LAB 5 ANALYSIS

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(Submitted with 4 of 4 grace days used)

PART A) Camera Calibration

Even though smartphone cameras are pre calibrated in factory, additional calibration is carried out to minimize the reprojection error through the use of a checkerboard patter (30x30mm squares in a 6 by 7 grid). Figure 1 shows the captured perspectives of the checker board from the camera's perspective and the checkerboard's perspective.

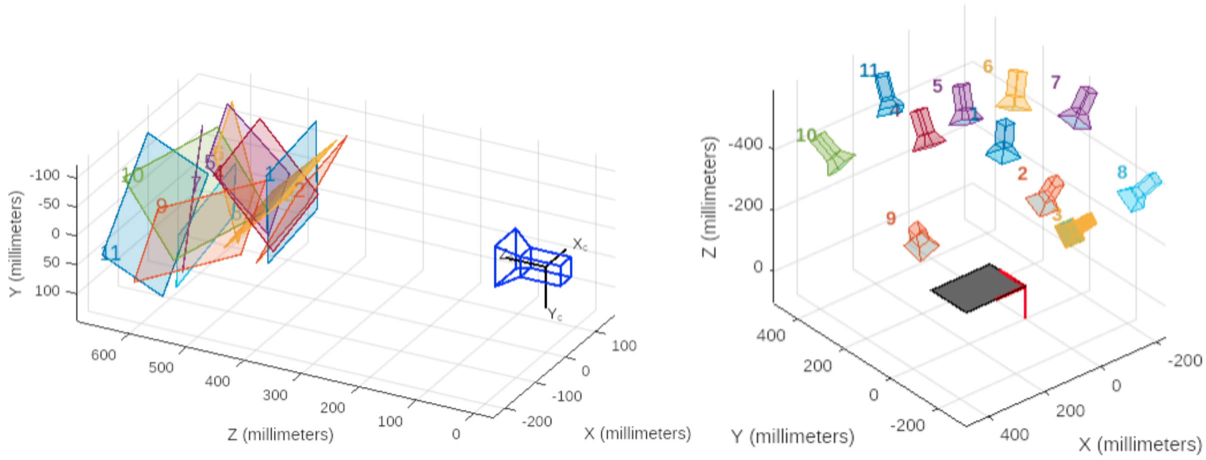

Figure 1. Frame perspectives (Camera frame and Checkerboard Frame)

The calibration toolbox in MATLAB handles the optimization of reprojection errors and returns camera calibration parameters for a desired level of error.

Figure 2 shows the reprojection error distribution over the 11 images captured for this purpose. The maximum mean-error in this case was 1.69 pixels, while the overall average was 1.26 pixels. Adding more images for calibration should ideally bring down this error value.

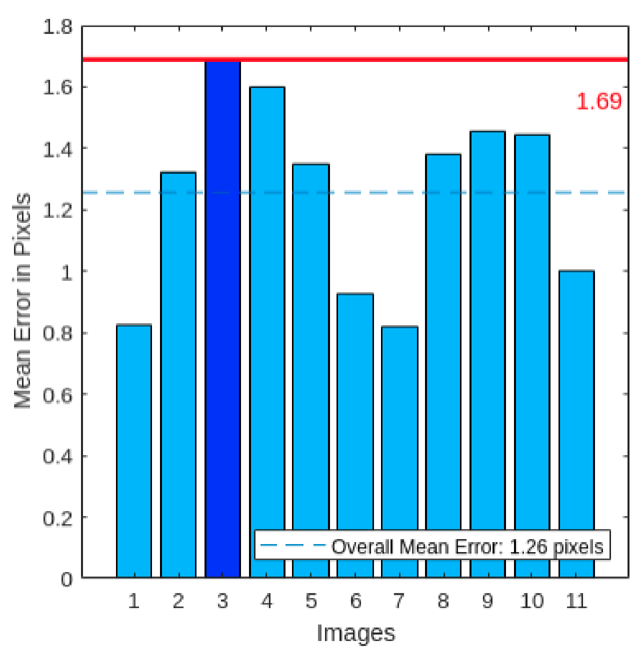

Figure 2. Reprojection error distribution

Figure 3 shows the error parameters estimated from this calibration procedure.

```
>> displayErrors(estimationErrors, cameraParams);

                         Standard Errors of Estimated Camera Parameters
                         ----------------------------------------------

Intrinsics
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Focal length (pixels):   [ 3057.6737 +/- 7.9843      3044.2453 +/- 8.6751  ]
Principal point (pixels):[ 2026.8852 +/- 3.2637       830.3477 +/- 4.0807  ]
Radial distortion:       [    0.1953 +/- 0.0170        -0.9631 +/- 0.1921        1.5281 +/- 0.6274  ]

Extrinsics
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Rotation vectors:
                         [   -0.0237 +/- 0.0020        -0.1093 +/- 0.0023        0.0138 +/- 0.0003  ]
                         [    0.4715 +/- 0.0019        -0.1071 +/- 0.0013        0.0188 +/- 0.0004  ]
                         [    0.7764 +/- 0.0016        -0.1078 +/- 0.0012        0.0372 +/- 0.0005  ]
                         [   -0.6885 +/- 0.0016        -0.1382 +/- 0.0011       -0.0499 +/- 0.0005  ]
                         [   -0.6915 +/- 0.0016        -0.3097 +/- 0.0012       -0.1274 +/- 0.0006  ]
                         [   -0.2536 +/- 0.0017        -0.3604 +/- 0.0016        0.0069 +/- 0.0005  ]
                         [    0.1197 +/- 0.0019        -0.4179 +/- 0.0018        0.0099 +/- 0.0005  ]
                         [    0.6039 +/- 0.0015        -0.4296 +/- 0.0012        0.2067 +/- 0.0006  ]
                         [    0.3269 +/- 0.0014         0.4348 +/- 0.0015        0.0090 +/- 0.0006  ]
                         [   -0.7425 +/- 0.0016         0.2876 +/- 0.0012        0.0537 +/- 0.0006  ]
                         [   -0.3593 +/- 0.0017         0.1392 +/- 0.0022       -0.7480 +/- 0.0005  ]

Translation vectors (millimeters):
                         [  -51.3266 +/- 0.4940       -74.2281 +/- 0.6134      458.8069 +/- 1.3253  ]
                         [  -58.1774 +/- 0.4332       -61.0379 +/- 0.5448      401.4392 +/- 1.0615  ]
                         [  -59.0243 +/- 0.4453       -49.2545 +/- 0.5647      418.7774 +/- 1.1370  ]
                         [ -106.8831 +/- 0.5417       -85.2441 +/- 0.6823      519.6834 +/- 1.2155  ]
                         [  -64.1784 +/- 0.5927       -76.2260 +/- 0.7339      556.2992 +/- 1.3604  ]
                         [  -39.5880 +/- 0.5988       -81.9745 +/- 0.7314      554.8429 +/- 1.5727  ]
                         [  -60.6937 +/- 0.6376       -30.5725 +/- 0.7830      580.3049 +/- 1.7264  ]
                         [  -41.3862 +/- 0.5627        13.7389 +/- 0.7097      521.2677 +/- 1.5146  ]
                         [ -239.2137 +/- 0.6008       -79.8522 +/- 0.7354      549.0575 +/- 1.3598  ]
                         [ -158.0834 +/- 0.6842       -74.0671 +/- 0.8569      652.0398 +/- 1.4511  ]
                         [ -240.3252 +/- 0.6979        22.6172 +/- 0.8515      646.0749 +/- 1.5898  ]
```

Figure 3. Standard camera parameter estimation error values (post calibration)

Additionally, Figure 4 depicts a sample photograph prior and post the calibration procedure. The calibration effects are negligible as expected due to the pre-calibration of the smartphone camera while being manufactured. However, there is an observable correction on the right-hand image with some minimal radial distortion being compensated, causing the image to look ‘flatter’.

Figure 4. Pre and post calibration photographs

Part B) Data Collection and Image Stitching

Three scenarios are used to generate mosaics.

- A building on Forsyth street- Structured entities with well-defined corners and high contrast edges and corners. The scene is shown in Figure 5.

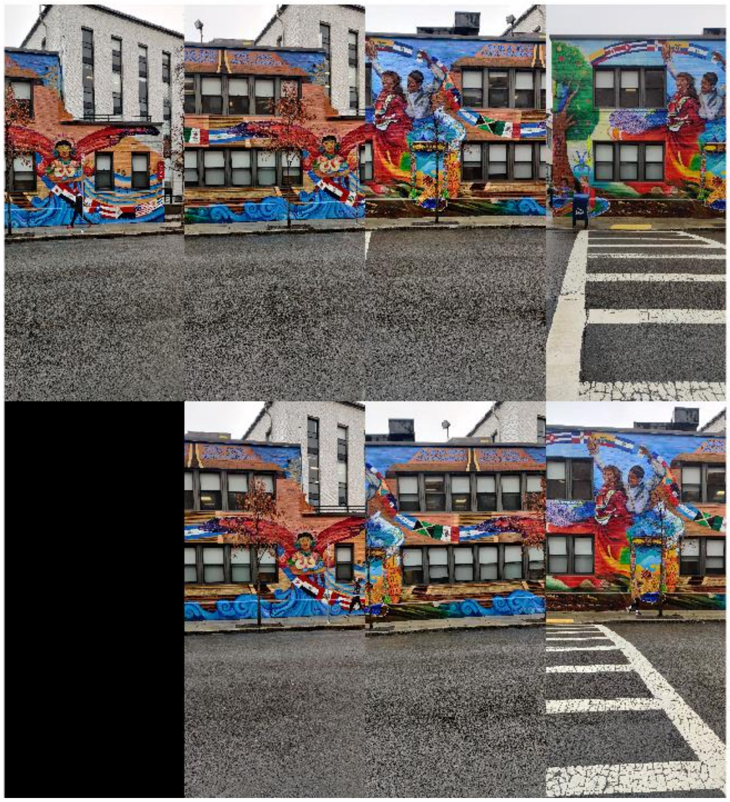

Figure 5. Mural scene

- A corridor with near monochrome low contrast cinder block walls. The scene is shown in Figure 6.

Figure 6. Cinder block scene

- An outdoor graffiti with few well defined corners or identifiable corners. This is shown in Figure 7.

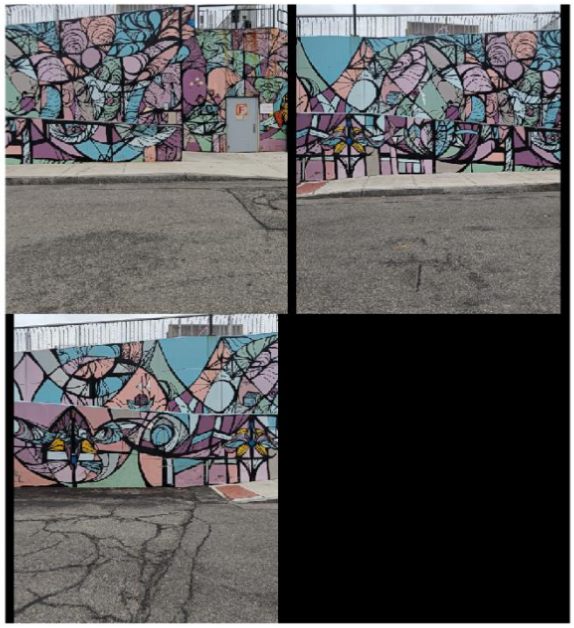

Figure 7. Graffiti scene

Part B1) Forsyth Building Mural

The scene in question was a dimly lit environment, and as such, contrast and exposure values varied a lot between consecutive shots. As such, various settings of the Harris corner detector were utilized in order to achieve the best mosaicking. To demonstrate the poor lighting and contrast conditions, 265 bin color histograms of sample images were formed, and it was observed there was a sharp discrepancy in the nature of the sample images 1 through 7. As such, histogram equalization with 256 sample bins was performed to somewhat equalize the contrast and color conditions before mosaicking is performed.

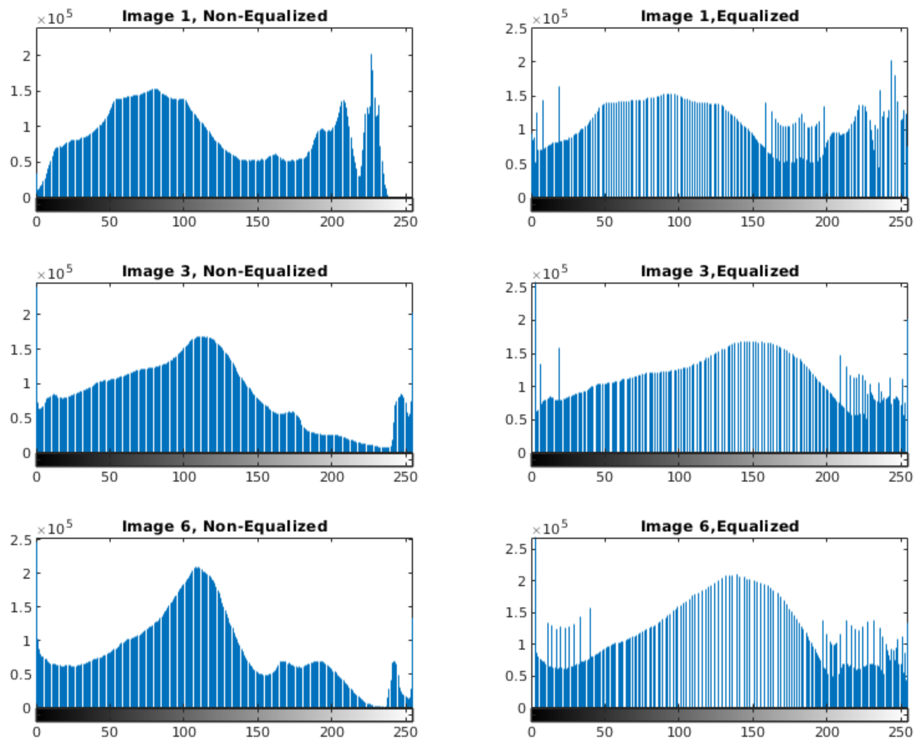

Figure 8. Histogram equalization (Forsyth Building Mural Scene)

Figure 8 shows the before and after of the histogram equalization procedure. Image 1 is strikingly different in the color nature which caused mosaicking to be poor without initialization.

For mosaicking, the Harris detector tile size and number of sample points are varied in order to achieve an acceptable mosaic. The tile size arrays used are T = [4,4] and T = [10,10] with the number of samples as N = 10000 or N = 20000. The best mosaic achieved was for the case of T = [4,4] with N = 20000. The top 2000 detected features with the most cornerness function response for one of the sample images is shown in Figure 9**.** All the images in the mosaic are scaled by a factor of 0.3 to account for the massive pixel count of these images making computation extremely slow.

*Figure 9. Detected features (**Left**: Non-equalized; **Right**: Equalized)*

Figure 10 shows how the features match between consecutive images when stitching them together. It can be observed there are outliers with dissimilar points from the top and bottom of the image getting unavoidably matched with each other.

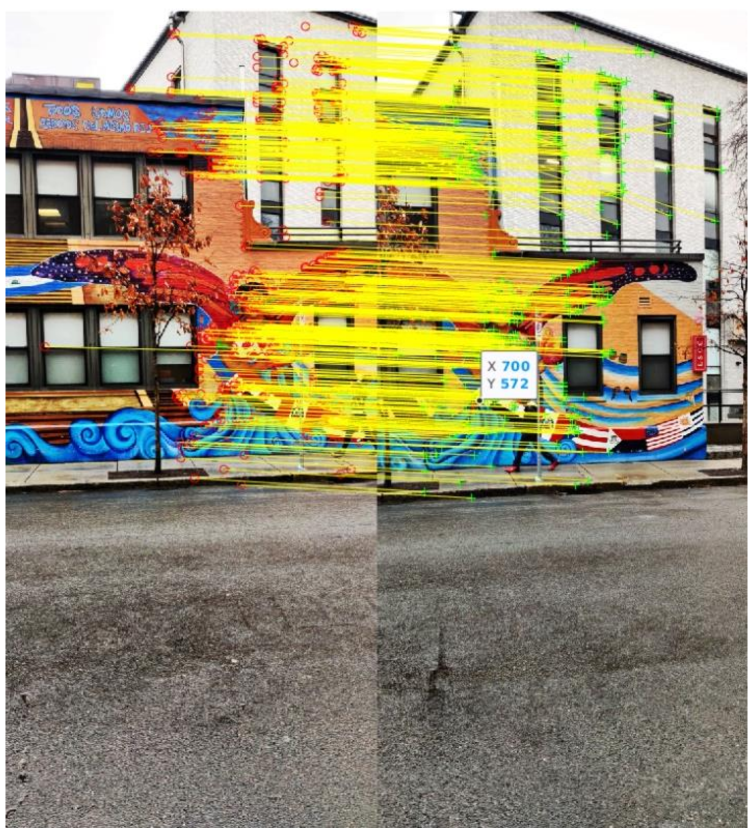

Figure 10. Matched features during image stitching

The mosaicking was performed on both the equalized and non-equalized images and it was observed that equalization did improve stitching results, however there were some regions in the left half of the mosaic (the zebra crossing for instance) which could not be improved upon. This could be due to poor handling of the camera while collecting samples, or a below threshold overlap between the samples, which does not allow for good associativity. Figure 11 shows the mosaicking results for the case of non-equalized samples, while Figure 12 shows improves upon the earlier mosaic with histogram equalization. The bin size is [4,4] and the number of samples in each case were taken as 10000.

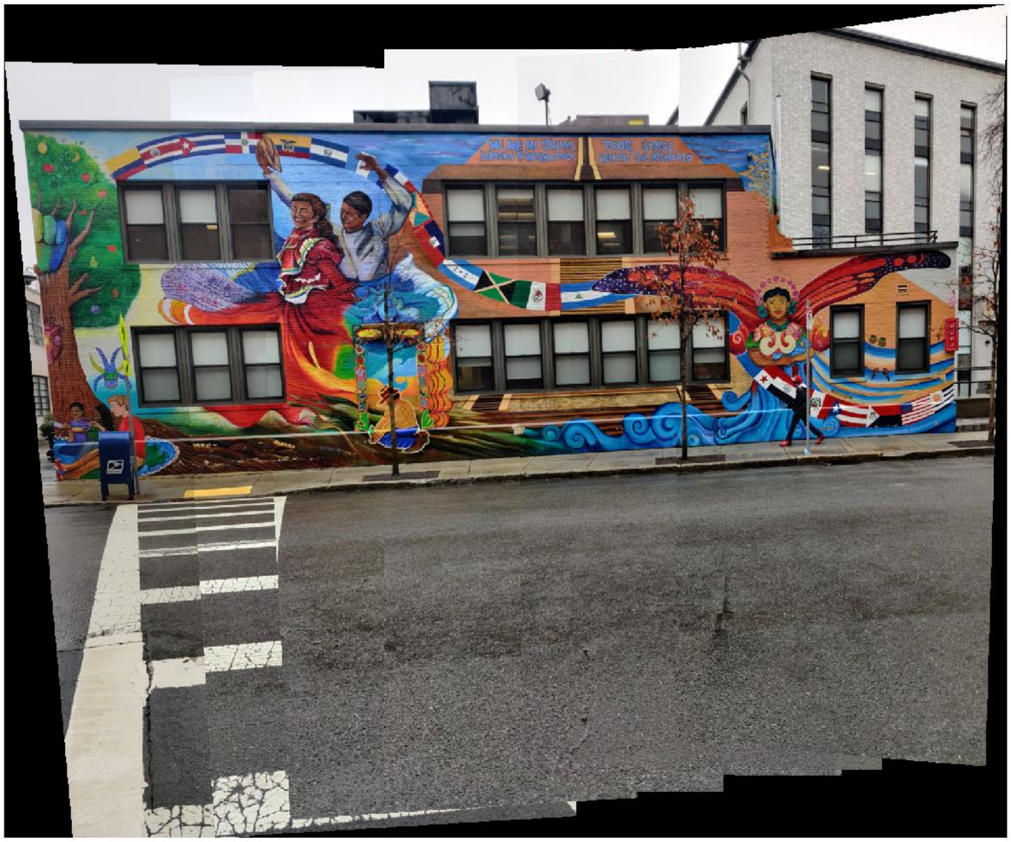

Figure 11. Forsyth mural mosaic (non-equalized)

Figure 12. Forsyth mural mosaic (equalized)

Part B2) Cinder Block wall

This was a challenging environment to mosaic with monochromatic features and low contrast lighting. Figure 13 shows the image histograms with histogram equalization performed on the 7 sample images.

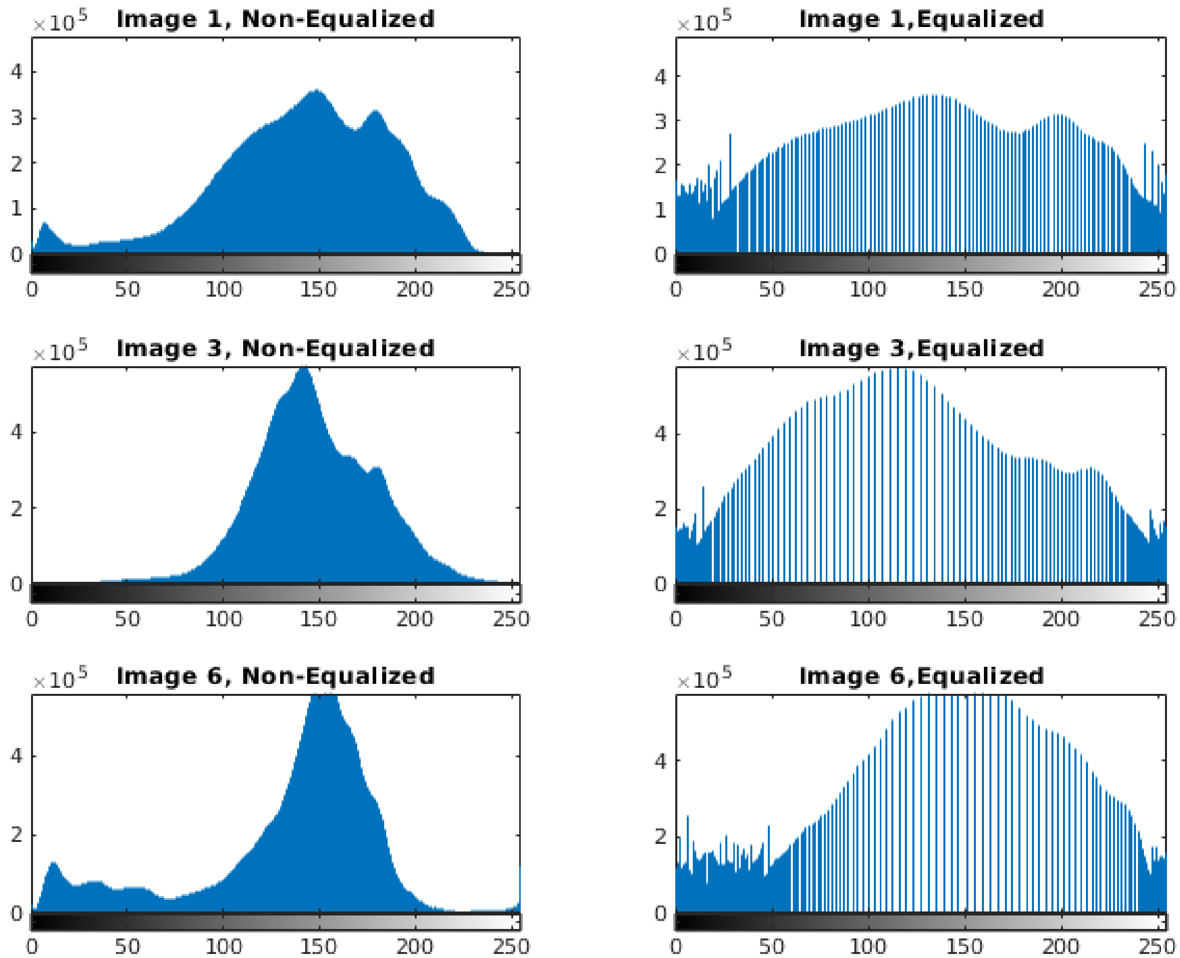

Figure 13. Histogram equalization (Cinder block wall scene)

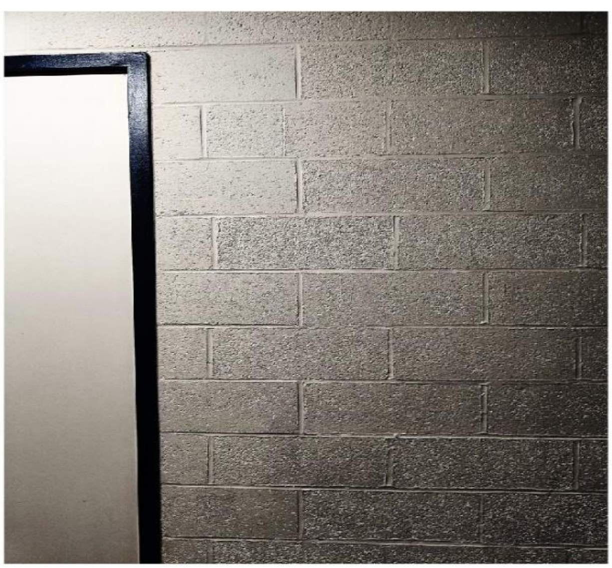

Figure 14. Undesirable contrast characteristics from histogram equalization

In this case, histogram equalization resulted in an undesirable level of contrast which caused a loss of discernible features and colored features, Error! Reference source not found. shows one of the sample images with histogram equalization performed on it.

This caused feature matching to eventually fail when using the Harris corner detector. As such the stitching process was carried out without histogram equalization.

For the Harris detector, a tile size of T = [2,2] with N=20000 sample points are used. The top 2000 detected features with the most cornerness function response for one of the sample images is shown in Figure 15**.** All the images in the mosaic are scaled by a factor of 0.3 to account for the massive pixel count of these images making computation extremely slow.

Figure 15. Detected Harris features (Cinder block wall scene)

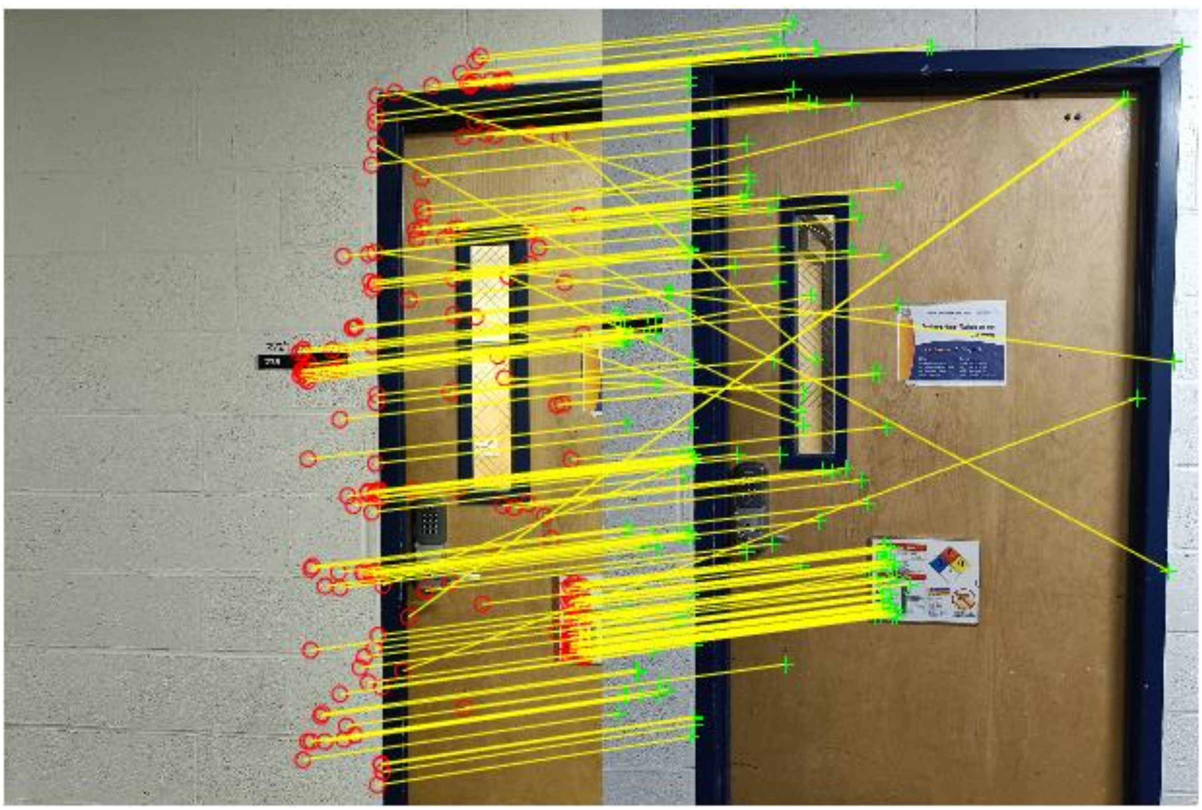

Figure 16. Matched features while stitching (Cinder block wall)

Figure 16 depicts the matched features between consecutive images. The featurelessness causes significantly more mismatches than the mural scene, resulting in a fairly incoherent mosaic. Figure 17 shows the final results for this scene. Lighting changes across the corridor significantly affected the perspective aligment, with some portions of the panorama looking tilted. However, the block alignments were maintained in this case.

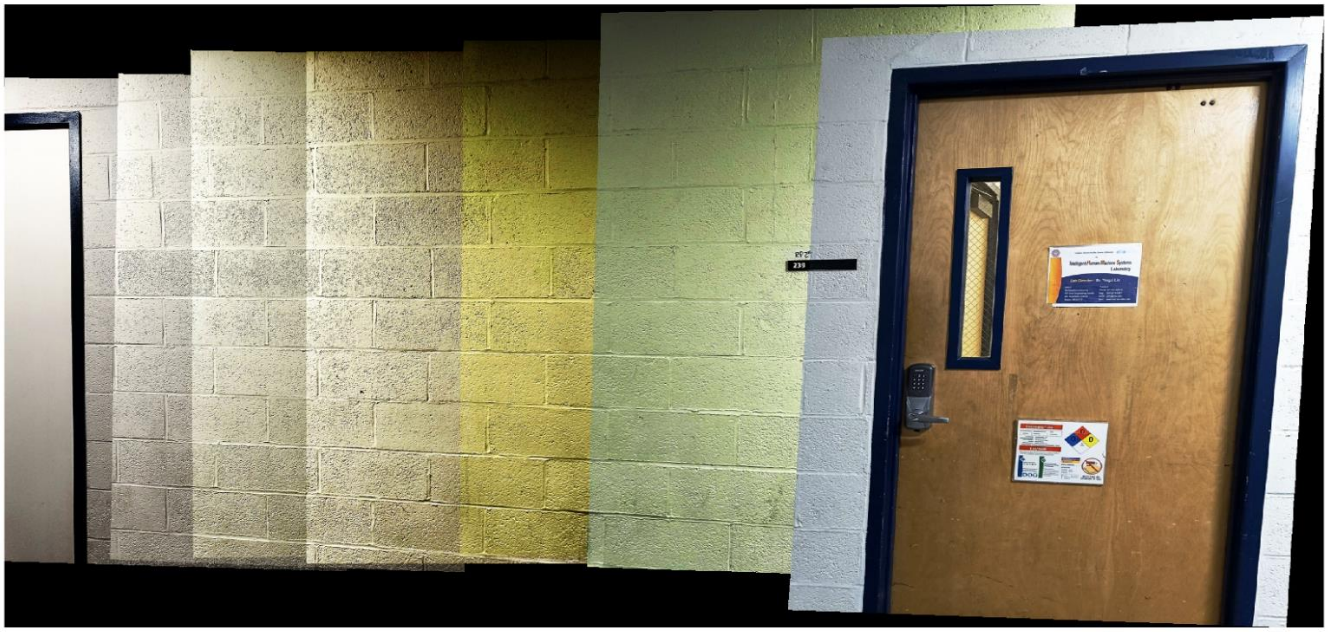

Figure 17. Cinder block wall mosaic (non-equalized)

Part B3) Graffiti Wall

This scene involved minimal (~15%) overlapping images of a wall graffiti with few discernible straight edges and corners. Since the scenario was an outdoor one, adverse lighting conditions prompted the use of histogram equalization to enhance the mosaicking performance. Figure depicts the image histograms with histogram equalization performed on the 3 sample images.

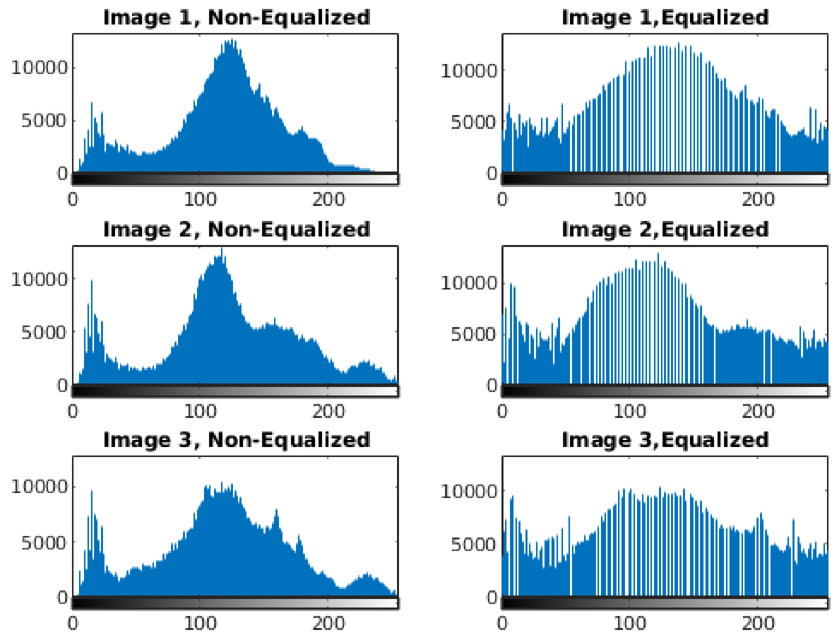

Figure 18. Histogram equalization (Cinder block wall scene

For the Harris detector, a tile size of T = [5,5] with N=20000 sample points are used. The top 5000 detected features with the most cornerness function response for one of the sample images is shown in Figure 19**.** All the images in the mosaic are scaled by a factor of 0.5.

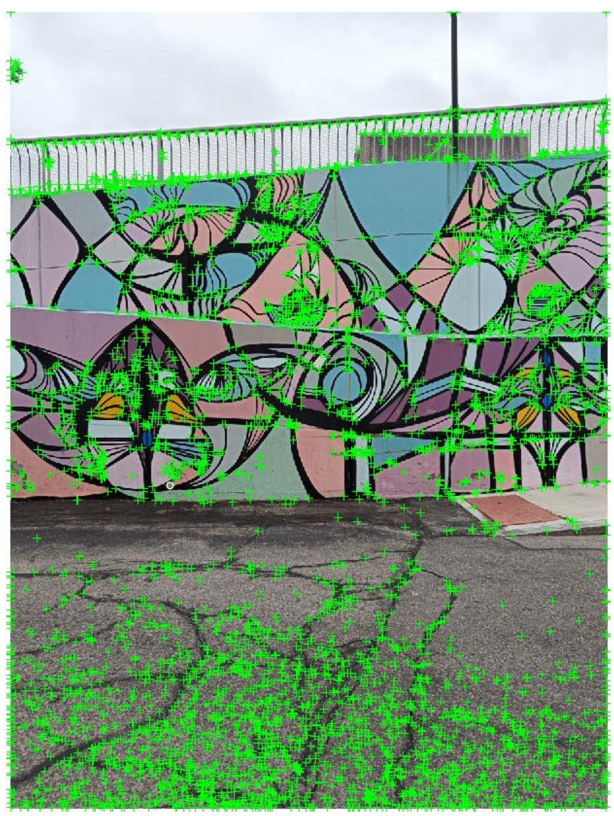

Figure 19. Detected Harris features (Graffiti scene)

Figure 20. depicts the matched features between consecutive images. The featurelessness causes significantly more mismatches than the mural scene, resulting in a fairly incoherent mosaic.

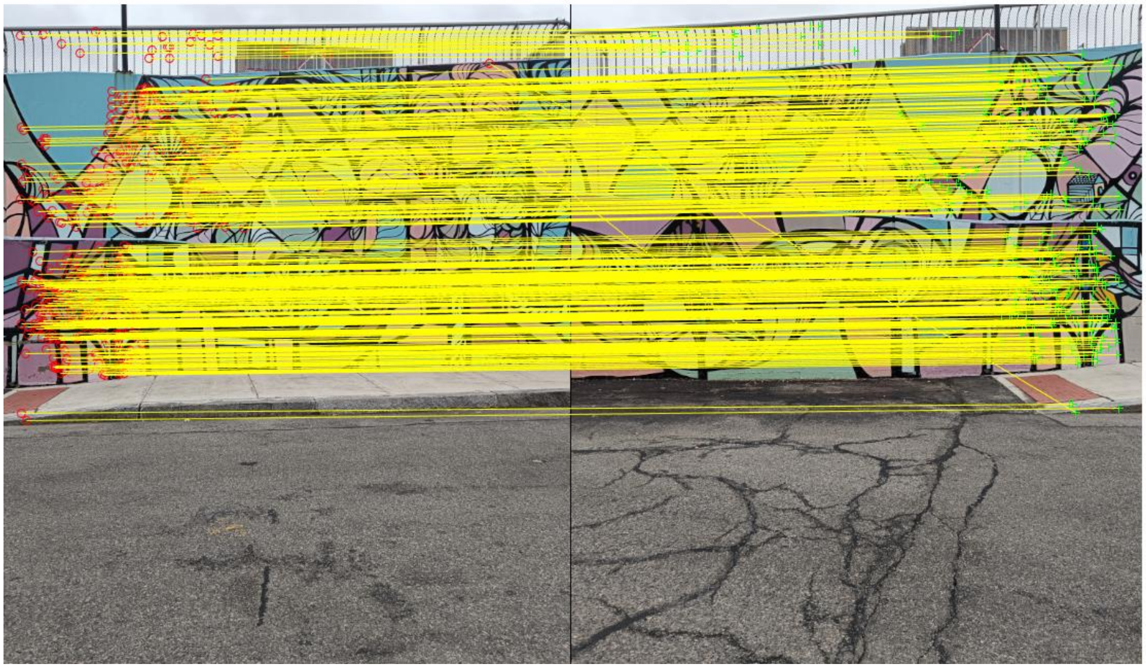

Figure 20. Matched features (Graffiti scene)

Figure 21 shows the final mosaic for this scenario. The lack of discernible features due to the 15% overlap criterion and few straight edges causes the stictch to be suboptimal with jarred transitions.

Figure 21. Graffiti wall mosaic (equalized)