EECE 5554 - RSN

Lab 5 Report

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1. Camera Calibration

1.1. Camera Images used for calibration

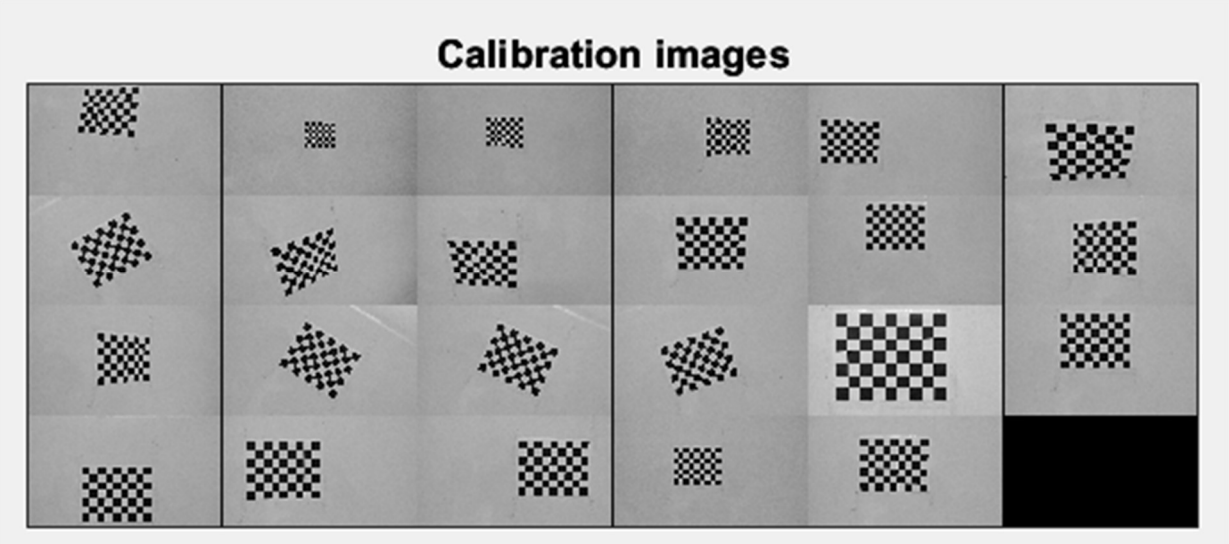


Figure 1: Images used for calibration

The above images are the complete group of images taken from a **OnePlus Nord phone camera**. Images from different sites and orientations were taken off checkerboard pattern paper, which was firmly attached to a whiteboard having each square as 30mm*30mm. Note that all four corners of the checkerboard pattern paper should be captured in the image.

Image Dimentions:4000*2252 pixels

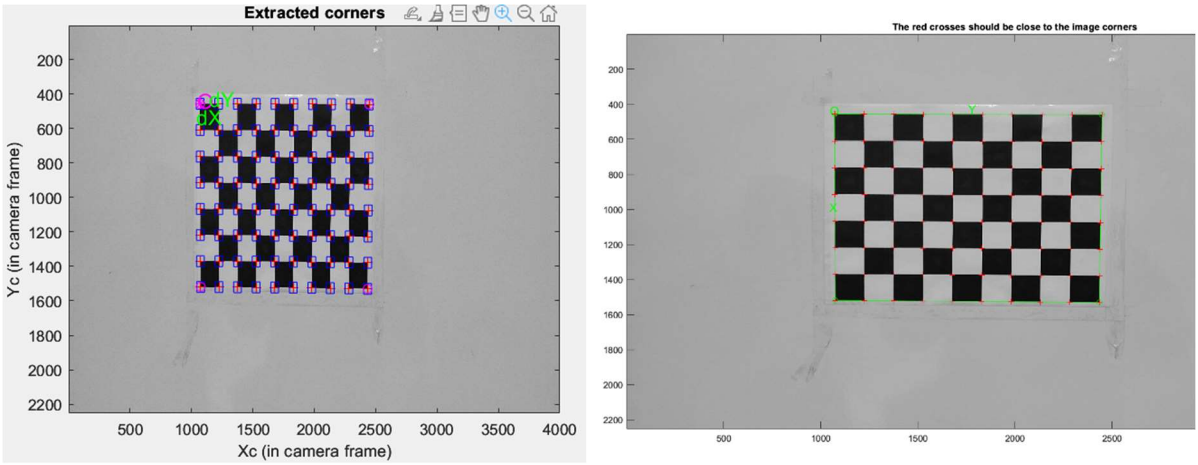


Figure 2: Extracted corners of the sample images

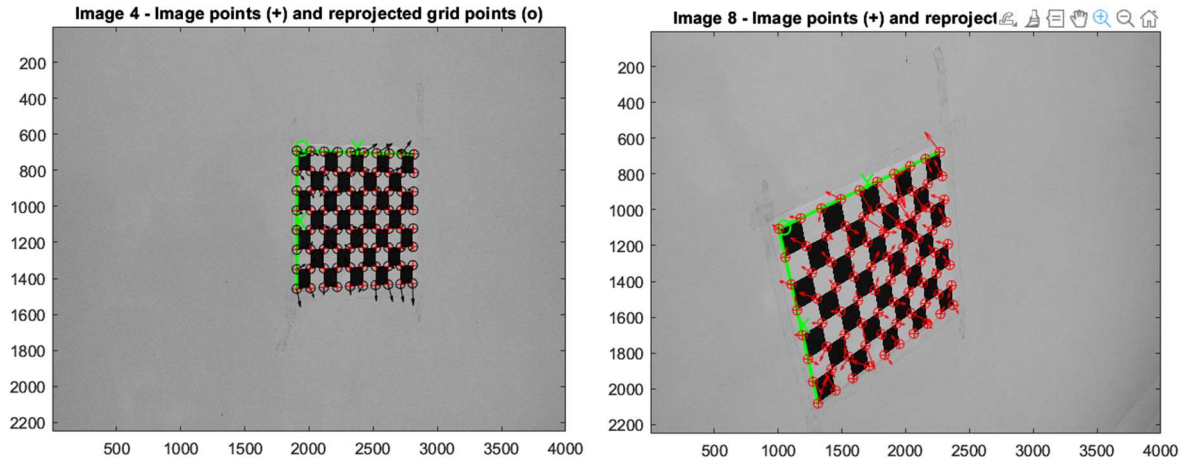


Figure 3: Samples of the reprojection of the grids onto the original images

Follow the steps and click on the four corners of the rectangular checkerboard pattern of all the images after which the MATLAB camera calibration toolbox automatically extracts the grid corners and provides a highlight to the points as shown in the above image.

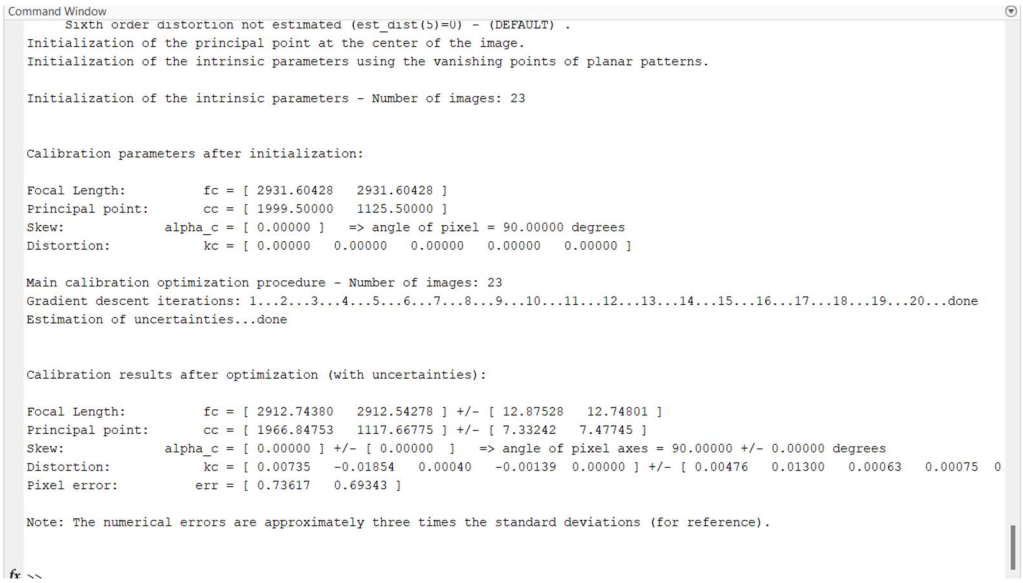


Figure 4: Parameters after the first calibration

The first calibration is done, and the parameters are obtained. It can be observed that there were 20 gradient descent iterations to obtain the minimum calibration parameters

The following results were obtained from the calibration

Principal point: cc = [1966.84753 1117.55775]

Distortion: kc = [0.00735 -0.01854 0.00040 -0.00139 0.00000]

Pixel error: err = [0.73617 0.66343]

1.2. Reprojection Pixel Error

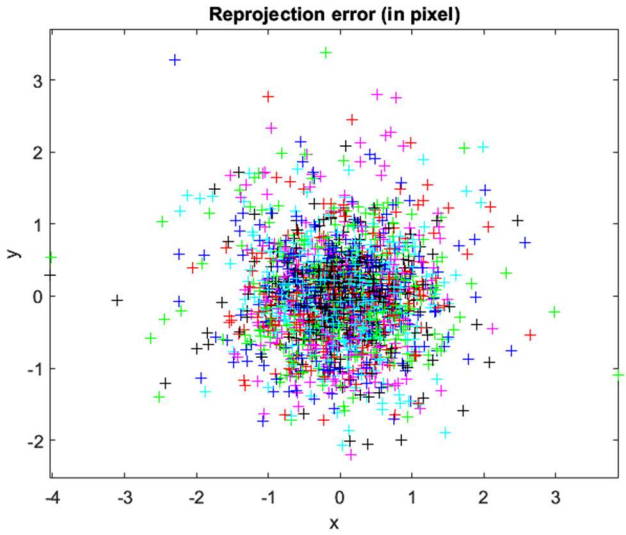


Figure 5: The reprojection error in pixel

The reprojection error graph is represented as a color-coded cross having the most frequent values between +1 and -1 pixels.

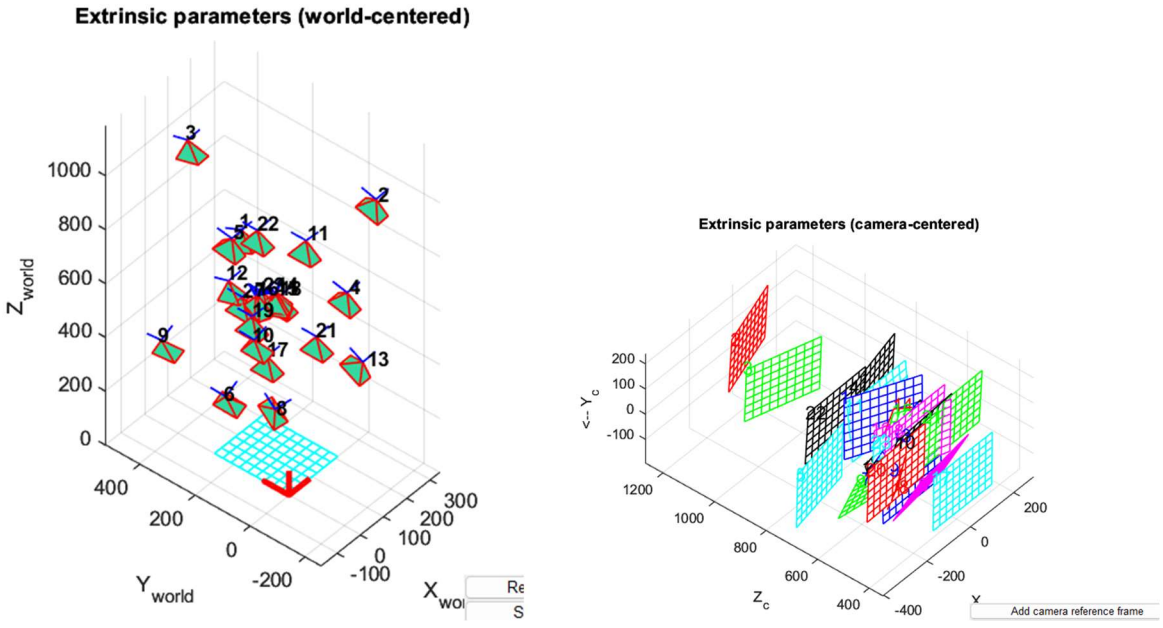


Figure 6: The Extrinsic Parameters from the World-cantered and Camera-cantered views

The extrinsic parameters are represented using the two graphs showing World-cantered and Camera-cantered view shown in the above in Figure 6.

1.3. Calibration Parameters

```
ommand Window
 wintx ([] = 5) =
 winty ([] = 5) =
 Window size = 11x11
 Number(s) of image(s) to process ([] = all images) =
 Use the projection of 3D grid or manual click ([]=auto, other=manual):
 Processing image 1...2...3...4...5...6...7...8...9...10...11...12...13...14...15...16...17...18...19...20...21...22...23...
 done

 Aspect ratio optimized (est_aspect_ratio = 1) -> both components of fc are estimated (DEFAULT).
 Principal point optimized (center_optim=1) - (DEFAULT). To reject principal point, set center_optim=0
 Skew not optimized (est_alpha=0) - (DEFAULT)
 Distortion not fully estimated (defined by the variable est_dist):
      Sixth order distortion not estimated (est_dist(5)=0) - (DEFAULT) .

 Main calibration optimization procedure - Number of images: 23
 Gradient descent iterations: 1...2...3...4...5...6...7...8...9...10...11...12...13...14...15...16...17...18...19...done
 Estimation of uncertainties...done


 Calibration results after optimization (with uncertainties):

 Focal Length:          fc = [ 2914.68790   2913.50519 ] +/- [ 12.26999   12.14254 ]
 Principal point:       cc = [ 1968.07400   1122.85275 ] +/- [ 6.99698   7.13698 ]
 Skew:             alpha_c = [ 0.00000 ] +/- [ 0.00000  ]   => angle of pixel axes = 90.00000 +/- 0.00000 degrees
 Distortion:            kc = [ 0.00900   -0.02413   0.00049   -0.00126  0.00000 ] +/- [ 0.00453   0.01239   0.00060   0.00072  0
 Pixel error:          err = [ 0.69946   0.66205 ]

 Note: The numerical errors are approximately three times the standard deviations (for reference).
```

Figure 7: Parameters after second corner calibration and computation

The **Recalibration** is done using the calibration toolbox. The subsequent image shows the new calibration results. It can be observed that there is only a slight improvement in the error values.

The following results were obtained from the calibration

Principal point: cc = [1968.07400 1122.85275]

Distortion: kc = [0.00900 -0.02413 0.00049 -0.00126 0.00000]

Pixel error: err = [0.69946 0.66205]

1.3. Image Before and After Calibration

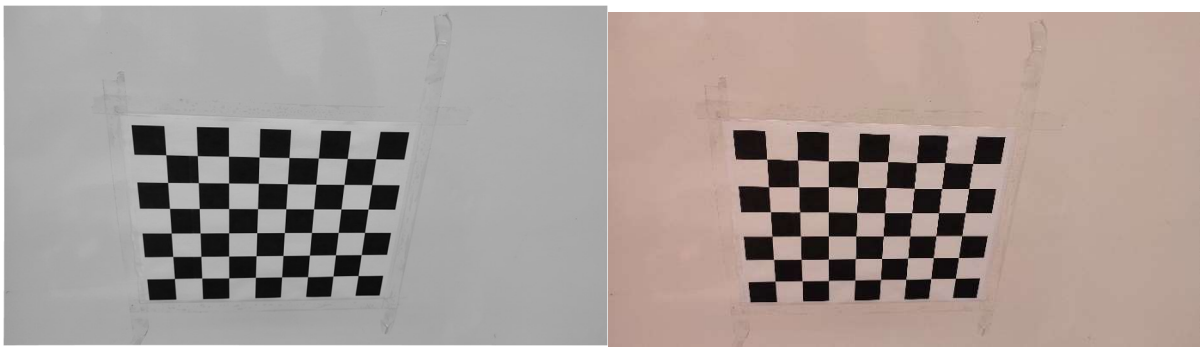


Figure 8: The left image is calibrated, and the right image is the uncalibrated image

On analyzing, the difference between the calibrated and uncalibrated image it is observed that **there is hardly any difference between the calibrated and uncalibrated image**.

On research, I figured out that this might be because the hardware or the phone that was used to collect the **images might have already had a distortion correction inbuilt** within the device as all the latest phones have this advanced feature to improve the quality of the Image.

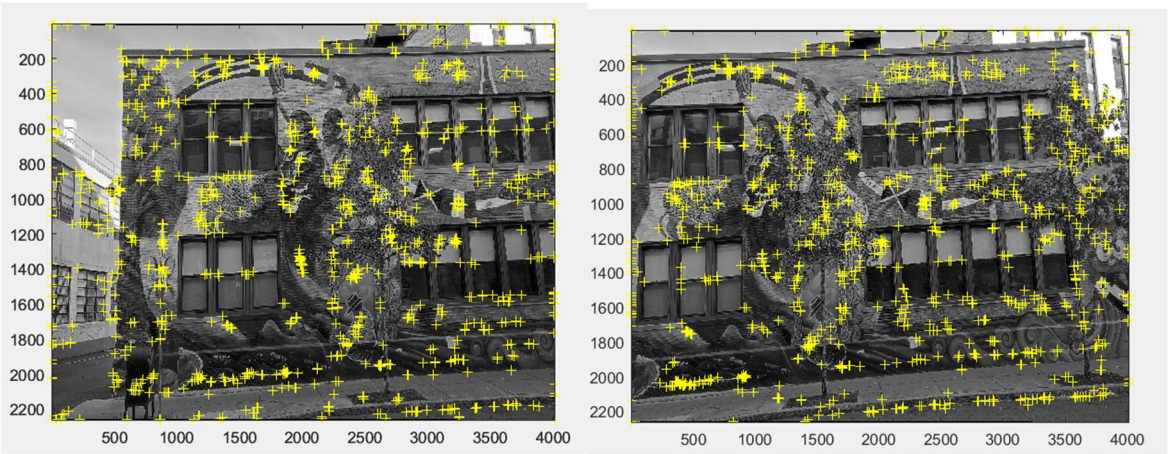
2. Latino Student Centre

2.1. Latino Student Centre Image set

Figure 9: The set of used images for Photo Mosaicking

The above given 6 images were used for the Harris filter photo mosaicking or image stitching. The images are taken from the Latino Student Centre located on Forsyth Street at Northeastern University.

2.2. Distribution of Harris corners on LSC Image set



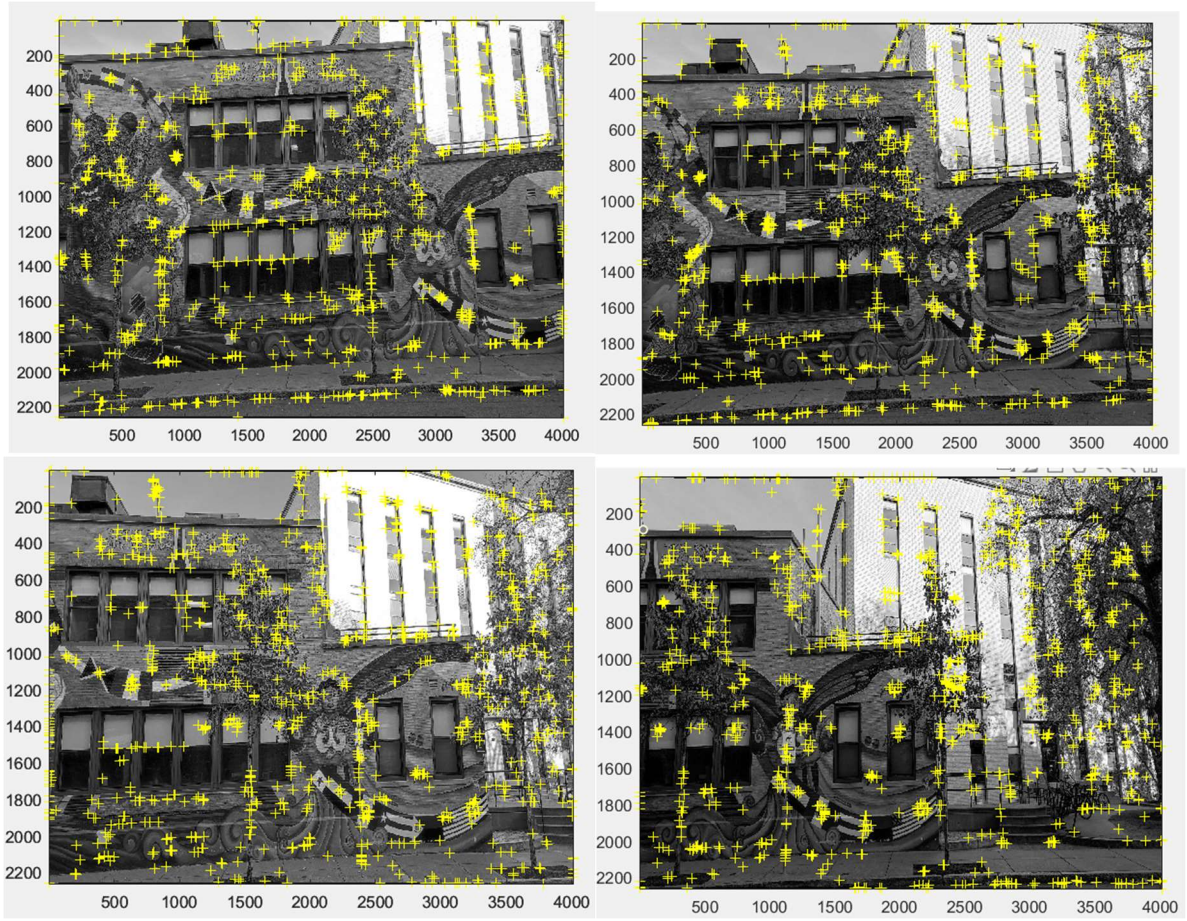


Figure 10: The Harris corner detector result

Harris corner detector is used to obtain the corner detector. The above images show the extracted corners from all 6 images that are used for the photo mosaic.

2.3. Final Latino Student Centre Mosaic

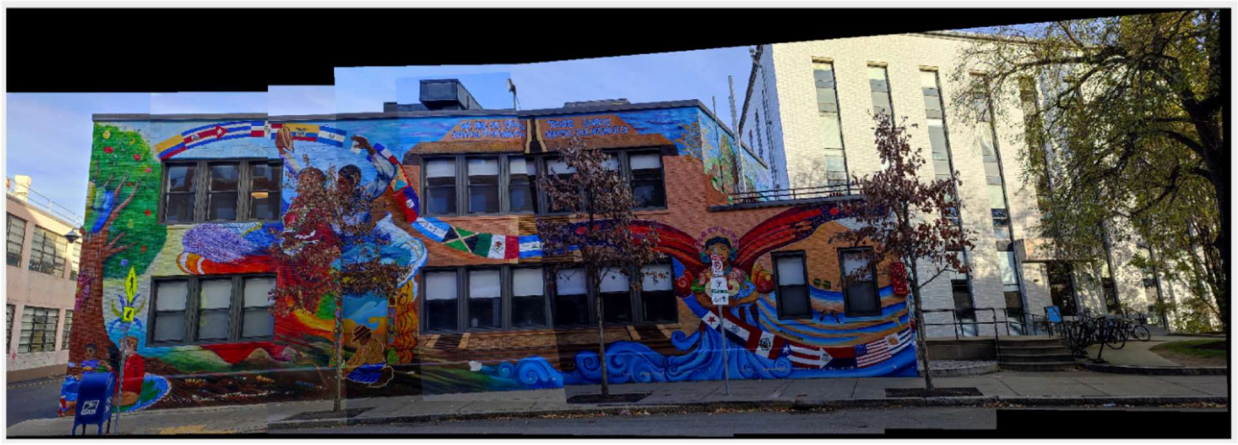


Figure 11: The Panoramic mosaic of the images

The above panoramic mosaic image is obtained by using the Harris filter. It can be observed that the stitching of all the images happens very accurately and there is very less loss of detail or distortion in the image

2.4. Discussion on Adjustment Steps

- The 6 images were taken and converted to greyscale and the camera calibration results with includes **Radial and Tangential distortion parameter**s are used to undistort the images.

- Corners were detected using the Harris corner detector on the undistorted image as shown in Figure 11
- The Harris.m file was changed with the parameters

```
N = 1100;       (number of interest points to return)
hsize = 5;      (size of gaussian smoothing mask)
sigma = 0.5;    (standard deviation of gaussian mask)
tile = [10 10]; (do not process image regionally)
```

With the above parameters, good results were obtained for photo mosaic

3. Brick Wall Mosaic

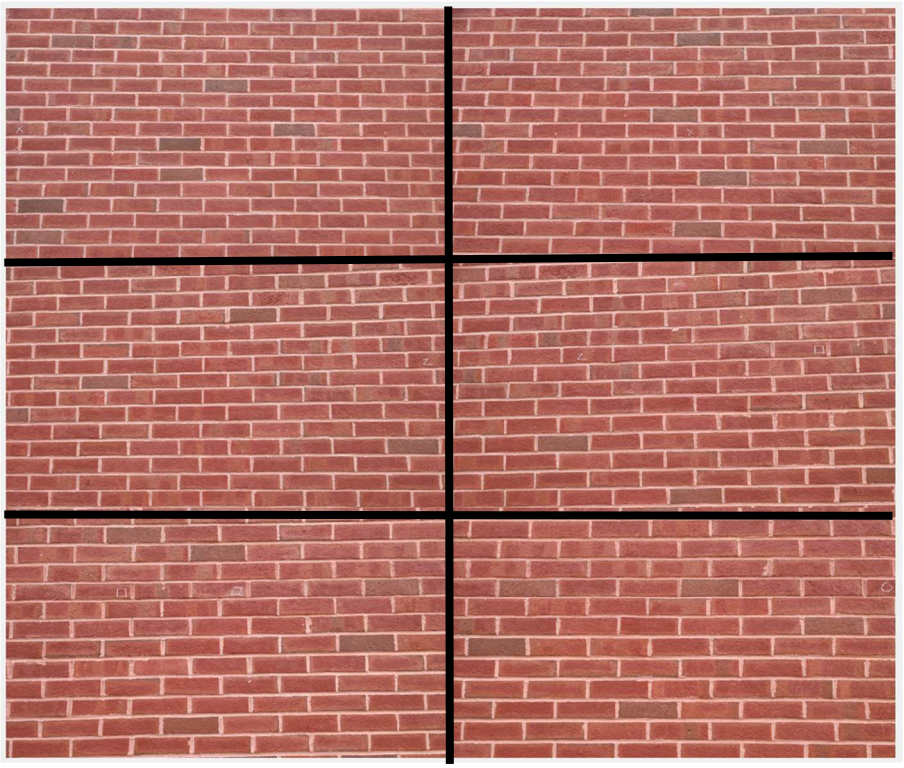
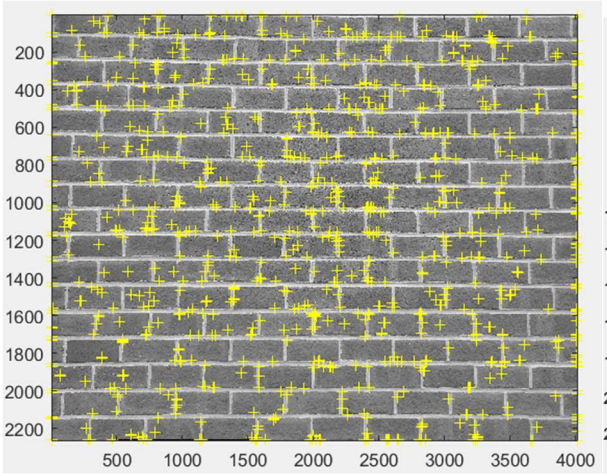
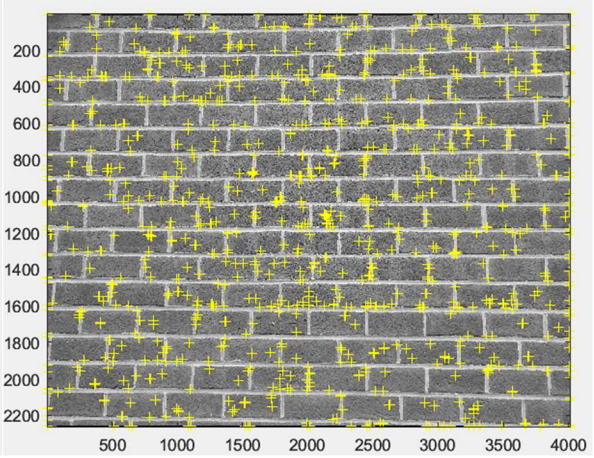


Figure 12: The set of six images of the brick wall

The pictures were taken of the brick wall behind Shillman hall.

3.1. Brick wall Initial Image with Harris Corners





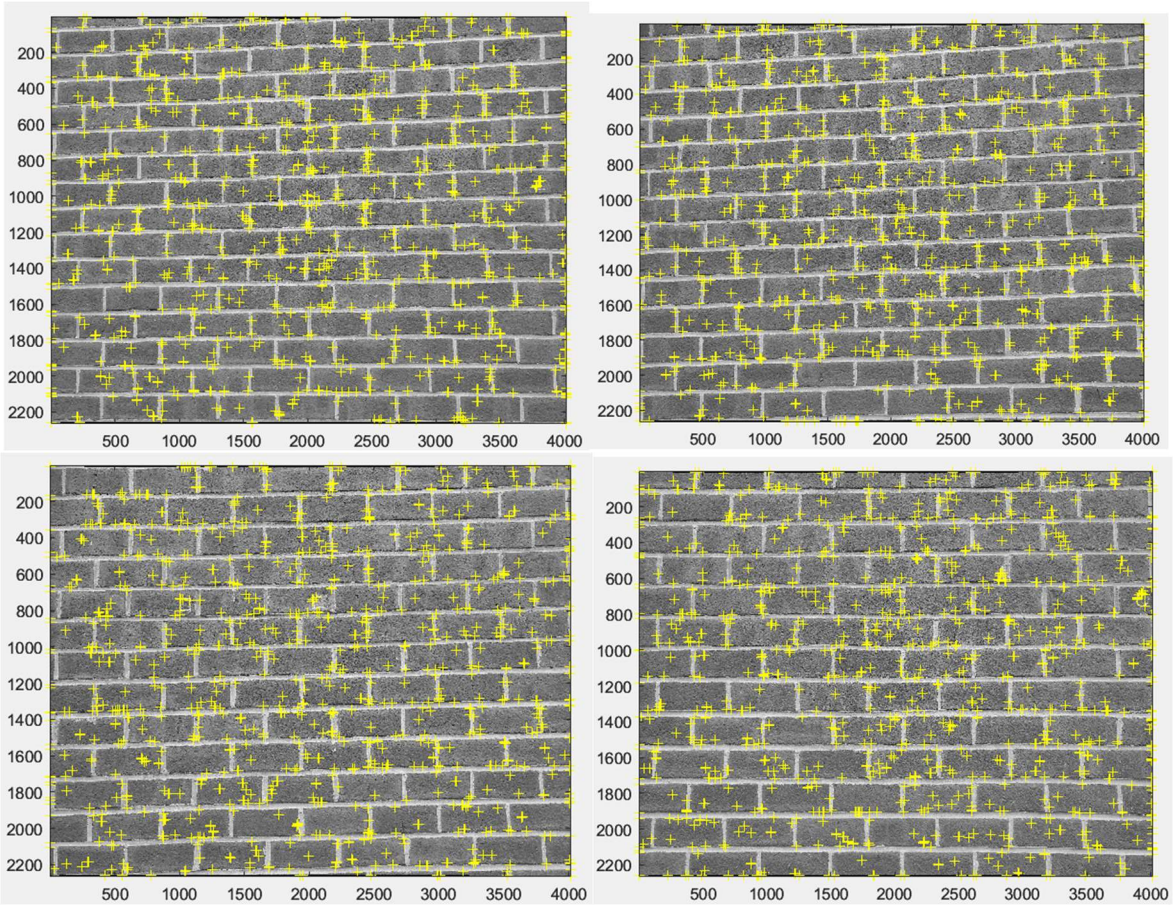


Figure 13: The Harris corners detector result

The above images in Figure 13 show the features detected by the Harris corners detector. These features are grouped and stitching of the images is done.

3.2. Final Brick wall image

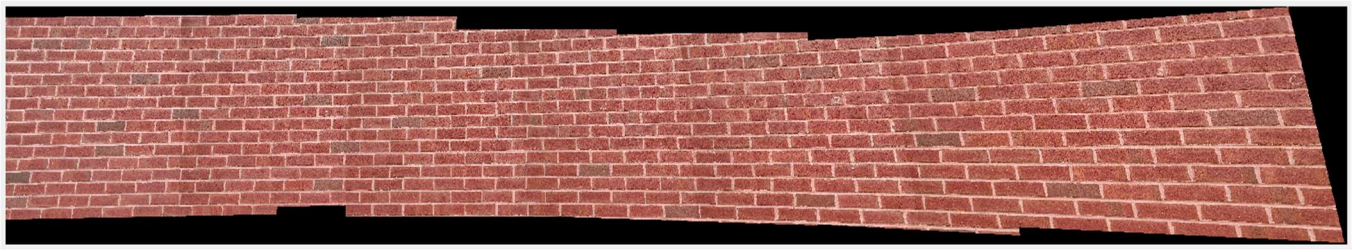


Figure 14: The Panoramic mosaic of the Brick wall images

3.3. Explanation of Brick wall performance comparison

- The 6 images are taken and converted to greyscale and the camera calibration results which include Radial and Tangential distortion parameters are used to undistort the images.
- Corners were detected using the Harris corners detector on the undistorted image as shown in Figure 11
- The Harris.m file was changed with the parameters

```
N = 1100;       (number of interest points to return)
hsize = 5;      (size of gaussian smoothing mask)
sigma = 0.5;    (standard deviation of gaussian mask)
tile = [10 10]; (do not process image regionally)
```

With the above parameters, good results were obtained for photo mosaic

- The photo mosaic of the Latino Student Centre appears to be of good quality as the pictures have a **substantial number of unique features**. Hence the images are being **stitched very accurately**.

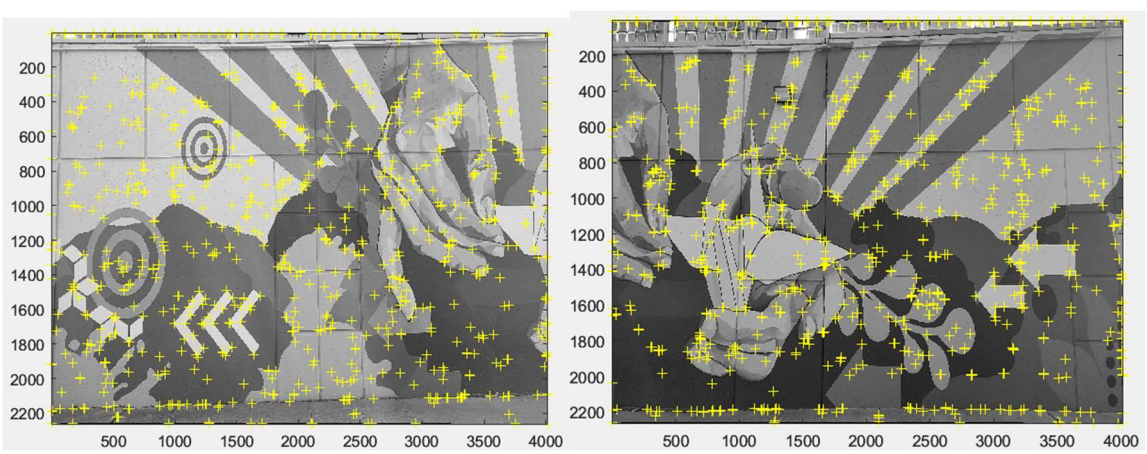
- But the photo mosaic of the brick wall appears to have slight imperfections as the images of the brick wall are very similar and there are very few unique features to match. Hence, **because of the lack of variety of features to match the brick the stitching of the images is not as accurate as the stitching of the images of Latino Student Centre**.

4. Mosaic

4.1. Ruggles mural with 15% overlap

Figure 15: The set of five images of the Ruggles mural with a 15% overlap

The set of 5 images is taken of the mural on the Ruggles T station in Forsyth Street.



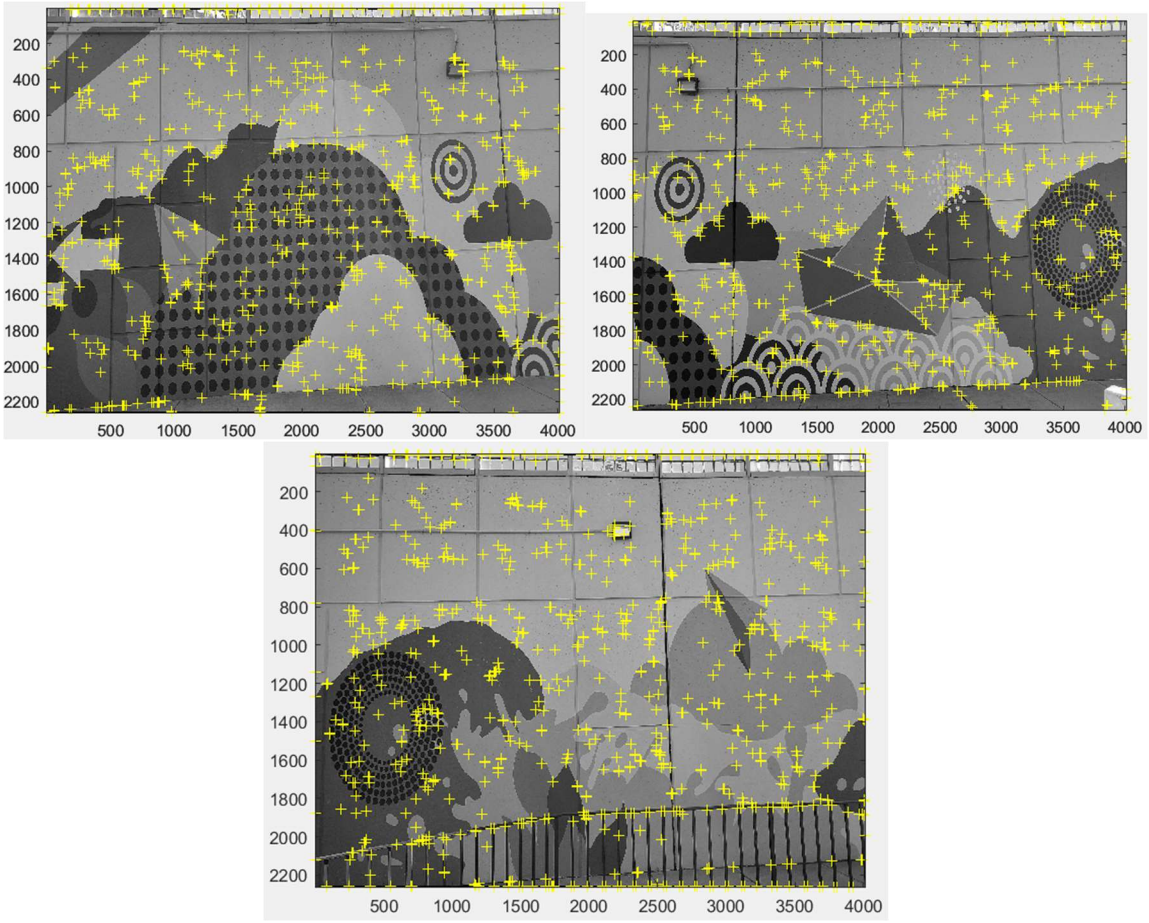


Figure 16: The Harris feature detector result of the Ruggles mural with a 15% overlap

The above pictures show the extracted features of the Ruggles mural

4.2. Ruggles mural with 50% overlap

Figure 17: The set of six images of the Ruggles mural with a 50% overlap

A set of 6 images were taken with 50% overlap from a mural that is outside the Ruggles T station.

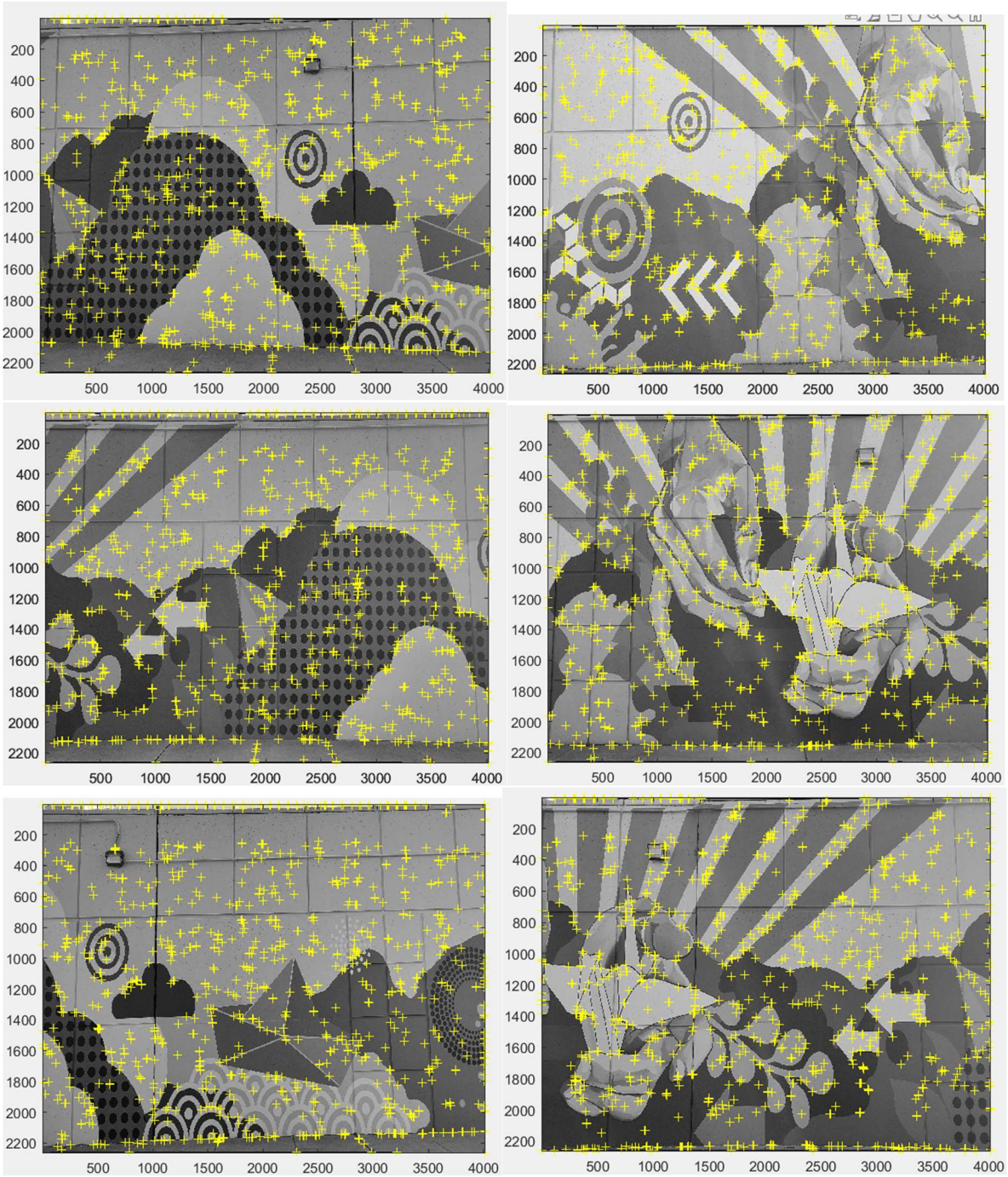


Figure 18: The Harris feature detector result of the Ruggles mural with 50% overlap

The above images in Figure 18 show the features detected by the Harris feature detector. These features are grouped and stitching of the images is done.

4.3. Final Mosaic with 15% overlap

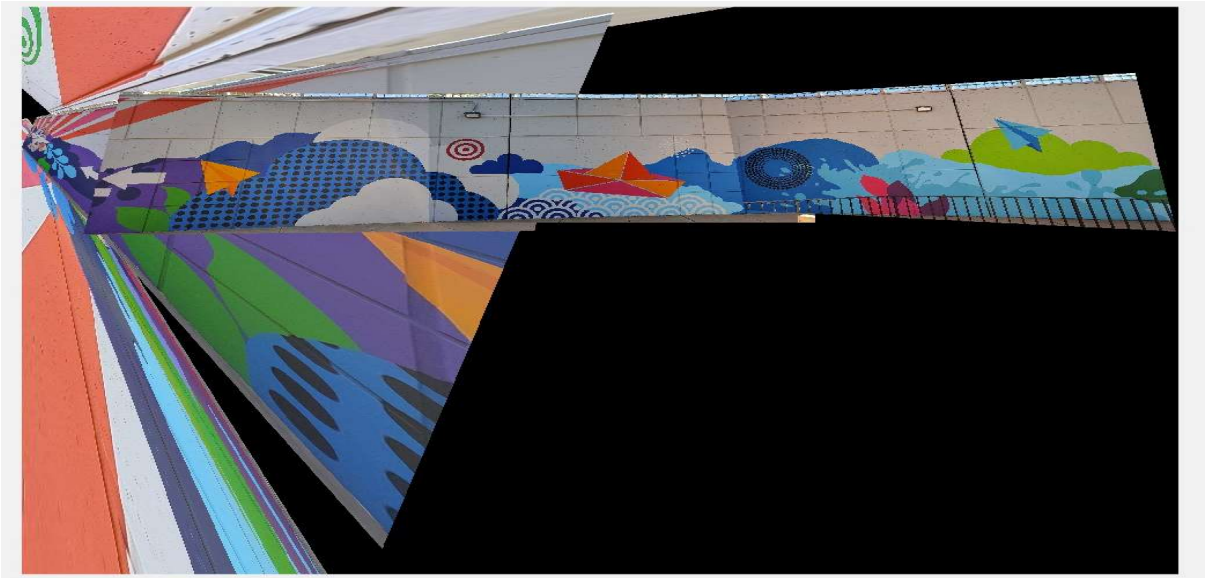


Figure 19: The final panoramic mosaic of Ruggers mural images with a 15% overlap

4.4. Final Mosaic with 50% overlap

Figure 20: The final panoramic mosaic of Ruggles mural images with 50% overlap

4.5. Discussion of performance with 15% and 50% overlap

The photo Mosaic of the mural at Ruggles station with an overlap of 15% is badly stitched. This is because the Harris feature detector only has a limited set features to compare with the next image and complete the stitching operation. Hence, with a low number of features to match the mosaicking is happening inaccurately.

4.6. Description of any adjustments

- The Harris.m file was run with the parameters given below to obtain a 50% overlap image

```
N = 1100;       (number of interest points to return)
hsize = 5;      (size of gaussian smoothing mask)
sigma = 0.5;    (standard deviation of gaussian mask)
tile = [10 10]; (do not process image regionally)
```

With the above parameters, it can be observed that the photo mosaic operation went through accurately.

- But when the same parameters were used over the images that have 15% overlap the mosaicking operation was failing. After adjusting the parameters slightly to the given parameters below better results were obtained. The Obtained mosaicking results are shown in Figure 19.
- The modified parameters in the Harris.m file

```
N = 2100;       (number of interest points to return)
hsize = 5;      (size of gaussian smoothing mask)
sigma = 0.5;    (standard deviation of gaussian mask)
tile = [15 15]; (do not process image regionally)
```

- But the final image is also not the best output because only 3 images are being accurately stitched with good accuracy and the first two image are being stitched in a skewed fashion.