camera.

The objectives of the measurement is outlined below in the requirements section.

Requirements

Assembly Fixture.

1. Demonstrate camera use and object targeting.
2. Compute location of key pads and pins.
3. Complete the measurement as quickly as possible.
4. Compare data to CAD model for the fixture.

Equipment Used

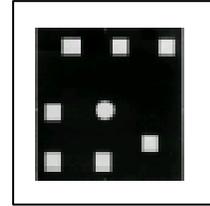
1. V-STARS S6 INCA Camera System
2. Various Feature Targets

Measurement Procedure

Targeting

In order to meet the measurement objectives outlined earlier it was necessary to target the fixture. In general, targets are placed on points or surfaces that are of interest. For surfaces, strips of retro-reflective tape of variable pitch and dot size are commonly used. They are relatively cheap, disposable and easy to apply. To coordinate tooling datums such as bushed holes or button datums, tooling targets are used. These come in a variety of shank and dot sizes. They are also available in variable orientations.

To automate the measurement process it was necessary to add “coded” targets to the object. These targets are automatically detected and help the software determine the location and orientation of the camera at the time the photograph was taken. They also help tie the entire object into a uniform coordinate system.



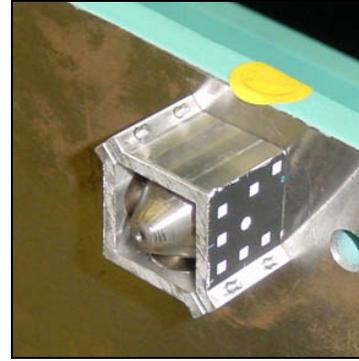
Feature targets were used to measure the location of all of the pads on the fixture and one of the pins. Feature targets are used to measure features such as planes, lines, and circles automatically. They are based on coded targets. The relationship of the coded target to the feature is determined by a one-time calibration.

To measure the feature(s), the appropriate feature target(s) is applied and a measurement completed. At the conclusion of the processing, the features are automatically created. There are four basic types of feature targets, plane, edge, corner, and circle. These are shown below:

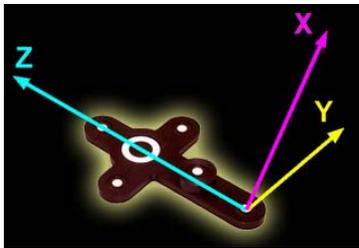
Type	Example	Function
Plane	<p>90° Orientation 45° Orientation</p>	The contact plane is defined.
Edge	<p>Determined Edge Contact Planes</p>	Two contact planes and the edge derived by their intersection are defined.
Corner	<p>Determined edge Determined corner</p> <p>Contact Planes</p>	Three contact planes, two edges and the corresponding corner are defined.
Circle	<p>Tangent Points Center Point</p>	The center point of a circle with known radius is defined.

In this measurement, a new type of circle feature target was assessed. The Feature Target is shown in the adjacent image.

The Feature Target is made up of two opposing right angle targets that are pinned so that they are always square to one another. Once each of the right angles is measured, it is possible to compute the diameter of the pin as well as its location. Once again, this happens automatically.



The use of the Feature Target removes the necessity to probe or target the pad area. This has significant time benefits.



The initial coordinates system and approximate 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 resection 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 Z-axis goes through Target 3 at the top of the bar. The positive X-axis is up out of the AutoBar. The diagram on the left shows both the AutoBar and its coordinate system.

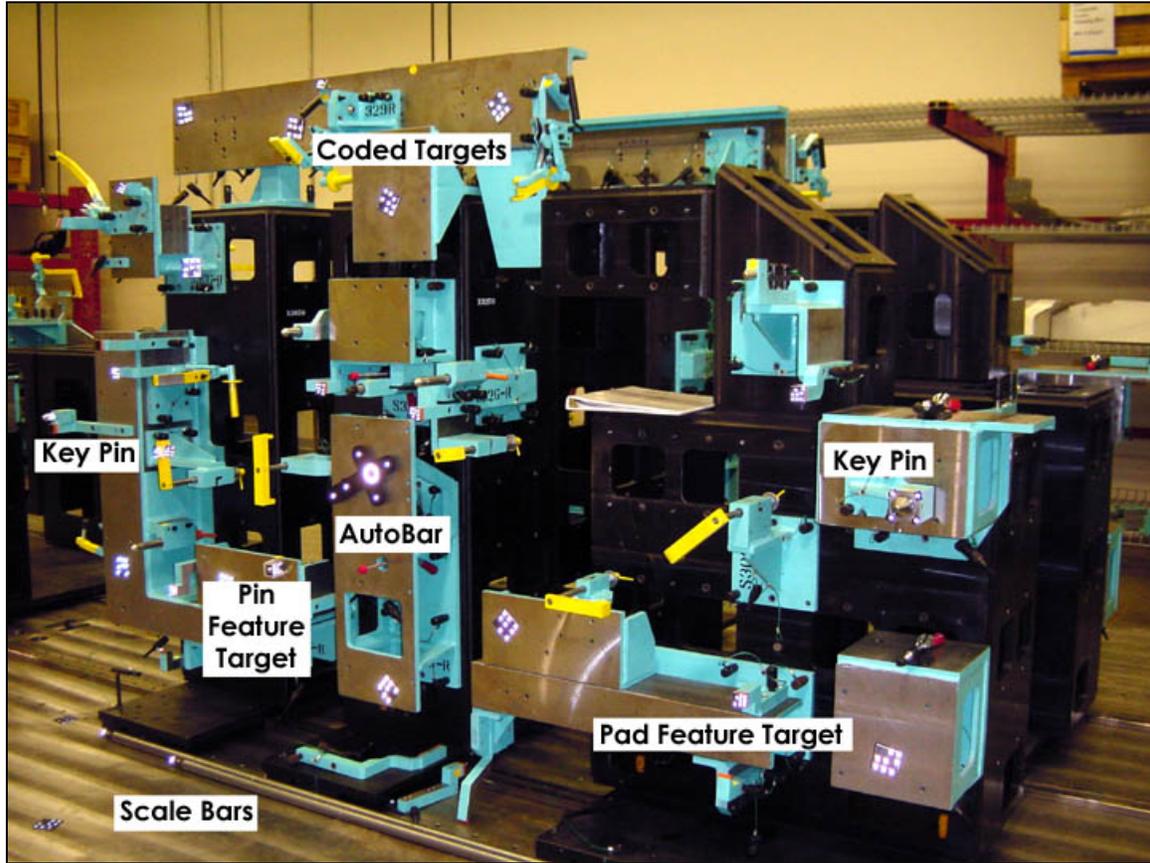
To scale a photogrammetric measurement, there must be at least one known distance. Normally this distance comes from a calibrated coded graphite scale bar or invar scale bar (Refer to adjacent image). Typically, multiple scales are used for redundancy. Two scale bars were used to complete each measurement.



Invar Scale Bar Kit

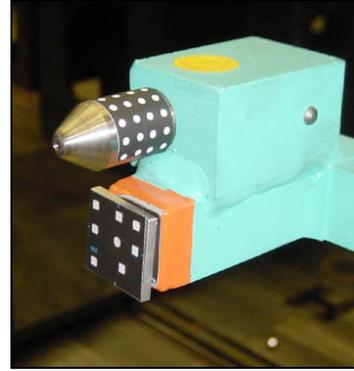
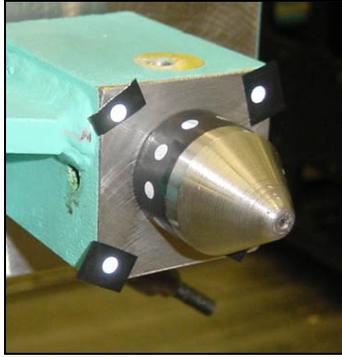
Scale bars made up of the same material as the Fixture are also popular as they have the same thermal expansion properties.

Some of the typical targeting features are shown in the image below: -



Targeting Used

1. AutoBar for initial coordinate system.
2. Coded targets to tie photography together.
3. Scale bars to scale the network.
4. Plane Feature Targets to locate pads. (Refer to image below)
5. Circle Feature Targets to locate pin.
6. Individual target to locate two addition pins. (Refer to image below)
7. Tooling targets to locate tooling holes in base.

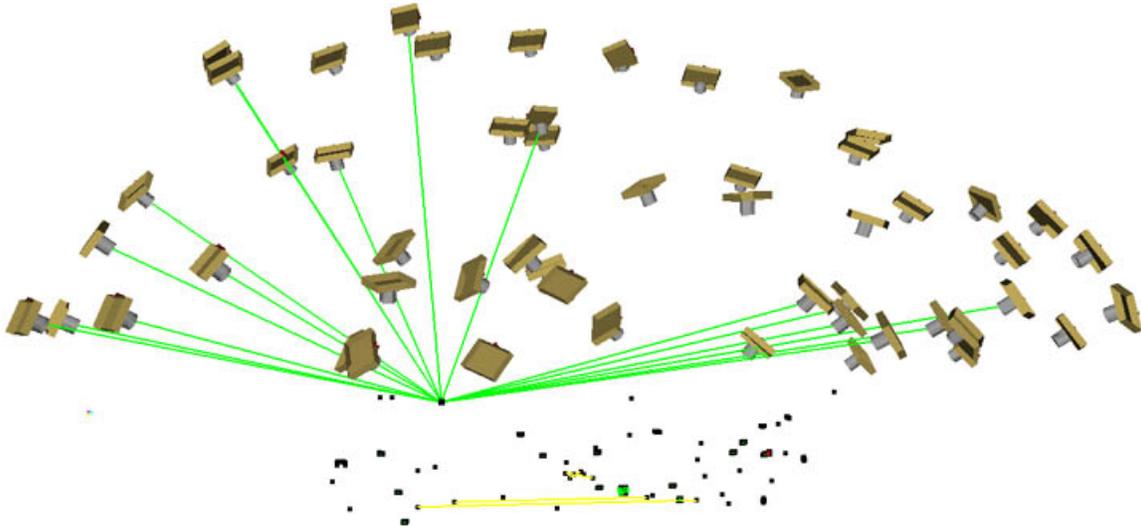


It is important to note that for a real measurement, adapters rather than targets would be used to measure the pins. Unfortunately, adapters were not available for the various pin sizes found on this fixture.

Photography

The photography is carried out once the object targeting is completed. 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 measurement, generally photos are taken both close to the ground and from an elevated position. The number of photos taken depends on the complexity of the measurement and accuracy requirements. In this measurement, the photography was straightforward.

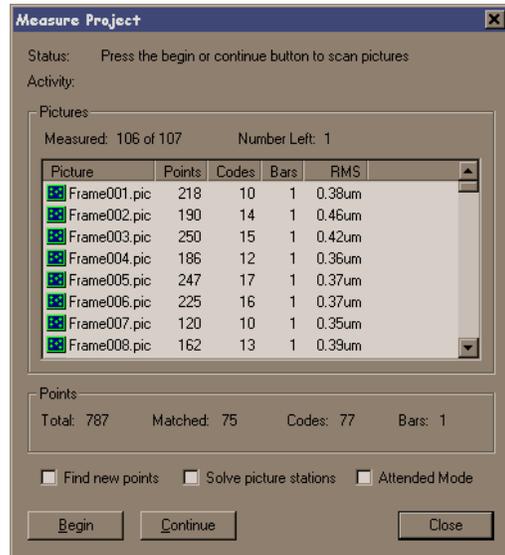
The geometry used to create the network for the measurement is illustrated in the image below. Also shown is an example of the rays of intersection to a point.



Processing

Once the photography has been completed the images are transferred to the system laptop. The images are stored on an IBM MicroDrive 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. A typical 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.



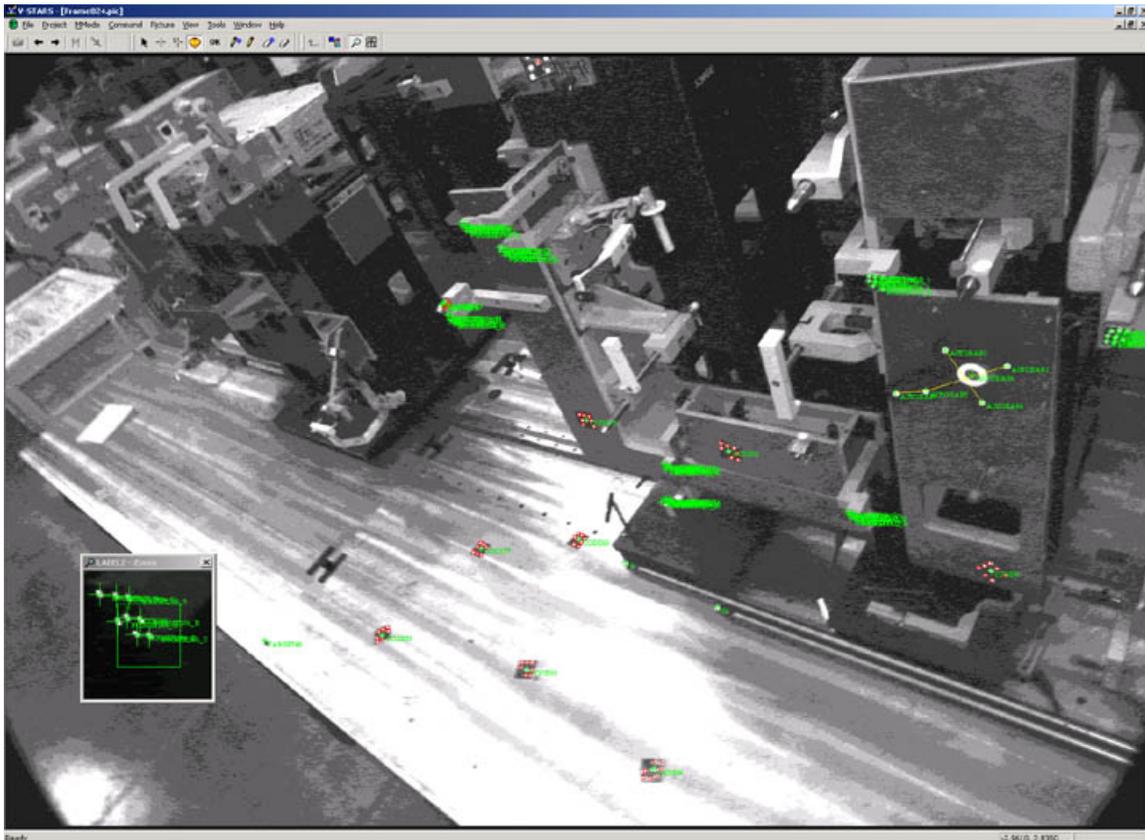
Typical AutoMeasure Dialog

The AutoMeasure routine will assign random labels to the points it finds. These labels start with the key word "Target" followed by a number. If specific labeling is required the random labels can be easily changed to labels defined by the user. This is possible in both the picture view and the graphical 3D view. In this measurement the labels were changed to simplify analysis.

Measurement Statistics

No. of photos	54
No. of points	208
Number of scale bars	2
Scale Agreement	0.007mm
Accuracy RMS X,Y,Z	X 0.011mm
	Y 0.015mm
	Z 0.011mm

Seen below is a typical measurement image.



The green crosses represent points that have been located in this particular image. Note that the image appears a little 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 the Feature Targets is shown in the zoom window in the corner. If the scale bar is visible then a yellow line will be drawn between the two ends.

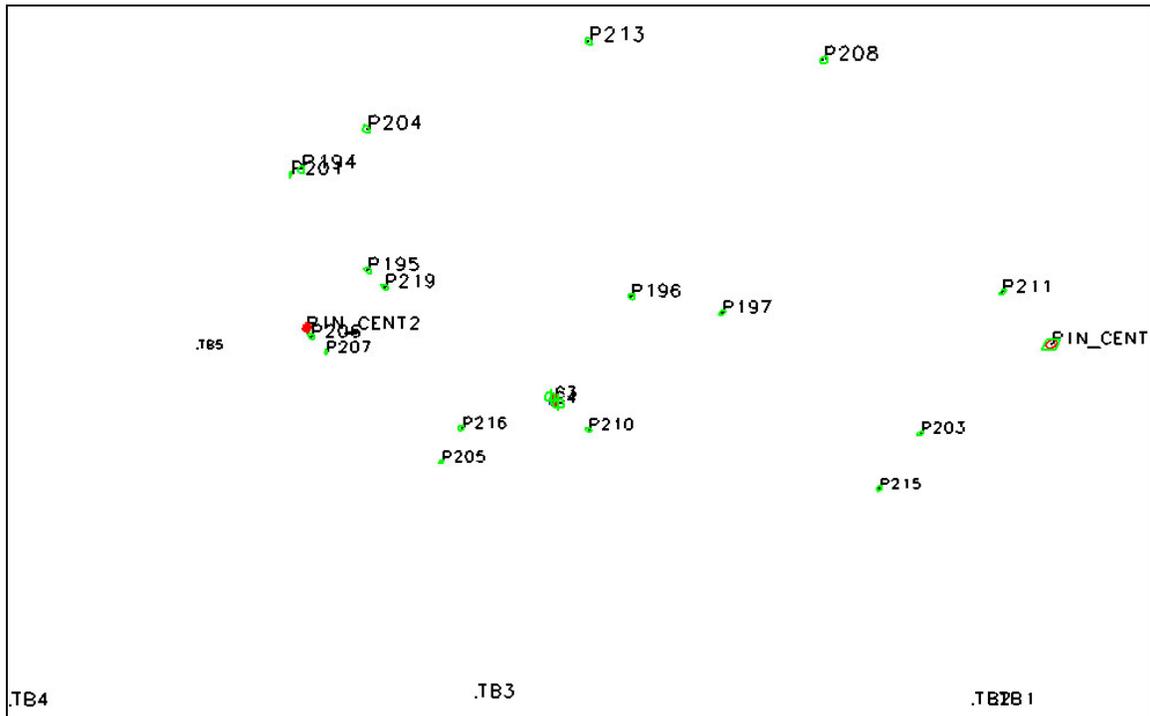
At the conclusion of the AutoMeasure the 3D data is written to a file. A typical point listing from the 3D file is shown in the adjacent image.

This point data can be analyzed within the V-STARS' SOLIDS module, easily exported to almost any CAD platform or other analysis program.

Point Label	X	Y	Z	Sigma X	Sigma Y	Sigma Z	Offset	Distort
AUTOBAR1	0.0002	-0.0000	-0.0002	0.0001	0.0000	0.0000	0.0000	0.0000
AUTOBAR2	0.0002	-0.0507	0.1139	0.0001	0.0000	0.0000	0.0000	0.0000
AUTOBAR3	0.0000	0.0000	0.1773	0.0001	0.0000	0.0000	0.0000	0.0000
AUTOBAR4	0.0000	0.0507	0.1140	0.0001	0.0000	0.0000	0.0000	0.0000
AUTOBAR5	0.0120	0.0000	0.0569	0.0001	0.0000	0.0000	0.0000	0.0000
AUTOBAR6	0.0001	0.0001	0.1272	0.0001	0.0000	0.0000	0.0000	0.0000
BP1	-2.4124	0.0070	9.9901	0.0006	0.0002	0.0002	0.0002	0.0000
BS1	-2.3705	0.7986	-9.7941	0.0002	0.0001	0.0001	0.0001	0.0000
CODE1	-2.6036	4.2035	4.8204	0.0002	0.0002	0.0001	0.0001	0.0000
CODE2	0.3099	1.9055	-0.4020	0.0002	0.0002	0.0002	0.0002	0.0000
CODE5	-1.0329	0.7115	-3.9801	0.0001	0.0001	0.0001	0.0001	0.0000
CODE6	-0.1347	-0.2348	-9.2510	0.0001	0.0001	0.0001	0.0001	0.0000
CODE7	-2.0924	-0.7821	2.8627	0.0001	0.0000	0.0001	0.0001	0.0000
CODE8	-12.2401	6.7397	-15.2500	0.0003	0.0001	0.0001	0.0001	0.0000
CODE9	-2.7518	4.0206	3.0958	0.0003	0.0003	0.0001	0.0001	0.0000
CODE10	0.3867	1.7759	-5.9284	0.0002	0.0001	0.0001	0.0001	0.0000
CODE11	-1.6466	4.0758	0.2547	0.0001	0.0001	0.0001	0.0001	0.0000
CODE13	-2.7290	4.3392	-3.5758	0.0003	0.0002	0.0002	0.0001	0.0000
CODE14	-12.2748	6.6771	-3.3756	0.0002	0.0001	0.0001	0.0001	0.0000
CODE15	-2.4832	3.3067	0.9534	0.0002	0.0001	0.0001	0.0001	0.0000
CODE17	-2.3241	3.9971	-5.2726	0.0003	0.0002	0.0001	0.0001	0.0000
CODE18	-12.8074	4.2349	0.2771	0.0002	0.0001	0.0001	0.0001	0.0000
CODE19	-13.2119	2.4353	1.4138	0.0001	0.0000	0.0001	0.0001	0.0000
CODE20	-12.2666	6.4742	3.7455	0.0003	0.0001	0.0001	0.0001	0.0000
CODE21	-12.4317	5.8322	1.0635	0.0003	0.0001	0.0001	0.0001	0.0000
CODE22	-12.5722	5.0806	5.0948	0.0002	0.0001	0.0001	0.0001	0.0000
CODE23	-13.5628	5.2443	1.1016	0.0003	0.0001	0.0001	0.0001	0.0000

Numbering Guide

The tooling targets in the base were called TB1 to TB5. The names of the other key points is shown in the image below.



Alignment

Typically one of the last tasks is alignment into the coordinate system of the object being measured. There are two basic types of alignment. The first is a simple Axis or 3-2-1 alignment. This alignment is based on three points – an origin, an axis point and a third point to define the plane in which the axis lies. The second type of alignment uses point correspondence from a known alignment (such as the CAD model) to transform the data into that coordinate system. This is a “best-fit” solution and is preferred as it involves greater redundancy.

For this measurement, the nominal data for the fixture and tooling holes was unavailable and hence it was not possible to align the data into the car coordinate system at the time this report was completed. Had the data been available a “best-fit” alignment would have been completed.

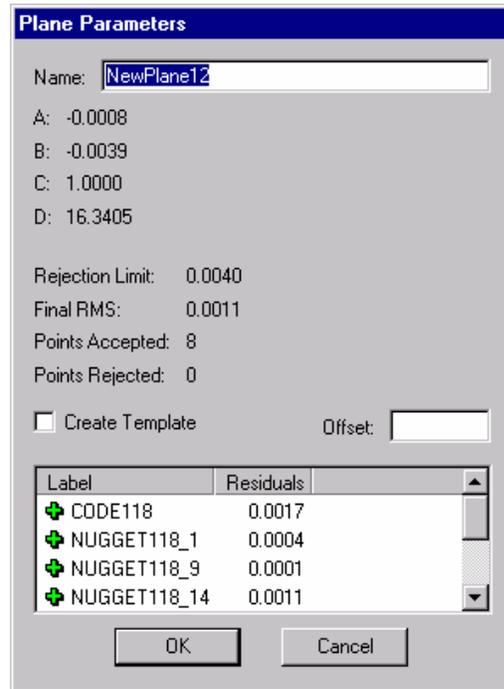
Analysis

SOLIDS is the geometric analysis module of V-STARS. For example, consider a simple function like determining the distance between two points. Computing the point-to-point distance is as simple as highlighting the two points and pressing "d". The result appears on the screen and is written to the 3D file.

Calculation of the Best-fit plane is also very simple. The plane points are highlighted and the "P" key is pressed. The plane dialog is shown in the adjacent image. The dialog gives you a few options and reports the results of the operation.

Similarly, best-fit lines, circles, cylinders, spheres, parabolas, etc. can also be calculated. SOLIDS also has the ability to measure between objects. For example, by selecting a point and a plane the normal distance can be computed. This makes SOLIDS a very useful analysis tool.

For this measurement, the functionality of SOLIDS was used to compute the best-fit circles and cylinders of the pins.



Typical Plane Dialog

Results

Coordinates

The point coordinates are tabulated below.

Point Label	X	Y	Z	Description
C3	3077.260	947.645	1615.419	Point on Pin1 Centerline
C4	3073.530	922.880	1619.505	Point on Pin1 Centerline
P194	4111.277	734.360	1721.567	PAD
P195	3786.326	796.127	1778.751	PAD
P196	3290.711	788.732	1212.750	PAD
P197	3094.952	778.577	1019.496	PAD
P201	4103.788	933.225	1815.721	PAD
P203	2305.028	851.788	691.195	PAD
P204	4090.303	786.197	1530.990	PAD
P205	3087.378	979.045	2063.202	PAD
P206	3714.222	832.579	2051.781	PAD
P207	3596.778	1056.562	2144.443	PAD
P208	3556.609	789.091	442.254	PAD
P210	2937.157	902.215	1580.037	PAD
P211	2689.567	731.002	308.601	PAD
P213	3940.894	822.434	928.836	PAD
P215	2083.614	981.088	891.814	PAD
P216	3174.651	920.935	1912.147	PAD
P219	3712.492	834.221	1782.463	PAD
PIN_CENT	2437.188	737.537	244.610	Center of Pin 2
PIN_CENT2	3743.322	824.008	2043.168	Center of Pin 3
TB1	1827.465	209.469	960.918	Tooling Hole
TB2	1868.842	213.680	1018.241	Tooling Hole
TB3	2707.746	303.674	2184.105	Tooling Hole
TB4	3453.384	337.282	3237.169	Tooling Hole
TB5	3696.263	1982.330	2960.127	Tooling Hole

The pin diameters were determined and tabulated in the following table.

PIN	Diameter(mm)
PIN1	24.986
PIN2	18.964
PIN3	31.714

Comparison to CAD Data

Unfortunately, no CAD data for the mating part for the fixture was available at the time this report was written. To evaluate the data, the deviation of the point to the corresponding surface is computed. This information is displayed as a colored directional vector for ease of interpretation. The results can also be reported as a text file.

Time Summary

Targeting	10 minutes
Photography	3 minutes
Processing	3 minutes
Analysis	4 minutes
Total	20 minutes

Concluding Remarks

The measurement undertaken has shown that V-STARS with the INCA S6 system and feature targets can be a very powerful measurement tool. The results of the measurement undertaken were very accurate and more importantly were produced quickly. The system is portable and capable of collecting data quickly enough to ensure minimal disruption to the production line. As a byproduct of this speed, traditional concerns regarding temperature variation are also eliminated.

GSI would like to thank Ford for welcoming us into their Dearborn facility. We will be happy to discuss the results of this report or any other aspect of the technology presented.