UTSA
The University of Texas at San Antonio™

Civil Infrastructure Vision
CIV Bridge© v1.0

Instructional Video

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Workshop Outline

1. Capabilities
2. CIV Bridge hardware and software
3. DIC principles
4. Accuracy validation
5. Conducting a Live Test
6. Post-processing images/data
   - Reprocess Existing Images
   - Interpolate Existing Data
   - Smooth Existing Data
   - Calculate from Data

Capabilities

1. Measures three-dimensional movement of targets in space
   - Uses two high-resolution / low-noise digital cameras
   - Digital Image Correlation algorithms and triangulation principles
2. Bridge edition calibrated for a large measurement volume (MV)
   1. Distance range 40 to 110ft
   2. Horizontal field of view 17 To 47ft
3. Measurement accuracy on the order of 1/100th inch over full MV
   - System accuracy achieved for ***small relative movements***
   - System ***not intended*** to deliver high accuracy for large movements that are greater than a few inches

2. CIV Bridge Hardware and Software

Hardware

1. Two high-resolution / low-noise digital cameras
   - Cameras attached to a hollow aluminum bar and protected by aluminum cases
   - Cameras spaced 30 inches
   - Relative positioning of cameras is key to measurements
   - ***MUST NOT*** bump the cameras
   - Protectives cases do not contact the cameras
   - Cables are bolted to the cases so any tugging on them would only affect the cases
   - But there is only so much abuse they can take without cameras being moved relative to the bar
2. Surveying tripod

Hardware

3. Laptop computer and PCIe expansion box
   - PCIe expansion box with dual GigE ports to connect both cameras
     - PCIe box connects to laptop through Thunderbolt wire
   - Laptop has dual hard-drives
     - C: drive is high-speed SSD PCIe drive
     - D: drive is regular spinning drive with higher capacity
     - ***USE*** the C: drive to save images during a Live Test to avoid image queues
     - D: drive is for backup and other storage

2. CIV Bridge Hardware and Software

Hardware

4. High Contrast Physical Targets (HCPT)
   - Foam core aluminum targets
   - Three sizes (4x4”), (7x7”), (10x10”); ***40 HCT of each size are provided***
   - Attached to aluminum angles
   - To be used in places where contrasting features are limited on bridge surface or where it is desired to have reference points when selecting targets
   - NOTE: in most cases, the CIV software does not require HCPT
5. Double-sided high-strength tape
   - ***High-strength double-sided tape is provided***
   - Attach double-sided tape on back and over full width of target
   - Tape will stick target to most surfaces
   - Wiping surface is recommended before attaching HCPT, but in many cases is not necessary
   - It is important that targets be attached firmly so they do not move or fall during a test
   - At the end of a test, the targets can easily be knocked off
6. Extension rod
   - A telescoping extension rod is provided to help attach HCPT
   - Rod maximum length 30 ft
   - Can use double-sided tape to temporarily attach targets to rod

Hardware (not supplied)

7. Portable power source
   - Can be a generator or battery pack
   - Please make sure the power supply provides a complete sinusoidal shape and not a step function
8. Distance measuring device
   - To make sure targets are within the measurement volume distance range a measuring device is needed
   - Tape measures or laser measuring devices can be used

Hardware (optional)

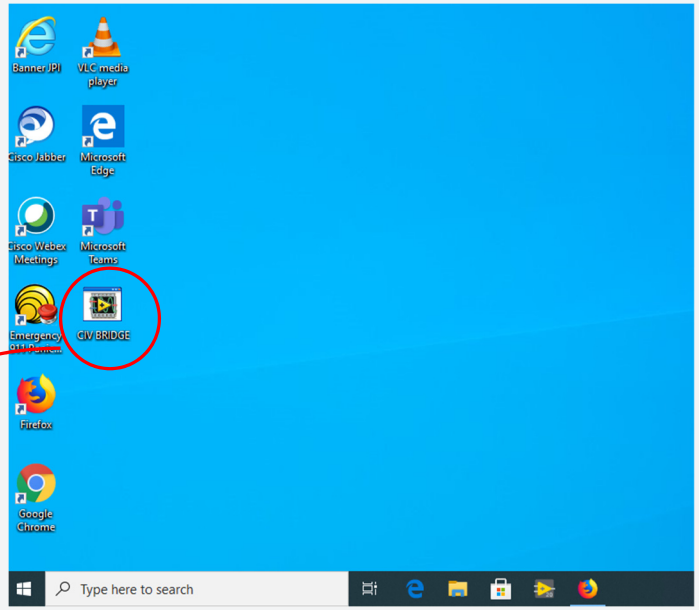
1. Optional lights
   - Optional flood lights can be used in low light conditions (e.g., dark under bridge location)
   - Any lights can be used. If halogen lights are used, do not place in line of sight as air ripples from heat rising from the lights can add noise to data
   - Optional ***lights are not supplied*** with the system

Hardware Connectivity

1. Laptop Computer and PCIe expansion box
   - Regular laptop; only requires power supply
   - The PCIe box connects to the computer using a Thunderbolt cable
   - The PCIe box need to be plugged into the power source using its power supply
   - The cameras plug into the dual GiGE Ethernet ports on the PCIe box
2. Cameras
   - Each camera needs to be plugged into a power source (110V alternating current)
   - Each camera draws about 6 watts of power
   - Each camera connects to the PCIe expansion box through an Ethernet cable (minimum Category 5e, maximum 100ft long)
   - ***DO NOT*** use the separate Ethernet port on the back of the computer
   - Make sure Ethernet cables are not damaged, otherwise replace (if replacing, ***be careful not to shift the camera position***)
   - Always use identical (same length and type) Ethernet cables

Software

1. One software: already installed on the computer
2. Run executable “CIV BRIDGE.exe” or shortcut on desktop
3. Two main modules (with sub-modules)
    1. Live Test
    2. Post-Processing
        1. Reprocess Existing Images
        2. Interpolate Existing Data
        3. Smooth Existing Data
        4. Calculate from Data
        5. Plot Processed Data
4. System is delivered pre-calibrated with calibration files



Instruction Manuals

1. User Manual
   - Provides more detail for content in this presentation
   - ***Pdf file provided in folder on computer desktop***

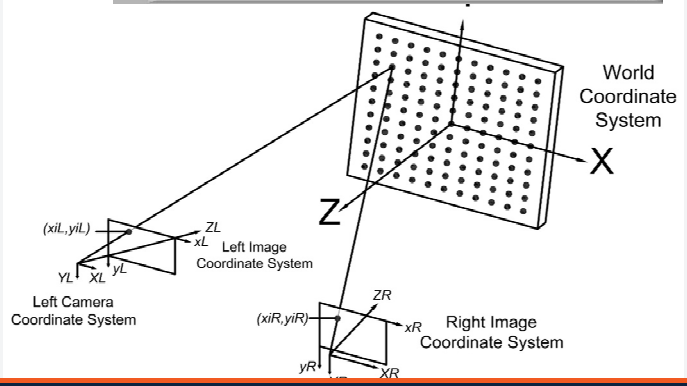
2. Calibration Validation Manual
   - Provides more detail on the Validation method described in this presentation
   - ***Pdf file provided in folder on computer desktop***

3. DIC Principles

3. DIC Principles

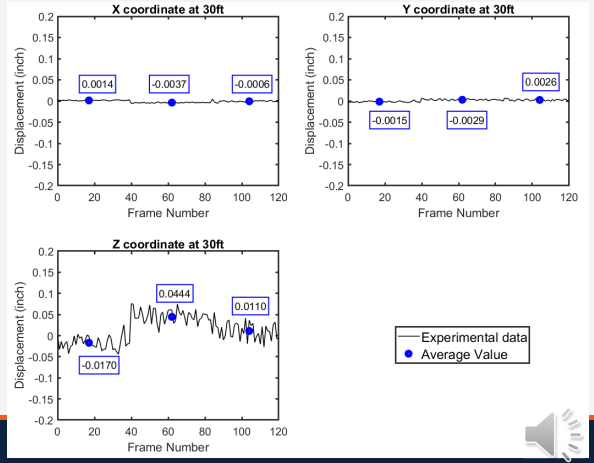
From Images to 3D Locations

1. DIC algorithms used to find a ñtargetòin each camera image
   - Å The same target is located in both Left and Right cameras images
2. Target consists of a sub-image cropped from the full image
3. Targets are located in pixel coordinates in sequential pairs of camera images over a test (with sub-pixel accuracy)
   - Å Targets must not change appearance substantially during a test
4. Left and Right camera pixel coordinates are then converted to 3D coordinates using principles of triangulation
   - Å The calibration process locates the cameras with respect to each other
   - Å This info is then used to triangulate the 3D location of targets



Measurement Accuracy and Noise

1. The accuracy of the CIV system over the full measurement volume is on the order of 1/100th inch (see validation section)
2. Accuracy is better in the XY plane of the cameras sensors
3. It is not as good in the Z direction (out-of-plane; towards or away from cameras)
4. Accuracy is typically better closer to the cameras
5. ***Set up system such that movement is mainly in the XY plane***
6. Noise in the measurement is relatively low in the XY plane and increases in the Z direction
7. Noise gets larger the farther a target is away from the cameras

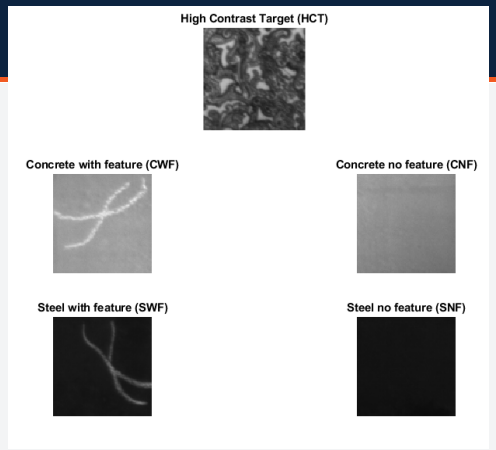


Target Quality Considerations

1. Target quality depends on the amount of contrasting features it contains

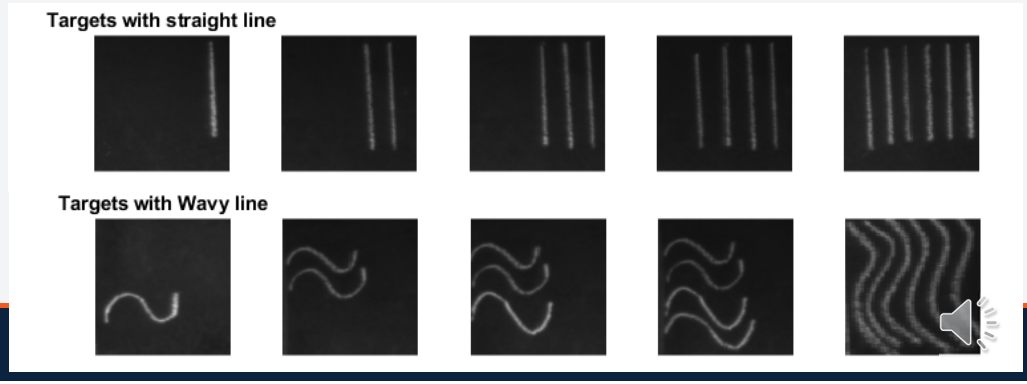
More features = better tracking / lower noise

Higher contrast (i.e., black over white) = better tracking / lower noise



2. CIV algorithms robust and only require minimal features to track targets
   - A single line on a plain surface suffices

3. Target size should be no less than 60x60 pixels
   - Recommended size 100x100 pixels
   - Larger targets do not yield improvements in readings

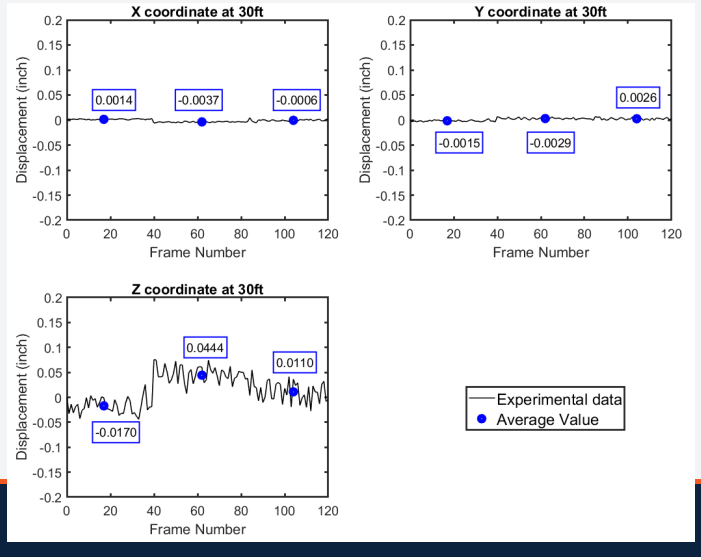


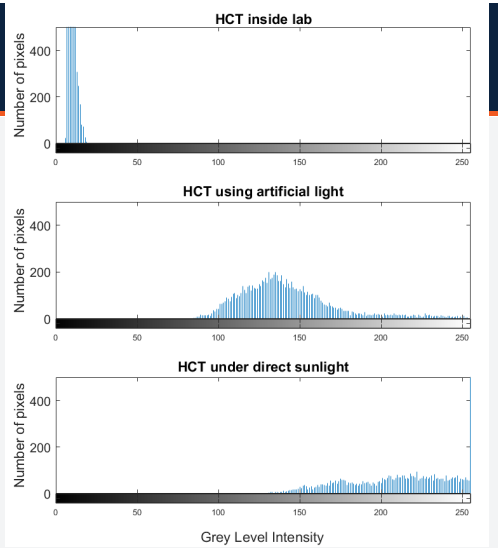
3. DIC Principles

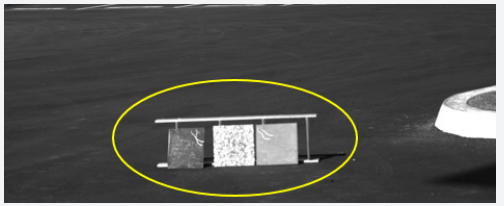
Lighting Considerations

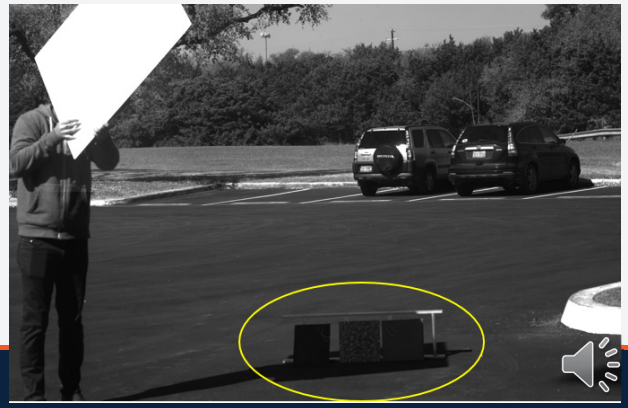
1. Target location depends on DIC perception of features in the target
2. Lighting variations during a test can generate fictitious movement of targets
3. CIV algorithms are robust with respect to light variations – but best avoid them

- If ***light variations*** are expected (moving clouds), ***HCPT are best*** (black on white minimizes light shift)









Vibration Considerations

1. Vibration of cameras and bridge induce noise in data
2. Minimizing vibrations
   - For cameras
     - stiff tripod
     - locate on “non-vibrating” surface when possible
     - Avoid high wind areas
   - For bridge
     - test on less windy days if possible

4. Accuracy Validation

Accuracy Validation Methods

The CIV system is only as accurate as its calibration

1. Laboratory gage-block verification/validation of calibration accuracy

2. In-field validation during bridge load-test

Gage-Block Validation of Calibration

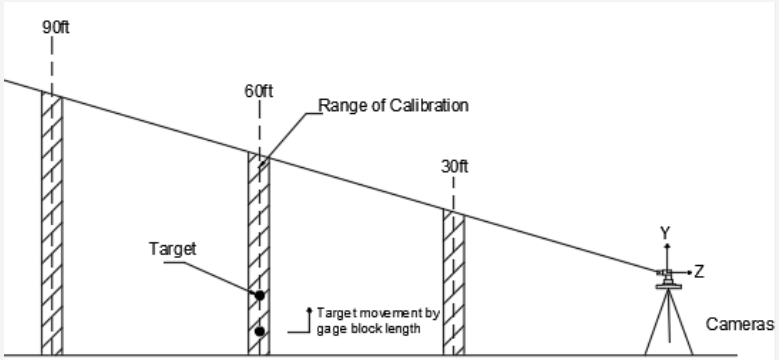
- As with all measurement instruments, ***drift occurs with time***
- Cameras may also be bumped accidentally

- A method is provided for users to verify accuracy at regular intervals
  - A ***Calibration Validation Manual*** is provided to describe the process
  - Also supplied: a gage-block measurement device and a spreadsheet that simplifies error calculations

- Should calibration accuracy come into question, please contact UTSA for re-calibration

Gage-Block Validation of Calibration

1. The supplied gage-block device issued to verify accuracy of displacement measurements over the full measurement volume of the system
2. Gage blocks with certified lengths are inserted into the device to translate a center target by their length
3. Comparison between measured target translation and gage-block length provides measurement accuracy
   - A supplied spreadsheet does the accuracy calculations for validation tests conducted per ***Calibration Validation Manual***

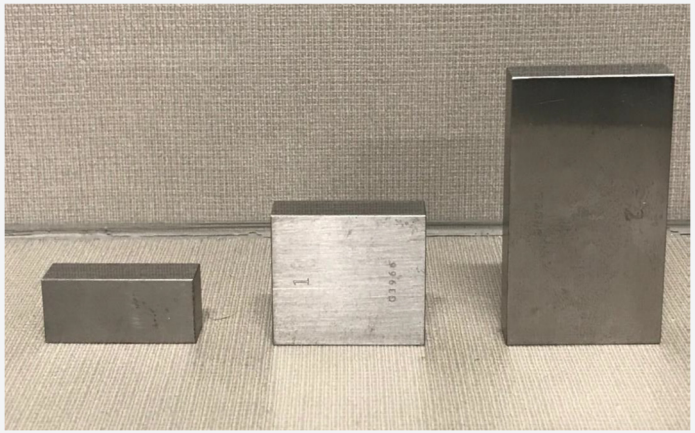


Gage-Block Validation of Calibration

- Tests performed across entire measurement volume
- Measurement distance range: 40 feet – 110 feet
- Three validation test distances
  - 40 feet
  - 75 feet
  - 110 feet
- Field of view at each distance is divided into 9 quadrants
- Two translation direction
  - Y-axis : in plane of camera sensors
  - Z-axis : perpendicular to plane of camera sensors (out-of-plane)
- Total number of accuracy tests necessary : 54

4. Accuracy Validation / gage blocks

Additional Hardware Requirements for Validation Test

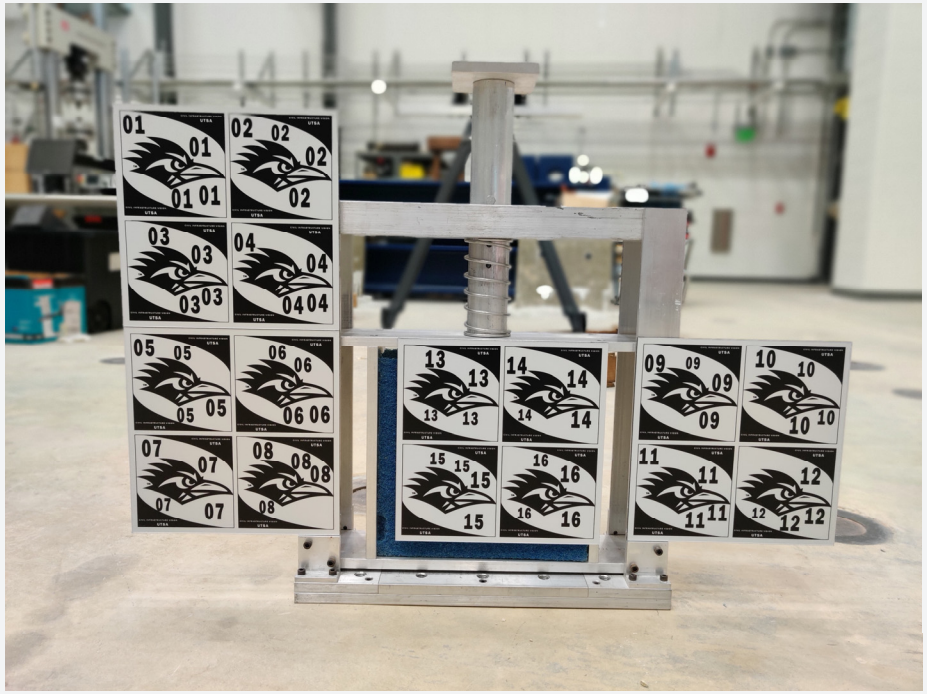


NIST certified gage blocks

Gage Block Test Device with HCPT attached

4. Accuracy Validation / gage blocks

Test setup in measurement directions



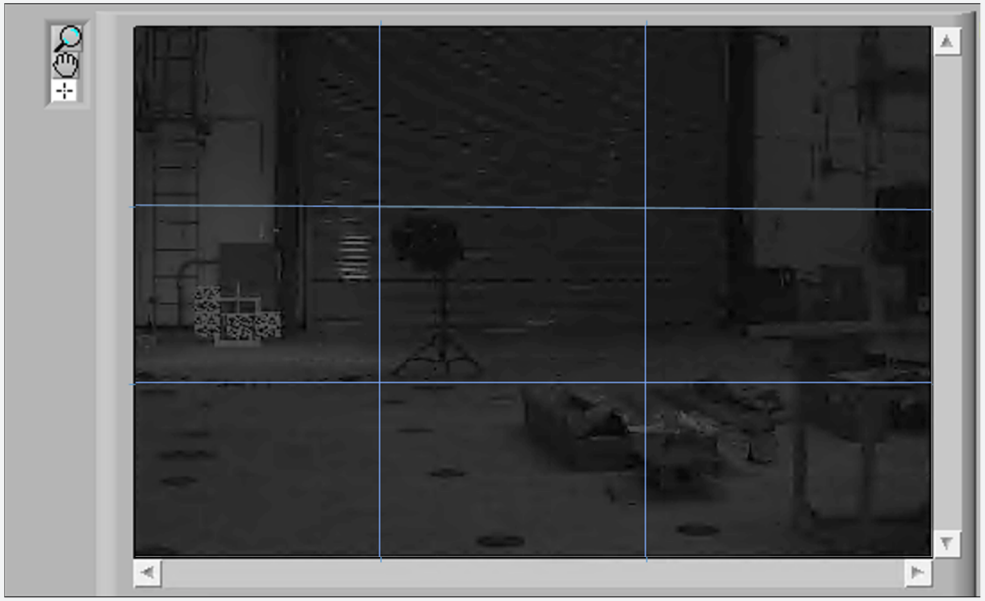
Gage Block Test device setup for acquiring translation data in Y-direction

Gage Block Test device setup for acquiring translation data in Z-direction

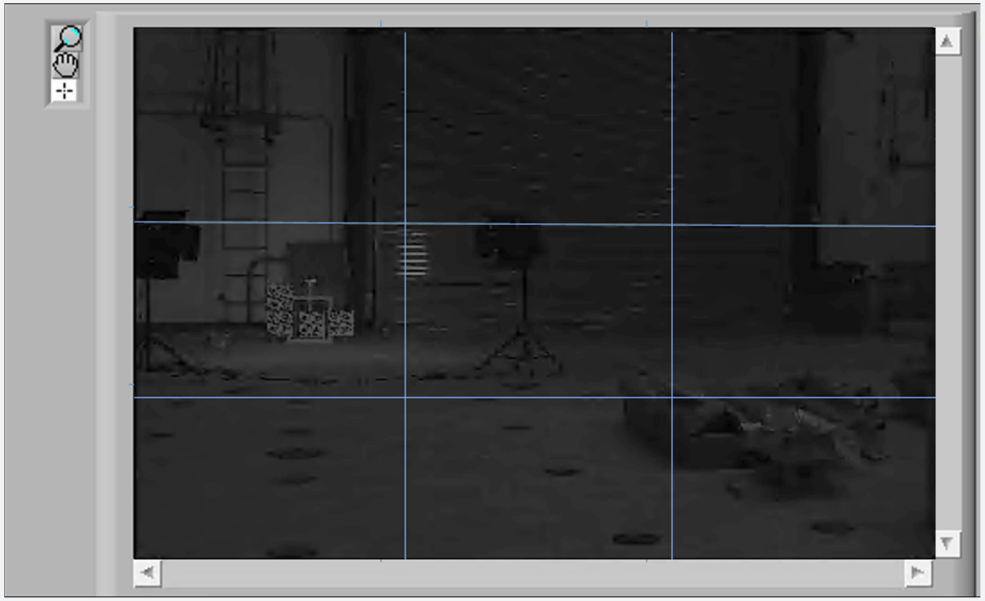
4. Accuracy Validation / Gage Blocks

Gage Block Test Device Setup in Fields of View

Middle Left Quadrant



Left Camera Image



Right Camera Image

4. Accuracy Validation / Gage Blocks

Acquiring Translation Data

1. Setup CIV system in desired location (preferably indoor)
2. Place gage-block test device in desired orientation (Y or Z axis direction)
3. Start a new Live Test in CIV software and follow steps described in the *Calibration Validation Manual*
4. Select reference axis system and Center Target for which translation data is required
   - Use 100x100 pixel target size
5. Track target locations before gage block is inserted and after
   - ***Do not move the device*** while inserting and removing gage blocks
6. Repeat for each of the 9 quadrants, two directions, and three distances to cover the measurement volume
7. Spot checking for a couple of distances and a single quadrant can also be done as a quick check

4. Accuracy Validation / Gage Blocks

Calculation Sheet

- Sample: Y-direction accuracy calculations at one distance
- A total of *6 sheets* are needed for the full measurement volume
  - ***Sheets delivered with system for Factory Calibration***
- Data needed to populate one table is from 9 Live Tests (one for each image quadrant)
- Similar sheets can be populated for each of the three distances and for the Y and Z directions

  - Errors on the order of 1/100th of an inch
  - Errors tend to be smaller in the center of the field of view as opposed to the edges
  - Errors tend to be smaller at shorter measurement distances

Image Quadrant	Gage Block Length (inch)	Location of Center Target in Y-axis (inch)	Error(inch)	Mean Absolute Error (inch)
Top Left	0			
	0.75			
	2.0			
Middle Left	0			
	0.75			
	2.0			
Bottom Left	0			
	0.75			
	2.0			
Top Center	0			
	0.75			
	2.0			
Middle Center	0	4.44750	0.00000	0.010896
	0.75	5.18499	-0.01251	
	2.0	6.43822	-0.00928	
Bottom Center	0			
	0.75			
	2.0			
Top Right	0			
	0.75			
	2.0			
Middle Right	0			
	0.75			
	2.0			
Bottom Right	0			
	0.75			
	2.0			
Overall Mean Absolute Error				
Standard Deviation				
Co-efficient of Variance(C.O.V)				

Bridge Load-Test Validation

- Farm Rd 1047, Lometa, TX
  Latitude: 31°18'50.31"N
  Longitude: 98°18'24.66"W
- Three continuous spans
  60’ - 75’ - 60’
- Height ~26’
- Creek crossing
- Load test organized by A&M as part of another TxDOT Project
- Monitored using traditional instrumentation

Steel Continuous Multi-Girder Bridge

4. Accuracy Validation / Bridge Load-Test

Bridge Load-Test Validation

- ***Setup only takes about 2 hours***
  - Including placement of optional HCPT

System about 100ft from bridge

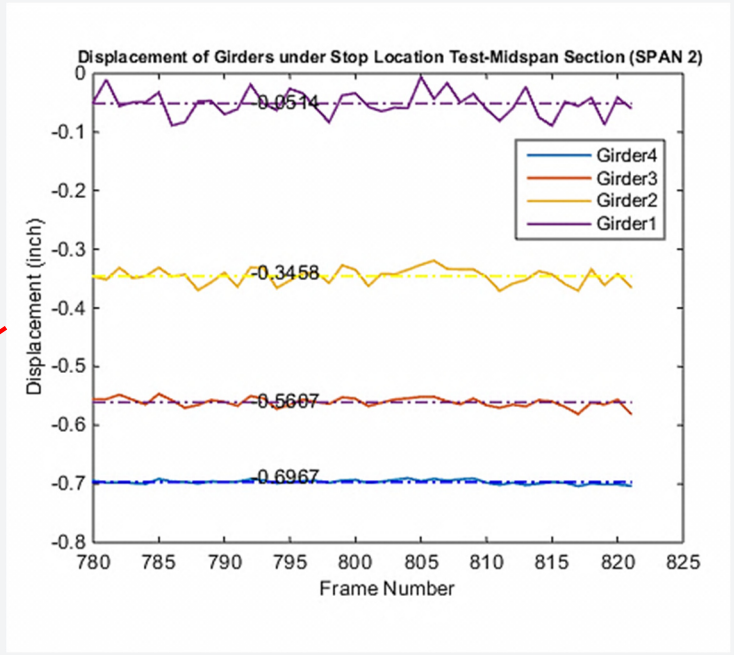
Bridge Load-Test Validation

Fixed Truck - Path 1

Deflections (in.)

Girders	G1	G2	G3	G4
A&M	0.049	0.280	0.526	0.755
UTSA	0.051	0.346	0.561	0.697
Difference	**-0.002**	**-0.066**	**-0.035**	**0.058**

- Noise increases with distance (G1 farthest)
- Noise increases with decreasing target size (G1 target smaller in pixels)



4. Accuracy Validation / Bridge Load-Test

Bridge Load-Test Validation

Fixed Truck - Path 2

Deflections (in.)

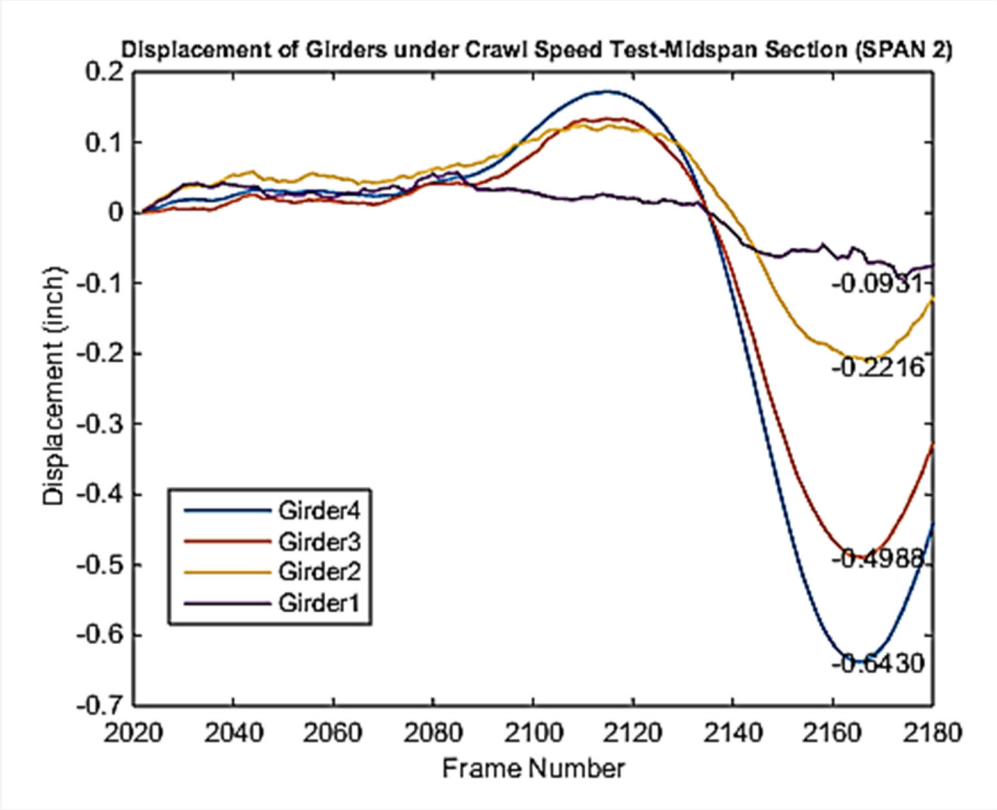
Girders	G1	G2	G3	G4
A&M	0.692	0.556	0.298	0.077
UTSA	0.739	0.551	0.287	0.067
Difference	**-0.047**	**0.005**	**0.011**	**0.010**

- Noise increases with distance (G1 farthest)
- Noise increases with decreasing target size (G1 target smaller in pixels)

4. Accuracy Validation / Bridge Load-Test

Bridge Load-Test Validation

Moving Truck - Path 1



Disclaimer

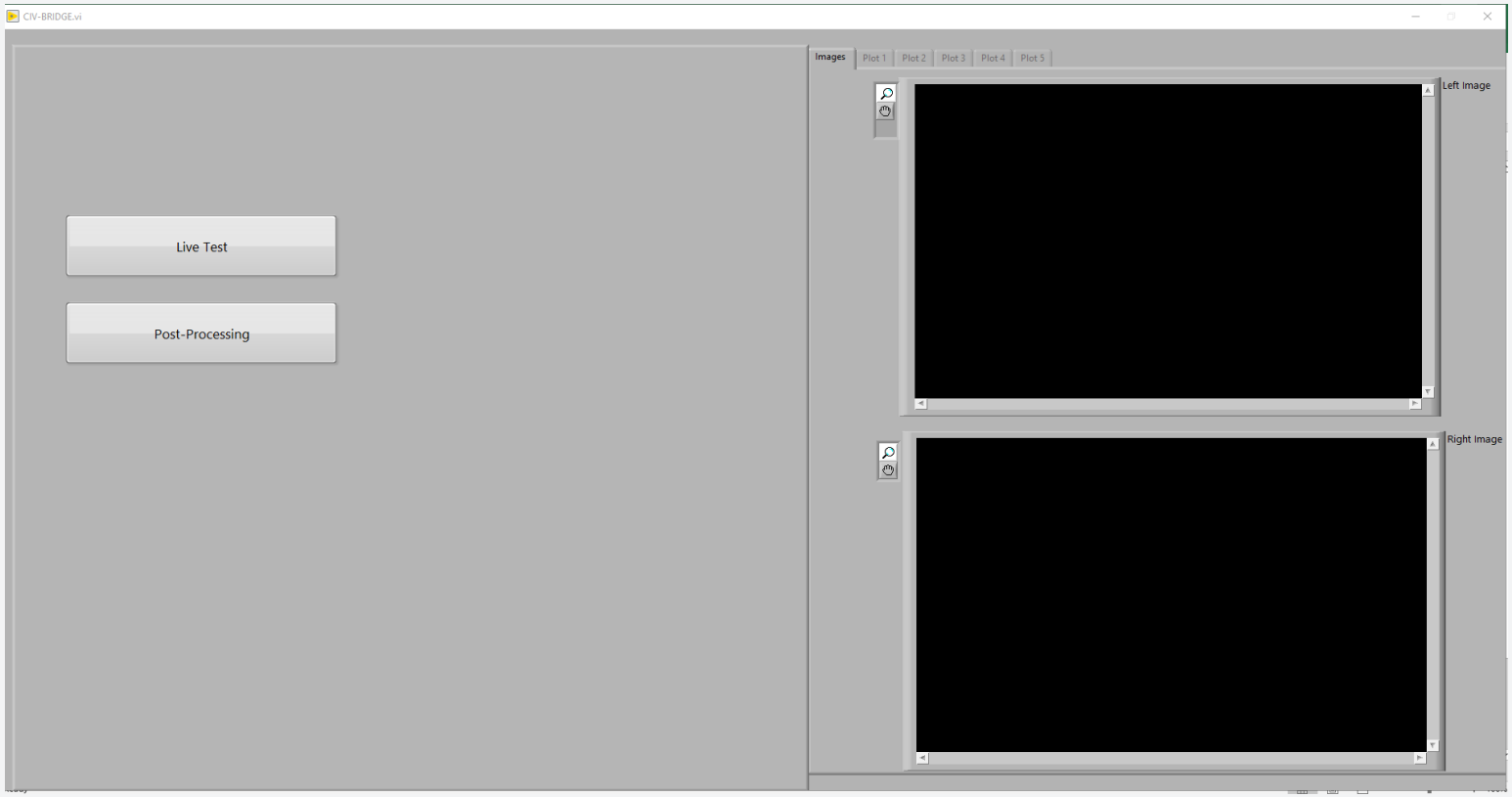
- We have made every effort to provide accurate measures of target movement
- As with all measurement instruments, drift may occurs with time
- Cameras may be bumped accidentally
- Should calibration accuracy come into question, please contact UTSA for re-calibration

- UTSA does not assume any responsibility for the accuracy of measurements

5. Live Test

5. Live Test

1. Main Menu



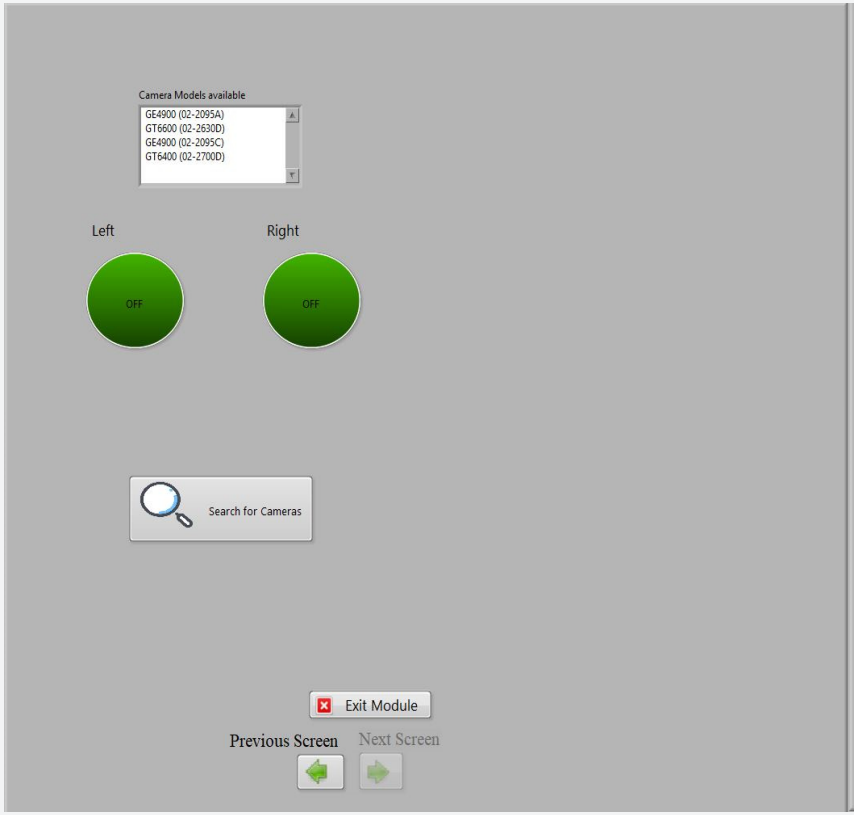
- Each **Live Test** and **Post-Processing** module will guide the user through a series of screens

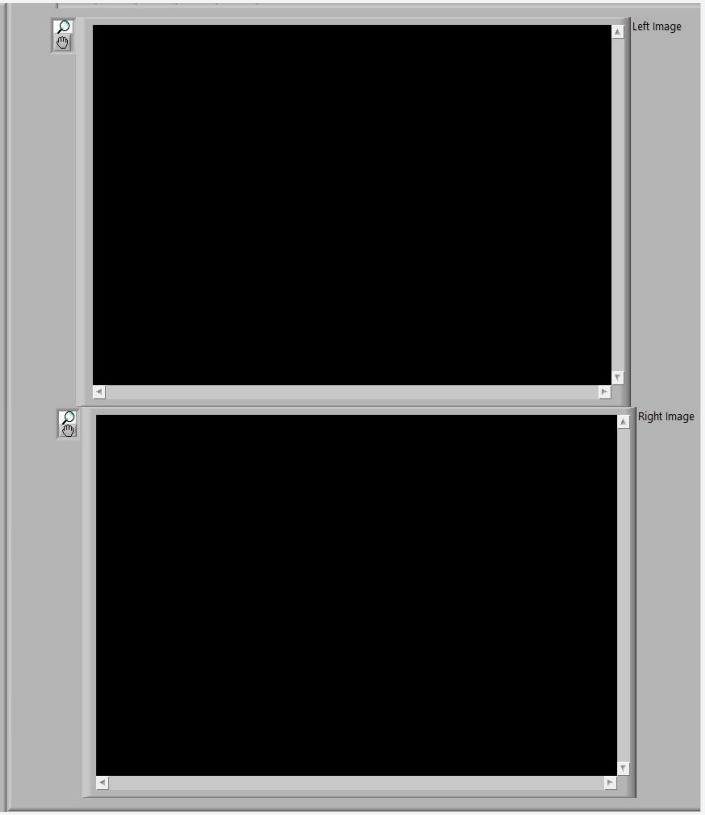
- At any point the program can be exited by clicking the X in the top right corner.

CAUTION: this will terminate the program and any data not saved until that point will be lost.

5. Live Test

2.Camera Detection

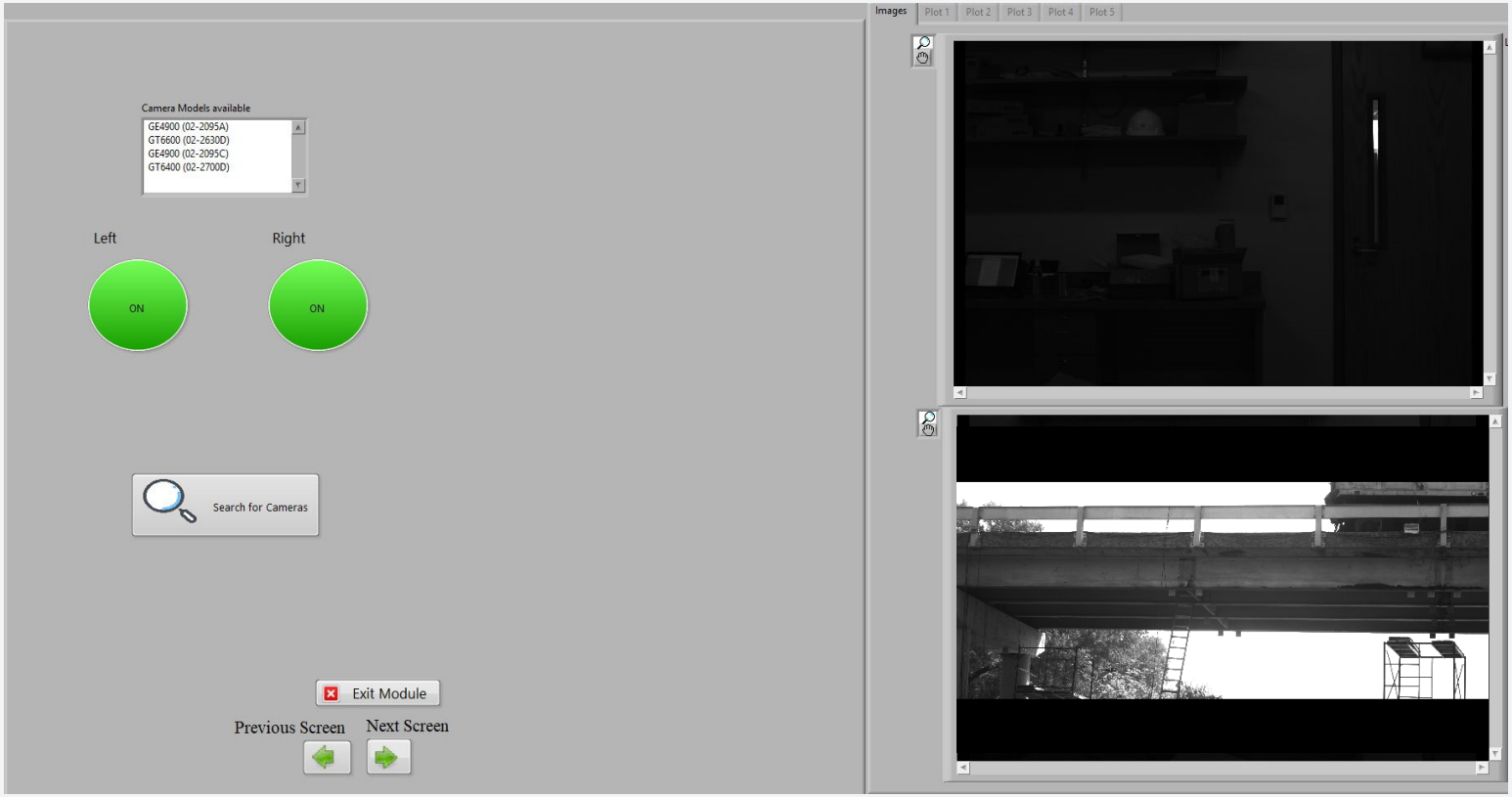




- Click on the Search for Cameras button to start the camera detection process
- Next screen is disabled unless the cameras are detected

5. Live Test

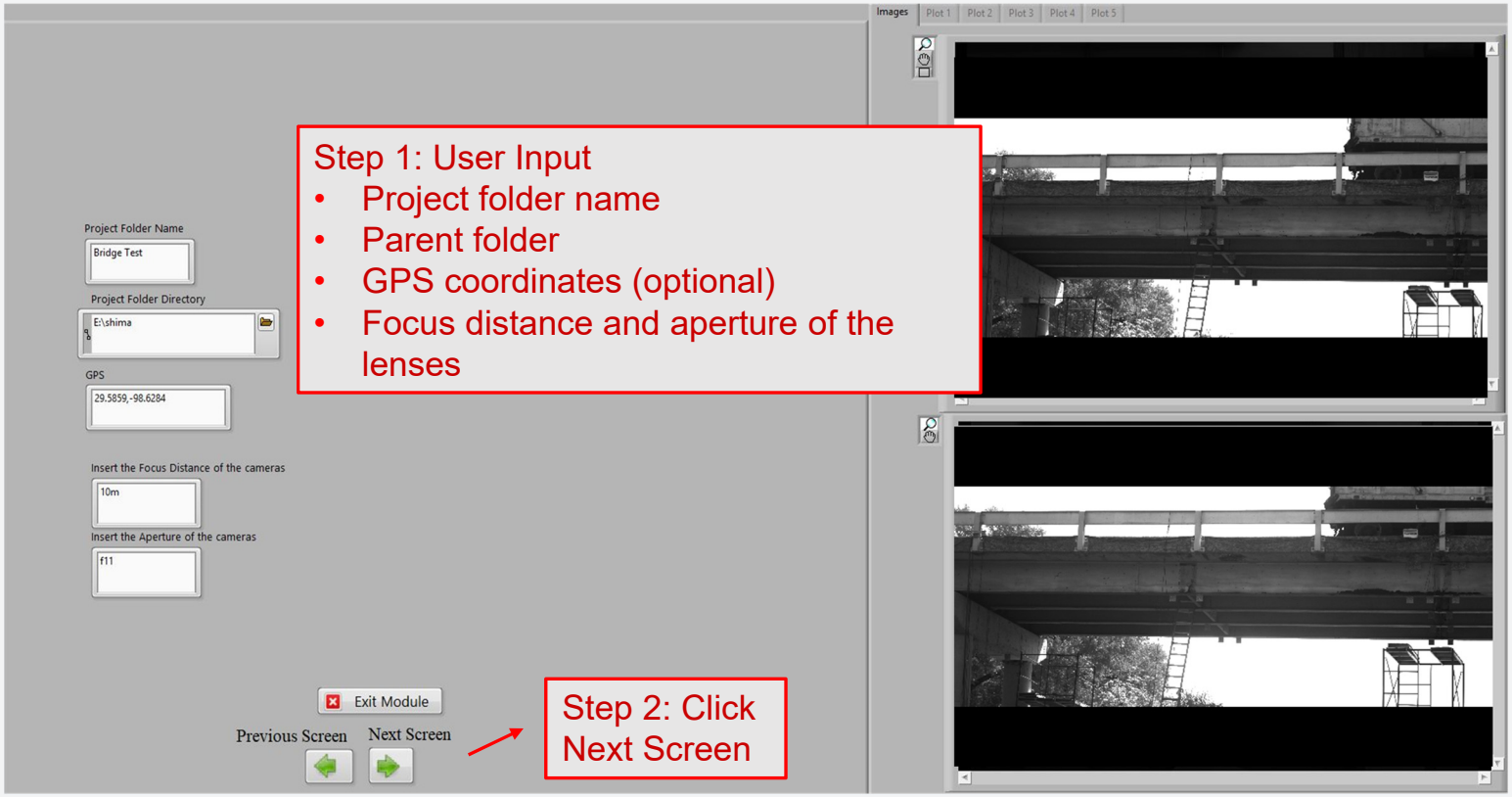
3.Camera Detection



- When the cameras are detected, the two circular markers will turn on. If not, the markers will remain dark green.
- Next Screen is activated for user to proceed to next steps

5. Live Test

4.Folder Selection



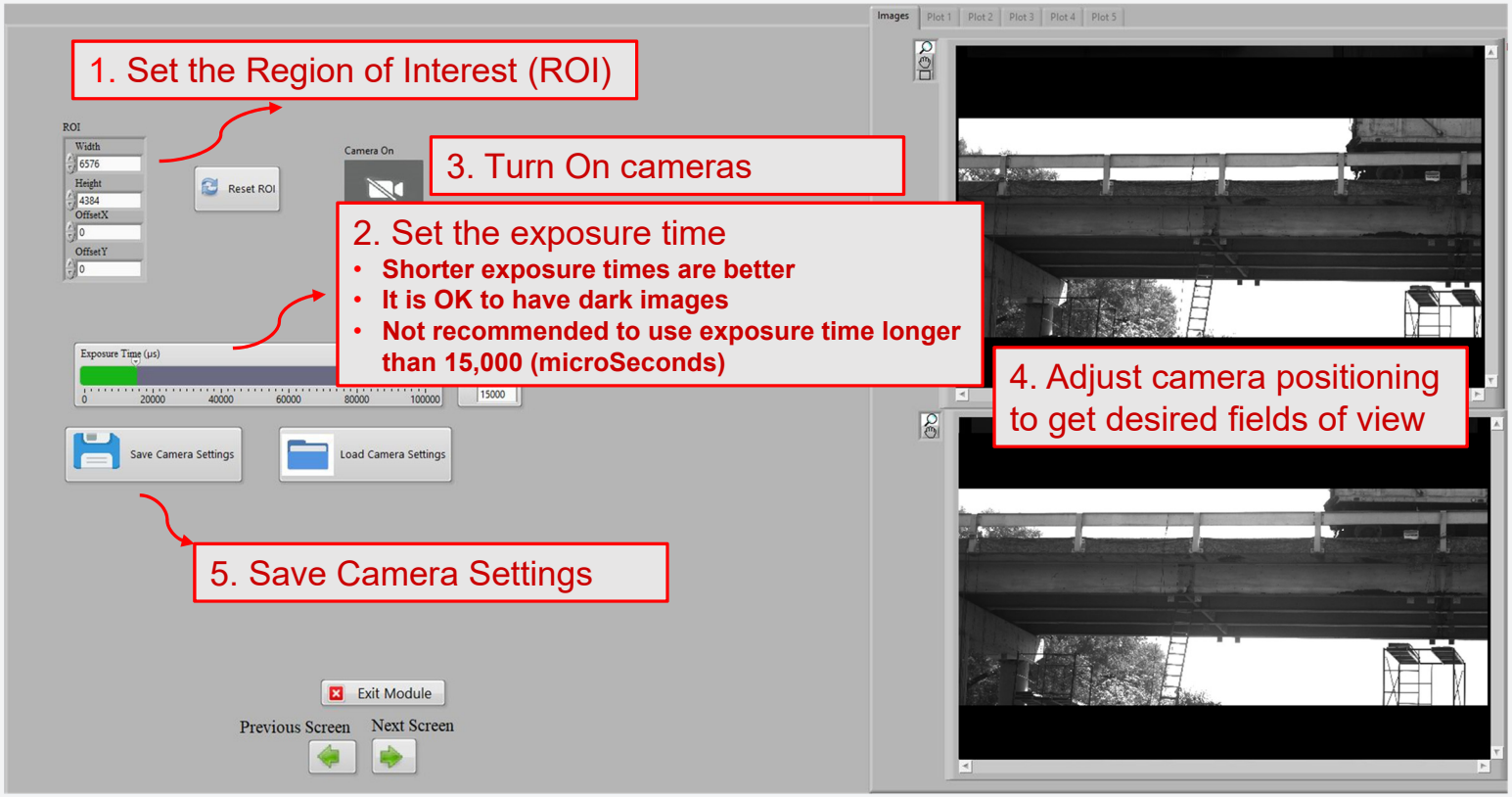
All provided information will be reproduced at the beginning of the output files.

A folder with the project name specified by the user will be created under the parent folder.

All the output files will be saved in the project folder.

5. Live Test

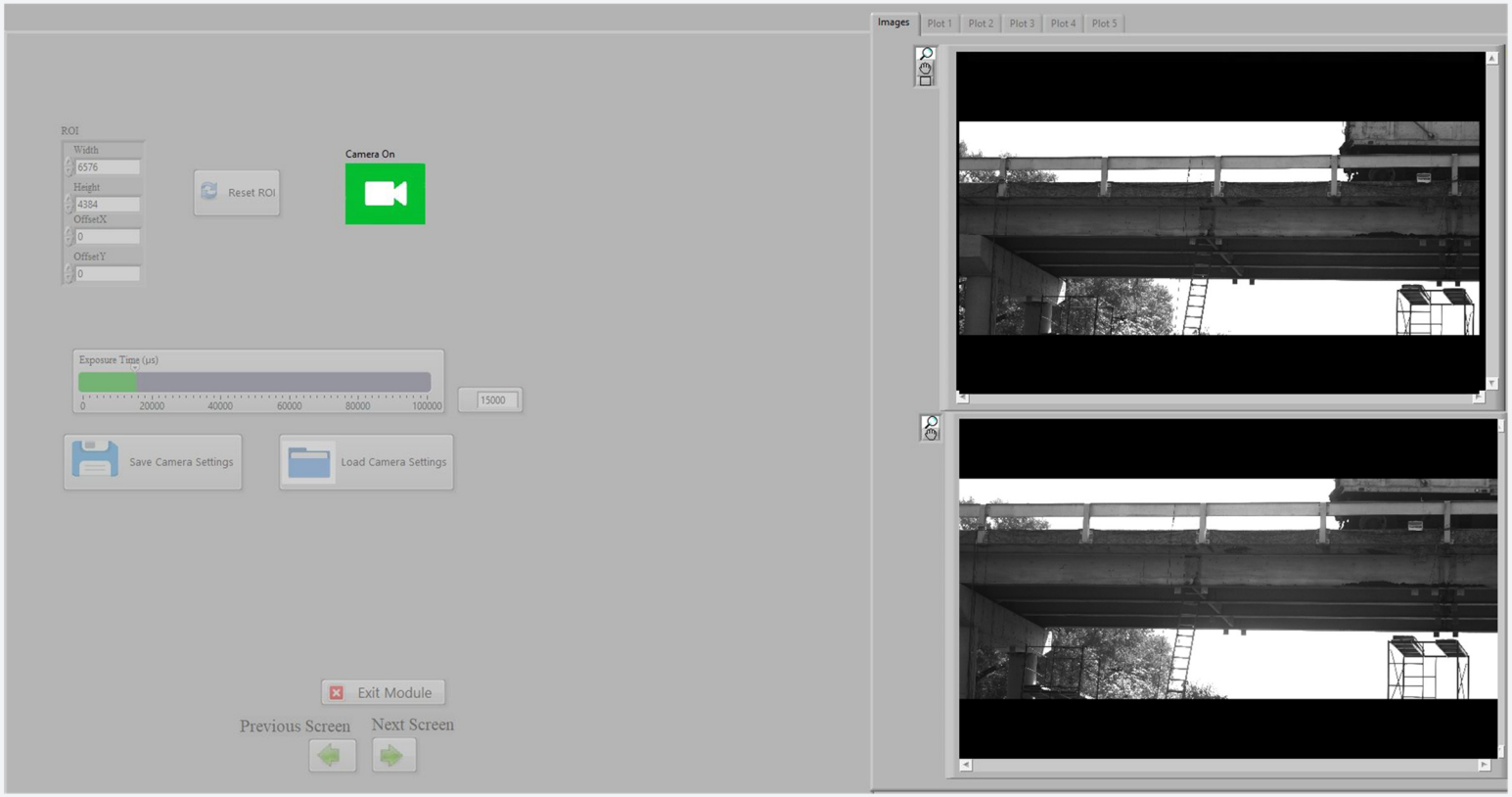
5.Camera setup



- The region of interest (ROI) changes the size of the images being acquired to only the region of interest.

5. Live Test

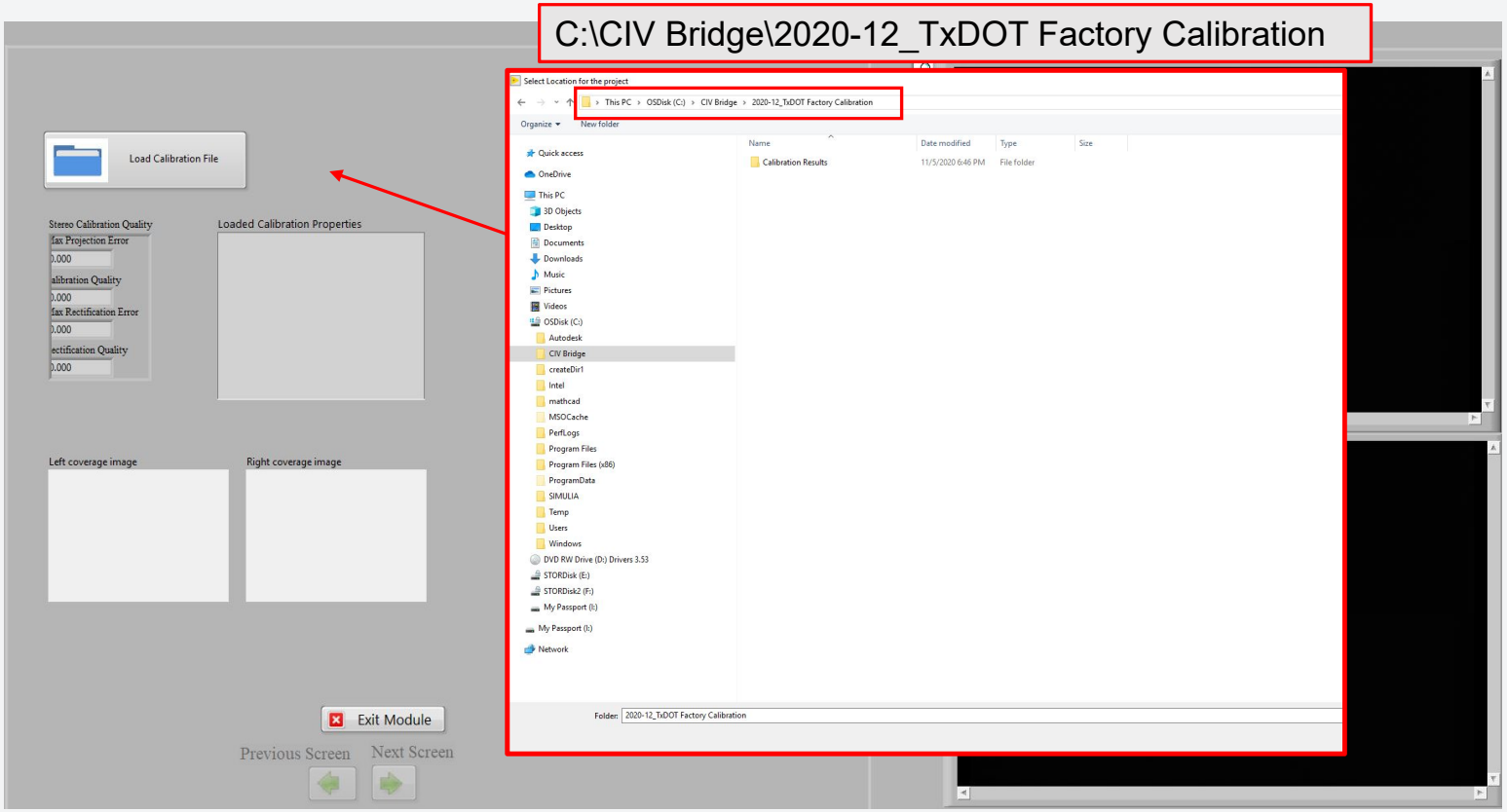
5.Camera setup



- When the cameras are on, the user cannot make any changes on the front panel.
- If changes need to be made, turn OFF cameras, make changes and then turn ON cameras.

5. Live Test

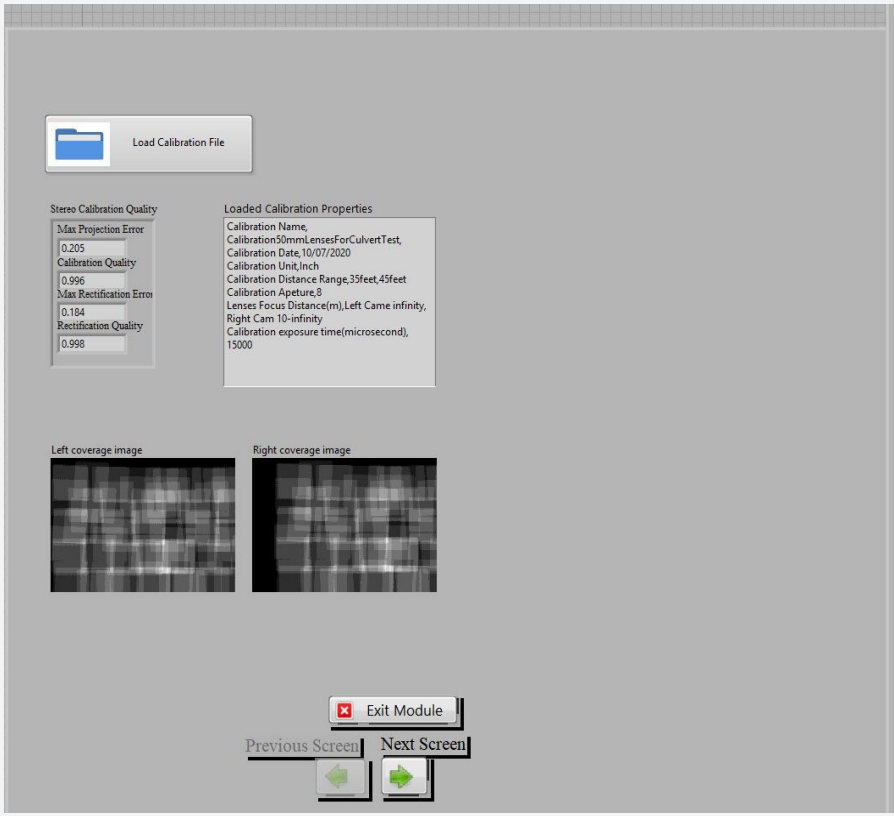
6.Load Calibration

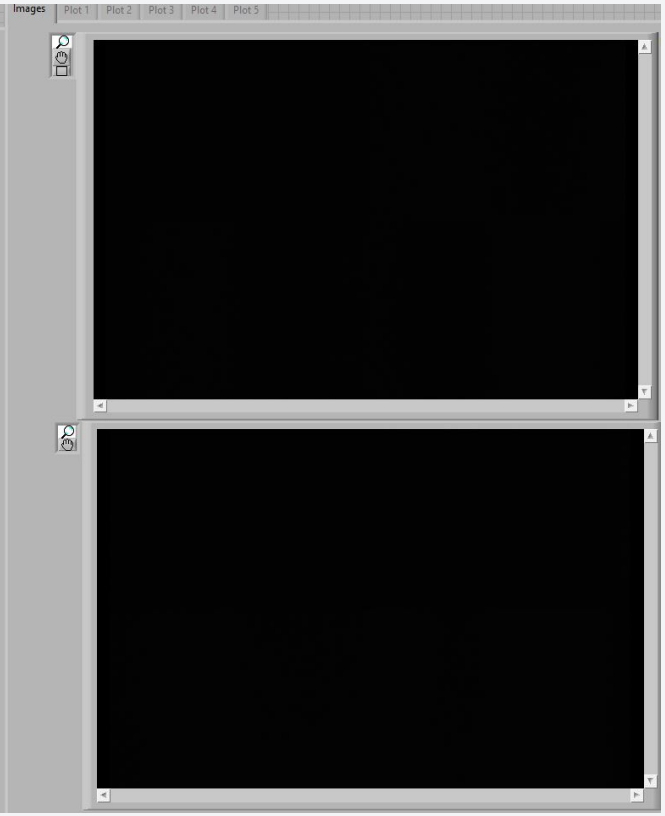


- Loading Calibration file is essential. User cannot Move to Next screen unless the Calibration is loaded
-
- Provide the location of the provided calibration files.
- C:\CIV Bridge\2020-12_TxDOT Factory Calibration

5. Live Test

6.Load Calibration





Once the calibration is loaded:

1. **calibration properties** can be seen on the screen.
2. **Stereo Calibration Quality** including:

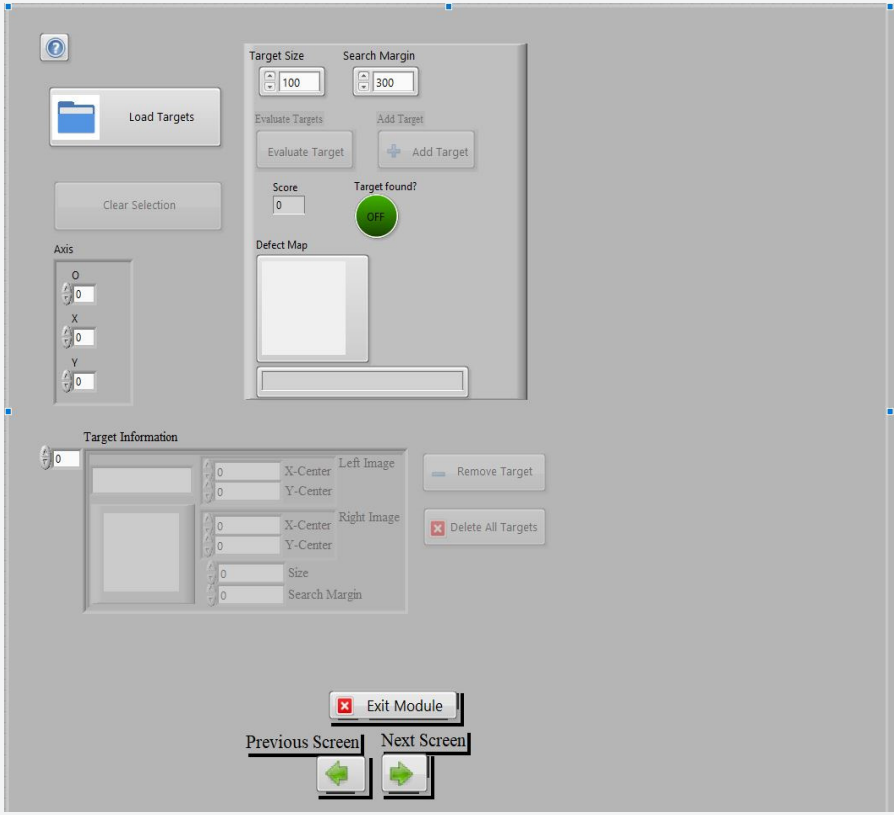
- Projection Error
- Calibration Quality
- Rectification Error
- Rectification Quality

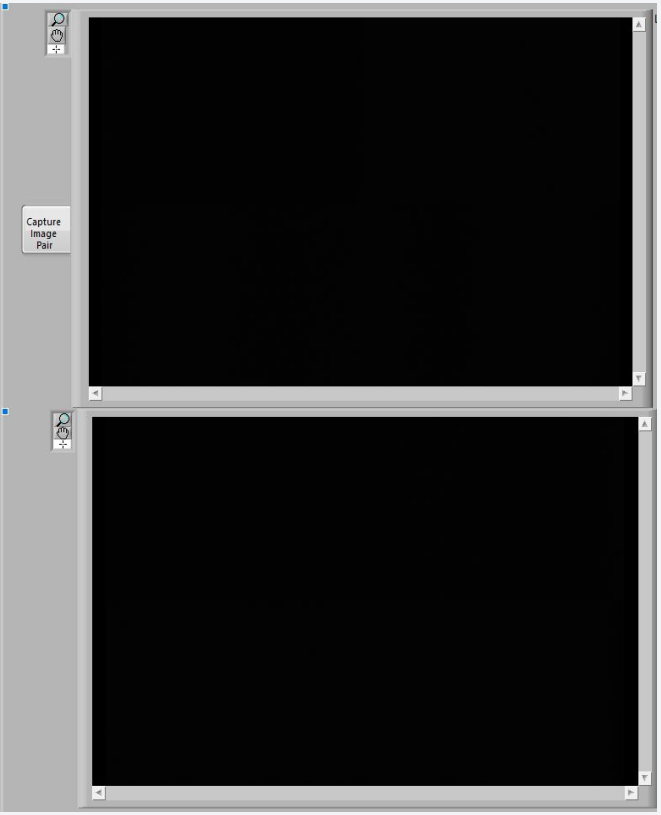
3. **Left and Right Coverage** maps are also shown.

5. Live Test

7.Target Selection

- **It is highly advisable to select a few targets for every test and plot their movement live to monitor progress and make sure everything is working well.**



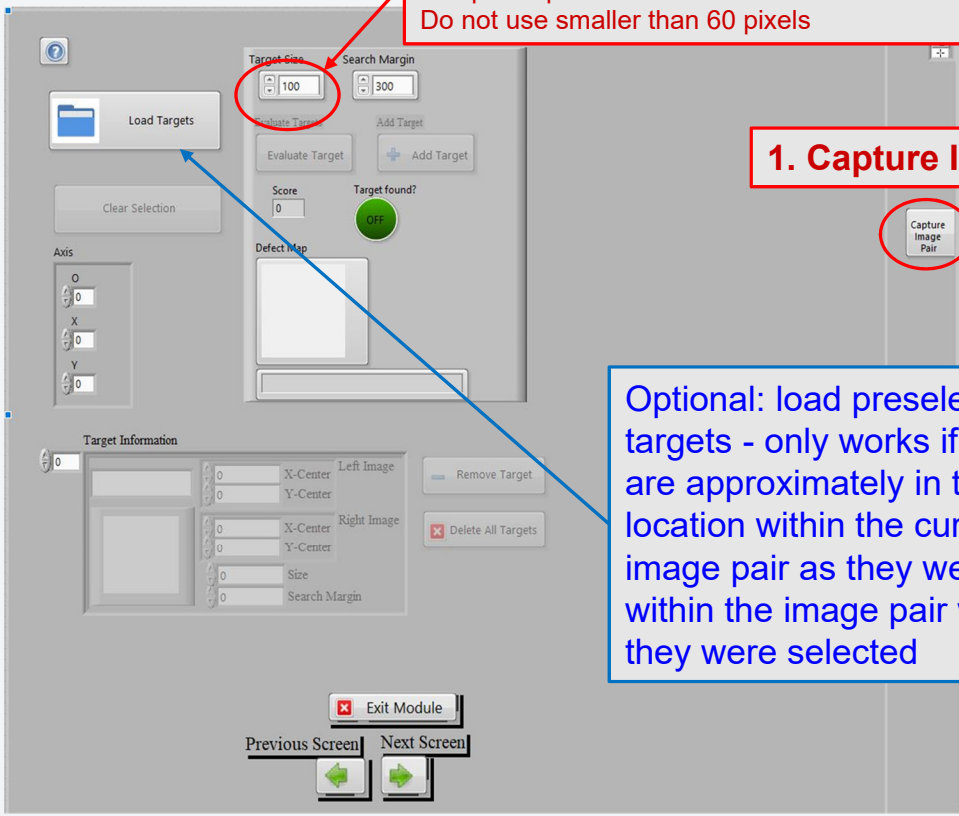


- Target consist of sub-images taken from the main images.
- The DIC algorithms track the sub-image location in successive images.

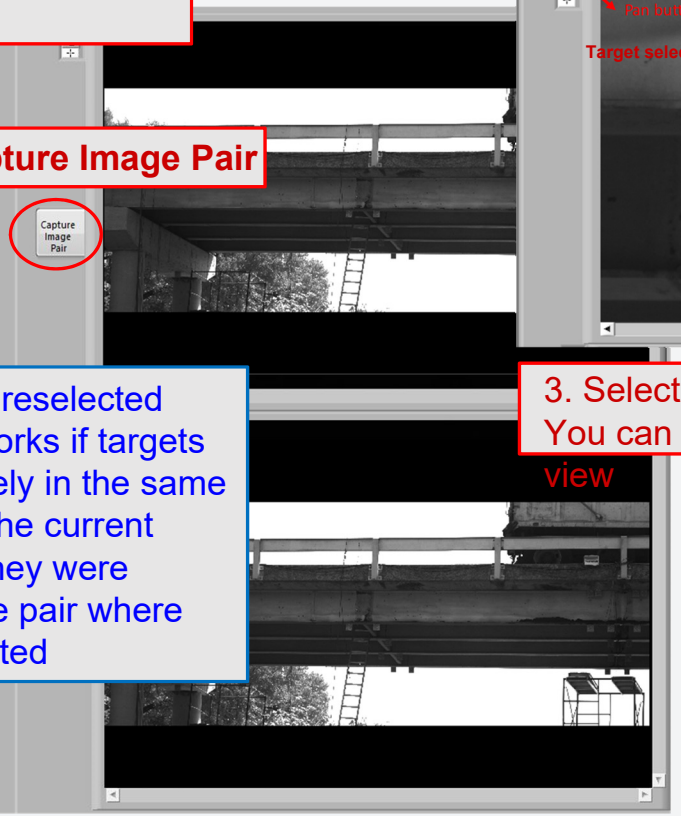
5. Live Test

7.Target Selection

2. Select Target Size
100 pixels preferred
Do not use smaller than 60 pixels



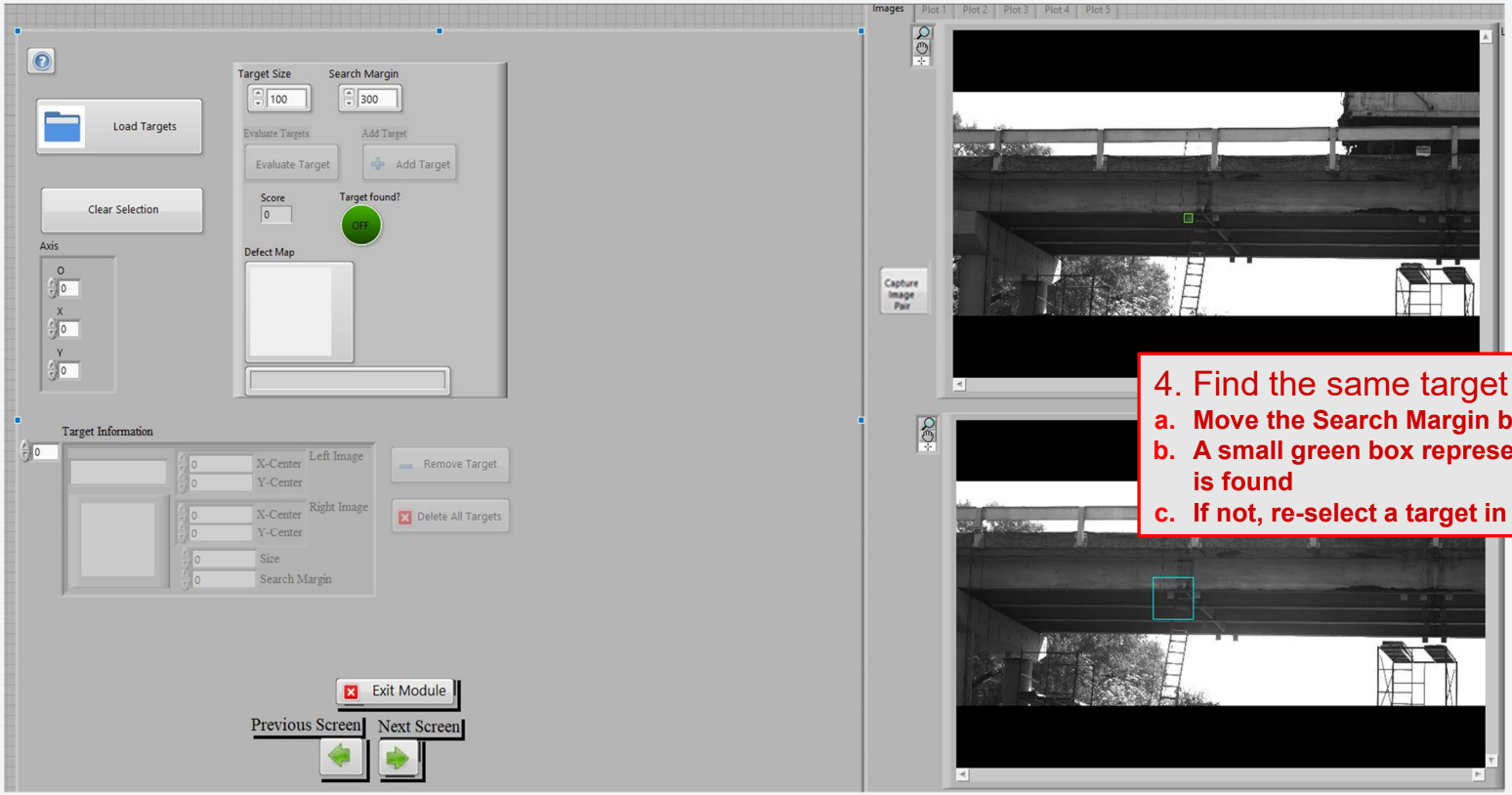
1. Capture Image Pair



Optional: load preselected targets - only works if targets are approximately in the same location within the current image pair as they were within the image pair where they were selected

3. Select a target in Left camera Image
You can zoom and pan to get a better view

5. Live Test

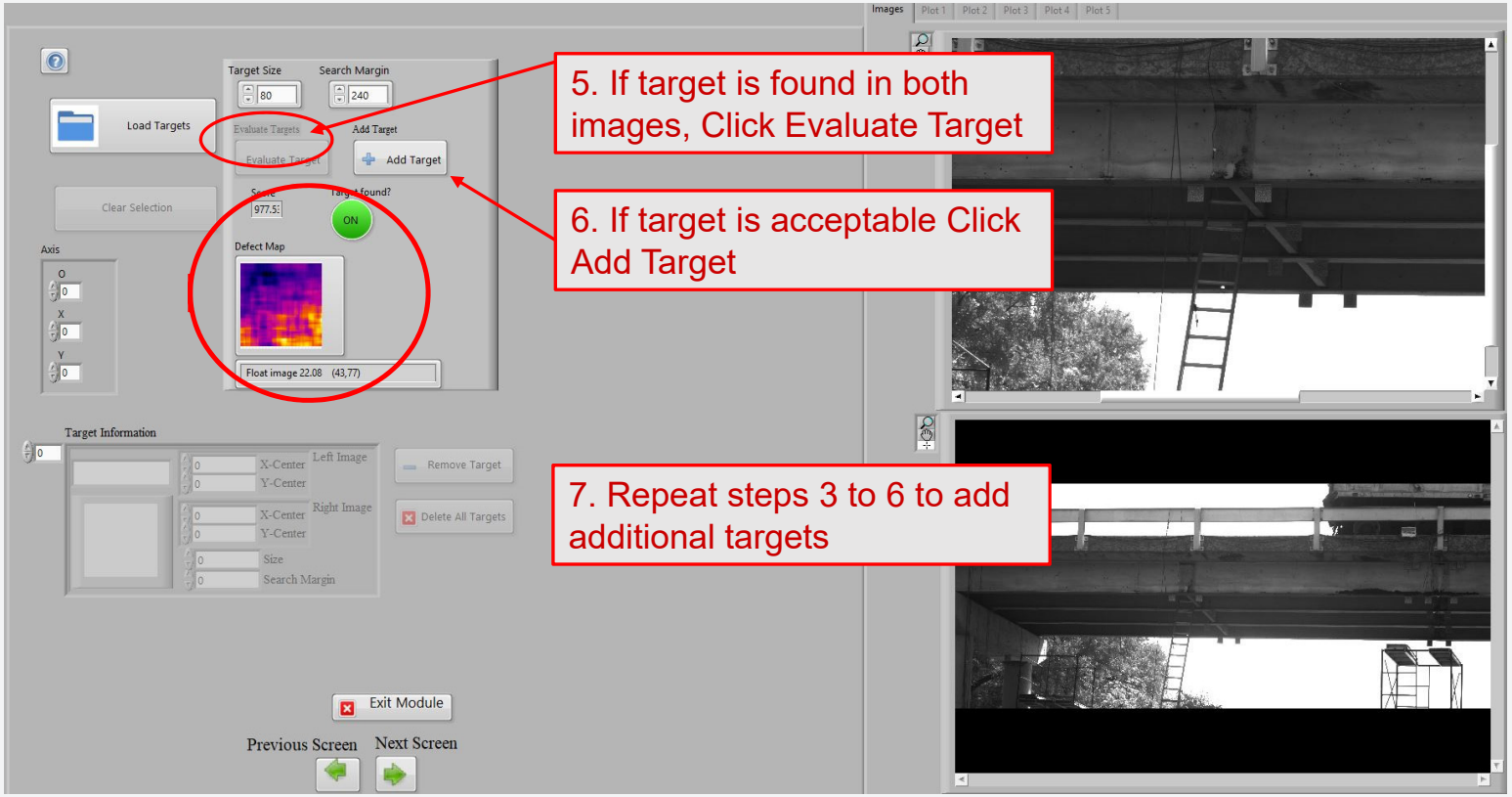


4. Find the same target in the Right camera Image

a. **Move the Search Margin box to where the target is located (click)**
b. **A small green box representing the target will appear if the target is found**
c. **If not, re-select a target in the Left camera image and repeat**

5. Live Test

7.Target Selection



5. If target is found in both images, Click Evaluate Target

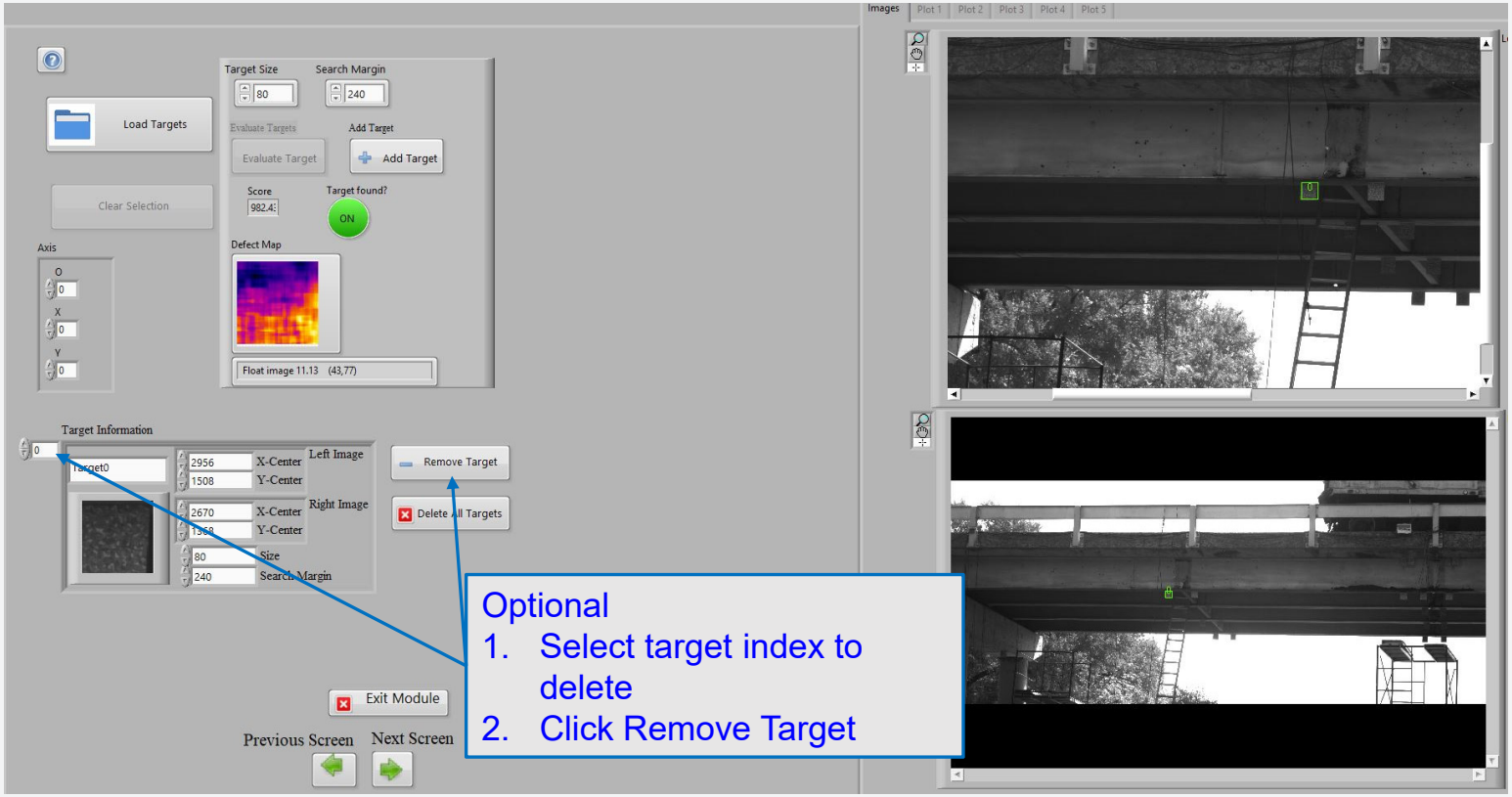
6. If target is acceptable Click Add Target

7. Repeat steps 3 to 6 to add additional targets

- The Match Score number indicates how well a target is located by the DIC algorithms.
- Targets with more contrasting features have higher Match Scores.
- The Match Scores range from 700 to 1000, where 700 equals the minimum match required for target to be found and 1000 equals a perfect match.
- Try to select targets with a Match Score of at least 900.
- The lower the Match Score, the more likely the target will be lost during a test.

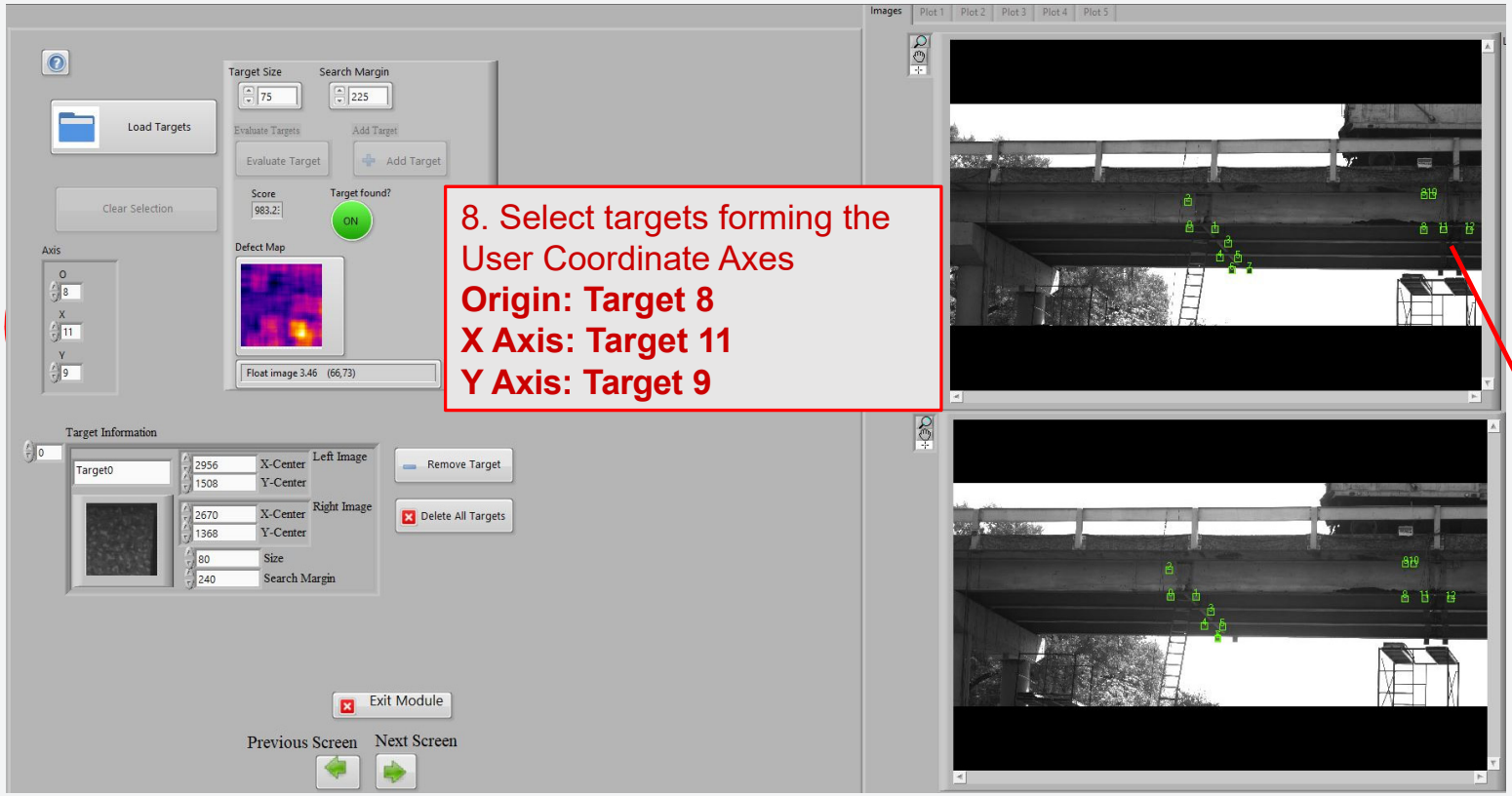
5. Live Test

7.Target Selection



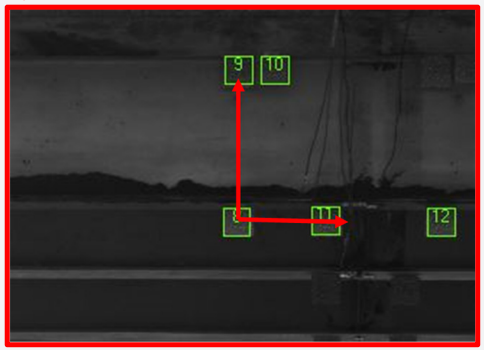
5. Live Test

7.Target Selection



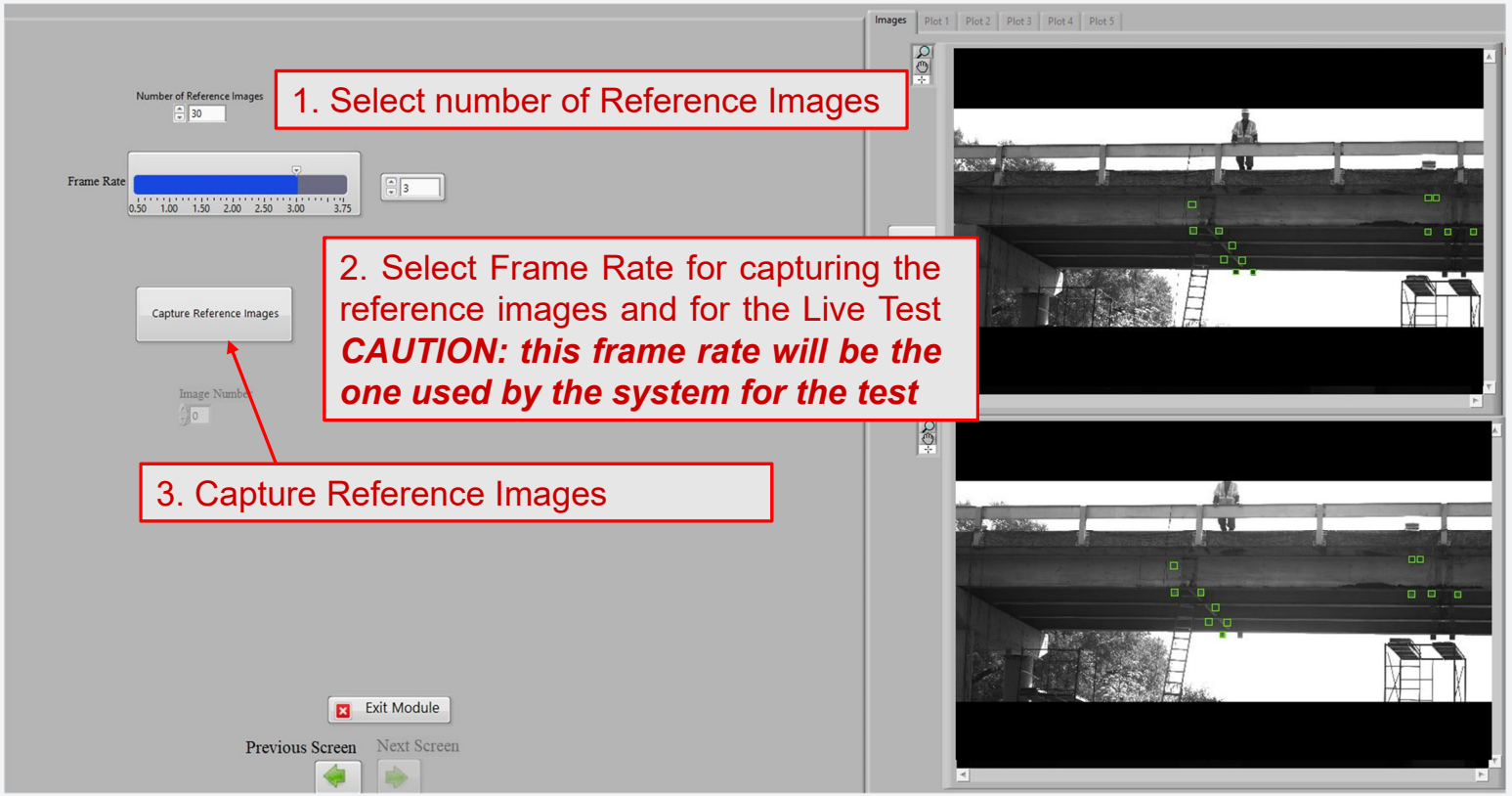
8. Select targets forming the User Coordinate Axes
Origin: Target 8
X Axis: Target 11
Y Axis: Target 9

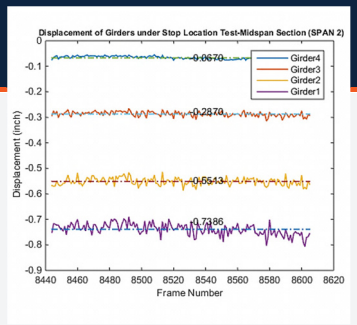
- From the selected targets, a user-defined reference axis can be assigned.
- The software will provide 3D spatial coordinates of targets both relative to the Left camera and relative to the User Coordinate Axis.



5. Live Test

8. Reference Images

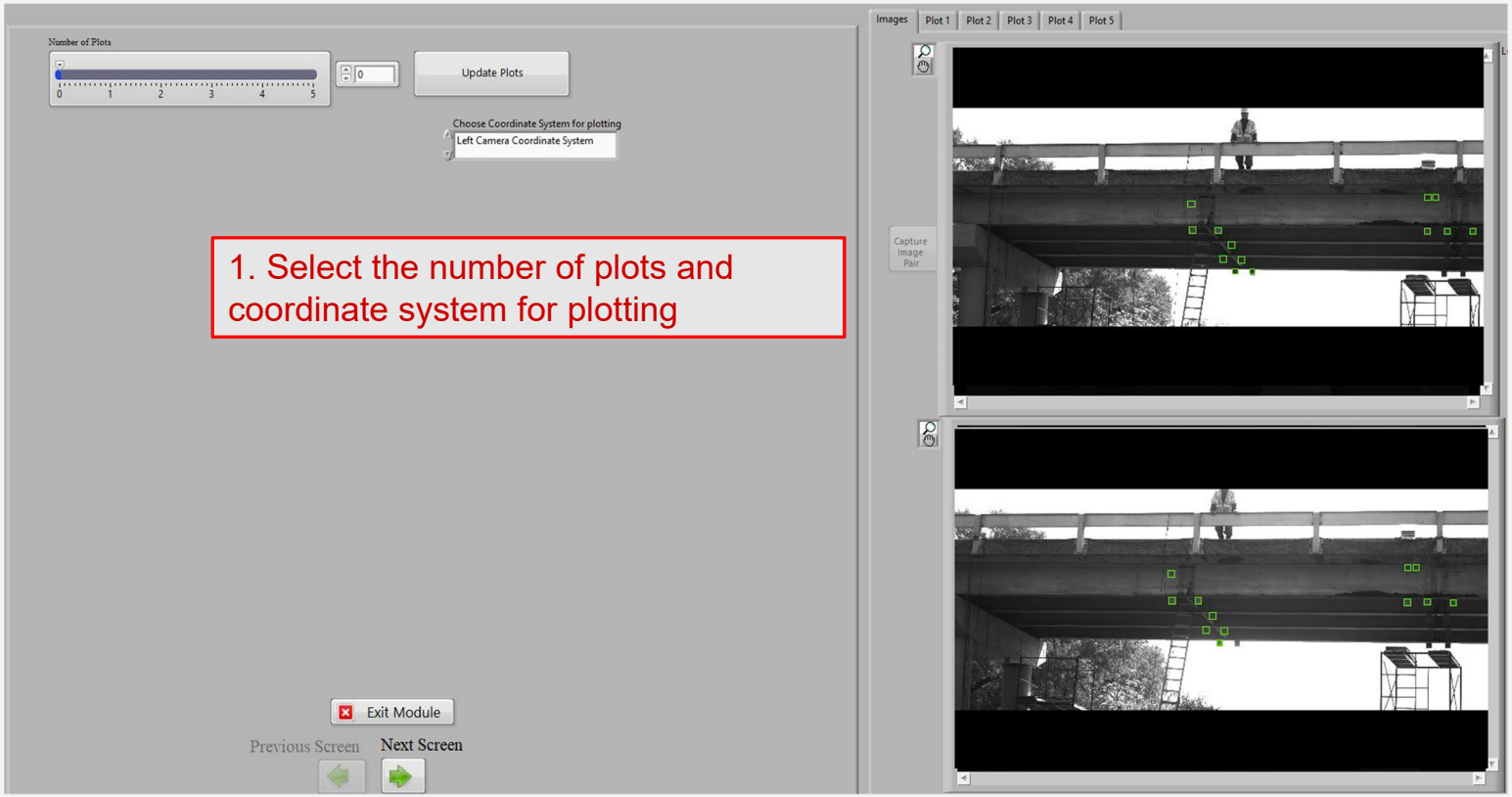




- Reference Images provide the baseline for all other measurements.
- Target X,Y,Z coordinates determined from the reference images will be averaged and those averaged locations will be used to represent the initial state.
- At least 30 Reference Images are recommended.
- Next Screen is not Enabled unless Reference Images are captured.

5. Live Test

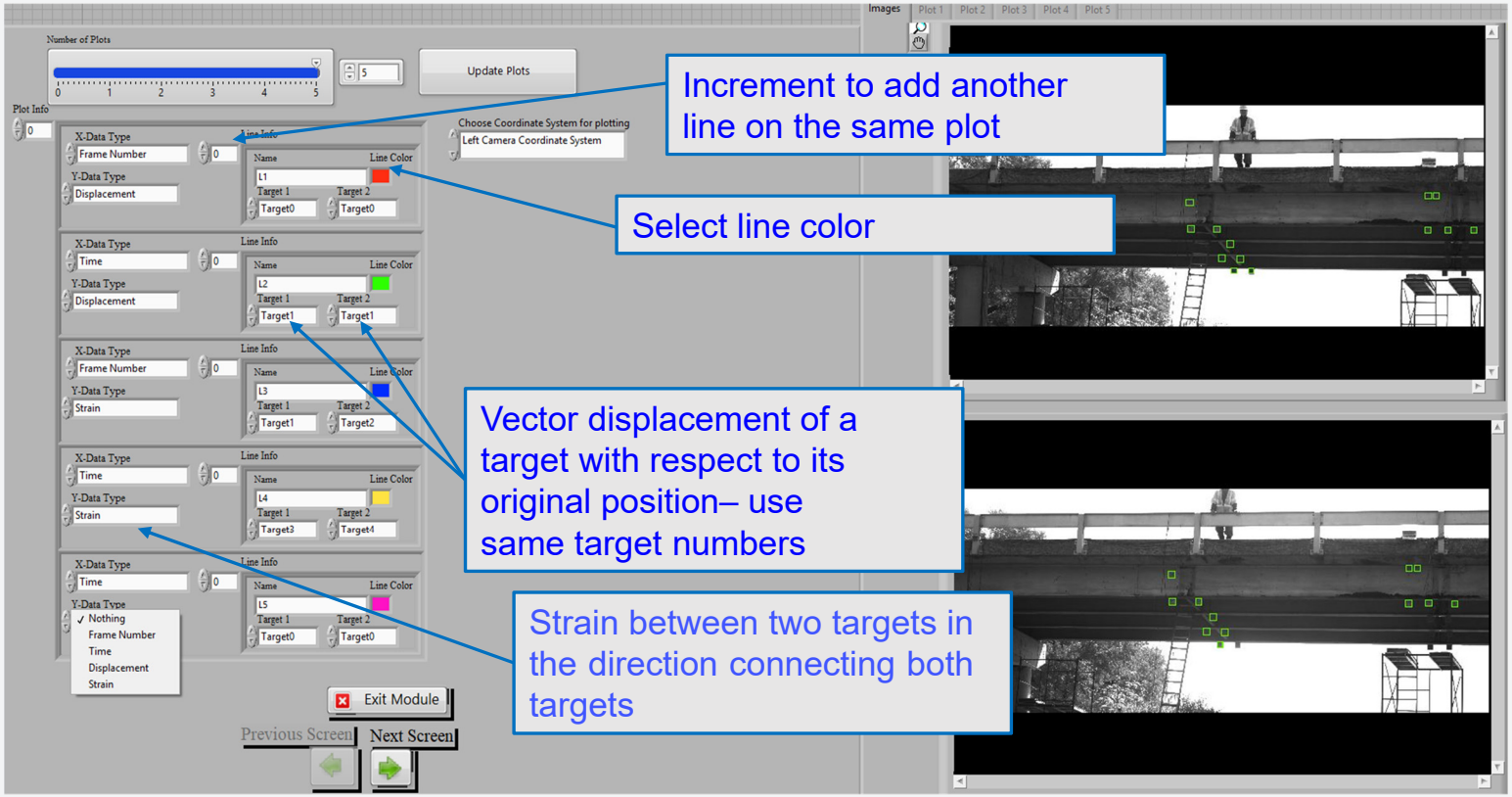
9.Plotting



- This screen is optional and can be used to setup plots of data quantitates that can be viewed live during a test
- A maximum of 5 plots can be viewed live during a test

5. Live Test

9.Plotting



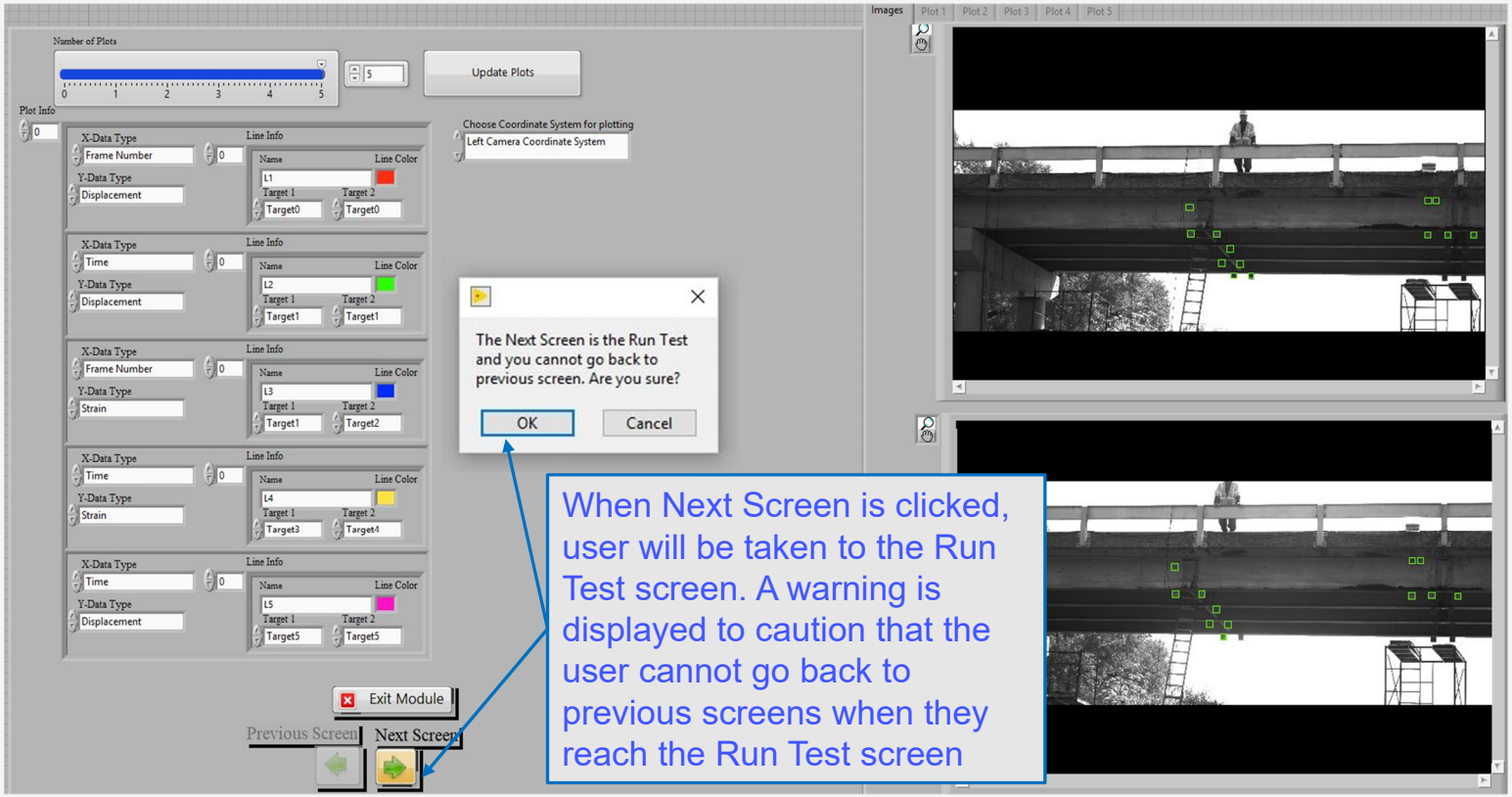
The User can select ***Frame Number, Time, Strain and Displacement*** for all the targets selected to plot

All plots types are XY line plots

Multiple lines can be plotted on the same plot

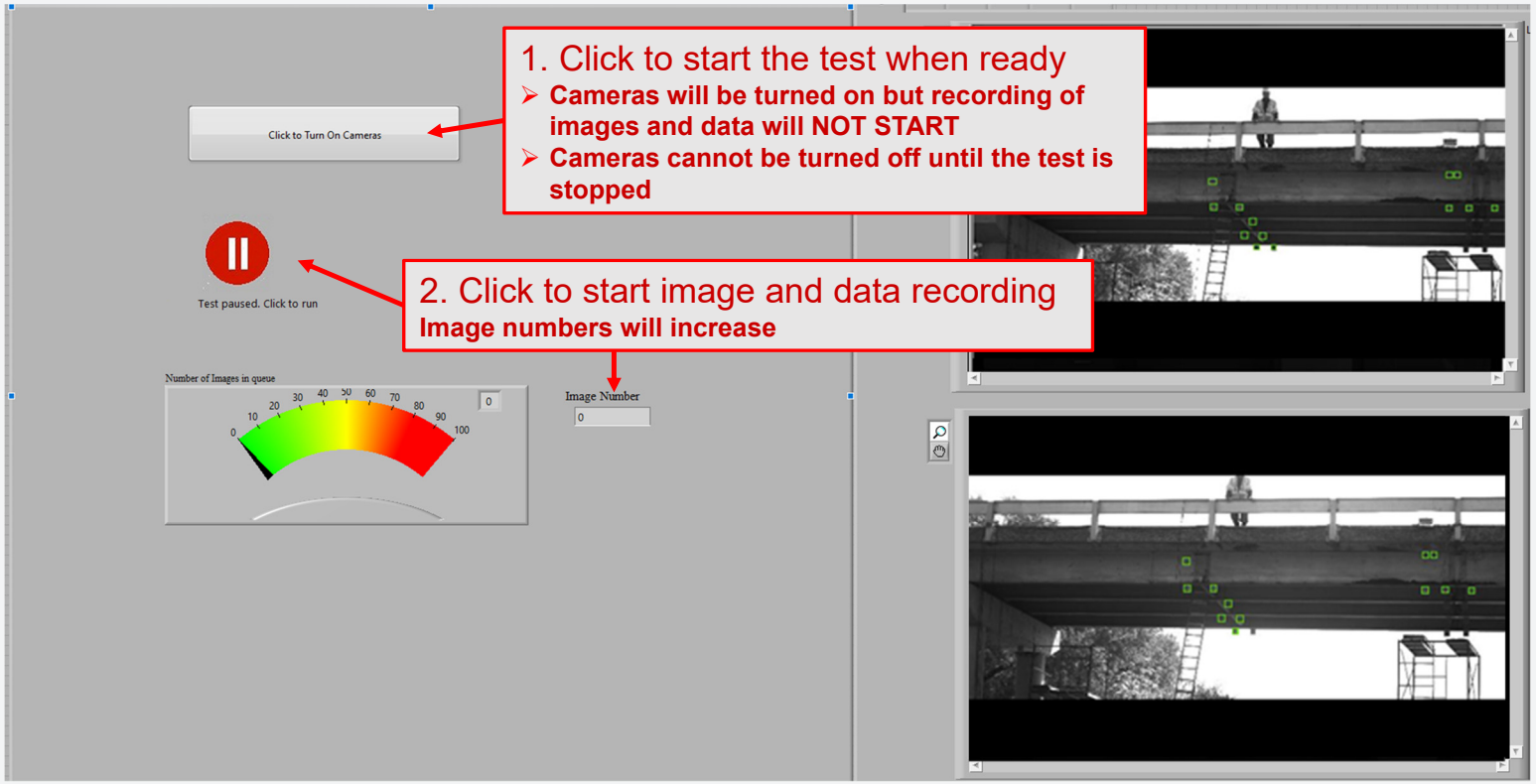
5. Live Test

9.Plotting



5. Live Test

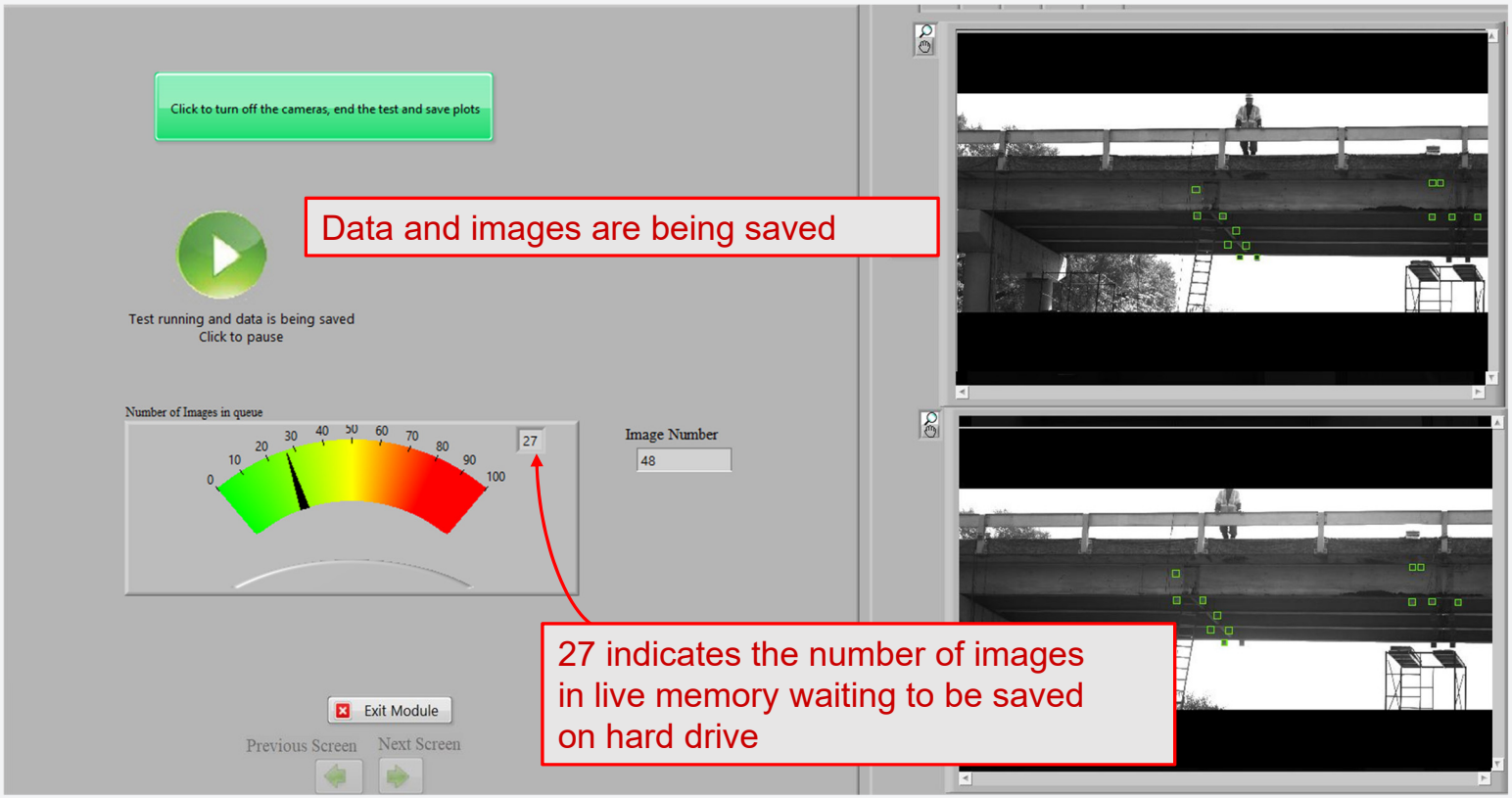
10.Run Test



- Before the test is started the cameras are off. This feature is provided since a long wait period may be needed before a test can be started.
- This keeps the cameras cool until the test.

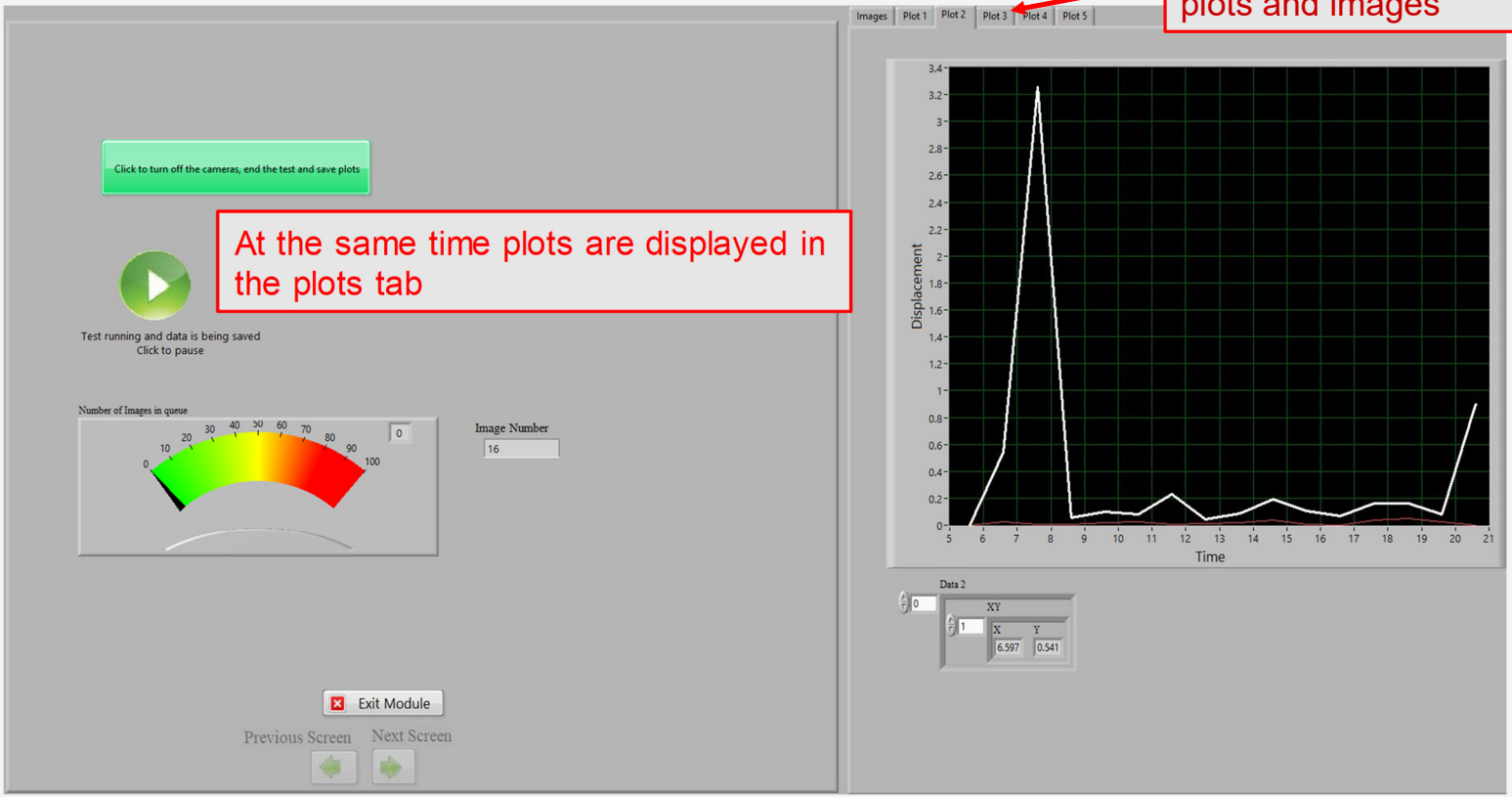
5. Live Test

10.Run Test



5. Live Test

10.Run Test

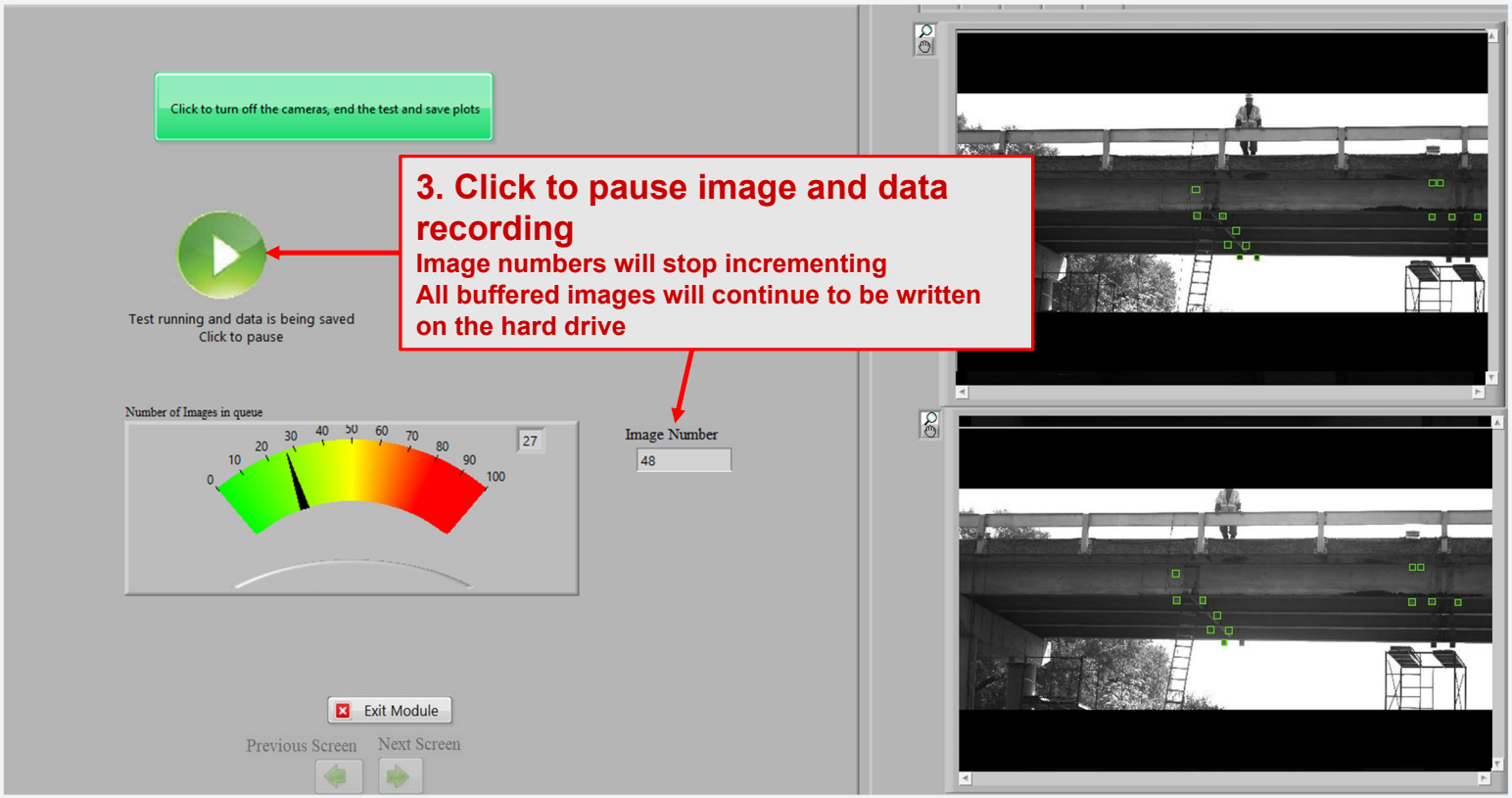


Click on the tabs to cycle between plots and images

At the same time plots are displayed in the plots tab

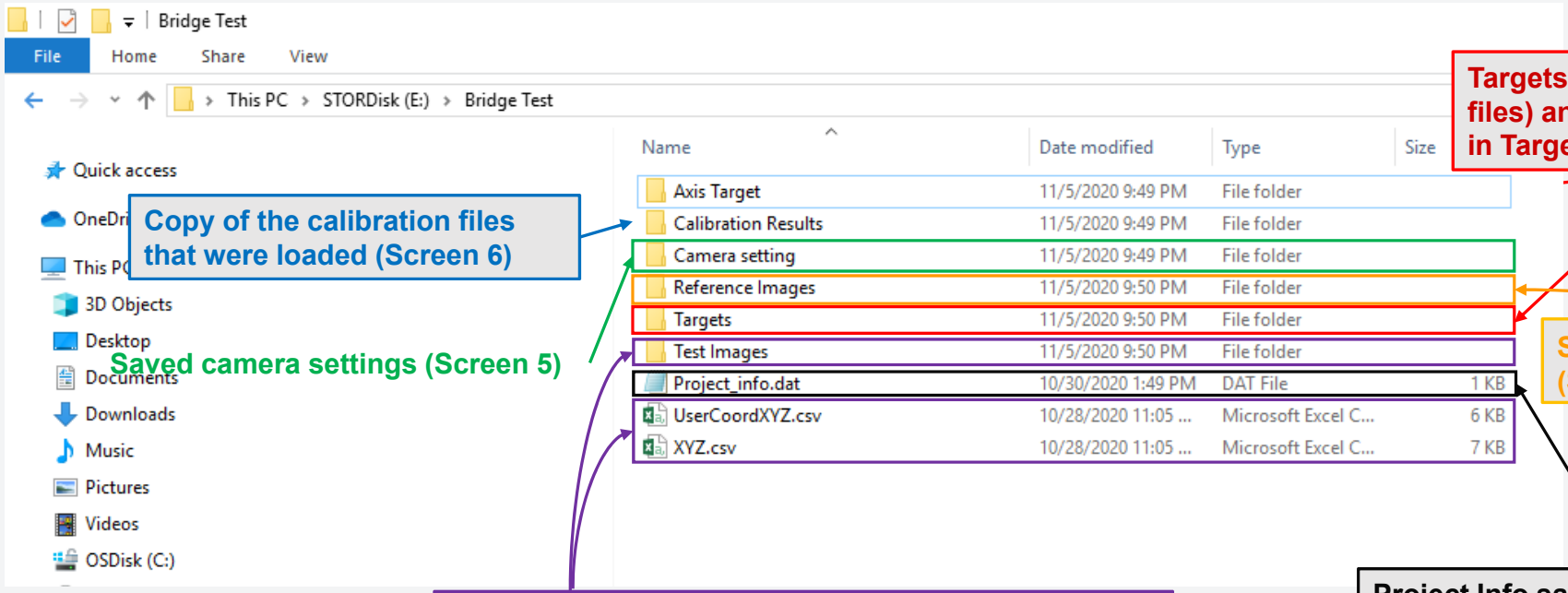
RUNING A LIVE TEST

10. Run Test



5. Live Test

Output Folder and File Structure



Copy of the calibration files that were loaded (Screen 6)

Saved camera settings (Screen 5)

Targets (cropped sub-image files) and Axis Targets saved in Target Selection (Screen 7)

Saved reference images (Screen 8)

Test images and data saved in Run Test (Screen 10)

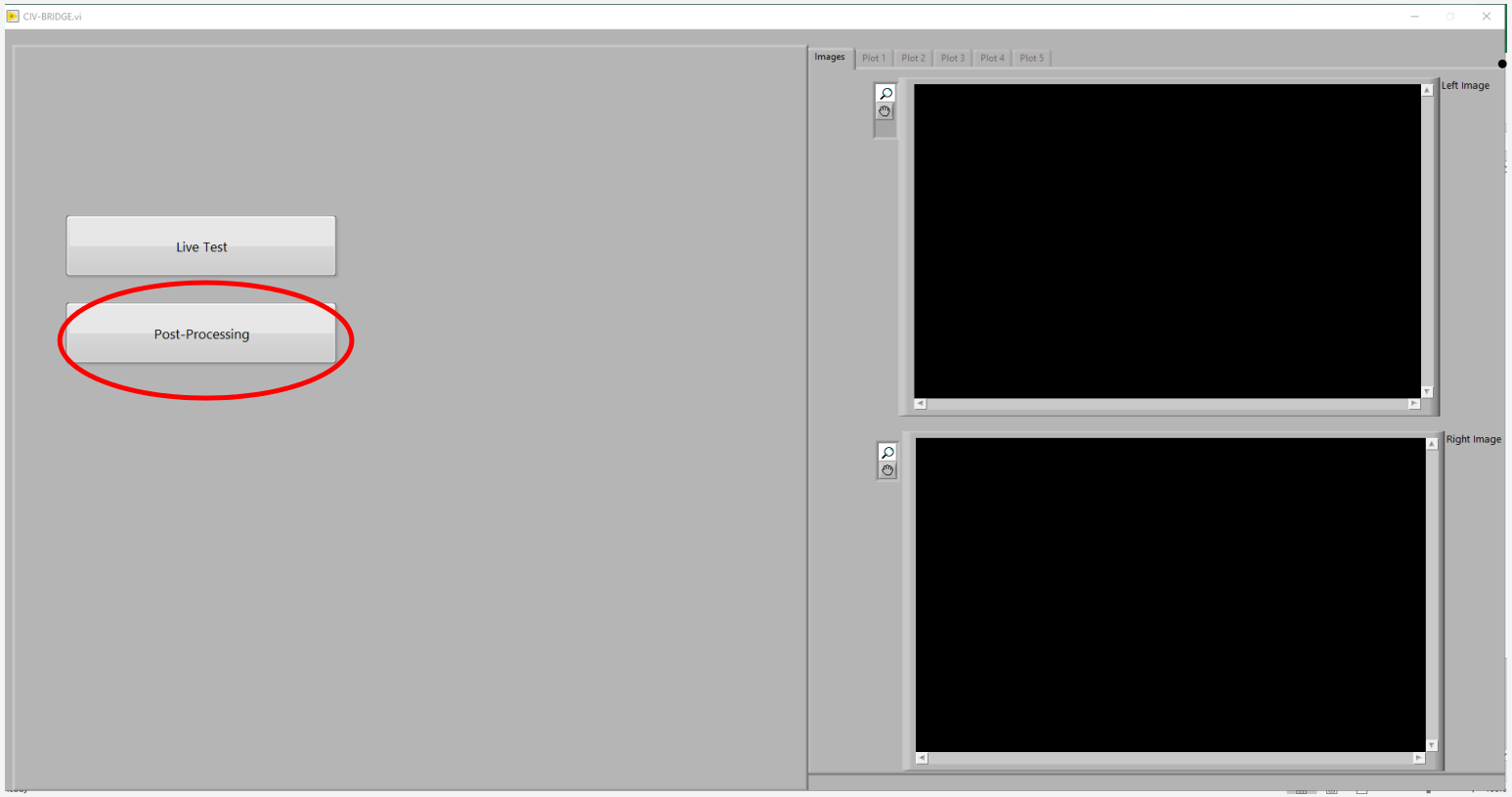
Project Info saved in Screen 4

6. Post-Processing

Reprocess Existing Images
Interpolate Existing Data
Smooth Existing Data
Calculate from Data
Plot Processed Data

6. Post-Processing

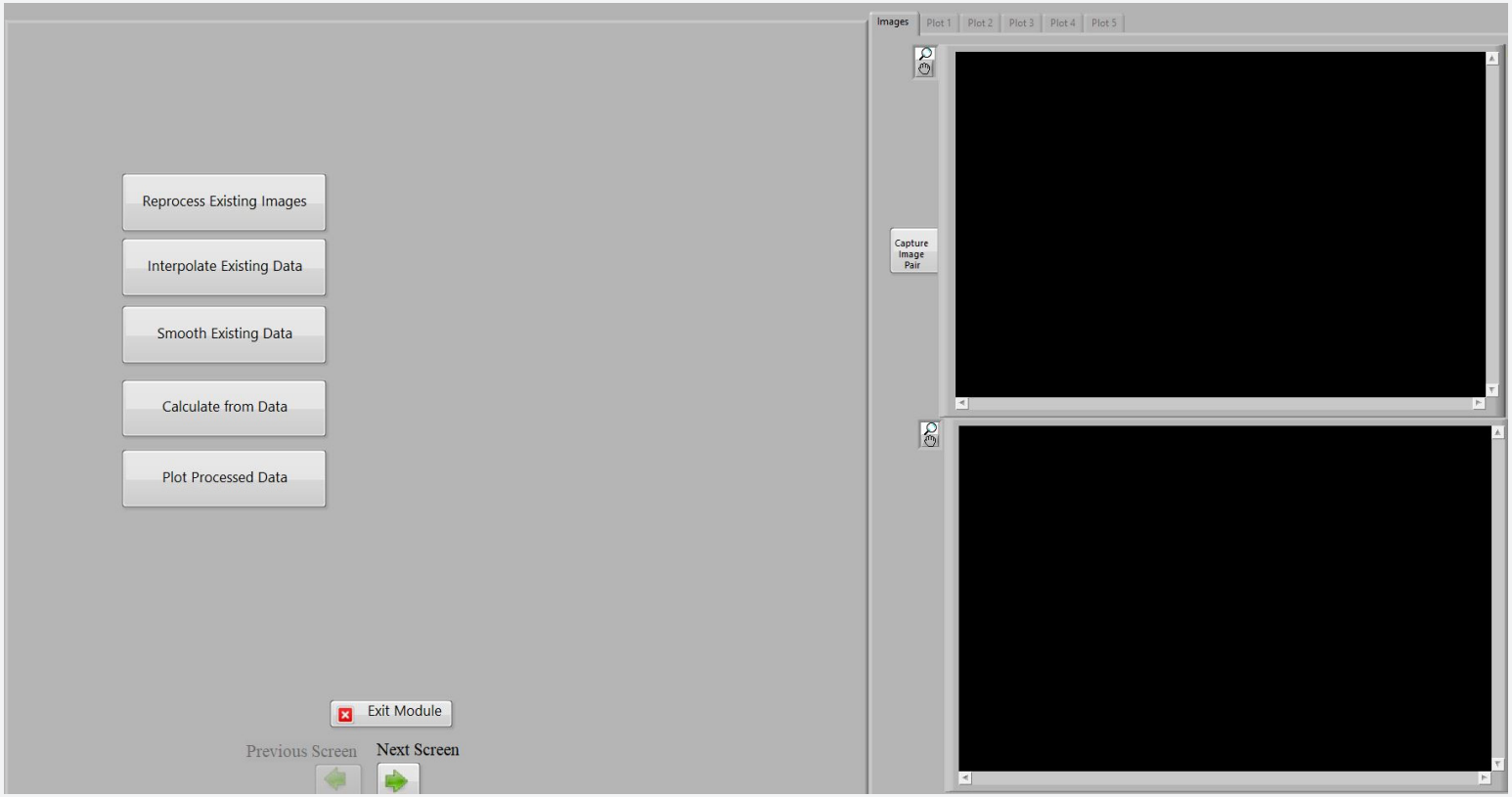
1.Main Menu



The goal of having post processing data modules is to allow user to process test images or data

- Extract additional data
- Selected different targets
- Select different coordinate axes
- etc.…

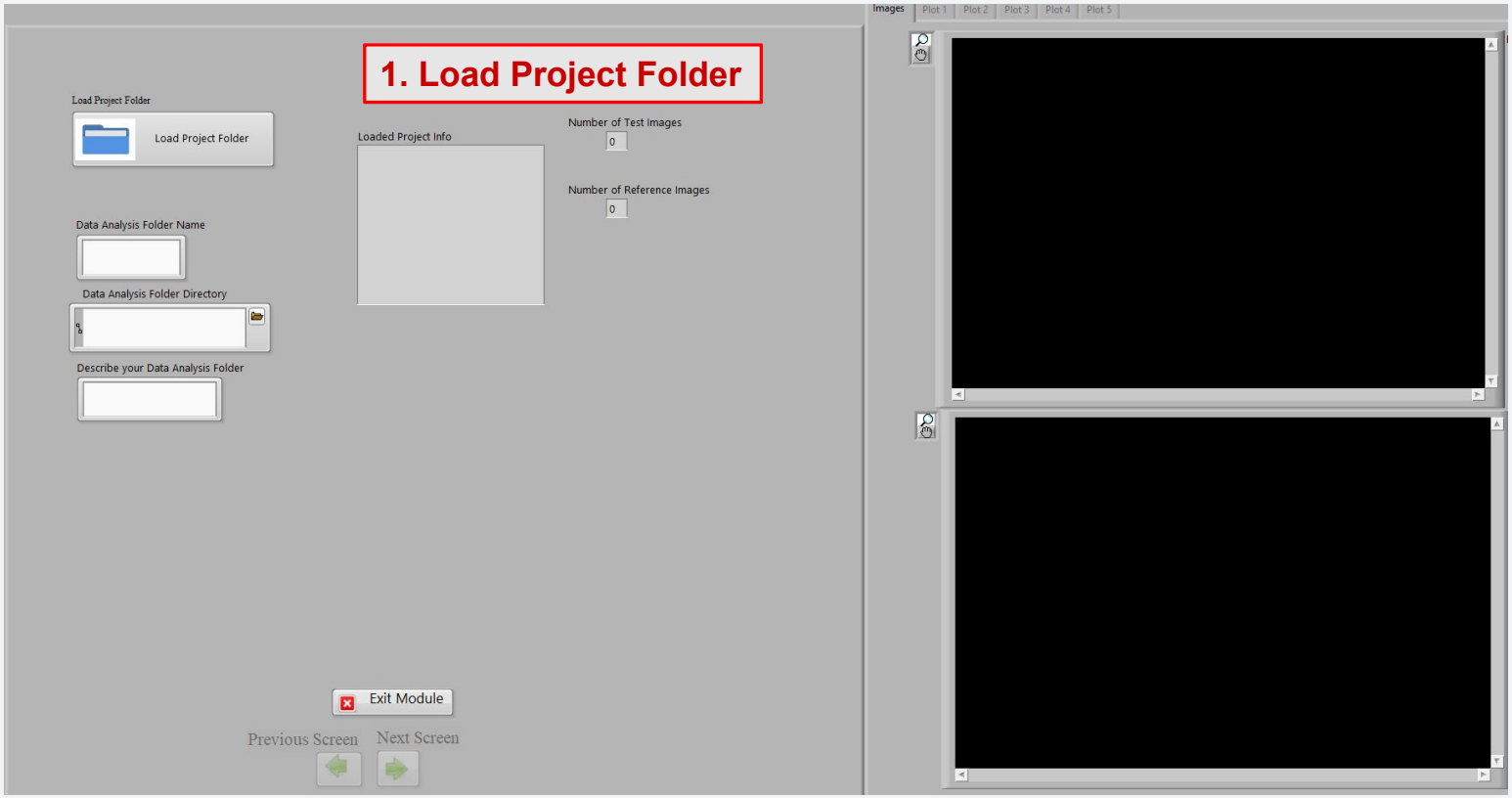
2. Post-Processing options



- **Reprocess Existing Images**
- Interpolate Existing Data
- Smooth Existing Data
- Calculate from Data
- Plot Processed Data

6. Post-Processing: Reprocess Existing Images

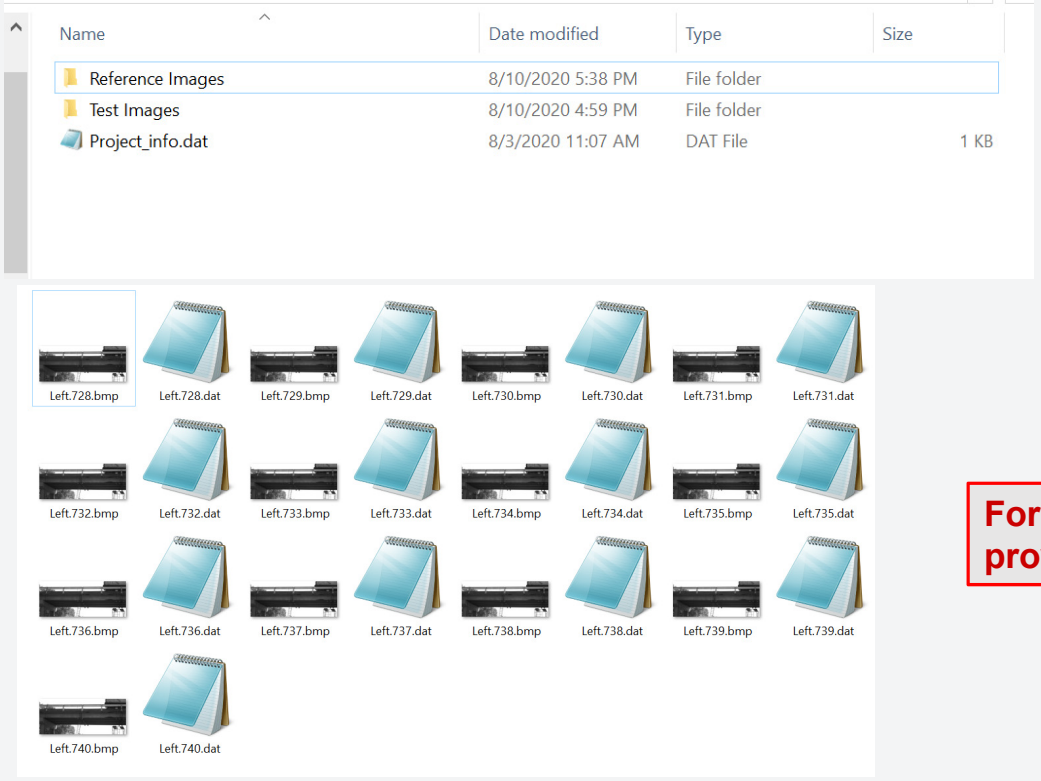
3. Folder Selection



6. Post-Processing: Reprocess Existing Images

3. Folder Selection

Project Folder

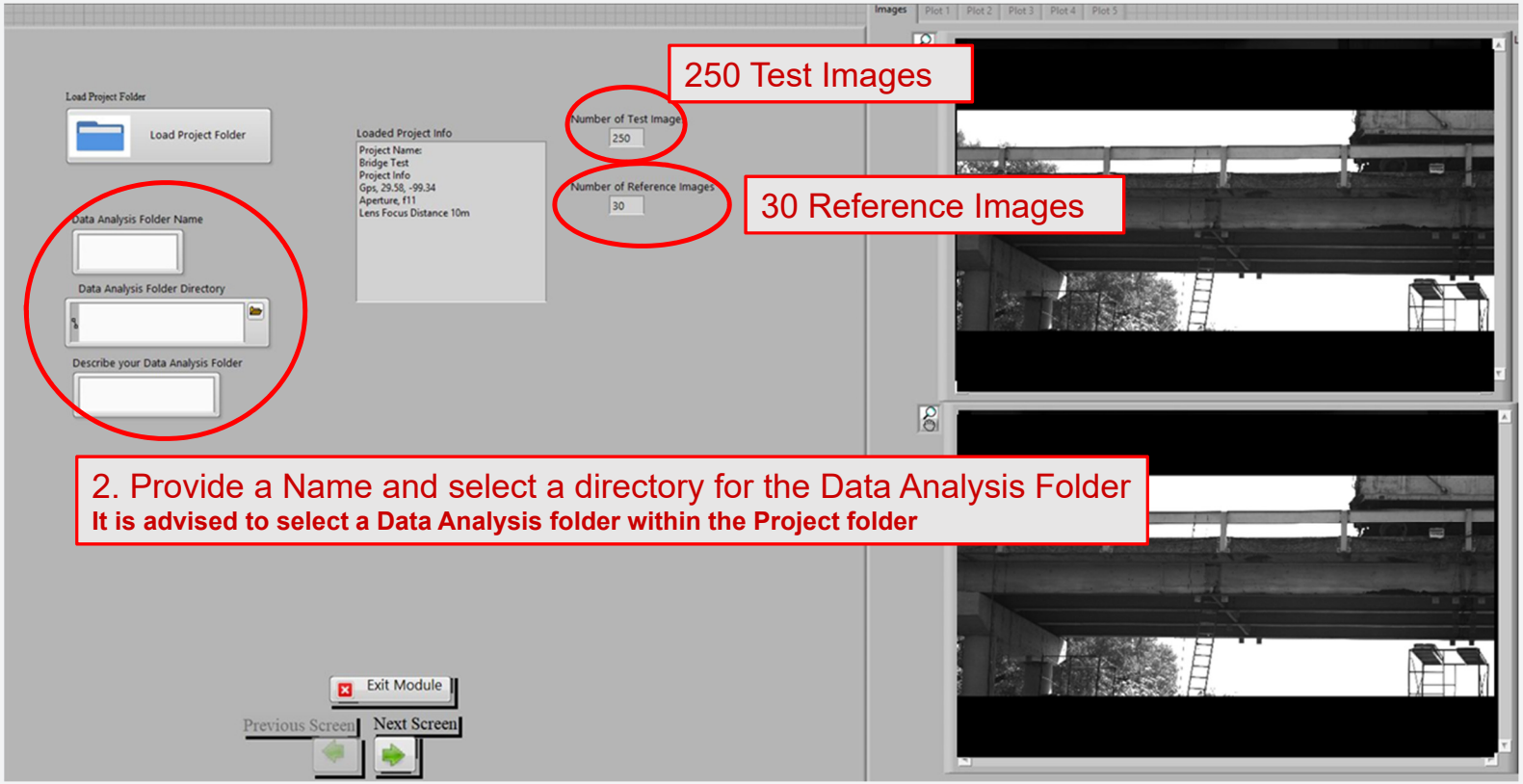


- The Project folder is the main folder provided in the Live Test.
- This folder at a minimum ***MUST*** contain Reference Images and Test Images. Reference Images including Left and Right camera folders contain the pairs of images saved in Live Test
- ***DO NOT change folder or filenames***

For each .bmp image file, a data file .dat is provided with the exact time of acquisition.

6. Post-Processing: Reprocess Existing Images

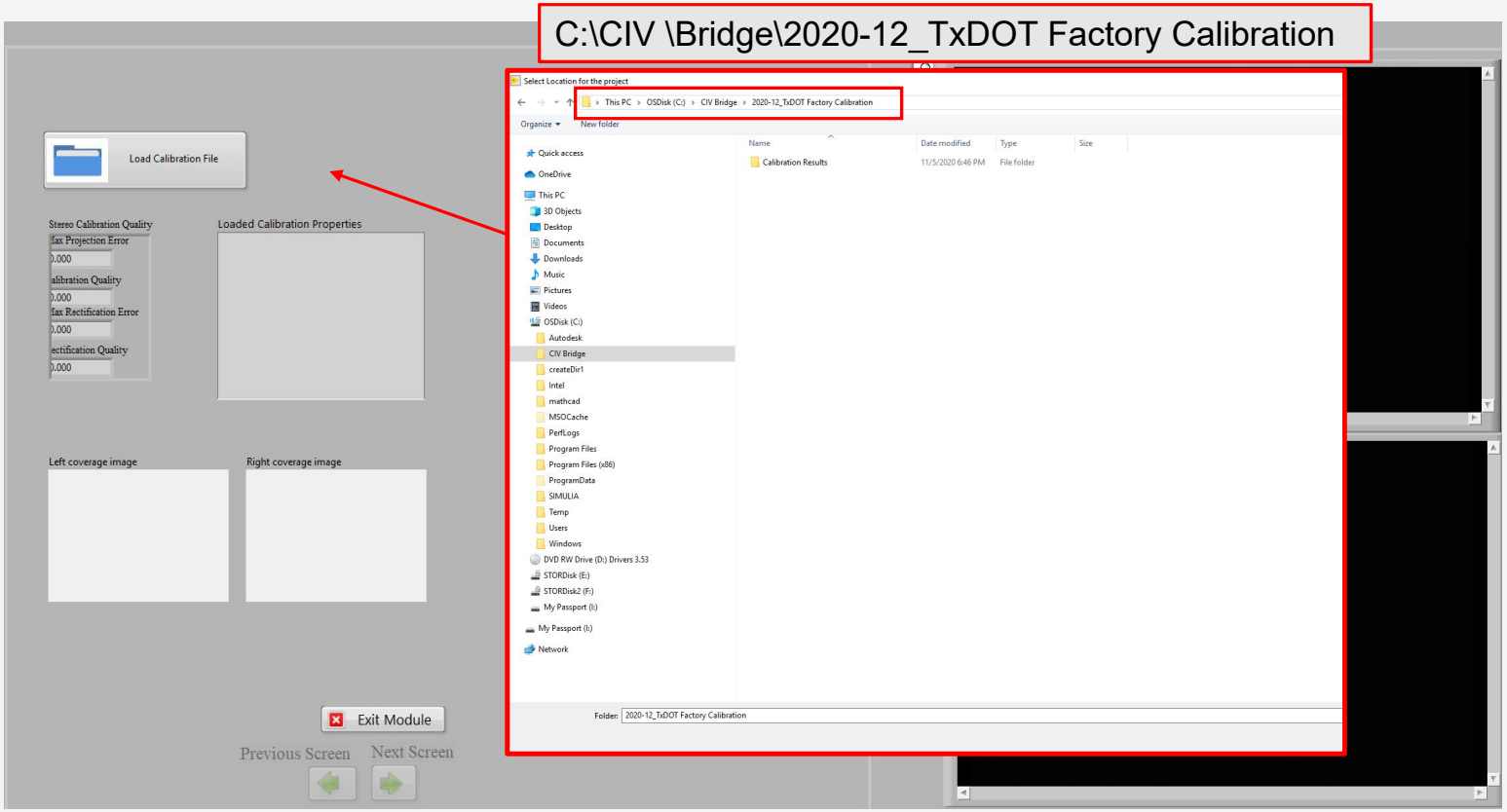
3. Folder Selection



Test Images and **Reference Images** with the project Information including **Project Name**, **GPS**, **Date and Time, Aperture and Focus Distance of lenses** are loaded.

6. Post-Processing: Reprocess Existing Images

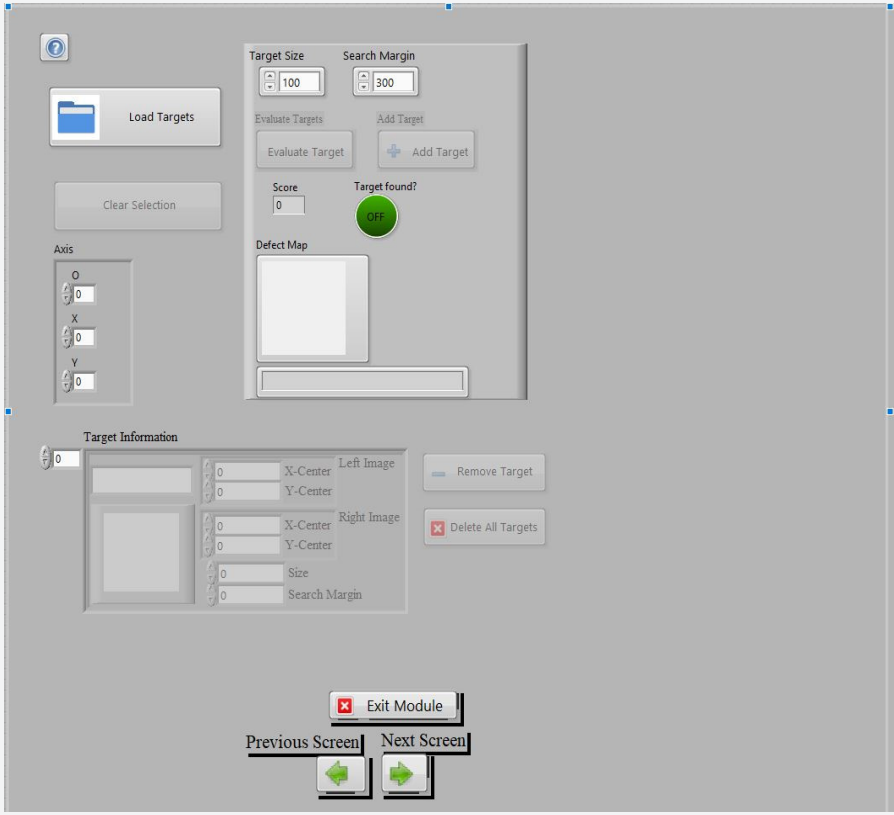
4.Load Calibration

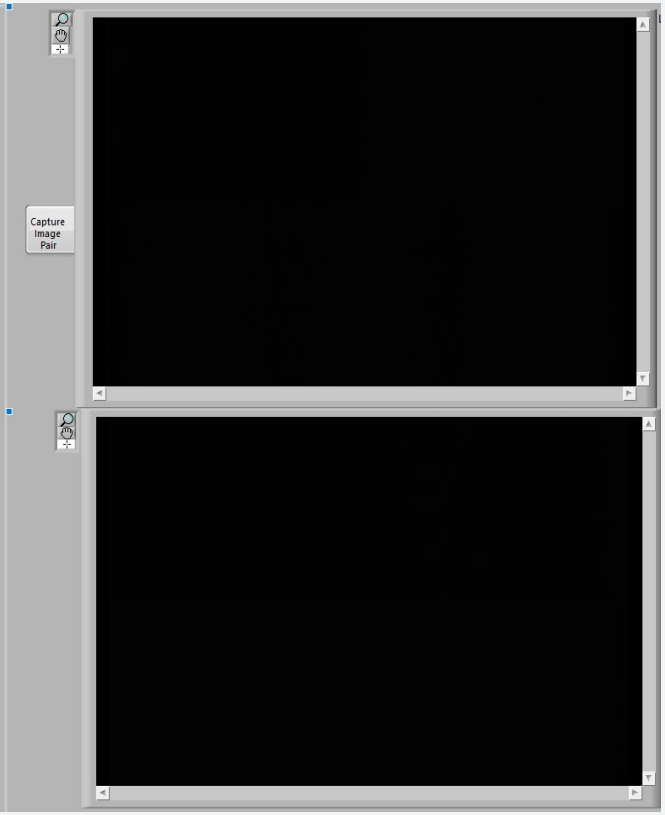


- Loading Calibration file is essential. User cannot Move to Next screen unless the Calibration is loaded
- Provide the location of the provided calibration files.
- C:\CIV Bridge\2020-12_TxDOT Factory Calibration

6. Post-Processing: Reprocess Existing Images

5.Target Selection

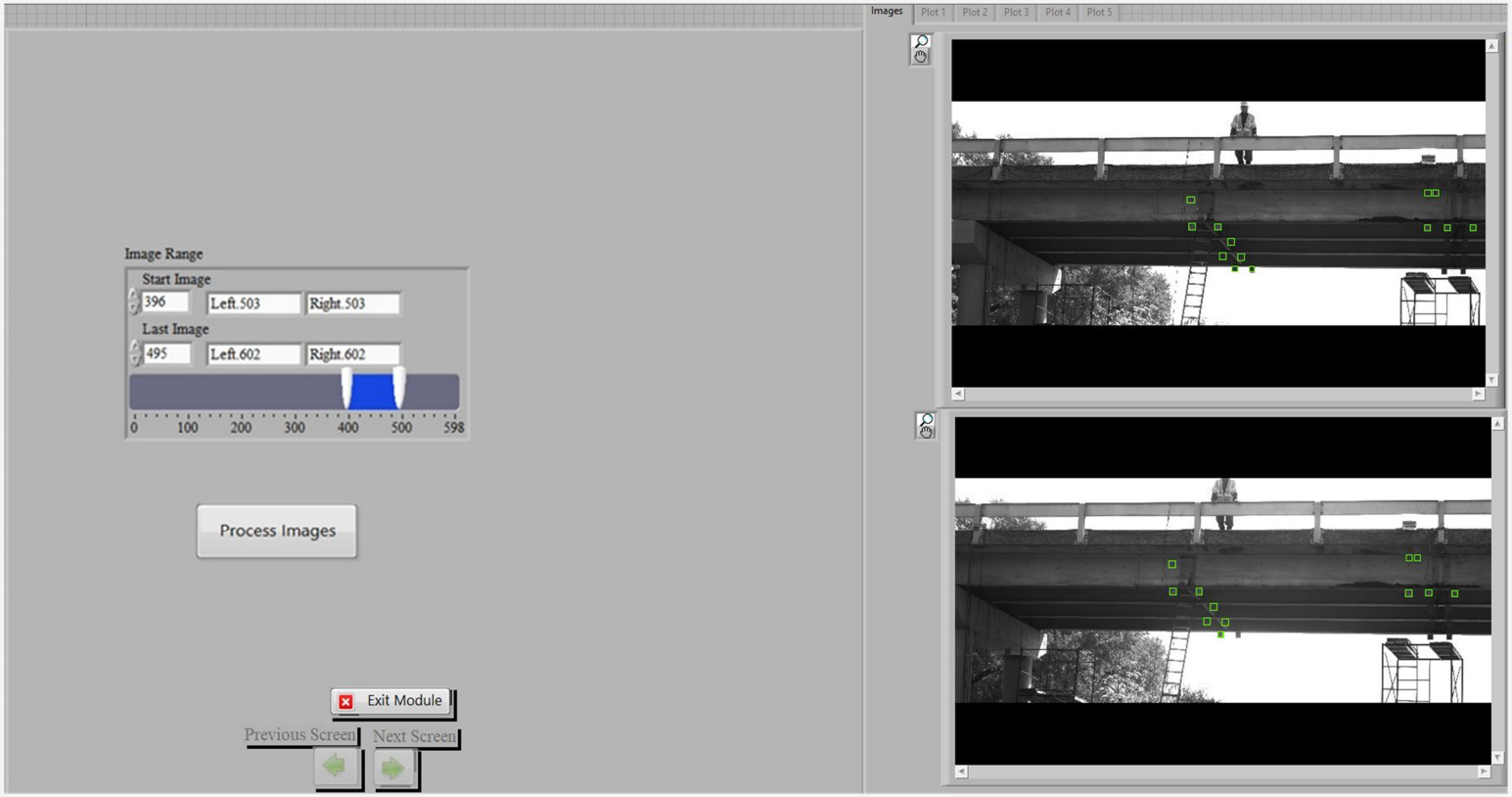




Same process as Target Selection in the Live Test

6. Post-Processing: Reprocess Existing Images

6. Simulate Test



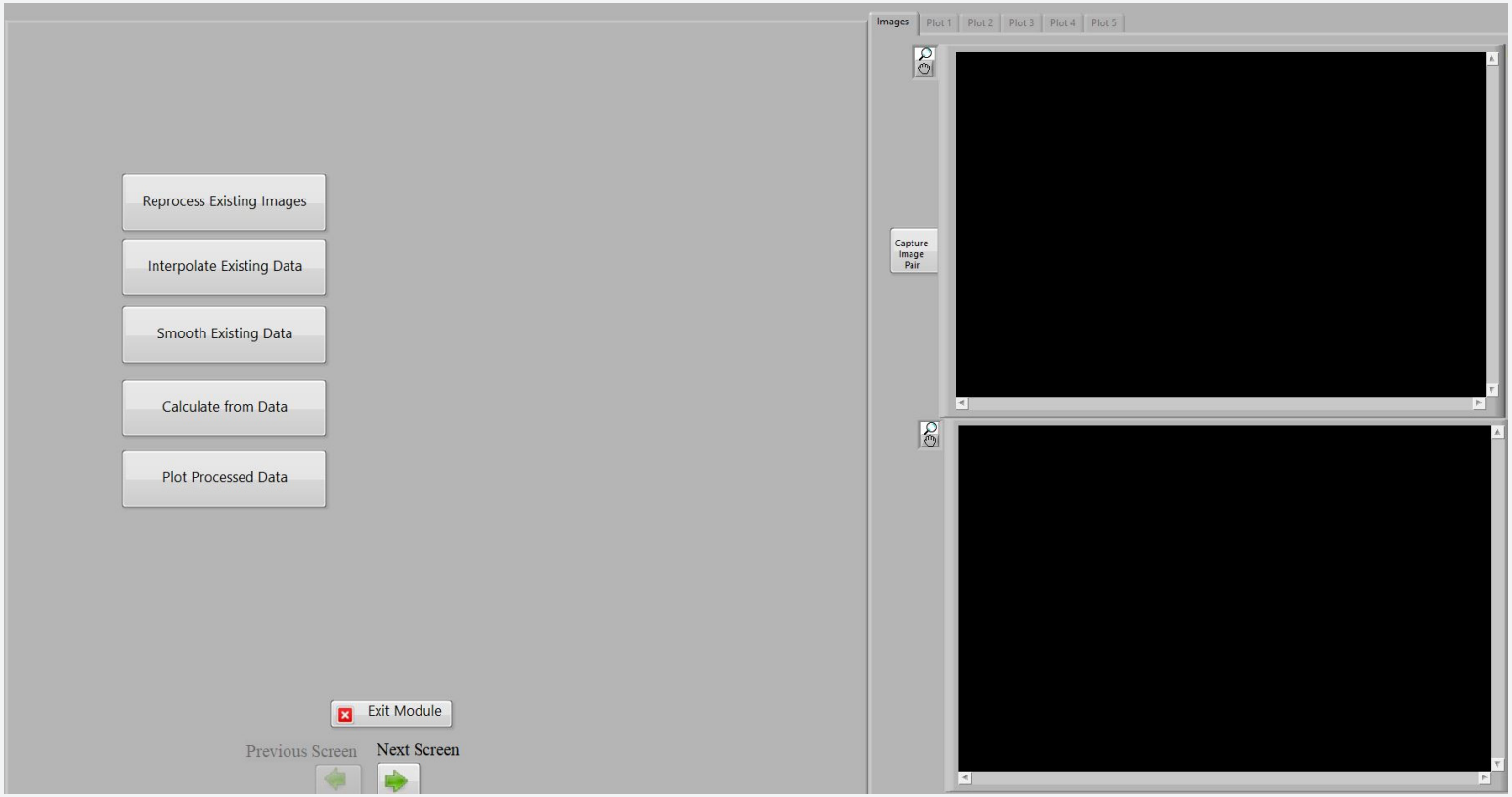
- The user needs to select the Image Range for the images to be reprocessed and then click on Process Images
- Output data files for the newly selected targets and image range will be produced within the Data Analysis folder

6. Post-Processing

Reprocess Existing Images
Interpolate Existing Data
Smooth Existing Data
Calculate from Data
Plot Processed Data

6. Post-Processing: Interpolate

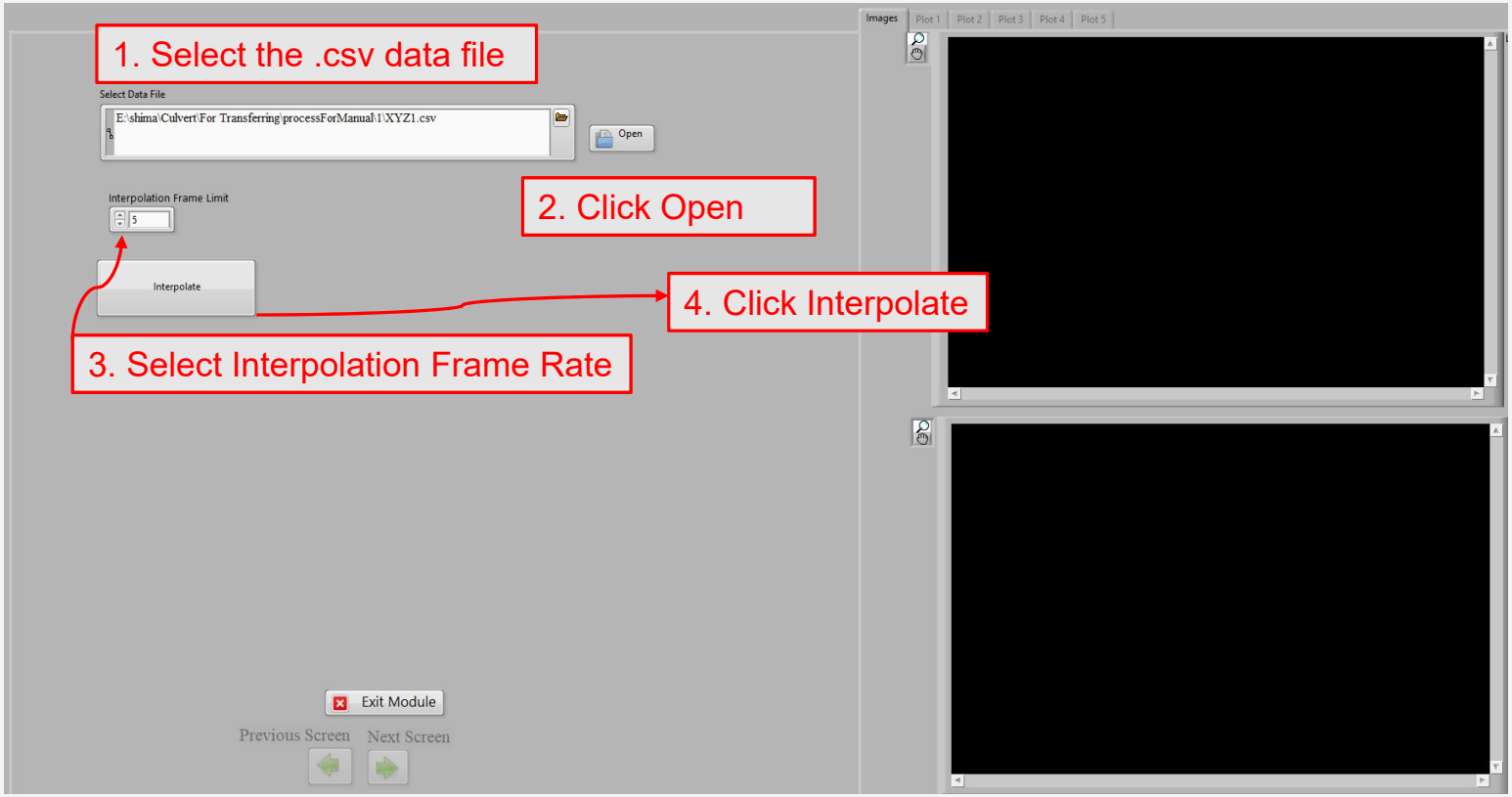
2.Post-Processing options



- Reprocess Existing Images
- **Interpolate Existing Data**
- Smooth Existing Data
- Calculate from Data
- Plot Processed Data

6. Post-Processing: Interpolate

3.Interpolate Existing Data



- The CIV program might lose targets intermittently.
- The interpolation function uses linear interpolation to fill in target location data for frames where a target is lost, basing itself on the target locations bounding the frames in which the target was lost.
- The user can indicate the maximum acceptable number of frames over which interpolation will be performed. If a target is lost for more sequential frames then the interpolation will not fill in the missing data.

6. Post-Processing: Interpolate

Interpolation function output

Original File

Project Name	Run-1																
Data Analysis Folder Name	1																
Analysis Date	10/7/2020																
Project Info																	
Gps	29.1839	-99.1979															
Aperture	8																
Lens Focus Distance	Infinity	infinity															
Exposure time	15000																
Frame Rate	3																
Coordinate system target numbers																	
Origin Target	0																
X axis Target	1																
Y axis Target	2																
Calibration Info																	
Calibration Name	Calibration50mmLensesForCulvertTest	Calibration Date	10/7/2020														
Calibration Unit	Inch																
Calibration Distance Range	35feet	45feet															
Calibration Apeture	8																
Lenses Focus Distance(m)	Left Cam infinity	Right Cam 10-infinity															
Calibration exposure time(microsecond)	15000																

Frame #	Time	X0	Y0	Z0	X1	Y1	Z1	X2	Y2	Z2	X3	Y3	Z3	X4	Y4	Z4
Ref Avg		31.624117	21.561528	-145.103	25.82849	21.73363	-146.509	31.66488	15.22094	-144.536	33.28034	-23.921	-173.37	NaN	NaN	NaN
503	08/31/2020 AM 10:43:18.940	31.60333	21.50215	-145.094	25.80678	21.67293	-146.496	31.6453	15.16281	-144.53	33.26122	-23.9902	-173.367	NaN	NaN	NaN
504	08/31/2020 AM 10:43:19.288	31.60459	21.50237	-145.097	25.81102	21.67585	-146.513	31.64526	15.16233	-144.53	33.25906	-23.9911	-173.364	33.37941	-19.6559	-173.879
505	08/31/2020 AM 10:43:19.605	31.5997	21.50013	-145.077	25.80924	21.67484	-146.503	31.64347	15.16167	-144.523	33.2704	-23.9972	-173.411	NaN	NaN	NaN
506	08/31/2020 AM 10:43:19.965	31.60241	21.50164	-145.088	25.80782	21.67306	-146.496	31.64444	15.16295	-144.526	33.2643	-23.993	-173.382	33.38223	-19.6574	-173.885
507	08/31/2020 AM 10:43:20.268	31.60393	21.50247	-145.097	25.81154	21.6752	-146.514	31.64614	15.16218	-144.534	33.26583	-23.9939	-173.387	NaN	NaN	NaN
508	08/31/2020 AM 10:43:20.620	31.60028	21.49999	-145.079	25.8067	21.67223	-146.495	31.64469	15.16128	-144.527	33.25587	-23.9884	-173.348	NaN	NaN	NaN
509	08/31/2020 AM 10:43:20.974	31.60086	21.49941	-145.081	25.80274	21.66944	-146.477	31.64285	15.16071	-144.522	33.25443	-23.9891	-173.341	33.38019	-19.6552	-173.874
510	08/31/2020 AM 10:43:21.304	31.59785	21.49754	-145.072	25.80385	21.66904	-146.475	31.64284	15.16014	-144.519	33.2577	-23.9902	-173.353	NaN	NaN	NaN
511	08/31/2020 AM 10:43:21.608	31.60186	21.50296	-145.091	25.80994	21.67452	-146.509	31.65161	15.16455	-144.555	33.25951	-23.9926	-173.363	NaN	NaN	NaN

Interpolated File

Project Name	Run-1																
Data Analysis Folder Name	1																
Analysis Date	44111																
Project Info																	
Gps	29.1839	-99.1979															
Aperture	8																
Lens Focus Distance	Infinity	10-infinity															
Exposure time	15000																
Frame Rate	3																
Coordinate system target numbers																	
Origin Target	0																
X axis Target	1																
Y axis Target	2																
Calibration Info																	
Calibration Name	Calibration50mmLensesForCulvertTest	Calibration Date	44111														
Calibration Unit	Inch																
Calibration Distance Range	35feet	45feet															
Calibration Apeture	8																
Lenses Focus Distance(m)	infinity	infinity															
Calibration exposure time(microsecond)	15000																
Source File Used		XYZ1.csv															
Interpolated	Frame Limit /5																

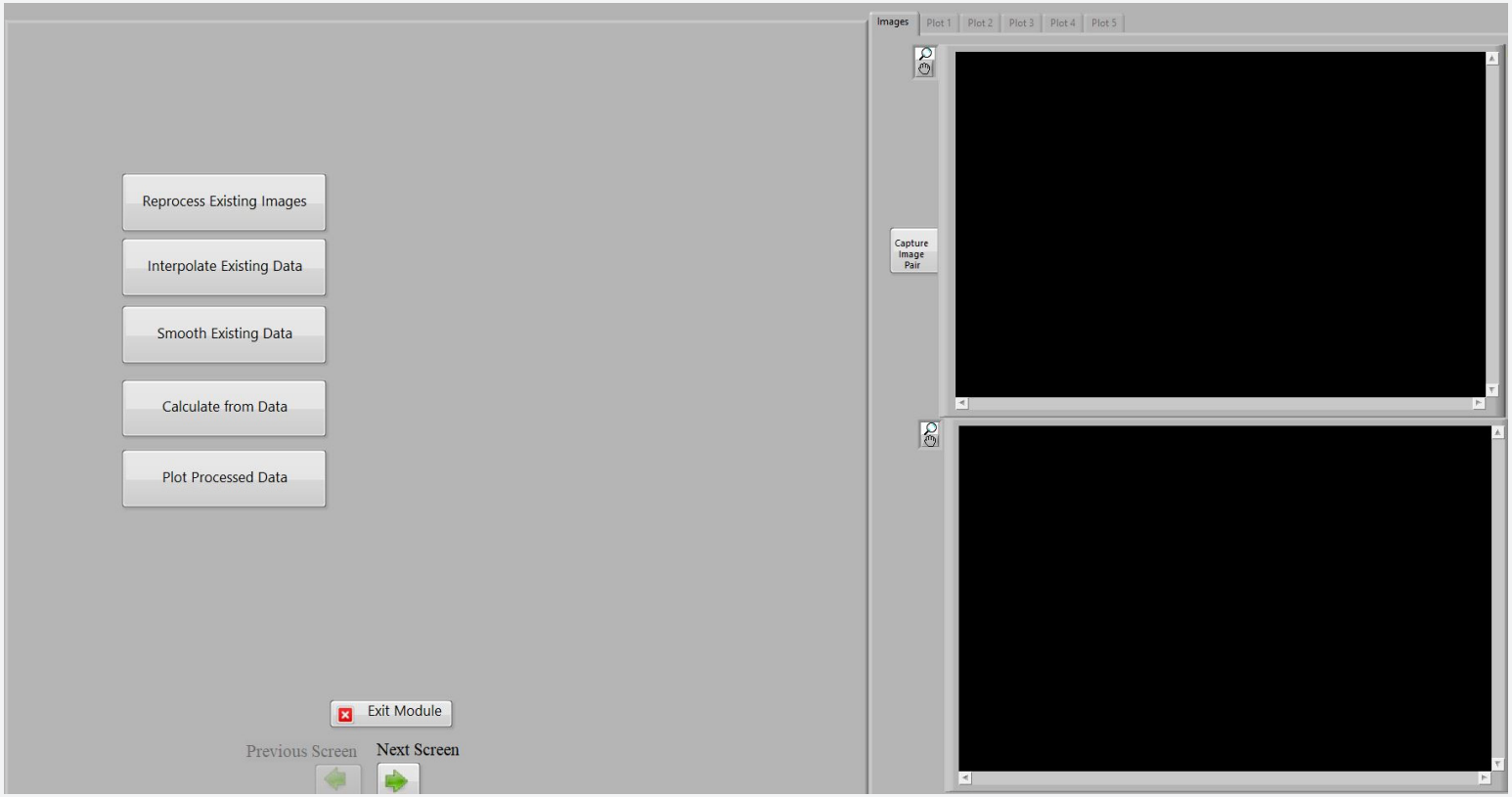
Frame #	Time	X0	Y0	Z0	X1	Y1	Z1	X2	Y2	Z2	X3	Y3	Z3	X4	Y4	Z4
Ref Avg		31.624117	21.56153	-145.103	25.82849	21.73363	-146.509	31.66488	15.22094	-144.536	33.28034	-23.921	-173.37	NaN	NaN	NaN
503	08/31/2020 AM 10:43:18.940	31.60333	21.50215	-145.094	25.80678	21.67293	-146.496	31.6453	15.16281	-144.53	33.26122	-23.9902	-173.367	NaN	NaN	NaN
504	08/31/2020 AM 10:43:19.288	31.60459	21.50237	-145.097	25.81102	21.67585	-146.513	31.64526	15.16233	-144.53	33.25906	-23.9911	-173.364	33.37941	-19.6559	-173.879
505	08/31/2020 AM 10:43:19.605	31.5997	21.50013	-145.077	25.80924	21.67484	-146.503	31.64347	15.16167	-144.523	33.2704	-23.9972	-173.411	33.38082	-19.6567	-173.882
506	08/31/2020 AM 10:43:19.965	31.60241	21.50164	-145.088	25.80782	21.67306	-146.496	31.64444	15.16295	-144.526	33.2643	-23.993	-173.382	33.38223	-19.6574	-173.885
507	08/31/2020 AM 10:43:20.268	31.60393	21.50247	-145.097	25.81154	21.6752	-146.514	31.64614	15.16218	-144.534	33.26583	-23.9939	-173.387	33.38155	-19.6567	-173.882
508	08/31/2020 AM 10:43:20.620	31.60028	21.49999	-145.079	25.8067	21.67223	-146.495	31.64469	15.16128	-144.527	33.25587	-23.9884	-173.348	33.38087	-19.6559	-173.878
509	08/31/2020 AM 10:43:20.974	31.60086	21.49941	-145.081	25.80274	21.66944	-146.477	31.64285	15.16071	-144.522	33.25443	-23.9891	-173.341	33.38019	-19.6552	-173.874
510	08/31/2020 AM 10:43:21.304	31.59785	21.49754	-145.072	25.80385	21.66904	-146.475	31.64284	15.16014	-144.519	33.2577	-23.9902	-173.353	33.38168	-19.6555	-173.88
511	08/31/2020 AM 10:43:21.608	31.60186	21.50296	-145.091	25.80994	21.67452	-146.509	31.65161	15.16455	-144.555	33.25951	-23.9926	-173.363	33.38316	-19.6558	-173.885

6. Post-Processing

Reprocess Existing Images
Interpolate Existing Data
Smooth Existing Data
Calculate from Data
Plot Processed Data

6. Post-Processing: Smooth

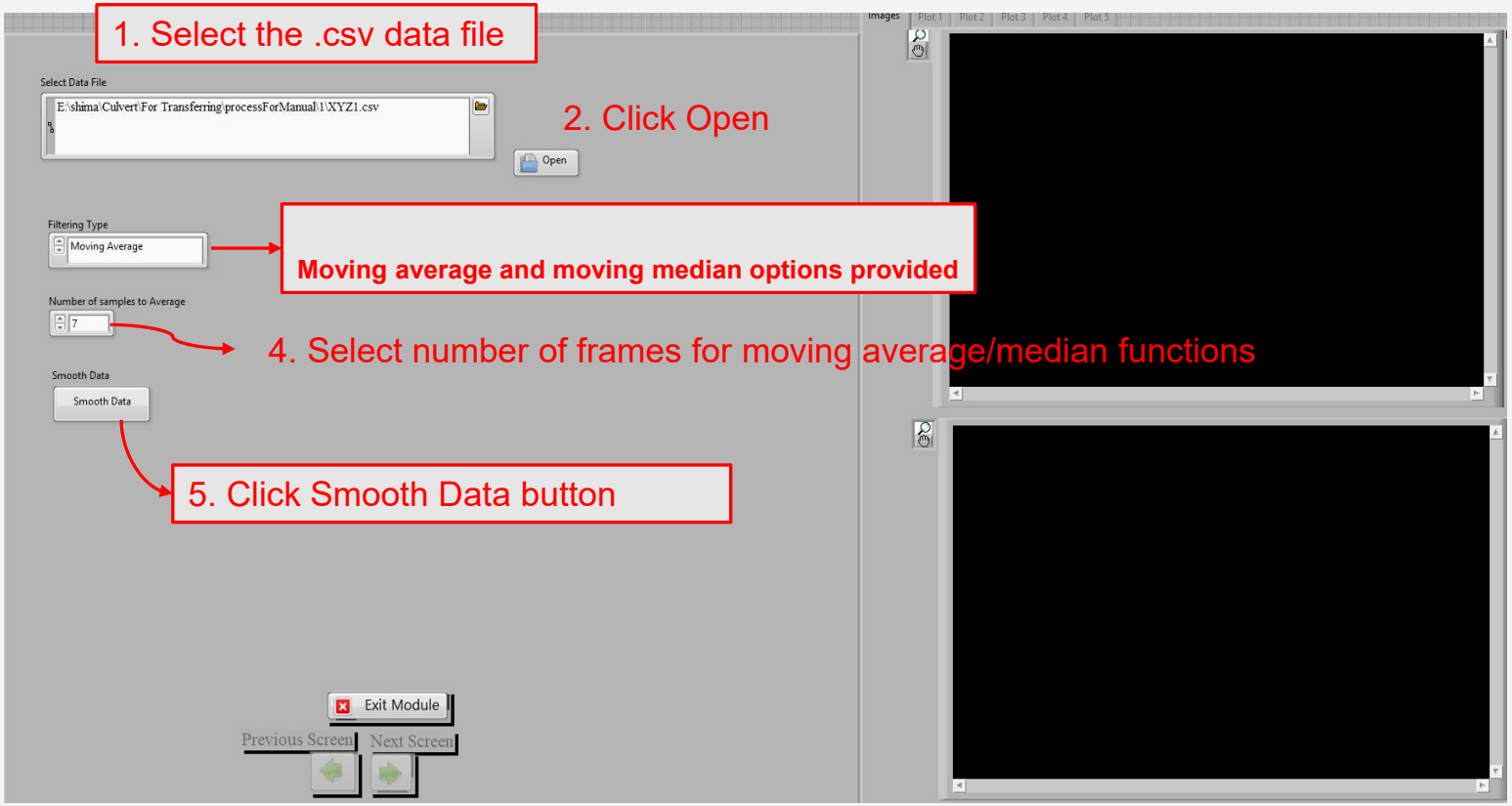
2. Post-Processing options



- Reprocess Existing Images
- Interpolate Existing Data
- **Smooth Existing Data**
- Calculate from Data
- Plot Processed Data

6. Post-Processing: Smooth

Smoothing Existing Data



6. Post-Processing: Smooth

Smoothing Function Output

- It is recommended to run the interpolation function before running the smoothing function.

Original File

Project Name	Run-1		
Data Analysis Folder Name	1		
Analysis Date	10/7/2020		
Project Info			
Gps	29.1839	-99.1979	
Aperture	8		
Lens Focus Distance	Infinity	10-infinity	
Exposure time	15000		
Frame Rate	3		
Coordinate system target numbers			
Origin Target	0		
X axis Target	1		
Y axis Target	2		
Calibration Info			
Calibration Name	Calibration50mmLensesForCulvertTest	Calibration Date	10/7/2020
Calibration Unit	Inch		
Calibration Distance Range	35feet	45feet	
Calibration Apeture	8		
Lenses Focus Distance(m)	Left Came infinity	Right Cam 10-infinity	
Calibration exposure time(microsecond)	15000		

Frame #	Time	X0	Y0	Z0	X1	Y1	Z1	X2	Y2	Z2	X3	Y3	Z3	X4	Y4	Z4
Ref Avg		31.624117	21.561528	-145.103	25.82849	21.73363	-146.509	31.66488	15.22094	-144.536	33.28034	-23.921	-173.37	NaN	NaN	NaN
503	08/31/2020 AM 10:43:18.940	31.60333	21.50215	-145.094	25.80678	21.67293	-146.496	31.6453	15.16281	-144.53	33.26122	-23.9902	-173.367	NaN	NaN	NaN
504	08/31/2020 AM 10:43:19.288	31.60459	21.50237	-145.097	25.81102	21.67585	-146.513	31.64526	15.16233	-144.53	33.25906	-23.9911	-173.364	33.37941	-19.6559	-173.879
505	08/31/2020 AM 10:43:19.605	31.5997	21.50013	-145.077	25.80924	21.67484	-146.503	31.64347	15.16167	-144.523	33.2704	-23.9972	-173.411	NaN	NaN	NaN
506	08/31/2020 AM 10:43:19.965	31.60241	21.50164	-145.088	25.80782	21.67306	-146.496	31.64444	15.16295	-144.526	33.2643	-23.993	-173.382	33.38223	-19.6574	-173.885
507	08/31/2020 AM 10:43:20.268	31.60393	21.50247	-145.097	25.81154	21.6752	-146.514	31.64614	15.16218	-144.534	33.26583	-23.9939	-173.387	NaN	NaN	NaN
508	08/31/2020 AM 10:43:20.620	31.60028	21.49999	-145.079	25.8067	21.67223	-146.495	31.64469	15.16128	-144.527	33.25587	-23.9884	-173.348	NaN	NaN	NaN
509	08/31/2020 AM 10:43:20.974	31.60086	21.49941	-145.081	25.80274	21.66944	-146.477	31.64285	15.16071	-144.522	33.25443	-23.9891	-173.341	33.38019	-19.6552	-173.874
510	08/31/2020 AM 10:43:21.304	31.59785	21.49754	-145.072	25.80385	21.66904	-146.475	31.64284	15.16014	-144.519	33.2577	-23.9902	-173.353	NaN	NaN	NaN
511	08/31/2020 AM 10:43:21.608	31.60186	21.50296	-145.091	25.80994	21.67452	-146.509	31.65161	15.16455	-144.555	33.25951	-23.9926	-173.363	NaN	NaN	NaN
512	08/31/2020 AM 10:43:21.935	31.60029	21.49998	-145.084	25.8059	21.67123	-146.491	31.63827	15.15799	-144.508	33.25768	-23.9911	-173.356	33.38465	-19.6561	-173.89
513	08/31/2020 AM 10:43:22.267	31.60169	21.5008	-145.088	25.80244	21.6686	-146.475	31.64408	15.161	-144.528	33.27	-23.9994	-173.408	NaN	NaN	NaN

Smoothed File

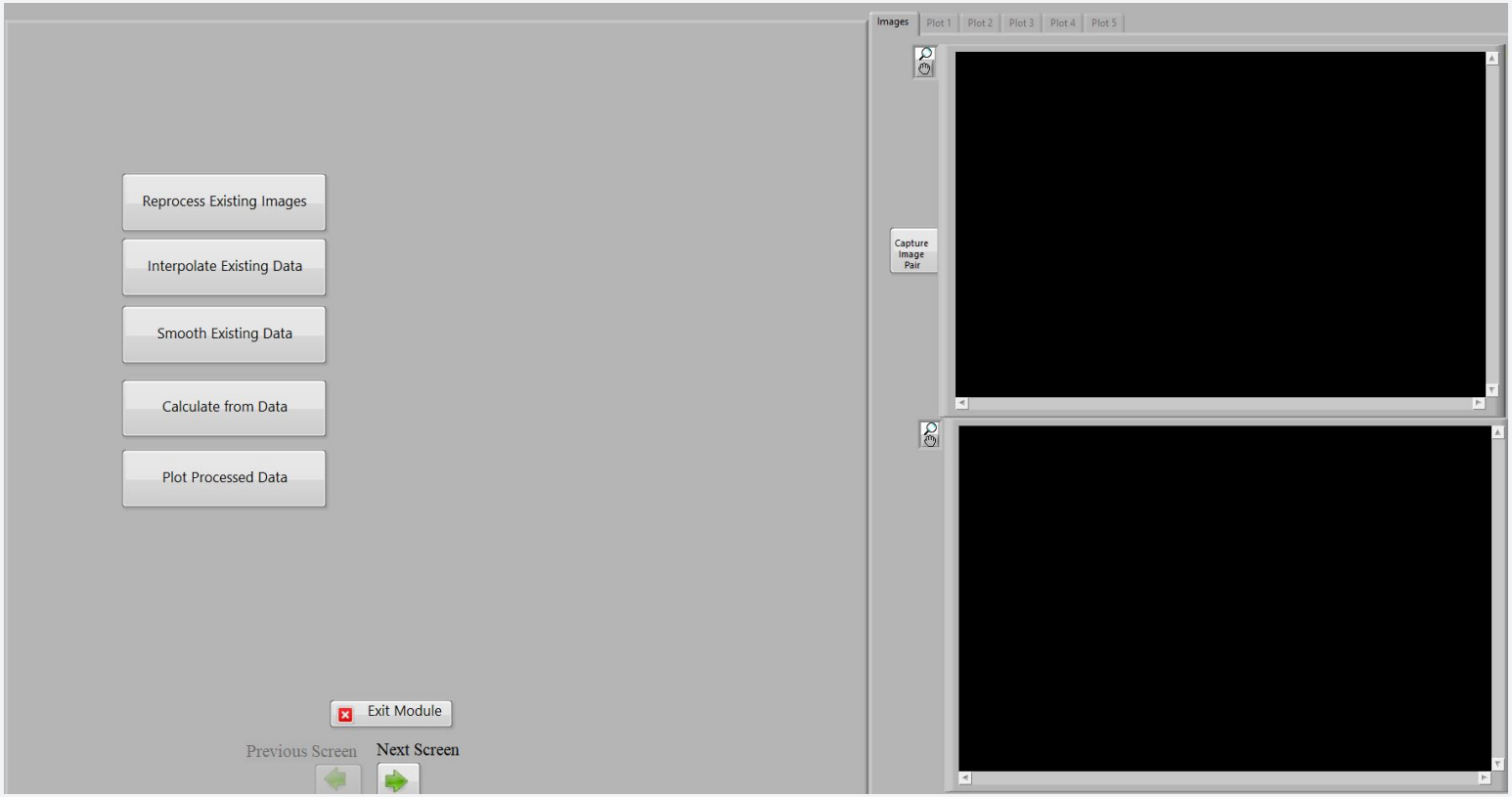
Project Name	Run-1		
Data Analysis Folder Name	1		
Analysis Date	44111		
Project Info			
Gps	29.1839	-99.1979	
Aperture	8		
Lens Focus Distance	Infinity	10-infinity	
Exposure time	15000		
Frame Rate	3		
Coordinate system target numbers			
Origin Target	0		
X axis Target	1		
Y axis Target	2		
Calibration Info			
Calibration Name	Calibration50mmLensesForCulvertTest	Calibration Date	44111
Calibration Unit	Inch		
Calibration Distance Range	35feet	45feet	
Calibration Apeture	8		
Lenses Focus Distance(m)	infinity	infinity	
Calibration exposure time(microsecond)	15000		
Source File Used		XYZ1.csv	
Smoothed	Moving Average/K7		

Frame #	Time	X0	Y0	Z0	X1	Y1	Z1	X2	Y2	Z2	X3	Y3	Z3	X4	Y4	Z4
Ref Avg		31.624117	21.561528	-145.103	25.82849	21.73363	-146.509	31.66488	15.22094	-144.536	33.28034	-23.921	-173.37	NaN	NaN	NaN
503	08/31/2020 AM 10:43:18.940	31.60333	21.50215	-145.094	25.80678	21.67293	-146.496	31.6453	15.16281	-144.53	33.26122	-23.9902	-173.367	NaN	NaN	NaN
504	08/31/2020 AM 10:43:19.288	31.60459	21.50237	-145.097	25.81102	21.67585	-146.513	31.64526	15.16233	-144.53	33.25906	-23.9911	-173.364	33.37941	-19.6559	-173.879
505	08/31/2020 AM 10:43:19.605	31.5997	21.50013	-145.077	25.80924	21.67484	-146.503	31.64347	15.16167	-144.523	33.2704	-23.9972	-173.411	NaN	NaN	NaN
506	08/31/2020 AM 10:43:19.965	31.60241	21.50164	-145.088	25.80782	21.67306	-146.496	31.64444	15.16295	-144.526	33.2643	-23.993	-173.382	33.38223	-19.6574	-173.885
507	08/31/2020 AM 10:43:20.268	31.60393	21.50247	-145.097	25.81154	21.6752	-146.514	31.64614	15.16218	-144.534	33.26583	-23.9939	-173.387	NaN	NaN	NaN
508	08/31/2020 AM 10:43:20.620	31.60028	21.49999	-145.079	25.8067	21.67223	-146.495	31.64469	15.16128	-144.527	33.25587	-23.9884	-173.348	NaN	NaN	NaN
509	08/31/2020 AM 10:43:20.974	31.60086	21.49941	-145.081	25.80274	21.66944	-146.477	31.64285	15.16071	-144.522	33.25443	-23.9891	-173.341	33.38019	-19.6552	-173.874
510	08/31/2020 AM 10:43:21.304	31.59785	21.49754	-145.072	25.80385	21.66904	-146.475	31.64284	15.16014	-144.519	33.2577	-23.9902	-173.353	NaN	NaN	NaN
511	08/31/2020 AM 10:43:21.608	31.60186	21.50296	-145.091	25.80994	21.67452	-146.509	31.65161	15.16455	-144.555	33.25951	-23.9926	-173.363	NaN	NaN	NaN

6. Post-Processing

Reprocess Existing Images
Interpolate Existing Data
Smooth Existing Data
Calculate from Data
Plot Processed Data

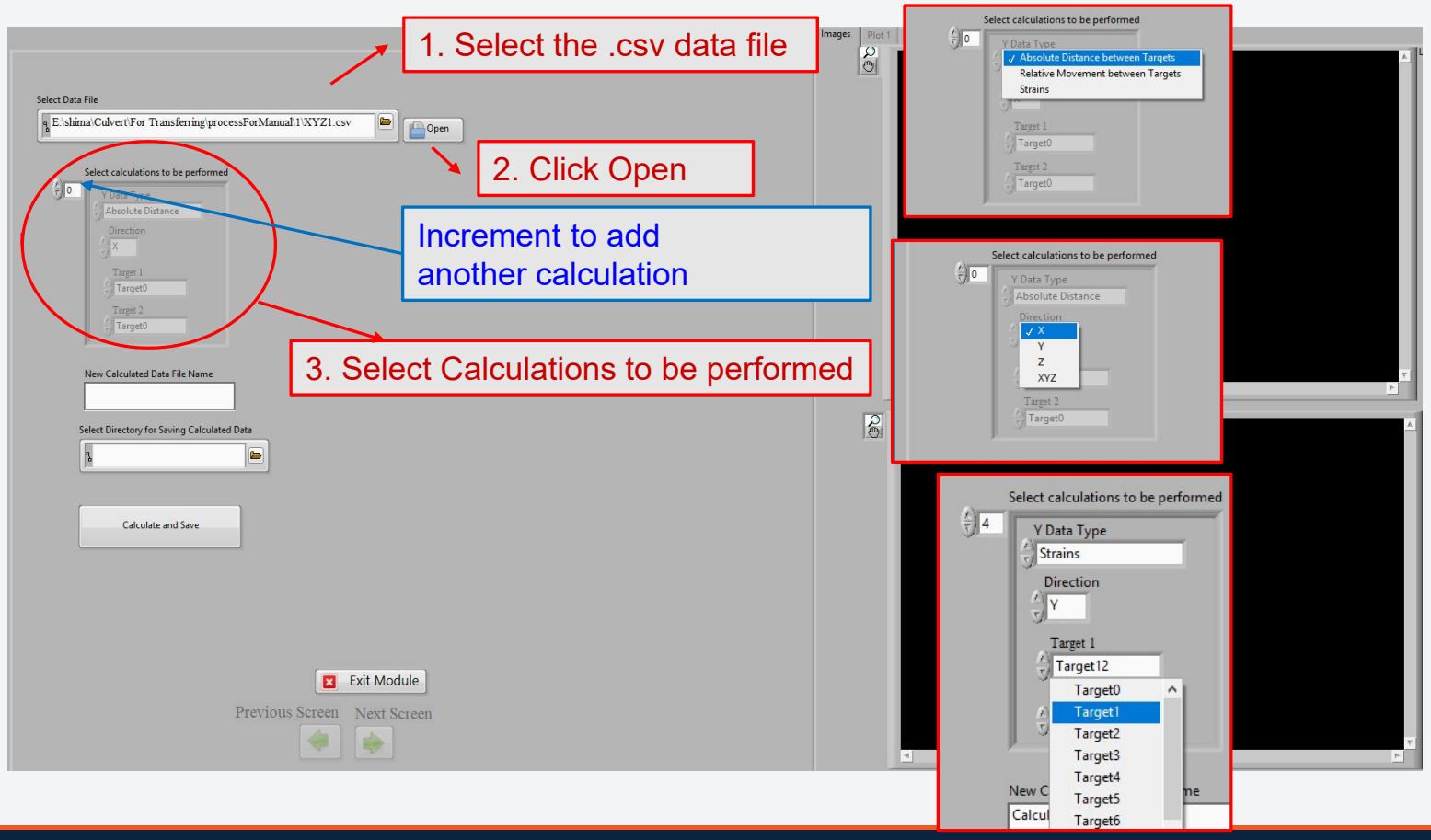
2.Post-Processing options



- Reprocess Existing Images
- Interpolate Existing Data
- Smooth Existing Data
- **Calculate from Data**
- Plot Processed Data

6. Post-Processing: Calculations

Calculate from Data



Calculation Types

- Absolute Distance between Targets
- Relative Movement between Targets
- Strains

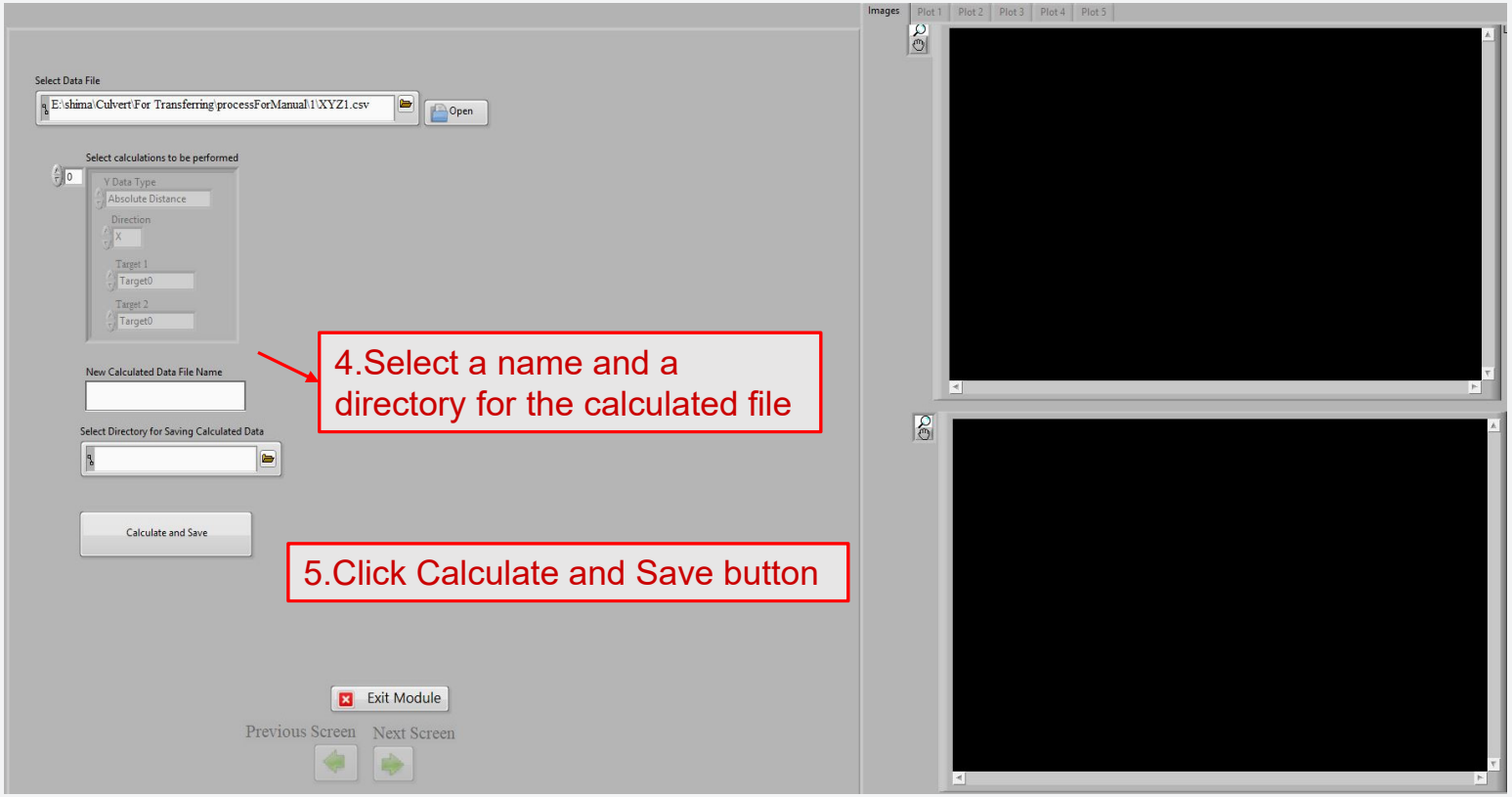
In directions of

- X
- Y
- Z
- XYZ which is $\sqrt{X^2 + Y^2 + Z^2}$

Calculations performed over all frames in the source file loaded

6. Post-Processing: Calculations

Calculate from Data



6. Post-Processing: Calculations

Calculate from Data

Project Name	Run-1		
Data Analysis Folder Name	1		
Analysis Date	10/7/2020		
Project Info			
Gps	29.1839	-99.1979	
Aperture	8		
Lens Focus Distance	Infinity	10-infinity	
Exposure time	15000		
Frame Rate	3		
Coordinate system target numbers			
Origin Target	0		
X axis Target	1		
Y axis Target	2		
Calibration Info			
Calibration Name	Calibration50mmLensesForCulvertTest	Calibration Date	10/7/2020
Calibration Unit	Inch		
Calibration Distance Range	35feet	45feet	
Calibration Apeture	8		
Lenses Focus Distance(m)	Left Came infinity	Right Cam 10-infinity	
Calibration exposure time(microsecond)	15000		

Frame #	Time	Absolute Distance between Targets/X/Target0-Targe	Absolute Distance between Targets/Y/Target2-Targe	Relative Movement between Targets/Y/Target6-Target7	Strains/XYZ/Target8-Target9	Strains/Y/Target12-Target13
503	08/31/2020 AM 10:43:18.940	-5.79046	-39.15887	10.559633		-1.546022
504	08/31/2020 AM 10:43:19.288	-5.79459	-39.15599	10.560103		-1.545897
505	08/31/2020 AM 10:43:19.605	-5.79239	-39.15603	10.561203		-1.546128
506	08/31/2020 AM 10:43:19.965	-5.79358	-39.14967	10.558103		-1.546025
507	08/31/2020 AM 10:43:20.268	-5.79812	-39.14984	10.557003		-1.546069
508	08/31/2020 AM 10:43:20.620	-5.794	-39.15037	10.558833		-1.545974
509	08/31/2020 AM 10:43:20.974	-5.79192	-39.15711	10.558333		-1.546019
510	08/31/2020 AM 10:43:21.304	-5.79439	-39.14908	10.558863		-1.545967
511	08/31/2020 AM 10:43:21.608	-5.79925	-39.1604	10.559053		-1.546033
512	08/31/2020 AM 10:43:21.935	-5.79757	-39.14785	10.557963		-1.54598
513	08/31/2020 AM 10:43:22.267	-5.79858	-39.15702	10.560073		-1.546039
514	08/31/2020 AM 10:43:22.609	-5.79423	-39.15555	10.558493		-1.546049
515	08/31/2020 AM 10:43:22.941	-5.79763	-39.15527	10.563383		-1.545981
516	08/31/2020 AM 10:43:23.275	-5.79742	-39.15669	10.560853		-1.545936
517	08/31/2020 AM 10:43:23.601	-5.79385	-39.1529	10.558003		-1.54593
518	08/31/2020 AM 10:43:23.935	-5.78953	-39.15165	10.558693		-1.546348
519	08/31/2020 AM 10:43:24.269	-5.79436	-39.15048	10.561563		-1.545938
520	08/31/2020 AM 10:43:24.642	-5.79662	-39.15296	10.560133		-1.545932
521	08/31/2020 AM 10:43:24.950	-5.79422	-39.15036	10.559163		-1.545962
522	08/31/2020 AM 10:43:25.281	-5.79335	-39.1531	10.561313		-1.545935
523	08/31/2020 AM 10:43:25.601	-5.79536	-39.15714	10.559053		-1.546048
524	08/31/2020 AM 10:43:25.935	-5.79603	-39.15111	10.558543		-1.545925
525	08/31/2020 AM 10:43:26.268	-5.79485	-39.15203	10.559013		-1.545975
526	08/31/2020 AM 10:43:26.601	-5.79619	-39.15276	10.559823		-1.545983
527	08/31/2020 AM 10:43:26.936	-5.79877	-39.15285	10.560713		-1.546047
528	08/31/2020 AM 10:43:27.268	-5.79334	-39.15388	10.560173		-1.545981
529	08/31/2020 AM 10:43:27.603	-5.79716	-39.14708	10.560793		-1.545956
530	08/31/2020 AM 10:43:27.939	-5.78872	-39.1555	10.560153		-1.545975
531	08/31/2020 AM 10:43:28.289	-5.79809	-39.15528	10.561283		-1.54598
532	08/31/2020 AM 10:43:28.604	-5.79732	-39.15097	10.559503		-1.545916
533	08/31/2020 AM 10:43:28.944	-5.79871	-39.15568	10.558403		-1.545767

Questions

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