Matt Luongo
EECE 5554 — Lab #5 Report
April 6th, 2023
Professor Dorsey

Introduction

Image mosaicing/mosaicking is a useful technique that allows a user to piece together several images into a mosaic. Image mosaicing compares features on two images, and detects where points of interest line up. The feature detection method we used in this lab is called the Harris method. Harris corner detection starts with a grayscale image. The next steps are using convolution to take the gradient of the color in the image, and finding the smallest eigenvalue of the structure tensor that is built from the gradients. In short, the script detects where an edge abruptly changes direction, because those gradient shifts can be compared between two images.

After finding the locations and metrics that pertain to the features in the image, we can use a stitching algorithm like ICP (iterative closest point). This algorithm estimates the transformation matrix between two images by using an RMS minimization technique, transforming the data, and iterating upon this process. There are other algorithms like RANSAC that can be used for this step.

The last step is to transform each image and overlay the images on top of one another, with feature locations matching up. This creates a panorama from a set of images.

Calibration

The first task in this lab was calibrating our phone cameras using the Caltech toolbox provided on Piazza. I used this set of 21 images to calibrate my phone camera (see Appendix A for larger pictures):

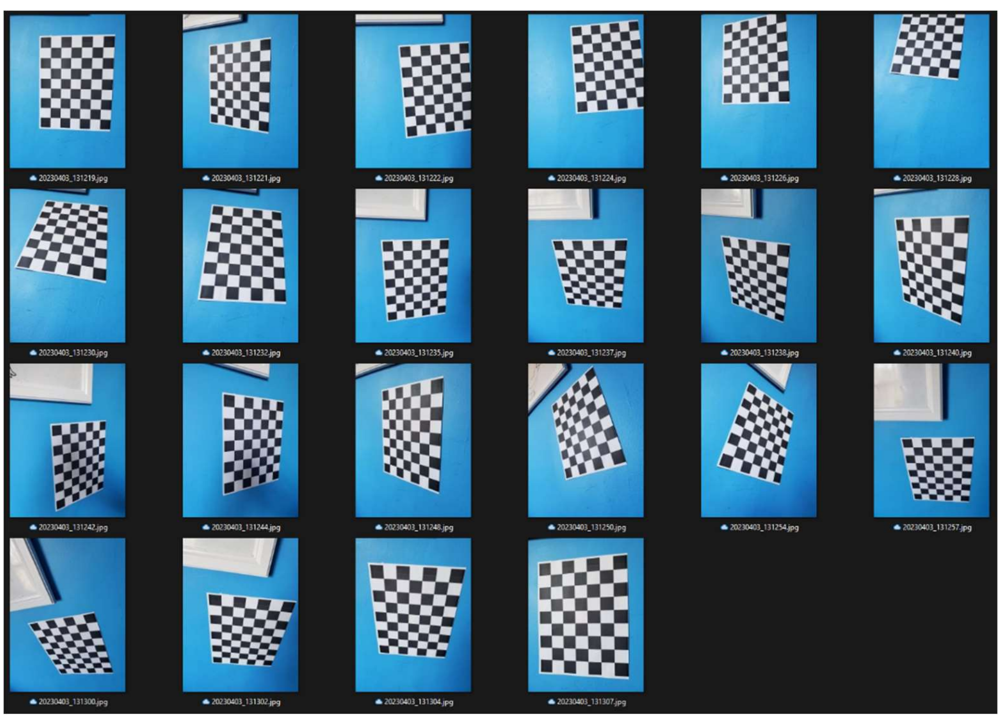

Figure 1: Calibration images for lab 5

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The full calibration parameters can be found in Appendix B. The skew parameter α_c was equal to zero. The distortion coefficients were equal to 0.0761, -0.2594, -0.0018, 0.0097, and zero. Also, the pixel errors were [1.73, 1.61]. The distortion parameter plots can be found below in Fig. 2:

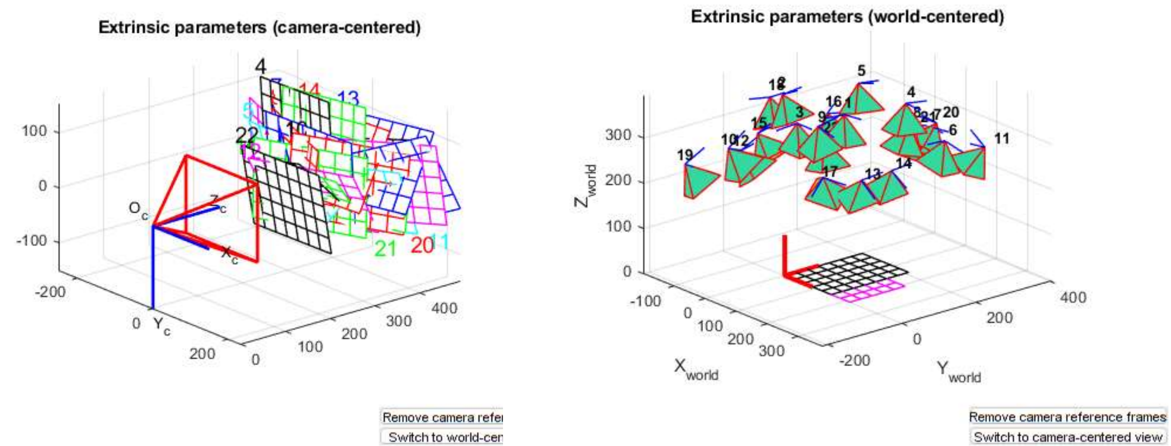

Figure 2: Extrinsic calibration parameters in camera centered (L) and world centered (R) schemes

The pixel error plot can be found here in Fig. 3:

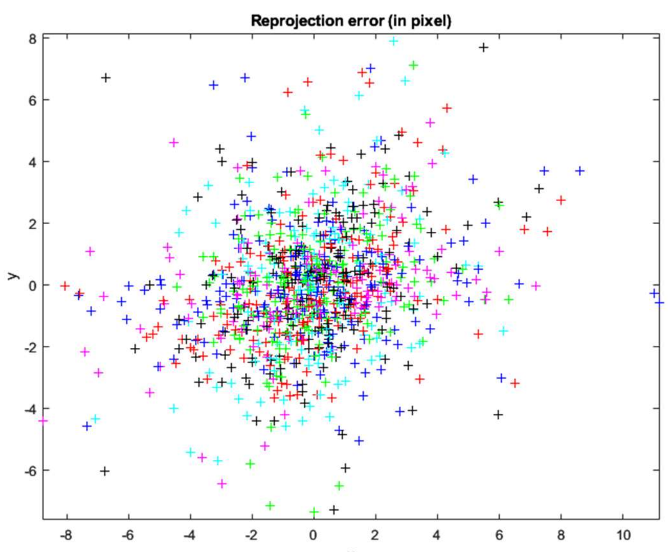

Figure 3: Pixel error plot

Since the images were taken in 4k resolution, the pixel error was assumed to be acceptable for the purposes of this lab. Notably, my phone camera already self-corrects for much of the distortion that an older camera would experience. For this reason, my undistorted images came out looking a lot worse than the originals. I ended up not using the undistort process for any of the photos I used in this lab because of this unfortunate fact.

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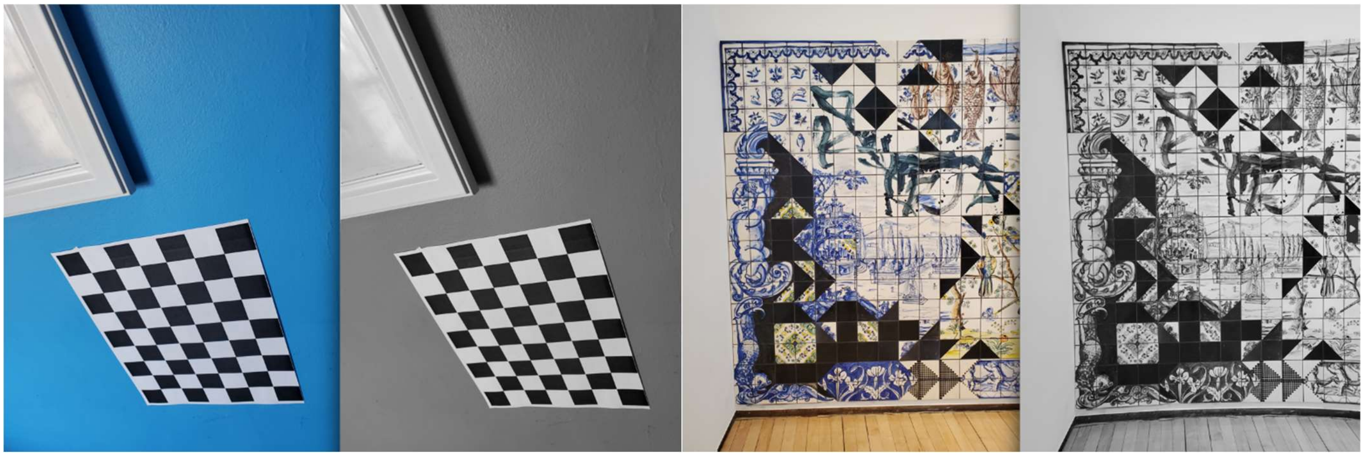

Figure 4: Original and "undistorted" images (L/R). Note the top and bottom of the image on the right half, which is clearly more distorted than its original counterpart.

Latinx Student Cultural Center Mosaic

The mural on the Latinx Student Center was the first mosaicing goal for this lab. The image set can be found below in Fig. 5. Note that images were to have roughly 50% overlap. Also, there was a bus parked in front of the mural when I had time to take pictures, so I was forced to include it in the mosaic. Harris corners and the final mosaic can be found in Figs. 5 & 6 respectively.

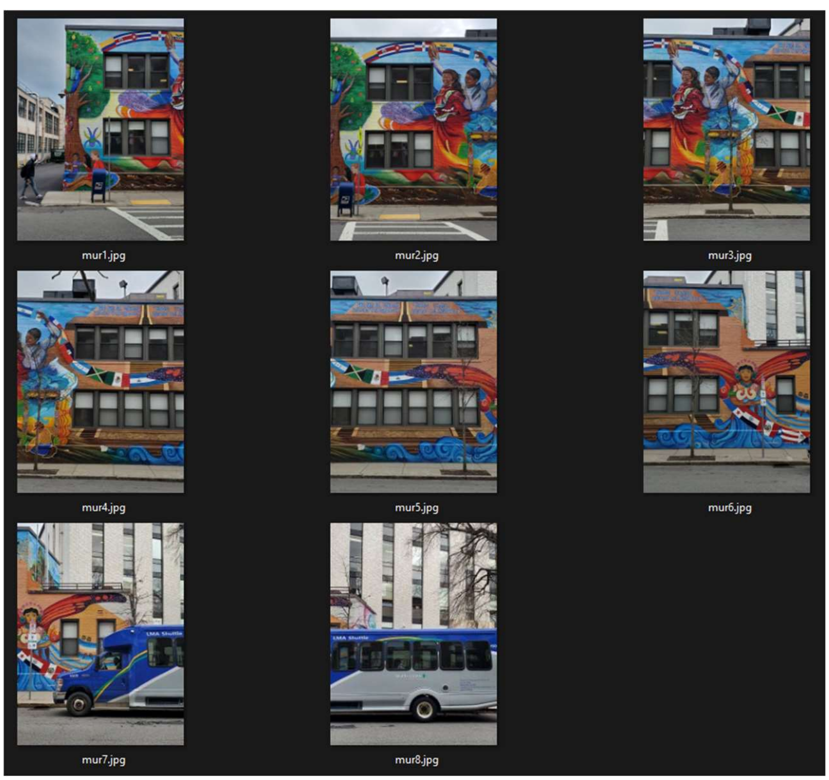

Figure 5: Image set for LSC mural

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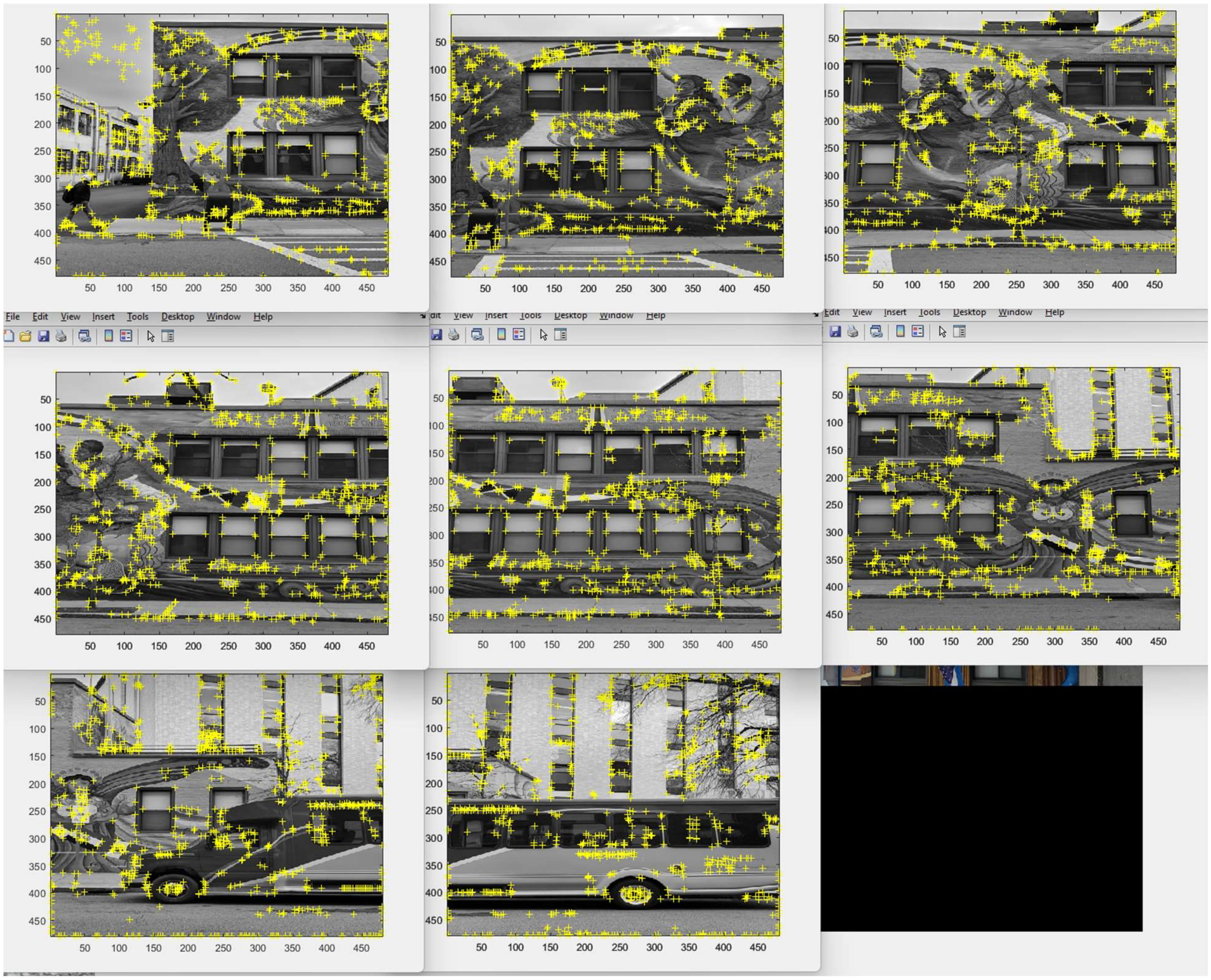

Figure 7: Harris corners detected on LSC images

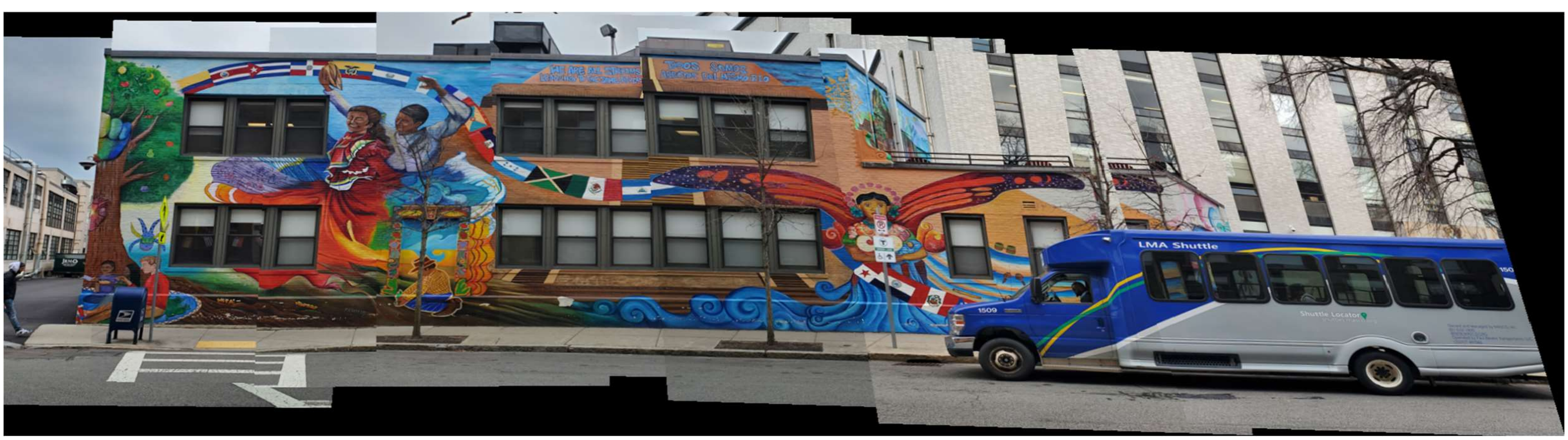

Figure 6: Full panorama of LSC mural

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I had to do a little adjustment of the code to get this mural together. I used a feature count of 1000 spread across a 4x4 tile layout to get a good result. I also had to scale my images down to 480 x 480 pixels to avoid matrix singularity errors. These steps produced a decent result, as seen above: The bus looks minimally distorted, and most of the mural lines up pretty well.

Brick Wall Mosaic

The second task in this lab was to create a similar mosaic for a brick wall, or a wall with heavily repeated patterns that would obfuscate feature matching. The images with Harris corners can be found in Fig. 8 below (raw images can be seen in Appendix A):

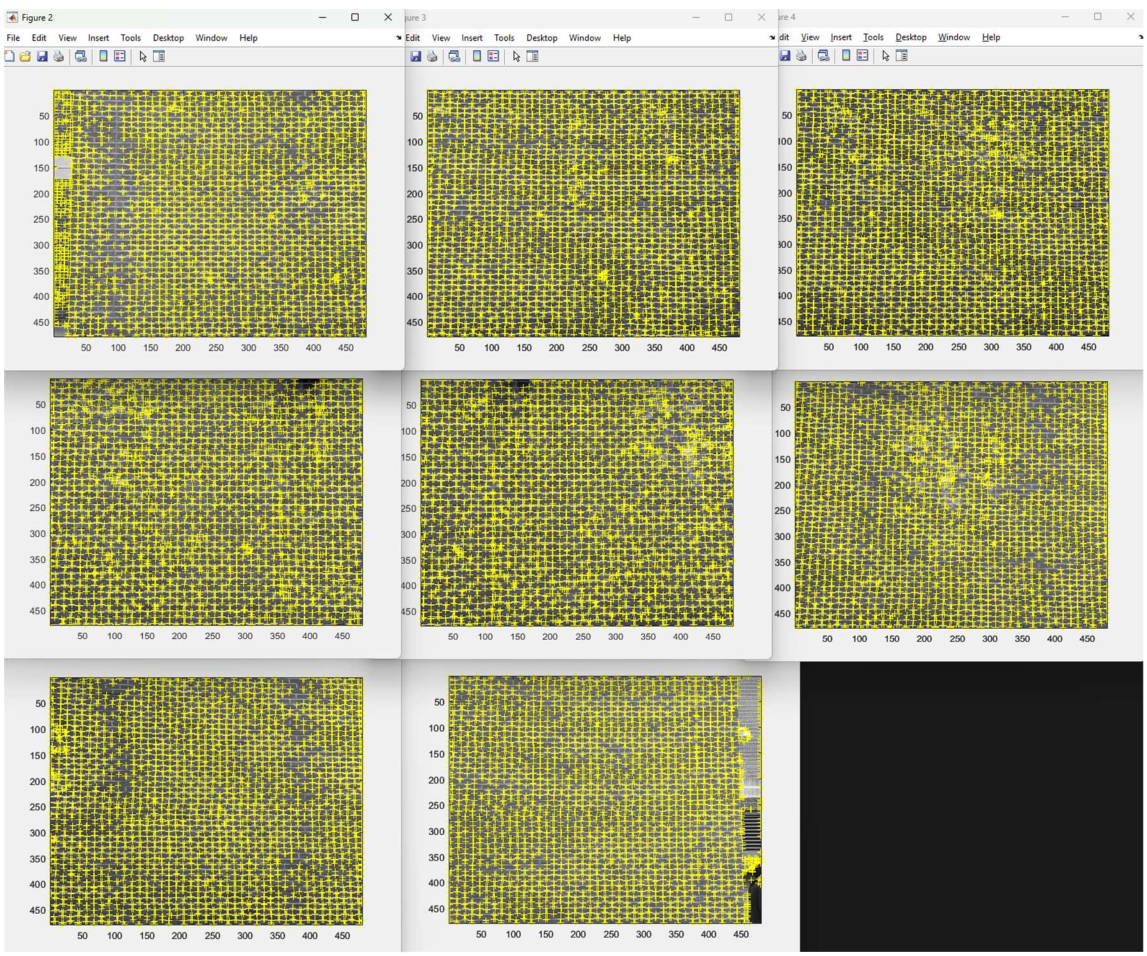

Figure 8: Harris corners for the brick wall images

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As stated above, the repeated features extracted from the brick corners made the mosaicing a little more challenging than it was for the LSC mural. The final mosaic can be seen below:

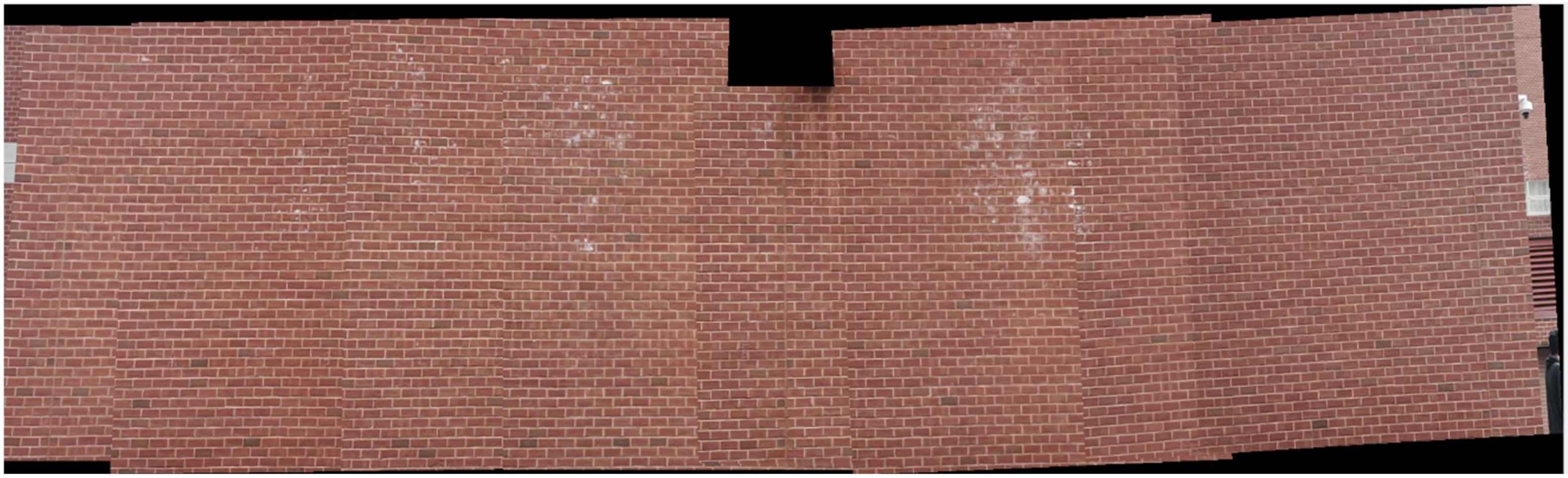

Figure 9: Brick wall mosaic

As seen above, the brick wall mosaic did a decent job at lining up the images, with some visible erroneous rotations. Firstly, I upped the feature count to 3200; with lower feature counts, the script could not find enough matching features to stitch the images. Also, an important note is that my walls were dirty/crusty, and there was a shadow from a light fixture that I cropped out of photos 4 & 5. It is a reasonable conclusion that dirty walls with uniquely placed shadows are able to be mosaiced with reasonable efficacy.

Final Mosaic: MassMOCA — Ceramics in the Expanded Field

The final mosaic I created was of a ceramic art piece at MassMOCA. The image sets with Harris corners for the 50% and 15% overlap sets can be found below in Figs. 10 & 11:

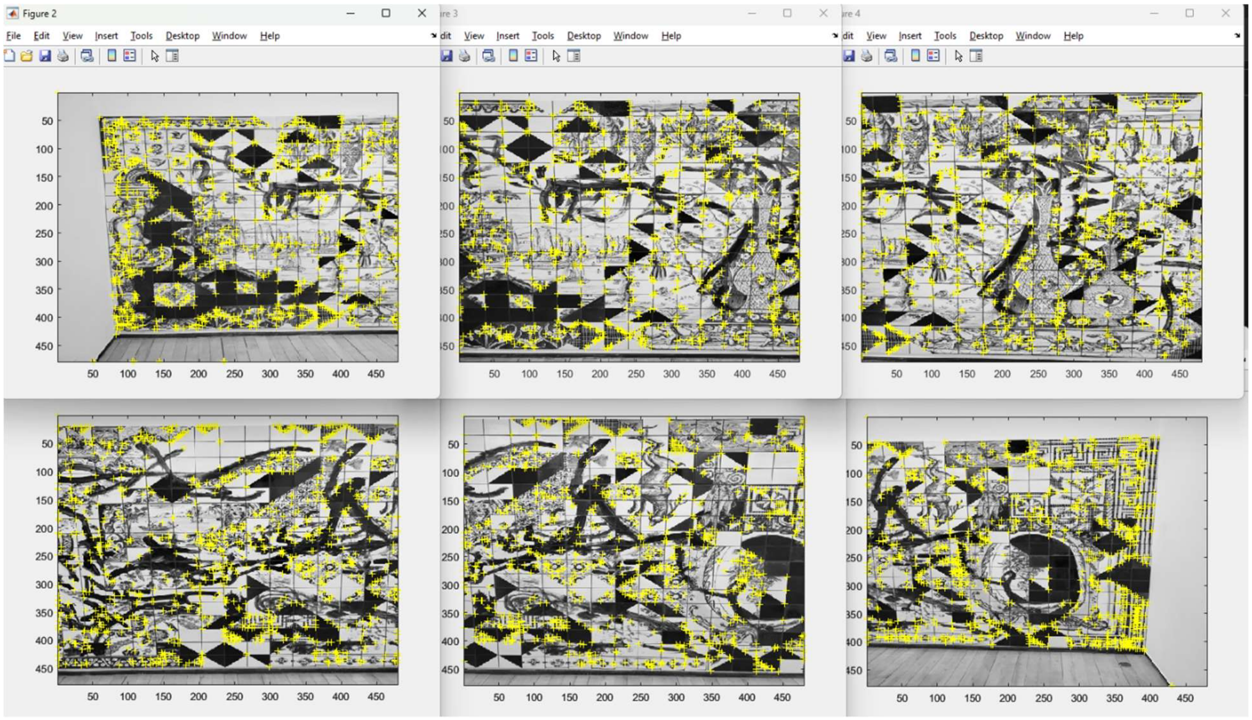

Figure 11: Harris corners for 50% overlap

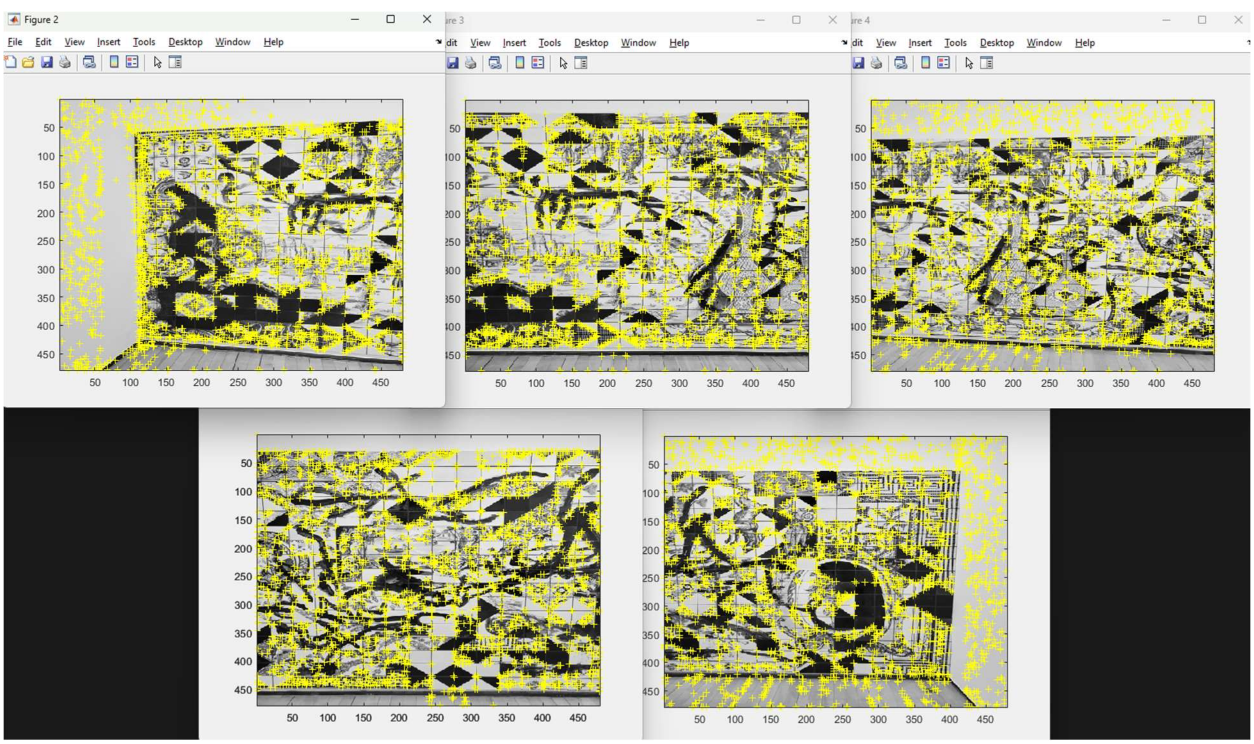

Figure 10: Harris corners for 15% overlap

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The final mosaics can be seen here (Figs. 12 & 13):

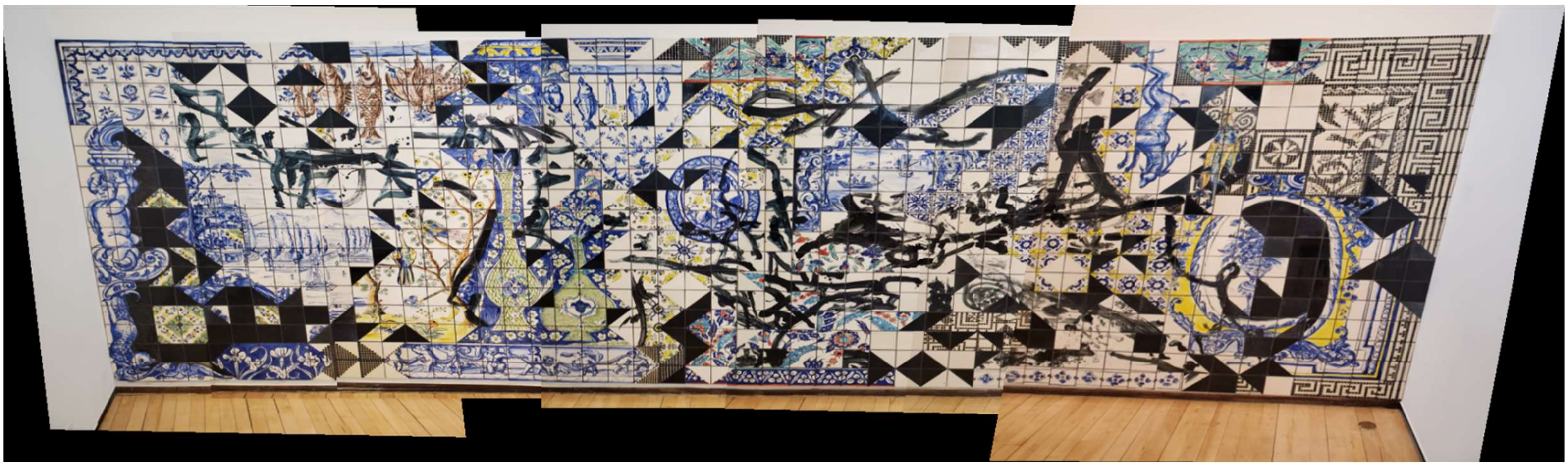

Figure 13: 50% overlap mosaic

Figure 12: 15% overlap mosaic

The 50% overlap images resulted in a good-quality mosaic: note that the images were taken reasonably close to the mosaic, so this procedure created a good-quality approximation of the art piece when the camera could not otherwise see the entire piece. The 15% overlap images found far fewer matching features, so the quality is a lot worse. I upped the feature count to 2400 and spread the features across an 8 x 8 pixel area with the tile setting for this mosaic. The quality is worse, but the stitching still succeeded; however, more rotations and misalignments are present in this mosaic.

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Conclusion

In retrospect, this lab was successful in demonstrating the methodologies of image mosaicing with practical examples. Also, the different scenarios (repeated patterns, little overlap) proved the challenges associated with image mosaicing programs. Please see the appendices for extra content associated with this lab.

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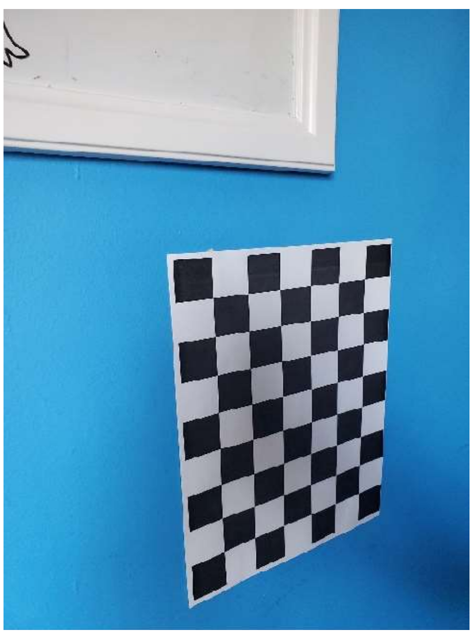
Appendix A — Im ages Used in Lab



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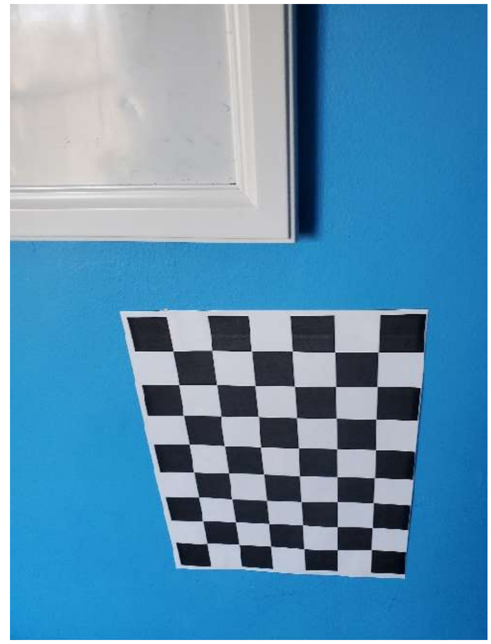
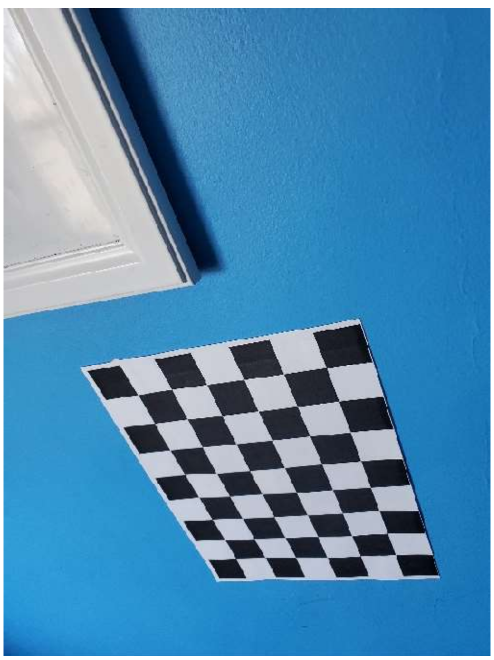

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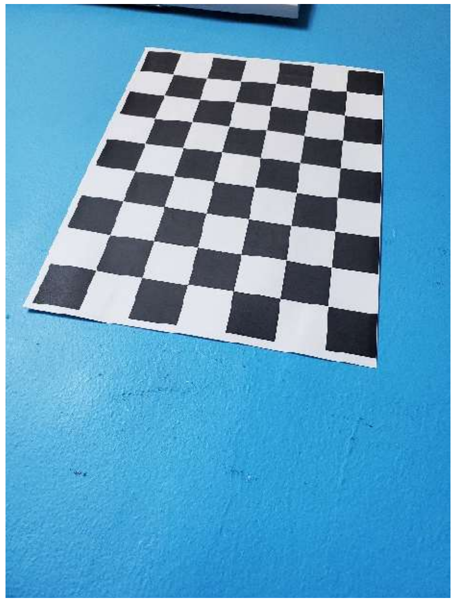

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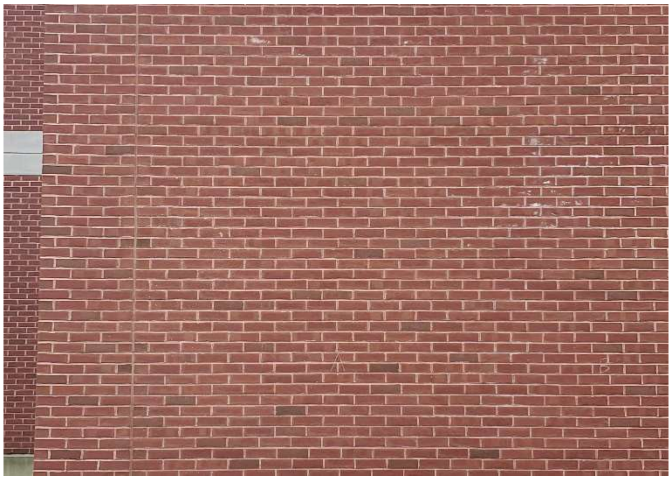
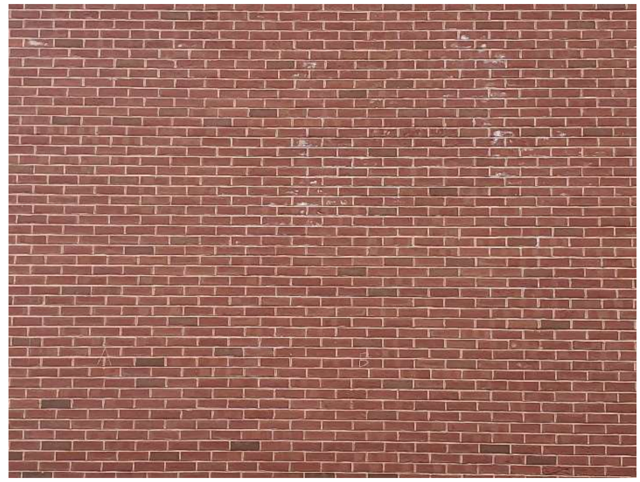
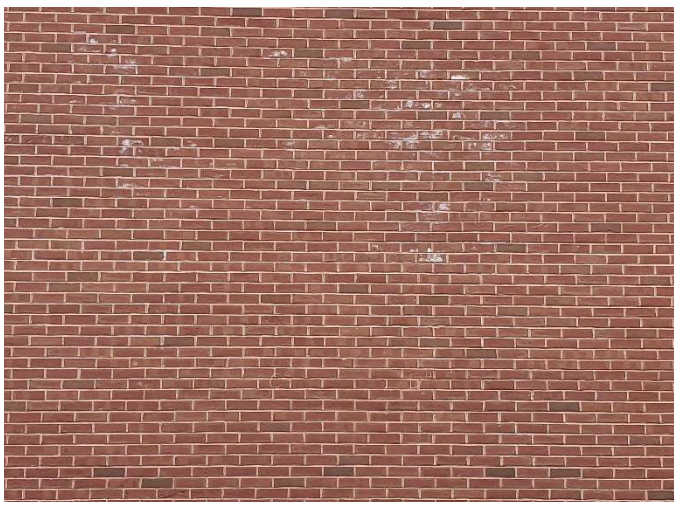
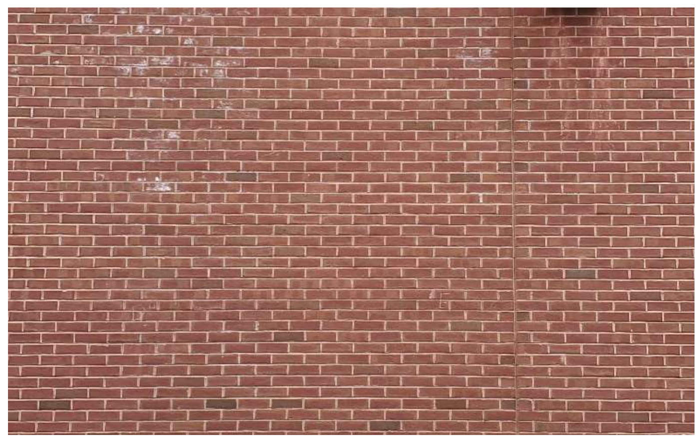
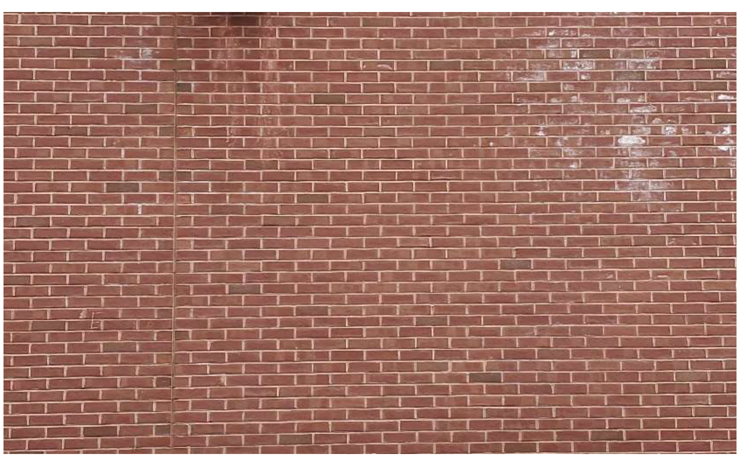


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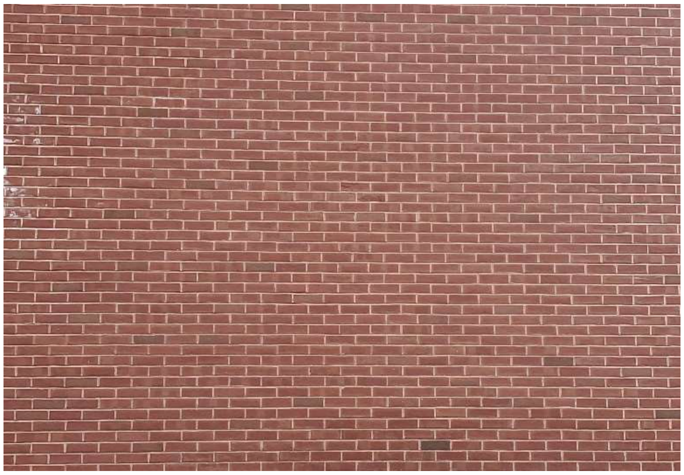

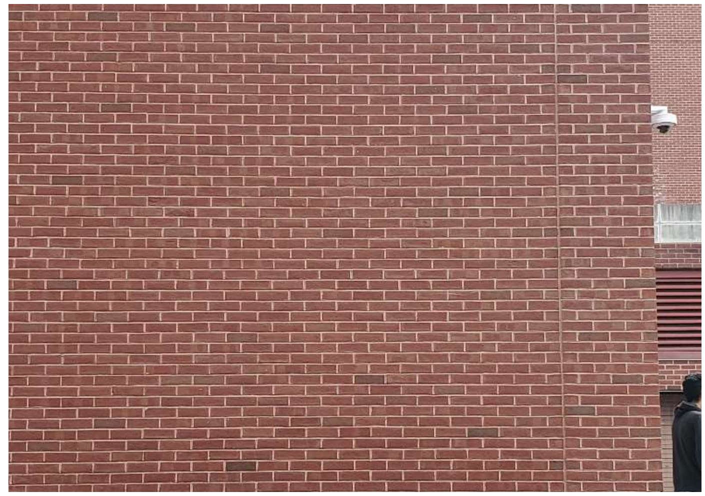

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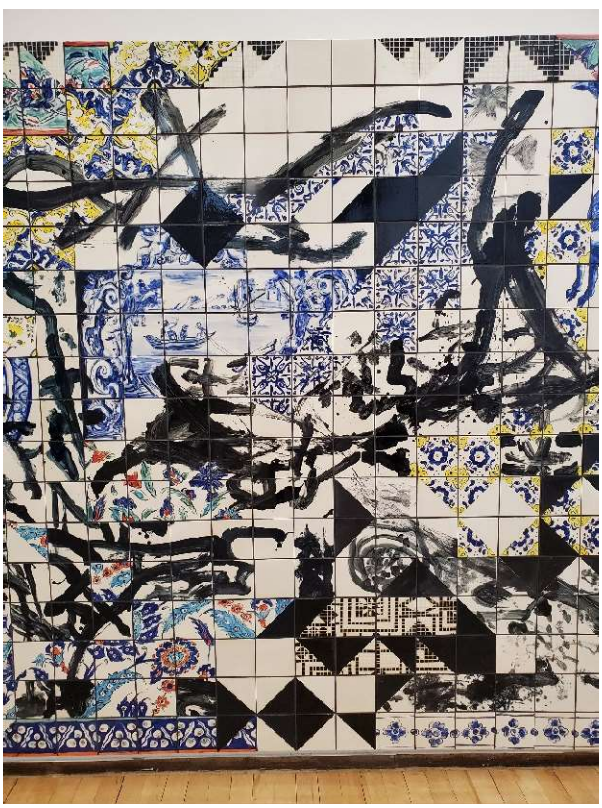
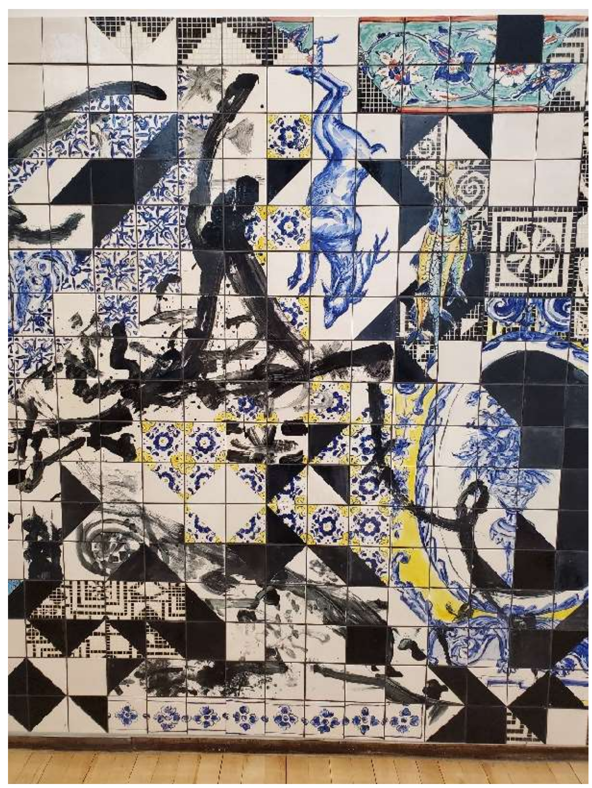

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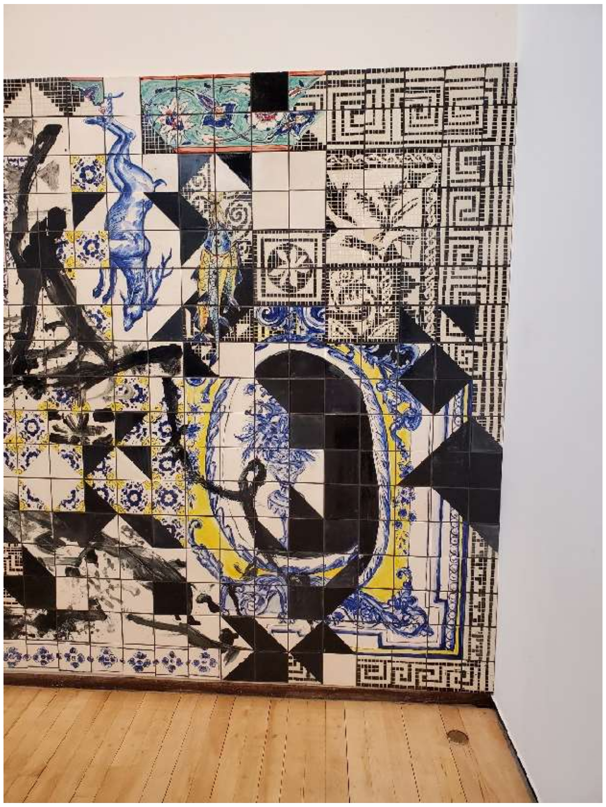

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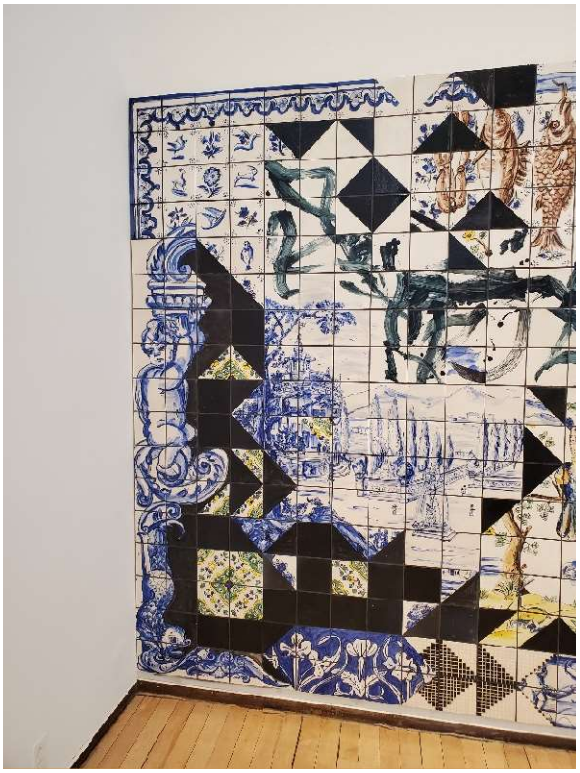

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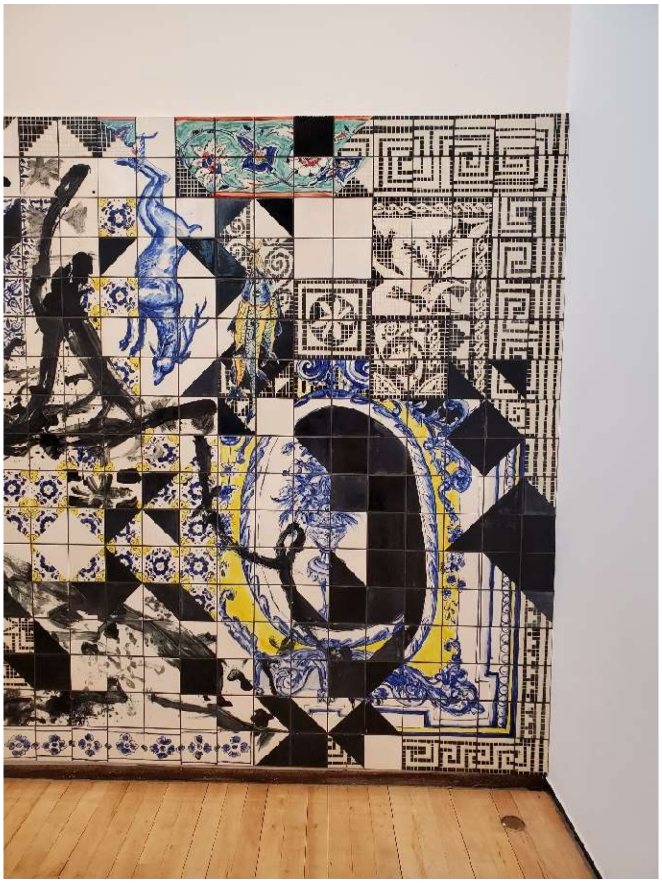

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Appendix B — Calibration Parameters

```
% Intrinsic and Extrinsic Camera Parameters
%
% This script file can be directly executed under Matlab to recover the camera intrinsic and extrinsic parameters.
% IMPORTANT: This file contains neither the structure of the calibration objects nor the image coordinates of the calibration points.
%            All those complementary variables are saved in the complete matlab data file Calib_Results.mat.
% For more information regarding the calibration model visit http://www.vision.caltech.edu/bouguetj/calib_doc/


%-- Focal length:
fc = [ 3170.338988302394682 ; 3192.024072084384898 ];

%-- Principal point:
cc = [ 1921.727325499089829 ; 1472.523152408793749 ];

%-- Skew coefficient:
alpha_c = 0.000000000000000;

%-- Distortion coefficients:
kc = [ 0.076070135889892 ; -0.259402210059299 ; -0.001758694846237 ; -0.009710790234998 ; 0.000000000000000 ];

%-- Focal length uncertainty:
fc_error = [ 16.542441315801103 ; 16.734420209778335 ];

%-- Principal point uncertainty:
cc_error = [ 13.752465905709824 ; 12.544902295463494 ];

%-- Skew coefficient uncertainty:
alpha_c_error = 0.000000000000000;

%-- Distortion coefficients uncertainty:
kc_error = [ 0.010734634013961 ; 0.031558502799357 ; 0.001530966065799 ; 0.001676134522235 ; 0.000000000000000 ];

%-- Image size:
nx = 4032;
ny = 3024;


%-- 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 = 22;                                     % Number of calibration images
```

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```
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 = [ -3.056548e+00 ; -3.026684e-02 ; -1.051302e-01 ];
Tc_1  = [ -1.167908e+02 ; 5.284894e+01 ; 3.596673e+02 ];
omc_error_1 = [ 7.824207e-03 ; 1.506134e-03 ; 1.042708e-02 ];
Tc_error_1  = [ 1.579224e+00 ; 1.433860e+00 ; 2.052223e+00 ];

%-- Image #2:
omc_2 = [ -1.990969e+00 ; -2.033774e+00 ; -5.123162e-01 ];
Tc_2  = [ -1.066286e+02 ; -5.266420e+01 ; 3.561163e+02 ];
omc_error_2 = [ 3.823314e-03 ; 4.759436e-03 ; 8.476085e-03 ];
Tc_error_2  = [ 1.563389e+00 ; 1.429507e+00 ; 2.049156e+00 ];

%-- Image #3:
omc_3 = [ 3.039147e+00 ; -1.218829e-01 ; 5.395438e-02 ];
Tc_3  = [ -9.215521e+01 ; 1.092935e+01 ; 3.634604e+02 ];
omc_error_3 = [ 6.907711e-03 ; 2.042399e-03 ; 1.012391e-02 ];
Tc_error_3  = [ 1.576824e+00 ; 1.456290e+00 ; 2.123434e+00 ];

%-- Image #4:
omc_4 = [ -2.241870e+00 ; -2.076237e+00 ; 1.074367e-01 ];
Tc_4  = [ -1.781817e+02 ; -1.323873e+02 ; 3.902126e+02 ];
omc_error_4 = [ 5.816296e-03 ; 3.727653e-03 ; 1.162321e-02 ];
Tc_error_4  = [ 1.763808e+00 ; 1.601151e+00 ; 2.139972e+00 ];

%-- Image #5:
omc_5 = [ -2.065454e+00 ; -1.990569e+00 ; -1.665096e-01 ];
Tc_5  = [ -1.968027e+02 ; -4.918120e+01 ; 3.804838e+02 ];
omc_error_5 = [ 4.680938e-03 ; 4.459717e-03 ; 9.583321e-03 ];
Tc_error_5  = [ 1.664636e+00 ; 1.574031e+00 ; 2.174636e+00 ];

%-- Image #6:
omc_6 = [ -2.992194e+00 ; -1.858229e-01 ; 3.525074e-01 ];
Tc_6  = [ -2.490745e+02 ; 7.372465e+01 ; 4.329513e+02 ];
omc_error_6 = [ 6.367517e-03 ; 2.635891e-03 ; 1.208989e-02 ];
Tc_error_6  = [ 2.047764e+00 ; 1.851161e+00 ; 2.438067e+00 ];
```

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```
%-- Image #7:
omc_7 = [ -1.726043e+00 ; -2.054488e+00 ; 4.938662e-01 ];
Tc_7  = [ -1.642189e+02 ; -9.483413e+01 ; 4.012921e+02 ];
omc_error_7 = [ 4.324543e-03 ; 3.868720e-03 ; 6.305752e-03 ];
Tc_error_7  = [ 1.791808e+00 ; 1.623828e+00 ; 1.860852e+00 ];

%-- Image #8:
omc_8 = [ -2.024430e+00 ; -2.150767e+00 ; 4.260212e-01 ];
Tc_8  = [ -1.295046e+02 ; -9.187680e+01 ; 3.760989e+02 ];
omc_error_8 = [ 4.453319e-03 ; 3.705939e-03 ; 7.680824e-03 ];
Tc_error_8  = [ 1.642014e+00 ; 1.489767e+00 ; 1.784431e+00 ];

%-- Image #9:
omc_9 = [ 2.065553e+00 ; 1.993369e+00 ; 1.196721e-02 ];
Tc_9  = [ -4.190857e+01 ; -8.186642e+01 ; 4.036600e+02 ];
omc_error_9 = [ 4.945661e-03 ; 4.654323e-03 ; 9.542948e-03 ];
Tc_error_9  = [ 1.767462e+00 ; 1.576293e+00 ; 2.240728e+00 ];

%-- Image #10:
omc_10 = [ 2.022132e+00 ; 1.958501e+00 ; 7.791587e-01 ];
Tc_10  = [ -3.175328e+01 ; -7.569747e+01 ; 3.406664e+02 ];
omc_error_10 = [ 4.800467e-03 ; 3.607679e-03 ; 7.612789e-03 ];
Tc_error_10  = [ 1.504060e+00 ; 1.340505e+00 ; 2.084583e+00 ];

%-- Image #11:
omc_11 = [ -1.828294e+00 ; 1.678536e+00 ; 2.513479e-02 ];
Tc_11  = [ 1.441789e+02 ; 8.342414e+01 ; 4.696141e+02 ];
omc_error_11 = [ 4.058739e-03 ; 4.014039e-03 ; 6.308043e-03 ];
Tc_error_11  = [ 2.074715e+00 ; 1.912846e+00 ; 2.225014e+00 ];

%-- Image #12:
omc_12 = [ -1.908206e+00 ; -2.070630e+00 ; -9.366292e-01 ];
Tc_12  = [ -6.263697e+01 ; -4.526023e+01 ; 2.638057e+02 ];
omc_error_12 = [ 2.894638e-03 ; 4.686088e-03 ; 7.156803e-03 ];
Tc_error_12  = [ 1.162491e+00 ; 1.050907e+00 ; 1.616835e+00 ];

%-- Image #13:
omc_13 = [ 1.917506e+00 ; 1.775705e+00 ; -3.626161e-01 ];
Tc_13  = [ -2.227319e+01 ; -1.070210e+02 ; 4.348372e+02 ];
omc_error_13 = [ 4.079385e-03 ; 4.324665e-03 ; 7.248531e-03 ];
Tc_error_13  = [ 1.920372e+00 ; 1.698207e+00 ; 2.039530e+00 ];

%-- Image #14:
omc_14 = [ 1.904919e+00 ; 1.887837e+00 ; -3.808744e-01 ];
Tc_14  = [ -8.432707e+01 ; -1.123240e+02 ; 4.014670e+02 ];
omc_error_14 = [ 3.501778e-03 ; 4.494406e-03 ; 6.833392e-03 ];
Tc_error_14  = [ 1.765785e+00 ; 1.574714e+00 ; 1.933328e+00 ];

%-- Image #15:
omc_15 = [ -1.826478e+00 ; -1.931746e+00 ; -7.895468e-01 ];
Tc_15  = [ -9.897928e+01 ; -3.756403e+01 ; 2.867001e+02 ];
omc_error_15 = [ 3.105932e-03 ; 4.428190e-03 ; 6.759487e-03 ];
```

```
Tc_error_15  = [ 1.256599e+00 ; 1.152057e+00 ; 1.704164e+00 ];

%-- Image #16:
omc_16 = [ -2.049877e+00 ; -1.409390e+00 ; -4.704597e-01 ];
Tc_16  = [ -1.551483e+02 ; -1.516108e+00 ; 3.518071e+02 ];
omc_error_16 = [ 3.841967e-03 ; 3.745771e-03 ; 6.305129e-03 ];
Tc_error_16  = [ 1.528733e+00 ; 1.417749e+00 ; 1.909680e+00 ];

%-- Image #17:
omc_17 = [ 2.528641e+00 ; 4.716021e-01 ; -3.792235e-01 ];
Tc_17  = [ -1.338864e+02 ; 1.752143e+01 ; 4.021513e+02 ];
omc_error_17 = [ 4.953809e-03 ; 2.568786e-03 ; 6.697883e-03 ];
Tc_error_17  = [ 1.742851e+00 ; 1.590676e+00 ; 2.077690e+00 ];

%-- Image #18:
omc_18 = [ -2.922041e+00 ; 7.435932e-02 ; -6.704495e-01 ];
Tc_18  = [ 3.462489e+01 ; 6.185220e+01 ; 3.776539e+02 ];
omc_error_18 = [ 5.595583e-03 ; 2.716130e-03 ; 9.036272e-03 ];
Tc_error_18  = [ 1.654827e+00 ; 1.482924e+00 ; 2.179495e+00 ];

%-- Image #19:
omc_19 = [ 2.291455e+00 ; 1.700862e+00 ; 8.818335e-01 ];
Tc_19  = [ 3.437797e+01 ; -4.806513e+01 ; 3.394904e+02 ];
omc_error_19 = [ 5.715427e-03 ; 3.343317e-03 ; 7.662184e-03 ];
Tc_error_19  = [ 1.498292e+00 ; 1.332405e+00 ; 2.049944e+00 ];

%-- Image #20:
omc_20 = [ -1.977454e+00 ; 1.795840e+00 ; -5.589117e-01 ];
Tc_20  = [ 1.619133e+02 ; 6.989871e+01 ; 4.232125e+02 ];
omc_error_20 = [ 4.735485e-03 ; 3.291752e-03 ; 6.909437e-03 ];
Tc_error_20  = [ 1.879709e+00 ; 1.727343e+00 ; 2.121490e+00 ];

%-- Image #21:
omc_21 = [ -1.990918e+00 ; 1.872050e+00 ; -4.145215e-01 ];
Tc_21  = [ 1.099880e+02 ; 8.103970e+01 ; 3.835997e+02 ];
omc_error_21 = [ 4.279300e-03 ; 3.566989e-03 ; 7.038681e-03 ];
Tc_error_21  = [ 1.676033e+00 ; 1.523773e+00 ; 1.885391e+00 ];

%-- Image #22:
omc_22 = [ -2.144807e+00 ; -2.101456e+00 ; -1.631670e-01 ];
Tc_22  = [ -9.256037e+01 ; -5.766413e+01 ; 2.755162e+02 ];
omc_error_22 = [ 3.665897e-03 ; 4.350356e-03 ; 8.308781e-03 ];
Tc_error_22  = [ 1.212002e+00 ; 1.106385e+00 ; 1.515740e+00 ];
```