Lab 5: Camera Mosaic

Abstract

In this lab, a calibrated smartphone camera was used to record images of various murals around the campus. A Harris corner detection function was then used on these images and the various murals were stitched together into a panorama by matching these corners using Matlab. The calibration parameters for the camera were computed using the Caltech Camera Calibration toolbox in Matlab.

Methodology

Image stitching of various images into a panorama can be done through two methods:

- Traditional direct method: Figures out where the various images are connected or overlapped using the intensities of individual pixels. This is, however, computationally very expensive and time-consuming.
- Feature matching: Figures out where images are connected or overlapped using different features in the image, such as corners and edges. This method is much faster and more efficient.

Images often suffer from distortion due to the camera lens. This lens distortion can be accounted for by modifying the images with the calibration parameters before usage. The calibration considers intrinsic parameters such as the focal length and extrinsic parameters such as the position and orientation of the camera.

The Harris Corner detection functions by calculating the sum squared differences(SSD) of all the pixels around a central pixel in a user-defined window. A change function is defined as the sum of these SSDs in each direction. This is then maximised and finally, the eigenvalues of the resultant matrix are calculated. If both the eigenvalues are large and similar to each other, then it is a corner. If one of the eigenvalues is much larger than the other, then it is an edge. Finally, if both are small, then it is a flat region.

This lab follows the following steps. Camera calibration parameters for the smartphone camera are first carried out using Caltech Camera Calibration Toolbox as mentioned in its documentation. After this four different image sets are taken from different locations on campus.

- Latinx Student Cultural Center - 6 images
- Shillman Backside (Brick wall) - 6 images
- Ruggles station wall Mural (in front of Shillman) - 6 images with 50% overlap
- Ruggles station wall Mural (in front of Shillman) - 4 images with 15% overlap

After calibration of these images to disregard any distortion caused by the lens, a Harris Corner detection function is used to find features (corners) from the images for matching. By matching these features, a Matlab script stitches these images together to give a panorama of their subjects.

Procedure

1. Camera Calibration

Calibration for the removal of lens distortion is done by using calibration parameters obtained from the Caltech Camera Calibration toolbox. For this toolbox, twenty images are taken from different viewing angles of a checkerboard sheet as shown in Fig.1.1 with a resolution of 1734x2312 pixels.

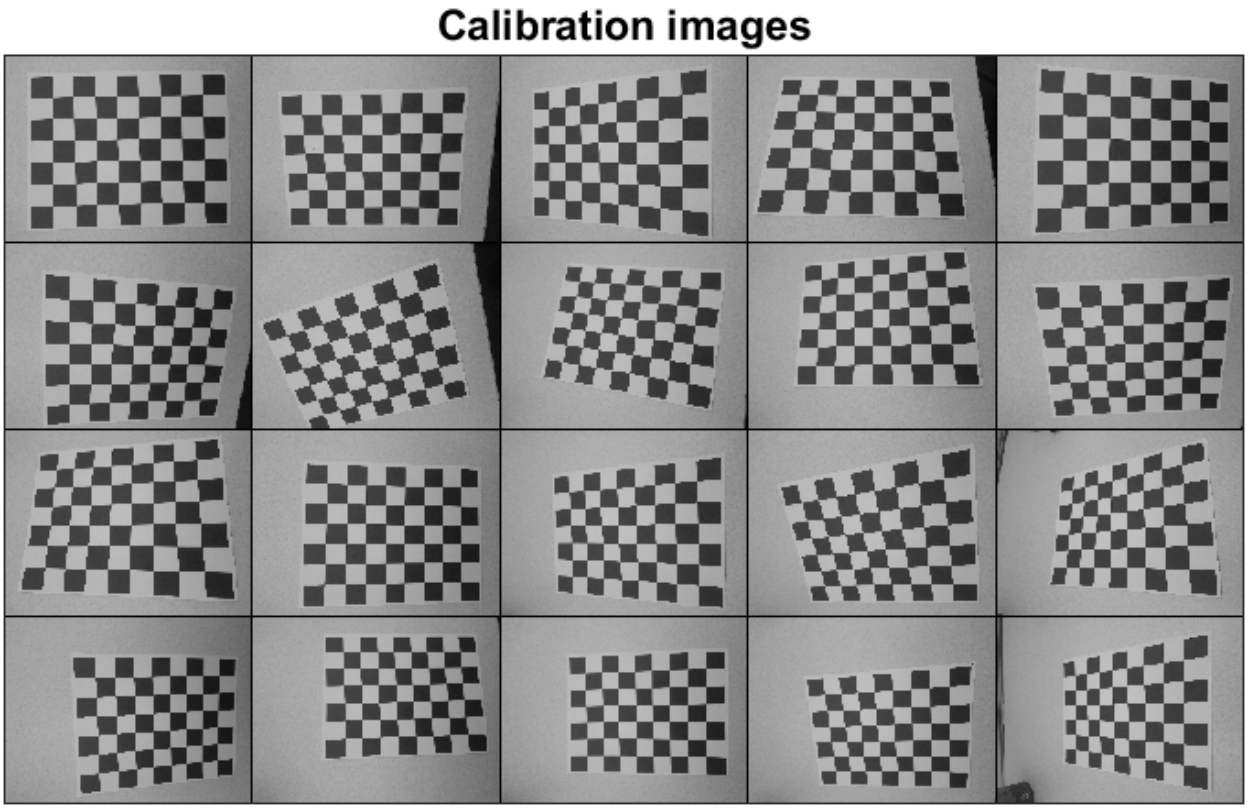

Fig 1.1 Twenty images of the checkerboard sheet for usage in the computation of calibration parameters

The next step is to load these into the workspace using the calib.m GUI. After which, the corner extraction is done by specifying a window for consideration by clicking on the four external corners. The origin (the first corner selected) is the same for all twenty images.
After this step, the calibrate option is selected from the GUI and this returns the parameters as shown in Fig 1.2 below.

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Calibration results after optimization (with uncertainties):

Focal Length:          fc = [ 1692.61543   1693.29174 ] +/- [ 5.87867   5.87783 ]
Principal point:       cc = [ 1164.87319   879.53961 ] +/- [ 3.03028   2.41870 ]
Skew:             alpha_c = [ 0.00000 ] +/- [ 0.00000  ]   => angle of pixel axes = 90.00000 +/- 0.00000 degrees
Distortion:            kc = [ 0.12077   -0.24047   0.00277   0.00040  0.00000 ] +/- [ 0.00586   0.01882   0.00055   0.00070  0.00000 ]
Pixel error:          err = [ 0.50243   0.49917 ]
```

Fig 1.2 Calibration parameters

This returns the pixel errors as 0.50243 and 0.49917 in the x and y directions respectively. This means that for 1734 pixels there can be an average of 0.5-pixel error in the x direction and for 2312 pixels there can be an average of 0.499 pixels of distortion in the y direction. The reprojection pixel errors for each corner are numerically shown in Fig 1.3 below.

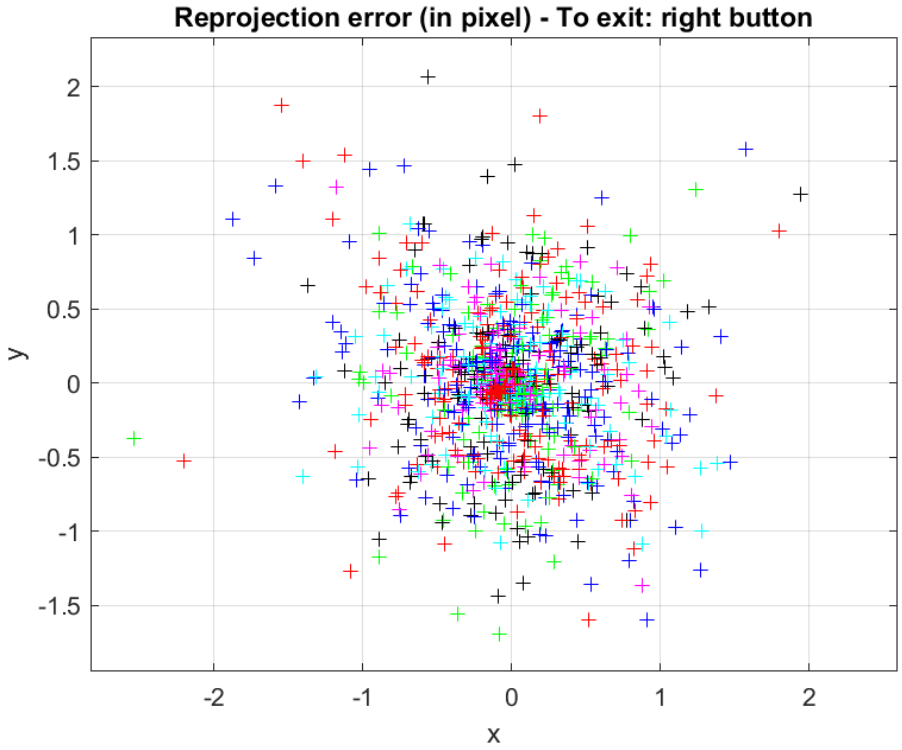


Fig 1.3 Reprojection pixel errors.

The errors are centred around zero and show a gaussian distribution around zero. The final pixel error mentioned above is an average of corners in twenty images.

This can be considered a good calibration parameter error. An image before and after calibration is shown below.

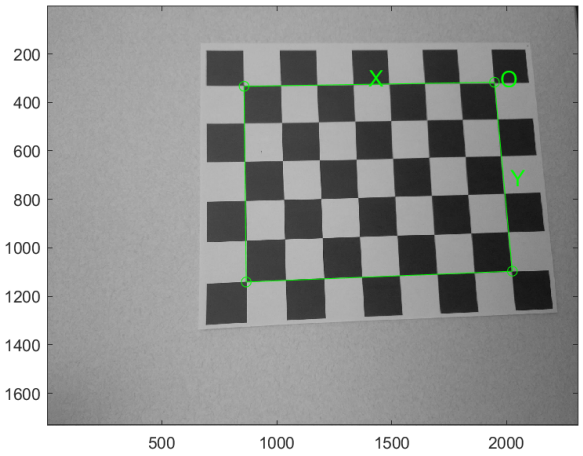


Fig 1.4 An image before calibration

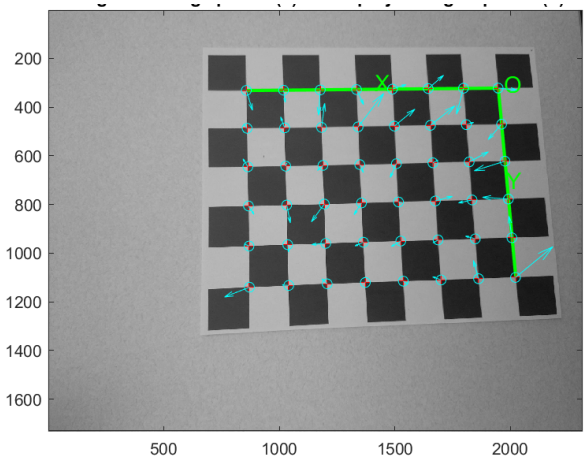


Fig 1.5 Same image after calibration

The extrinsic parameters are plotted in 3D with respect to the camera frame as well as the world frame as seen in Fig 1.6 and 1.7 respectively. The red pyramid in Fig 1.6 represents the camera and the in Fig 1.7, every green pyramid represents the position and orientation of the camera for each image in the world frame.

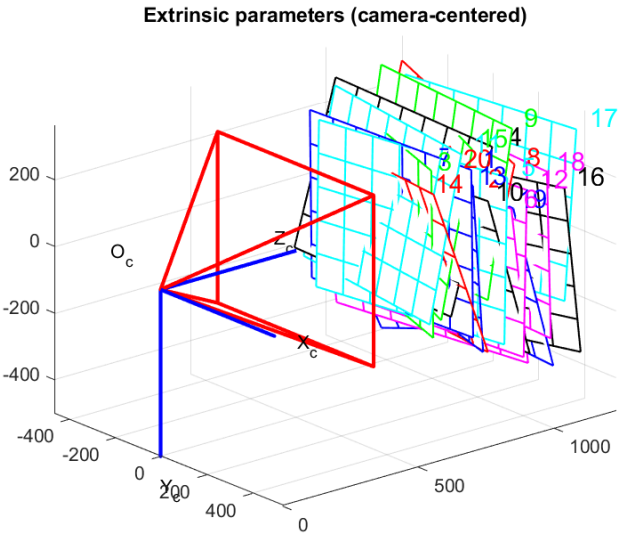


Fig 1.6 Extrinsic parameters(camera centred)

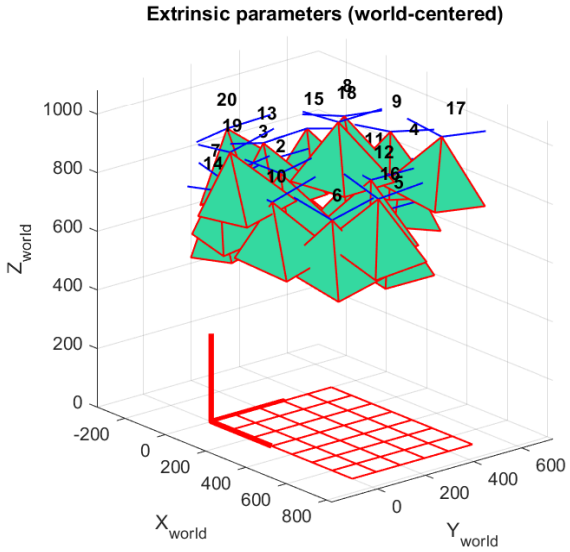


Fig 1.7 Extrinsic parameters(world centred)

2. Latinx Student Center Mural

Six images were taken of the mural in daylight while moving parallel to the wall as shown in Fig 2.1 below. Some observations about the images before processing:

- These images need not be calibrated as the smartphone automatically calibrates them.
- They have a resolution of 1512 x 2016 pixels (they were downsized when exported).
- The final image was taken slightly further than expected.

Fig 2.1 Image set for LSC Mural.

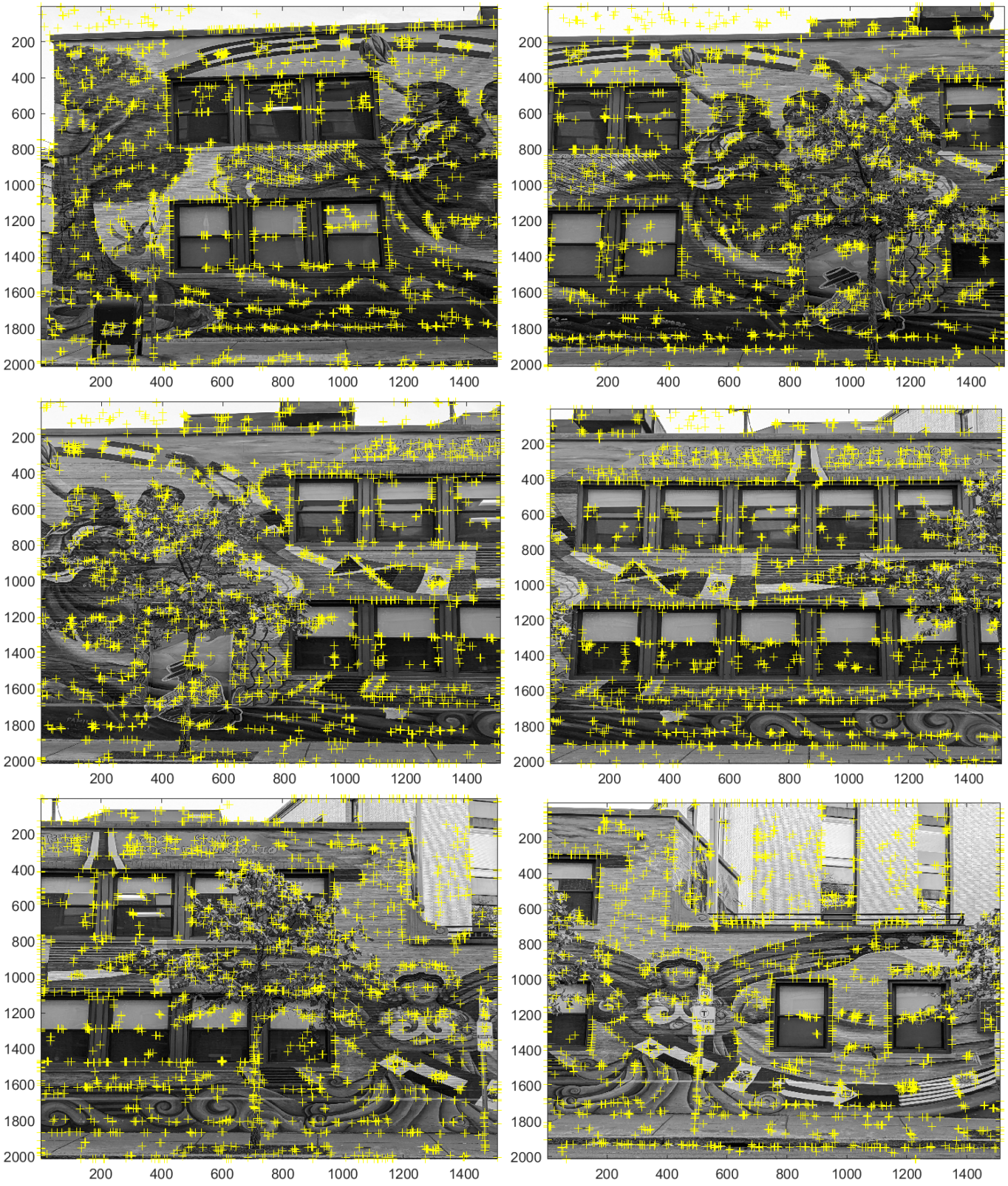


Fig 2.2 Distribution of Harris corners across LSU image set.

The Harris corner detection function was given the arguments of tile size of (15 x 15) and the number of corners as 2000. The maximum number of trials in the 'estimateGeometricTransform' function was set to 12000. The function 'projtform2d' was replaced with 'affine2d' since the photos were not collected in close proximity to the building. The final stitched image comes out as shown in Fig 2.3 below.

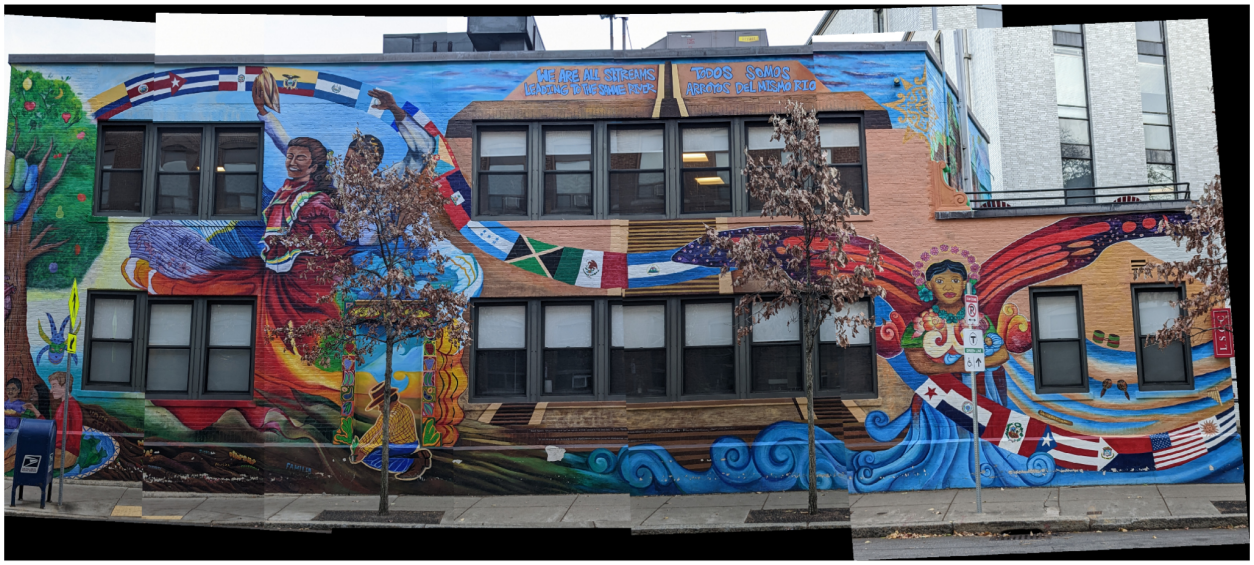


Fig 2.3 Final stitched mosaic of the LSC mural.

Some observations about the final mosaic are:

- The final image in the mosaic seems slightly out of place. This is because of the earlier-mentioned issue in the collection.
- This image set had plenty of distinguishing features and hence, required easier parameters for proper acceptable output.
- The parameters were relaxed from the default values because of the number of features. (The number of corners required was reduced, and the window size was increased)
- Some other adjustments were done in the code for usage with the Harris corner detection function as discussed above the final mosaic.

.m files you used for this mosaic :

- FeatureBasedPanoramicImageStitchingExample.m
- harris.m
- convolve2.m

3. Cinder block/brick wall “mosaic”

Six images were taken of the brick wall behind Shillman Hall in daylight while moving parallel to the wall as shown in Fig 3.1 below. Some observations about the images before processing:

- These images need not be calibrated as the smartphone automatically calibrates them.
- They have a resolution of 1512 x 2016 pixels (they were downsized when exported).

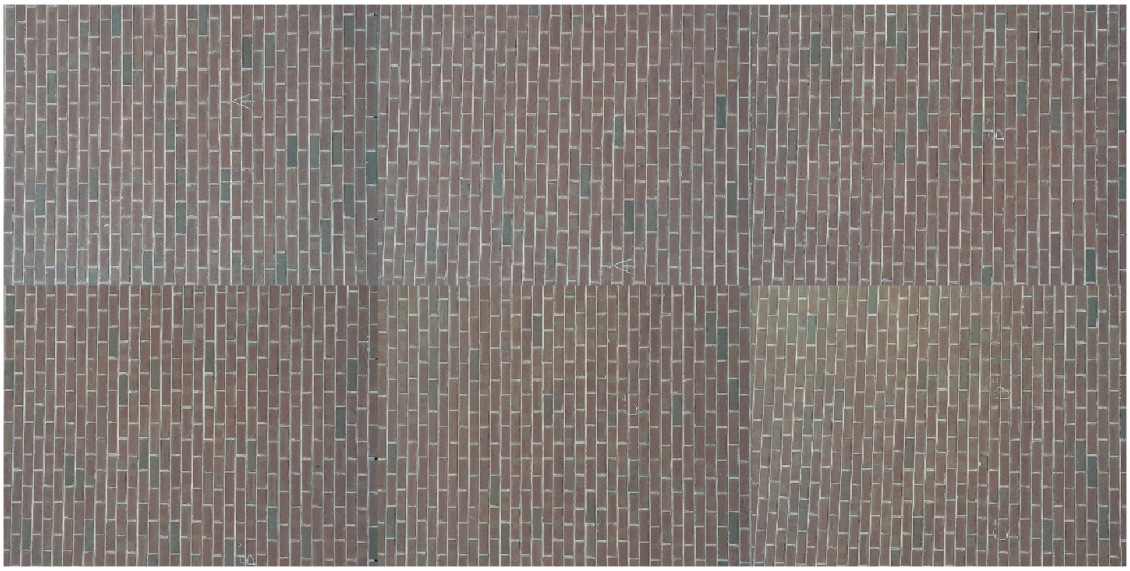
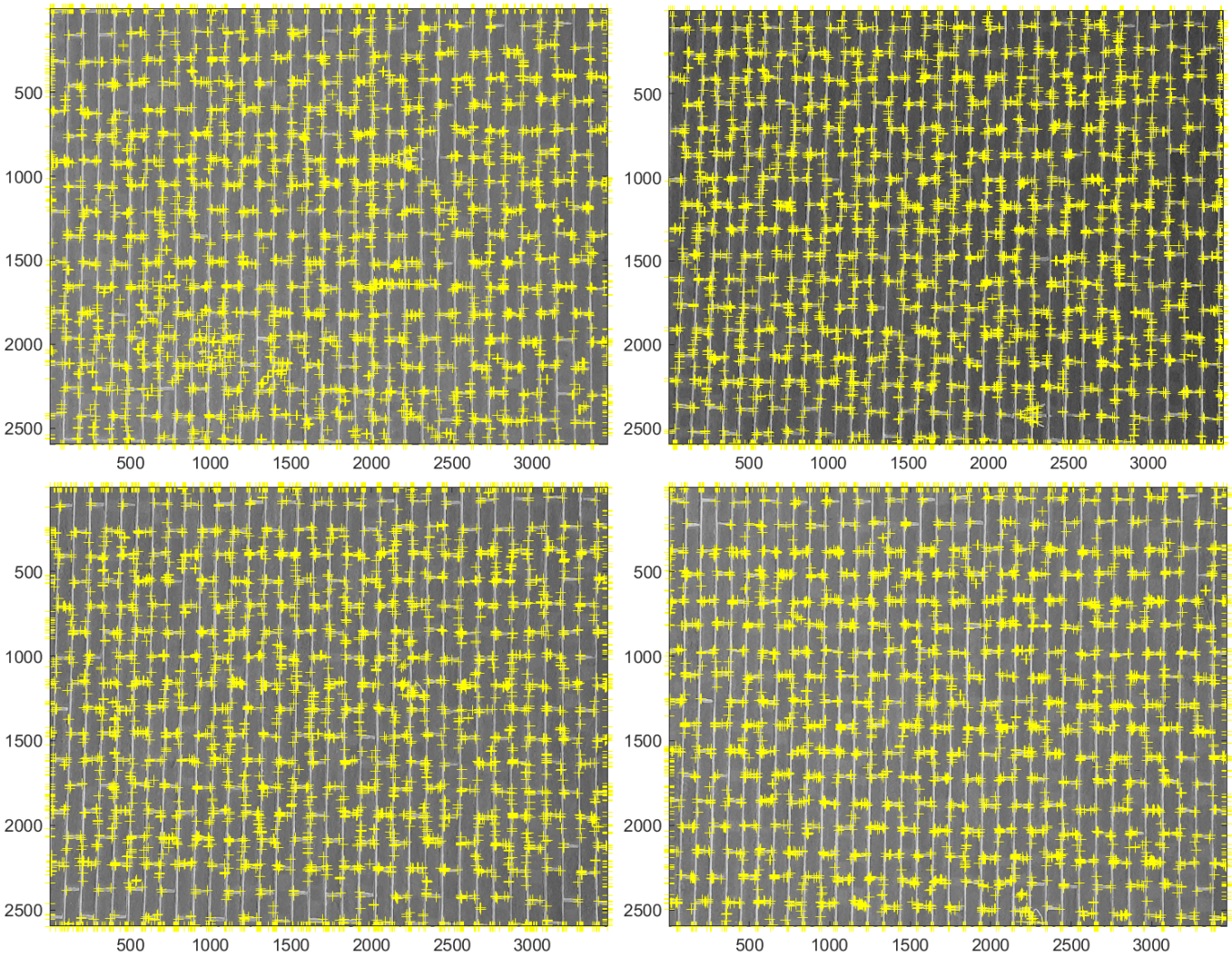


Fig 3.1 Image set for the Brick wall set.



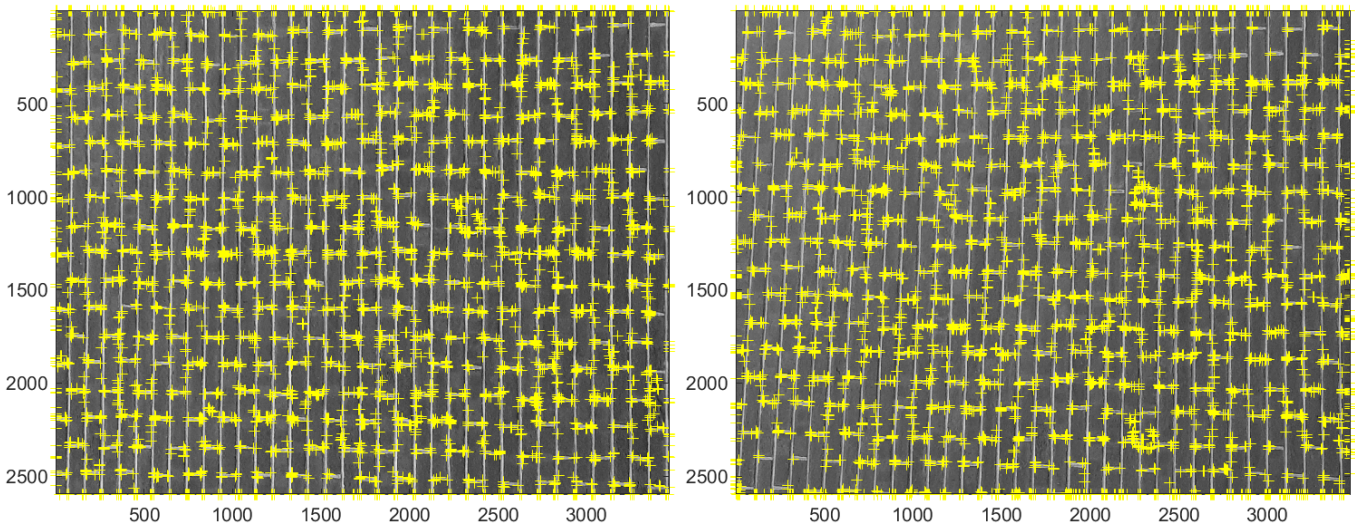


Fig 2.2 Distribution of Harris corners across brick wall image set.

The Harris corner detection function was given the arguments of tile size of (10 x 10) and the number of corners as 4000. The maximum number of trials in the 'estimateGeometricTransform' function was set to 12000. The function 'projtform2d' was replaced with 'affine2d' since the photos were not collected in close proximity to the building. The final stitched image comes out as shown in Fig 3.3 below.

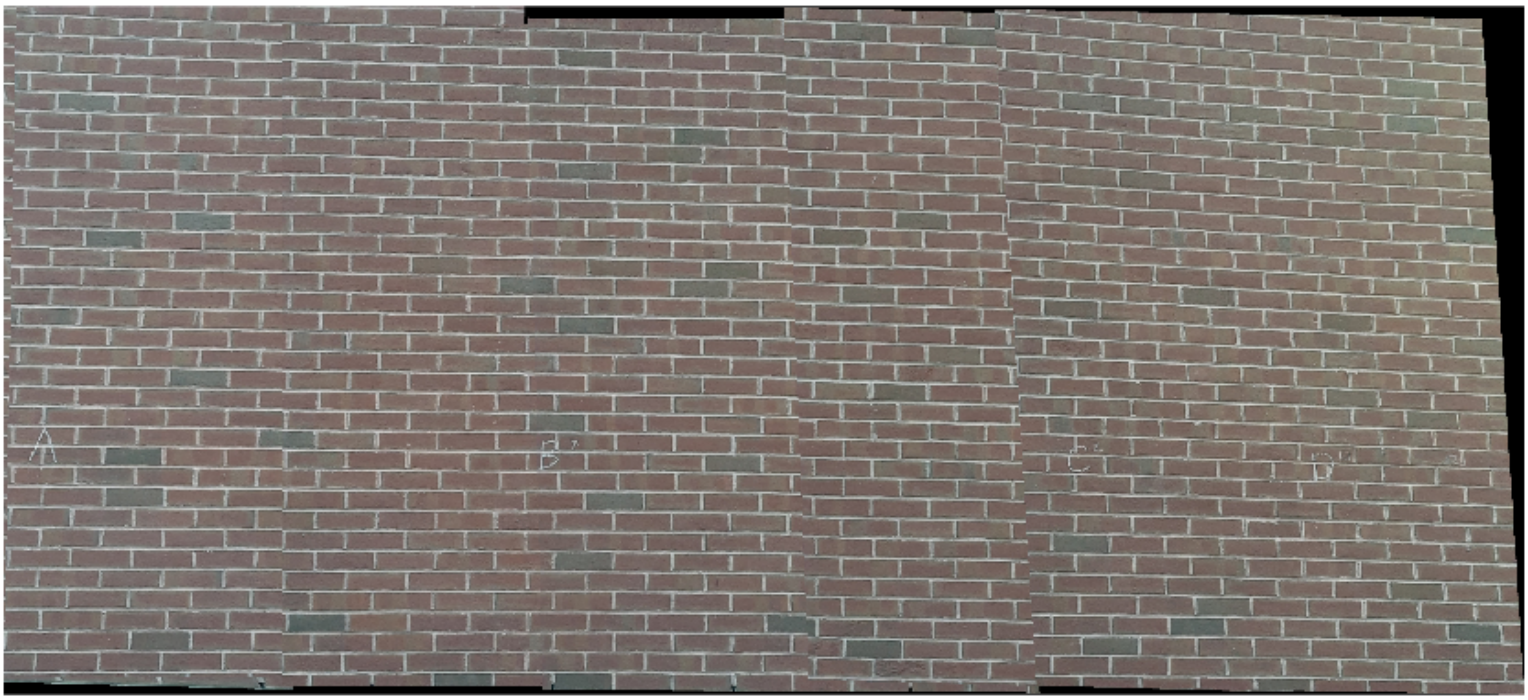


Fig 2.3 Final stitched mosaic of the brick wall.

Some observations about the final mosaic are:

- The final mosaic is not as perfect as the LSC mural mosaic
- This image set had a lack of distinguishing features and had similar features throughout the image sets. This is the reason why the relaxed parameters used for the LSC mural did not work for this image set.
- The parameters were stricter than the values used for the LSC mural because of the fewer unique features. (The number of corners required was increased, and the window size was decreased).

- Some other adjustments were done in the code for usage with the Harris corner detection function as discussed above the final mosaic.

.m files you used for this mosaic :

- FeatureBasedPanoramicImageStitchingExample.m
- Harris.m
- Convolve2.m

4. Third "mosaic" from the Ruggles wall mural

Images were taken of the mural wall of Ruggles of Shillman Hall in daylight while moving parallel to the wall as shown in Fig 4.1 and Fig 4.2 below. Fig 4.1 has six images with 50% overlap and Fig 4.2 has 4 images of the same length with 15% overlap. Some observations about the images before processing:

- These images need not be calibrated as the smartphone automatically calibrates them.
- They have a resolution of 1512 x 2016 pixels (they were downsized when exported).

Fig 4.1 Image set for 50% overlap.

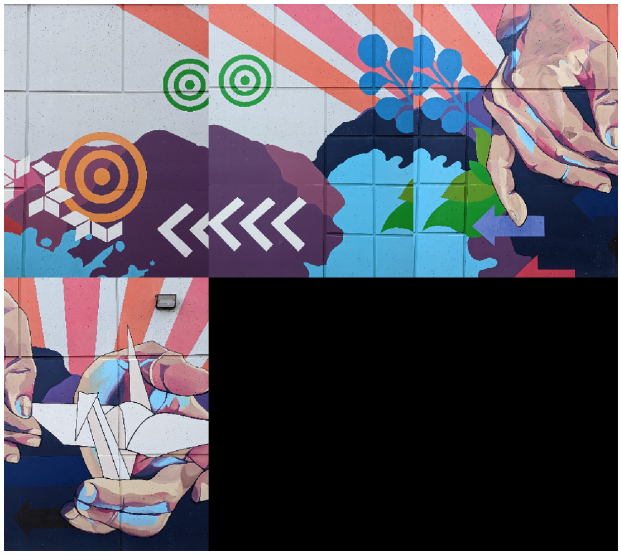
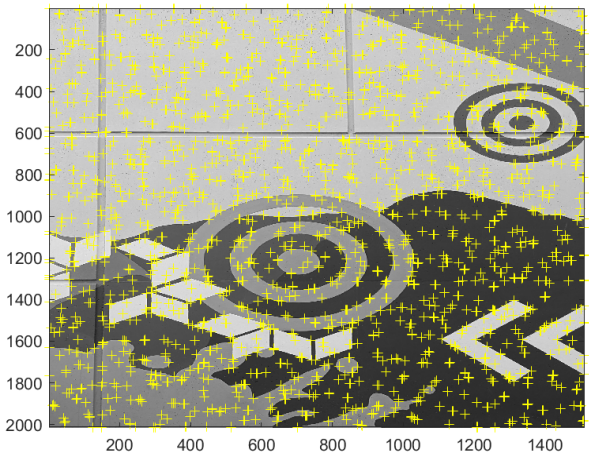
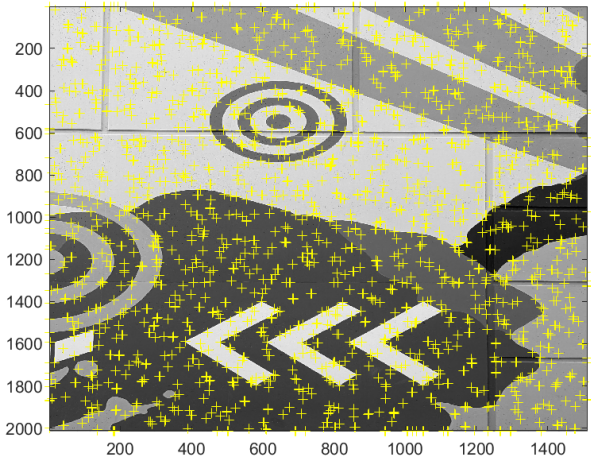


Fig 4.2 Image set for 15% overlap.





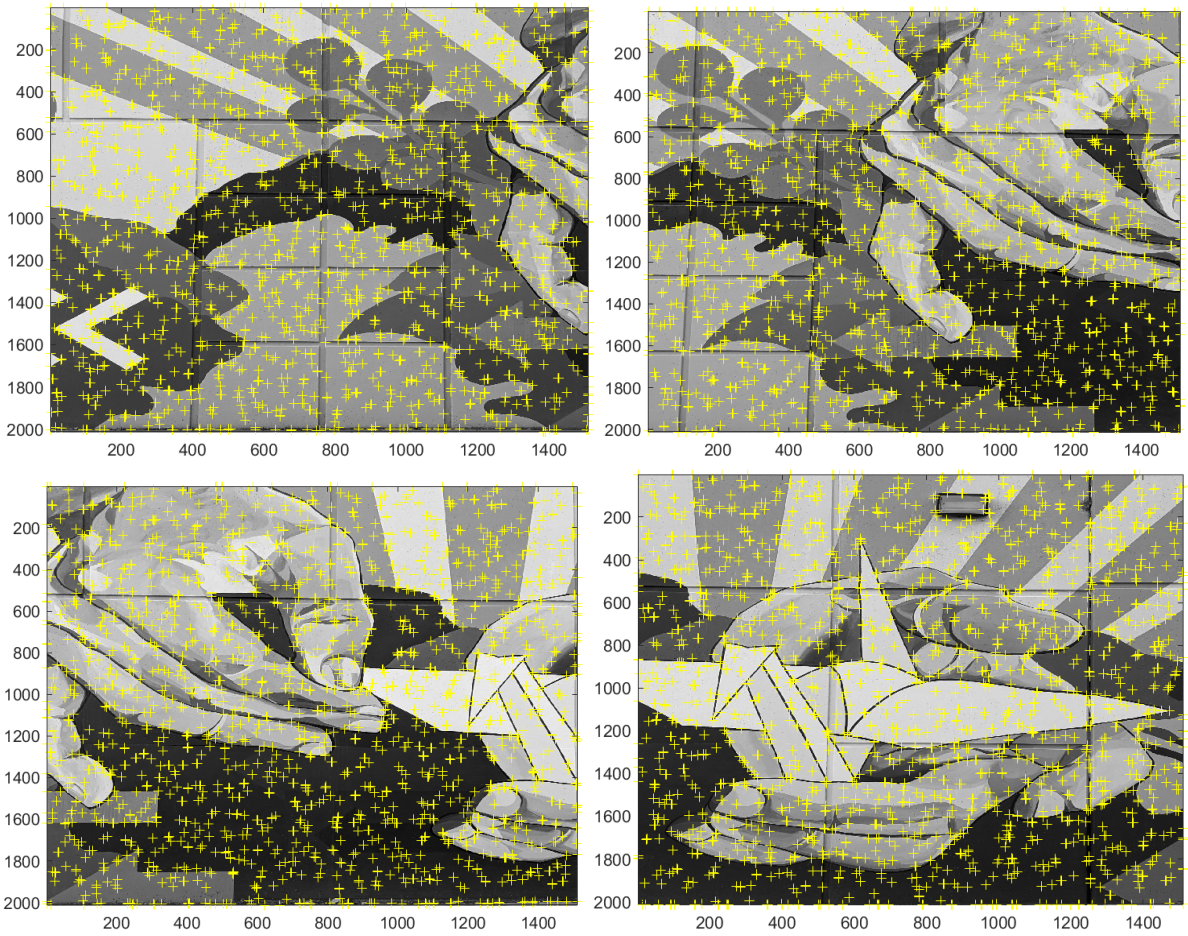
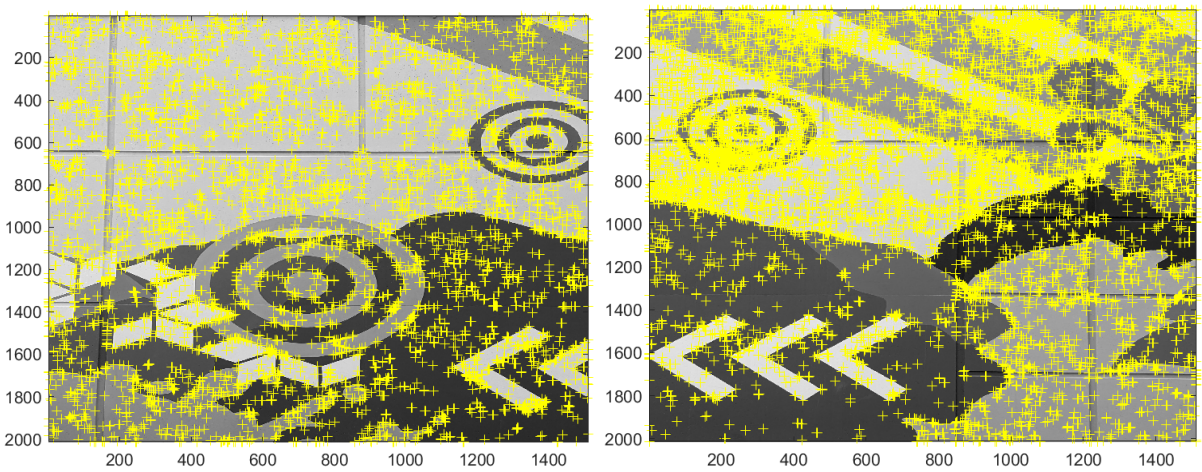


Fig 4.3 Distribution of Harris corners across 50% overlap image set.



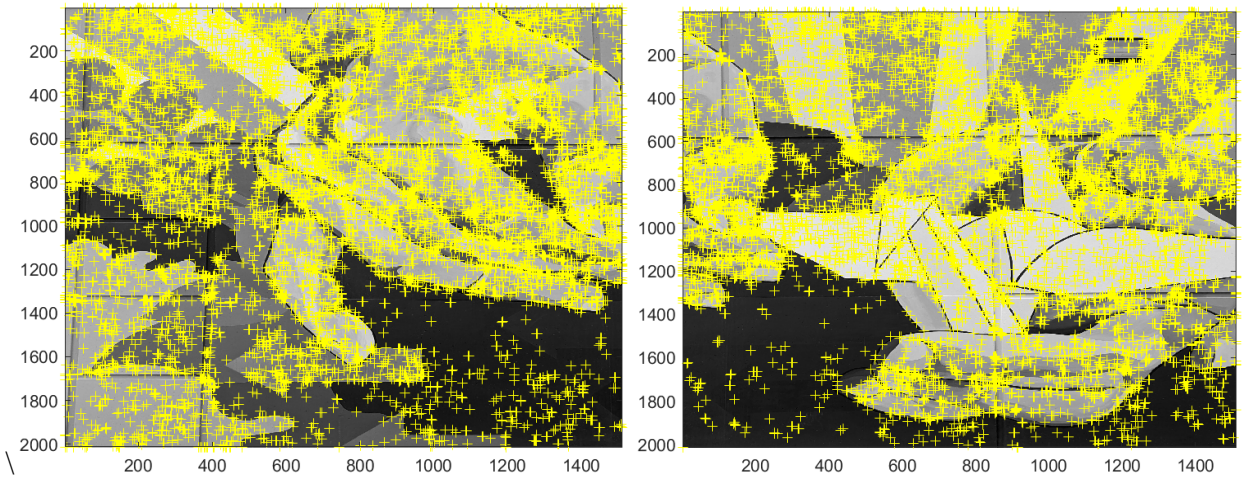


Fig 4.4 Distribution of Harris corners across 15% overlap image set.

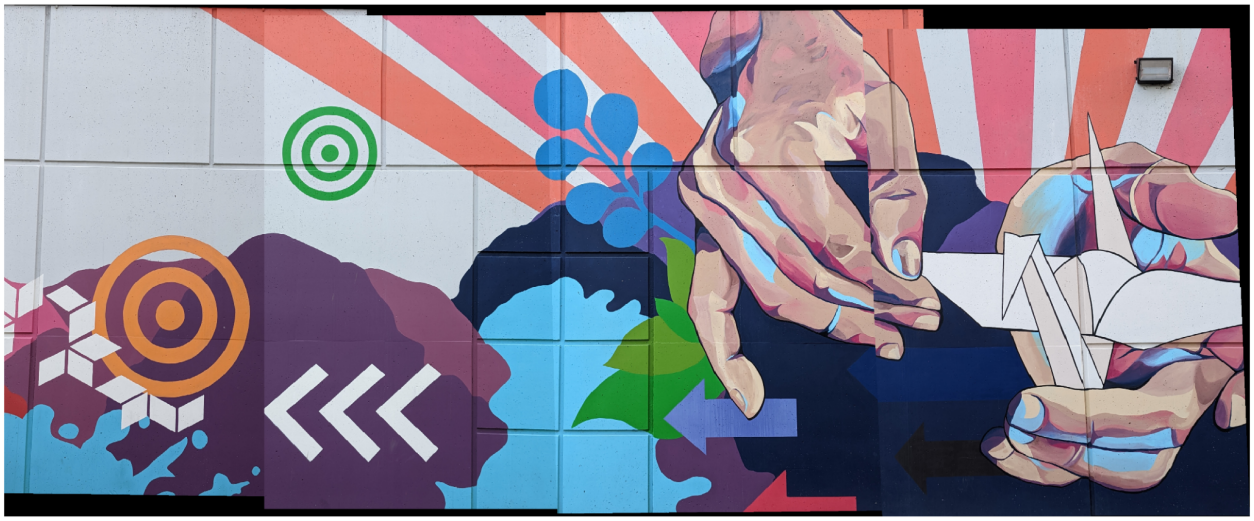


Fig 4.5 Final stitched mosaic of the 15% overlap.

Fig 4.6 Final stitched mosaic of the 50% overlap.

Some observations about the final mosaics are:

- The 50% overlap set had conditions as [25,25] for window size and 2000 corners. These were relaxed and easier conditions because of the larger number of similar features between images.
- The 15% overlap set had conditions as [10,10] for window size and 5000 corners. These were stricter as there were fewer common features and the number of corners in the overlap area had to be increased to find overlap.

.m files you used for this mosaic :

- FeatureBasedPanoramicImageStitchingExample.m
- Harris.m
- Convolve2.m

Conclusions

With more overlap and more unique features between the images of a set, this image stitching becomes much easier. This was seen in the comparison between the LSC mural and the brick wall where the brick wall has visibly fewer unique features. The 50% and 15% overlap cases of the same mural also demonstrated that more overlap helps with easier stitching and more relaxed conditions.

References

[1] Mistry, Shreyas, and Arpita Patel. "Image stitching using Harris feature detection." *International Research Journal of Engineering and Technology (IRJET)* 3.04 (2016): 2220-6.

[2]https://www.cs.umd.edu/class/fall2019/cmsc426-0201/files/12_HarrisCornerDetection.pdf

[3] https://medium.com/data-breach/introduction-to-harris-corner-detector-32a88850b3f6

[4] https://en.wikipedia.org/wiki/Image_stitching

[5] https://www.mathworks.com/help/vision/ug/camera-calibration.html