V-STARS Tutorials

Introduction

These tutorials will guide you through several V-STARS measurements. The measurements all use the same set of pictures, but they are measured in different ways to illustrate different features of the software. It is important to follow the instructions exactly as you do each measurement, or else you may not get the results shown here, and the tutorial will not be effective. Later, you can experiment with the measurements and try different things to more fully explore how V-STARS works.

The tutorials assume you are familiar with photogrammetry. If you are not, you should refer to the Basics of Photogrammetry before proceeding.

The photography was taken with an INCA6.3 camera with a 17mm lens. However, the example is also applicable to any V-STARS system or camera.

If V-STARS is installed on any other driver other than the C driver, then it may be necessary to import the project images manually.

Installing the V-STARS Tutorial

To ensure that you start the tutorial from the beginning, you need to "install" it before you begin. To do this:

1. Press the Windows **Start** button.

2. Select **Programs** from the **Start** menu.

3. Select **V-STARS** from the **Programs** menu.

4. Select **V-STARS Demo Install** from the **V-stars** menu.

The system will install the V-STARS demonstration tutorial. This process only takes a few seconds.
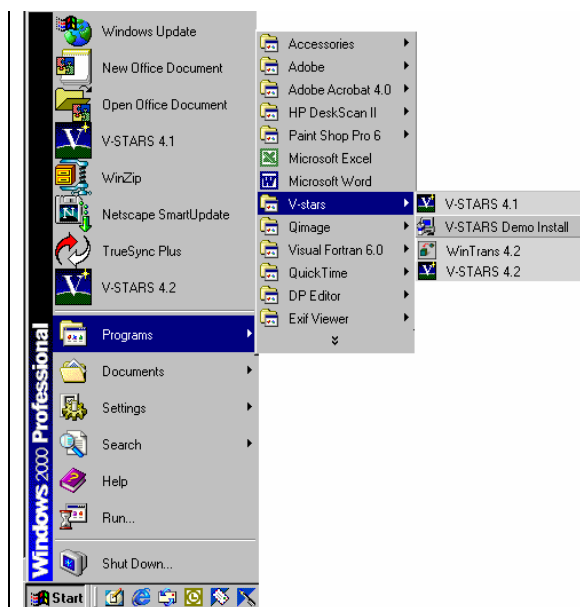
The Tutorial Measurement Object

The measurement uses the V-STARS training fixture. It is a rectangular frame 1.2 meters (48 inches) wide, 0.75 meters (30 inches) high and 0.75 meters (30 inches) deep. The frame has retro-reflective targets on the front face and on the interior face of the back of the frame.

The fixture also has an AutoBar attached to the front face. The AutoBar defines the local V-STARS coordinate system; the origin is at the bottom target on the bar, the Y-axis is up, and the Z-axis is to the left. The positive X-axis is perpendicular to the plane of the AutoBar. The accompanying image displays the AutoBar coordinate system.
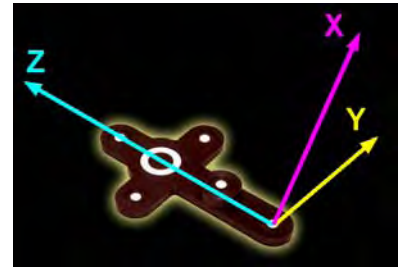
The tutorial measurement uses millimeters as the unit of measure.

We have adopted a user coordinate system that has the origin at the bottom left corner of the front face of the fixture. The X-axis is to the right, the Y-axis is up (perpendicular to X) and the positive Z-axis is perpendicular to the other two. After the measurement, the results can be transformed from the local AutoBar coordinate system into the user coordinate system using the 3-D Viewer in V-STARS. The AutoBar and user coordinate systems are shown below.

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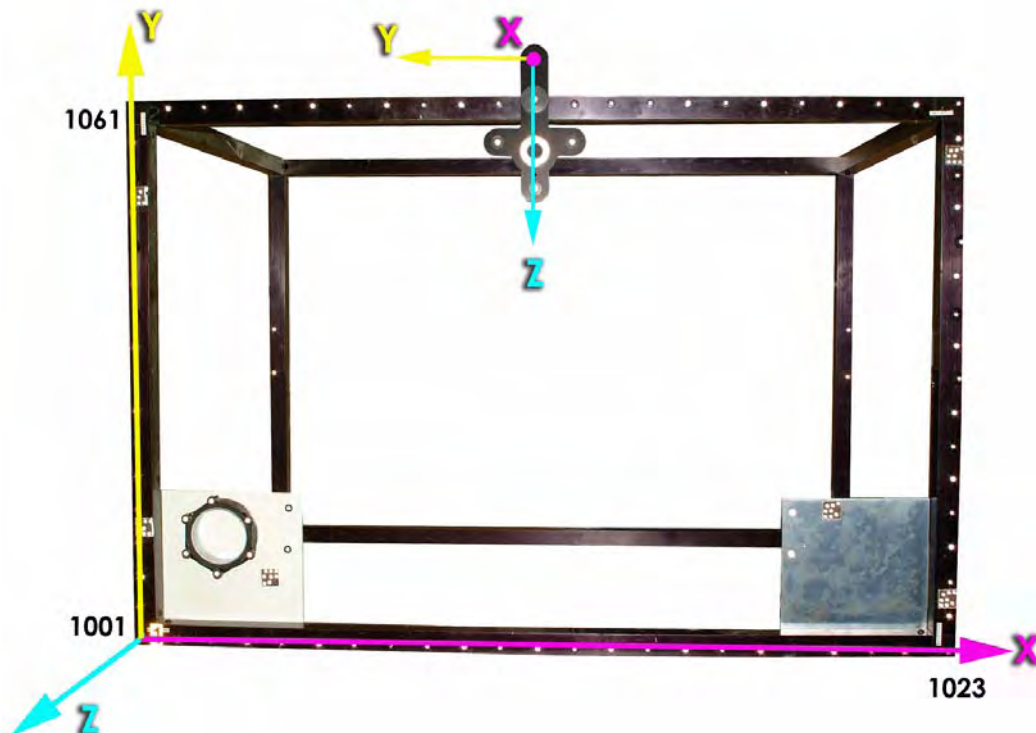
The image below shows some of the items of interest on the frame and the point labels they have been assigned.
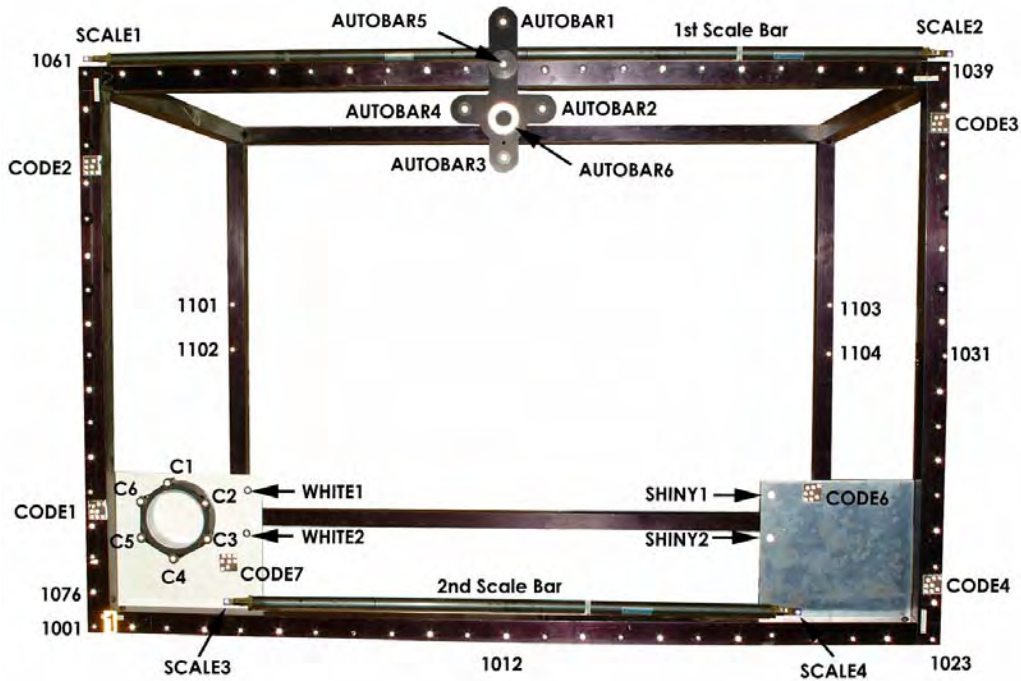
📒 A black circular border has been digitally added to the points WHITE1 and WHITE2 on the image above to help you see the points on the white plate.

We will concentrate on measuring the front face (face #1) of the frame. We have added four points to the interior face of the back of the frame to add some 3-dimensionality to the measurement. This will provide a better solution. We have also rigidly attached two scale bars to the object that will be used to scale the measurement. There are also two plates attached to the bottom corners of the frame. The one in the left corner is white; the one in the right corner is shiny aluminum. There are two retro-reflective targets on each plate. We will also measure these targets to show how easily retro-reflective targets can be measured even against bright backgrounds. Also on the white plate is a bolt circle fixture with six targeted points.

There are 106 targeted measurement points. The adopted point-labeling scheme is as follows:

Points	Number	Description
AUTOBAR1-6	6	The six points on the AutoBar (including the ringed point)
CODE1-4,6,7	6	Coded targets
1001-1076	76	Located on the front face, starting at the bottom left corner and going counterclockwise around the frame.
1101-1104	4	Located on the interior of the rear face.
SCALE1,2	2	Scale bar located on the top of the frame
SCALE3,4	2	Scale bar located on the bottom of the frame
WHITE1,2	2	Targets on white plate
SHINY1,2	2	Targets on shiny aluminum plate
C1-6	6	On bolt circle on white plate
TOTAL	**106**	Total number of points in project.

The targets on the front face are of two different sizes. The odd-numbered targets are 3mm in diameter; the even-numbered ones (and all other targets) are 6mm in diameter. Although you can use different target sizes on a measurement so long as the minimum Target Size requirements are met, we recommend you try to use the same size targets on a measurement whenever possible. Refer to the Basics of Photogrammetry for more information. However, target sizes that vary by up to 2 to 1 in size are usually acceptable, as this tutorial will illustrate.

The Tutorial Measurement Plan

We want to achieve good accuracy and reliability with a reasonable amount of effort. Good planning is needed to ensure that this happens. The V-STARS Planning Checklist should be used as a guide, and is reproduced here. Refer to the Basics of Photogrammetry section for more information on where these planning checks come from.

V-STARS Planning Checks

1) **Triangulation Requirements:**
    a) Need two different sightings of every point (prefer four as a minimum).
    b) Need good intersection angles between points (60°-120° is good).

2) Resection Requirements:

    a) Need to see the AutoBar or four known points in every picture (points cannot be in a line).
    b) Need at least 12 **well-distributed** points on every photo (but 20 is better).

3) Self-Calibration Requirements

    a) Need to roll camera by 90° (at least once, more is better).
    b) Need at least four to six photographs (four if not flat, six if flat).
    c) Need photographs from at least three different locations.
    d) Need at least 20 **well-distributed** points in the entire measurement (but 40 is better).

4) Overlap Requirements

📒 Only needed if entire object is not seen at once). Not applicable for this measurement.

    a) Need at least three common points for adjacent sections (but more is better).
    b) Common points cannot be in a line (triangle or better).

5) Scale Requirements (only needed if accurate scaling is needed)

    a) At least one known distance available (prefer at least three).
    b) Scale distance is as long as practicable.

The plan is to take photographs from four different locations around the front of the frame as shown in the figure. The camera is located at 90° spacing around the frame, at about a 45° angle to the center of the frame. This provides good intersection and viewing angles to all the targets. We will take the top and bottom photographs with the normal horizontal roll, and then take the left and right photographs with the camera rolled to the vertical position. This will allow us to self-calibrate the camera. The four points on the back of the frame provide enough 3-dimensional distribution for a good self-calibration to be achieved with just four photographs. A review of the planning checklist above shows this plan should meet all the requirements for a successful measurement.
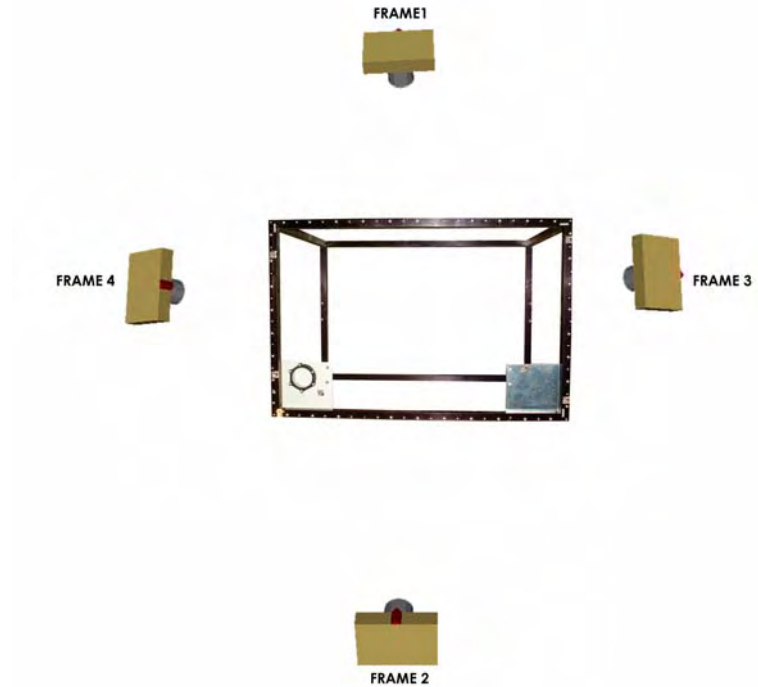
Tutorial Descriptions

We will measure the frame a number of times in these tutorials. We will measure it once as an initial measurement, and then a second time as a repeat measurement.

In a repeat measurement, approximate coordinates are available for some, if not all, of the target points, while in an initial measurement no coordinates are available for any of the points.

In the first tutorial, we measure the frame as an initial measurement using the AutoMeasure command. This will give you some experience with the most common method of operation.

In the second tutorial, we will also measure the frame, but as a repeat measurement, and using the some of the measurement information created in the first tutorial. We will use the AutoMeasure routine again, but this time we will use an existing data file that has initial coordinates for the points.

First Tutorial

Initial Measurement with AutoMeasure

The new AutoMeasure command greatly automates measurements whether they are initial or repeat measurements. It is by far the most common way to process images to produce coordinates. In the past, it was necessary to reduce the pictures using tedious manual methods. In some cases, it still may be necessary for you to measure some pictures and/or points that the AutoMeasure process failed to measure automatically. These types of situations are also covered.

This first tutorial will take you through a measurement using AutoMeasure so you will better understand the most commonly used way in which pictures are processed to produce coordinates.

In the course of this measurement, you will learn to:

1. Start V-STARS and open an existing project.
2. Familiarize yourself with some of the different objects/items in V-STARS.
3. Use AutoMeasure to measure the image points on the pictures.
4. Manually rename measured points.
5. Delete false points.
6. Use scale bars to scale the measurement.
7. Run the Bundle Adjustment to produce the 3-D coordinates of the points from their measured images.
8. Inspect the Bundle results for any problems.
9. Construct average and vector points from measured points.
10. Perform basic coordinate transformations.
11. Check scale results, and measure point-to-point distances.

Setting up the Measurement

First, we setup the tutorial measurement by doing the following:

1. Starting V-STARS.

2. Opening the tutorial project.

3. Familiarizing you with the V-STARS windows.

Starting V-STARS
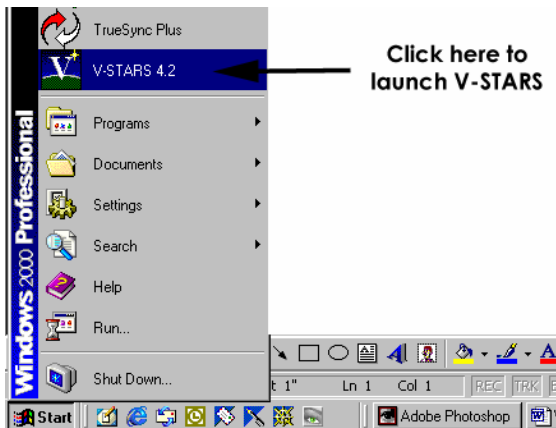
Click here to launch V-STARS

1. Start **V-STARS** by clicking on the ![Start] button at the bottom left of the screen. A list will pop-up displaying some selections.

2. Click on the **V-STARS** option to start the program.

3. V-STARS will open and a blank screen will be displayed with a menu of selections at the top.
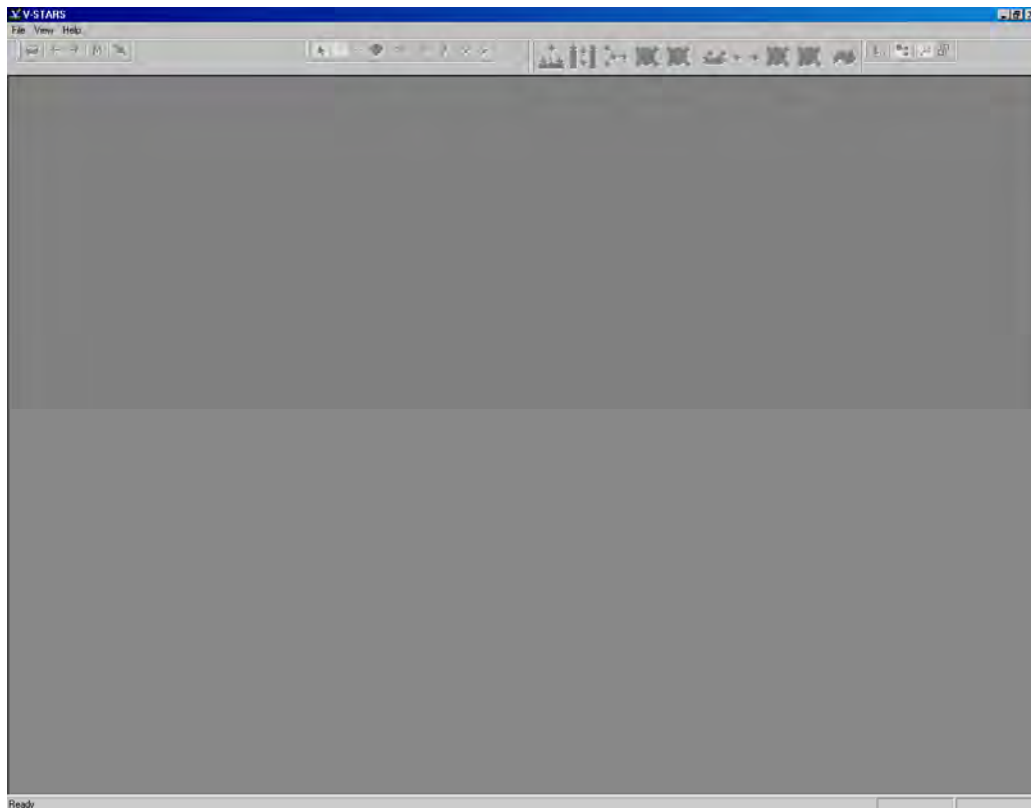
Opening the Project

To simplify and standardize the tutorial we have already created a V-STARS project for this measurement. We will start by opening this existing project.

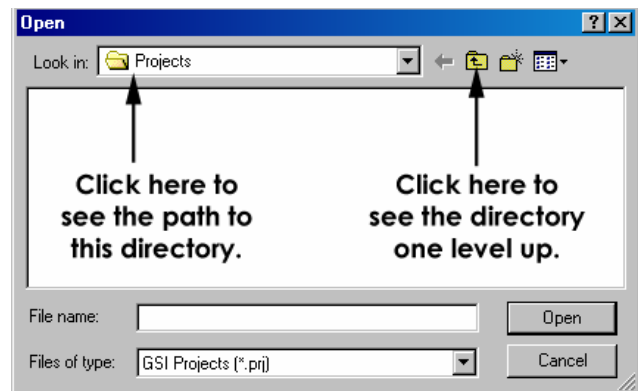1) Open the tutorial project by selecting **Open** from the **File** menu. V-STARS will open a dialog box, similar to the one below, showing all the current projects in your default project directory.
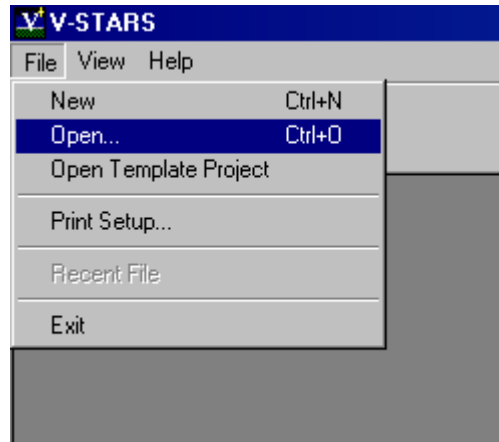
2) As this is a demonstration project, it has been saved in the `C:\Vstars\Demos` directory. Go to this directory using the standard methods available in the dialog box and open the folder icon for the `FRAME INITIAL MEASUREMENT`. If there is no such folder in the demo directory, verify that the demonstration tutorials have been installed as described earlier in the **Installing the V-STARS Tutorial** section.

3) Select the FRAME INITIAL MEASUREMENT.prj file and press the **Open** button.

4) V-STARS will open the tutorial project.

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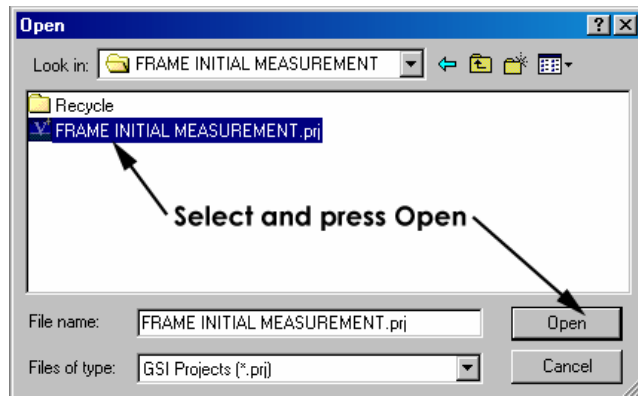
Examining the Project

After opening, the display should appear as shown below. Don't be alarmed if the thumbnails all appear on one line.

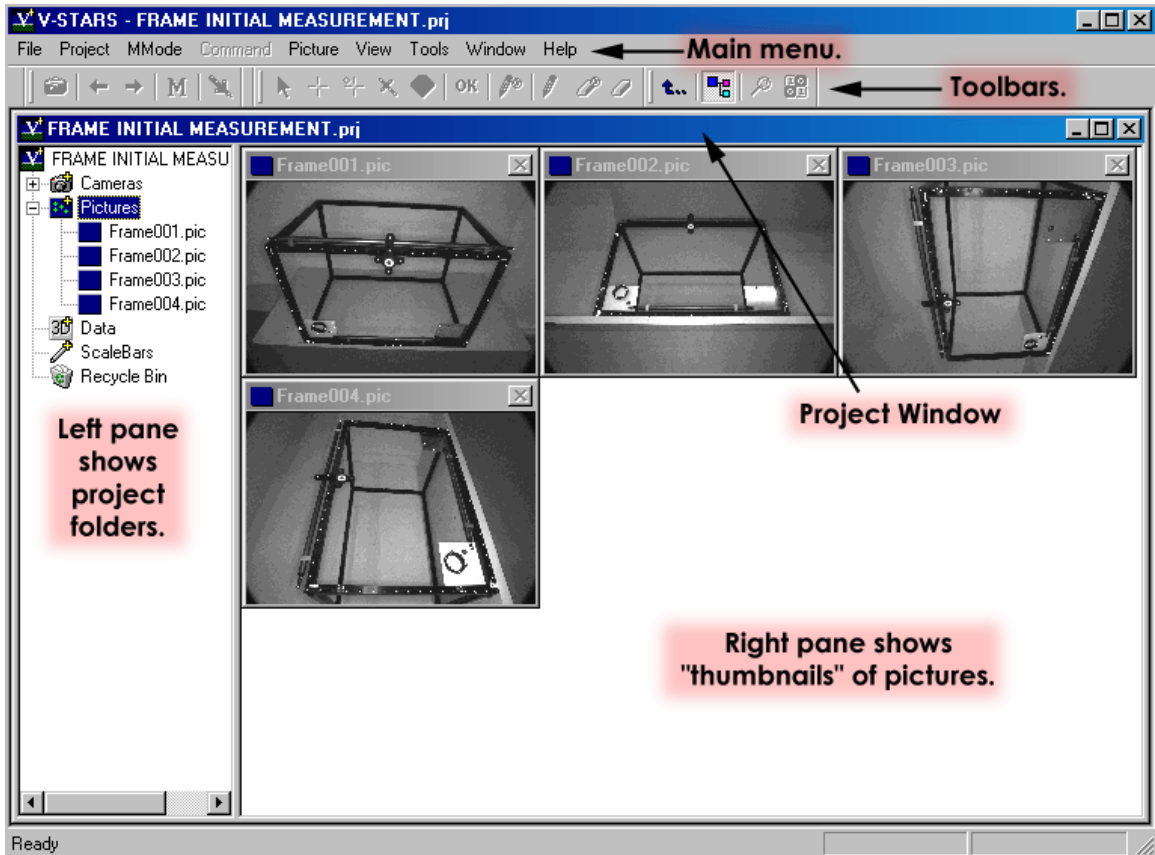The main menu at the top of the screen contains commands that are used throughout V-STARS. Below the main menu are the toolbars containing icons that represent frequently used commands. Below this is the project window. It has two "panes", left and right. The right pane of the window now displays overviews (called thumbnails) of the four pictures we took of the frame. The left pane displays all the components of the project (cameras, pictures, 3D coordinate data, scale bars, etc.). These components are stored in folders. These folders work the same way as in Windows Explorer.

Access the first picture by either clicking on its thumbnail (if you do not see the thumbnails, click on Pictures), or by double-clicking on FRAME001.PIC. A "picture window" will appear with the full image. The first picture was taken from above the frame. Let's do some exploring to learn more about V-STARS. First, the small window in the bottom, left corner of the screen is called the Zoom window. It is like a magnifying glass into the picture window. As you move the cursor over the picture, you will see a

magnified view in the Zoom window. The green rectangle in the Zoom window is the measuring area, also known as the Region of Interest (ROI); the target center must be inside this rectangle to be measured.
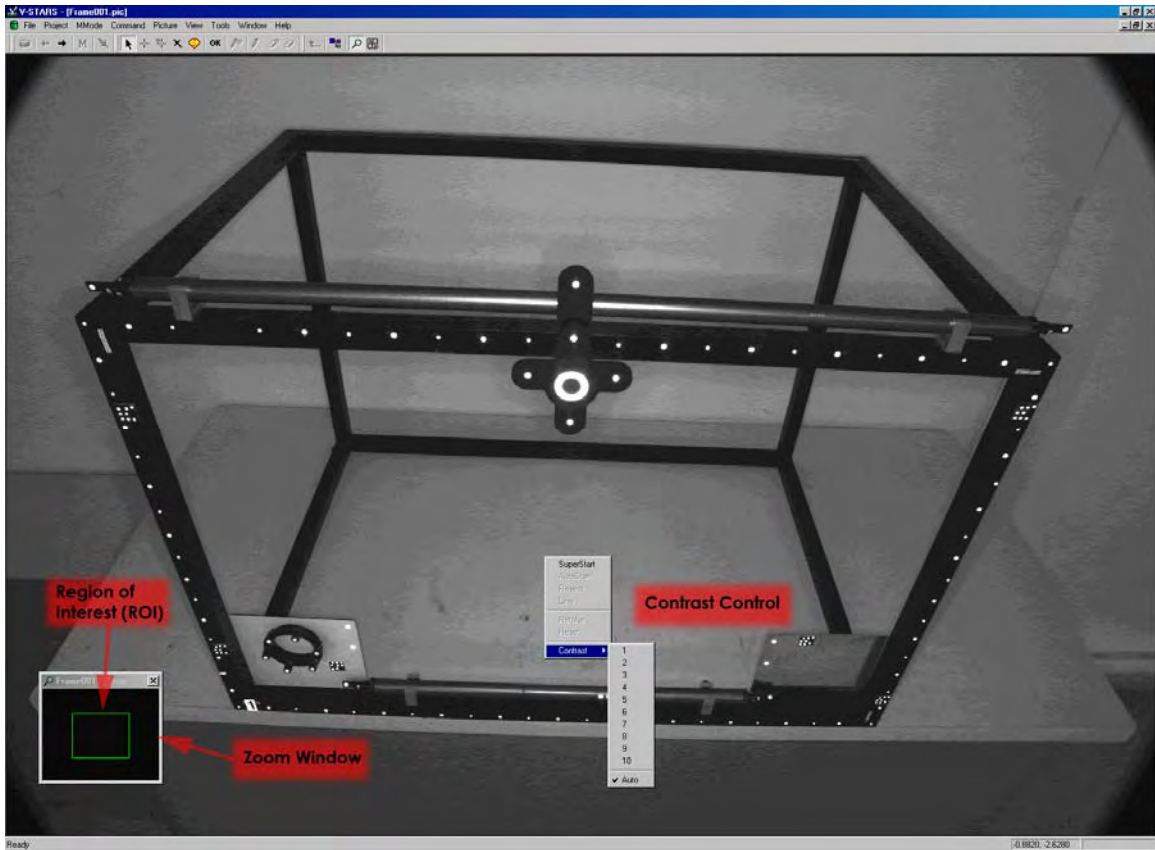
Right now, the picture contrast is enhanced. To see what the picture actually looks like, select **Contrast** from the **Picture** menu and select **1**. Notice now the picture is darker. We have deliberately underexposed the background to make the targets easier to find and measure. V-STARS can automatically adjust the contrast for each picture when the contrast is set to **Auto**. We usually recommend you use this setting.

You can also access some of the more frequently used commands by right-clicking the mouse in the picture window, and selecting the command from the pop-up menu. To illustrate this, turn the Auto-contrast back on by right clicking the mouse in the picture window, and selecting **Contrast**. Then, select **Auto**. The picture contrast will be enhanced again.

The picture contrast setting has no effect on the measurement; it only helps you see the picture.

The Measurement

Running AutoMeasure

The AutoMeasure procedure is a collection of V-STARS routines that are automatically called to automate the measurement and processing of the pictures. When set up and used properly, the AutoMeasure command performs an entire measurement with little more than the push of a single button. However, this level of automation actually requires more diligence by the operator. AutoMeasure requires so little operator involvement in the actual measuring that it is easy to overlook potential problems. The operator must examine the results carefully to make sure no point measurements are missed, and must make sure no false points are measured.

Maximize the V-STARS application window and the Project window. For convenience, the various Windows icons are explained in the adjacent image.

Minimize
Maximize
Close
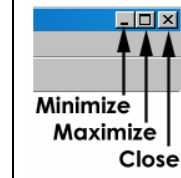
📒 Some of the diagrams in this manual will not correspond exactly due to differences in the screen resolution between your computer and the one used to create the manual.
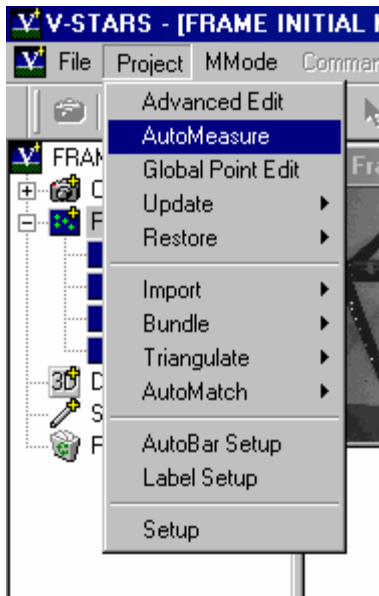
1. Select the **AutoMeasure** command from the **Project** menu. The **AutoMeasure** Dialog will open.

The **AutoMeasure** command opens the **Measure Project** dialog shown. From this dialog, it

is possible to complete the entire V-STARS measurement.

Measure Project

Status: Press the begin or continue button to scan pictures
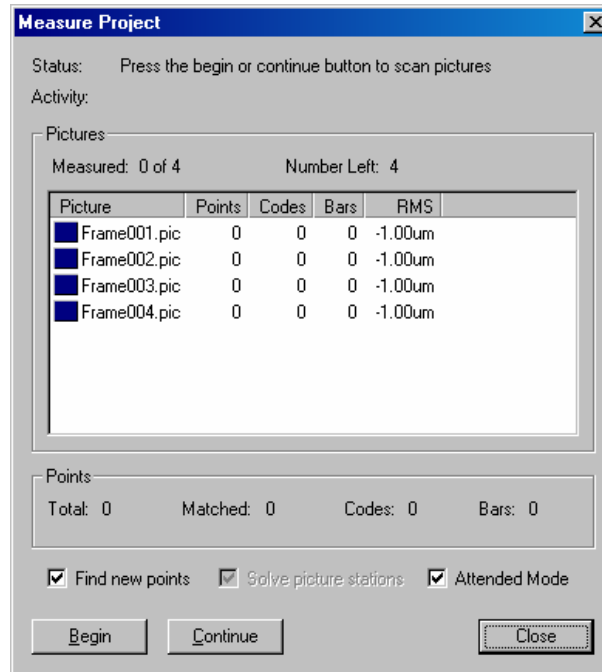Activity:

Pictures

Measured: 0 of 4   Number Left: 4

Picture	Points	Codes	Bars	RMS
Frame001.pic	0	0	0	-1.00um
Frame002.pic	0	0	0	-1.00um
Frame003.pic	0	0	0	-1.00um
Frame004.pic	0	0	0	-1.00um

Points

Total: 0   Matched: 0   Codes: 0   Bars: 0

☑ Find new points   ☑ Solve picture stations   ☑ Attended Mode

Begin   Continue   Close

2. The AutoMeasure dialog box displays the starting status of the process. We have four unmeasured pictures, and of course, have no measured points of any kind. The Find New Points box is checked since this is an initial measurement. The Attended box is also checked so we can monitor the AutoMeasure operation as it proceeds. Press the **Begin** button to start AutoMeasure.

3. AutoMeasure first scans all the pictures to find all candidate targets including the AutoBar and any coded targets. AutoMeasure displays each picture as it is measured. Notice the picture icons change to indicate the status of the picture measurement.
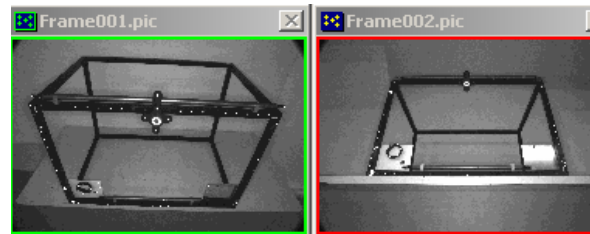
Scanned & measured.   **Only scanned.**

Also the border around the picture thumbnails change color to indicate the picture status. A green border means the picture was scanned and measured, while a red border means the picture was only scanned; a picture solution was not possible because no AutoBar was found.

4. We have scanned the pictures for all the points we can. Now we want to find the points and identify and measure them. We can use a method called AutoMatching to automatically identify all new points. However, for the AutoMatching to work best, we need the best possible solution for the picture stations. We already have a good solution, but we can get a better one by running a preliminary Bundle adjustment. This will give us a new and better solution for all the measured target points as well.

5. When done scanning, AutoMeasure will display the current results.

The next step is to get a better solution for the pictures.

We got a solution for 3 of the 4 pictures.

No AutoBar found. AutoBar1 is blocked. No solution yet, but we have coded targets in the picture.

This shows the quality of the picture solution. A value of < 1um indicates good AutoBar and coded target values as well as a good camera calibration.

Press the Continue button to go to the next AutoMeasure step.

6. Press the **Continue** button at the bottom of the AutoMeasure dialog to go on. V-STARS will run the Bundle adjustment, and display its progress in the Activity line. When it is done, the dialog should appear as shown below.

Measure Project

Status: Press the continue button to AutoMatch pictures ← The next step is to AutoMatch the pictures.

Activity: Done solving picture stations

Pictures

Measured: 4 of 4 ← Number Left: 0 ← We got a solution for all of the pictures.

Picture	Points	Codes	Bars	RMS
Frame001.pic	12	6	1	0.23um
Frame002.pic	11	6	0	0.25um
Frame003.pic	12	6	1	0.20um
Frame004.pic	11	5	1	0.19um

No AutoBar found, but a solution has been found using the coded targets in the picture.

The ⊠ icons indicate that we have coordinated 4 of the 4 pictures.

This shows the quality of the picture solution. These values are lower than before as the coordinate values and camera parameters have improved.

Points

Total: 12   Matched: 0   Codes: 6   Bars: 1

☑ Find new points   ☑ Solve picture stations   ☑ Attended Mode

Begin   Continue   Quit

Press the Continue button to go to the next AutoMeasure step.

7. We now have a better solution for the picture stations, and can proceed to AutoMatch all the pictures to measure the points. Press the **Continue** button to proceed to the next step and AutoMatch the pictures. V-STARS will display an AutoMatch dialog box to indicate the progress of the operation.

AutoMatch All Pictures

Setting up AutoMatch for 4 pictures

Estimated time left:

New points identified: 0

Stop

When done, the AutoMeasure dialog box should appear as shown below.

Measure Project				
Status: Press the continue button to run the final bundle				
Activity: Done AutoMatching				

Pictures

Measured: 4 of 4   Number Left: 0

Picture	Points	Codes	Bars	RMS
Frame001.pic	101	6	1	0.23um
Frame002.pic	99	6	0	0.25um
Frame003.pic	101	6	1	0.20um
Frame004.pic	100	5	1	0.19um

Points

Total: 101   Matched: 89   Codes: 6   Bars: 1

☑ Find new points   ☑ Solve picture stations   ☑ Attended Mode

Begin   Continue   Quit

The next step is to run the final bundle.

We now have about 100 points in each of the four pictures.

This box shows that 89 points have been AutoMatched. The total number of points is now 101. 6 codes + 6 AutoBar + 89 points.

Press the Continue button to go to the final bundle stage of the AutoMeasure.

Press the **Continue** button to proceed to the next step and run the Bundle adjustment on the four pictures. The progress of the adjustment will be displayed, and when done the Bundle Summary dialog box should appear as shown below.
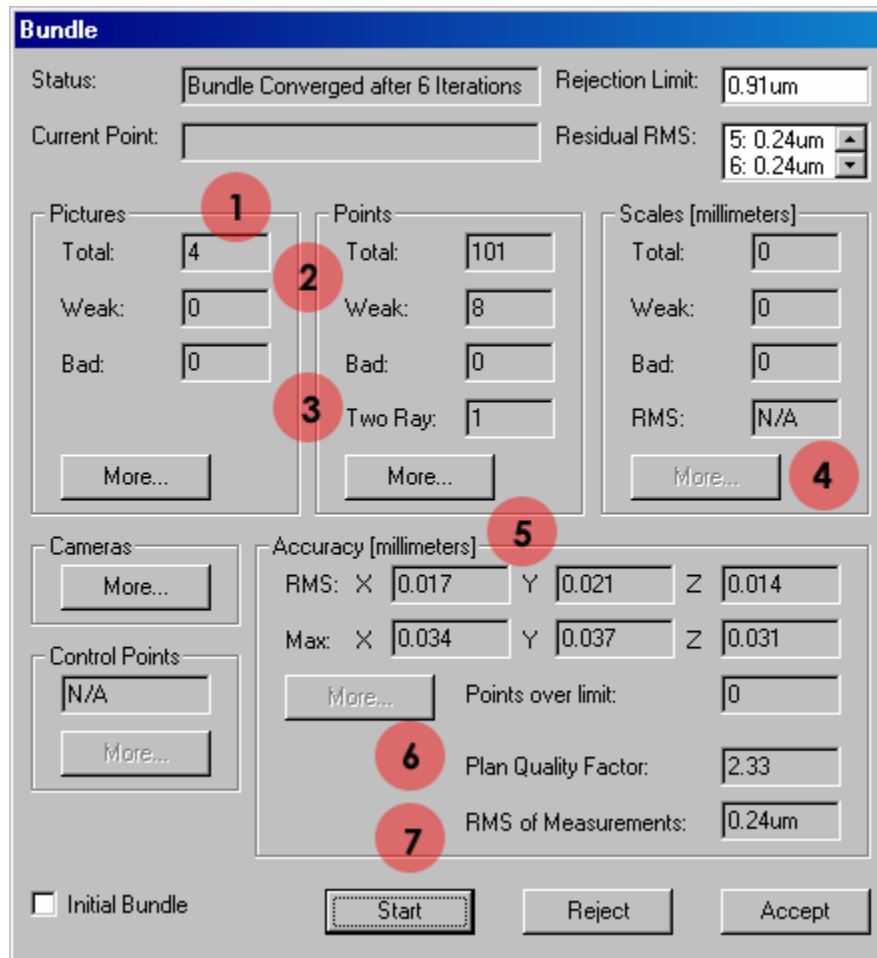
① All four pictures were processed, and none of the pictures was bad or weak. Pictures are usually bad because they do not have enough points for an acceptable solution. Pictures are usually weak because they do not have enough points for a good solution.
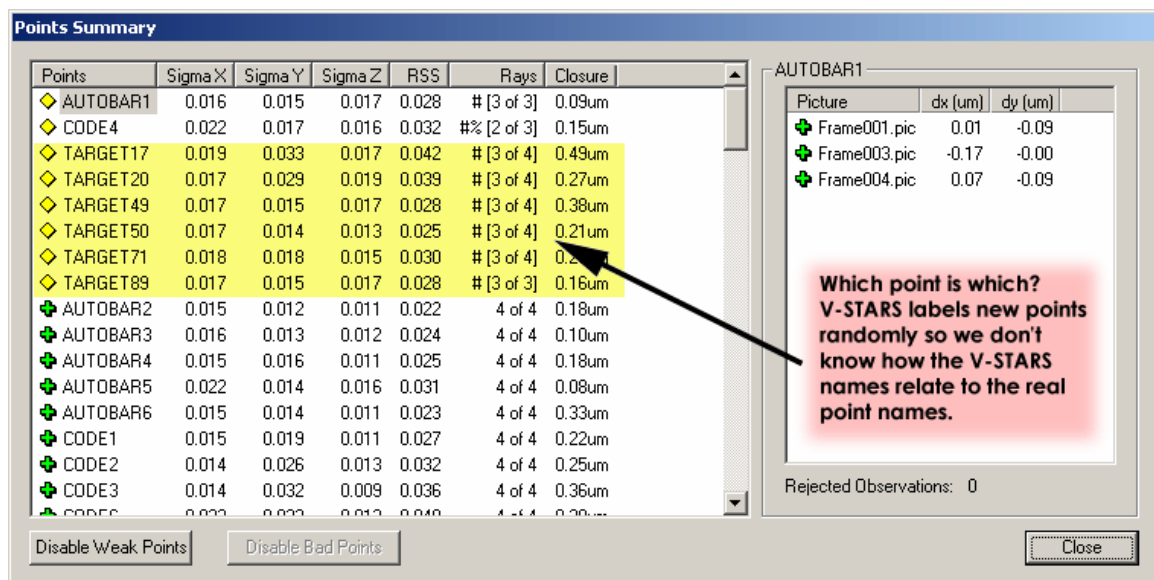
② No points are considered bad but there are several weak points to examine. A total of 101 points are in the bundle. You will recall that there should be 106 points. Where are the other points? We need to investigate further.

③ One of the points is a so-called two-ray point, which means it was seen in only two photographs. Two-ray points may have poor accuracy, and should be avoided if possible.

④ No scale bars were used to scale the measurement. Although we measured the scale bar targets, we neglected to enter the calibrated distances for the scale bars. In this case, the Bundle adjustment uses the AutoBar to provide nominal scale for the measurement.

⑤ The RMS of the accuracy estimates for the X, Y and Z coordinates for all the points is reasonable, but somewhat higher than expected.

6 The plan quality factor is over 2. In a well-designed measurement, the plan quality factor is usually between 1 and 2. The higher than expected plan quality factor reduces accuracy.

7 The RMS of measurements is low; this number indicates the quality of the measurement. The lower the number, the better the measurement accuracy. A number of 0.40μm or less is typical.

If you do not get the results listed here, you should press the **Reject** button. Then, review the tutorial instructions for the first four pictures, and correct any problems. Finally, re-run the bundle so you get the results listed here before proceeding with the tutorial. If all this fails, consider starting over.

8. Press the **More** button in the Point section to examine the points in more deail.

Points Summary

Points	Sigma X	Sigma Y	Sigma Z	RSS	Rays	Closure
◇ AUTOBAR1	0.016	0.015	0.017	0.028	# [3 of 3]	0.09um
◇ CODE4	0.022	0.017	0.016	0.032	#% [2 of 3]	0.15um
◇ TARGET17	0.019	0.033	0.017	0.042	# [3 of 4]	0.49um
◇ TARGET20	0.017	0.029	0.019	0.039	# [3 of 4]	0.27um
◇ TARGET49	0.017	0.015	0.017	0.028	# [3 of 4]	0.38um
◇ TARGET50	0.017	0.014	0.013	0.025	# [3 of 4]	0.21um
◇ TARGET71	0.018	0.018	0.015	0.030	# [3 of 4]	0.2
◇ TARGET89	0.017	0.015	0.017	0.028	# [3 of 3]	0.16um
✚ AUTOBAR2	0.015	0.012	0.011	0.022	4 of 4	0.18um
✚ AUTOBAR3	0.016	0.013	0.012	0.024	4 of 4	0.10um
✚ AUTOBAR4	0.015	0.016	0.011	0.025	4 of 4	0.18um
✚ AUTOBAR5	0.022	0.014	0.016	0.031	4 of 4	0.08um
✚ AUTOBAR6	0.015	0.014	0.011	0.023	4 of 4	0.33um
✚ CODE1	0.015	0.019	0.011	0.027	4 of 4	0.22um
✚ CODE2	0.014	0.026	0.013	0.032	4 of 4	0.25um
✚ CODE3	0.014	0.032	0.009	0.036	4 of 4	0.36um
✚ CODE5	0.022	0.022	0.012	0.048	4 of 4	0.29um

AUTOBAR1

Picture	dx (um)	dy (um)
✚ Frame001.pic	0.01	-0.09
✚ Frame003.pic	-0.17	-0.00
✚ Frame004.pic	0.07	-0.09

Which point is which? V-STARS labels new points randomly so we don't know how the V-STARS names relate to the real point names.

Rejected Observations: 0

Disable Weak Points   Disable Bad Points   Close

9. The **Points Summary** has a lot of useful information, but without the right point labels we can't determine what points are missing or weak. Let close the Bundle and re-label the points V-STARS has found. Press the **Close** button and then the **Accept** button on the **Bundle** dialog.
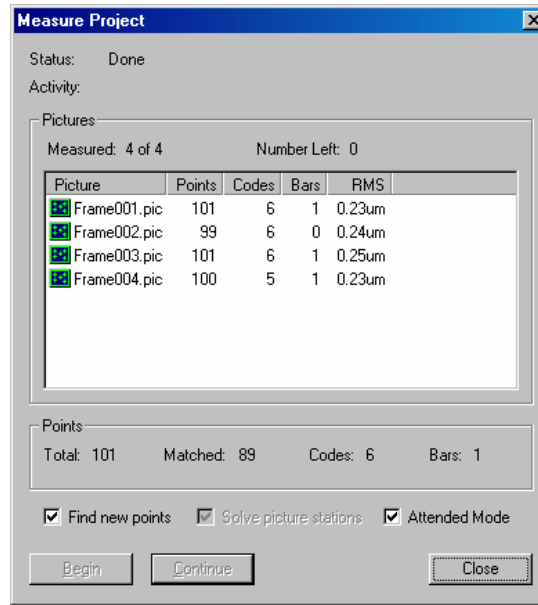
10. Press the **Close** button to exit the AutoMeasure Procedure.

Renaming the Points

📒 Renaming of points is only necessary if specific point labels are necessary. Often for analysis or extraction to a third party CAD package, specific point labels are not important.

Points in V-STARS can be renamed in both the 3D Graphical View and in the pictures. You will typically find it easier to re-label points from the Picture view as it contains other visual information to make it easier to identify points.

Let's start with the Picture renaming. Later in the other tutorials, we will rename points within the Graphical View.

Access the first picture by either clicking on its thumbnail (if you do not see the thumbnails, click on Pictures), or by double-clicking on FRAME001.PIC. A "picture window" will appear with the full image.
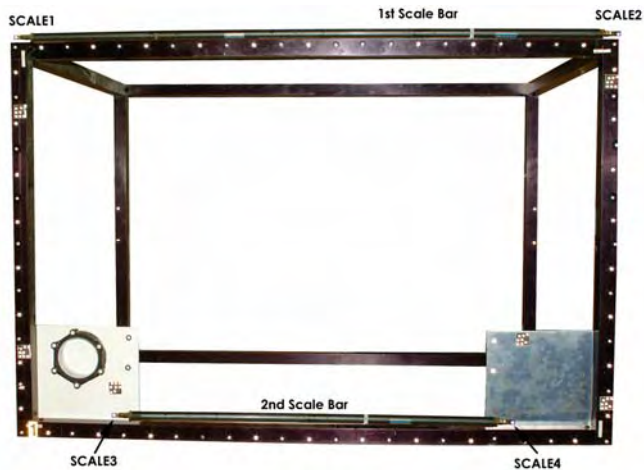
There is a Labels toolbar () at the top of the screen that is used to relabel and erase points. If you dwell on each toolbar icon for a short time, a "tool tip" will appear describing what the icon does. To globally rename the points, do the following:

1.   Click on the global rename icon on the toolbar.

📒 Make sure you select the global rename icon and not the local rename icon or you will only relabel in this picture.

2. Lets start by renaming the scale bars. The adjacent diagram shows the labeling we have adopted for the scale bars.
Move the cursor to the top, left scale bar point (it is now called TARGET5). Notice the cursor has changed shape to match the icon.

3. Relabel the point to **SCALE1**. Type in the correct label (case does not matter) scale1 and then press the ". The current label is displayed in the Zoom Window's title bar.


4. Bring the target center inside the measuring rectangle.

5. Press the left button on the mouse. The point is relabeled.

The point is **globally** relabeled to **SCALE1**; we have changed the label to **SCALE1** in **all** pictures, and in the **current** driver file. We have NOT measured the target; that has already been done. We are just globally changing its label.

Notice the current label displayed in the Zoom Window's title bar is automatically incremented and is now **SCALE2**. This is the top, right scale bar point (currently called TARGET88). Re-label it in the same way, and then relabel the two bottom scale bar points. **SCALE3** is the left one, (now called TARGET30), and **SCALE4** is the right one (called TARGET63).
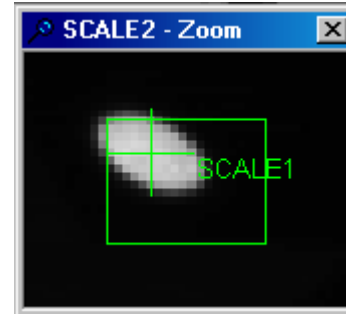
If you accidentally rename the wrong point and then try to rename the right point by resetting the label, you will get the following caution. This caution is used to prevent you from having duplicate names in the project.


To overcome this problem set the label to **TEMP1** or any other label not in use. Rename the incorrect point **TEMP1** and then proceed with the renaming process. When you rename a point that is not called **TARGET** you will be given a confirmation window. Press **Yes** if you still wish to rename the point.
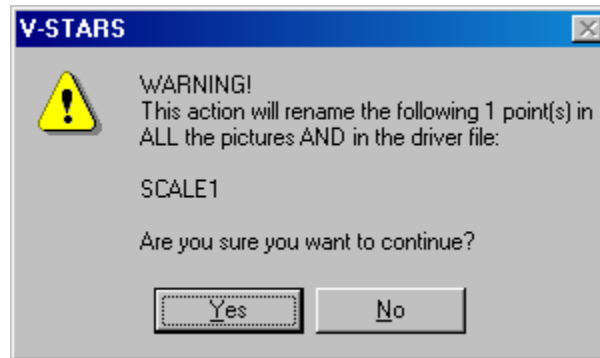
Use the following as a guide for the renaming the other points called TARGET in the project.

1001-1076

Located on the front face, starting at the bottom left corner and going counterclockwise around the frame.
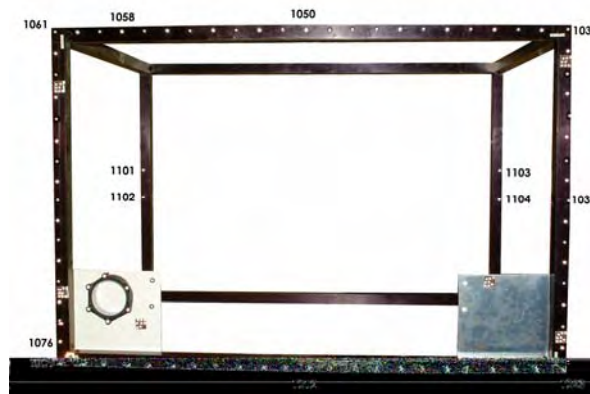
1. Start with point **1001** (TARGET18) in the bottom left corner. Set the current label to **1001**.

2. Relabel the point. Notice the label is automatically incremented to **1002**.

3. Relabel point **1002** (TARGET20) next. This is the point immediately to the right of **1001**.

Rather than continuing like this, we will use the **Line** command in V-STARS to take advantage of the fact that the points along the bottom of the frame are evenly spaced. The **Line** command uses the two most recently measured points to predict the location of the next point on the line. The **Line** command continues until no point is found in the measuring rectangle. The command also automatically increments the point label. The **Line** command will be used to re-label all the remaining points on the bottom of the frame.

4. You can select the Line command in several ways:

   a) Select **Line** from the **Command** menu.
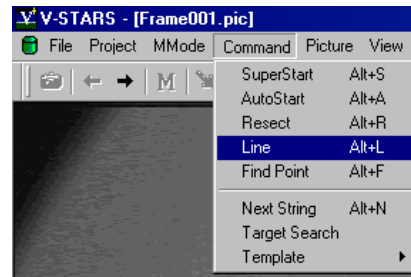
   b) Right click the mouse and select **Line** from the pop-up menu.
   c) Use the **Xl** shortcut key combination
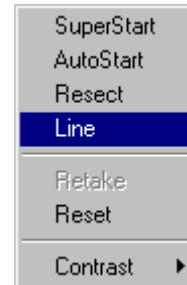
5. The line command will relabel all of the points on the bottom of the frame. The last relabeled point is **1022** in the bottom, right corner of the frame. The point **1023** has been missed as it lies just outside the search window. Relabel point **1023**. (TARGET70)
6. As we have changed direction, manually rename **1024** (TARGET71)and select the **Line** command. This time the renaming process stops at point **1031** (TARGET79). The target spacing is too irregular for the **Line** command to work consistently. Let's manually rename the line instead using a different technique.

7. Go to the area of **1031** (TARGET79)and press the left mouse button down. Drag a box around the target and then release the mouse button. The point called TARGET79 will be renamed to **1031**. Use this technique to rename all the remaining points in the line.
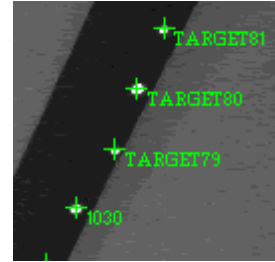
Large numbers of points can be renamed quickly using the drag feature. This is very useful when you wish to rename groups of points and are not concerned with their order.

8. Relabel the next point around the frame to **1040** (currently TARGET77). Select the line command to relabel the points on the top of the frame. The line command will end trying to relabel point **1050**. This point is blocked by the AutoBar and has not been measured. This is one of the points that was missing at the end of the AutoMeasure. We must skip it and resume our renaming with point 1051, which is the next point on the frame. Press the [SPACE] to increment the point label to **1051**.

The point label can be decremented by holding the │ key and then pressing the [SPACE].

9. Relabel point **1051**.
10. Relabel point **1052**.
11. Resume renaming with the **Line** command. The line command will end trying to relabel point **1058**. If you look carefully, you will notice that this target is actually missing! It turns out that, we forgot to install this target. This is another point that was missed in the AutoMeasure. Press the [SPACE] to skip point **1058**.
12. Relabel points **1059** and **1060**.
13. Finally, relabel point **1061**, which is the top, left corner point.
14. We have now relabeled the points on the top, side and bottom of the frame.

15. We still have a few points to rename. You can use more than one picture to relabel points. We do not have to do this since all the points are visible here, but to illustrate this, close this picture and open the second picture. You can do this automatically using the **Next Picture** arrow [→] or X2
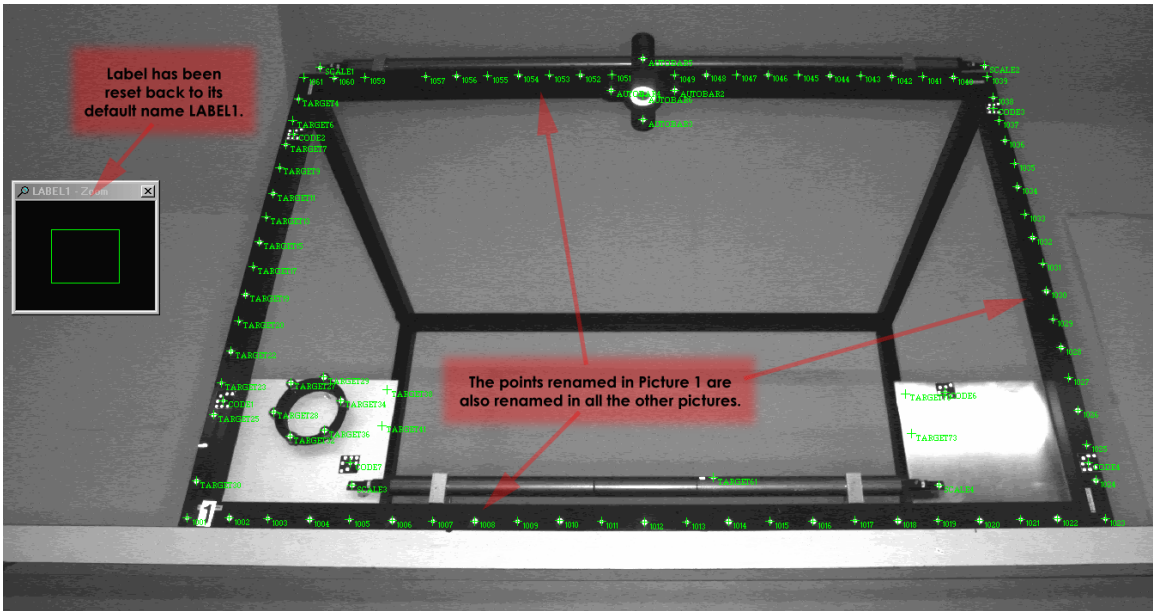
16. Set the label to **1062** and rename the points from **1062** to **1075** using the **Line** method or by manually clicking on the points.

17. You will notice that when you reach **1075** there is no cross. Inspection of the images reveals that **1075** is actually a bad target. V-STARS was smart enough to realize this and has not measured the point. This is another point we have missed. Skip this point by hitting the [SPACE] and rename the last point **1076**.
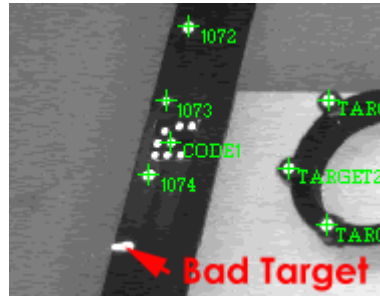
18. The renaming of the points on the frame is complete all except for the points on the interior of the rear face (**1101**-**1104**). It turns out we were unable to measure these points for reasons to be explained later, so we cannot rename them yet.

To AutoMatch a point, it must be seen in a minimum of three pictures ("three-ray point").

19. This completes the renaming of the main points on the frame.

Let's move on to some of the features on the frame.

White Plate

C1 – C6
Located on bolt circle on white plate.

WHITE1 and 2
Single dots on white plate.
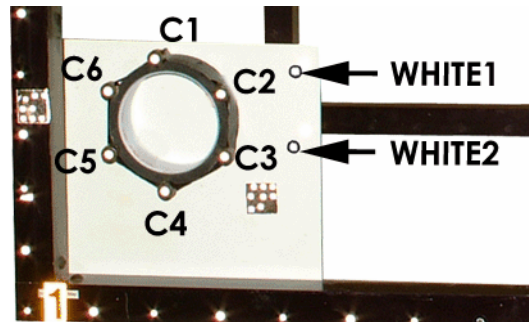
Shiny Plate

SHINY1 and 2
Single dots on Aluminum plate.
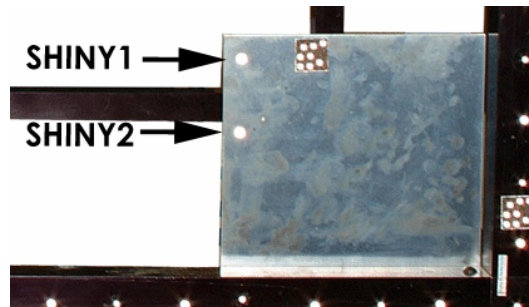
Rename the points on the White Plate and the Shiny Plate in the same manner as the other points you have renamed.

You have now finished the point renaming. Let's review the pictures to make sure that we haven't missed anything. Open the first picture again.

Examination of Picture 1 reveals that all the TARGETS in our list have been renamed. We also see that the AutoMatch has picked up two extra targets.
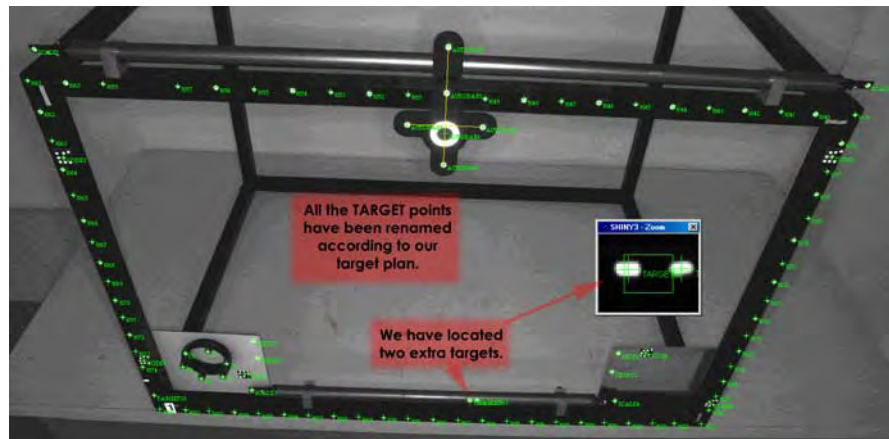
Look at the two false targets by moving the cursor over them until the Zoom window looks as shown in the adjacent image.
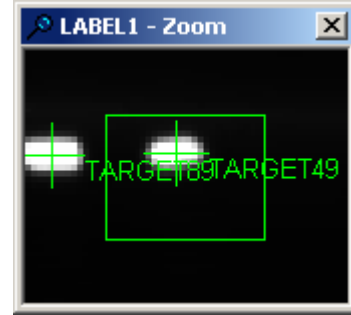
The two false targets are actually reflections from the scale bar. These reflections were of the right shape and quality on enough pictures to AutoMatch. This can happen on occasion, especially if there are round, bright lights in the scene. However, we can easily delete these from the measurement, as we shall see shortly.

We can delete the two false targets (TARGET49, TARGET89) on the scale bar by doing the following.

1. Click on the global delete icon ✎ from the Labels toolbar.

📋   Make sure you select the global delete icon and not the local delete icon, or you will only delete in this picture.

2. Move the cursor to the two false targets. Notice the cursor has changed to the global delete cursor. You can delete the targets two ways.

3. Drag a window around both targets, and delete them at the same time by left-clicking (make sure you drag the window around just the two false targets). Alternatively, bring each target into the measuring rectangle, and left-click to delete it.

4. You will be asked to confirm the deletion(s). Click **Yes** to accept the point deletions. The points will be deleted in **all** pictures, and in the **current** driver file.

5. Close the picture before proceeding with the tutorial.
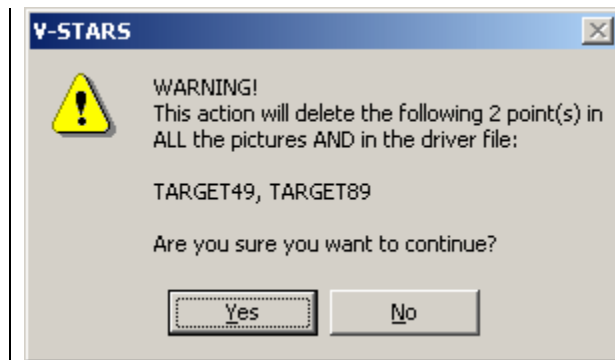
Having renamed the points and deleted the additional points found by AutoMatch let's return to the Bundle process.

Re-running the Bundle
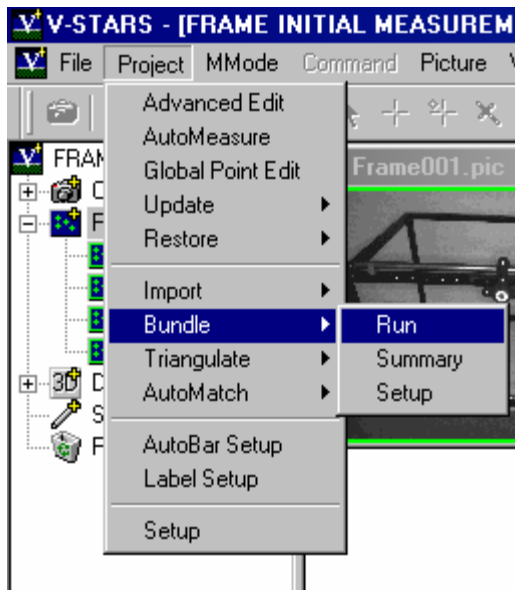
Highlight the **Bundle** command from the **Project** menu. Select the **Run** command and the **Bundle** Dialog will open.
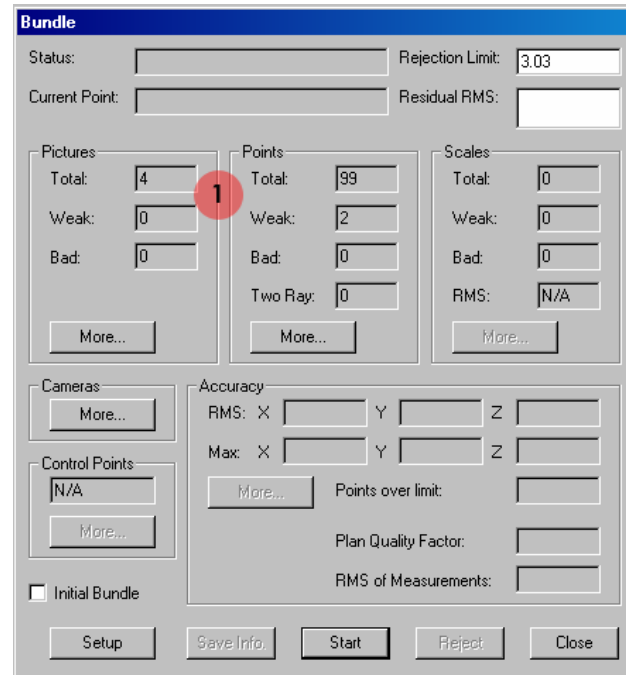
1 There are a total of 99 points listed. There should be 106. From our renaming process, we know that there are seven points missing. These are 1101-1104, 1050, 1058 and 1075.

The missing points are summarized in the table below.

Point(s)	Problem
1050	Blocked by AutoBar
1058	Missing, forgot to install target
1075	Bad target, damaged and unmeasurable
1101-1104	Rear targets, blocked by scale bar and frame

These problems have been deliberately introduced into the tutorial to show how they are handled. There is nothing we can do to fix the problems with these pictures. We will have to take steps later in the tutorial to recover from these problems.

Press the **Start** button to start the Bundle process. Since we deleted the two false targets, the Bundle results are slightly different.

Bundle

Status:	Bundle Converged after 4 Iterations
Current Point:	

Rejection Limit: 0.90um

Residual RMS: 3: 0.23um / 4: 0.23um

Pictures
Total: 4
Weak: 0
Bad: 0
More...

Points
Total: 99
Weak: 6
Bad: 0
Two Ray: 1
More...

Scales [millimeters]
Total: 0
Weak: 0
Bad: 0
RMS: N/A
More...

Cameras
More...

Control Points
N/A
More...

☐ Initial Bundle

Accuracy [millimeters]
RMS: X 0.017   Y 0.022   Z 0.014
Max: X 0.034   Y 0.038   Z 0.031
More...
Points over limit: 0
Plan Quality Factor: 2.38
RMS of Measurements: 0.23um

Setup | Save Info. | Start | Reject | Accept

1 All four pictures were processed, and none of the pictures was bad or weak.

2 No points are considered bad but there are several weak points to examine. A total of 99 points are in the bundle. We have identified the points that are missing.

3 One of the points is a so-called two-ray point, which means it was seen in only two photographs.

4 No scale bars were used to scale the measurement. Although we renamed the scale bar targets, we neglected to enter the calibrated distances for the scale bars.

5 The RMS of the accuracy estimates for the X, Y and Z coordinates for all the points is reasonable, but still somewhat higher than expected.

6 The plan quality factor is over 2. In a well-designed measurement, the plan quality factor is usually between 1 and 2.

7 The RMS of measurements is low; this number indicates the quality of the measurement.

Press the **More** button in the Points section to see which points are weak and why. The dialog box shown below will appear.
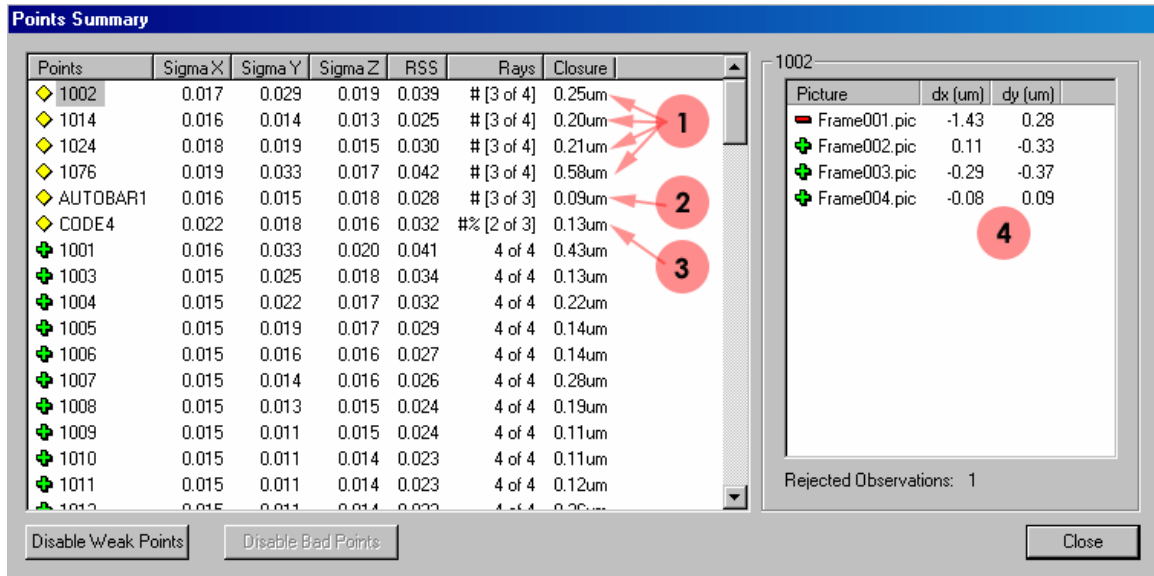
1 These four points had an observation rejected and became weak as they only have three accepted rays.

2 AutoBar1 is also a three ray point as the point was not seen in Picture 2.

3 CODE4 is a so-called two-ray point, which means it was seen in only two photographs. The third observation was rejected.

4 Clicking on a point displays the pictures that viewed the point. This is very helpful to trace where points have been rejected.

📝 The various criteria for bad and weak points can be changed if desired. Refer to the Bundle Statistics - INI File Default Settings in the manual for details.

Weak points are listed below any bad points. Brackets [ ] are placed around the values that are considered weak, and an explanatory character is placed outside the brackets. For example, several points are weak because they have had one poor quality observation removed by the automatic editing criteria, as indicated by brackets [ ] around the rays field. There is also a # sign in front of the brackets to indicate the point has less than the required minimum number of rays. (#[3 of 4]). Also, one point (CODE4) lost 1 of 3 rays, and has a % sign as well to indicate that it is weak not only because of the number of rays but also because it lost a high percentage of observations (#%[2 of 3]). There are several other weak criteria that are checked for but none of them were found here. A more complete explanation of bad and weak criteria is provided in the Bundle Section of the manual. When you are done looking at the points, click the **Close** button at the bottom of the dialog to return to the **Bundle Summary** dialog.

Although we have some problems with the measurement, overall it is acceptable so press the **Accept** button. V-STARS will then make a new driver file using the coordinates from the Bundle.

Problems with the Measurement

Despite our efforts to plan and execute a good measurement, we have encountered some problems. These are:

1. Seven of the 106 points were not measured. The points were lost for several reasons including: unaccounted for blockage (points 1050, and 1101-4), bad camera aiming (1101-4), a missing target (1058), and a damaged target (1075). In addition, we have several points that are considered weak for various reasons.

2. The plan quality factor is higher than normal. This is because the four points on the rear face (1101-4) were not measured, so we ended up measuring a flat object with only four photographs. In the first two photographs, the points were unexpectedly blocked, and in the third and fourth photos, some were missed because of poor aiming. If you remember our planning checklist, a flat object should be measured with at least six pictures. As a result, we have a weak camera calibration that increases the plan quality factor, and therefore reduces the accuracy.

3. We have not precisely scaled the measurement using the calibrated scale bar distances.

What we do at this point depends on the requirements. In some cases, we can tolerate a few missing points; in others we cannot. In addition, despite the weak camera calibration, and the lack of scale, the accuracy may be acceptable. If we still meet the requirements for the measurement, we are done. Otherwise, we must take steps to recover from these problems. In the next part of the tutorial, we assume that these problems are unacceptable, and devise solutions to correct them.

Solutions to Tutorial Problems

Usually problems with measurements fall into two categories; either there are problems with implementation of the plan, or there are problems with the plan itself. The target blocked by the AutoBar (**1050**), the missing target (**1058**), and the damaged target (**1075)** are examples of problems with implementation. The plan is OK, but we did not execute the plan well. If the plan is OK, the usual solution is to fix the implementation problems, and re-take the photography according to the plan.

However, we also have problems with the plan. The pictures from the top and bottom cannot see the targets on the rear face. (Assume we cannot move the camera or these targets to make them visible).

We will take the following steps to solve these problems:

1. Enter the scale distances so we can properly scale the measurement.

2. Remove the AutoBar so we can see the blocked target **1050**.

3. Install the missing target **1058**.

4. Replace the damaged target **1075**.

5. Take four more photographs from the corners of the front face of the frame. We should be able to see the points on the back face of the frame **1101-4** from these locations. Again, to get the strongest self-calibration, we will roll the camera to the vertical position for two of these pictures, and take the other two in the normal horizontal position.
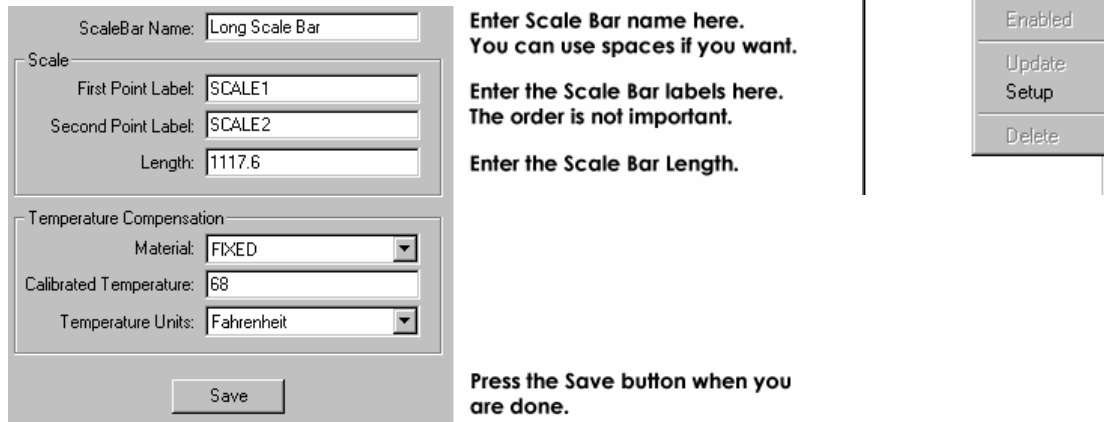
We will add these four new photographs to the original four to complete a successful measurement. The layout of the camera locations for the modified plan is shown below.
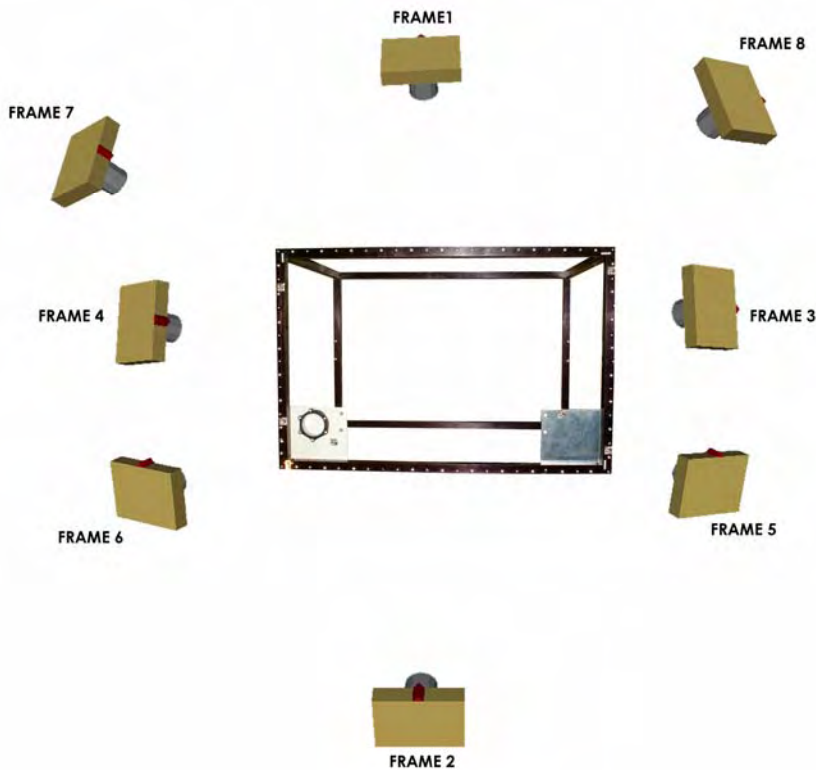
Entering the Scale Distances

We can enter the scale distances any time before the final processing of the pictures by the Bundle adjustment. To enter the scale distances:

1. Right click on the Scale Bars folder, and select **New**. The Scale Bar dialog box shown below will appear.

2. First, we will give each scale bar a name. The name is arbitrary but should be meaningful. In the Scale Bar Name field, type: **Long Scale Bar**.

☝ You can use the **Q** to move to the next input box.

3. The long scale bar is at the top of the frame and its two targets were labeled **SCALE1** and **SCALE2**. Type these labels into the Point Label fields. Case does not matter. Also, you can enter the labels in either order.

4. The calibrated length for the long scale bar is **1117.6** millimeters. Type this value into the Length field.

5. We will not use temperature compensation for this measurement, so we are done with this scale bar. Press **Save** to save the data.

6. Repeat steps 1-5 above for the second scale bar. Use **Short Scale Bar** for the name. The scale bar labels are **SCALE3** and **SCALE4**, and the calibrated length is **736.6** millimeters.

☝ You can place regularly used scale bar files in the GSI system directory. When a project is created, they will automatically be imported. This is much easier and more reliable than manually entering the distances as we did above.

Taking the New Photographs

There are some rules you should observe when taking additional photographs of an object:

1. The object must be stable between the two photographic sessions. You can move the object between sessions, but the object must not deform as a result of the movement.

2. In working on the object, (removing AutoBar, applying new targets, etc.) you must not deform the object because of your work. Take special care to avoid disturbing the scale bars since these are often attached to the object only semi-rigidly and can be easily moved.

3. The object's temperature should not change significantly between sessions. Even if it does change significantly, you are still OK if the scale bar and object are made of the same material and have about the same thermal mass.

4. If you are unsure about any of these conditions, you should go ahead and re-shoot all the pictures. In fact, you should re-do all the pictures whenever you can, just in case something has changed. For the tutorial, we will not re-shoot the first four pictures.

Adding the New Pictures.

To access the four new pictures we took, right-click on the pictures folder ![Pictures icon] Pictures, and select **Include All Images** from the pop-up menu that appears.
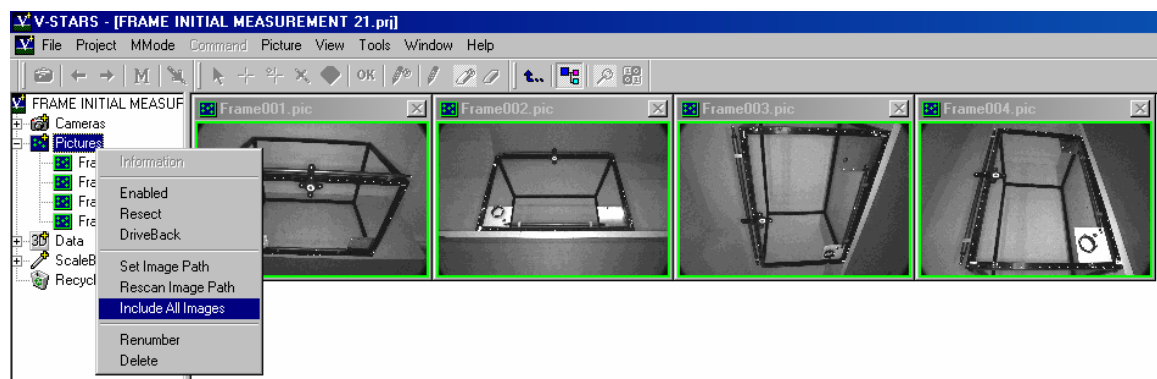
The four new thumbnails should appear.

New image have
blue icons indicating
they are unmeasured.
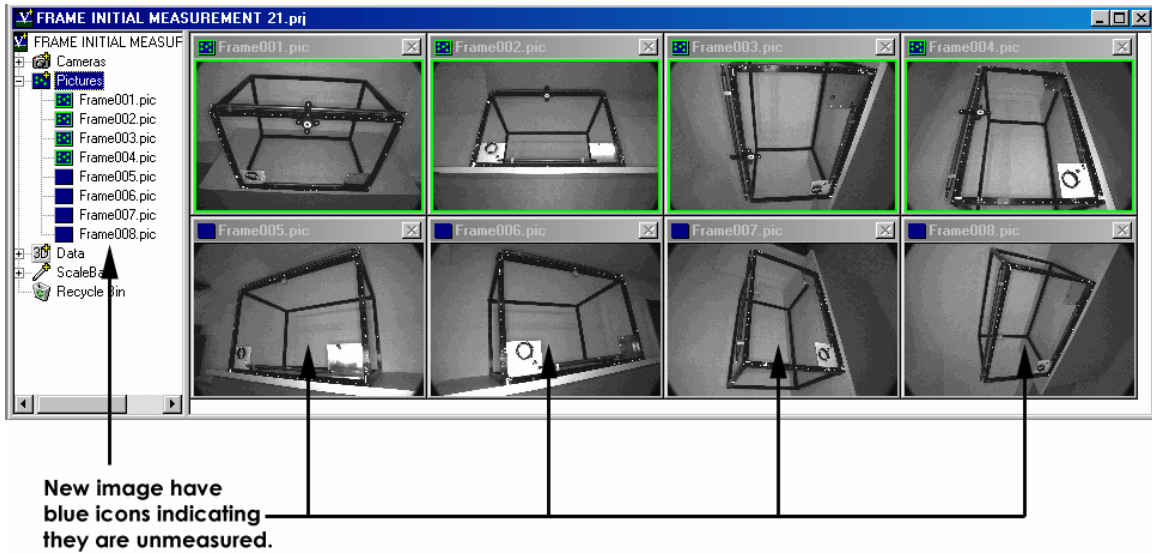
AutoMeasuring the New Pictures

To continue with AutoMeasure on the new pictures, do the following:

1. Select **AutoMeasure** from the **Project** menu. The AutoMeasure dialog should appear as shown.

2. Leave the **Attended** box checked so we can continue to monitor the AutoMeasure process.
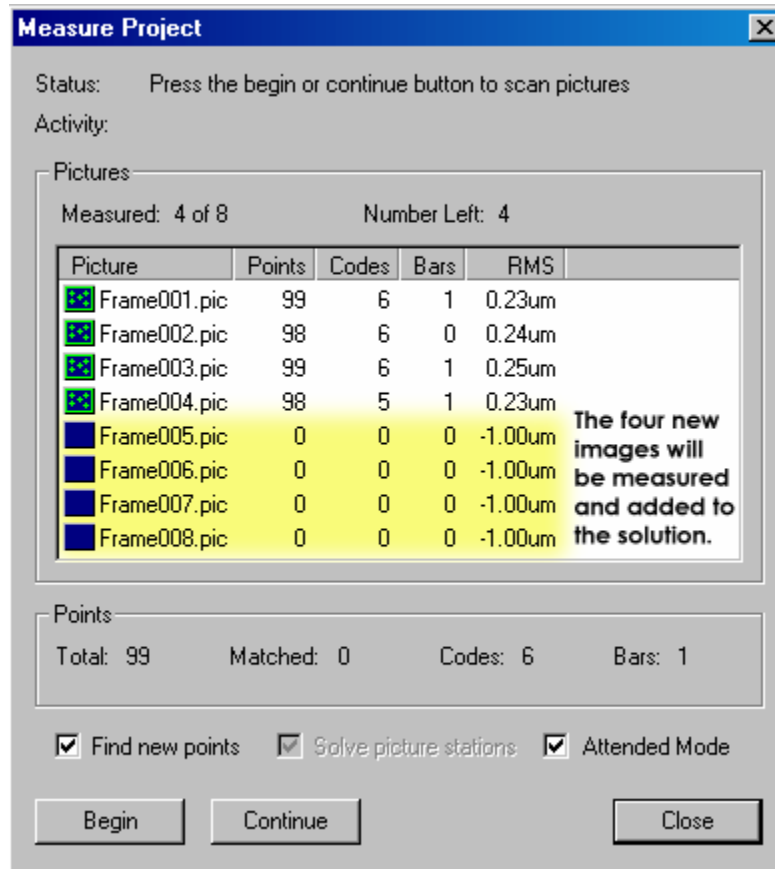

3. Press the **Continue** button to contiue with AutoMeasuring the new pictures.

📓 Pressing the **Begin** button will cause the AutoMeasure routine to re-scan and measure the first four pictures again. This is unnecessary as they have already been measured.

Scanning the New Pictures

AutoMeasure will scan the new pictures one at a time. When done, the AutoMeasure dialog box should appear as shown below.
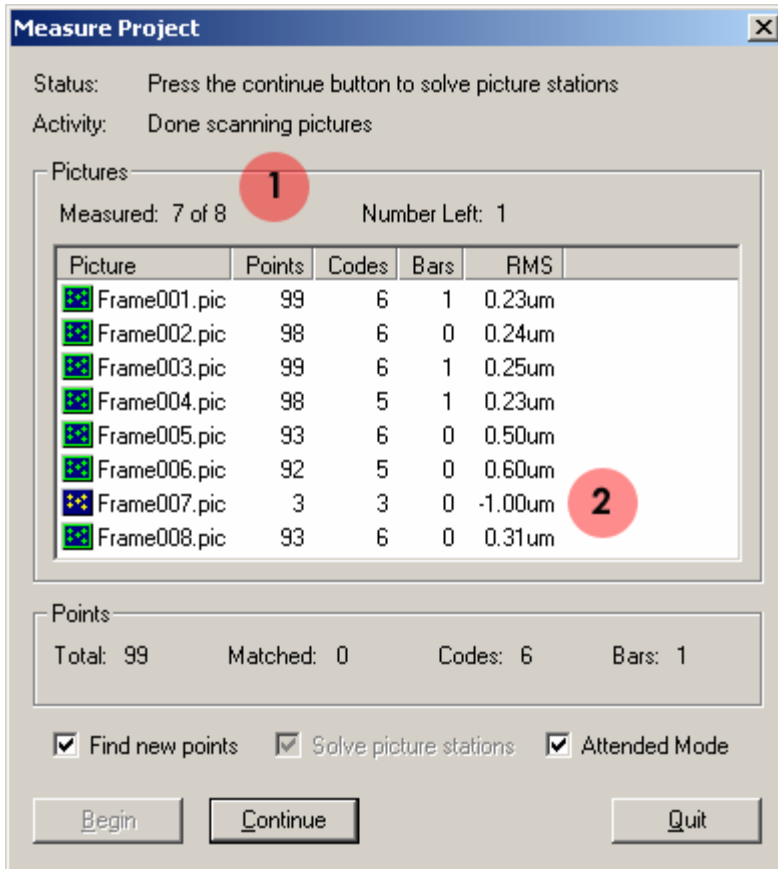
① The seventh picture was scanned but not measured.

② Only three coded targets were detected. A minimum of four are needed to determine the camera orientation.

We were not able to measure the seventh picture; only three coded targets were found and we need at least four. We can proceed without it by pressing the **Continue** button, but we want to include it. We can measure this picture ourselves by exiting the AutoMeasure command at this point. Do this by pressing the **Quit** button.

Measuring the Seventh Picture

Notice the icon for the seventh picture does not have a border around it as the other pictures do. In addition, its thumbnail has a red border around it. These both indicate that, the picture was scanned but is unmeasured.
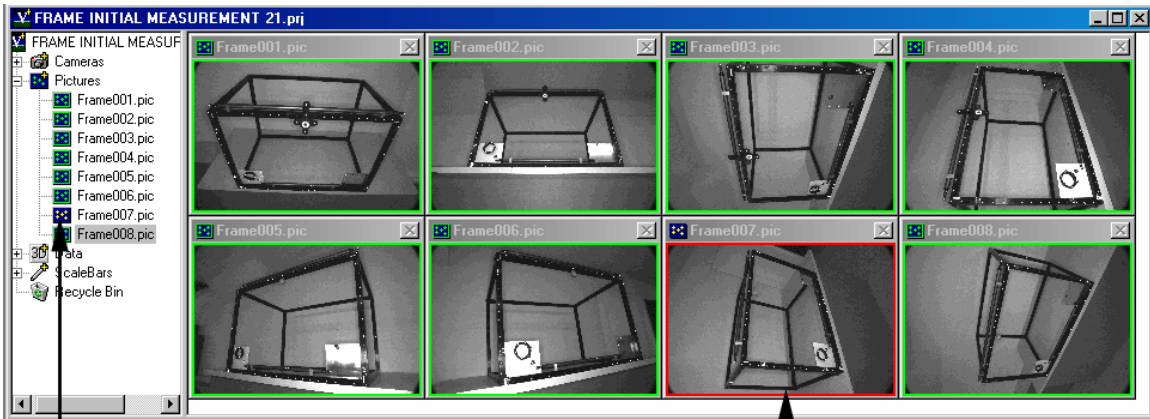
Icon indicates that the picture was scanned, but not measured.

The seventh frame had a red border around it indicating that it is unresected.

Access the seventh picture by either clicking on its thumbnail, or double-clicking on its picture icon ▓. The seventh picture was taken from the top, left side. It should appear as shown below.
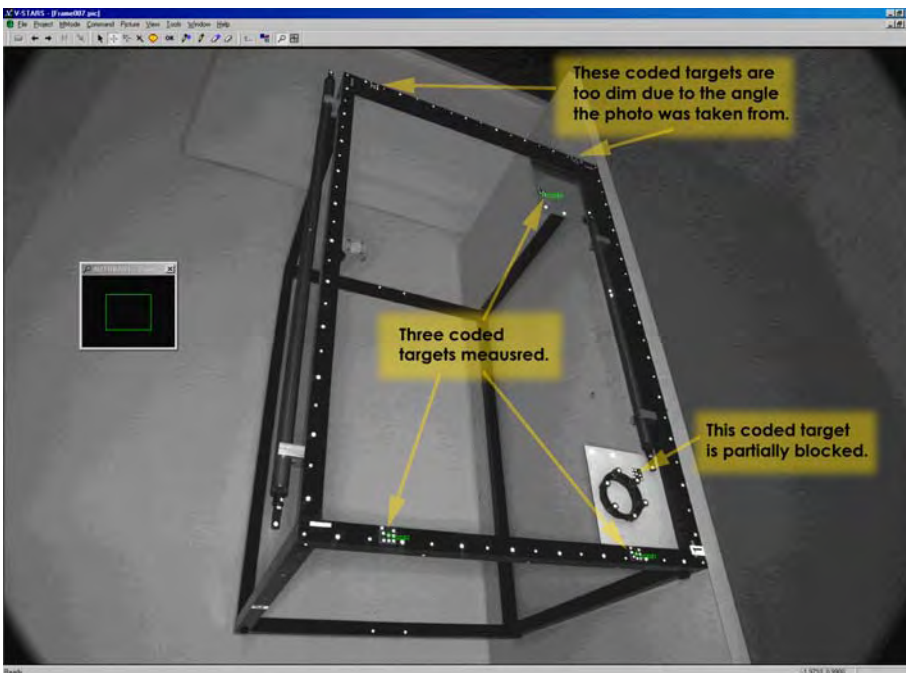
When the AutoMeasure command tried to SuperStart this picture, it was unable to find four coded targets. Of the six coded targets on the frame, only three were decoded (Code1 and Code2 on the left side of the fixture, and Code6 on the shiny plate). The codes on the right side of the fixture (Code3 and Code4) are viewed too obliquely and therefore are too dim to be decoded. (You can use the Zoom window to see how dim they are.) Code7 on the white plate was missed as well because one of the squares around the code is blocked by a point on the bolt circle. Since AutoMeasure was unable to automatically identify four known

points, we will have to use the AutoStart procedure to measure this picture.

The AutoStart procedure needs four identified points. We already have three so we must find and measure one more known point. You can use any known point. We will use the scale point at the top, left corner of the frame. This is the large target on the long scale bar. Set the current label to this point by typing: SCALE1. However, instead of measuring the correct scale point, measure the other scale point on the bar as shown below (SCALE2) to see what happens.
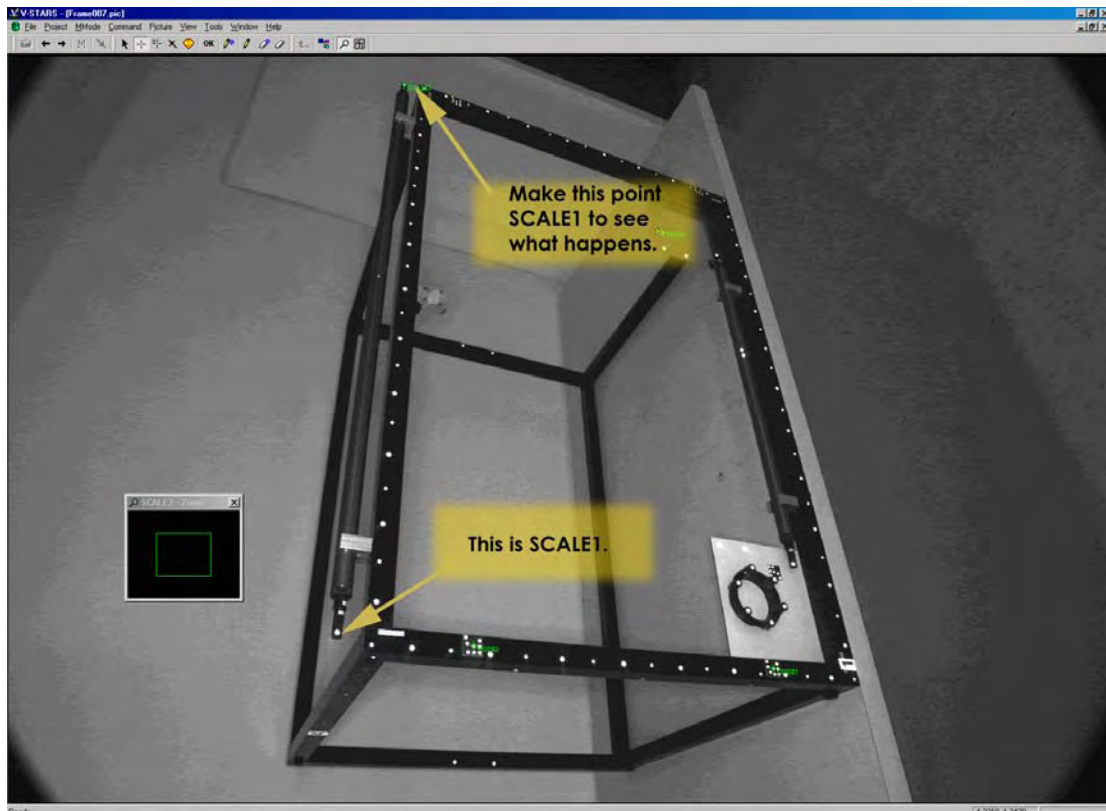
You can AutoStart on these four points in several ways:

1. Select **AutoStart** from the **Command** menu.

2. Right click in the picture window and select **AutoStart** from the pop-up menu.

3. Use the **Xa** shortcut keyboard command.

If you measure the wrong point(s), as we did here, the AutoStart procedure will either fail completely as occurs here and give you **The Resection Failed** message, or you will miss many of the target points (and they will be red). If either situation occurs, you can try again by repeating the steps above after you reset the picture.

To do this, do the following:

1. Run the **SuperStart** (Xs) command. Press **Yes**. It will fail again because it can only find three coded targets.

2. Answer **No** to the question about resetting the picture. Now we only have to measure one more point.

3. Set the current label to SCALE1 by typing SCALE1 and then press.".
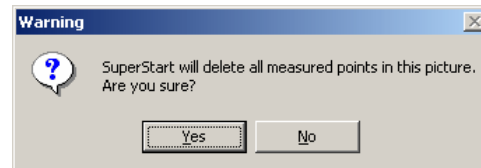
4. Measure the correct scale bar point.

5. Run AutoStart (Xa) V-STARS will measure all the visible points in the driver file.

When you have successfully AutoStarted, the picture should appear as below.

Notice that two targets on the lower right side of the fixture (1025, 1027) are marked in red. These two targets were too small and dim to measure. There is nothing we can do to recover them. We have now measured the seventh picture. Close the picture. Next, we can process all eight pictures.
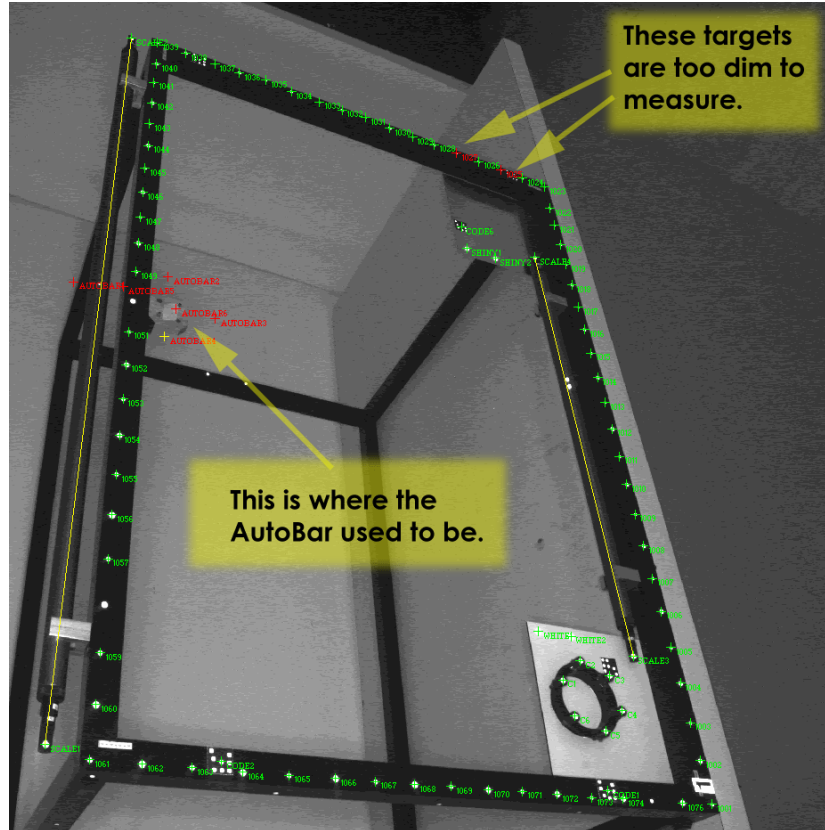
Continuing the AutoMeasure

Resume the AutoMeasure command by selecting **AutoMeasure** from the **Project** menu again. Notice the AutoMeasure Dialog now includes the current statistics for the seventh picture that we just measured. Press the **Continue** button. The AutoMeasure command will quickly check the pictures, determine they are all scanned, and display the dialog again with a new status message. Press the **Continue** to solve the picture stations. Next, press the **Continue** button run the AutoMatch on all eight pictures. Press the **Continue** button again to run the Bundle Adjustment.

The Bundle adjustment will display its progress, and when done, will display the Bundle Summary dialog box shown below.
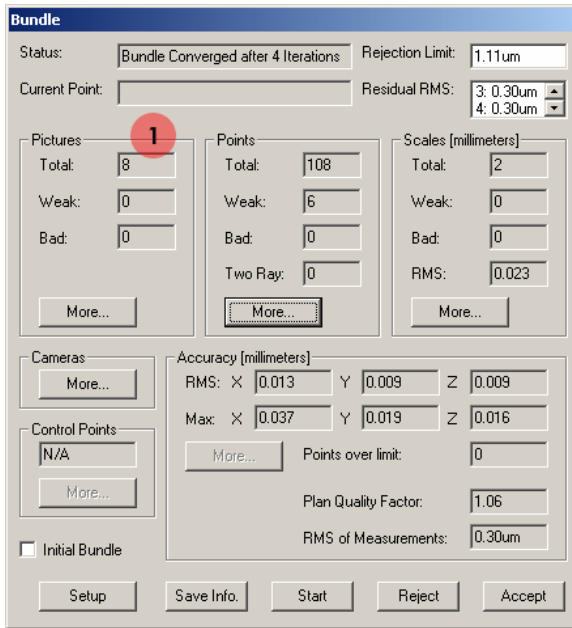
1 We now have 108 points instead of 106. We need to determine where the two extra points are and delete them.

Press the **More** button in the points section to see more information about the points we have measured. Once again, we are faced with the problem of points called TARGET, rather than our pre-defined labels.

Press **Close** and then **Accept** the Bundle. We are going to rename the remaining target points.
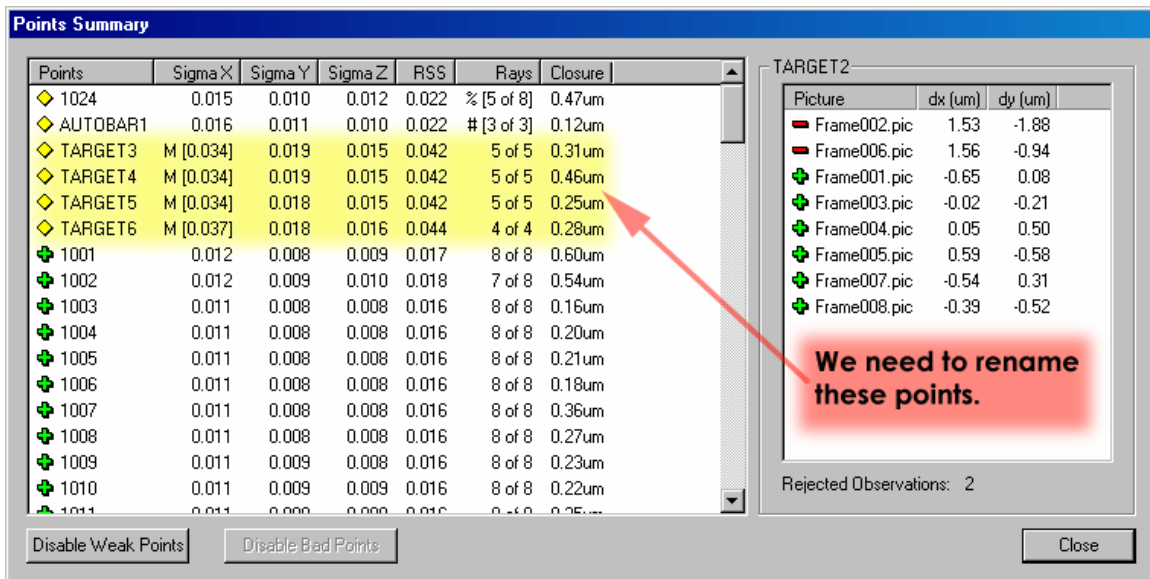
Deleting, SuperFinding and Renaming the Target Points

Access the sixth picture by either clicking on its thumbnail (if you do not see the thumbnails, click on Pictures ▦), or by double-clicking on FRAME006.PIC. A "picture window" will appear with the full image.

You should now be able to see the seven points that were not measured in the first four pictures. You should also see that the false points on the scale bar have returned. Even though we deleted these points earlier,

AutoMatch has found them again for us. We will need to Globally Delete them again. Let's take advantage of this and demonstrate another V-STARS feature. Let's see what happens when you accidentally delete a real target. To do so:

1. Click on the global delete icon from the Labels toolbar.
2. Move the cursor to the two false targets.

3.   Drag a window around both targets, and the three targets directly beneath. (1013, 1014, 1015).

4.   Press **Yes** to accept the deletion.
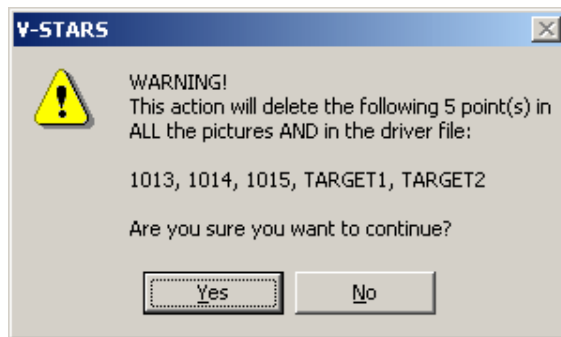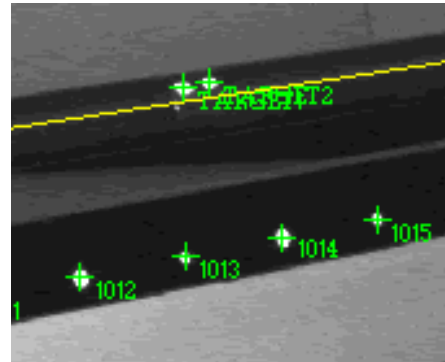
The SuperFind feature allows points to be measured in all images (in which they exist) by measuring them in a single image. The point is measured in the current picture and then automatically in any other pictures that see the point. This very useful to measure points missed by AutoMatch or to measure points that were accidentally deleted. It is also useful in cases where you may not want to run the AutoMatch just to measure a handful of points. Let's remeasure the three points we deleted.

1. Select the SuperFind cursor from the measurement toolbar.
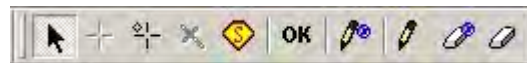
2. The cursor will change to the shape of the SuperFind cursor.
3. Type in **1013**.
4. Move the point that corresponds to **1013** inside the measurement window.
5. Click on the point. The point should now be marked with a cross and labeled **1013**. The label will automatically update to **1014**.
6. Repeat steps 4-6 for points **1014** and **1015**.

7. The 3D coordinates of the points will be automatically added to the current driver file. For the highest accuracy you should re-run the bundle after all points are measured.
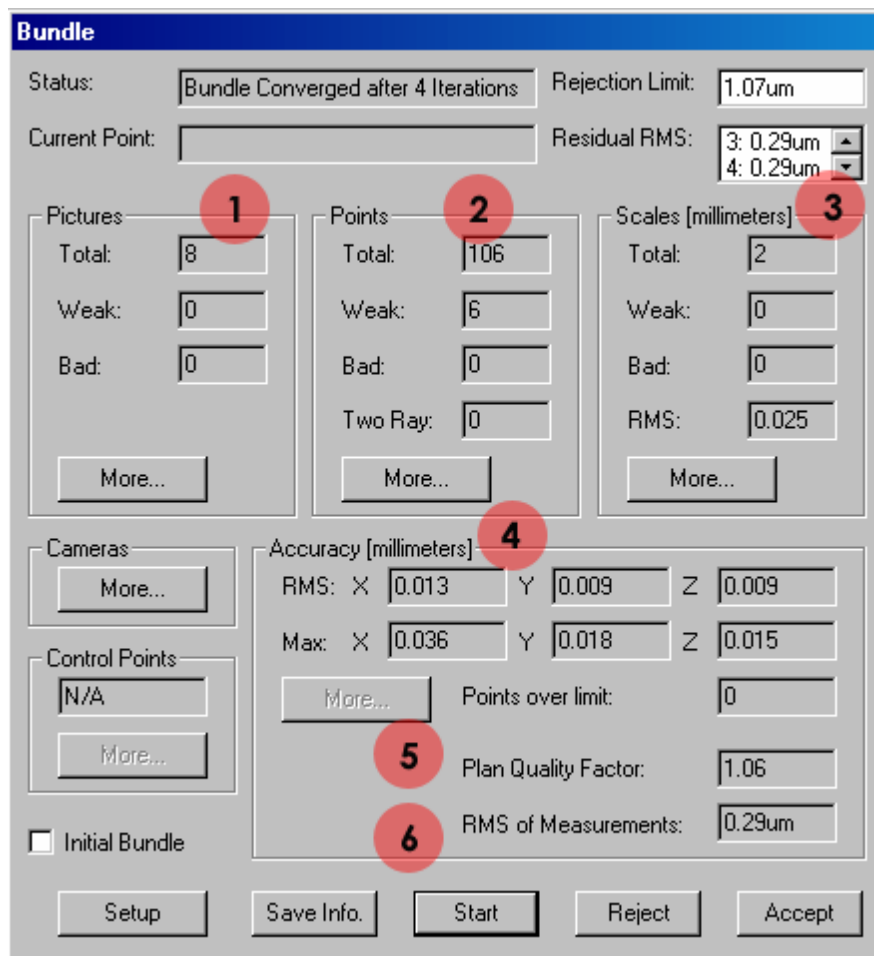
Next, relabel the target points by doing the following:

1. Click on the global rename icon ![icon] on the toolbar.

2. Set the label to 1050 and relabel the point between 1049 and 1051.
3. Set the label to 1058 and relabel the point.
4. Set the label to 1075 and relabel the point.
5. Relabel 1101-1104.

We are now ready to run the final bundle.

Running the Final Bundle

Highlight the **Bundle** command from the **Project** menu. Select the **Run** command and the **Bundle** Dialog will open. Press the **Start** button to bundle the points.

The key features to notice once again are:

1 All eight pictures were processed, and none of the pictures was weak or bad. Pictures are usually bad because they do not have enough acceptable points for a solution.

2 Now all 106 points were measured, and no points were lost due to bad measurements. In addition, there are no two-ray points so every point was successfully measured in at least three photographs. However, there are still a few weak points. We will press the Points **More** button later to get more information about these points.

3 Both scale bars were measured. Press the Scale **More** button to get more information about the bars if you like. The calibrated scale distances agree to the measured differences to –0.020mm and 0.030mm respectively. Therefore, the RMS difference (0.025mm) between the calibrated and measured distances is reasonable. The two scale bars not only scale the measurement; they also provide an external check on the validity of the internal accuracy estimates.

Scale Summary			
ScaleBars	**Calibrated Dist**	**Measured Diff**	
Long Scale Bar	1117.600	-0.020	
Short Scale Bar	736.600	0.030	

SCALE1		SCALE2	
Rays:	8 of 8	Rays:	8 of 8
SX:	0.011	SX:	0.011
SY:	0.008	SY:	0.008
SZ:	0.007	SZ:	0.008

OK

4 The accuracy estimates are smaller than before; this is expected since we have taken more pictures. No points are over the 0.050mm limit we have specified, however the maximum X accuracy estimate (0.036mm) is nearly triple the X RMS (0.013mm) for all the points. We should investigate this.

5 Unlike earlier, the plan quality factor is close to 1. The camera calibration is now much stronger, due to the additional pictures and the measurement of the four points on the back of the frame. This is reflected in the improved plan quality factor. A plan quality factor less than 2 is typical for a well-planned and executed measurement.

6 The RMS of measurements is still low, but is somewhat larger than before. This is typical. As we add pictures, the RMS tends to get larger because the measurement errors have less freedom to adjust. A number of 0.40μm or less is typical. A larger number could be caused by many problems including:

1. A dirty lens. It is important to keep the lens clean and dry.
2. Dirty targets. Targets should be kept clean and dry.
3. Deformation of the object. The measured object must not change shape during the photography. This includes any artifacts (AutoBar, scale bars, etc.) attached to the object.
4. Extremely overexposed or underexposed targets.

If you do not get the results listed here, you should press the **Reject** button. Then, review the tutorial instructions for the last four pictures, and correct any problems. Finally, re-run the bundle so you get the results listed here before proceeding with the tutorial.

We still have a handful of weak points. Click on the Points **More** button to find out more about them. The dialog box shown below should appear.

Click on the column heading to sort the points by content.

Points Summary

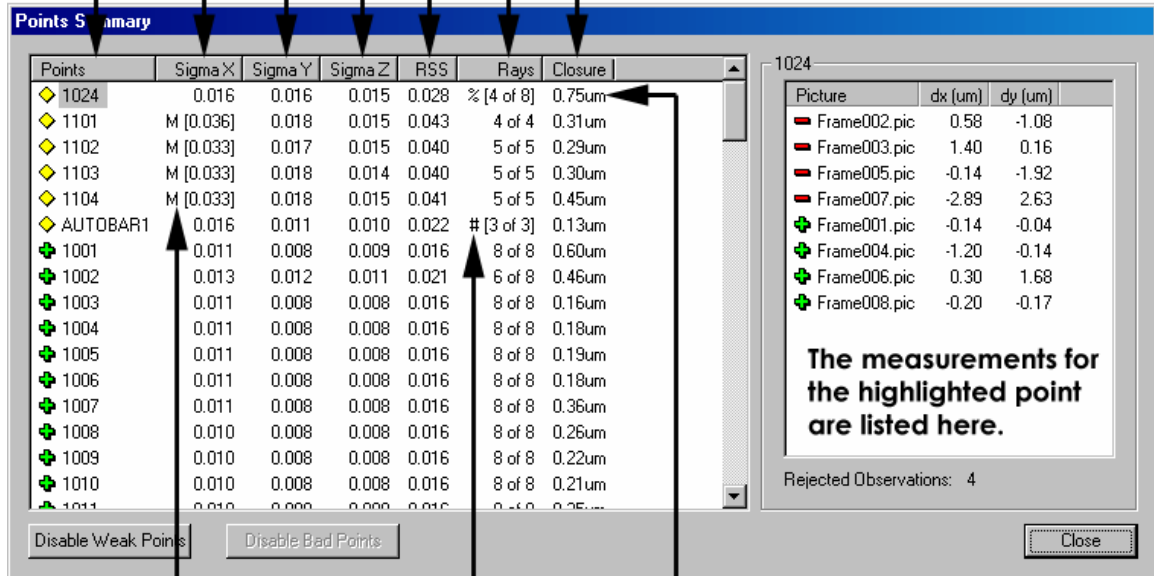| Points	Sigma X	Sigma Y	Sigma Z	RSS	Rays	Closure
◇ 1024	0.016	0.016	0.015	0.028	% [4 of 8]	0.75um
◇ 1101	M [0.036]	0.018	0.015	0.043	4 of 4	0.31um
◇ 1102	M [0.033]	0.017	0.015	0.040	5 of 5	0.29um
◇ 1103	M [0.033]	0.018	0.014	0.040	5 of 5	0.30um
◇ 1104	M [0.033]	0.018	0.015	0.041	5 of 5	0.45um
◇ AUTOBAR1	0.016	0.011	0.010	0.022	# [3 of 3]	0.13um
✚ 1001	0.011	0.008	0.009	0.016	8 of 8	0.60um
✚ 1002	0.013	0.012	0.011	0.021	6 of 8	0.46um
✚ 1003	0.011	0.008	0.008	0.016	8 of 8	0.16um
✚ 1004	0.011	0.008	0.008	0.016	8 of 8	0.18um
✚ 1005	0.011	0.008	0.008	0.016	8 of 8	0.19um
✚ 1006	0.011	0.008	0.008	0.016	8 of 8	0.18um
✚ 1007	0.011	0.008	0.008	0.016	8 of 8	0.36um
✚ 1008	0.010	0.008	0.008	0.016	8 of 8	0.26um
✚ 1009	0.010	0.008	0.008	0.016	8 of 8	0.22um
✚ 1010	0.010	0.008	0.008	0.016	8 of 8	0.21um
✚ 1011	0.010	0.008	0.008	0.016	8 of 8	0.25um

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Picture	dx (um)	dy (um)
▬ Frame002.pic	0.58	-1.08
▬ Frame003.pic	1.40	0.16
▬ Frame005.pic	-0.14	-1.92
▬ Frame007.pic	-2.89	2.63
✚ Frame001.pic	-0.14	-0.04
✚ Frame004.pic	-1.20	-0.14
✚ Frame006.pic	0.30	1.68
✚ Frame008.pic	-0.20	-0.17

The measurements for the highlighted point are listed here.

Rejected Observations: 4

Disable Weak Points   Disable Bad Points   Close

The letter M denotes points whose sigma value is 3 times higher than the median value.

The # sign denotes a point that has a too few rays.

The % sign denotes a point that has lost a high % of rays.

The weak points are listed at the top. Brackets [] are placed around the items that are weak, and the symbol to the left of the bracket indicates

why the item is weak as shown above. You can sort items by column by clicking on the button at the top of the column. You can use this feature to quickly find the points with the lowest/highest accuracy, or the fewest/most rays, etc.

Notice the four points on the back of the frame (1101-4) are weak because their X accuracies are large relative to the other points. This is due to the fact they are farther away, and the intersection angles are narrower than for the points on the front of the frame.

When you are done looking at the points, do the following:

Click the **Close** button at the bottom of the dialog to return to the Bundle Summary dialog.

We have a successful measurement. We have measured all 106 points, and we have no two-ray points. No pictures were bad. The RMS of measurements is low. The accuracy estimates are good, and the plan quality factor is close to one. Both scale bars were measured; the RMS difference between the two scale bars is good, and is consistent with our accuracy estimates. Therefore, press the **Accept** button to accept the results.

Renaming the 3D files.

Because of all the AutoMeasuring we have done, V-STARS has created quite a few 3D files along the way. These files are like stepping-stones to our final destination. For the most part, they can be deleted. Let's examine some of the files that V-STARS has generated.

Now that we have run the final bundle, let's change the name of Bundle6 to Final Bundle. This will help us in the event that we ever have to refer back to a project.
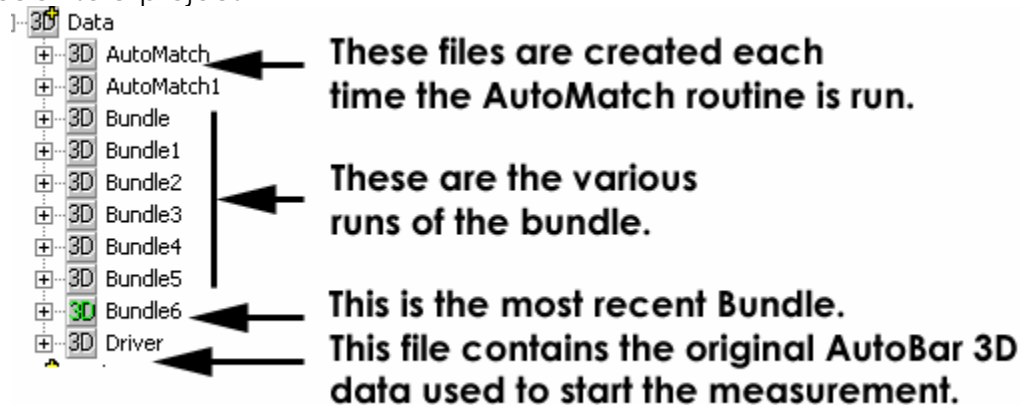
To change the name of a file, hover over it and click. The current name will be highlighted. Type in the new name and then click anywhere outside the name to accept the new name.

田 3D Bundle5
田 3D Bundle6
田 3D Driver

Change **Bundle6** to **Final Bundle**.

Double click on the 3D to list all the 3D files in the right pane. Highlight all the 3D files except for the Final Bundle and press S to move them to the Recycle bin. As with Windows, the files can be restored if you change your mind and decided you need them.

Inspecting the Results Graphically

You can look at the individual point measurements graphically using the 3-D Viewer module included with V-STARS. To use the viewer do the following:

1. Click on the 3-D data 3D Data folder in the Project view.
2. Double click on the latest results file (it will be called Final Bundle 3D Final Bundle). A graphical view of the measured points will be displayed in the window to the right.

3. Click in this window to make it active (the window's red border will disappear).

4. Press the

SPACE

to fit the measured data in the window.
5. Press the X key (case does not matter) to view the object from the +X axis. You should see the picture shown.
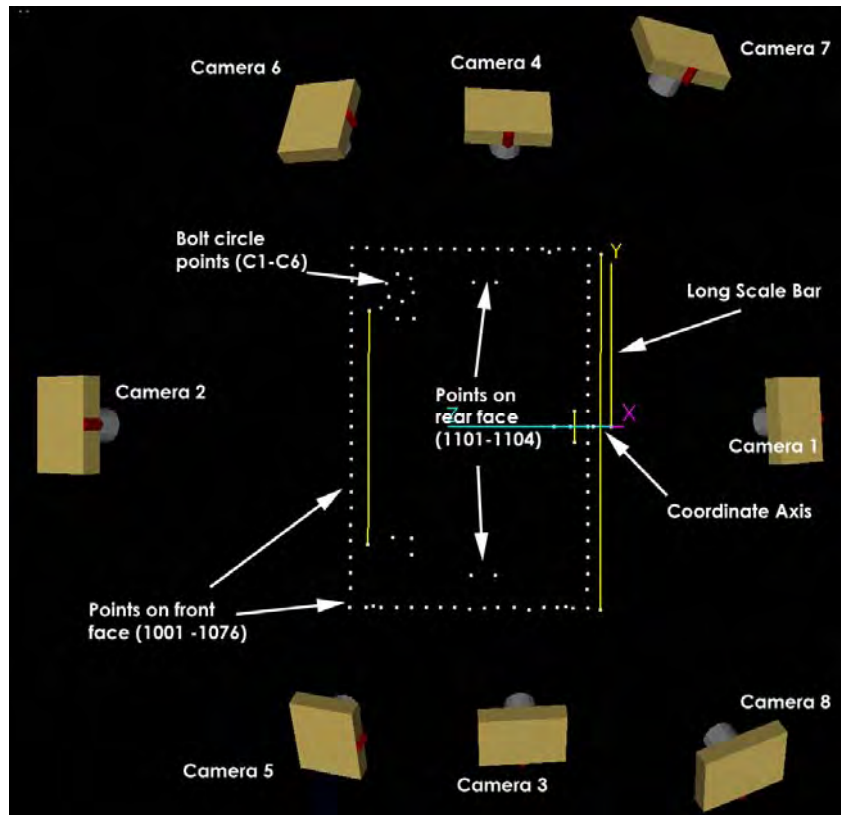
The cameras and points are displayed from the standard viewpoint. Although this seems strange because the frame is on its side, this is because the standard view is down the positive X-axis with the coordinate system's Z-axis to the left, and the Y-axis up. Remember, the coordinate system is defined by the AutoBar. Notice that the coordinate axes are displayed with the origin at the AutoBar; the Z-axis is to the left, and the Y-axis is up.
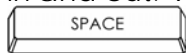
We will provide some brief instruction on using the 3-D viewer; refer to the manual for more information on using the 3-D Viewer. You can use the mouse to change the viewpoint, to select items, and to select commands. The mouse functions are summarized in the table below.

Mouse Button	Action	Hold-down Key	Description
Left	Click	None	Select single item
Left	Drag	None	Select multiple items
Right	Click	None	Activate pop-up command menu
Right	Drag	None	Rotate view point
Right	Drag	?	Pan view point

Try holding the right mouse button down and moving the mouse (called a drag operation). This will rotate the viewpoint. Moving the mouse up and down rotates around the screen's horizontal axis; moving it left and right rotates around the vertical axis. You can use the { / B arrow keys to rotate the view counterclockwise and clockwise. The G / V arrows zoom the viewpoint

in and out. Alternatively, highlight the group of points and press the SPACE to zoom in on them.

Hold down the ? key while using the arrow keys to increase the effect. Experiment with these operations for a while until you are comfortable using the mouse and keyboard to change your view. If you get lost,

just press the SPACE to do a fit. If you like, also press the X to view down the X-axis, and restore the original view.

Press the b key, and the point labels will be displayed. You can make the labels larger by pressing the j key. Make them smaller by pressing the h key. The default is to display every label. However, this may make the display too cluttered. You can decrease the label rate by pressing the o

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key. You can increase it again by pressing the **i** key. Some of the common commands are summarized in the table below.

View

Fit	SPACE
Fit to X, Y, Z axis	xyz
Zoom in / out	G / V
Rotate CCW / CW	{ / B
Reset view settings	/
Residual scale Inc / Dec	1 / 2

Display

Line width Inc / Dec	7 / 8
Point size Inc / Dec	9 / 0
Axis size Inc / Dec	; / '
Toggle point labels	b
Label size Inc / Dec	h / j
Label skip freq. Inc / Dec	i / o
Toggle Picture Stations	k
Toggle point rays	n
Toggle 3D data file title	t

Object Analysis and Creation

Point Distance	d
Average Point	a
Vector Point	v

Inspecting the Results Textually
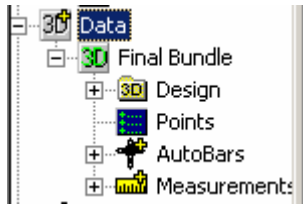
To view the measured data in text form, click on the points icon ▦ for the Final Bundle 3D Final Bundle. After a few seconds, all the measured points will be listed.

Each record of the file contains the point's label, followed by the X,Y,Z coordinates of the points followed by the X,Y,Z accuracy estimates (also called Sigmas) for the point. There is also a column for the point offset and description. You can use the scroll bar to navigate through the file. The coordinates are in millimeters, and in the coordinate system defined by the AutoBar. You can transform these coordinates into the user-defined coordinate system we described at the beginning of the tutorial. We will do this later in the tutorial using the transformation capabilities in the 3D Viewer.

Point Label	X	Y	Z	Sigma X	Sigma Y	Sigma Z	Offset	Description
1001	-9.701	559.940	812.769	0.011	0.008	0.009	0.000	
1002	-9.663	506.809	812.091	0.013	0.012	0.011	0.000	
1003	-9.334	458.505	812.111	0.011	0.008	0.008	0.000	
1004	-8.997	405.884	812.888	0.011	0.008	0.008	0.000	
1005	-8.664	356.626	812.882	0.011	0.008	0.008	0.000	
1006	-8.309	303.889	813.156	0.011	0.008	0.008	0.000	
1007	-7.970	254.186	813.377	0.011	0.008	0.008	0.000	
1008	-7.656	203.193	813.068	0.010	0.008	0.008	0.000	
1009	-7.304	151.666	813.165	0.010	0.008	0.008	0.000	
1010	-6.957	100.650	812.563	0.010	0.008	0.008	0.000	
1011	-6.614	50.850	813.518	0.010	0.008	0.008	0.000	
1012	-6.253	-0.811	814.274	0.010	0.008	0.008	0.000	
1013	-5.888	-51.502	814.303	0.010	0.008	0.008	0.000	
1014	-5.549	-101.521	813.964	0.010	0.008	0.008	0.000	
1015	-5.173	-151.816	814.037	0.010	0.008	0.008	0.000	
1016	-4.811	-203.531	814.346	0.011	0.008	0.008	0.000	
1017	-4.475	-253.893	814.146	0.011	0.008	0.008	0.000	
1018	-4.103	-306.360	814.889	0.011	0.008	0.008	0.000	
1019	-3.714	-355.092	814.729	0.011	0.008	0.008	0.000	

Constructing Points

Sometimes the measured target points are not what we actually need to measure. Instead, the actual measurement must be derived from one or more measured points. For example, the actual point might be offset some distance from a measured point in some direction, or we might derive the center of an object from points placed on the periphery because the center point cannot be measured directly. V-STARS provides ways to build or "construct" such points from measured points. Some of the points V-STARS can construct are vector points and average points. We shall see here how they are created and used.

An especially nice feature of construction points is that once created, they can then be recreated automatically on subsequent measurements, thereby relieving the operator of a tedious and error-prone task. We show how this is done in the next tutorial.

Constructing Average Points

First, we shall show how average points are constructed. Generally, you construct an average point by selecting a group of points to average, and providing a name for the average point. That's it! You can select points in several ways. We will construct several average points to show different ways to select the points, and different uses of average points. The techniques shown here are used throughout V-STARS to select points for some type of analysis. Once you are familiar with using them here, you will find it easy to extend the concept to other functions.

1. To activate the graphical view, click on the Final Bundle 3D Final Bundle file again.
2. Then, click in the 3D Viewer window to make it active. The red border will disappear.

On our frame we have placed six targets on a bolt circle. The average of these points is the center of the circle. (A better way is to do a best-fit circle on the points, but we assume here that the optional **SOLIDS** package, which can do this, is not available).

We will use the 3D Viewer to select these six points using their labels, by doing the following.

1. Select the Average Point Command by either right-clicking and selecting **Average** from the pop-up menu, or by pressing the **a** key (case does not matter). A list of all the measured points will be displayed.

2. Scroll down the list until you come to the six circle points (C1-C6)
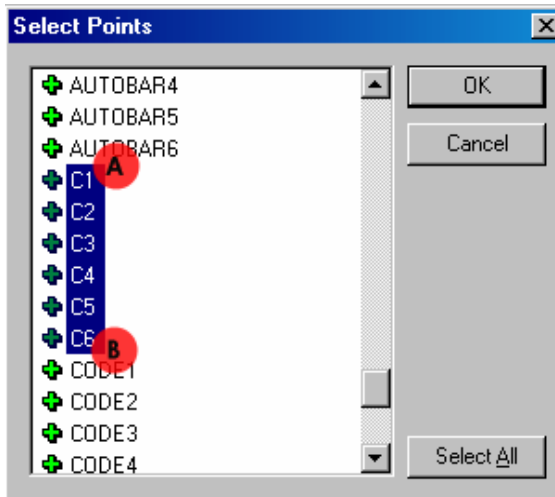
1. Select them by either of the methods shown below. Use the method you find easier for selecting consecutive points.
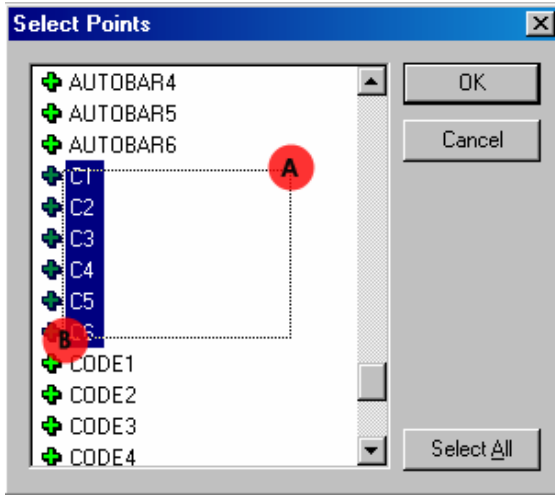
1) Move the cursor to the right of the first point, **A**, and hold down the left mouse button.

2) Then move the cursor to **B** and release the button. This is a "drag" selection.

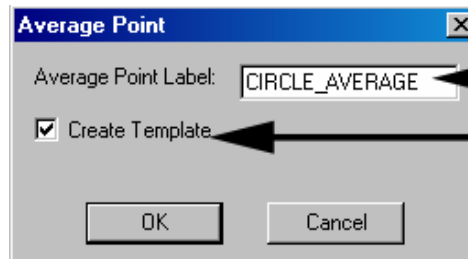3) Press the OK button to exit the select point dialog.

1) Click on the first point. **A**

2) Hold the [C·Shift] key, and click on the 6th point at **B**.

3) Press the OK key to exit the dialog.

4. Type the label CIRCLE_AVERAGE in the **Average Point** Dialog box that appears next, check the **Create Template** check box and

Enter a point name.

Check here to create a template for future use.

press the **OK** button (or press **"**). A new point should appear in the 3D Viewer in the middle of the bolt circle. To confirm the point label is correct, dwell on the point with the cursor until the tool tip displays the point's name.
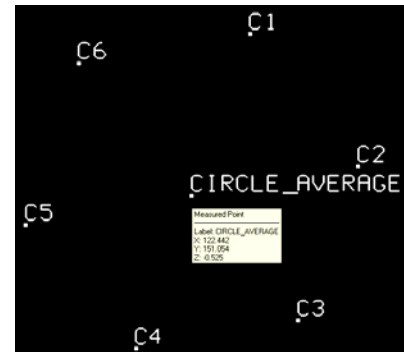
You can also use an average point to measure the mid-point of two targeted points. This is useful when the desired point cannot be targeted directly. For example, a targeting fixture called a "sine bar" is often used to measure the center point of a hinge line. In the next examples, we will select the points graphically using the 3-D Viewer. First, we are going to create an average point using the two points on the left side of the back face of the frame (**1101,1102**).

To do this, do the following.
1. Select the points, **1101** and **1102** as shown in the adjacent image.
2. As before, select the **Average** Point Command by either right-clicking and selecting **Average** from the pop-up menu, or by pressing the **a** key.
3. In the Average Point dialog box label field, type in the label: **1100**, and press the **OK** button.

4. The average point will appear between the two selected points. If you like, confirm the point label by dwelling on the point with the cursor until the tool tip displays the point's name
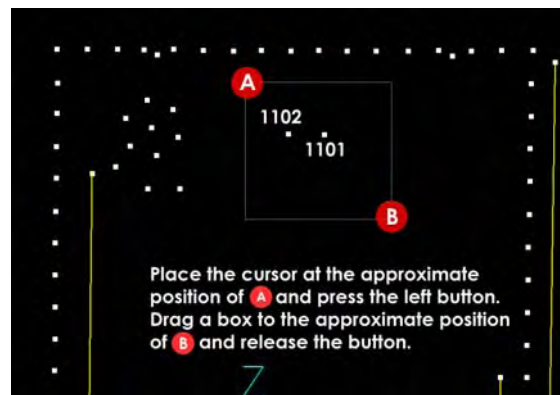
4. Do the same thing with the two points on the right side of back face of the frame (**1103,1104**). Use **1105** for the point's label. We now have two average points for the back face of the frame.

We have now selected points in two ways (by label, and graphically). If you select the **Average** Point command when no points are graphically selected, the point labels are automatically listed so you can select by label. If points are already selected graphically, the command uses those points. All the viewer analysis commands work this way. You can use these two selection methods for all the other analysis commands (vector, line, plane circle, etc.).

As a final average point example, we will show that you can use constructed points to make another constructed point. In this case, we will select the two average points we just created to make another average point which represents the mid-point of the back face. You can select these points by label or graphically as you prefer, but in both cases you will have to use slightly different methods than before since these points cannot be selected in a single operation. We describe both methods below.

Depending on how you have rotated the frame in the view, you may find it difficult to drag a single selection window around the two middle points. Instead let's use this as an opportunity to show how to select multiple points graphically using multiple selection operations.

To do this, do the following.
1. Select the left average point (1100) as you would normally select a point (it will be highlighted).

2. Select the right average point but also hold down the ?key. This is an example
     of a "multi-select". It keeps the previous selection(s) so long as you hold down the ? key while selecting.
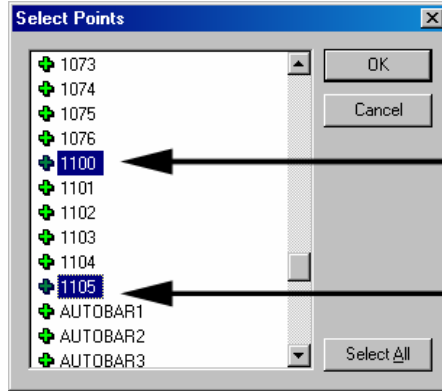3. Select the **Average** Point command.
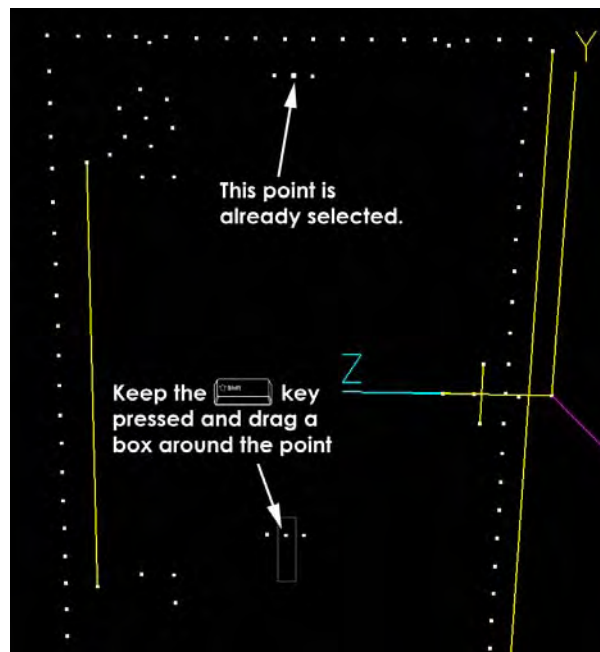
4. Give the point the label **1106**.

5. Press the **Cancel** button. This will cancel the construction of the average point.
Click anywhere in the view that does not contain an object. The points will now be deselected.

☞ If you are multi-selecting lots of points, you may find it easier to turn A on so you do not have to hold down the ? key each time you make a selection.

To select the points by label, do the following:

This point is already selected.

Press the [Ctrl] key and click on 1105.

1. Select the **Average** Point command.
2. Scroll down to the **1100** points. Now you cannot drag around the two points because they are not consecutive.

3. Click on the **1100** point to select it.

4. Hold down the Z key and click on the **1105** point. The two points should be highlighted.

5. Press the **OK** button.

6. Give the point the label **1106**.

7. Press the **OK** button to construct the average point.

You see the new points in the graphical view. You can also see them in text view as we showed before by doing the following:

1. If you have not done so already, click on Final Bundle 🔲 Final Bundle

2. Click on the points icon 🔲. The points will be listed in the right pane.

3. Confirm that the new constructed points are in the 3D file. Use the scroll bars to see points that are not shown.

Notice, we also now have a new folder called Construction 🏗 Construction. This is where the information used to construct the average points is stored.

Click on the Construction folder, and then on the **Average** Points folder. The information about the four average points we constructed will be displayed as shown in the adjacent image.

| Point Label	Labels	Wildcards
➕ 1100	2	0
➕ 1105	2	0
➕ 1106	2	0
➕ CIRCLE_AVERAGE	6	0

Constructing Vector Points

Constructing vector points is like constructing average points. A vector point is always constructed from just two points. Let's construct some from

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the frame points. We will also show how you can select points in the text view.

Do the following:

1. Click on the Final Bundle [3D Final Bundle] file's points icon [icon] to bring up the text view of the points.

2. Select the first two points on the front face of the frame (**1001**, **1002**) using the same techniques you used earlier for selecting average points by label.

3. With the two points highlighted, right-click (make sure the cursor remains on the highlighted selection), and select **Vector** from the pop-up menu. The dialog box shown below will be displayed.

4. The diagram shows a new vector point will be constructed going from point **1001** to **1002**. However, we want the vector point to go the other way, from **1002** to **1001** so it will be more visible. So, click on the **Flip** button to change things around the way we want.
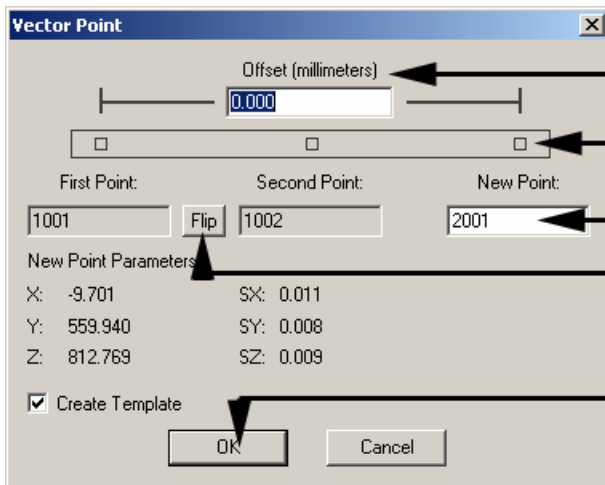
The vector offset distance. If a negative number is entered, a point is created in the opposite direction.

This diagram will show how the vector point will be created.

Enter the new point label.

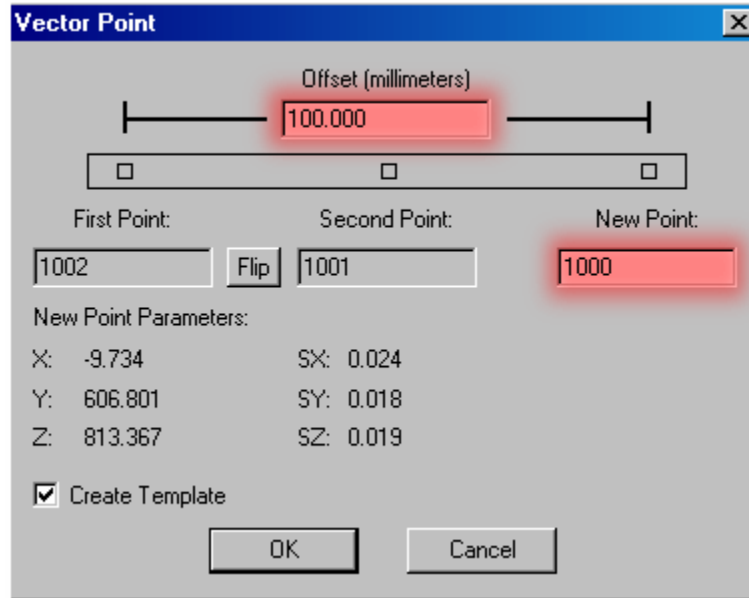**Press Flip to swap the first and second points.**

Press the OK button to create the point.

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5. Enter **100** for the offset. The vector point will be **100mm** from point **1002** toward point **1001**.

6. Enter **1000** for the vector point label.

7. Press the **OK** button to exit the dialog and make the point.

8. Scroll down to the end of the points list to confirm that the new point (**1000**) has been added.

Vector Point

Offset (millimeters)

```
100.000
```

First Point:		Second Point:	New Point:
1002	Flip	1001	1000

New Point Parameters:

X: -9.734   SX: 0.024

Y: 606.801   SY: 0.018

Z: 813.367   SZ: 0.019

☑ Create Template

OK   Cancel

Return to the graphical view for the next example by doing the following:

1. Click on the Final Bundle **3D Final Bundle**. The vector point we just created should be displayed.

2. Click in the 3D Viewer window to make it active. The window's red border should disappear.

3. Zoom in by pressing the **G** key until the frame fills most of the window.

Set the label display to your liking, and then make a new vector point graphically using the two points on the shiny plate by doing the following.

1. Graphically select the two points on the shiny plate (**SHINY1**, **SHINY2**) by holding down the left mouse button, and dragging the mouse just around these two points.

2. Bring up the vector dialog by either right-clicking and selecting **Vector** from the pop-up menu, or by pressing the **V** key.

3. The offset we entered earlier is displayed. Keep the offset at **100mm**.

4. Change the New Point label name to **SHINY3**

5. Press the **OK** button. The new vector point should appear.

Make a vector point from the two points on the white plate by label by doing the following:

1. Select the **Vector** command by either right-clicking and selecting **Vector** from the pop-up menu, or by pressing the **V** key.

2. Scroll down the list of points that appears and select the two points (**WHITE1**, **WHITE2**)

3. Press the **OK** button. The vector dialog will be displayed.

4. Keep the offset at **100mm**.

5. Change the direction of the vector by pressing the **Flip** button.

6. Change the New Point label to **WHITE0.**

7. Press the **OK** button.

The new vector point should appear. Notice it is in the opposite direction of the vector point we made using the points on the shiny plate. The average and vector points we constructed should appear as shown below. (To get the orientation shown below, use the C key to rotate the view.)
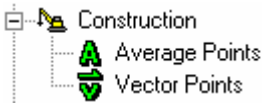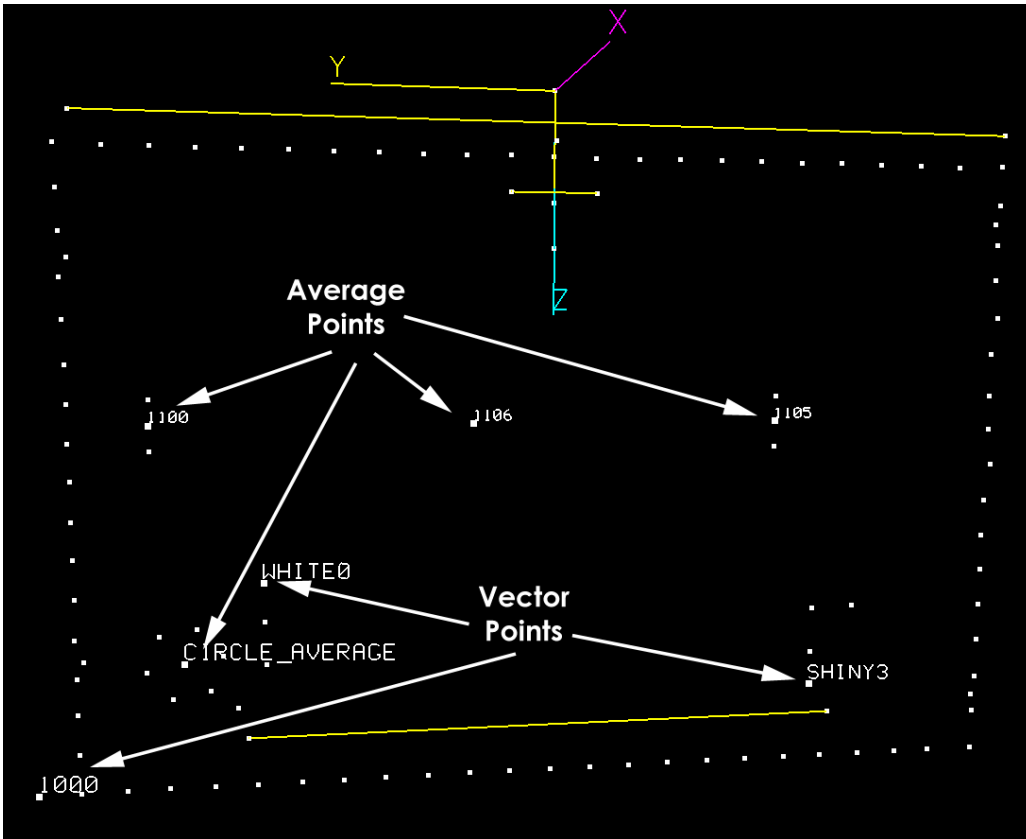
Notice we now have a new vector folder in the construction area. Click on the folder and the vector points we constructed should be displayed as shown below.

Point Label	Point Label 1	Point Label 2	Distance
✛ 1000	1002	1001	100.000
✛ SHINY3	SHINY1	SHINY2	100.000
✛ WHITE0	WHITE2	WHITE1	100.000

Basic Transformation

So far, we have worked with the results in the coordinate system defined by the AutoBar. This is not the desired final coordinate system. Remember we have defined a user coordinate system that has the origin at the bottom left corner of the front face of the fixture. The X-axis is to the right, the Y-axis is up (perpendicular to X) and the positive Z-axis is

perpendicular to the other two. The current and desired coordinate systems are shown again below.
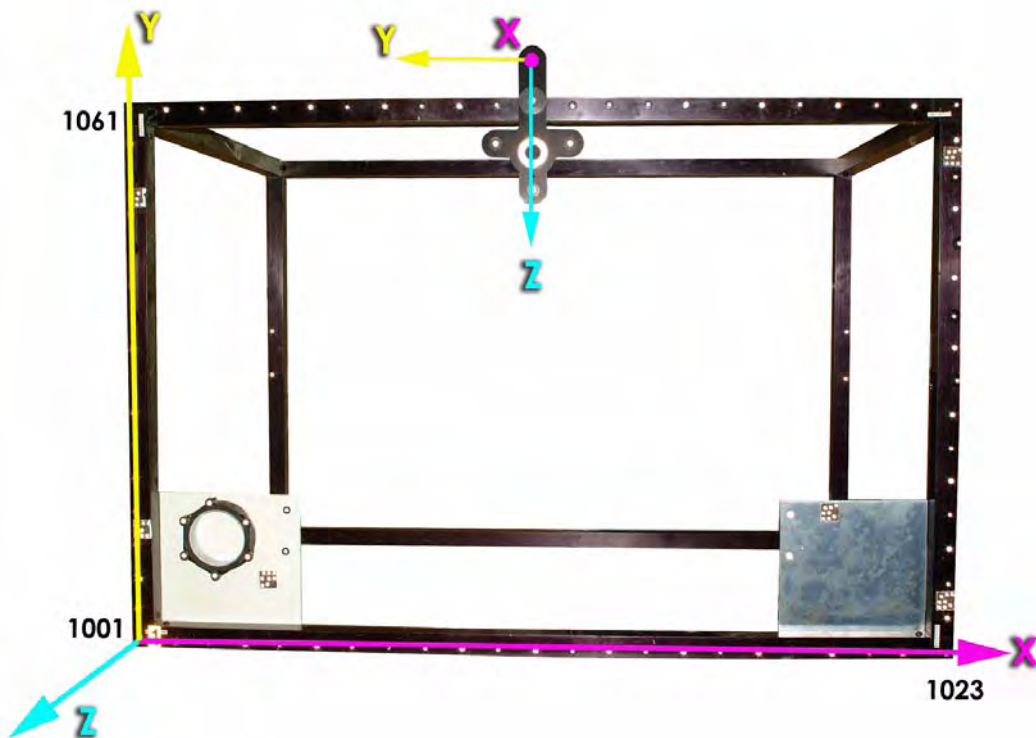

We now show a basic way to transform the results into the desired coordinate system. We will use three corner points on the front face of the frame to define our new coordinate system. We will place the origin at point **1001** in the bottom, left corner of the frame. The positive X-axis will go thru point **1023** at the bottom right corner of the frame. The XY plane will go thru these two points and point **1061** in the top, left corner. The positive Z-axis will be out of the front face of the frame.

This type of transformation is called an **Axis Alignment** because the coordinate axes are aligned so they are parallel or perpendicular to our selected line (**1001 - 1023**). This is an easy type of coordinate system to use and understand, but as we shall see in later tutorials, axis aligned coordinate systems have some limitations, and potential problems.

To perform the axis alignment, we will use the 3D Viewer. Do the following.

1. Select the three points graphically using the multi-select techniques described earlier (hold down the ? key while selecting the second and third points). Order of point selection is important in an axis alignment, so select **1001** first, **1023** second, and **1061** last as shown below.
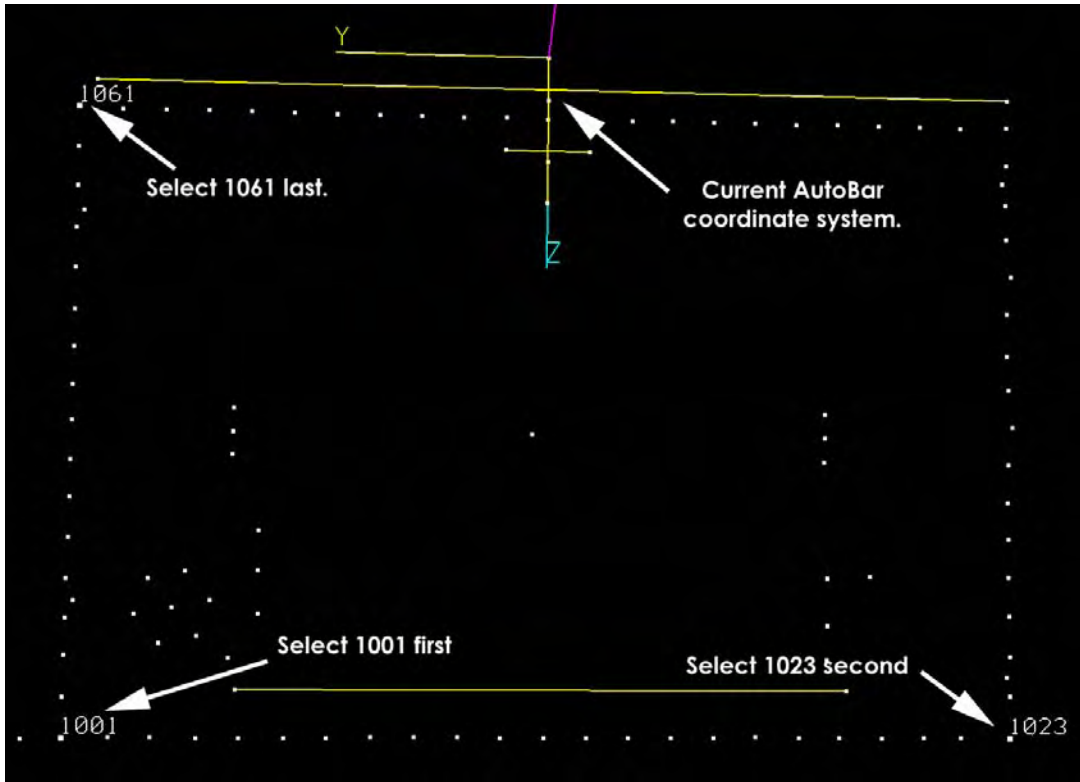
2.   Next, perform the **Axis Alignment** by right-clicking in the 3D Viewer. Select **Alignment** from the pop-up menu, and select **Axis** from the sub-menu. The dialog box below should appear.
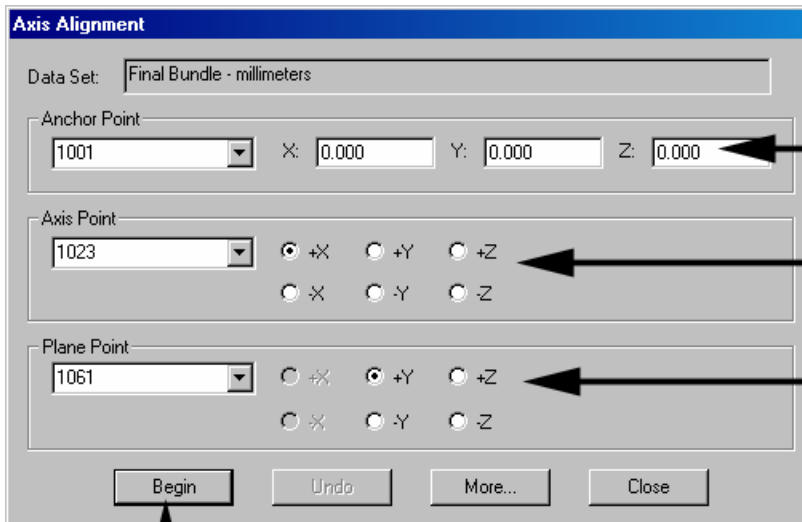
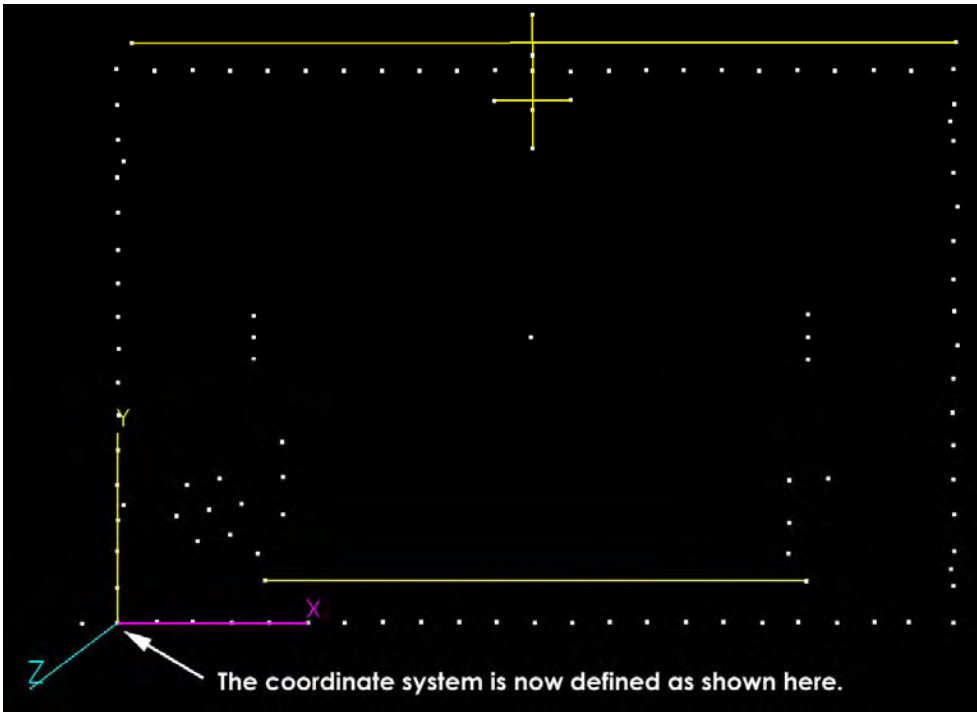Point 1001 will be at these coordinates, in this case, the Origin.

The +X axis will go from 1001 to 1023.

The +X +Y plane will go through 1001, 1023, and 1061

Press Begin to complete the transformation.

3.   Check to see you have the same selections as listed above, and press the **Begin** button.

4.   Press the **Close** button. The measurement results are now in the new coordinate system as shown below.

5.   To make the view the same as below, press the **Z** to look down the Z-axis, and press the ⌴SPACE⌴ to fit the view onto the screen. If you like, press the **G** key until the frame is the size you want. Notice the coordinate axes have been relocated to define the new coordinate system.


The coordinate system is now defined as shown here.

6.   Make the coordinate axes bigger by successively pressing the ' key to confirm the X axis goes thru point 1023. You can make the axes smaller again if you like by pressing the ;.

The measurements have now all been transformed into the new axis aligned coordinate system. Click on the points icon ▦ for the Final Bundle measurements, and look at the point coordinates. Confirm that point 1001 is at (0,0,0); that point 1023 has a positive X value, and Y and Z are 0, and the Z coordinate for point 1061 is also 0. This is the desired user coordinate system.
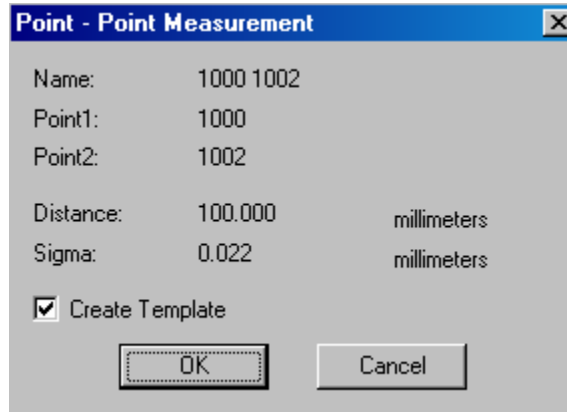
Measuring Distances

As the final exercise of this tutorial we will measure some point to point distances. Let's check the vector point distances. Again, we can select points for the command in several ways. Measure the distance from point

1002 to **1000** (our first vector point) selecting the points in the text view by doing the following.

1. The Final Bundle points should already be displayed textually. If they are not, click on the Final Bundle, and click on the points icon ▦ . The points will be listed in the right pane.

2. Select points **1000** and **1002** in the text view using the multi-select techniques you learned earlier.

3. Right-click and select **Distance** from the pop-up menu. The dialog box below should appear showing the distance is **100mm** as it should be.

Point - Point Measurement

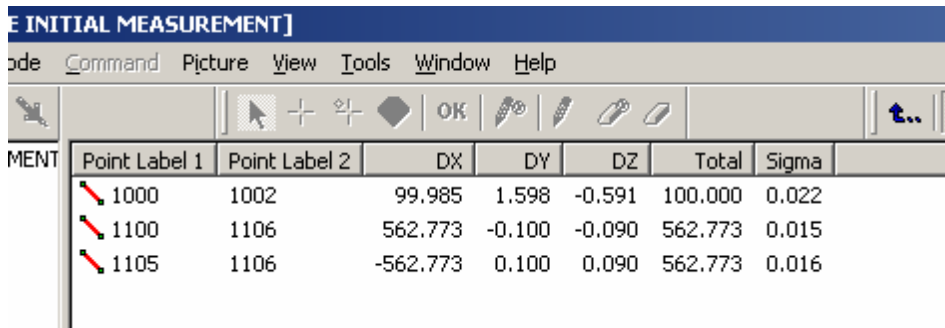|		
Name:	1000 1002	
Point1:	1000	
Point2:	1002	
Distance:	100.000	millimeters
Sigma:	0.022	millimeters

☑ Create Template

[OK]   [Cancel]

4. Click **OK**.

Notice how the default name for the measurement is derived from the two point labels. The distance measurement confirms a property of the Axis Alignment; it does not change the scale of the measurement.

You can also select point pairs in the graphical view just as you did for vector points earlier. In this case, you can also use the d key to select the distance command. Using the 3D Viewer, measure the distance from point **1100** to **1106**, and from point **1105** to **1106**. Notice the two distances are equal as they must be since point **1106** was constructed as the average of **1100** and **1105**.

If it's not already open, open the Final Bundle 3D file measurements folder 📊 Measurements and click on the **Point to Point** measurements folder ↘ Point to Point to see the stored distance measurements as shown below.

Point Label 1	Point Label 2	DX	DY	DZ	Total	Sigma
↘ 1000	1002	99.985	1.598	-0.591	100.000	0.022
↘ 1100	1106	562.773	-0.100	-0.090	562.773	0.015
↘ 1105	1106	-562.773	0.100	0.090	562.773	0.016

Congratulations

Congratulations! You have successfully completed this tutorial. You have encountered some typical problems, and seen how they are handled. You have also performed some basic analysis using the 3D Viewer. But do not stop now; there is more to learn.

Second Tutorial

Repeat Measurement with AutoMeasure

If you have not done the previous tutorial, you should do it before proceeding.

If you have installed V-STARS on a drive other than C drive then references to C drive should be replaced with whatever drive you installed V-STARS onto.

In this tutorial, we will repeat the measurement of the frame using the same eight photographs. This time we will take advantage of some of the work we completed in the first tutorial. We will also utilize a driver file to guide the measurement.

In the course of this tutorial, you will learn to:
1. Start V-STARS and open an existing project.
2. Familiarize yourself with some of the different objects/items in V-STARS.
3. Import a Driver file into a project
4. Import scale bars into a project
5. Import construction objects into a project
6. Use AutoMeasure to measure the image points on the pictures with a driver file.
7. Manually rename measured points.
8. Run the Bundle Adjustment to produce the 3-D coordinates of the points from their measured images.
9. Examine how Construction object are used.
10. Align design and measured data using advanced techniques.
11. Compute and display differences between design and measured values.
12. Produce an output report.

Setting up the Measurement

First, we setup the tutorial measurement by doing the following:

1. Start V-STARS.
2. Open the second tutorial project.

To setup the measurement do the following:

1. Start **V-STARS** by clicking on the **Start** button at the bottom left of the screen. A list will pop-up displaying some selections.
2. Click on the **V-STARS** option to start the program.

Opening the Project

Once again, to simplify and standardize the tutorial we have already created a V-STARS project for this measurement. We will start by opening this existing project.

1. Open the tutorial project by selecting **Open** from the **File** menu. V-STARS will open a dialog box showing all the current projects in your default project directory.

2. As this is a demonstration project, it has been saved in the `C:\Vstars\Demos` directory. Go to this directory using the standard methods available in the dialog box and open the folder icon for the `FRAME REPEAT MEASUREMENT`. If there is no such folder in the demo directory, verify that the demonstration tutorials have been installed as described in the **Installing the V-STARS Tutorial** section.

3. Select the FRAME REPEAT MEASUREMENT.prj file and press the **Open** button.
4. V-STARS will open the tutorial project.
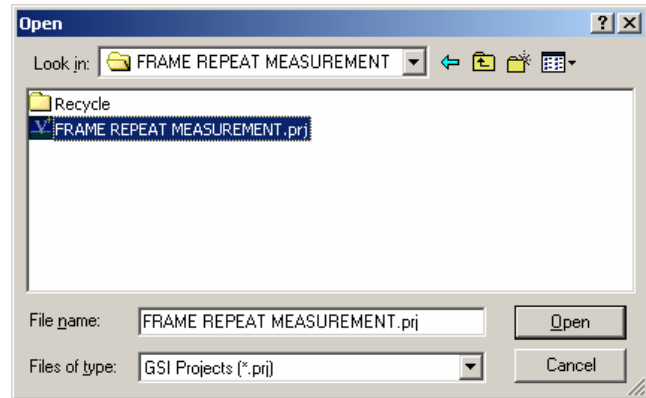
Examining the Project

After opening, the display should appear as shown below.
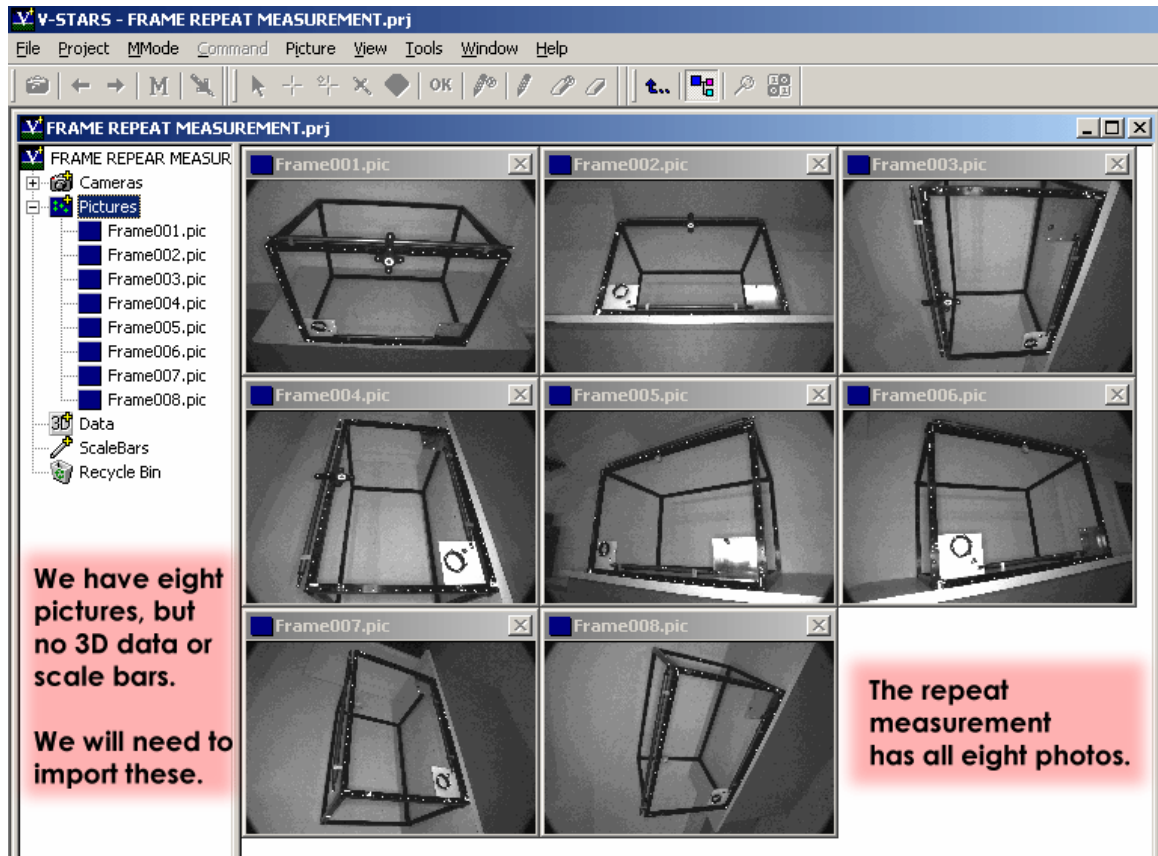
📝 Don't be concerned if the thumbnails are arranged differently. Their positioning will depend on the size of your window.

This project has all the elements of the first tutorial. This time we are going to start with all eight pictures. In this tutorial, we are also going to make use of the scale bars created in the first tutorial as well as the construction objects. In addition, we are going to start with a 3D file of the frame. This is called a driver file. It contains coordinate data for each of the frame points.

The Frame Points Driver represents the values of the frame when it was first manufactured. We expect the targets to be about the same, but suspect that something has happened to the top right corner. To confirm this we will ultimately compare our coordinates to this data in a transformation. Let's begin by importing the necessary objects.

Importing the Driver.

The Frame Points Driver is located in the `C:\Vstars\Demos` directory. Let's import the file as our driver. There are two main ways to import a driver file. We will show you both methods and let you decide which you prefer.

Right click on the 🔲 and select **Driver File** from the **Import** menu item.

Alternatively, you can select **Driver** from the **Import** menu under the **Project** menu.

In both cases, you will be presented with the standard file dialog. The file is called Frame Points.3D and is located in the `C:\Vstars\Demos` directory. Press **Open** to import the file.
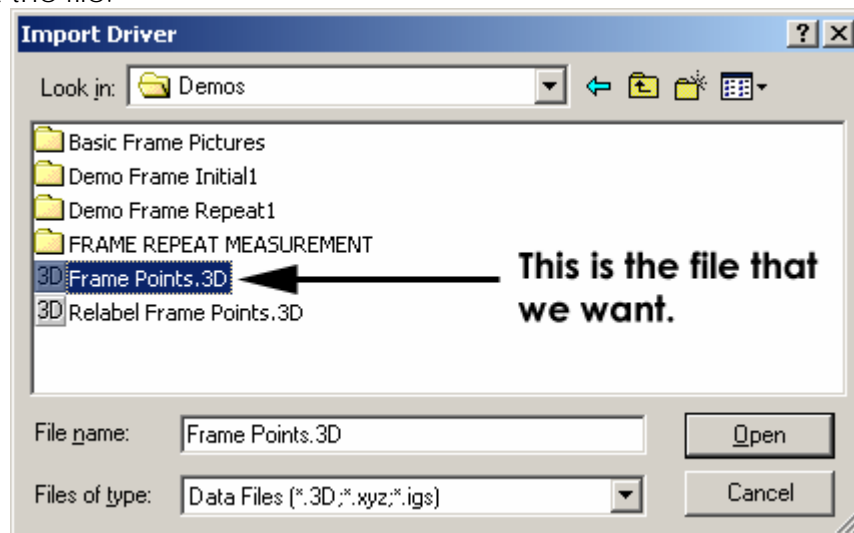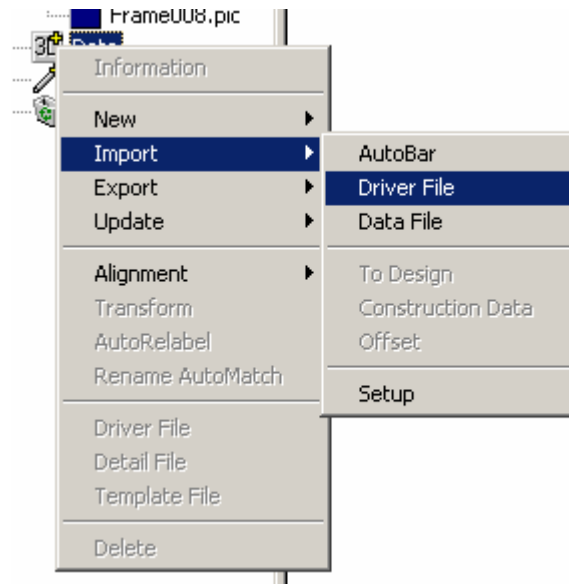
Expand the tree of the Frame Points file by pressing the ⊞ symbol beside it.

You will note that the file has a design folder in it. The points are stored in this area. The points could have also been stored in the regular points area. The advantage of the design area is that the points are copied over after each bundle. This allows V-STARS to automatically complete the alignment at the end of the bundle. We will talk more about the alignments later in the tutorial.
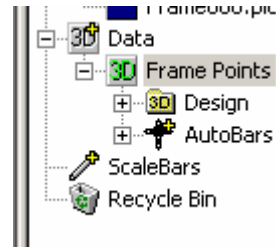
📒 The coordinates for the four scale points are not available in the driver since these are different for every measurement due to the scale bars not being permanently attached to the frame.

📒 The design points, including the AutoBar points, are in the user coordinate system. This will be our working coordinate system from the start, unlike in the first tutorial, where, at the end we had to transform the results from the original coordinate system defined by the AutoBar into the user coordinate system.
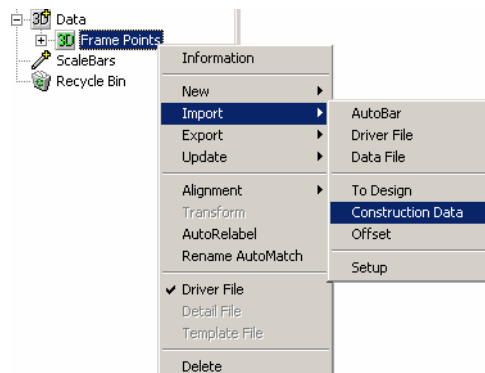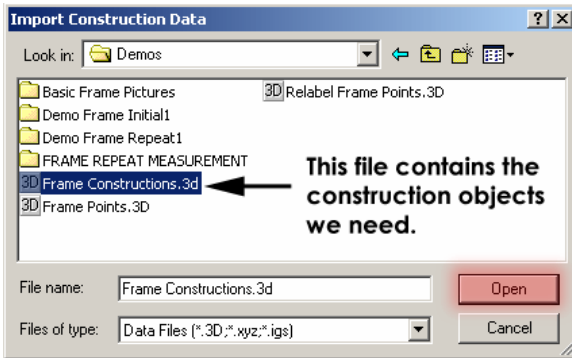
Importing the Construction Data.

Construction objects allow constructed point and object entities, such as vector points, planes, lines, etc. to be automatically computed at the end of each bundle. In the first tutorial, you will recall, that we created a number of average and vector constructions. Let's take advantage of those constructions and import them into the current driver. Once the bundle is run all the necessary points will be created automatically for us.

📒 For convenience, we have placed the construction objects into a file called Frame Constructions.3D. Construction objects can be imported from any 3D file.

Let's import the construction objects within this file to our driver file.

1. Right-click on the Frame Points driver file and select **Construction Data** under the **Import** option.
2. The windows file dialog will open.
3. The construction data is located in Frame Constructions.3D. This file is located in the `C:\Vstars\Demos` directory.
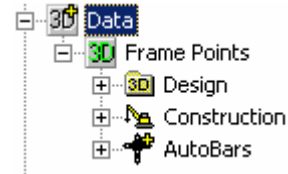4. Select the file and press **Open**.

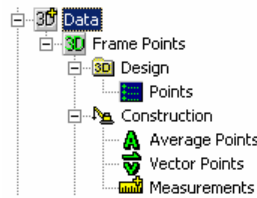5. A summary of the construction object imported will appear.
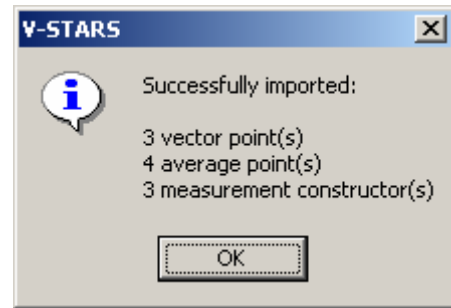
Examining the Driver.

Let's go back and examine how the driver has changed. Select the ⊞ adjacent to the **3D** file to open it.

The file should contain the following icons. Press the ⊞ beside the **3D** and 🔧 folders to open them.

If you click on the **A**, **v̄**, or 📏 icons you will see the various constructions that have been created.
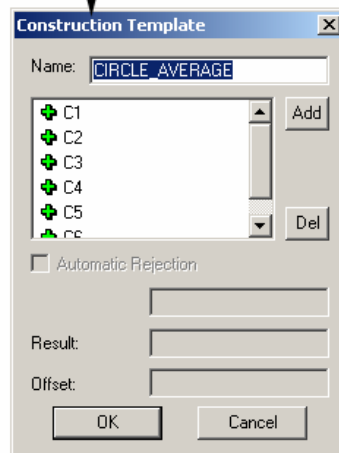

This is the frame driver data.

These are the various constructions we have imported.

These are the various templates that we created in the first tutorial.


Double-click to open the object and modify it.

Press OK to close the template object.
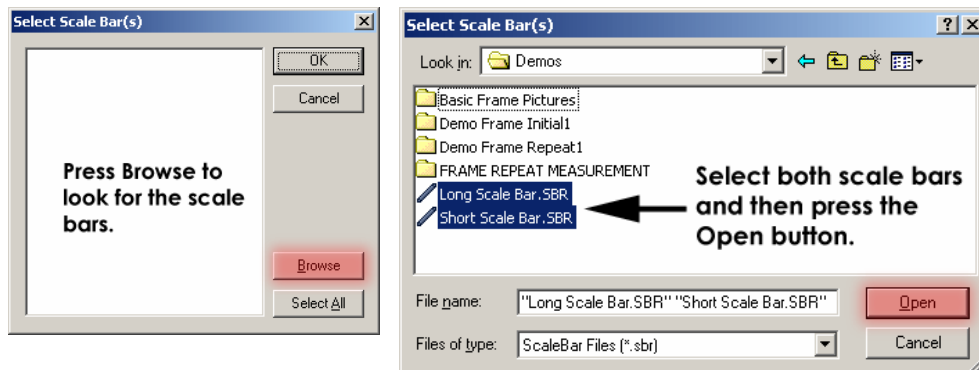
Importing the Scale Bars.

In the first tutorial we created the two scale bars objects that defined the labels and lengths of the scale we used. We could create these scale bars again, but that would be redundant and prone to error. Let's import the scale bars into the project.

📒 For convenience, we have placed the scale bar objects in the `C:\Vstars\Demos` directory.

1. Right-click on the Scale Bars folder icon 🖊 on the project tree.
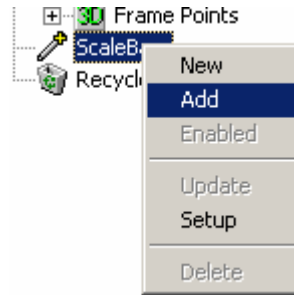
2. Select **Add** from the menu to Add a scale bar to the project. The following dialog box will appear.

3. Press the **Browse** button to go to the directory that has the scale bars in it. The scale bar objects are in the `C:\Vstars\Demos` directory.

4. Select both scale bars and press **Open** to import them.
5. Open the Scale bars folder to verify that the scale has been imported.

We are now ready to proceed with the AutoMeasure.

📒 You did not have to open up the folders as we just did before proceeding. This was done just to show you all the data that you have imported.

The Measurement

Running AutoMeasure

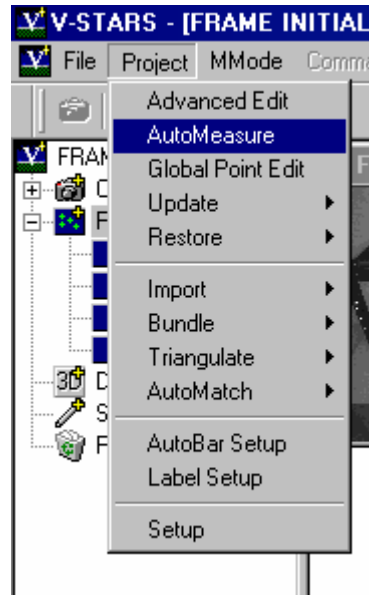
Select the **AutoMeasure** command from the **Project** menu. The **AutoMeasure** command opens the **Measure Project** dialog shown. From this dialog, it is possible to complete the entire V-STARS measurement.
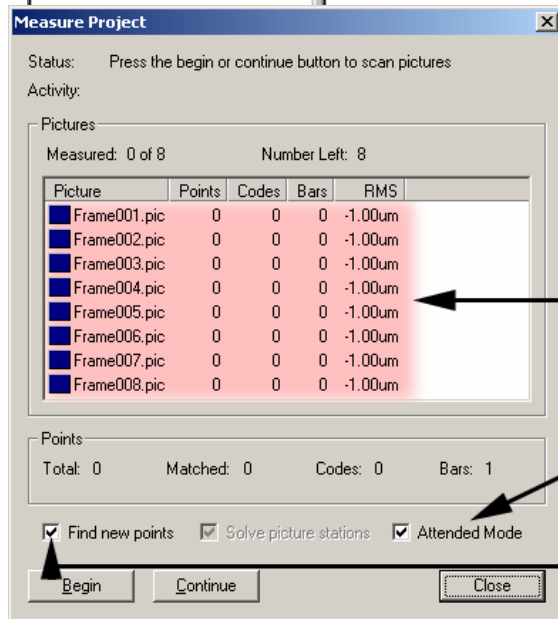
We are going to start with all eight images.

Attended mode is checked so we can control the process.

Find new points is checked so that we can find the scale points.

Press **Begin** to start the AutoMeasure.

When done scanning, AutoMeasure will display the current results.

The next step is to get a better solution for the pictures.

We got a solution for 7 of the 8 pictures.

This shows the quality of the picture solution. A value of < 1um indicates good AutoBar and coded target values as well as a good camera calibration.

Only three coded targets found. We will need to identify one more point to AutoStart the picture.

We have driven to the frame points, codes and AutoBar.

**Press Quit to exit AutoMeasure so that we can measure the 7th picture manually.**

We need to manually measure picture 7, so lets break out of AutoMeasure by pressing the **Quit** button.

Measuring the Seventh Picture

Notice the icon for the seventh picture does not have a border around it as the other pictures do. In addition, its thumbnail has a red border around it. These both indicate, the picture was scanned but is unmeasured.

Access the seventh picture by either clicking on its thumbnail, or double-clicking on its picture icon . The seventh picture was taken from the top, left side. We have the same problems as we had in the first tutorial. These as shown below.

You will recall that when the AutoMeasure command tried to SuperStart this picture, it was unable to find four coded targets. Of the six coded targets on the frame, only three were decoded (Code1 and Code2 on the left side of the fixture, and Code6 on the shiny plate). Since AutoMeasure was unable to automatically identify four known points, we will have to use the AutoStart procedure to measure this picture.

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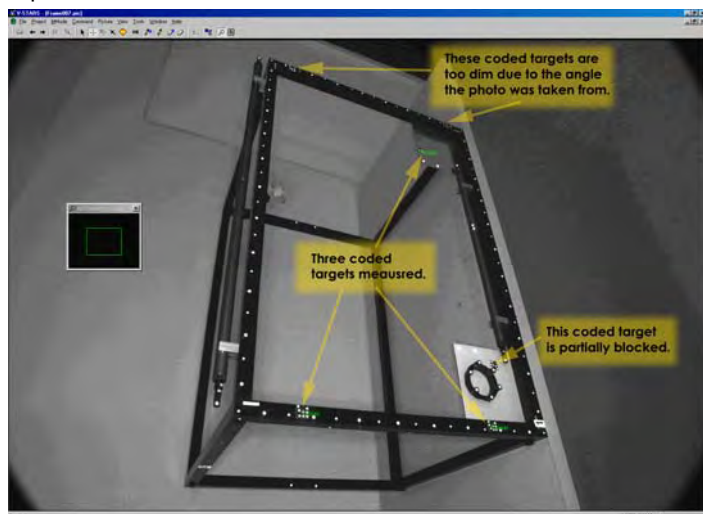
The AutoStart procedure needs four identified points. We already have three so we must find and measure one more known point. You can use any known point. An easy point to locate is **1001**. It is in the bottom left corner of the frame and the number "**1**" is to the right of it. Set the current label to this point by typing **1001**. Measure **1001** by clicking on the target and then AutoStart. You can AutoStart on these four points in several ways:

1. Select **AutoStart** from the **Command** menu.

2. Right click in the picture window and select **AutoStart** from the pop-up menu.

3. Use the **Xa** shortcut keyboard command.

If you measure the wrong point(s), as we did in the first tutorial, the AutoStart procedure will either fail completely and give you **The Resection Failed** message, or you will miss many of the target points (and they will be red). If either situation occurs, you can try again by repeating the steps above after you reset the picture.

To reset the picture, do the following:

1. Run the **SuperStart** (**Xs**) command. Press **Yes**. It will fail again because it can only find three coded targets.

2. Answer **No** to the question about resetting the picture. Now we only have to measure one more point.

3. Set the current label the name of the point you wish to manually identify.

4. Measure the point.
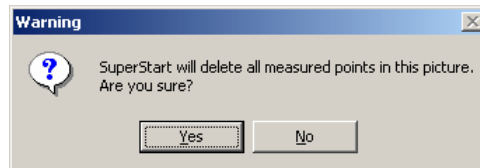
Run AutoStart (**Xa**) V-STARS will measure all the visible points in the driver file.

When you have successfully AutoStarted, the picture should appear as below.
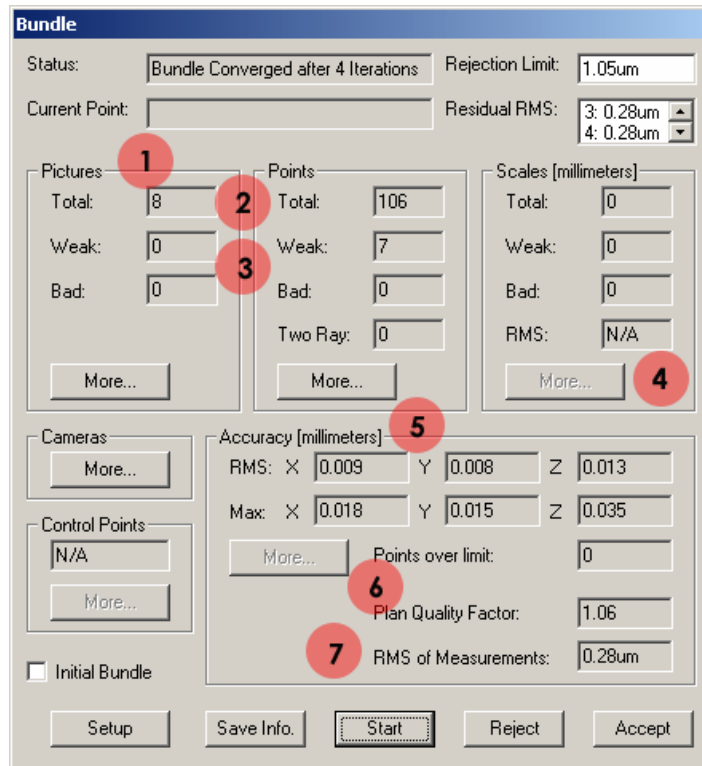
Notice that there are no scale bar points. This is because they haven't been AutoMatched yet.
We have now measured the seventh picture. Close the picture. We will now process all eight pictures.
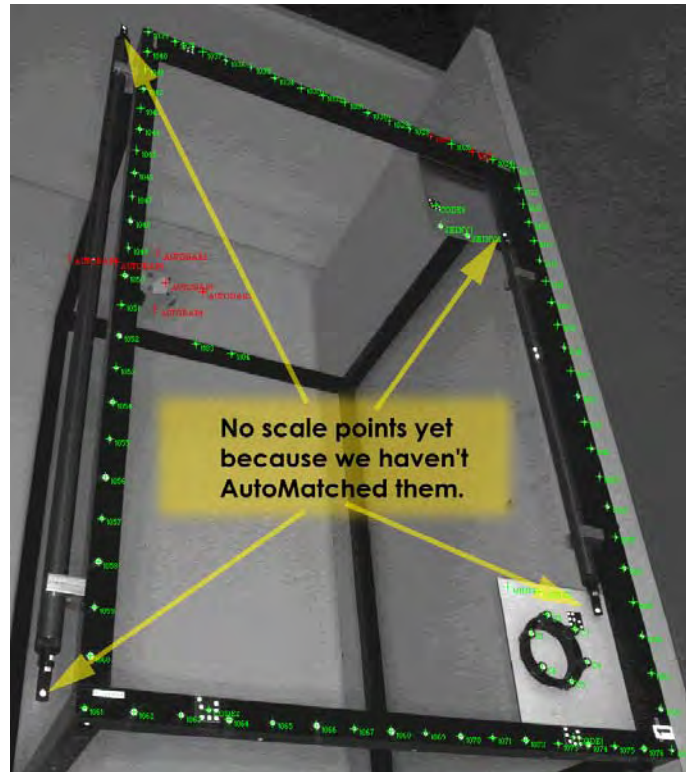
No scale points yet because we haven't AutoMatched them.

Continuing the AutoMeasure

Resume the AutoMeasure command by selecting **AutoMeasure** from the **Project** menu again. Notice the AutoMeasure Dialog now includes the current statistics for the seventh picture that we just measured. Press the **Continue** button. The AutoMeasure command will quickly check the pictures, determine they are all scanned, and display the dialog again with a new status message. Press the **Continue** button run the AutoMatch on all eight pictures. Press the **Continue** button again to run the Bundle Adjustment.

The Bundle adjustment will display its progress, and when done, will display the Bundle Summary dialog box shown below.

The key features to notice once again are:

1 All eight pictures were processed, and none of the pictures was weak or bad. Pictures are usually bad because they do not have enough acceptable points for a solution.

2 All 106 points were measured, and no points were lost due to bad measurements. In addition, there are no two-ray points so every point was successfully measured in at least three photographs.

3 There are still a few weak points. We will press the Points **More** button later to get more information about these points.

4 We have imported the scale bars, but there are no scale bars present. We have just AutoMatched the scale points and therefore they don't have the correct names. We will need to rename the scale points.
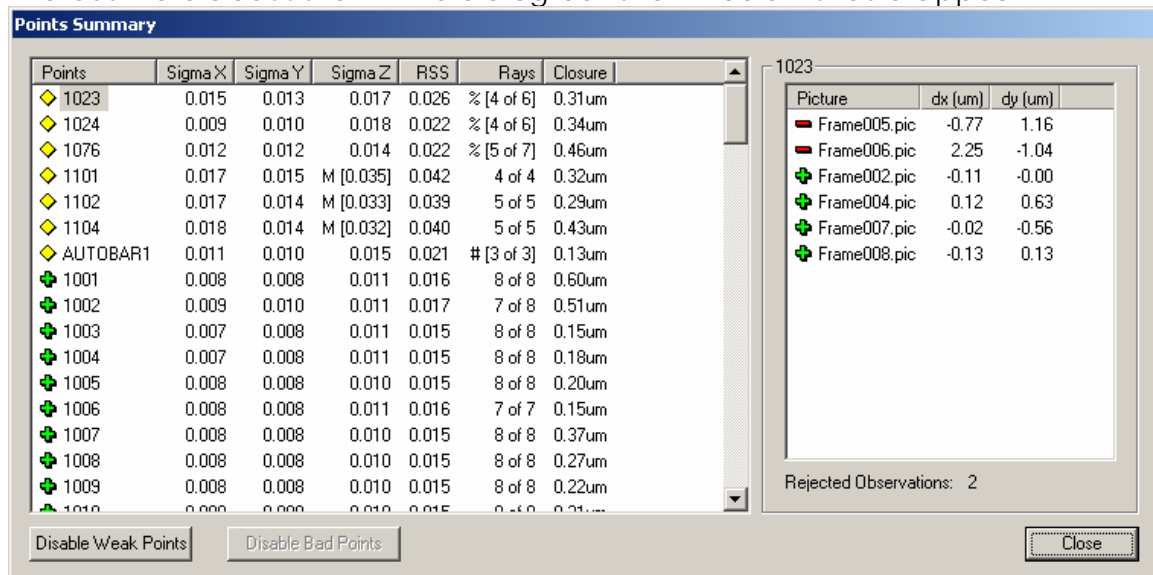
5 The accuracy estimates are small and acceptable. This is expected since we have used all eight pictures. No points are over the 0.050mm limit we have specified, however the maximum Z accuracy estimate (0.035mm) is nearly triple the Z RMS (0.013mm) for all the points. We should investigate this.

6 The plan quality factor is close to 1.0. The camera calibration is strong. This is reflected in the plan quality factor. A plan quality factor less than 2 is typical for a well-planned and executed measurement.

7 The RMS of measurements is low and acceptable.

If you do not get the results listed here, you should press the **Reject** button. Then, review the tutorial instructions and correct any problems. Finally, re-run the bundle so you get the results listed here before proceeding with the tutorial.

We still have a handful of weak points. Click on the Points **More** button to find out more about them. The dialog box shown below should appear.

Points Summary

Points	Sigma X	Sigma Y	Sigma Z	RSS	Rays	Closure
◇ 1023	0.015	0.013	0.017	0.026	% [4 of 6]	0.31um
◇ 1024	0.009	0.010	0.018	0.022	% [4 of 6]	0.34um
◇ 1076	0.012	0.012	0.014	0.022	% [5 of 7]	0.46um
◇ 1101	0.017	0.015	M [0.035]	0.042	4 of 4	0.32um
◇ 1102	0.017	0.014	M [0.033]	0.039	5 of 5	0.29um
◇ 1104	0.018	0.014	M [0.032]	0.040	5 of 5	0.43um
◇ AUTOBAR1	0.011	0.010	0.015	0.021	# [3 of 3]	0.13um
✚ 1001	0.008	0.008	0.011	0.016	8 of 8	0.60um
✚ 1002	0.009	0.010	0.011	0.017	7 of 8	0.51um
✚ 1003	0.007	0.008	0.011	0.015	8 of 8	0.15um
✚ 1004	0.007	0.008	0.011	0.015	8 of 8	0.18um
✚ 1005	0.008	0.008	0.010	0.015	8 of 8	0.20um
✚ 1006	0.008	0.008	0.011	0.016	7 of 7	0.15um
✚ 1007	0.008	0.008	0.010	0.015	8 of 8	0.37um
✚ 1008	0.008	0.008	0.010	0.015	8 of 8	0.27um
✚ 1009	0.008	0.008	0.010	0.015	8 of 8	0.22um
✚ 1010	0.009	0.009	0.010	0.015	8 of 8	0.21um

1023

Picture	dx (um)	dy (um)
▬ Frame005.pic	-0.77	1.16
▬ Frame006.pic	2.25	-1.04
✚ Frame002.pic	-0.11	-0.00
✚ Frame004.pic	0.12	0.63
✚ Frame007.pic	-0.02	-0.56
✚ Frame008.pic	-0.13	0.13

Rejected Observations: 2

Disable Weak Points   Disable Bad Points   Close

Once again, the points at the back of the frame are weak due to their location. The point 1103 has just passed the Median test and is not listed as Weak. The points **1023**, **1024** and **1076** have failed the Percentage test. AutoBar1 has failed the number test (<4 rays).

Once you are satisfied, press the **Close** button. Accept the Bundle by pressing the **Accept** button. We will now rename the scale points.

Renaming the Scale Points

Access the first picture by either clicking on its thumbnail (if you do not see the thumbnails, click on Pictures ✜), or by double-clicking on FRAME001.PIC. A "picture window" will appear with the full image.

There is a Labels toolbar (🖊🖊🖊🖊) at the top of the screen that is used to relabel and erase points. If you dwell on each toolbar icon for a short time, a "tool tip" will appear describing what the icon does. To globally rename the points, do the following:

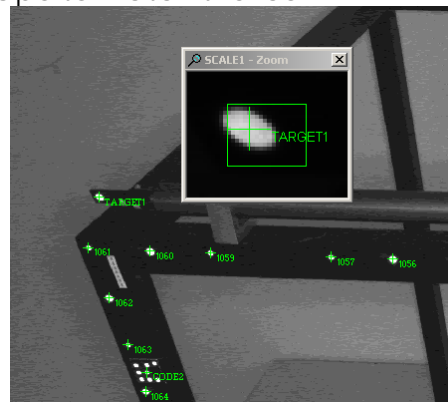1. Click on the global rename icon 🖊 on the toolbar.

📒 Make sure you select the global rename icon and not the local rename icon or you will only relabel in this picture.

2. Commence by renaming the top scale bar. The adjacent diagram shows the labeling we have adopted for the scale bars. Move the cursor to the top, left scale bar point (it is now called TARGET1).

Notice the cursor has changed shape to match the icon.

3. Relabel the point to **SCALE1**.

   Type in the correct label (case does not matter) scale1 and then press the ". The current label is displayed in the Zoom Window's title bar.

4. Bring the target center inside the measuring rectangle.
5. Press the left button on the mouse. The point is relabeled.

The point is **globally** relabeled to **SCALE1**; we have changed the label to **SCALE1** in **all** pictures, and in the **current** driver file. We have NOT

measured the target; that has already been done. We are just globally changing its label.

Notice the current label displayed in the Zoom Window's title bar is automatically incremented and is now **SCALE2**. This is the top, right scale bar point (currently called TARGET3). Re-label it in the same way, and then relabel the two bottom scale bar points. **SCALE3** is the left one, (now called TARGET2), and **SCALE4** is the right one (called TARGET4).
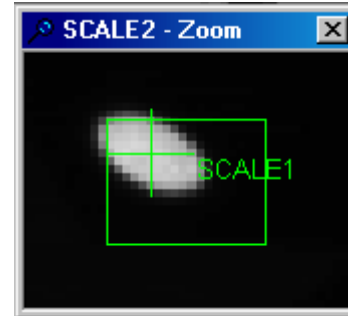
Once you are done, the image should look as follows.
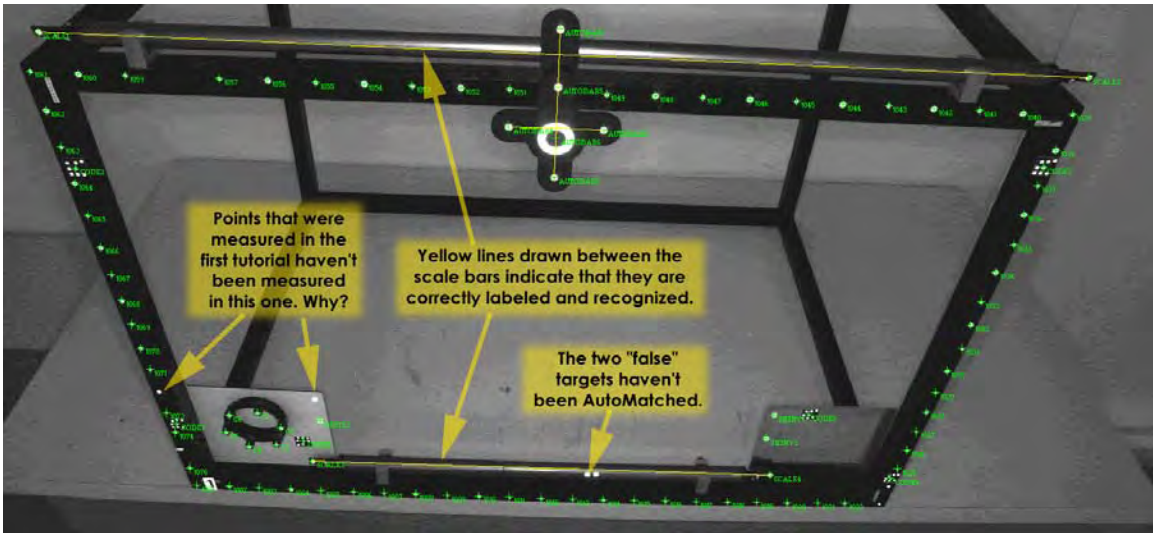
The main thing to note is that there are now yellow lines drawn between the ends of each of the scale bars. This indicates that we have correctly renamed our scale points. If one or both of the lines are missing then we have either renamed the points incorrectly or that the scale bars haven't been imported. The other thing to note is that there seem to be some points that haven't been measured. Let's find out why.

Target Filters

Examination of the first picture indicates that there are some differences between the first and second tutorial measurement. We also see that some of the false points haven't been AutoMatched this time. There is obviously something different between the two tutorials.

As it turns out, we have switched on some targets filters in this tutorial. The filters are located under **Project**- **Advanced Edit** – **General** – **Target Criteria**.

The target filters are very effective in removing false targets. This, in turn makes AutoMatching faster and more reliable. In some cases, they will remove legitimate targets. If so, this is generally because those targets are of poor quality and will be rejected in the Bundle adjustment anyway. One filter removes targets whose shape is unacceptable (Shape Filter); the other filters out targets that are too dim (Brightness Filter).
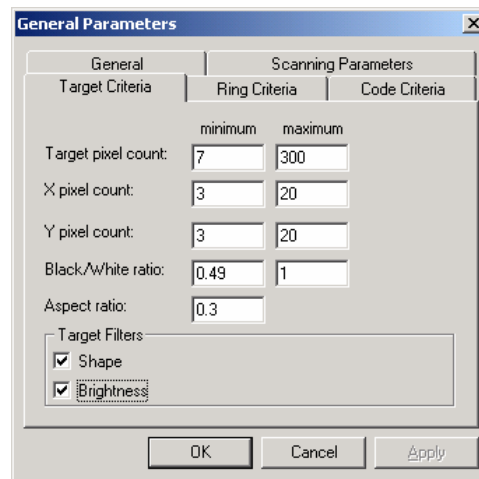
By default, the filters are switched on. They can be disabled by simply un-checking the boxes and rescanning the images.

The filters are only available in Version 4.2 and higher.

Running the Final Bundle.

We have renamed the scale bars and are now ready to run the final bundle. We can run the Bundle via the **AutoMeasure** command or we can go directly to the Bundle process via the Bundle menu command.

Select **Run** from the **Bundle** command on the **Project** menu. Press **Start** to commence the bundle process. You should get the following results.

The key features to notice once again are:

1 All eight pictures were processed, and none of the pictures was weak or bad.

2 All 106 points were measured.

3 There are still a few weak points. We will press the Points **More** button later to get more information about these points.

4 The scale bars are now present and we have good scale agreement.

5 The accuracy estimates are small and acceptable.

6 The plan quality factor is close to 1.0.

**7** The RMS of measurements is low and acceptable.

Press the **Accept** command to accept the results. Let's examine the
results of the Bundle process.

📒 If you do not get the results listed here, you should press the **Reject**
button. Then, review the tutorial instructions and correct any problems.
Finally, re-run the bundle so you get the results listed here before
proceeding with the tutorial.

Inspecting the Results Graphically

You can look at the individual point measurements graphically using the
3-D Viewer module included with V-STARS. To use the viewer do the
following:

1.   Click on the 3-D data 🗂 Data folder in the Project view.
2.   Double click on the latest results file (it will be called Bundle2 and have
the green 3D icon 🟩). A graphical view of the measured points will be
displayed in the window to the right.
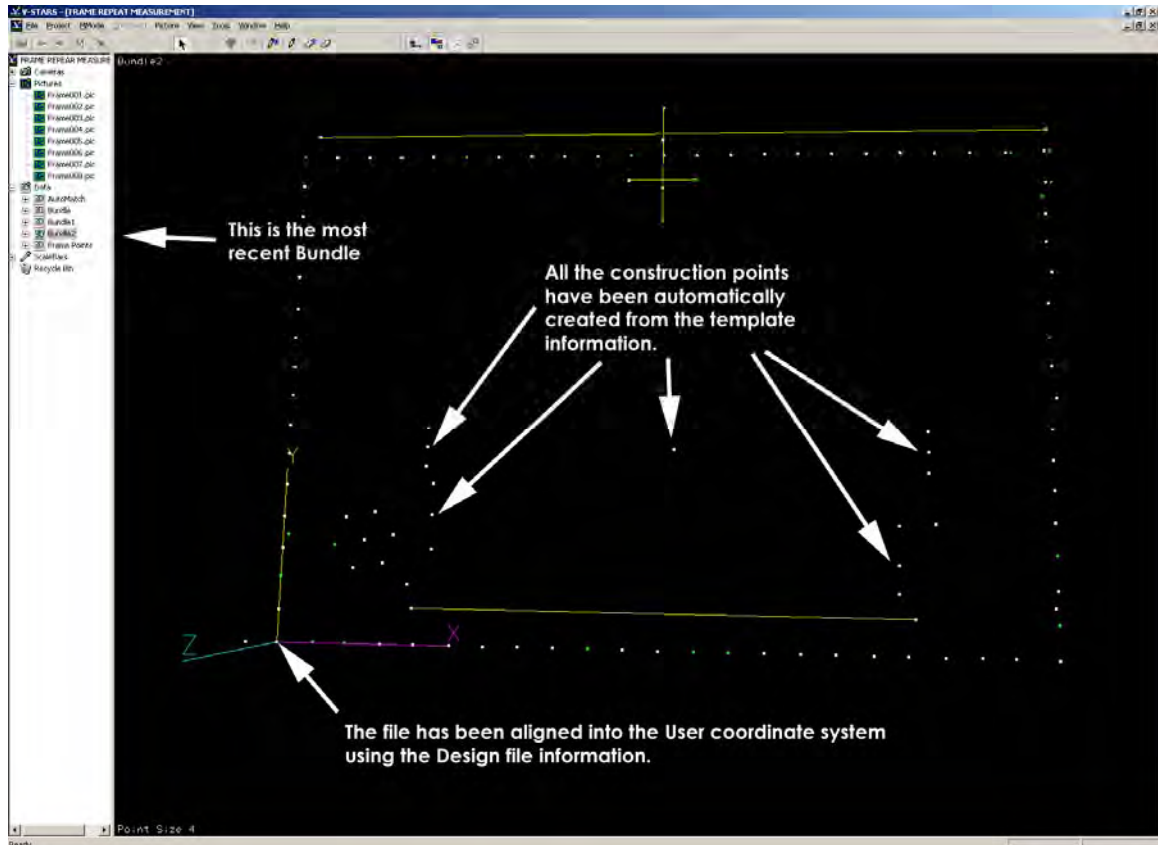
3.   Click in this window to make it active (the window's red border will
disappear).

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4. Press the [SPACE] to fit the measured data in the window.
5. The first thing to note is that all the vector points, average points and distance calculations have been completed for us. The information necessary to create these objects and measurements came from the construction objects.
6. The other thing to note is that the data has already been aligned for us in the User coordinate system. This was done using the coordinate points in the Design section of Bundle2. You will recall that this Design information was stored in the original driver file. It has been fathered down into each of the subsequent bundles.
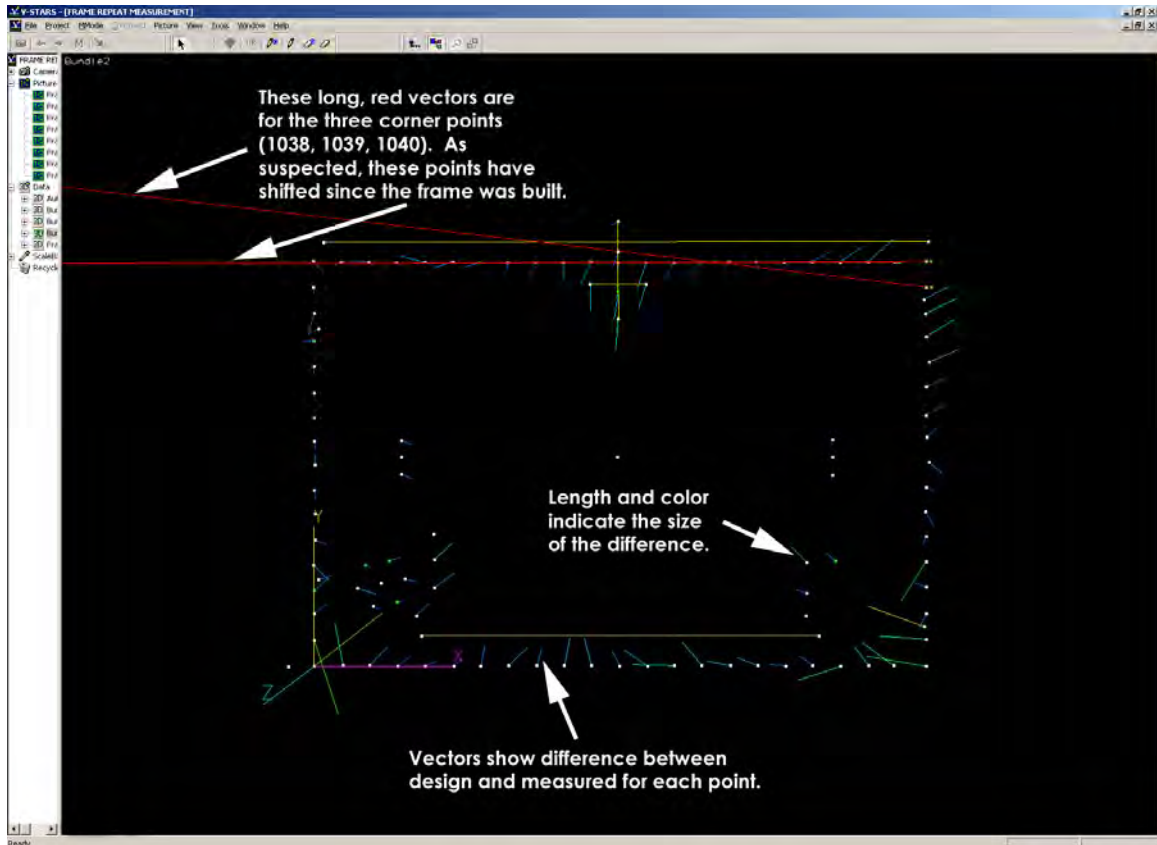
The Alignment

Comparing to Design

Often one needs to compare the measured data to some set of design data to check conformance of the actual product to design. As it turns out, V-STARS has already done this for us automatically; all we have to do is turn it on! Remember the Frame Points 3D file we used as our initial driver file is the actual design data for the part. Also, remember we earlier imported this data to the design area of our Bundle 3D file to provide a complete and current drive file for all 106 measured points. It turns out the design data was automatically carried forward into our current latest Bundle results (3D file Bundle2). Now we want to compare this design data to the actual final measurement. This is easily done using the 3-D viewer.

To do this, do the following:

1. Activate the graphical view again for the measured results by clicking on the 3D icon for the Bundle2 file.

2. If you have not already done so, return to the original view we had earlier by clicking in the 3D window to make it active (the red border should disappear), and pressing the [SPACE] bar and then the **Z** key. Use the up and down arrow keys to zoom the view as necessary.

3. Press the * key to display the differences between the design and measured values.

   📒 You can press the * key again to turn off the display. The 3D viewer window should appear as shown below.

4. Press the * key to switch the vectors off again.

These long, red vectors are for the three corner points (1038, 1039, 1040). As suspected, these points have shifted since the frame was built.

Length and color indicate the size of the difference.

Vectors show difference between design and measured for each point.

The length and color of the vectors indicate the difference between the design and measured value for the point. Notice the vectors for the three corner points (1038,1039,1040) are very long and red. Remember it was suspected that this corner had somehow changed since the frame was built. It appears that these points have actually moved significantly. To see how much the points actually moved, place the cursor on each vector, and a "tool tip" will appear showing the point label, and the amount of the difference. (The vectors for 1039 and 1040 are nearly in line with each other and appear as one, so only two vectors are visible). These points have moved about 8mm. The vectors are actually greatly enlarged; if they weren't, the vectors for most of the measurements would not be visible since they are very small relative to the size of the object. Place the cursor on several of the other vectors, and you will see the differences are less than 0.1mm. To see how the colors of the vectors relate to their length, press the **U** key; a "tolerance bar" that shows this information will be displayed. To turn the tolerance bar display off, press the **U** key again.
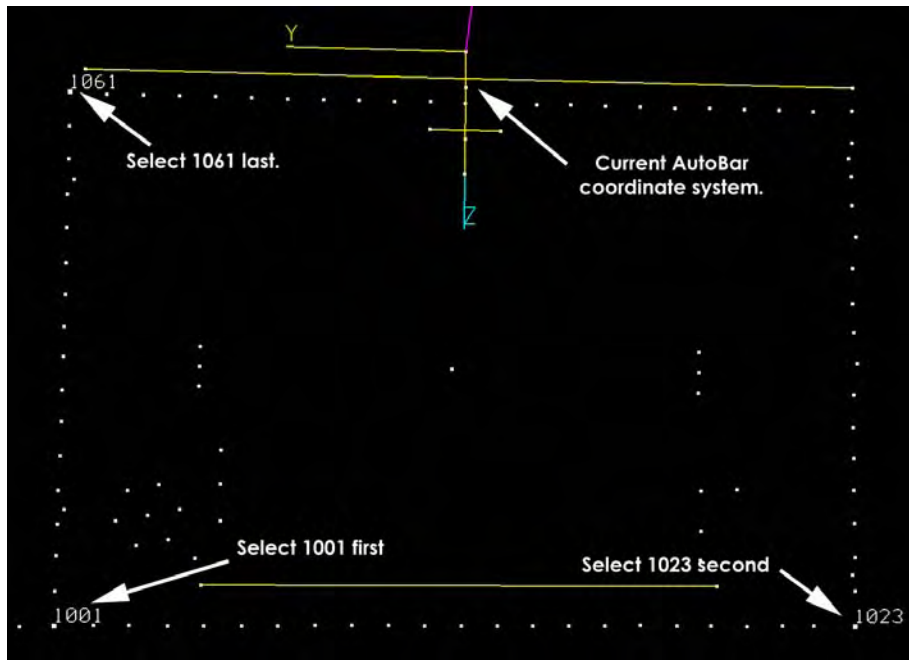
Completing an Axis Alignment

Let's examine what happens when we complete an Axis alignment on the data. From the first tutorial you learnt that the Axis alignment is the
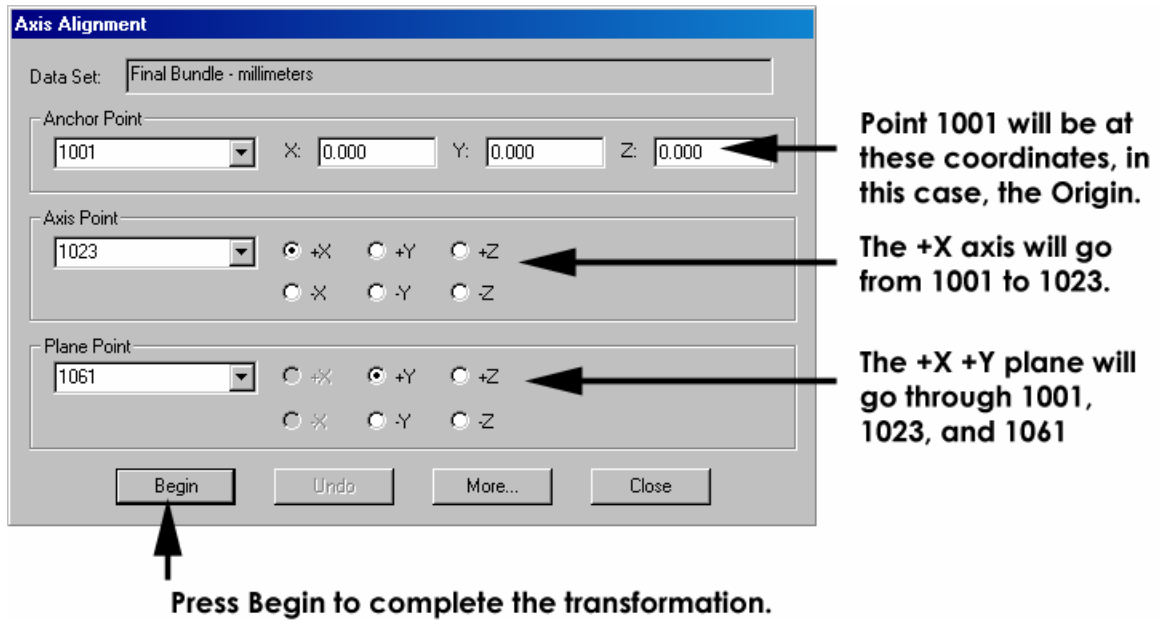
most simplistic alignment, but subject to limitations and problems. This axis alignment will demonstrate some of these limitations and problems. Again, we will use three corner points on the front face of the frame to define our coordinate system. We will place the origin at point **1001** in the bottom, left corner of the frame. The positive X-axis will go thru point **1023** at the bottom right corner of the frame. The XY plane will go thru these two points and point **1061** in the top, left corner. The positive Z-axis will be out of the front face of the frame.

To perform the axis alignment, we will use the 3D Viewer. Do the following.
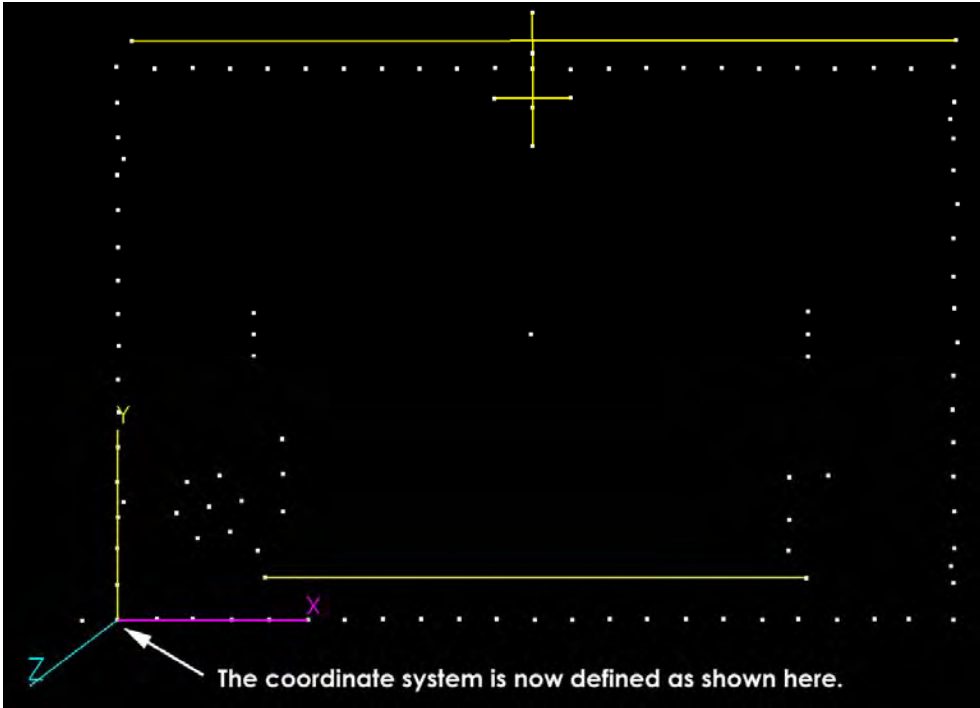
1.   Select the three points graphically using the multi-select techniques described earlier (hold down the ? key while selecting the second and third points). Order of point selection is important in an axis alignment, so select **1001** first, **1023** second, and **1061** last as shown below.


2.   Next, perform the **Axis Alignment** by right-clicking in the 3D Viewer. Select **Alignment** from the pop-up menu, and select **Axis** from the sub-menu. The dialog box below should appear.

Axis Alignment

Data Set: Final Bundle - millimeters

Anchor Point
1001   X: 0.000   Y: 0.000   Z: 0.000

→ **Point 1001 will be at these coordinates, in this case, the Origin.**

Axis Point
1023   ⊙ +X   ○ +Y   ○ +Z
        ○ -X   ○ -Y   ○ -Z

→ **The +X axis will go from 1001 to 1023.**

Plane Point
1061   ○ +X   ⊙ +Y   ○ +Z
        ○ -X   ○ -Y   ○ -Z

→ **The +X +Y plane will go through 1001, 1023, and 1061**

[Begin] [Undo] [More...] [Close]

↑ **Press Begin to complete the transformation.**

3. Check to see you have the same selections as listed above, and press the **Begin** button.

4. Press the **Close** button. The measurement results are now in the new coordinate system as shown below.

5. To make the view the same as below, press the **Z** to look down the Z-axis, and press the ⌷SPACE⌷ to fit the view onto the screen. If you like, press the **G** key until the frame is the size you want. Notice the coordinate axes have been relocated to define the new coordinate system.
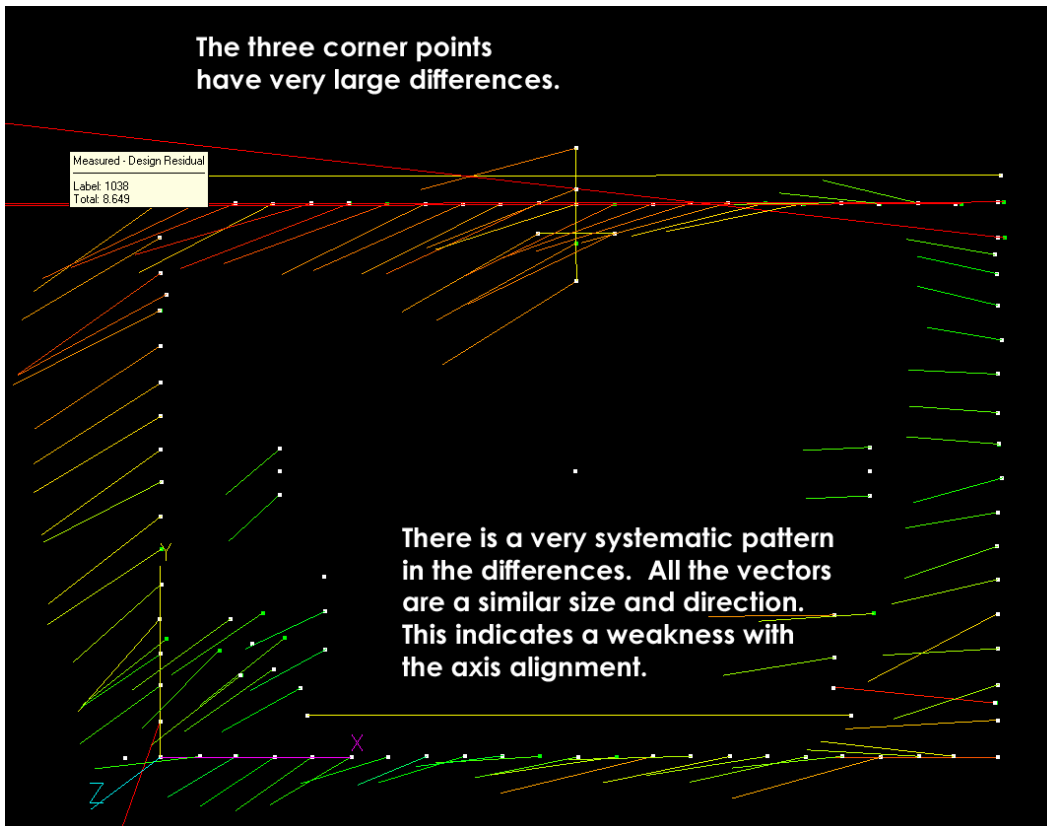
The coordinate system is now defined as shown here.

6. Make the coordinate axes bigger by successively pressing the ' key to confirm the X-axis goes thru point 1023. You can make the axes smaller again if you like by pressing the ; .

The measurements have now all been transformed into the new axis aligned coordinate system. Click on the points icon for the Final Bundle measurements, and look at the point coordinates. Confirm that point 1001 is at (0,0,0); that point 1023 has a positive X value, and Y and Z are 0, and the Z coordinate for point 1061 is also 0. This is the desired user coordinate system.

Let's examine what the difference vectors look like after the Axis Alignment on three points.

Press the * key to display the differences between the design and measured values.

The three corner points
have very large differences.

Measured - Design Residual

Label: 1038
Total: 8.649

There is a very systematic pattern
in the differences. All the vectors
are a similar size and direction.
This indicates a weakness with
the axis alignment.

There is a very systematic pattern in the differences. All the vectors are a similar size and direction. This indicates a weakness with the axis alignment. The Quick alignment after the bundle produced an alignment with smaller differences. Let's re-create that alignment using the alignment menu options.

Completing the Quick Alignment

To do the Quick Alignment, do the following:

1. Right-click in the 3D Viewer window of Bundle2 to bring up the pop-up menu.

2. Select **Alignment** from the menu. A sub-menu will appear.

3. Select **Quick** from the sub-menu.

4. Press the **Begin** button on the Quick Alignment dialog box that appears to run the Quick Alignment.
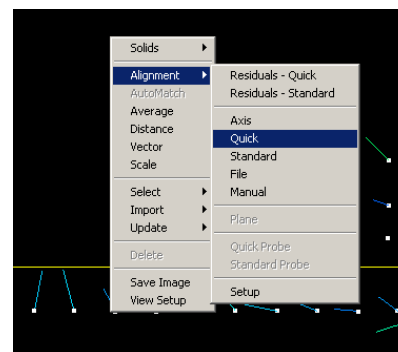
The results are shown below.
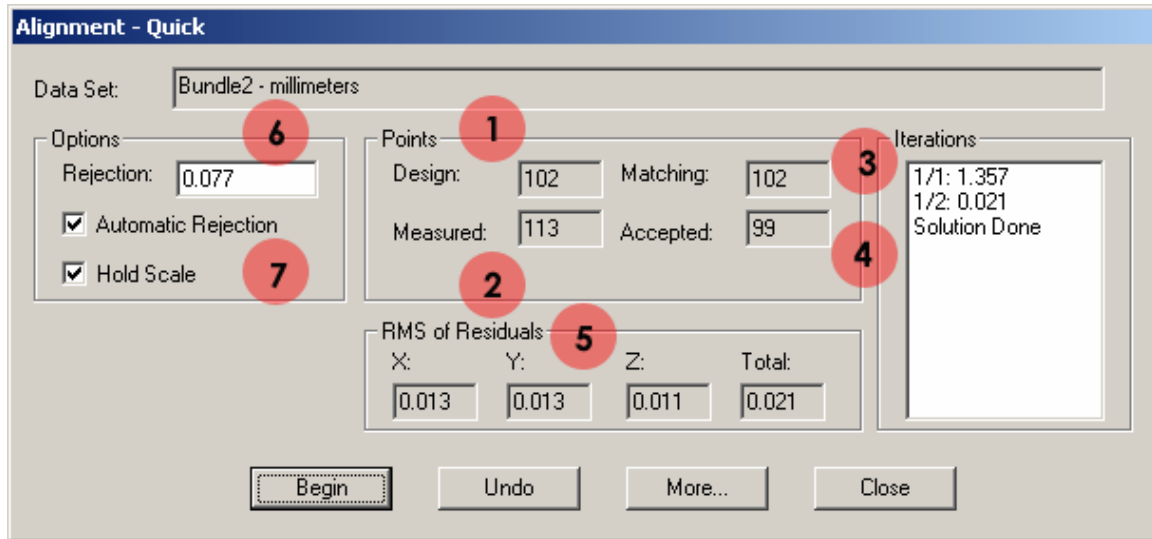
The key things to note are:

1 102 design points were found. This is as we expect. We had 102 design points and the four scale bar points. The design points are used to transform the measurement into the design coordinate system.

2 113 points were measured. 106 points were created by measuring targets, and seven more points were constructed from these measurements.

3 102 points matched between the design data and the measured data. So all design points were measured.

4 99 points were accepted. Three points were rejected because the measured values did not agree with the design values better than the automatic rejection limit. These were the three corner points.

5 The RMS of the agreement for the 99 accepted points is small and acceptable.

6 Since the automatic rejection check box was checked, the Quick Alignment automatically rejected points based on the quality of the transformation. Any point with a disagreement between the design and measured values after transformation larger than the value shown is automatically removed from the transformation. In this case, three points were removed.

7 Since the Hold Scale check box is on, the scale from the measurement will be preserved in the transformation. Otherwise, the measurement results would also be scaled to agree with the design

values. Whether to hold scale or not depends on the application and purpose of the measurement.

Look at the individual point results by pressing the **More...** button at the bottom of the dialog. The rejected points appear at the top of the list.

Click to view the Design data.

Click to view the measured coordinates. These are in the aligned coordinate system.

Click to view the differences between the design and measured points.

These points were rejected.

This is the RMS of all the accepted points.

Enter a new rejection factor and press the Recalc button to recalculate the alignment.

Label	DX	DY	DZ	Total
1038	-8.522	0.974	0.059	8.578
1039	-7.846	-0.024	0.050	7.846
1040	-7.843	-0.025	0.052	7.843
1001	0.051	0.039	0.004	0.064
1002	-0.002	0.034	0.015	0.037
1003	0.013	0.014	-0.000	0.019
1004	0.009	0.007	-0.001	0.012
1005	0.008	0.002	-0.008	0.011
1006	0.005	0.004	-0.007	0.010
1007	0.002	0.014	-0.004	0.015
1008	0.014	0.014	0.003	0.020

RMS of Residuals
X: 0.013   Y: 0.013   Z: 0.011   Total: 0.021

Rejection: 0.077   Recalc...   Save

OK   Cancel   Apply

Press the **OK** button to close the dialog. If you did not get the results shown here, press the **Undo** button, and then the **Close** button to exit the Quick Alignment without applying the transformation. Review the tutorial to fix any problems, and try again. If everything is OK, press the **Close** button to apply the transformation. The differences are identical to those before we applied the Axis Alignment.

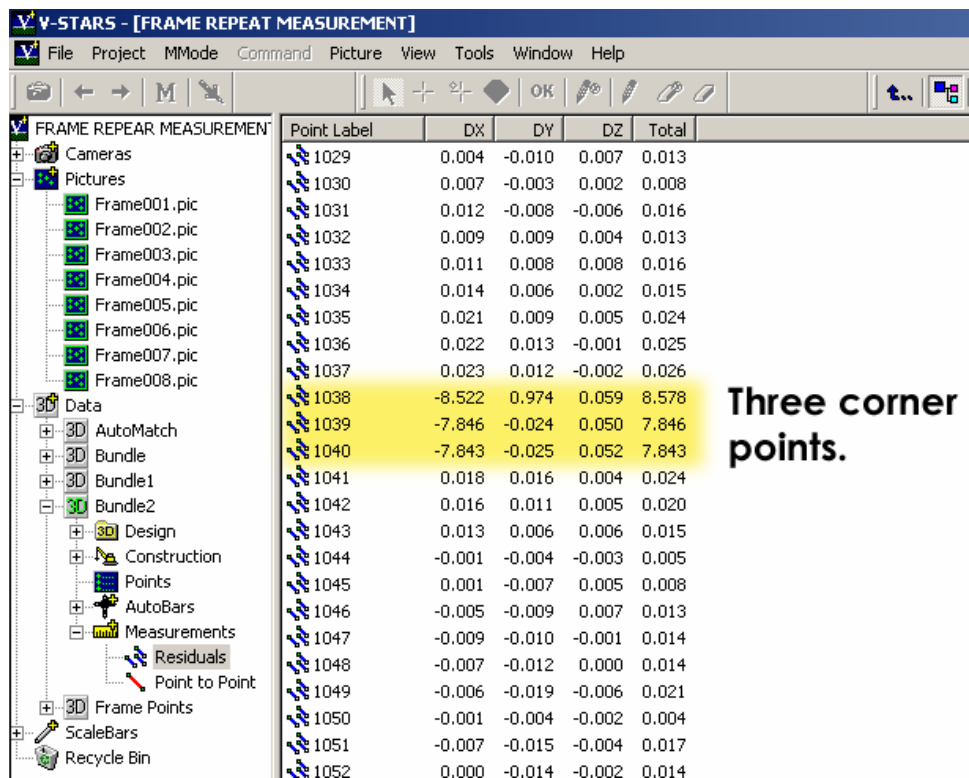The construction points have no residuals as they have no design value.
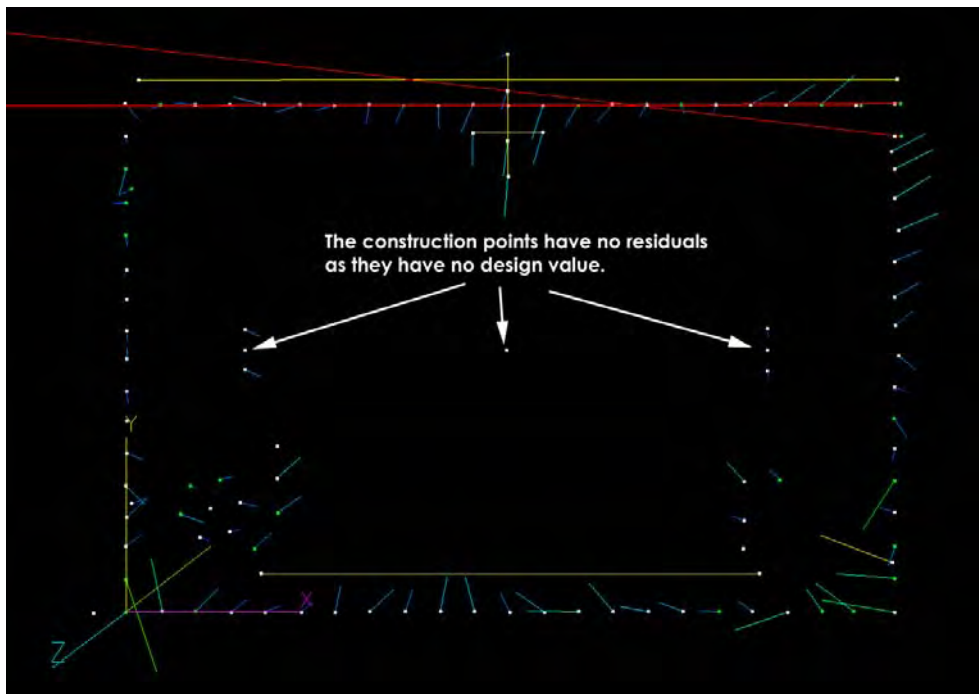
📒 When you apply the transformation, the original measured coordinates are replaced by the new, transformed measured coordinates. The original coordinates are not saved anywhere; they are lost.

You can also view the differences in text form by doing the following:

1. If you do not already see the Measurements folder 📏 Measurements under the Bundle2.3D file, double-click on the 3D Bundle2 icon 🆔 Bundle2 or click on its + button to see it.

2. Double-click on the Measurements folder icon 📏 Measurements or click on its ⊞ button to see the measurements.

3. Click on the Residuals icon ✴.

After a few seconds, the differences will be listed. If you like, scroll down a bit, and you will see the large differences for the three corner points (1038,1039,1040).


| Point Label	DX	DY	DZ	Total
1029	0.004	-0.010	0.007	0.013
1030	0.007	-0.003	0.002	0.008
1031	0.012	-0.008	-0.006	0.016
1032	0.009	0.009	0.004	0.013
1033	0.011	0.008	0.008	0.016
1034	0.014	0.006	0.002	0.015
1035	0.021	0.009	0.005	0.024
1036	0.022	0.013	-0.001	0.025
1037	0.023	0.012	-0.002	0.026
1038	-8.522	0.974	0.059	8.578
1039	-7.846	-0.024	0.050	7.846
1040	-7.843	-0.025	0.052	7.843
1041	0.018	0.016	0.004	0.024
1042	0.016	0.011	0.005	0.020
1043	0.013	0.006	0.006	0.015
1044	-0.001	-0.004	-0.003	0.005
1045	0.001	-0.007	0.005	0.008
1046	-0.005	-0.009	0.007	0.013
1047	-0.009	-0.010	-0.001	0.014
1048	-0.007	-0.012	0.000	0.014
1049	-0.006	-0.019	-0.006	0.021
1050	-0.001	-0.004	-0.002	0.004
1051	-0.007	-0.015	-0.004	0.017
1052	0.000	-0.014	-0.002	0.014

Three corner points.

Reports

The last thing we wish to do in this tutorial is to generate a report. Reports in V-STARS are generated using the **Report** option on the **File** menu. Prior to generating the report, we need to decide exactly what we wish to report. To do this select, the **Report Setup** command under the **File** menu. The following report screen will open.
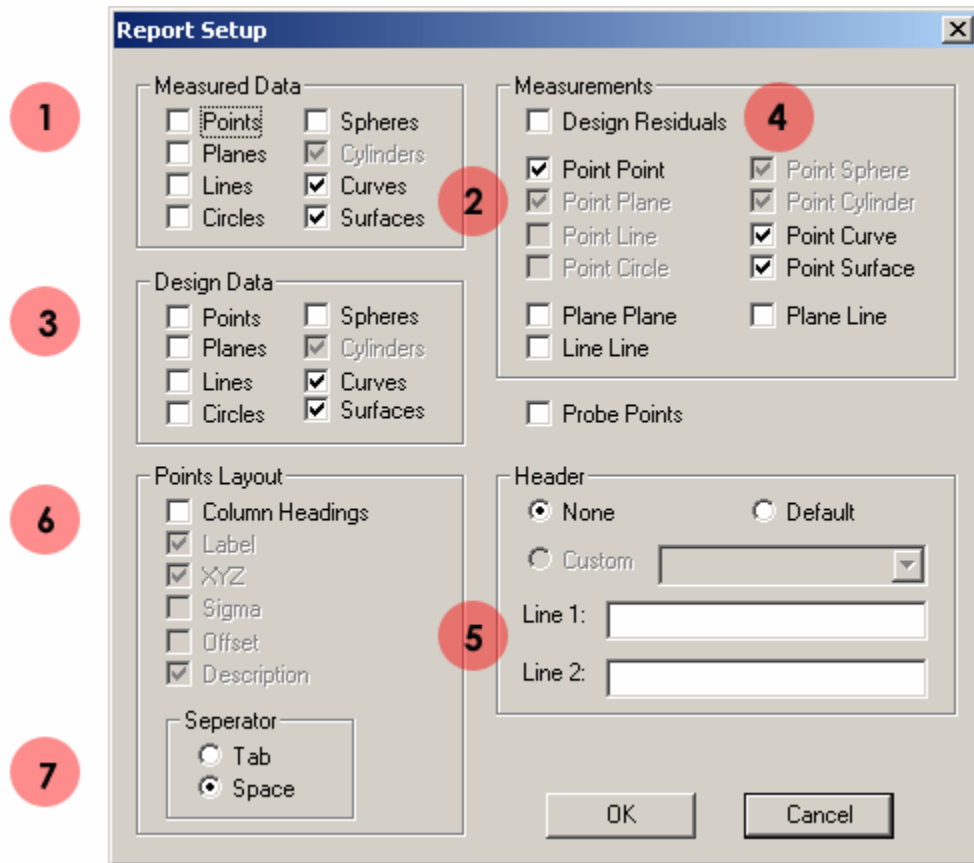
1 Check the points box to write the measured points to the output report.

2 Uncheck the Curves and Surfaces box, as we have no curves and surfaces. Do the same thing in the Design area.

3 Check the points box to write the design points to the output report.

4 Check the Design Residuals box to view the Design to Measured Residuals.

5 Enter header information in these input boxes.

6 Output column labels to the report.

7 Write the Report using either Tab or Space delimited fields.

The dialog should appear as follows. Press the **OK** button when the report has been setup.
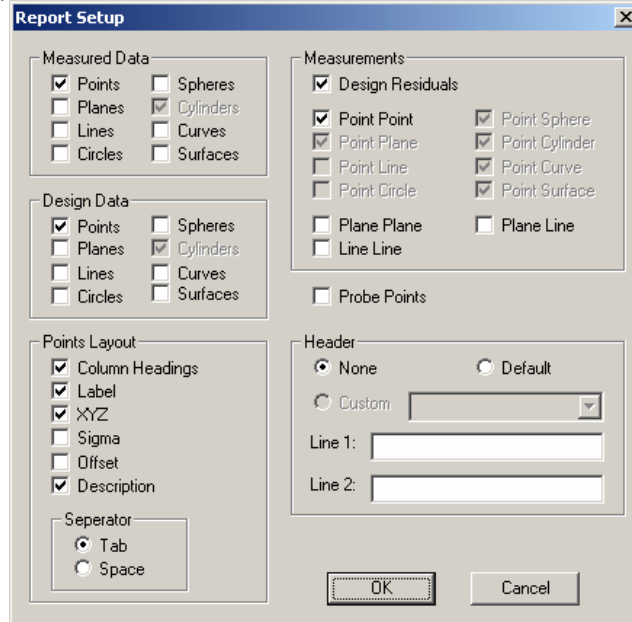
To generate the report select the **Report** option from the **File** menu. Specify the file/s you wish to report and their location. Open the file and examine the contents.

Congratulations

Congratulations! You have successfully completed this tutorial. You have done a repeat measurement using the AutoMeasure command. You have encountered some typical problems, and seen how they are handled. You have also performed advanced transformations using the 3D Viewer.

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