

Laboratory 1

Basics: Using VIC-EDU System for Non-contacting Surface Measurements

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I. OVERVIEW

The purpose of this laboratory is to provide the necessary background for using the VIC-EDU system to obtain reliable measurements of surface deformation on specimens. This laboratory will cover the following aspects of using the VIC-EDU system:

- Showing and explaining the components in the VIC-EDU system
- Describing how to physically set up the VIC-EDU system for measurements
- Describing the image acquisition process using the software acquisition component VIC-Snap (EDU) to capture test images
- Demonstrating how to capture calibration images with the VIC-EDU system using the supplied calibration target and VIC-Snap (EDU)
- Showing procedure for using calibration images to complete calibration of the VIC-EDU system
- Preparing the specimen and then applying a high contrast speckle pattern with the appropriate size and spatial variation for accurate stereo image measurements
- Explaining how to set up VIC-3D (EDU) to acquire and store images of the specimen during mechanical loading
- Demonstrating how to analyze images with VIC-3D (EDU) to obtain various types of data including surface displacements and strains
- Demonstrating how to use VIC-3D (EDU) to view the measurement data
- Demonstrating how to use VIC-3D (EDU) to plot measurement data in selected formats.

After learning these aspects of the VIC-EDU system, you will use the system to obtain measurements of a specimen that has been rigidly rotated and displaced. Using these images, you will output the measured displacements and strains and discuss your results.

NOTE Throughout these labs, we refer to the VIC-EDU system in two ways. The hardware (case, cameras, cords, calibration targets) are referred to as "VIC-EDU" and the software (the special version of VIC-3D and VIC-Snap that are designed for this system) as "VIC-3D (EDU)" and "VIC-Snap (EDU)".

II. UNBOXING THE VIC-EDU SYSTEM

The entire VIC-EDU measurement system is shipped to you in a vibration-protected case. Figure 1 shows the interior of the case as it should look when it arrives. It should include:



1. The stereo vision measurement head containing two cameras for stereo imaging, a light to illuminate specimen, and connections required to power the cameras and output data
2. Benro tripod. The stereo-vision measurement system labeled 1 is mounted on the tripod head
3. Power supply and the two required cables for connection of the VIC-EDU system to power and to user-supplied computer
4. USB Drive for installing VIC-3D (EDU) and VIC-Snap (EDU) software
5. Bottle of black ink used with supplied roller to apply the black speckle pattern
6. Roller with 0.026" dot size in a nominally random pattern
7. Ink pad
8. Calibration target. For the fixed focal distance stereo-vision measurement head, a dot spacing of 14mm is ideal for calibration of the system.

Figure 1: Top view of contents in VIC-EDU vibration-protected case

A typical VIC-EDU system (Item 1 in Figure 1) is shown mounted on a Benro tripod (Item 2 in Figure 1) in Figure 2. The included power supply (Item 3 in Figure 1) provides the necessary power for the VIC-EDU stereo cameras. Each camera has imaging resolution of 1920 vertical pixels and 1200 horizontal pixels. Exposure times can be varied between 19 μ s to 1s. The cameras have fixed focal length so that the system has a focused field of view of 200mm vertically and 150mm horizontally.

Manufacturer studies with the VIC-EDU system have shown the following variability in the measurements;

- in-plane displacement is $\pm 2\mu\text{m}$
- out-of-plane displacement is $\pm 4\mu\text{m}$
- in-plane strains are $\pm 50\mu\epsilon$

These values are essentially bounds on the measurements so that values obtained that are well above these limits will be accurate.

The VIC-Snap (EDU) image acquisition software (Item 4 in Figure 1) for the VIC-EDU system allows the user to acquire live images. When acquiring images during an experiment, the software will allow the user to acquire an image as fast as every 2s. For each experiment, the user can capture up to 100 tagged images specifically for analysis within the VIC-3D (EDU) software.

To ensure that you will have a pattern with the appropriate speckle size, the VIC-EDU system contains a bottle of ink, a rubber roller, and an ink pad (Items 5, 6 & 7 in Figure 1). The ink pad can be refilled using the supplied bottle of ink. The roller and ink pad are used to apply a speckle pattern with an average size of 0.125 inches on the specimen surface for accurate pattern matching and thus accurate displacement measurement.

Prior to performing an experiment, the VIC-EDU measurement system is calibrated using the VIC-3D (EDU) software and the included calibration pattern with an appropriate dot size and dot spacing (Item 8 in Figure 1). Based on manufacturer studies, the calibration target has dots with 14mm spacing.

Also included in the box and as a PDF online (link in Reference 1), but not shown in Figure 1, is the **VIC-EDU User's Manual**. The manual will be referred to throughout this laboratory, and the user is encouraged to read the entire manual prior to and when setting up the VIC-EDU system.



Figure 2: VIC-EDU system mounted on a Benro tripod

NOTE

Since existing laboratories already have a variety of computers available, the VIC-EDU system does not include a laptop for interfacing with the VIC-EDU measurement head. Thus, when setting up the VIC-EDU system, you should identify the laboratory computer preferred for use with the VIC-EDU system and have it available.

III. SETTING UP THE VIC-EDU MEASUREMENT SYSTEM HARDWARE

After opening the VIC-EDU measurement system case, the VIC-EDU measurement head (Item 1 in Figure 1) should be carefully removed. As shown in Figure 3, the back of the VIC-EDU measurement head has two ports. The port shown on the right side in Figure 3 is for a USB 3.0 Type A to Type B cable. The Type B end is inserted into the right side plug and the Type A end is inserted into your computer's USB 3.0 port. The left-most port is for the power cable. The VIC-EDU system uses a single power supply (Item 3 in Figure 1) to power the light and system fan.

Since all optical components, including lights, cameras, lenses, and optical filters are pre-installed in the VIC-EDU measurement head, once the measurement head is attached to the tripod and the two cables are routed to the electrical socket and computer from the measurement head, the system is ready for imaging and data acquisition. Please refer to the VIC-EDU User's Manual for details regarding attachment of the measurement head to the Benro tripod.

To obtain focused images of a specimen, the manufacturer's studies for the fixed focal length VIC-EDU system have shown that the distance from the front of the VIC-EDU head to the specimen surface is approximately 0.50m.



Figure 3: Photograph of back panel for VIC-EDU measurement head. Rectangular USB cable is for the cameras. Round cable is the power supply connection

CAUTION Though the VIC-EDU measurement head is sturdy, if the unit is inadvertently dropped or impacted, then it is possible for the internal optical components to be shifted or damaged, requiring the unit to be returned to CSI for replacement or repair. PLEASE handle the unit with care and return the unit to the case whenever it is not in use.

IV. INITIATING THE SOFTWARE FOR IMAGE ACQUISITION

Once the VIC-EDU measurement head has been powered up and connected to the laboratory computer, the VIC-EDU measurement head should be mounted to the Benro tripod and arranged in the laboratory to begin acquiring images. The images do not have to be of the experimental specimen at this point.

Once positioned to view an object that is in focus, you are ready to acquire and store images. To do this, install the VIC-3D (EDU) software on your computer. After installing the software, initiate image acquisition by opening VIC-Snap (EDU) installed on the computer. Since the VIC-EDU system has pre-specified camera types (Point Grey for most systems), you should see two live image feeds from each camera in the system.

There are several imaging considerations to investigate as soon as the live images are visible on your laptop, and these are highlighted in the following sub-sections.

IV.a. Centering specimen in both cameras

To acquire measurement data over the largest region on the specimen, it is important that the same specimen region is viewed by both cameras. One way to do this is to use internal functions within VIC-Snap (EDU) on pages 3 and 4 of the User's Manual, and is described briefly here.

- Identify a specific point and locate its pixel position in both images with the VIC-3D (EDU) cross-hair.
- Move specimen using the ROTATION function in VIC-Snap (EDU) and by manual translation of the specimen, system, or both until the point is approximately centered (pixel (600, 960)) in both images.
- Ensure the region remains in focus in both cameras by visually assessing the sharpness of the images. Use the focus tool in VIC-3D (EDU) to achieve the sharpest focus possible.

IV.b. Optimizing lighting without overexposure or underexposure

To obtain accurate measurements using the VIC-EDU system, the image of a surface of the specimen must not be over-exposed (too bright) or under-exposed (too dark). Appropriate exposure is obtained by controlling both the exposure time and the orientation of the polarizers on the lenses. This is discussed in detail on pages 3-5 of the User's Manual and you should employ these procedures while viewing the live images, varying both exposure time and polarizer orientation to see how the specimen image is modified.

NOTE In addition to maximizing the region over which measurements can be obtained, centering of a common region in both cameras also provides another benefit; reducing the potential for optical distortions to affect the measurements. Additional discussion of this issue is available in a variety of publications, including [2].

V. VIC-EDU SYSTEM CALIBRATION

Now that the VIC-EDU system is operational, it is possible to acquire and store images in system memory. To do so, you will use the supplied calibration target (Item 8 in Figure 1) with the VIC-EDU system and the VIC-3D (EDU) software. Details regarding the calibration process are shown in the VIC-EDU User's Manual on pages 5-8. Briefly, the operational VIC-EDU system is placed in position and the calibration target is placed about 0.50m in front of the VIC-EDU system to view a live image.

After centering, focusing, and optimizing exposure, images such as shown in Fig. 4 are obtained for the calibration target. Once high quality (e.g., high contrast, sharply focused) images are obtained, the calibration process for the VIC-EDU system is initiated. Key points in the calibration process are as follows;

- Rotate target about three perpendicular axes
 - Rotate without defocusing the grid pattern
- Always be sure that the three special dots are present in BOTH images
- Acquire between 30-50 images of the target in different, focused orientations.

After acquiring all calibration images, the calibration process can be completed and the calibration parameters obtained following the process described in the VIC-EDU User's Manual. It is important to emphasize that the "Score" value must be within the recommended range to ensure reliable measurements with the system. If the "Score" is too high, refer to the User's Manual, pgs. 7 and 8, to correct imaging issues prior to repeating the calibration process.

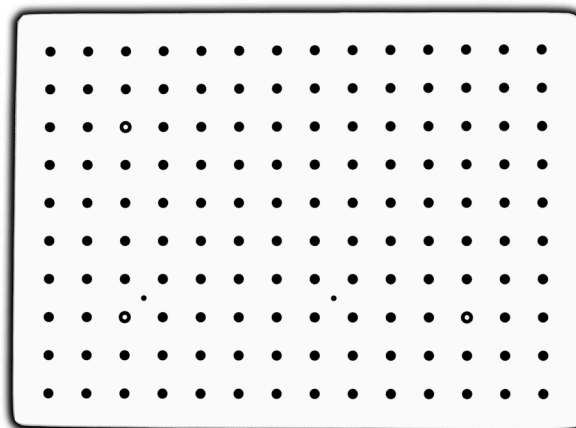


Figure 4: Photograph of a typical calibration target used to calibrate stereo-vision measurement systems such as VIC-EDU

VI. EXPERIMENTAL PREPARATIONS

After successfully calibrating the VIC-EDU system, it is time to prepare the test specimen. The process is described in detail in the Correlated Solutions Inc. application note AN-1701 [3]. The process is briefly summarized here:

- Use coarse and fine grit sandpaper to smooth surface and remove unwanted adherent materials
- Use CSM-2 degreaser or similar cleaning agent to remove any residual oils and metal particles left on the surface by sanding. Repeat this as needed.
- Allow surface to dry and then paint the specimen surface. DO NOT paint specimen in same room where imaging is performed, as it will degrade the optical imaging elements. Typically, surface is initially painted white.
- Use only enough paint to coat surface and minimize reflections; DO NOT OVERPAINT SURFACE.
- After the paint has dried, apply a random dot pattern with size of 0.026" (0.635 mm) using the supplied roller and ink pad. It should require approximately 2-3 passes in order to achieve the 50/50 ratio of white to black that we are aiming for. Remember, do not smear the pattern as this can degrade quality of measurements.
- Use care to apply distinct dots. To improve contrast, you may want to perform multiple passes with the roller. Do not try to align the passes, just apply pattern on top of the previous one, checking the pattern using VIC-3D (EDU) tools.

Please refer to [3] for additional details regarding effective specimen surface preparation.

VII. PERFORMING EXPERIMENT WITH IMAGE ACQUISITION

Once calibration is complete, it is time to acquire images of the as-patterned specimen and store them. To do so, click on *Edit Files* in VIC-3D (EDU) and rename the image prefix to indicate test images are being stored. To begin storing images with this name, you can either (a) do it manually using the Spacebar or the Capture icon in VIC-3D (EDU) or (b) use the *Time Capture* option and set the time between image acquisitions. Refer to the User Manual, page 6, for additional details.

NOTE

It is true that, in principle, a calibrated VIC-EDU measurement system can be moved to a new position without affecting the calibration. Since excessive handling of the system always has the possibility of affecting the internal components, it is recommended that the system be placed in its final position for the experiment and the calibration target placed just in front of the location where the specimen will be located. In this way, calibration can be performed without moving the VIC-EDU system. Once the calibration is complete, the specimen is simply put in place and the experiment performed.

VIII. IMAGE ANALYSIS FOR DEFORMATION MEASUREMENTS

After acquiring experimental images, the VIC-EDU software is used to extract the deformation measurements by performing image analysis using the calibration parameters. The software has incredible flexibility in how to perform the analysis. Many of the capabilities and options are described on pages 9-19 of the VIC-EDU User's Manual. After importing your images using the Speckle Images icon or via the Project file menu, key parameters needed for all analyses are as follows:

- Region of Interest (ROI): The region on the specimen where data is to be obtained is to be selected. See pgs 8-10 in User's Manual.
- Subset size selection: All subsets are square, so a single pixel dimension is requested when making the selection. See pgs 8-10 in User's Manual.

- Step size selection: The pixel distance in each direction between subsets that are analyzed within the ROI. See pgs 8-10 in User's Manual.
- Initial Guess: In most cases, the software does not need an initial guess. However, if the motions are large due to the loading, then the VIC-EDU software may require an initial guess before beginning the analysis. The process for doing this is described on pgs 9-11 in the User's Manual.

With this information, the VIC-3D (EDU) image analysis software can be initiated using the **Start Analysis** icon. This will open a window that gives additional analysis options, as discussed on pgs 10-13 in the User's Manual. Please refer to the discussion provided in the User's Manual to make your selection. Once all analysis options have been selected, the analysis is initiated via the Run button. After analysis has been completed, the measurement data is now available for post-processing.

Post-Processing and Plots

A rather complete discussion of various output variables and how to display the results is given on pages 14-19 in the User's Manual. You should review this in detail prior to initiating detailed processing of the data.

IX. LABORATORY RESULTS TO BE PRESENTED

1. Speckle pattern a planar specimen using the procedure described above. Once patterned, use the VIC-EDU measurement system to acquire focused images of the specimen.
 - Take a photograph showing both the VIC-EDU measurement system and the specimen and show in your report.
 - Take both images of the specimen that are recorded by VIC-EDU and show these in the report.
2. An important parameter in optical imaging is the distance you can move a specimen towards and away from the cameras while continuing to acquire well-focused images. Known as Depth Of Field (DOF), you will experimentally estimate DOF for a planar specimen. See Fig. 5 for description.

- Place specimen at about 0.50m from measurement head
- Orient specimen to be roughly parallel to centerline of measurement head
- Place ruler perpendicular to specimen surface
- Use live imaging
- Move specimen TOWARDS measurement head until you can see slight blurring. Record ruler reading, d_f
- Move specimen AWAY from measurement head until it becomes focused and then slightly blurred. Record ruler reading, d_b
- $DOF = \pm \frac{d_f - d_b}{2}$
- Repeat this process 10 times. Record data in table and include in report.

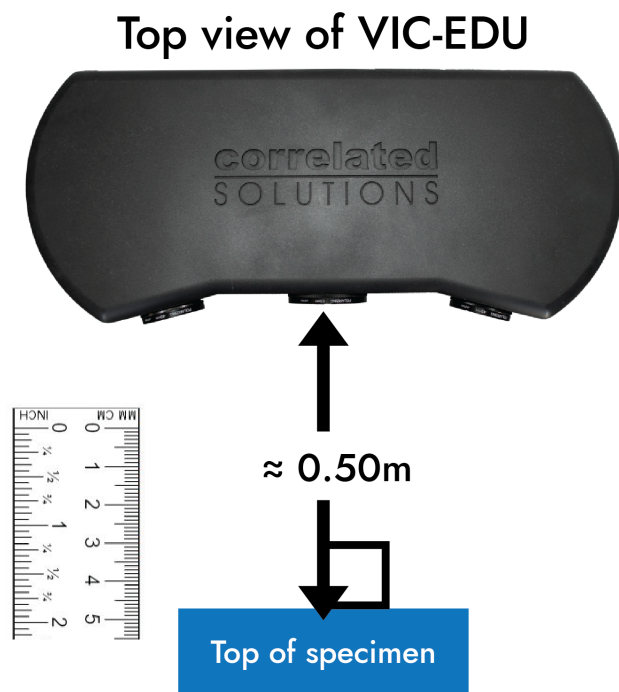


Figure 5: Schematic of experimental setup

- Suppose a specimen of horizontal length, L , is rotated by an angle, θ , about an axis near the center of the front surface, as shown on the right. Determine the maximum angle that the specimen can be rotated so that all points on the front surface are within DOF determined in Question 2.

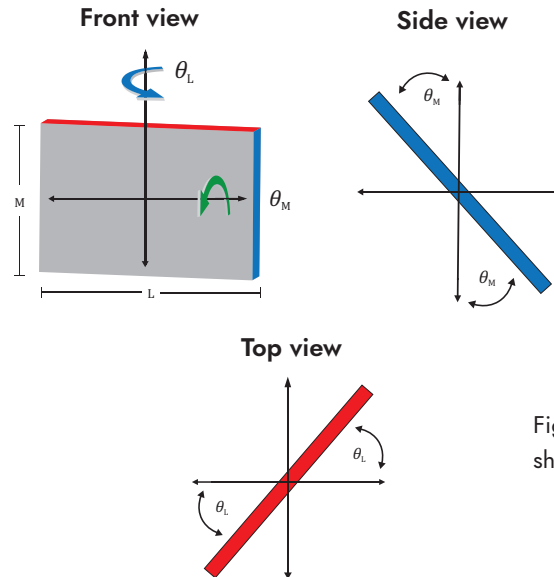


Figure 6: Schematic of specimen showing rotations θ_L and θ_M for step 3

- Determine the maximum angle that the target can rotate for both θ_L and θ_M , where L and M are the actual dimensions of the calibration target provided with the VIC-EDU system. See Fig. 6 to provide additional guidance. You should measure both L and M if these dimensions are not engraved on the target. You may want to consider equations such as the following.

$$\theta_L = \sin^{-1}\left(\frac{2 \text{ DOF}}{L}\right) \quad \theta_M = \sin^{-1}\left(\frac{2 \text{ DOF}}{M}\right)$$

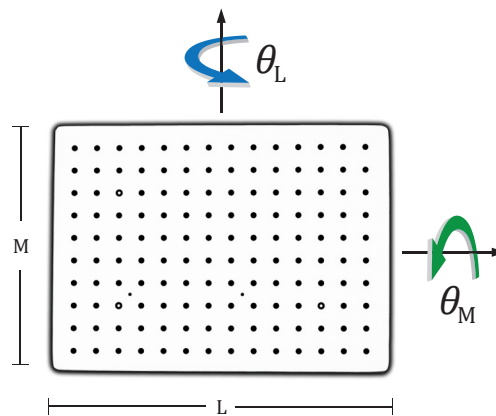


Figure 7: Schematic of calibration grid and rotations

- Use the as-supplied calibration target and perform a complete calibration of the VIC-EDU system. A typical target is shown in Figure 7. Include the following in your report.
 - Number of calibration images
 - One of the calibration target images
 - Calibration reported by the VIC-3D (EDU) software, including two screenshots similar to the following, if not already in the report. The project files on right should contain camera parameters for both camera 1 and camera 2, as well as the transformations. Examples are shown below in Figures 8 & 9 for your use.

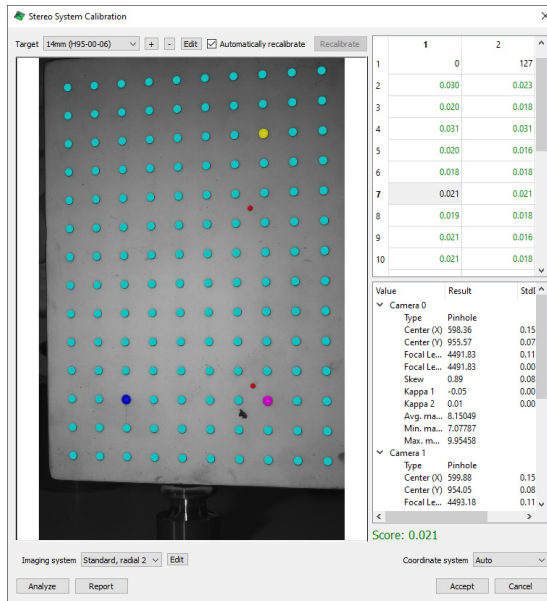


Figure 8: Calibration dialog window

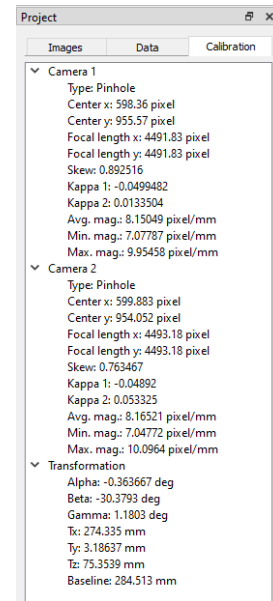


Figure 9: Calibration tab in project workspace

- Using the VIC-EDU system, acquire two pairs of test images of the as-patterned specimen after it has been centered, focused and properly exposed. Both pairs of images should be taken without moving the specimen. Include one pair of test images in the report.
 - The two image pairs are to be analyzed using the VIC-3D (EDU) software to obtain and report data over a 500 x 500 pixel region centered in the image. Fill in the table below to provide a list of all options/parameters used in the analysis
 - ROI: ~500 x 500 pixels; Subset size; Step size
 - Found in Start Analysis dialog: Subset Weights; Interpolation method; Correlation criterion
 - Found in Start Analysis dialog: Consistency Threshold; Confidence Margin; Matchability Threshold
 - Found in Start Analysis dialog: Auto Plane Fit was enabled; Confidence Margins computed or not; Strain filter size and type of strain calculated.

The data you are to report are as follows:

- 2D full-field plot of the SHAPE of the surface ($z(x, y)$) for the ROI after enabling the Auto Plane Fit option, where x and y are nominally horizontal and vertical lines, respectively, on the specimen and z is orthogonal to both x and y lines
- 2D full-field plot of the out-of-plane displacement field, $W(x, y)$, for the ROI
- Extraction plot for the Lagrangian strain e_{xx} with a filter size of 15 for a horizontal line passing through the center of the ROI
 - Recalculate strain for e_{xx} using a filter size of 5 (refer to pages 14 – 19 in the User's Manual)
 - Show extracted line with both filter results on same extraction plot
- Extraction plot for the Von Mises strain with a filter size of 15 for a vertical line passing through the center of the ROI
- Recalculate strain for e_{xx} using a filter size of 5 (refer to pages 14 – 19 in the User's Manual)
- Show extracted line with both filter results on same extraction plot.

Lab 1 - Stereo DIC Image Analysis Parameters

Region of Interest (ROI) (pixels x pixels)	
Field of View (pixels x pixels)	
Digital magnification (pixels/mm)	
Subset size (pixels)	
Subset spacing (pixels)	
Correlation criteria used	
Subset weighting	
Interpolation method	
Consistency threshold (pixels)	
Confidence margin (pixels)	
Matching threshold (pixels)	
Strain metric type	
Strain filter size (N x N pixels ²)	
Strain filter type	
Auto-plane fit	Yes or No

NOTES

X. REFERENCES

1. VIC-EDU User's Manual, Correlated Solutions Incorporated, www.correlatedsolutions.com
2. MA Sutton, JJ Orteu, and HW Schreier, Image Correlation for Shape Motion and Deformation Measurements; Theory and Applications, Springer (2009) ISBN: 978-0-387-78746-6.
3. Application Note AN-1701: Speckle Pattern Fundamentals, <http://www.correlatedsolutions.com/support/index.php?/Knowledgebase/Article/View/80/1/speckle-pattern-fundamentals>.