

EECE 5554 Robotics Sensing and Navigation LAB 5

Calibration and photomosaicing using RGB camera

Data Analysis by: Arvinder Singh

1 late day used



Description

In this lab, we are first calibrating our camera to find the reprojection error and then we are using Harris detector to extract features from an image and then we are using those features to stitch together a set of images and create a panorama.

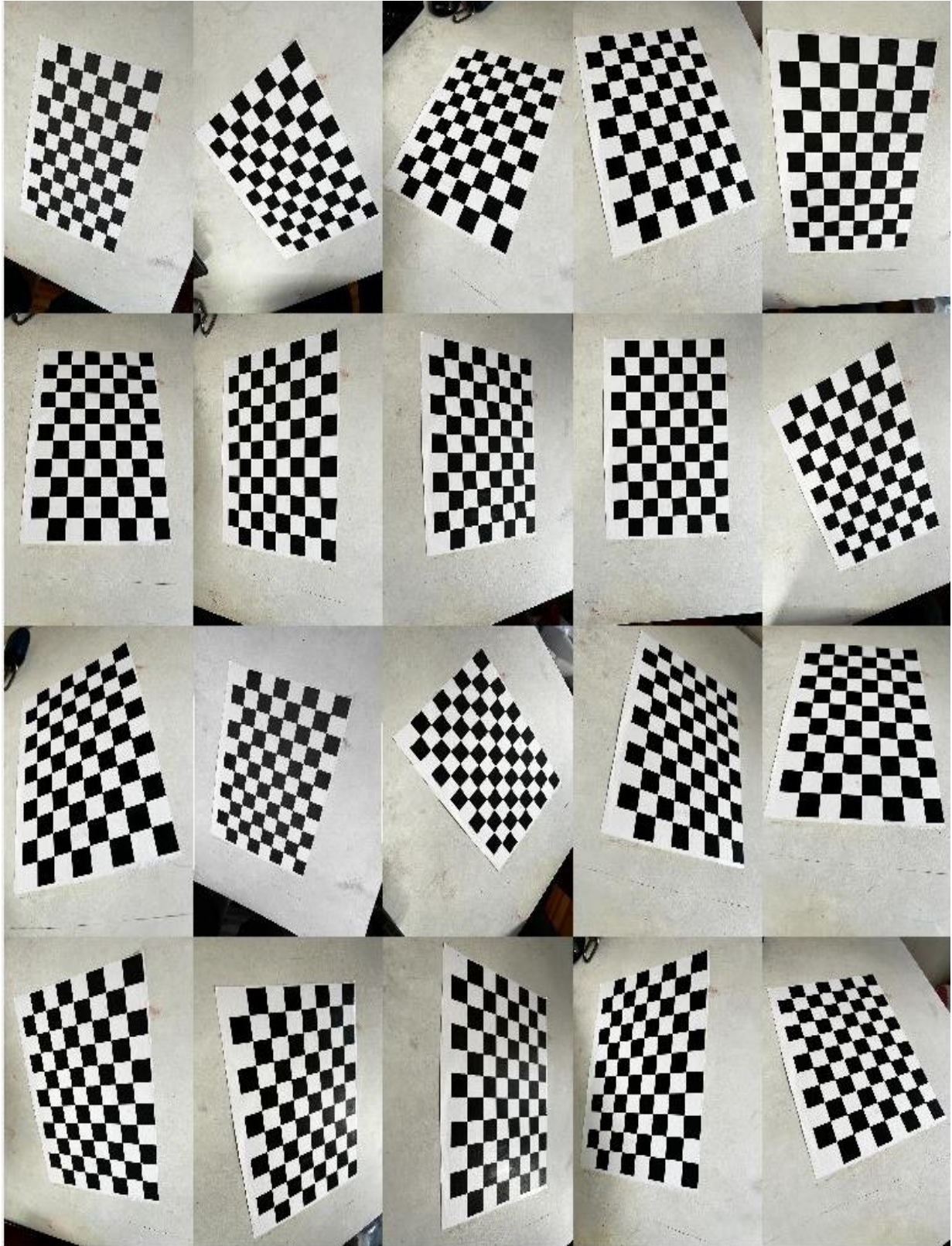
Data Set collection:

1. Camera Calibration
2. Latino Students Center building (50% overlap)
3. Cinder block wall (50% overlap)
4. Dinosaur Mural (15% overlap)

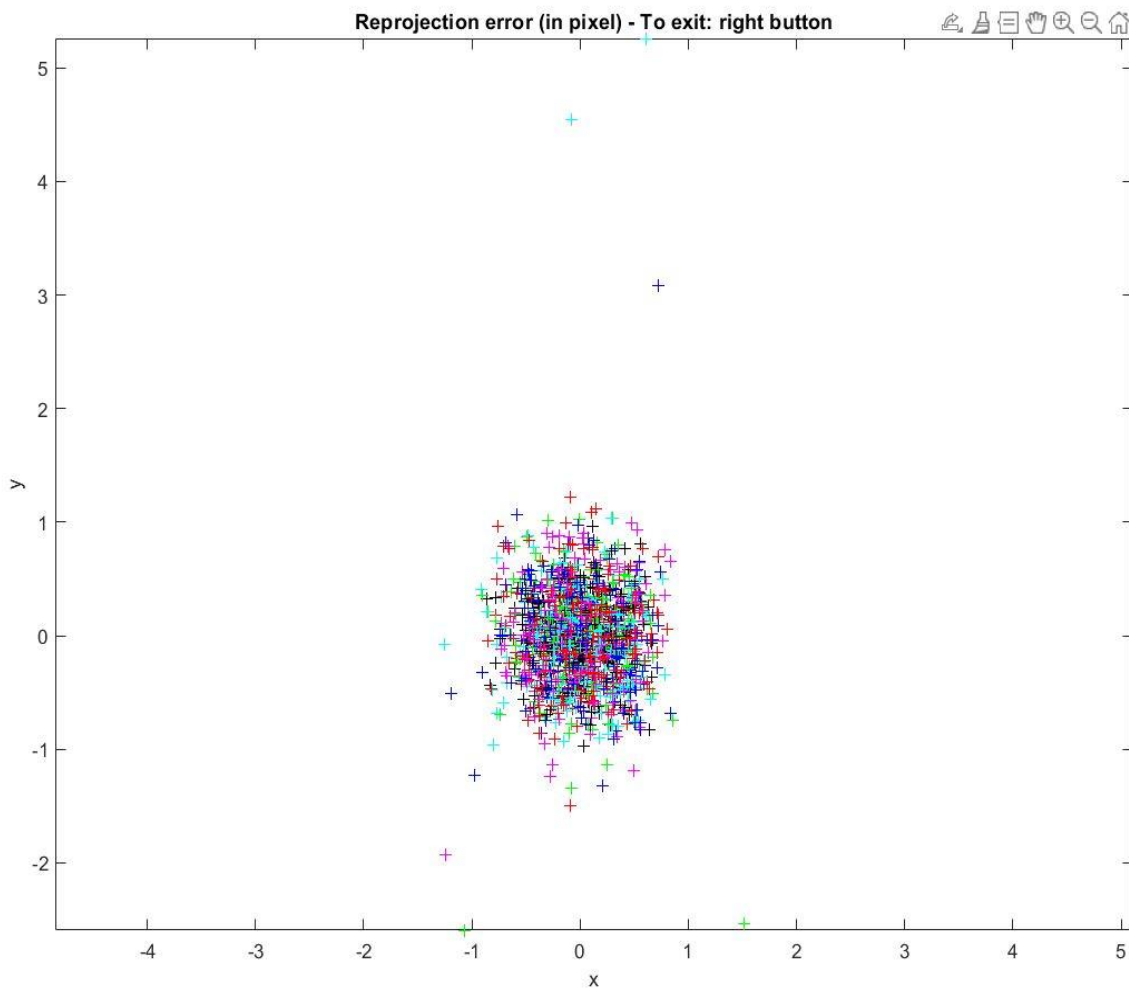
1. Camera Calibration:

Calibration Pictures:

(Length of squares = breadth of squares = 25mm)



Reprojection pixel error:



Calibration parameters:

Calibration results (with uncertainties):

Focal Length: $fc = [1225.93317 \quad 1221.86867] \pm [2.37921 \quad 2.45103]$
Principal point: $cc = [590.07217 \quad 809.13705] \pm [1.89713 \quad 2.43884]$
Skew: $\alpha_c = [0.00000] \pm [0.00000] \Rightarrow \text{angle of pixel axes} = 90.00000 \pm 0.00000 \text{ degrees}$
Distortion: $kc = [0.12084 \quad -0.31294 \quad -0.00004 \quad 0.00038 \quad 0.00000] \pm [0.00607 \quad 0.02132 \quad 0.00088 \quad 0.00064 \quad 0.00000]$
Pixel error: $err = [0.35115 \quad 0.45917]$

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


```

%-- Focal length:
fc = [ 1225.933174625423590 ; 1221.868668962815946 ];

%-- Principal point:
cc = [ 590.072165553389937 ; 809.137050533510092 ];

%-- Skew coefficient:
alpha_c = 0.000000000000000;

%-- Distortion coefficients:
kc = [ 0.120841621886988 ; -0.312938161108367 ; -0.000042921339600 ;
0.000382916777326 ; 0.000000000000000 ];

%-- Focal length uncertainty:
fc_error = [ 2.379211425614602 ; 2.451033173211635 ];

%-- Principal point uncertainty:
cc_error = [ 1.897128182379947 ; 2.438841626192407 ];

%-- Skew coefficient uncertainty:
alpha_c_error = 0.000000000000000;

%-- Distortion coefficients uncertainty:
kc_error = [ 0.006066196026168 ; 0.021316941937553 ; 0.000878676978308 ;
0.000636118153779 ; 0.000000000000000 ];

%-- Image size:
nx = 1200;
ny = 1600;

%-- Various other variables (may be ignored if you do not use the Matlab
Calibration Toolbox):
%-- Those variables are used to control which intrinsic parameters should be
optimized

n_ima = 20; % Number of calibration images
est_fc = [ 1 ; 1 ]; % Estimation indicator of the two
focal variables
est_aspect_ratio = 1; % Estimation indicator of the aspect
ratio fc(2)/fc(1)
center_optim = 1; % Estimation indicator of the
principal point
est_alpha = 0; % Estimation indicator of the
skew coefficient
est_dist = [ 1 ; 1 ; 1 ; 1 ; 0 ]; % Estimation indicator of the distortion
coefficients

%-- Extrinsic parameters:
%-- The rotation (omc_kk) and the translation (Tc_kk) vectors for every
calibration image and their uncertainties

%-- Image #1:
omc_1 = [ -1.677303e+00 ; -2.224436e+00 ; -6.640861e-02 ];
Tc_1 = [ -7.055412e+01 ; -1.332921e+02 ; 3.336913e+02 ];
omc_error_1 = [ 1.956478e-03 ; 1.945776e-03 ; 3.968422e-03 ];
Tc_error_1 = [ 5.289985e-01 ; 6.797607e-01 ; 7.815114e-01 ];

```

```

%-- Image #2:
omc_2 = [ 1.050205e+00 ; 2.628360e+00 ; 2.198539e-01 ];
Tc_2 = [ 8.546530e+00 ; -1.687691e+02 ; 3.665879e+02 ];
omc_error_2 = [ 1.253180e-03 ; 2.675288e-03 ; 3.982419e-03 ];
Tc_error_2 = [ 5.885895e-01 ; 7.400789e-01 ; 8.729886e-01 ];

%-- Image #3:
omc_3 = [ 1.884334e+00 ; 1.947728e+00 ; -4.668757e-01 ];
Tc_3 = [ -6.217260e+01 ; -1.860060e+02 ; 3.461451e+02 ];
omc_error_3 = [ 1.594088e-03 ; 1.908634e-03 ; 2.980548e-03 ];
Tc_error_3 = [ 5.757820e-01 ; 7.105347e-01 ; 7.010700e-01 ];

%-- Image #4:
omc_4 = [ -1.950608e+00 ; -1.759281e+00 ; 1.652224e-01 ];
Tc_4 = [ -1.009957e+02 ; -1.034706e+02 ; 3.096966e+02 ];
omc_error_4 = [ 1.925952e-03 ; 1.335885e-03 ; 3.021736e-03 ];
Tc_error_4 = [ 4.872640e-01 ; 6.261403e-01 ; 6.433642e-01 ];

%-- Image #5:
omc_5 = [ 2.211812e+00 ; 1.837037e+00 ; 7.384224e-01 ];
Tc_5 = [ -4.493735e+01 ; -7.792935e+01 ; 2.361004e+02 ];
omc_error_5 = [ 2.103365e-03 ; 1.214678e-03 ; 3.197955e-03 ];
Tc_error_5 = [ 3.812138e-01 ; 4.768716e-01 ; 5.917494e-01 ];

%-- Image #6:
omc_6 = [ 1.832701e+00 ; 1.849231e+00 ; 5.846232e-01 ];
Tc_6 = [ -1.128600e+01 ; -1.217088e+02 ; 2.587859e+02 ];
omc_error_6 = [ 1.978914e-03 ; 1.308388e-03 ; 2.827830e-03 ];
Tc_error_6 = [ 4.193282e-01 ; 5.180323e-01 ; 6.222110e-01 ];

%-- Image #7:
omc_7 = [ -2.002740e+00 ; -2.073341e+00 ; 6.469975e-01 ];
Tc_7 = [ -9.719512e+01 ; -1.480629e+02 ; 3.613004e+02 ];
omc_error_7 = [ 1.983038e-03 ; 1.291006e-03 ; 3.438216e-03 ];
Tc_error_7 = [ 5.819444e-01 ; 7.391108e-01 ; 7.111323e-01 ];

%-- Image #8:
omc_8 = [ 2.156347e+00 ; 1.491739e+00 ; -1.780798e-01 ];
Tc_8 = [ -1.116695e+02 ; -1.377171e+02 ; 3.449385e+02 ];
omc_error_8 = [ 2.024853e-03 ; 1.530677e-03 ; 2.813000e-03 ];
Tc_error_8 = [ 5.528311e-01 ; 7.016098e-01 ; 7.258464e-01 ];

%-- Image #9:
omc_9 = [ -1.486920e+00 ; -2.448738e+00 ; -9.477938e-01 ];
Tc_9 = [ -1.217102e+01 ; -1.051624e+02 ; 2.767600e+02 ];
omc_error_9 = [ 1.217224e-03 ; 2.381542e-03 ; 3.496409e-03 ];
Tc_error_9 = [ 4.452570e-01 ; 5.729389e-01 ; 7.340943e-01 ];

%-- Image #10:
omc_10 = [ -8.074942e-01 ; -2.711039e+00 ; -5.918022e-01 ];
Tc_10 = [ 6.283747e+00 ; -1.010638e+02 ; 2.827408e+02 ];
omc_error_10 = [ 1.044085e-03 ; 2.345851e-03 ; 3.694660e-03 ];
Tc_error_10 = [ 4.506443e-01 ; 5.812804e-01 ; 7.171328e-01 ];

%-- Image #11:
omc_11 = [ 1.583390e+00 ; 2.429496e+00 ; -7.212475e-01 ];
Tc_11 = [ -9.209976e+00 ; -1.630720e+02 ; 3.944672e+02 ];
omc_error_11 = [ 1.185596e-03 ; 2.199562e-03 ; 3.442983e-03 ];

```

```
Tc_error_11 = [ 6.288000e-01 ; 7.975469e-01 ; 7.340916e-01 ];
```

```
%-- Image #12:
```

```
omc_12 = [ 2.176993e+00 ; 1.644160e+00 ; -9.414998e-02 ];  
Tc_12 = [ -1.041134e+02 ; -1.408156e+02 ; 3.148233e+02 ];  
omc_error_12 = [ 1.968935e-03 ; 1.566691e-03 ; 3.043287e-03 ];  
Tc_error_12 = [ 5.086240e-01 ; 6.391106e-01 ; 6.914872e-01 ];
```

```
%-- Image #13:
```

```
omc_13 = [ -2.020862e+00 ; -2.054554e+00 ; -5.072901e-01 ];  
Tc_13 = [ -6.994290e+01 ; -9.916654e+01 ; 2.447059e+02 ];  
omc_error_13 = [ 1.675029e-03 ; 1.867603e-03 ; 3.398927e-03 ];  
Tc_error_13 = [ 3.975752e-01 ; 5.108225e-01 ; 5.849385e-01 ];
```

```
%-- Image #14:
```

```
omc_14 = [ 2.023584e+00 ; 2.014435e+00 ; -3.265071e-01 ];  
Tc_14 = [ -7.161749e+01 ; -1.561236e+02 ; 3.536340e+02 ];  
omc_error_14 = [ 1.737910e-03 ; 1.883009e-03 ; 3.430130e-03 ];  
Tc_error_14 = [ 5.678454e-01 ; 7.131822e-01 ; 7.287361e-01 ];
```

```
%-- Image #15:
```

```
omc_15 = [ -1.994619e+00 ; -1.992764e+00 ; 4.253397e-01 ];  
Tc_15 = [ -8.614794e+01 ; -1.414458e+02 ; 3.551110e+02 ];  
omc_error_15 = [ 2.046226e-03 ; 1.452459e-03 ; 3.520789e-03 ];  
Tc_error_15 = [ 5.667720e-01 ; 7.161371e-01 ; 7.303917e-01 ];
```

```
%-- Image #16:
```

```
omc_16 = [ 2.009448e+00 ; 1.936572e+00 ; 4.060372e-01 ];  
Tc_16 = [ -5.108681e+01 ; -1.473248e+02 ; 3.146466e+02 ];  
omc_error_16 = [ 2.042550e-03 ; 1.644680e-03 ; 3.478667e-03 ];  
Tc_error_16 = [ 5.146695e-01 ; 6.338310e-01 ; 7.705518e-01 ];
```

```
%-- Image #17:
```

```
omc_17 = [ 2.213019e+00 ; 2.145774e+00 ; 1.076250e-02 ];  
Tc_17 = [ -7.072732e+01 ; -1.589253e+02 ; 3.385470e+02 ];  
omc_error_17 = [ 2.211246e-03 ; 2.295310e-03 ; 4.772495e-03 ];  
Tc_error_17 = [ 5.491610e-01 ; 6.820841e-01 ; 8.017708e-01 ];
```

```
%-- Image #18:
```

```
omc_18 = [ -2.412463e+00 ; -1.576194e+00 ; -2.616514e-01 ];  
Tc_18 = [ -9.825275e+01 ; -6.794384e+01 ; 3.193962e+02 ];  
omc_error_18 = [ 2.539059e-03 ; 1.766809e-03 ; 3.855261e-03 ];  
Tc_error_18 = [ 5.059367e-01 ; 6.481178e-01 ; 7.336941e-01 ];
```

```
%-- Image #19:
```

```
omc_19 = [ 2.316649e+00 ; 1.827844e+00 ; -8.441163e-01 ];  
Tc_19 = [ -1.095920e+02 ; -1.142154e+02 ; 3.578182e+02 ];  
omc_error_19 = [ 1.476001e-03 ; 2.050895e-03 ; 3.090352e-03 ];  
Tc_error_19 = [ 5.687110e-01 ; 7.328976e-01 ; 6.184315e-01 ];
```

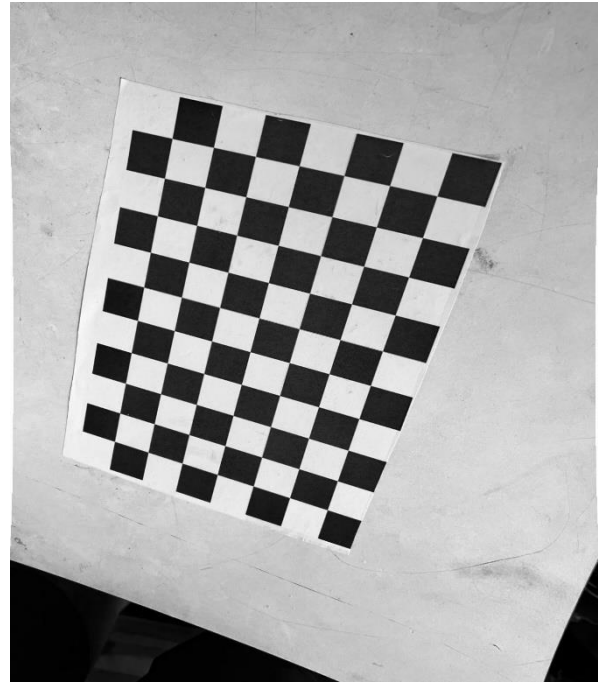
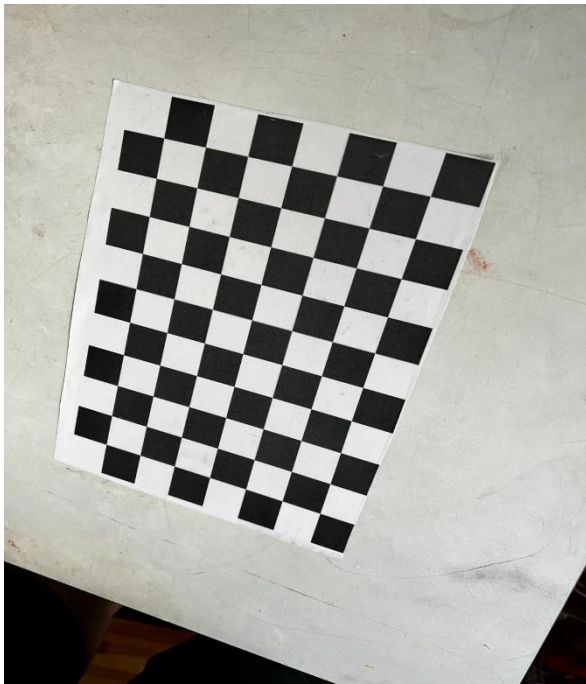
```
%-- Image #20:
```

```
omc_20 = [ 1.610279e+00 ; 1.971731e+00 ; 2.684963e-02 ];  
Tc_20 = [ -1.344272e+01 ; -1.741275e+02 ; 3.302510e+02 ];  
omc_error_20 = [ 1.741716e-03 ; 1.626571e-03 ; 2.774223e-03 ];  
Tc_error_20 = [ 5.401302e-01 ; 6.656576e-01 ; 7.150993e-01 ];
```

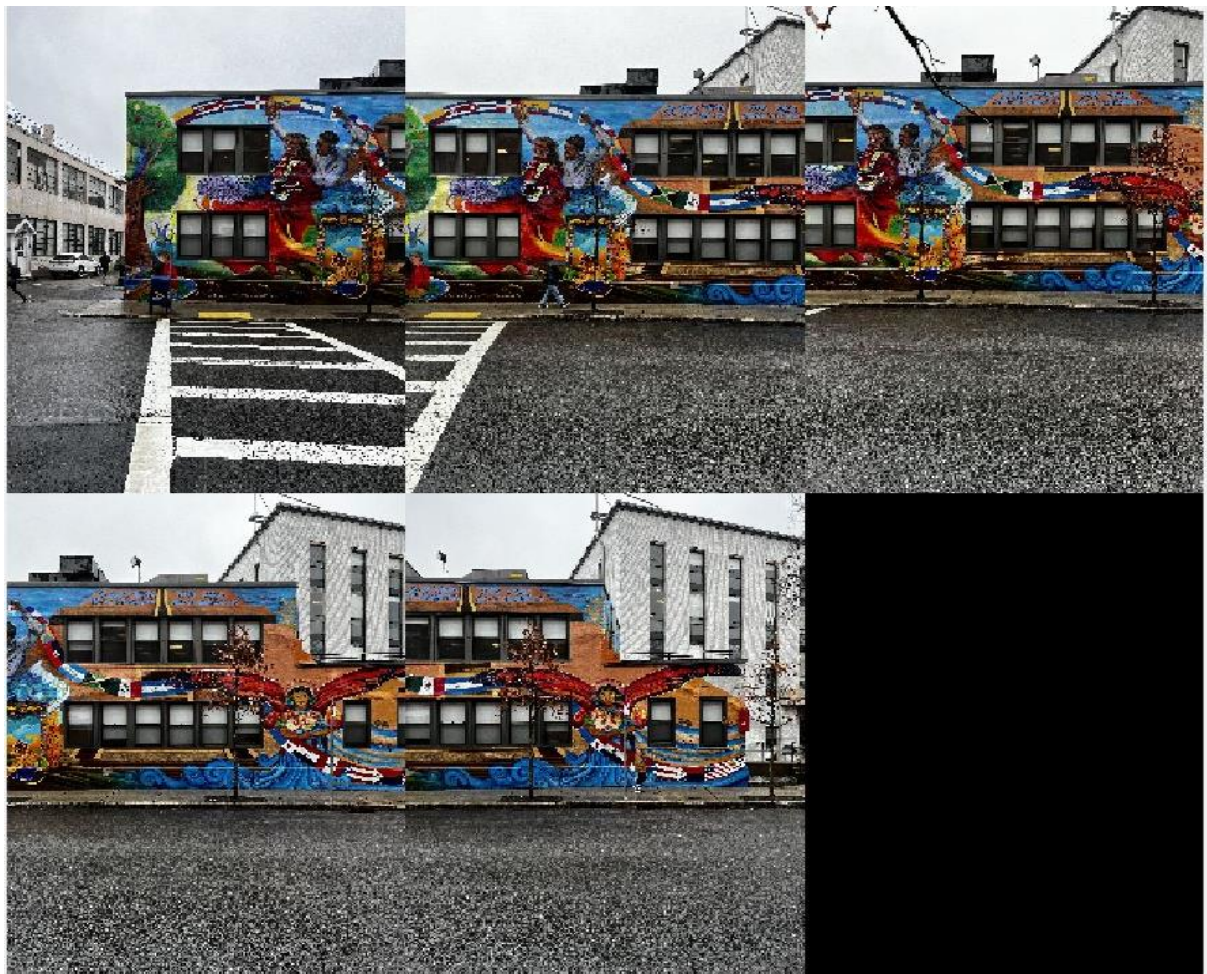
Image before

and

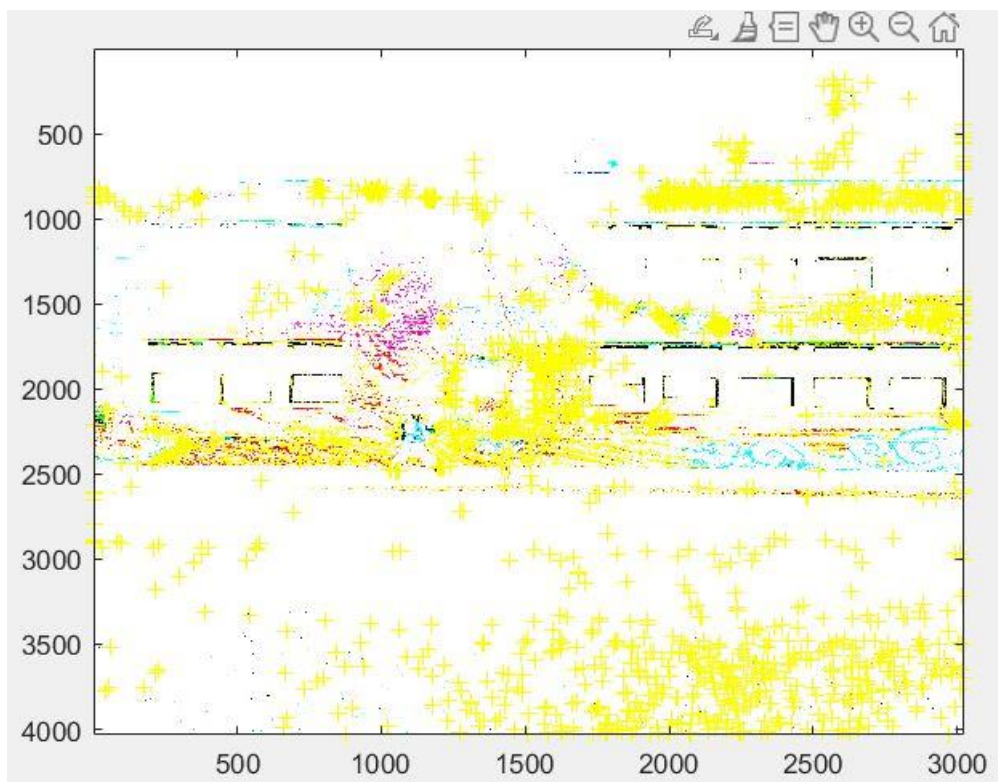
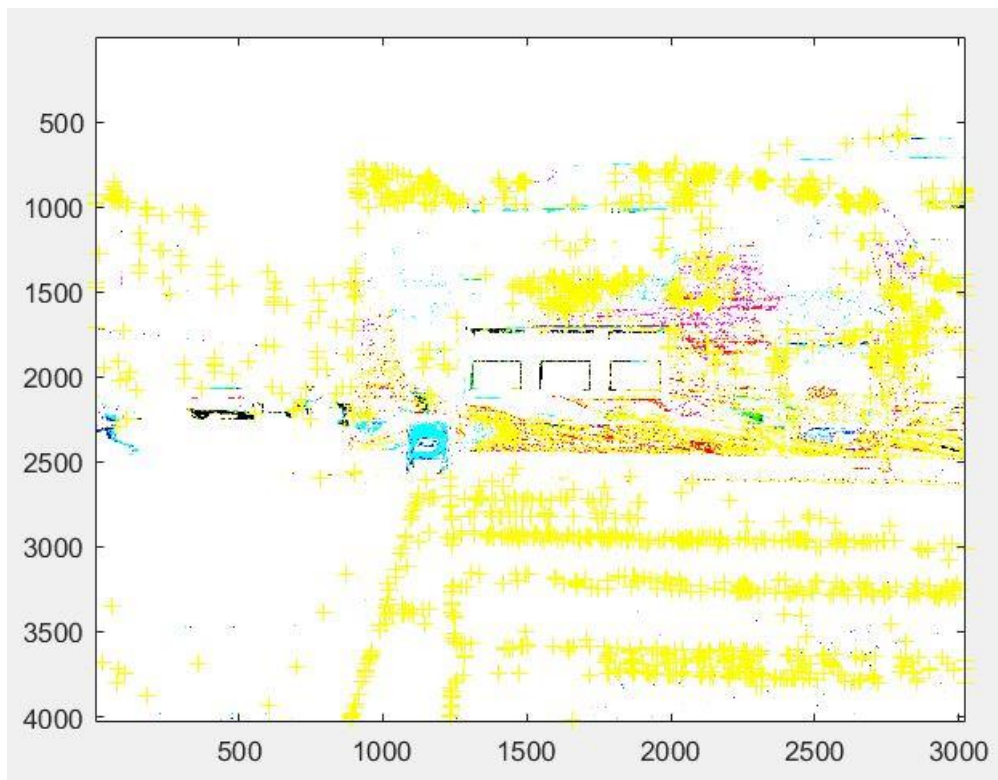
after calibration:



2. Mosaic Latino Students Center building (50% overlap)



Distribution of Harris Corners:



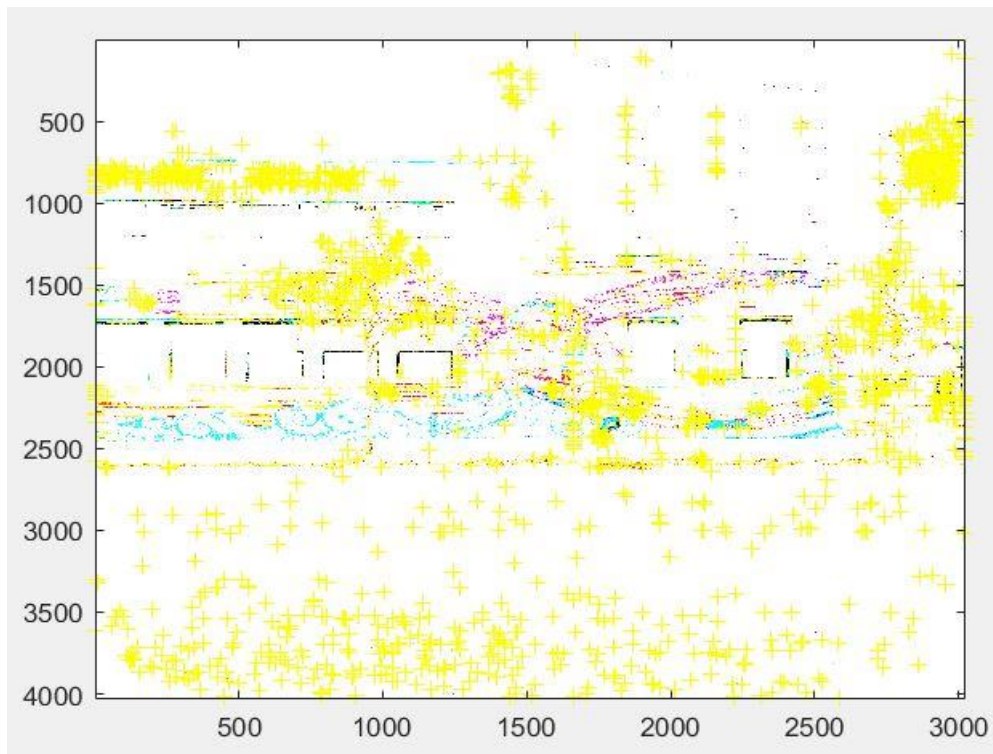


Image stitching using default settings:

```
[y,x,m] = harris(I,2000,'tile',[2 2],'disp')
```

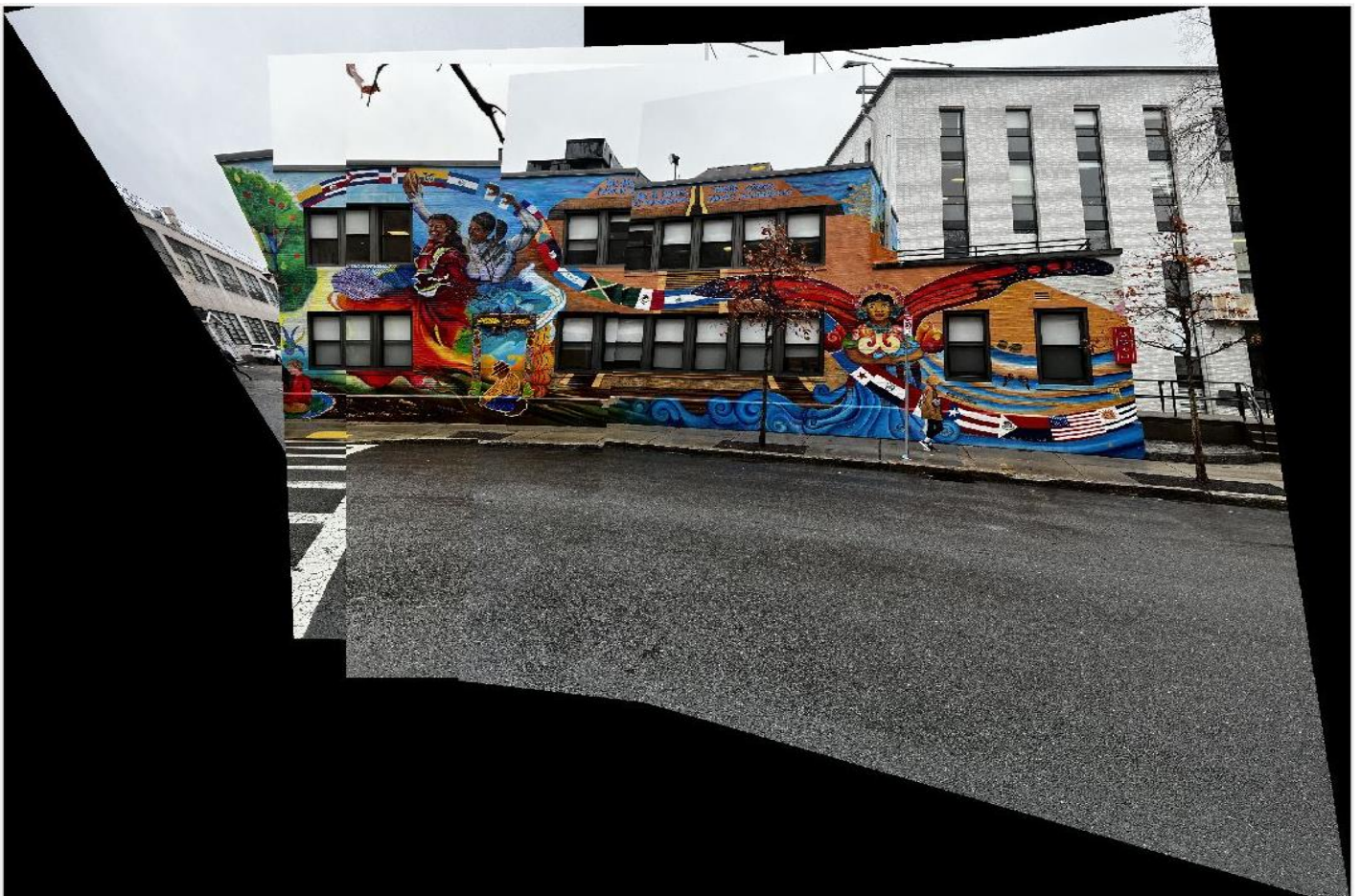
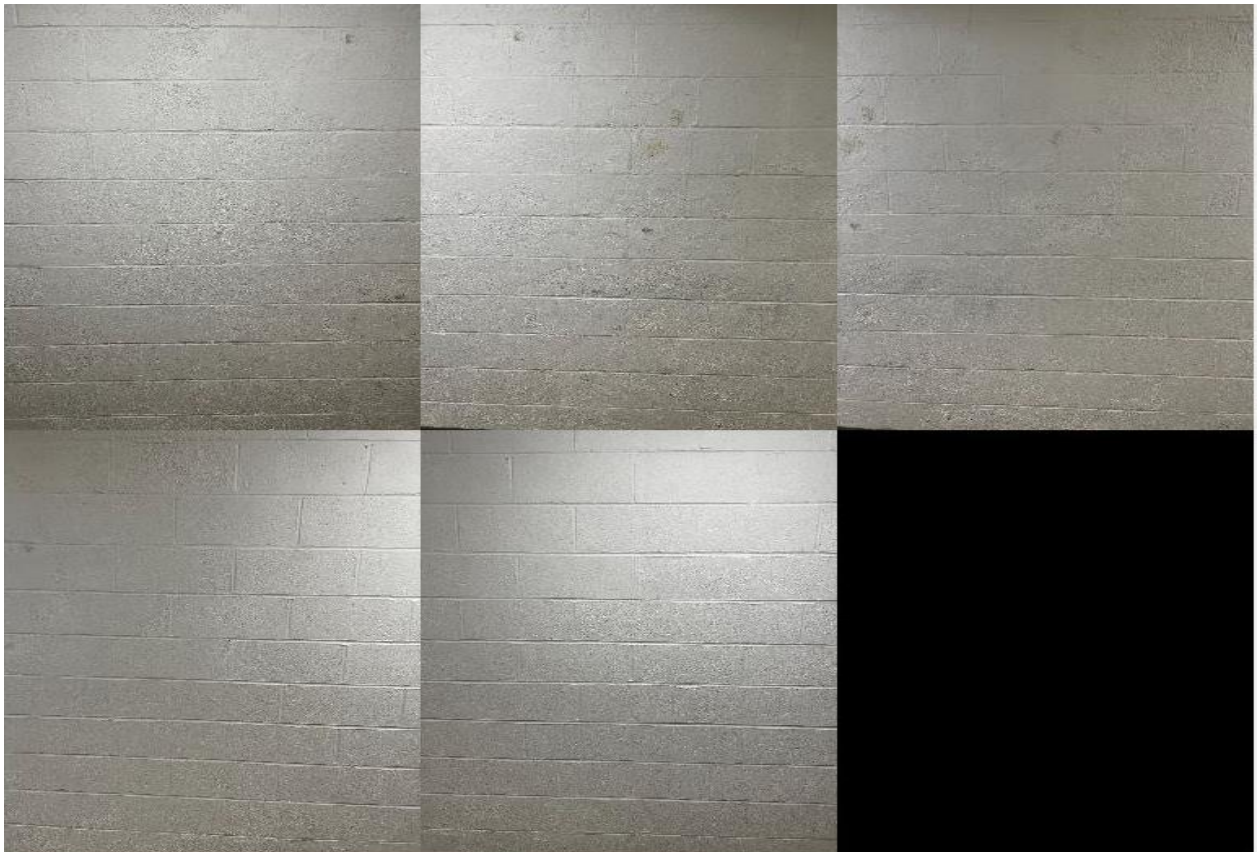


Image stitching using custom settings:

```
[y,x,m] = harris(I,5000, 'tile',[4 4], 'sigma', 1, 'hsize', 3)
```



3. Cinder block imagery

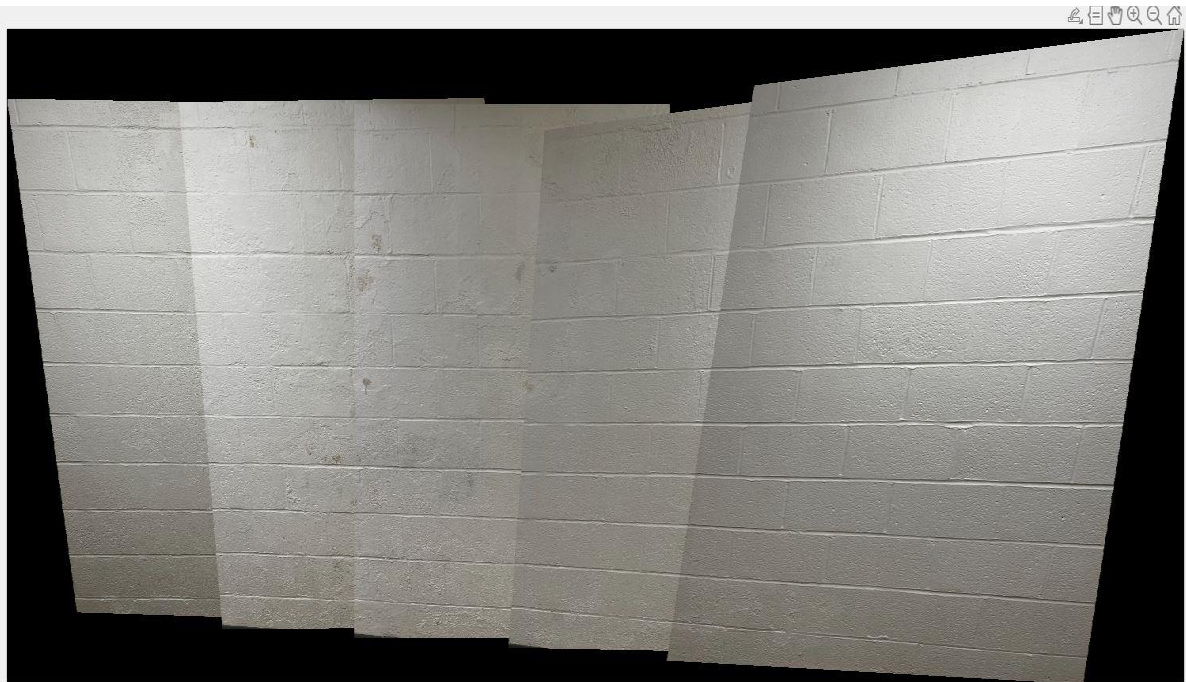


Cinder block image stitching:

```
[y,x,m] = harris(I,4000, 'tile',[2 2]);
```

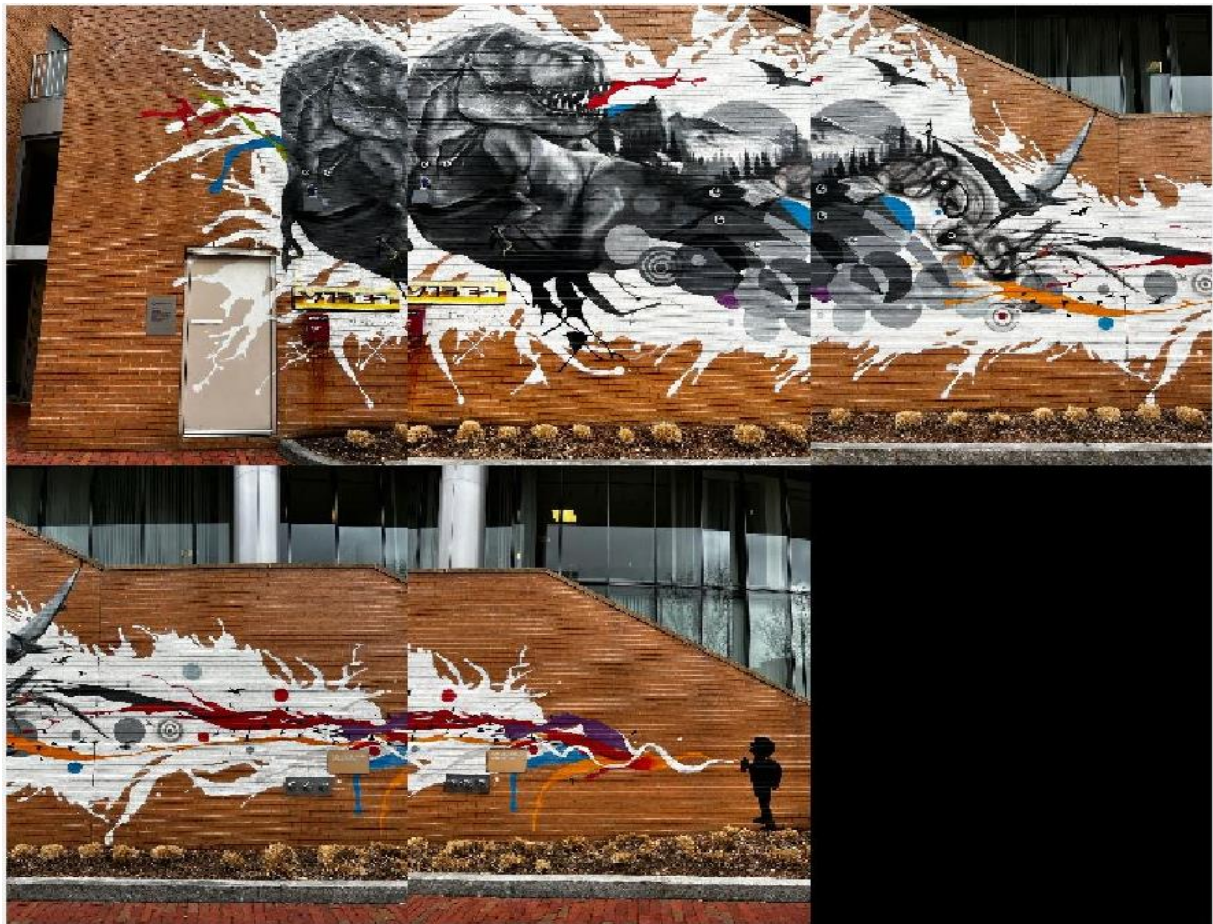


```
[y,x,m] = harris(I,8000, 'tile',[2 2]);
```



Even after increasing maximum number of interest points to return, the mosaic is not improved much. The code fails in this case because cinder brick wall has similar features at different points which makes it really hard for the algorithm to match features. At low 'N', the mosaic does not work. It keeps throwing out an error that minimum number of points in each set should be more than 4. It is just for $N > 4000$ that this algorithm work. This is because there are not a lot of features to extract and match for a cinder block image.

4. Mosaic (15% overlap)

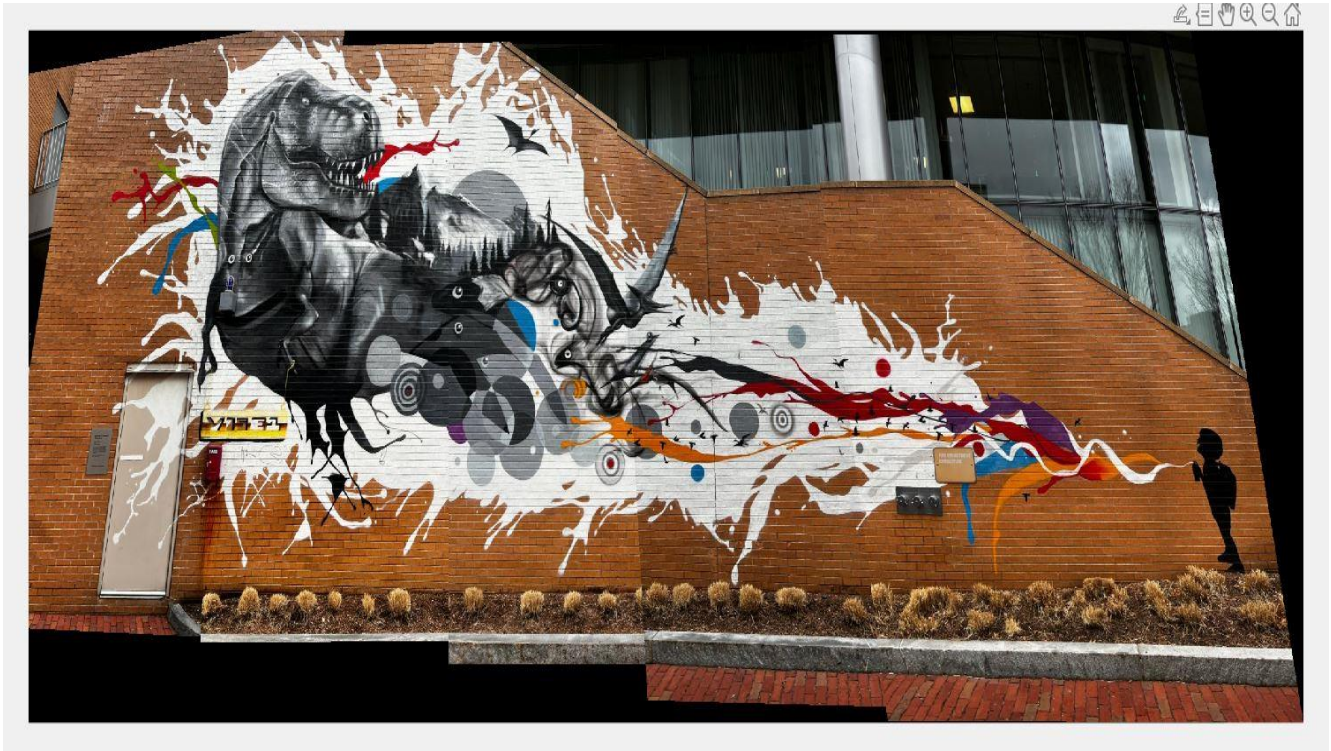


- `lf[y,x,m] = harris(I, N < 10000, 'tile',[5 5], 'sigma', 1, 'hsize', 3)`



The mosaic is not very good looking because the maximum number of interest points to return are less even after increasing the tile size, the overlap is only 15% so we have to force the algorithm to increase the maximum number of interest points to return to get a better mosaic.

- If `[y,x,m] = harris(I, N > 10000, 'tile',[5 5], 'sigma', 1, 'hsize', 3)`



Above we can see that Increasing the maximum number of interest points to return improves our mosaic when the overlap between images is less.