LAB 5

Overview:

In this lab, we will be working on Photomosaicing using Harris Corner detector and Image stitching algorithm and tune the parameter for these algorithms to generate best results for the collected images.

Overall process of image stitching:

Image -> Grayscale Image -> Detect Interest points (corners) -> Estimate feature vector around interest points -> Identify matching points in two images (Using feature vector at interest points) -> Estimate transformations between corresponding matching points -> Identify center image based on transformation values -> Apply transformations and image sequence -> Generate panorama

Tuning parameters:

Harris Detector:

1. **Max Points:** We are defining the maximum number of points to be extracted by the harris detector having maximum strength.
2. **Window size:** We are giving the number of rows and columns to divide the image and then extract minimum number of corners in each of these grids. This parameter enables to capture points evenly across image. It plays significant role when interest points are on the corners while majority of corners are at the image center.

Image Stitching (Estimating transformation):

1. **Transformation:** This parameter defines the type of transformation to estimate between two images. It can take 4 values – rigid, similarity, affine, projective. We choose the type of transformation based on the images. Usually, when photos are taken from a close distance projective transformation gives good results, while when images are taken from far, then Affine and Similarity works better. Furthermore, affine tends to give better results when we need to preserve parallel lines in the images, for example- Brick wall, building with many windows, etc.
2. **Confidence:** This parameter defines the accuracy in calculating transformation between two images. Usually, we prefer this parameter to be as high as possible (more than 95%) but in some cases high value leads to generating transformation matrices which are non-invertible thus estimated transformation could not be applied to the image back.

General Observations in working with Photo mosaicking:

- Better results for the images were obtained when images were given in right sequence, as large transformations decrease performance of the used algorithm.

CAMERA CALIBRATION:

We are using Caltech Calibration Toolbox for calibrating phone camera. In case of calibrating a phone camera, estimated reprojection errors comes out to be very less. Possible reasoning for these low error values is that the images produced by our phone camera are pre-processed by the phone manufacturers. Camera images used for calculating calibration parameters and reprojection error are represented in *Figure 1*. Estimated reprojection error along with calibration parameters are shown in *Figure 2* and reprojection error corresponding to all corners in each image is shown in *Figure 3.* While calculating the reprojection errors large values were observed, to improve on this, we recomputed the corners for twice using reduced window size for corner detection. This significantly improved the reprojection error results – minimizing it to [0.70 0.72] in final calibration as shown in *Figure 2*, bottom.

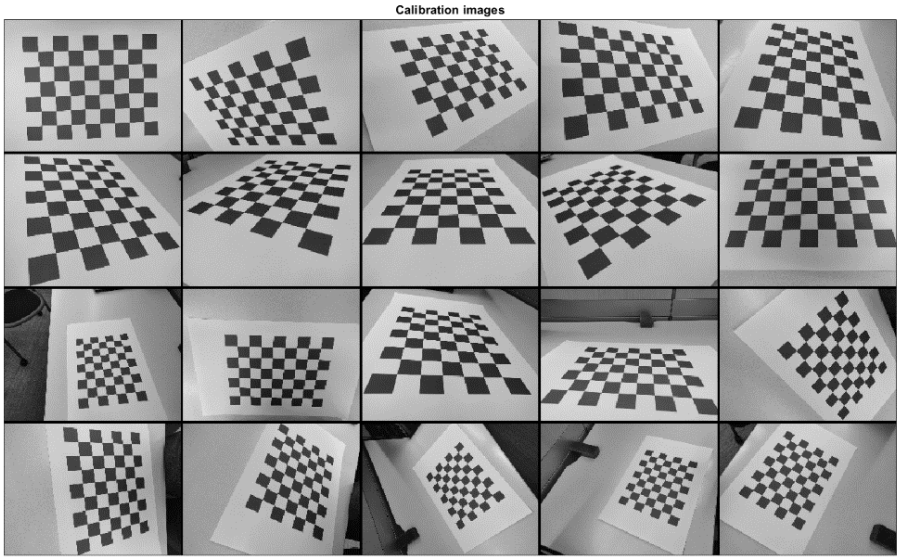

Figure 1: Calibration images

Window size for corner detection: [36 36]

```
Focal Length:          fc = [ 3858.13797   3888.21757 ] +/- [ 91.11115   105.96090 ]
Principal point:       cc = [ 2109.30922   1813.10310 ] +/- [ 122.42403   83.91709 ]
Skew:             alpha_c = [ 0.00000 ] +/- [ 0.00000  ]   => angle of pixel axes = 90.00000 +/- 0.00000 degrees
Distortion:            kc = [ 0.05360   -0.61407   0.01033   -0.02366  0.00000 ] +/- [ 0.06939   0.24311   0.00658   0.00875  0.00000 ]
Pixel error:          err = [ 22.41821   11.15115 ]
```

Window size for corner detection: [5 5]

```
Focal Length:          fc = [ 3835.38286   3860.95971 ] +/- [ 8.98749   10.46239 ]
Principal point:       cc = [ 2126.45873   1810.81607 ] +/- [ 11.74070   8.15948 ]
Skew:             alpha_c = [ 0.00000 ] +/- [ 0.00000  ]   => angle of pixel axes = 90.00000 +/- 0.00000 degrees
Distortion:            kc = [ 0.06783   -0.65517   0.00942   -0.02188  0.00000 ] +/- [ 0.00708   0.02509   0.00066   0.00085  0.00000 ]
Pixel error:          err = [ 1.82828   1.68792 ]
```

Window size for corner detection: [2 2]

```
Focal Length:          fc = [ 3738.10442   3746.32511 ] +/- [ 3.65385   4.22792 ]
Principal point:       cc = [ 2228.92465   1760.91943 ] +/- [ 5.45242   4.22321 ]
Skew:             alpha_c = [ 0.00000 ] +/- [ 0.00000  ]   => angle of pixel axes = 90.00000 +/- 0.00000 degrees
Distortion:            kc = [ 0.03644   -0.35082   0.00204   -0.01177  0.00000 ] +/- [ 0.00386   0.01277   0.00036   0.00044  0.00000 ]
Pixel error:          err = [ 0.70212   0.72341 ]
```

Figure 2: Calibration parameters and reprojection errors

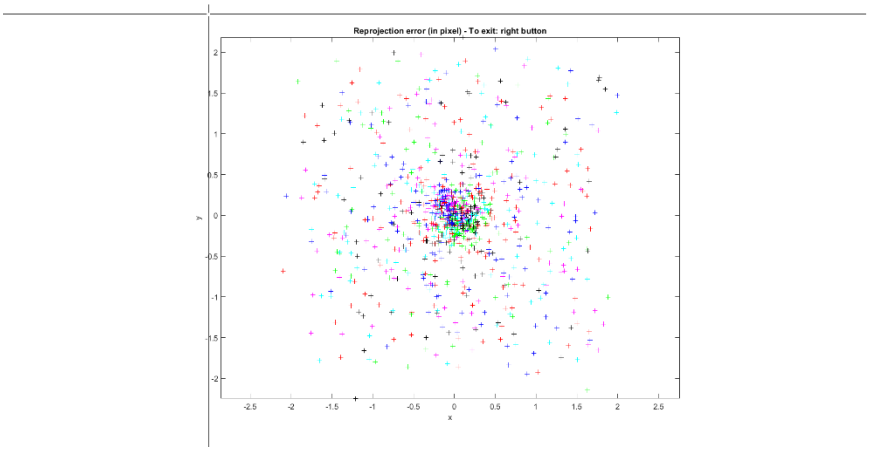

Figure 3: Reprojection error for all corners in each image

Undistorting the Image 7 with the estimated intrinsic parameters, majorly differences are observed at the corners of images. These differences are significant in images for which camera was at large angles with respect to calibration grid. Original Image vs Undistorted image are shown in *Figure 4*.

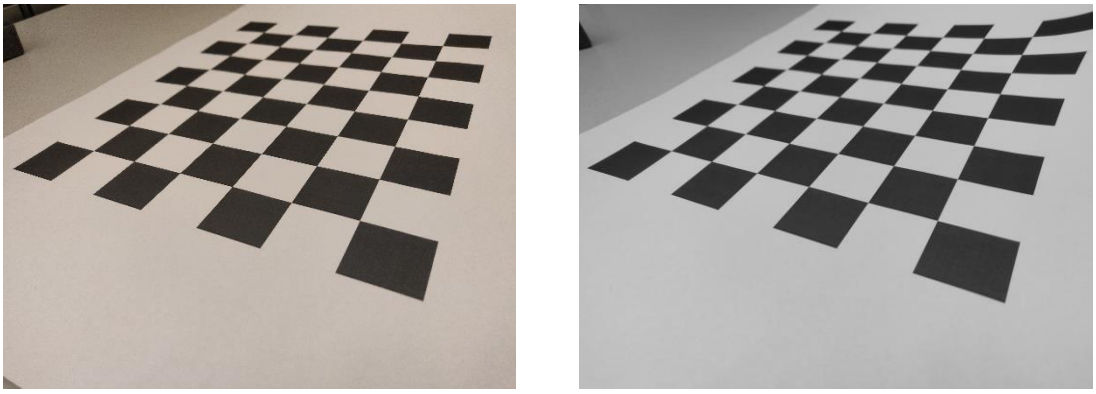

Figure 4: Original image (left), Undistorted image (right)

Additionally, the CALTECH camera toolbox provides an interesting feature to observe the orientation of camera frame to take the calibration images, which helps in qualitative analysis of the calibration method. *Figure 4* represents the reference camera frames generated by the toolbox. Visually analyzing image 14 in *Figure 4* and reference frame for image 14 in *Figure 5*, makes sense.

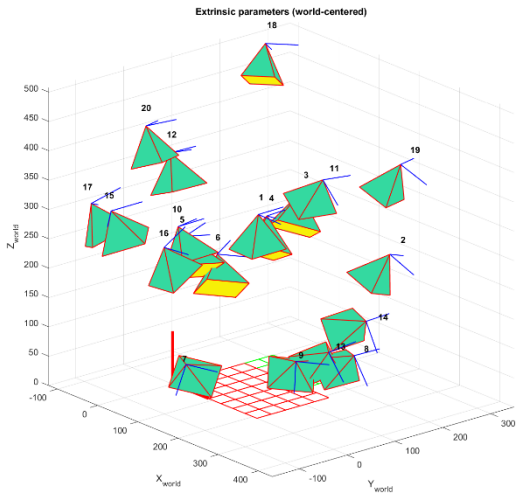

Figure 5: Estimated camera frames or pose corresponding to each image

LSC MOSAIC:

Original images dataset used for image stitching is shown in *Figure 6.* In this part of the lab, we are applying the Harris Corner Detector Algorithm to estimate points of interest – Corners in each image which are further used for locating and estimating transformations of features around these points in two images. While using the Harris Detector, input arguments (Maximum points and Window size) are tuned to ensure points of interests are distributed through-out the image; effects are shown in *Figure 7*, which gives better performance when generating panorama. Detected points of interests in each image are shown in *Figure 8.*

Figure 6: Original Images for Panorama stitching for LSC building

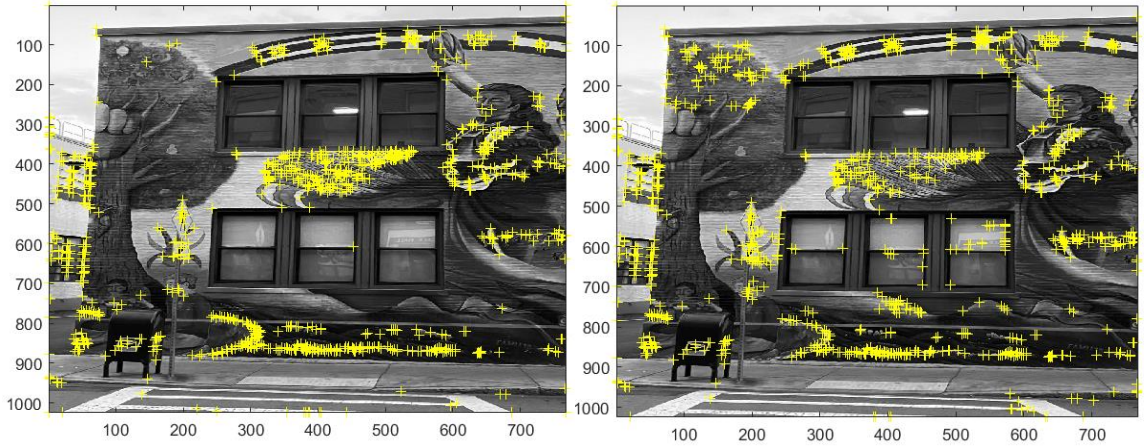

Figure 7: Detected corners (1000) for window-size [1 1] (left) and [4 4] (right)

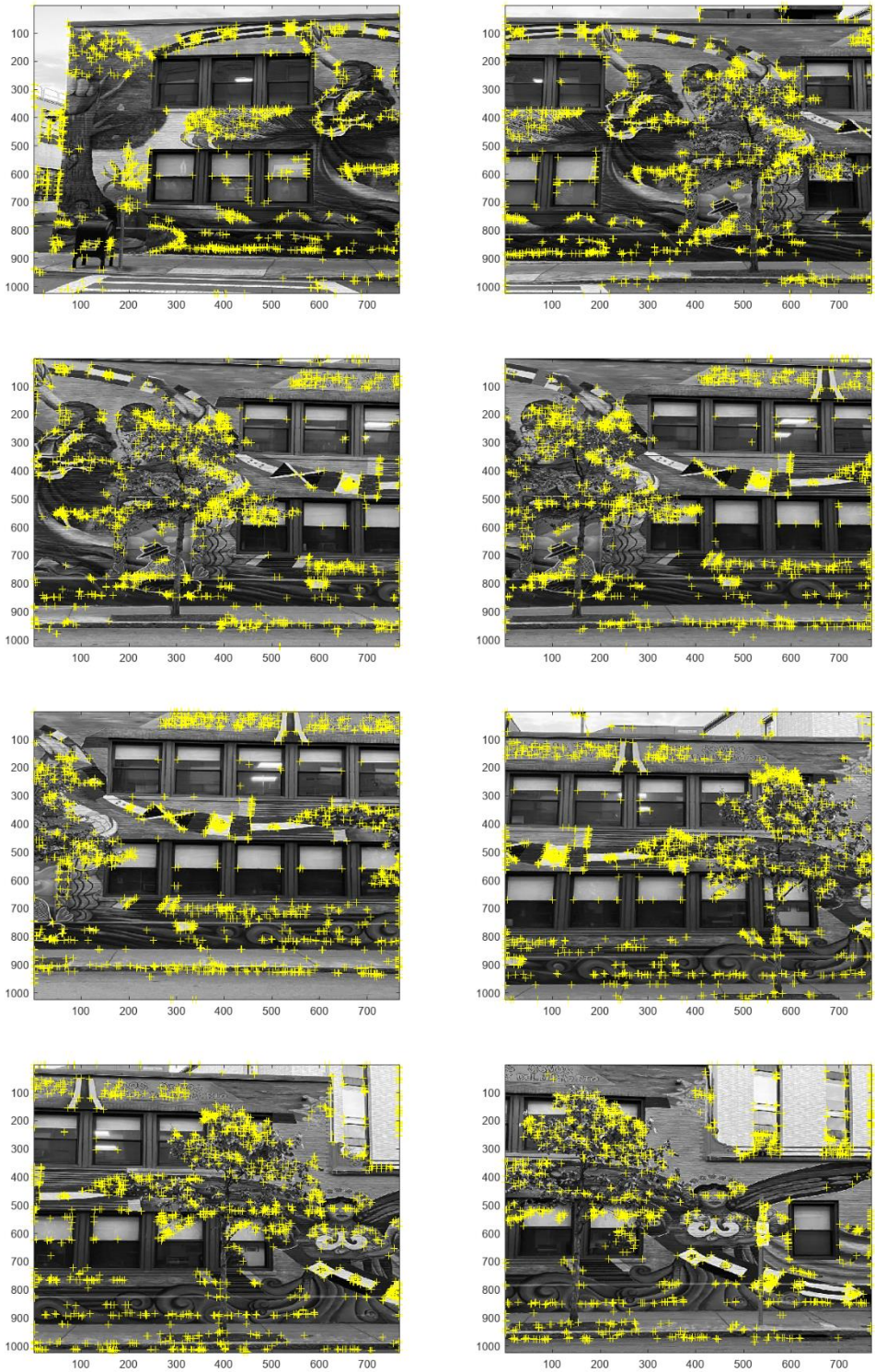

Figure 8: Detected corners in each referred image for LSC panorama stitching

Further, after estimating the feature vector around Harris corners and matching the points across two images, we use estgeotform2D function in MATLAB to estimate the geometric transformation. We can define the type of Geometric transformation to be estimated by this function and based on different type we get different results for image stitching. Iterating with different transformation, projective transformation suits best for this image mosaic. Result for different transformations (other parameters same) are shown in *Figure 9.*

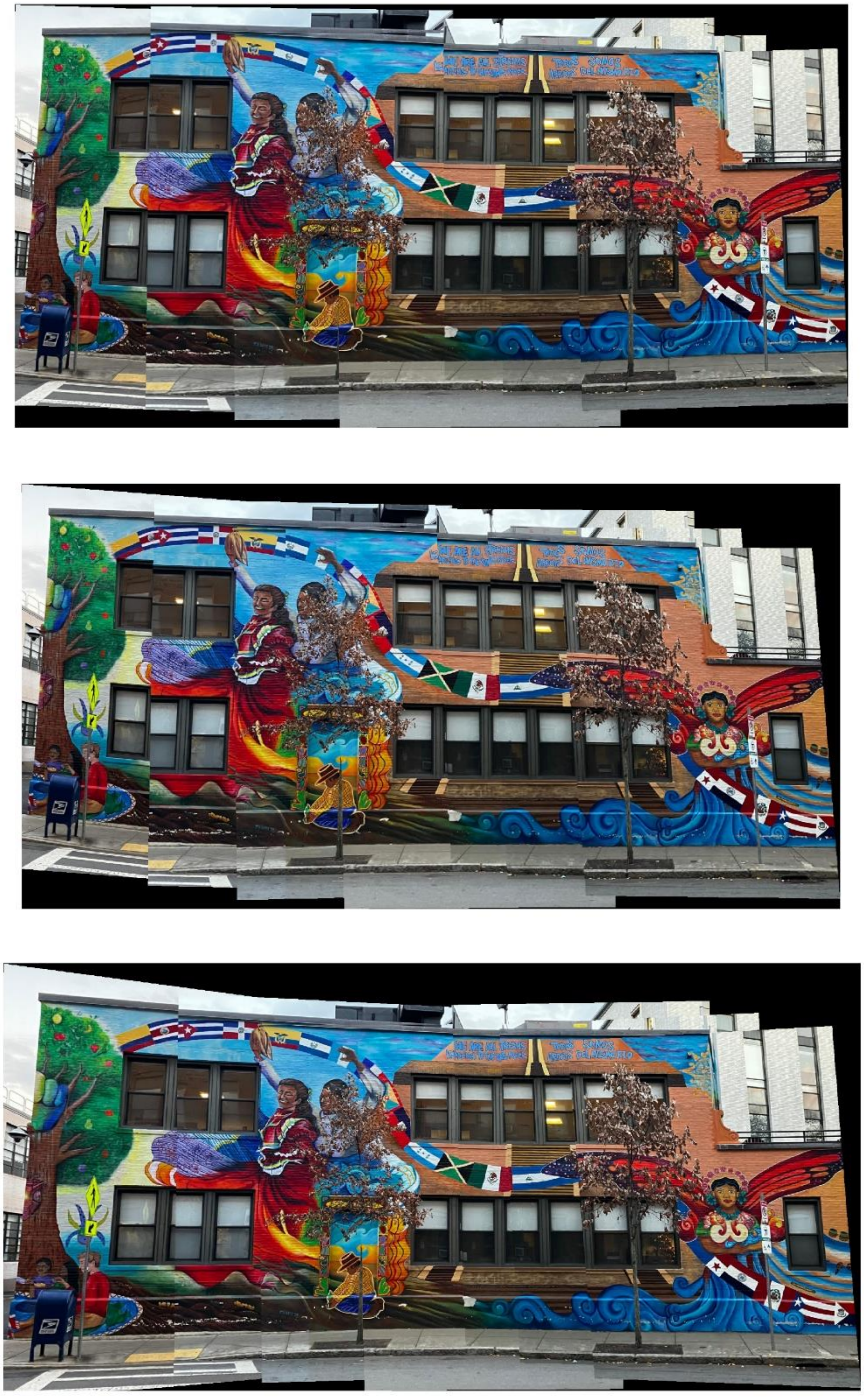

Figure 9: Similarity (top), Affine (middle), and Projective (bottom) Transformations

From qualitative analysis (visual observations), Projective transformation gives best results as for other transformations leftmost part of panorama does not go well with corresponding next image, though remaining photo stitching looks decent. To generate the final image (*Figure 9*, bottom) following parameters are used:
Harris Corner Detection Arguments - Max Points = 1500, Grid Divisions = [4 4]
Estimate Geometric Transformation arguments - Projective transformation, Confidence = 99.9%

CINDER / BRICK WALL MOSAIC:

While working with brick or Cinder wall dataset, large number of iterations were required to even generate the Panorama. Image set used for this part are shown in *Figure 10*. Detected corners by Harris detector are shown in *Figure 11*.

Compared to LSC mural, generating a panorama for this required larger number of harris corners to estimate transformation matrices. Additionally, the confidence level corresponding to estimating transformation was much less (80% vs 99.9% in LSC). Possible explanation for this difference is the large number of repetitive features across the image or lack of unique features.

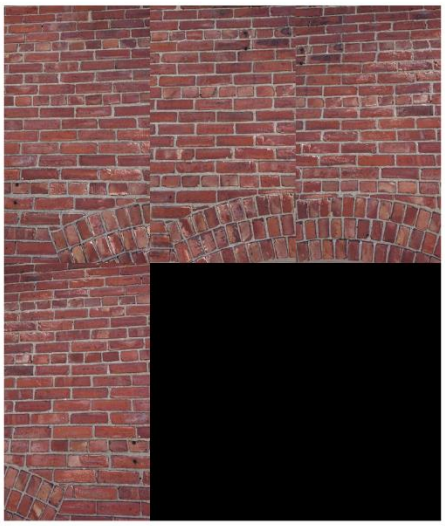

Figure 10: Image set for Brick / Cinder wall mosaic

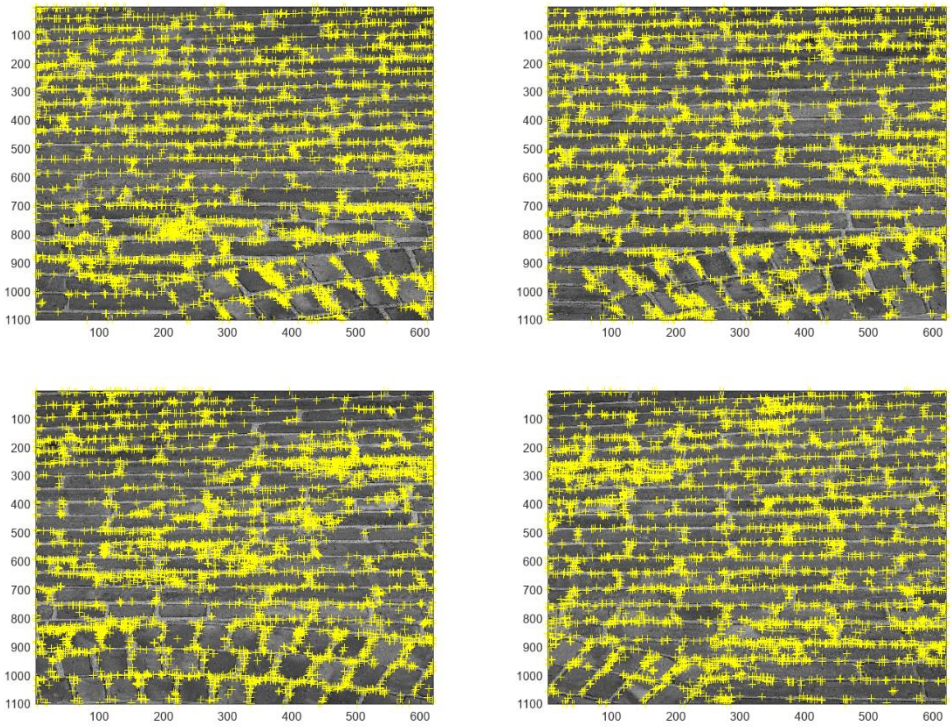

Figure 11: Detected corners for parameters: Max points = 4000, Window size = [4 2]

After determining the points of interests, features are estimated around these points which are further used for generating transformation matrix. In our case, matched points of interest for few images were less than 20, which restricts us to use similarity/affine transformation. Intuitively, affine transformation should work better for a brick wall as it maintains parallel lines, so we tested with Affine transformation. For a confidence of 95% used for similarity transformation, we get an error in inverting transformations. Further iterating with lower confidence values, we get best results. However, generated panorama stitches 3 of 4 images, left-most image is pushed back for all iterations. To generate the final image (*Figure 12, bottom right*) following parameters are used:

Harris Corner Detection Arguments - Max Points = 4000, Grid Divisions = [4 2]
Estimate Geometric Transformation arguments - Affine transformation, Confidence = 80%

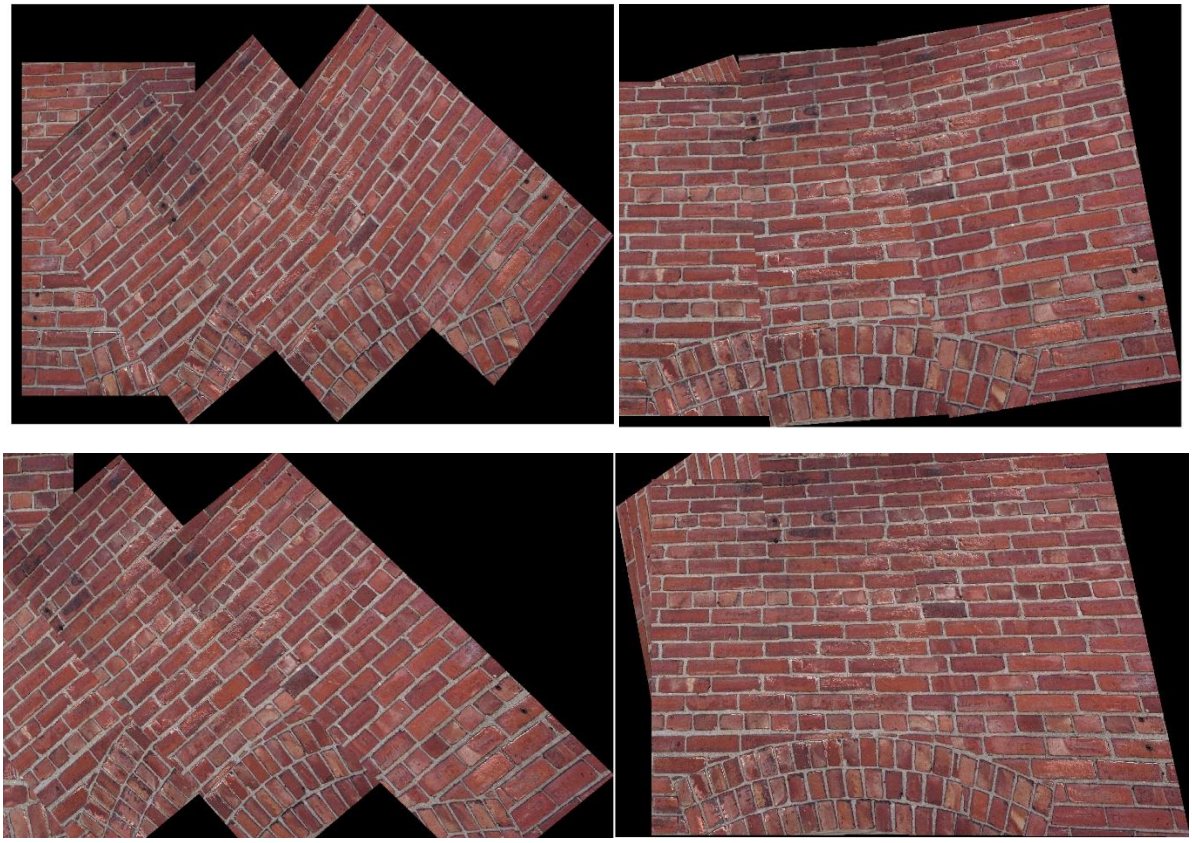

Figure 12: Panorama generated for brick wall mosaic under different conditions
Parameters- Corner points=4000(common), Window size, Transformation, Confidence level
Top-left: [2 2] Similarity 95%; **Top right**: [4 2] Similarity 95%; **Bottom left**: [4 2] Affine 90%; **Bottom right**: [4 2] Affine 80%

MURAL 50% OVERLAP:

Images used for second mural stitching is taken outside Ruggles stations and the image set used is shown in *Figure 13*. Also, the detected corners from Harris Detector are shown in *Figure 14*. For Harris detector we are using max points – 1500 and window size [4 4] to ensure distributed corners.

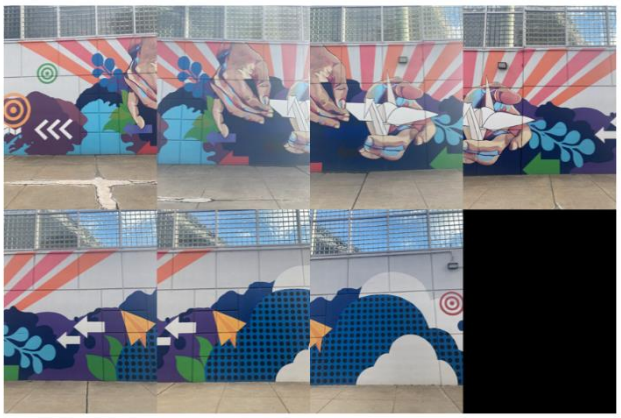

Figure 13: Image set for second mural panorama stitching

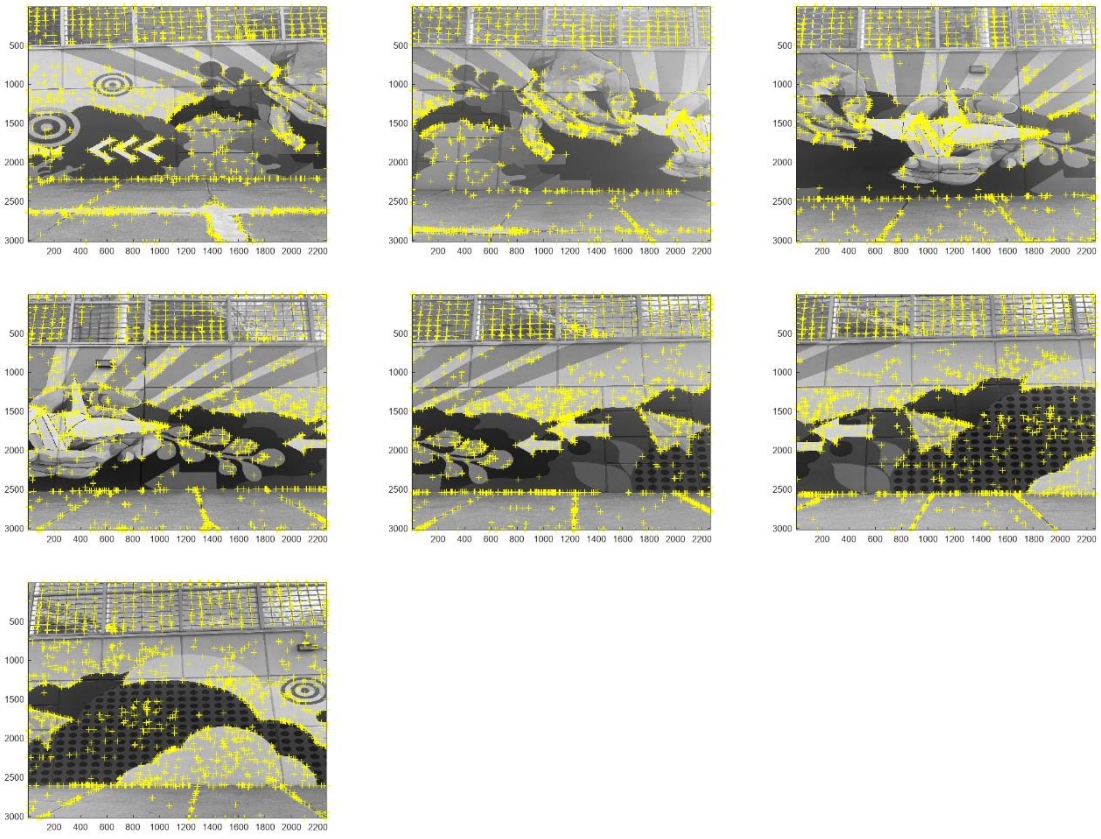

Figure 14: Detected corners across all images from image set

In the estgeotform2d function, we tried iterating with different transformations and got best results for affine transformations. Projective transformations do not work well as the distance between the first image and the last image is large and the images were taken from farther distance compared to Mural 1. On iterating, we get best results (*Figure 15, bottom*) for following parameters:
Harris Corner Detection Arguments - Max Points = 1500, Grid Divisions = [4 4]
Estimate Geometric Transformation – Affine transformation, Confidence = 99%

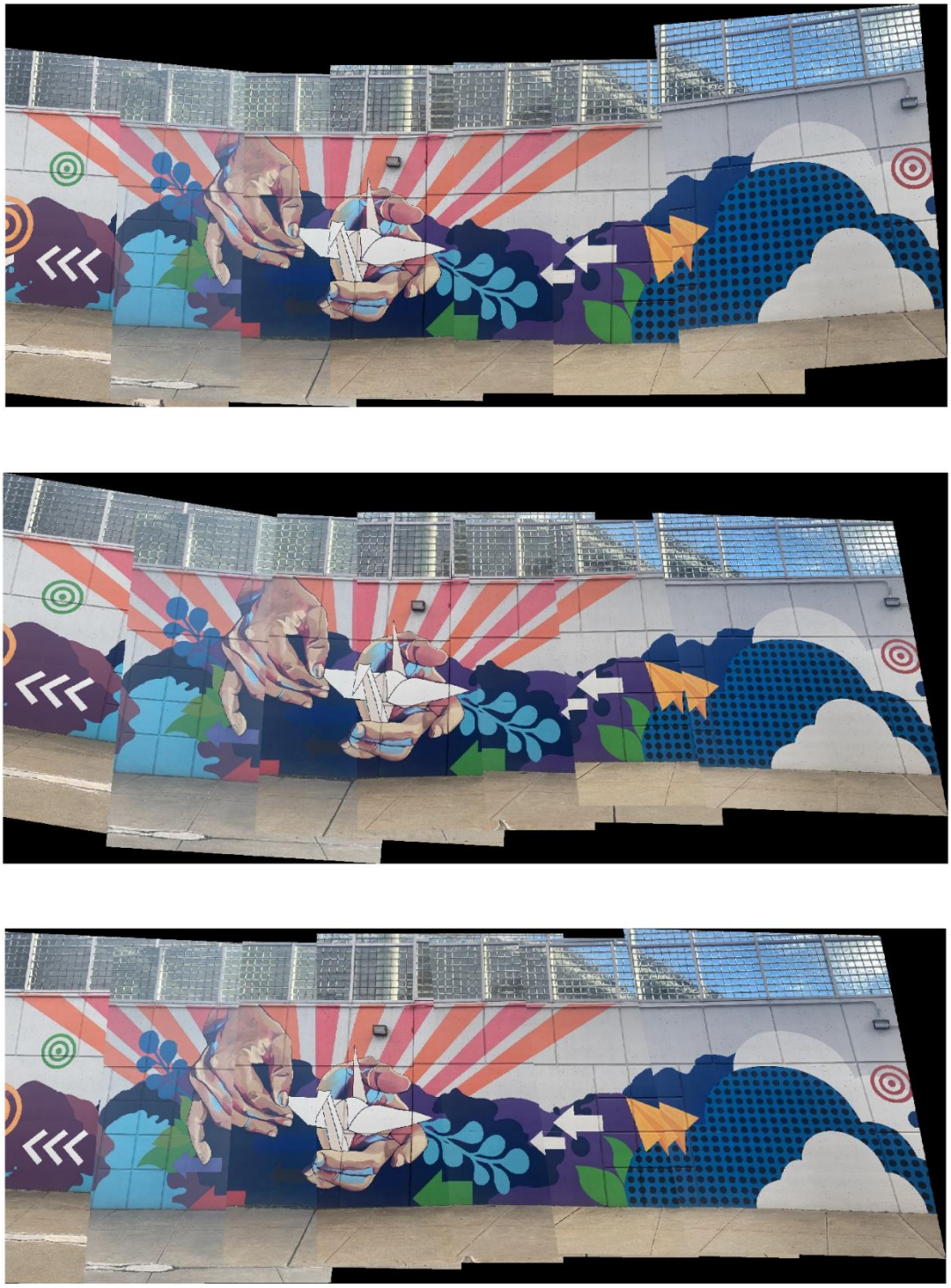

Figure 15: Panoramic stitching of second Mural using different transformations keeping other parameters same Max points=1500, Window size=[4 4] and Confidence=99%
Top: Projective, **Middle:** Similarity, **Bottom:** Affine

MURAL 15% OVERLAP:

Image set for mural 2 with 15% overlapping is shown in Figure 16, followed by detected corners in Figure 17. While running the Harris corner, it was important to ensure that sufficiently large number of corners are detected on the left and right most regions of the image as limited overlapping between consecutive images. To ensure this condition, max corners detected were increased to 3000 with detection for window size [4 4]. Detected corners across images are shown in *Figure 18*.

Figure 17: Image set for Mural 2 with 15% overlapping

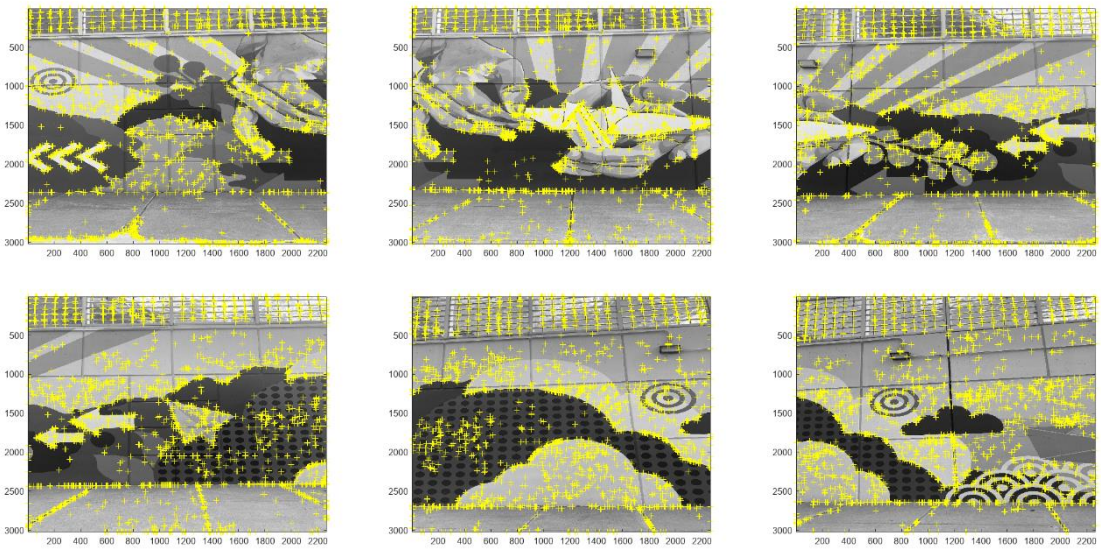

Figure 18: Detected Harris corners across images

Iterating with different parameters there were multiple errors in estimating transformations compared to images with 50% overlapping. Number of matched points between consecutive images significantly reduced which prevented us to use projective transformations as it requires minimum of 20 matched points between all images. Additionally, confidence value for estimating geometric transformations needs to be reduced to 80-95%, depending on other parameters used. After iterating with different parameters, best results (*Figure 19, bottom*) were obtained with following parameters:

Harris Corner Detection Arguments - Max Points = 3000, Grid Divisions = [4 4]
Estimate Geometric Transformation – Affine transformation, Confidence = 90%

Figure 19: Panoramic stitching of Mural 2 with different parameters
Top left: 2000 [2 2] Similarity, **Top right**: 3000 [5 5] Similarity, **Middle**: 3000 [2 2] Affine, **Bottom**: 3000 [4 4] Affine