# Robotics Sensing and Navigation
# ECE 5554
# LAB-5

## ***CAMERA CALIBRATION:***

Checker box of size 9*7 with 30mm size was used to calibrate cellphone's camera. Below is the collection of images taken with different combination of skewness, position and angles.

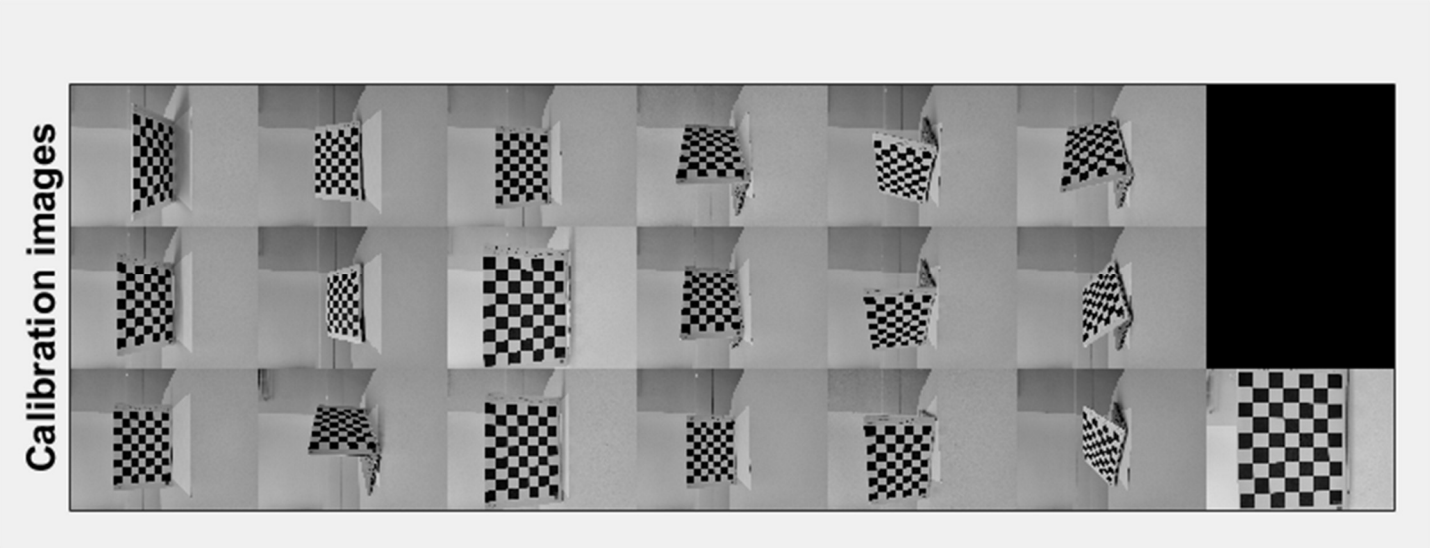


Figure1: Images taken for calibration

```
Calibration parameters after initialization:

Focal Length:          fc = [ 3426.74992   3426.74992 ]
Principal point:       cc = [ 1735.50000   2311.50000 ]
Skew:             alpha_c = [ 0.00000 ]   => angle of pixel = 90.00000 degrees
Distortion:            kc = [ 0.00000   0.00000   0.00000   0.00000   0.00000 ]

Main calibration optimization procedure - Number of images: 19
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 = [ 3413.86773   3437.40914 ] +/- [ 9.46068   9.38112 ]
Principal point:       cc = [ 1736.54407   2299.08464 ] +/- [ 10.76514   10.72279 ]
Skew:             alpha_c = [ 0.00000 ] +/- [ 0.00000  ]   => angle of pixel axes = 90.00000 +/- 0.00000 degrees
Distortion:            kc = [ 0.11040   -0.28393   -0.00155   -0.00180  0.00000 ] +/- [ 0.00857   0.02986   0.00111   0.00117  0.00000 ]
Pixel error:          err = [ 0.66650   0.65337 ]

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

Figure2: Camera Calibration Results

The above results represent the calibrated data from for images in figure1 and the pixel error is [0.66650, 0.65337]

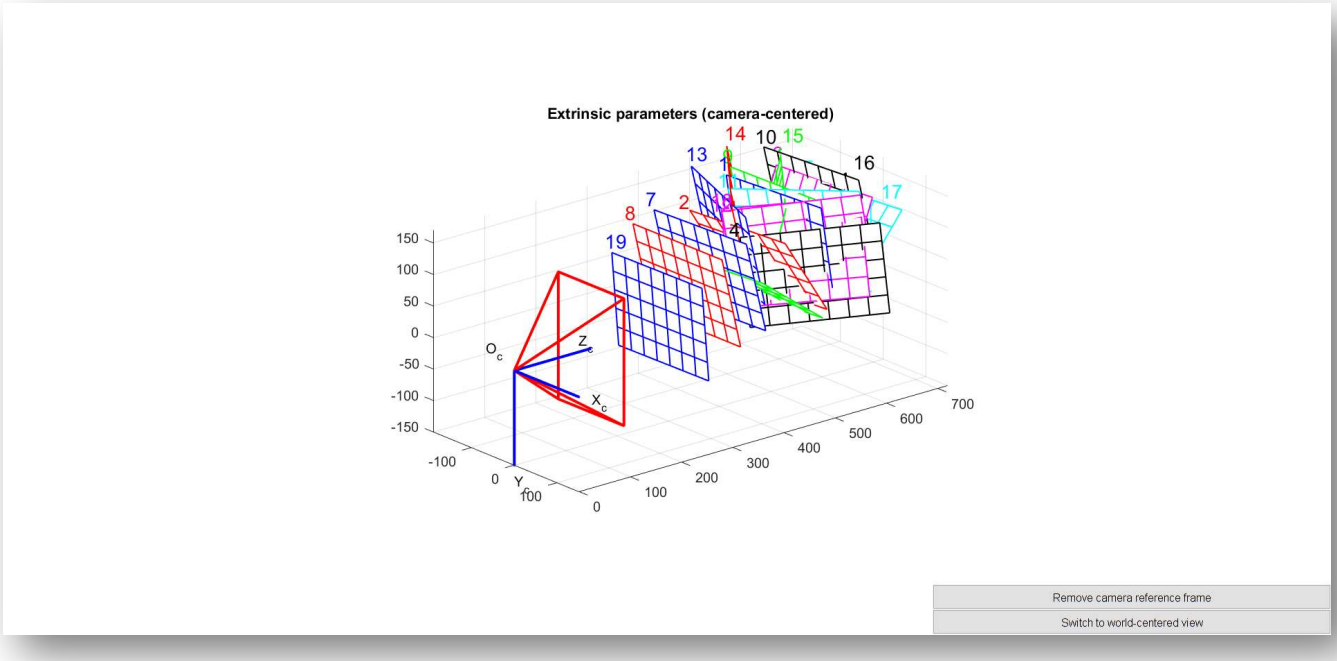


Figure3: Extrinsic Parameter Camera Centered View

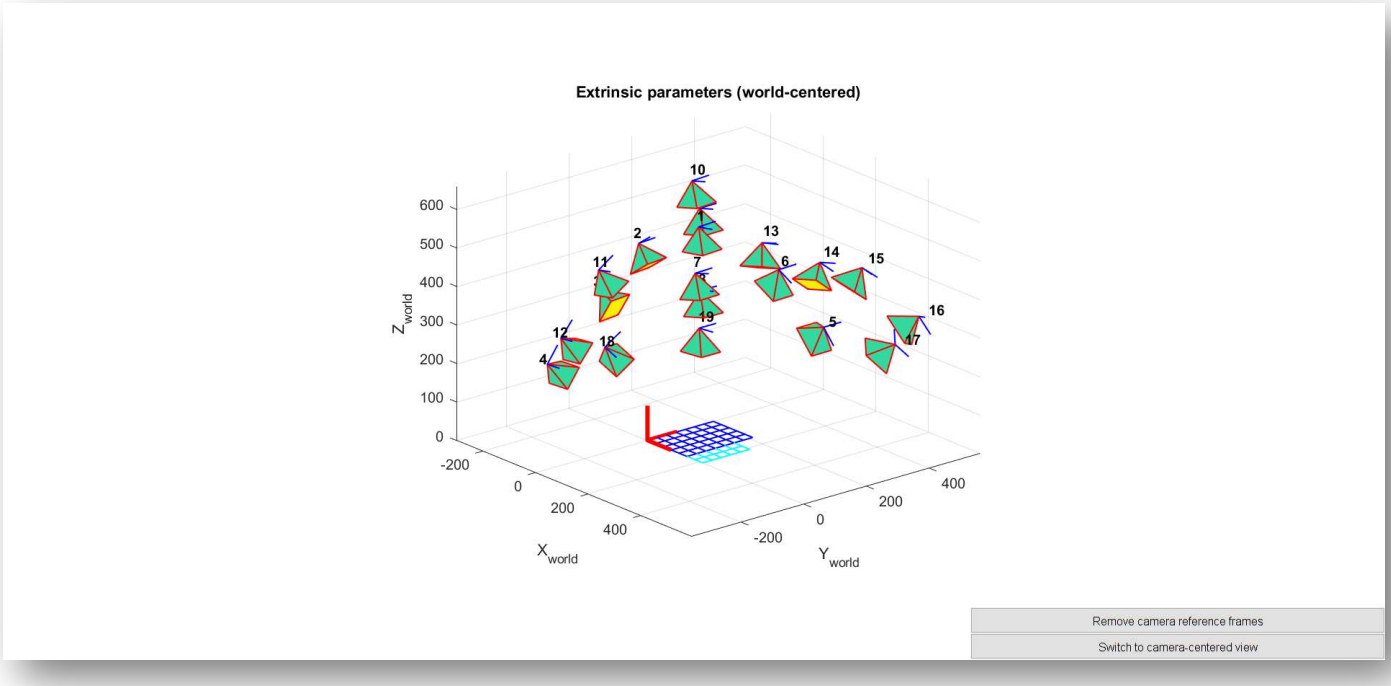


Figure4: Extrinsic Parameter World Centered View

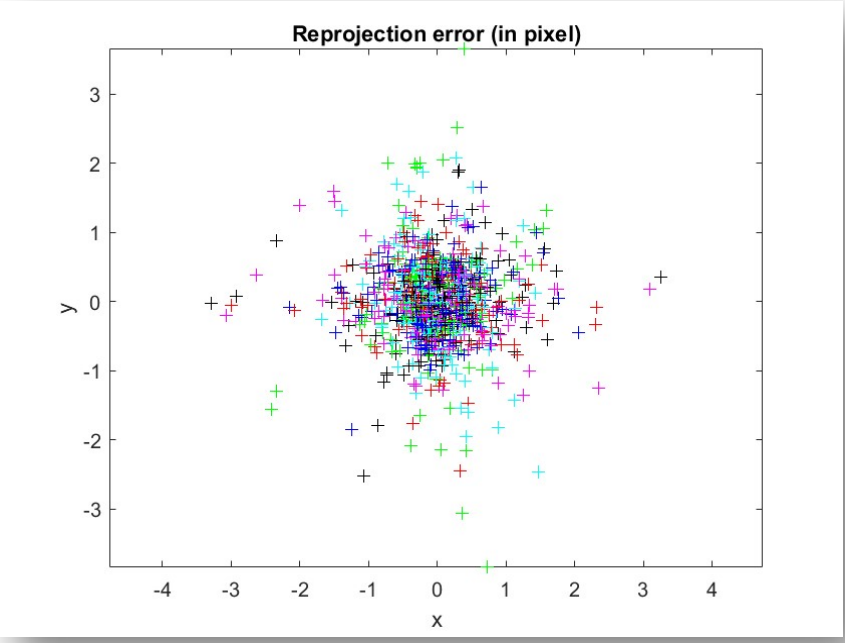


Figure5: Reprojection pixel error

The reprojection pixel error is converged towards center giving a conclusion the cell phone's camera is calibrated well and is reasonable. The reason behind less reprojection pixel error is that our cameras are already calibrated.

Figure6: Original Distorted Image in grayscale

Figure7: Undistorted image generated using calib toolbox

The above two images show distorted (original image) and undistorted images from calibration toolbox. We apply calibration to get undistorted image from image which is already calibrated by the phone's manufacturers. Hence we get the image as figure7 which has slight curvature.

## ***FORSYTH STREET:***

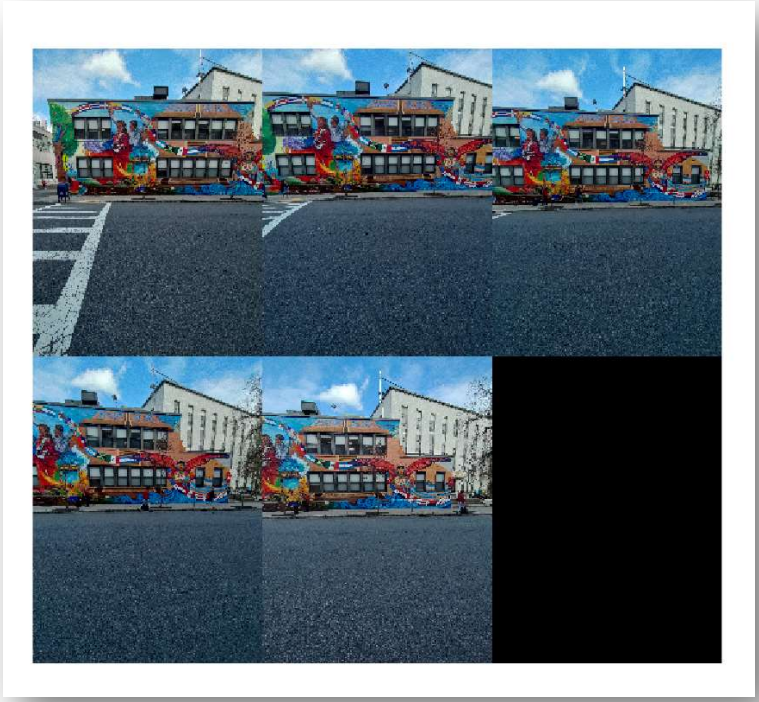

Figure8: Montage of Latino student building in Forsyth Street

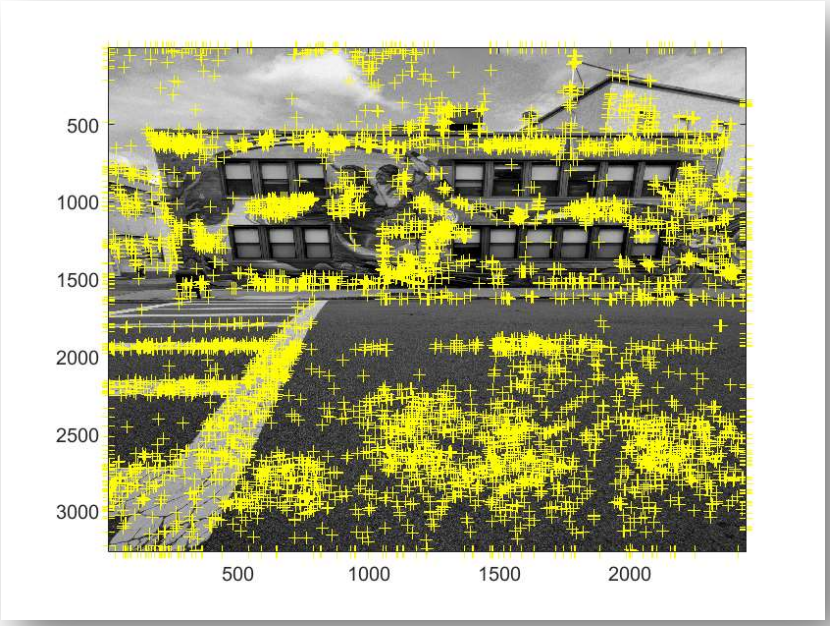


Figure9: Feature detected using Harris Corner detection (second image from montage)

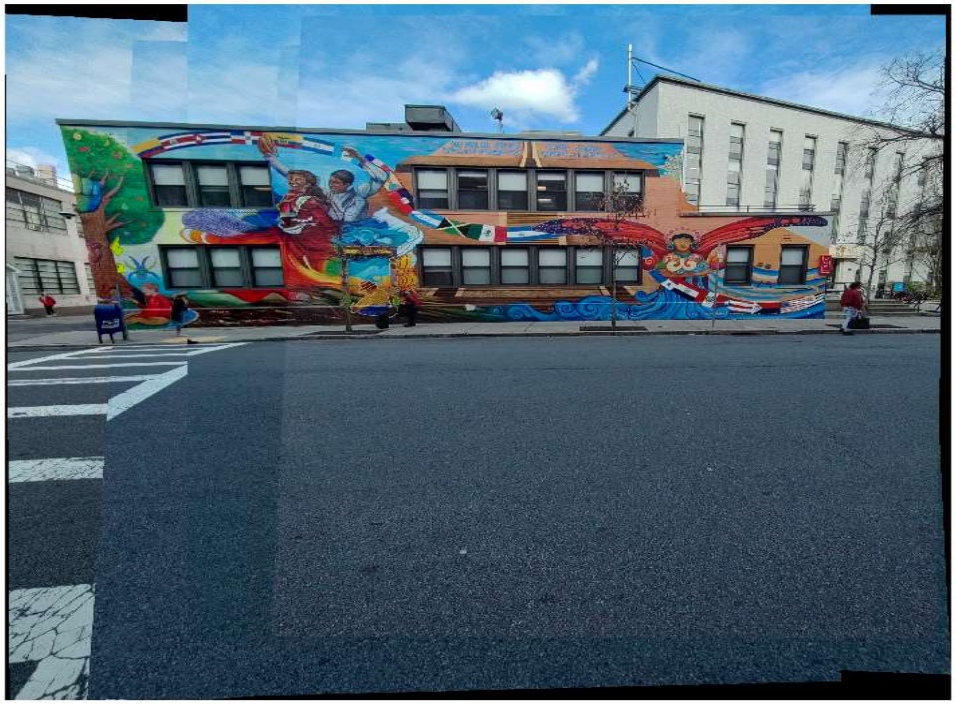

Figure10: Mosaic Image after applying Harris Corner Detection

| Tile Size | Number of Features | Confidence | Maximum Trials |
|---|---|---|---|
| [5, 5] | 7000(Maximum) | 99.99 | 2500 |
| [5, 5] | 500(Minimum) | 99.99 | 2500 |

Table 1: Description of Parameters

In the Forsyth Street, five images were taken with overlapping features and the above parameters were used to obtain the final mosaic images. We utilize a projective transformation between matched points. We can see that we have obtained a mosaic image similar to original images after using Harris corner detection. There is an offset in the crosswalks, this because the homography is not formed between two images. The reason behind this we have two different planes, one being the wall and second being the road. Homography doesn't form between the two planes.

Computation cost decreases when we use minimum number of features to perform the same operation with acceptable output of mosaic. Instead of using maximum number of features.

## ***RUGGLES STATION:***

A similar execution w.r.t forsyth street was perfomed on images taken from the Ruggles station to see the outcome of different texture and colors. Below are the observations made:

| Tile Size | Number of Features | Confidence | Maximum Trials |
|---|---|---|---|
| [5, 5] | 7000(Maximum) | 99.99 | 2500 |
| [5, 5] | 2000(Minimum) | 99.99 | 2500 |

Table2: Description of Parameters

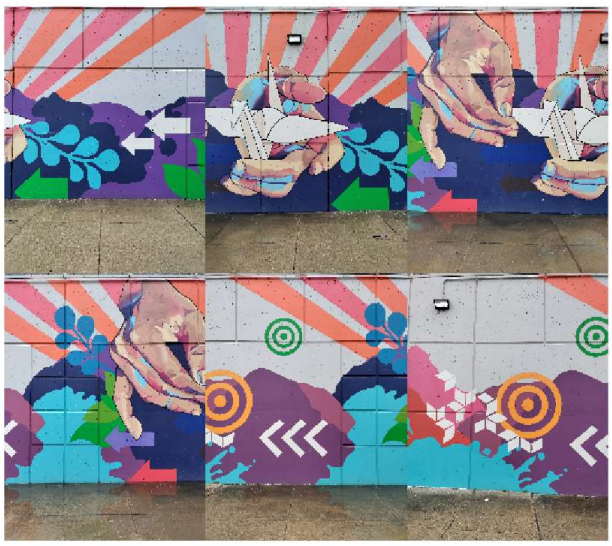

Figure 11: Montage of Ruggles Station's graffiti

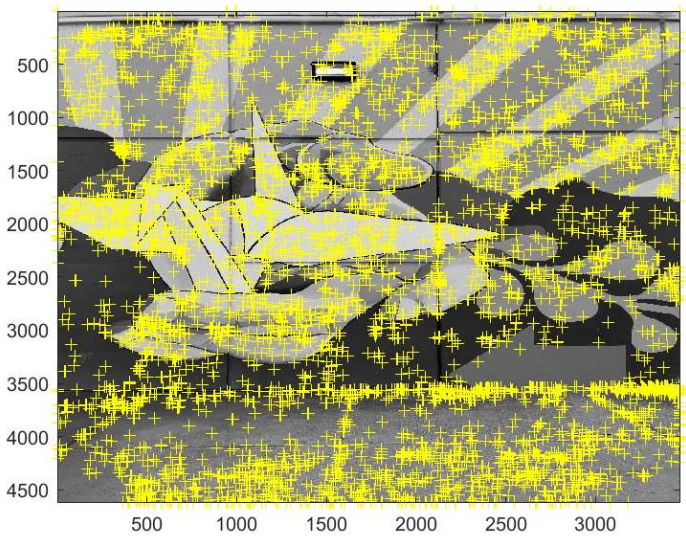


Figure 12: Feature detected using Harris Corner detection (Third image from montage)

Figure 13: Mosaic Image after applying Harris Corner Detection

The mosaic formed is very much similar to the original images shown in montage. Variations can be seen in flooring because of less features and similarities. Homography doesn't apply to two different planes hence we get slight mismatch.

Computation cost decreases when we use minimum number of features to perform the same operation with acceptable output of mosaic. Instead of using maximum number of features.

## ***CINDER BLOCK WALL WITH 50% OVERLAPPING:***

| Tile Size | Number of Features | Confidence | Maximum Trials |
|---|---|---|---|
| [5, 5] | 7000(Maximum) | 99.99 | 2500 |
| [5, 5] | 500(Minimum) | 99.99 | 2500 |

Table 3: Description of Parameters

Below images of cinder brick wall were taken near West village Residence and the above parameters were utilized. We can see we have got a good mosaic image after applying Harris corner detection. The reason behind this is features have we been detected because of the tree's reflection on to the wall and features have been detected in places with yellow cinder bricks as you can see in the figure 15.

Computation cost decreases when we use minimum number of features to perform the same operation with acceptable output of mosaic. Instead of using maximum number of features.

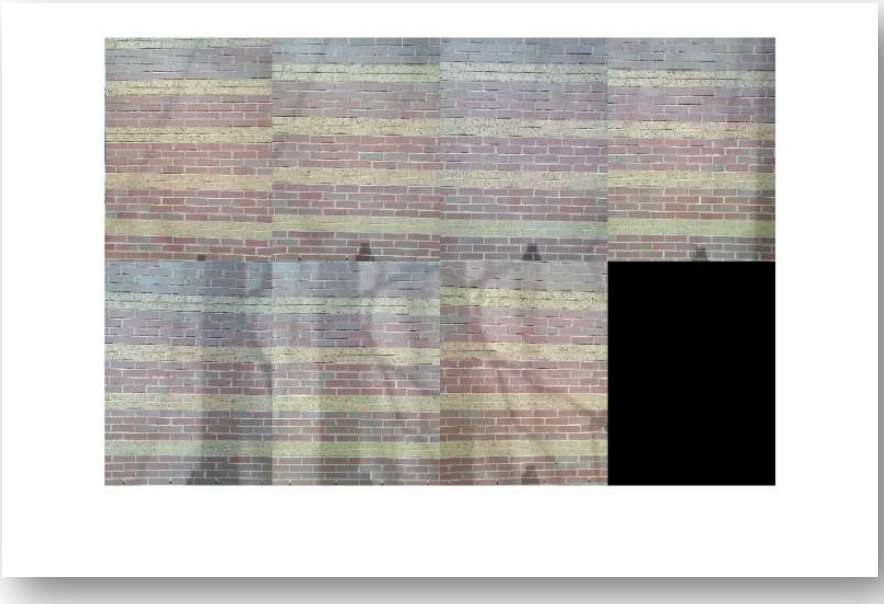

Figure14: Montage of Cinder brick wall

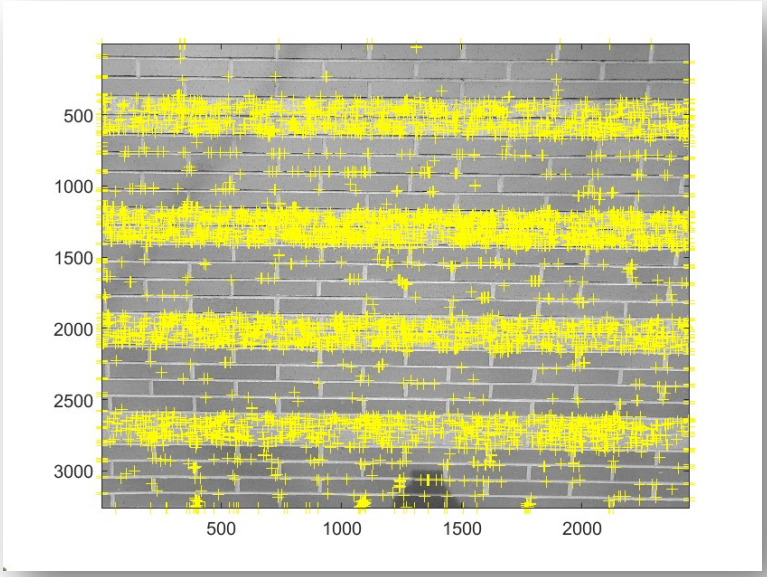


Figure15: Feature detected using Harris Corner detection (Second image from montage)

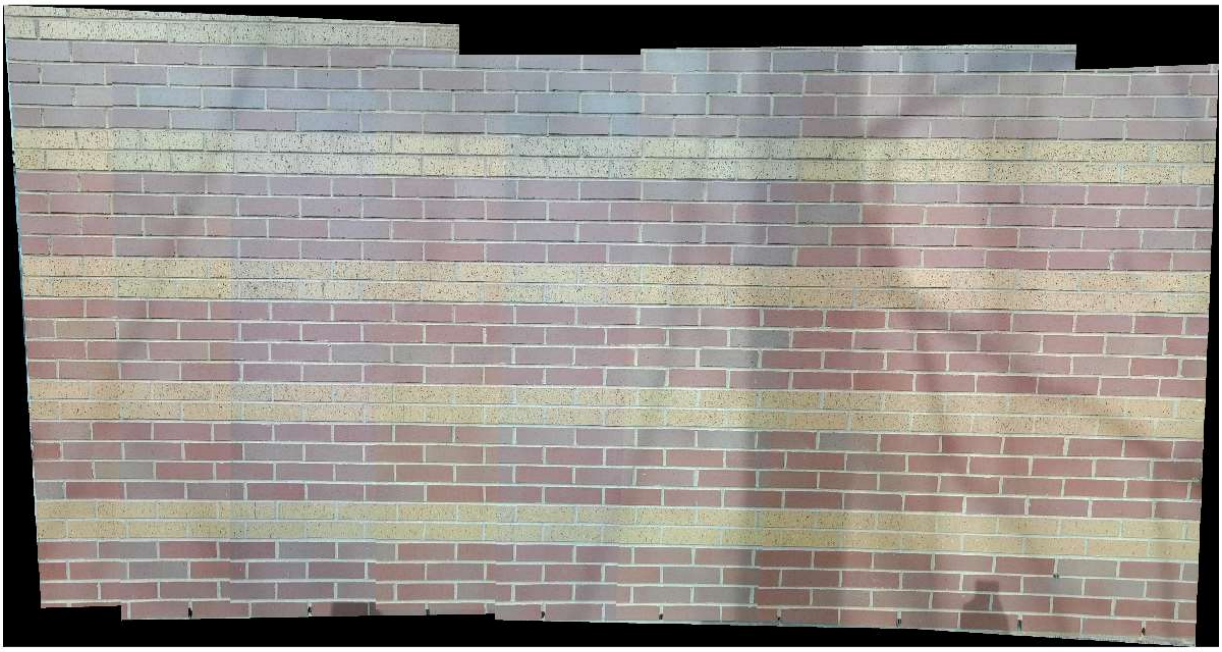

Figure16: Mosaic Image after applying Harris Corner Detection

## ***GRAFITTI ART 15% OVERLAPPING:***

In the street next to Ryder's Hall, four images were taken with approximately 15% overlapping features and the below parameters were used to obtain the final mosaic images. We utilize a projective transformation between matched points. We can see that we have obtained a mosaic image similar to original images after using Harris corner detection. There is an offset in the flooring and places where glasses are present, this because the homography is not formed between two images.

Computation cost decreases when we use minimum number of features to perform the same operation with acceptable output of mosaic. Instead of using maximum number of features.

| Tile Size | Number of Features | Confidence | Maximum Trials |
|---|---|---|---|
| [5, 5] | 7000(Maximum) | 99.99 | 2500 |
| [5, 5] | 1000(Minimum) | 99.99 | 2500 |

Table4: Mosaic Image after applying Harris Corner Detection

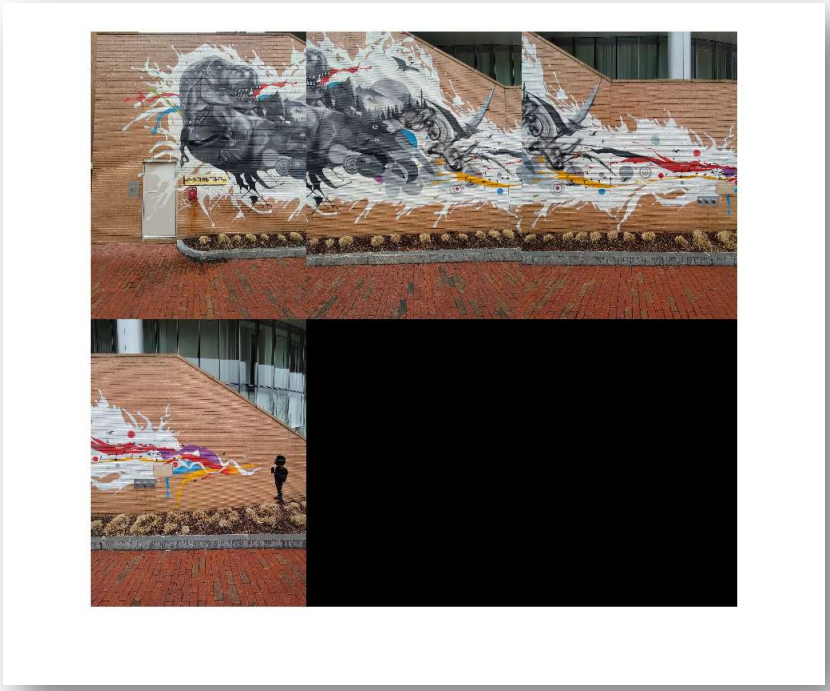

Figure17: Montage of Dragon graffiti with 15% overlapping

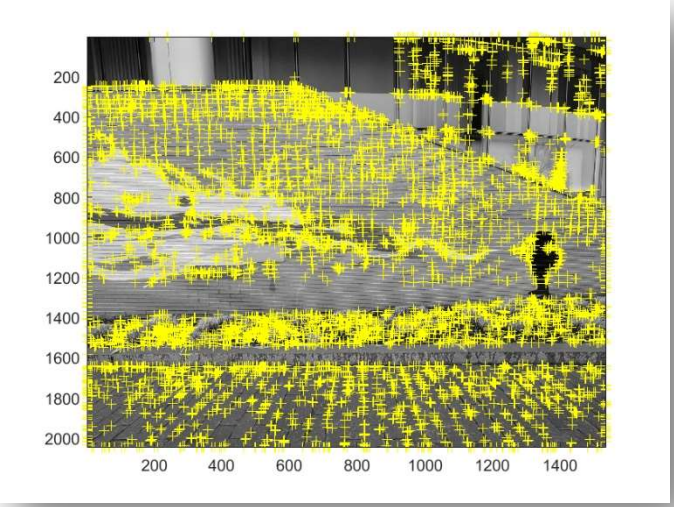


Figure18: Feature detected using Harris Corner detection (Fourth image from montage)

Figure19: Mosaic Image after applying Harris Corner Detection

## ***References:***

http://www.vision.caltech.edu/bouguetj/calib_doc/

https://www.mathworks.com/help/vision/ug/feature-based-panoramic-image-stitching.html?searchHighlight=panorama&s_tid=doc_srchtitle