Lab Report 5
EECE 5554: Robot Sensing and Navigation
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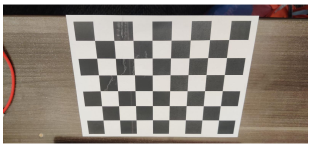
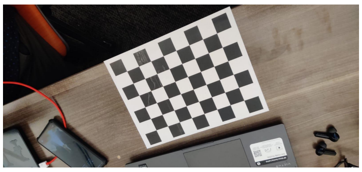
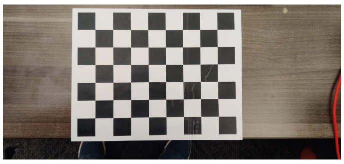
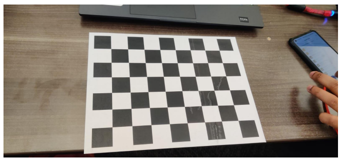
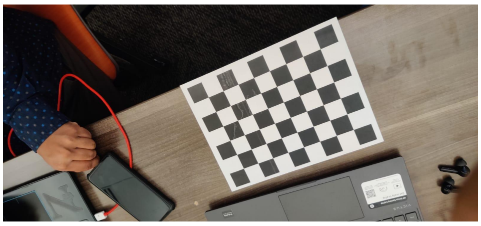
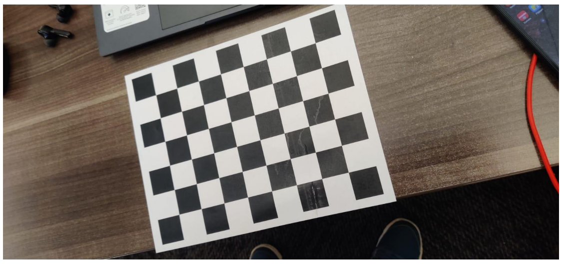
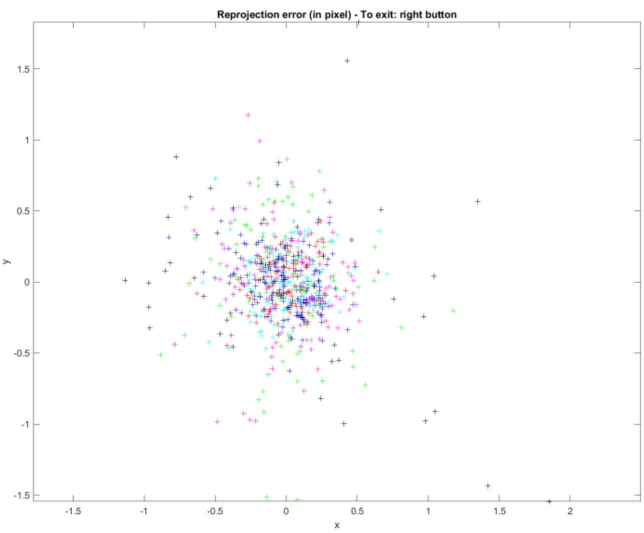
1. Camera Calibration

Camera Calibration estimates the parameters of a lens and image sensor of an image or video camera. We can use these parameters to correct lens distortion, measure the size of an object in world units, or determine the location of the camera in the scene. These tasks are used in applications such as machine vision to detect and measure objects. Calibration images were taken of a 7x9 checkerboard with 30mm x 30mm squares each. I have taken 14 images of checker box for calibration that are fed into Caltech Camera Calibration Toolbox.

On the first attempt of Calibration I got a reprojection error of greater than [1.2047 1.3356] which is not acceptable. These values were relatively large for a good quality calibration. The images taken had a resolution of 4000x3000 pixels. So, in order to reduce the error. I reduced the pixel of my images from 4000x3000 to 1600x729 then, the standard deviation of the reprojection error came to be [0.30477 0.33431]

The reprojection error is plotted in the form of colour-coded crosses. The spread of the reprojection error are mostly between +/-0.5 pixels shown in Figure There is a Circular pattern formed which is the due to excitation of every axis of calibration images, and capturing different angles to the calibration plane.



Calibration Parameters

The calibration algorithm calculates the camera matrix using the extrinsic and intrinsic parameters. The extrinsic parameters represent a rigid transformation from 3-D world coordinate system to the 3-D camera's coordinate system. The intrinsic parameters represent a projective transformation from the 3-D camera's coordinates into the 2-D image coordinates.

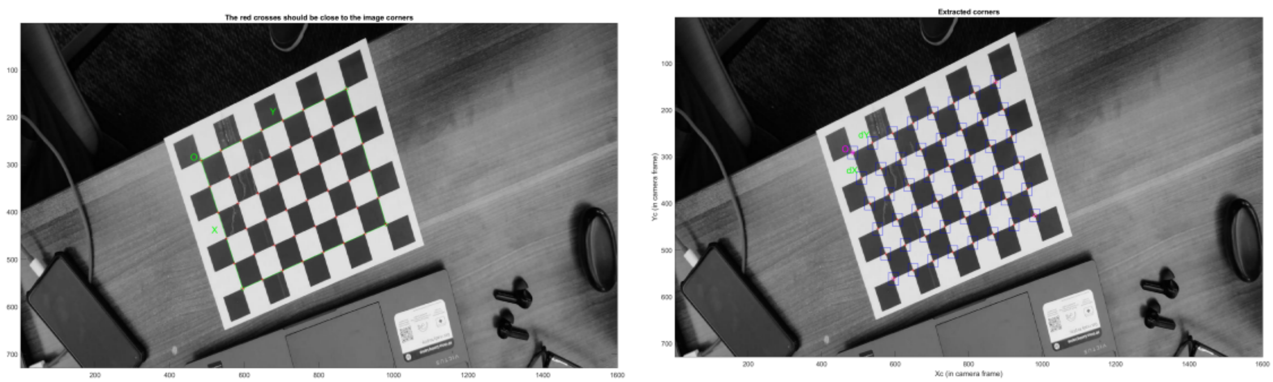
where,

K = [fx s cx]   cc is the principal point in pixels.
[0 fy cy]   fc is Focal length in pixels.
[0 0 1]   s is Skew coefficient

cc = [807.62977 367.03141] +/- [7.90037 6.12553] is Optical center (the principal point), in pixels. fc = [1242.95966 1241.11876] +/- [9.00486 9.19975] is Focal length in pixels. s is Skew coefficient, which is non-zero if the image axes are not perpendicular.

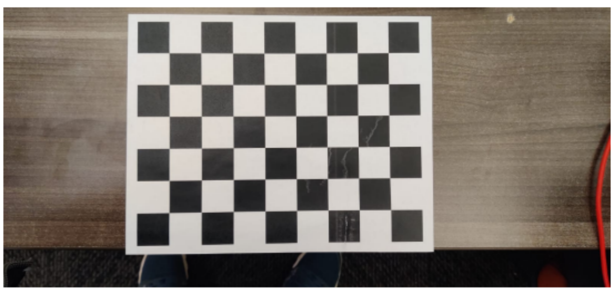
Intrinsic Parameter: The intrinsic parameters include the focal length, the optical center, also known as the principal point, and the skew coefficient. The camera intrinsic matrix, K, is defined as: [fx s cx; 0 fy cy; 0 0 1]

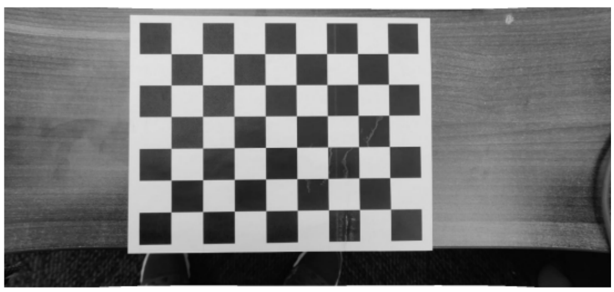
The Distortion coefficients calculated after optimization is represented by kc. The distortion coefficients k1, k2, k3 represent the radial distortion coefficients and p1, p2 represent the tangential distortion. The magnitude of tangential distortion coefficients is smaller than the radial distortion coefficients because many modern camera lenses are already optimized for tangential distortion. Distortion Coefficient = [k1 k2 p1 p2 k3] kc = [0.16654 −0.57067 0.00066 0.00226 0.00000] +/- [0.02008 0.14405 0.00226 0.00300 0.00000]



Before and after calibration

The distortion parameter values are present due to some reasons like first, we haven't done the extraction of corners carefully on some highly distorted images. Second, due to the depth of field (DOF) of the image, some grid points are blurred when the image is taken at a very slanting angle resulting in poor extraction of the corners.



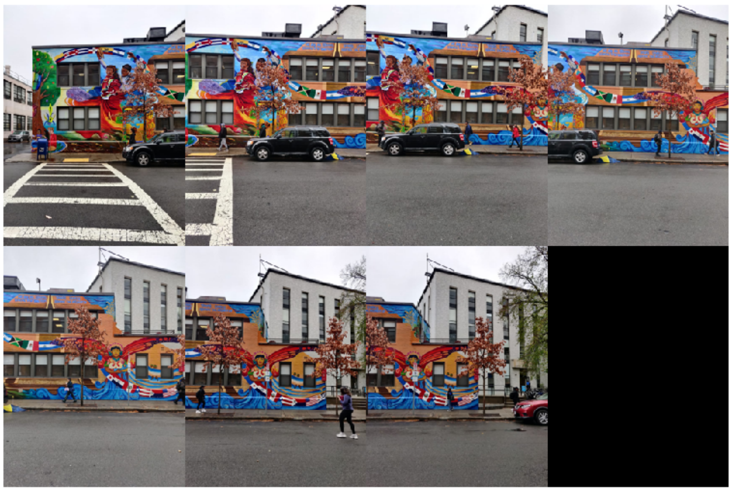


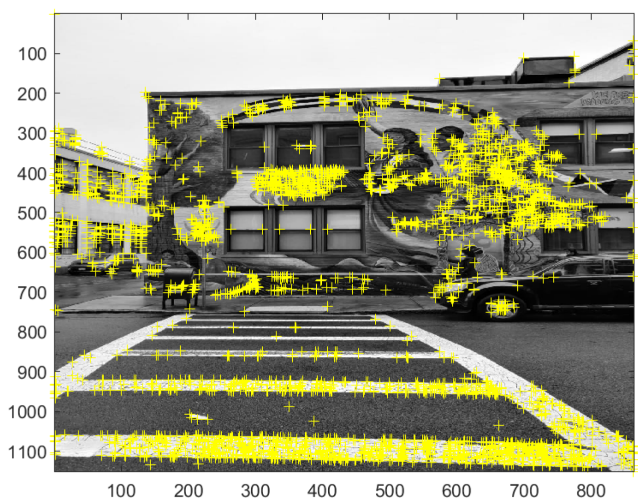
The above picture depicts calibration image and Undistorted image.
The colored image is the original images while the black and white image is the undistorted images produced by the calibration toolbox.

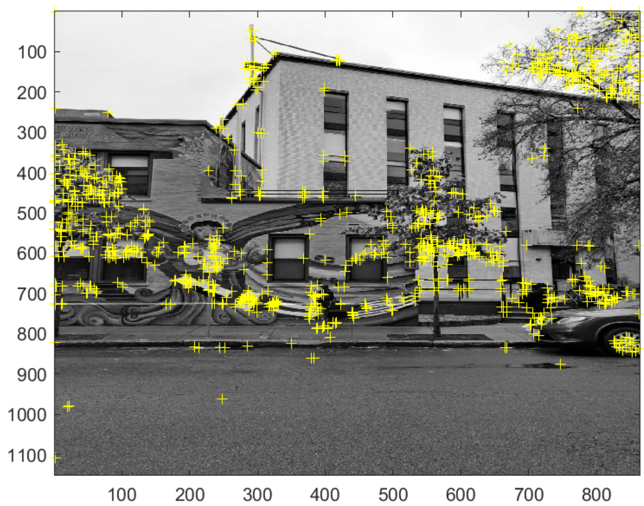
2. Image Mosaicing

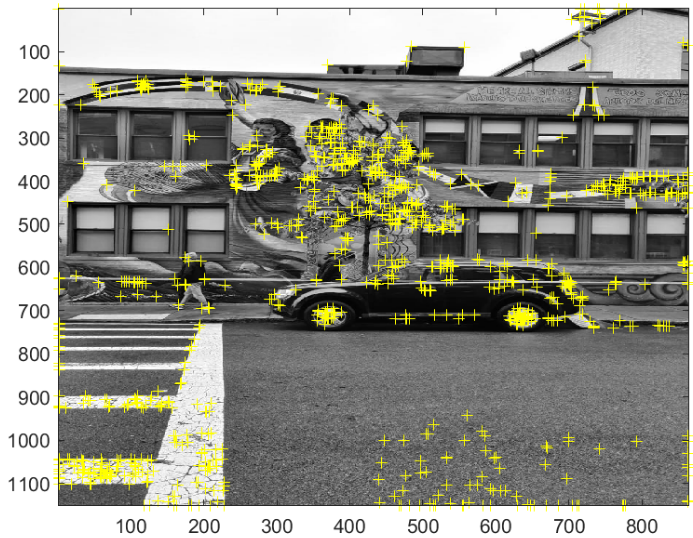
2.1 Mural images on the Latino Students Center building

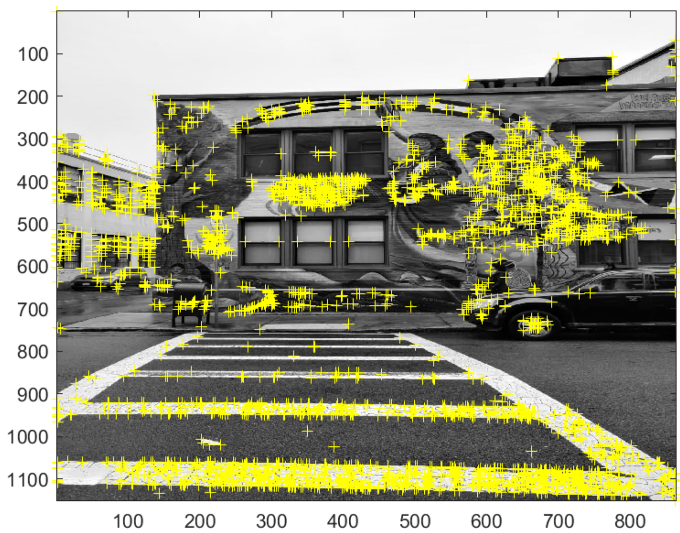
The photos were captured at Forsyth street. Earlier, the images could be compensated for the camera distortions using the 'Undistort image' feature of the calibration tool and the resulting images produced by the toolbox would be in black-and-white. But nowadays, phone cameras have evolved, due to which they already provides us the undistorted images, and if we try to undistort image using the toolbox it will make the images even more distorted and bending towards the corner





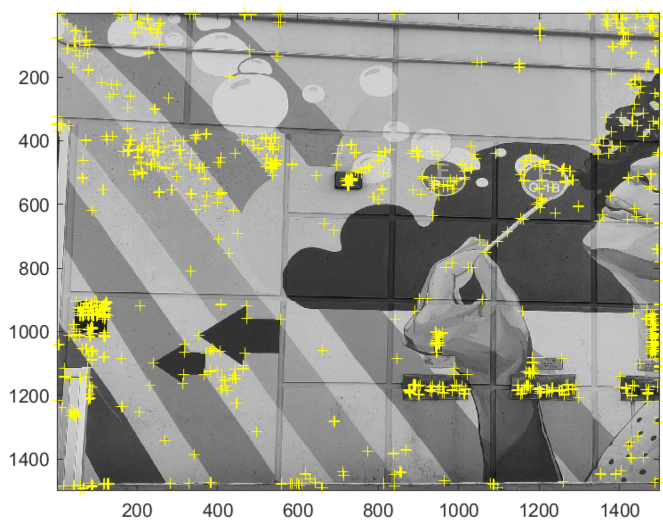


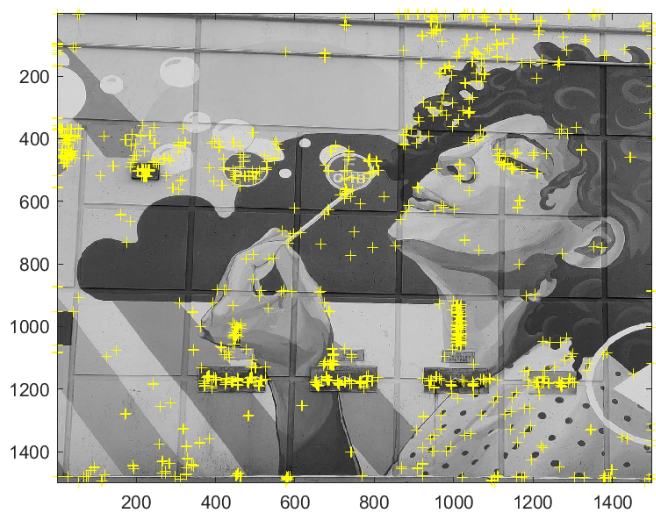




These 8 sets of images are used for stitching the images together are the original ones since they are actually the undistorted ones. The parameters used for implementation of these parts are the default ones. The Harris Corner Detector was set with 1,000 features, and a ‘tile’ approach of 2 rows and 2 columns. The features were distributed sufficiently across the image. The tile approach distributed the features across the image, which provided a non-maximal suppression effect to the features. Also enabled the smoothing filtering in the frequency domain. From Fig. It is obvious that the panorama creation is successful and the images are stitched properly. The final image is best aligned near the buildings.However, some misalignment is present at the road-crosswalk part. The main reason could be because the detector we used to create panorama is a 2D detector, and it is hard to blend the 3D structures of the road. Hence, we can say that the Harris feature detector tries to detect corners. And it helps detect a lot of the corners of different features of the buildings such as the building borders, windows, railings, etc. That’s why the building has more features and the road/crosswalk/car has less features.

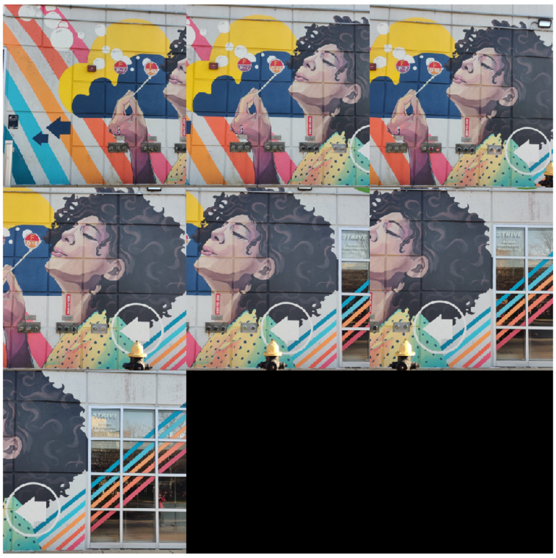
2.2 Ruggles Mural with 50% Overlapping





A set of 7 photos were captured at Ruggles with 50% overlapping. The parameters used for implementation of these part are the default ones.The Harris Corner Detector was set with 1,000 features, and ‘tile’ approach of 2 rows and 2 columns.

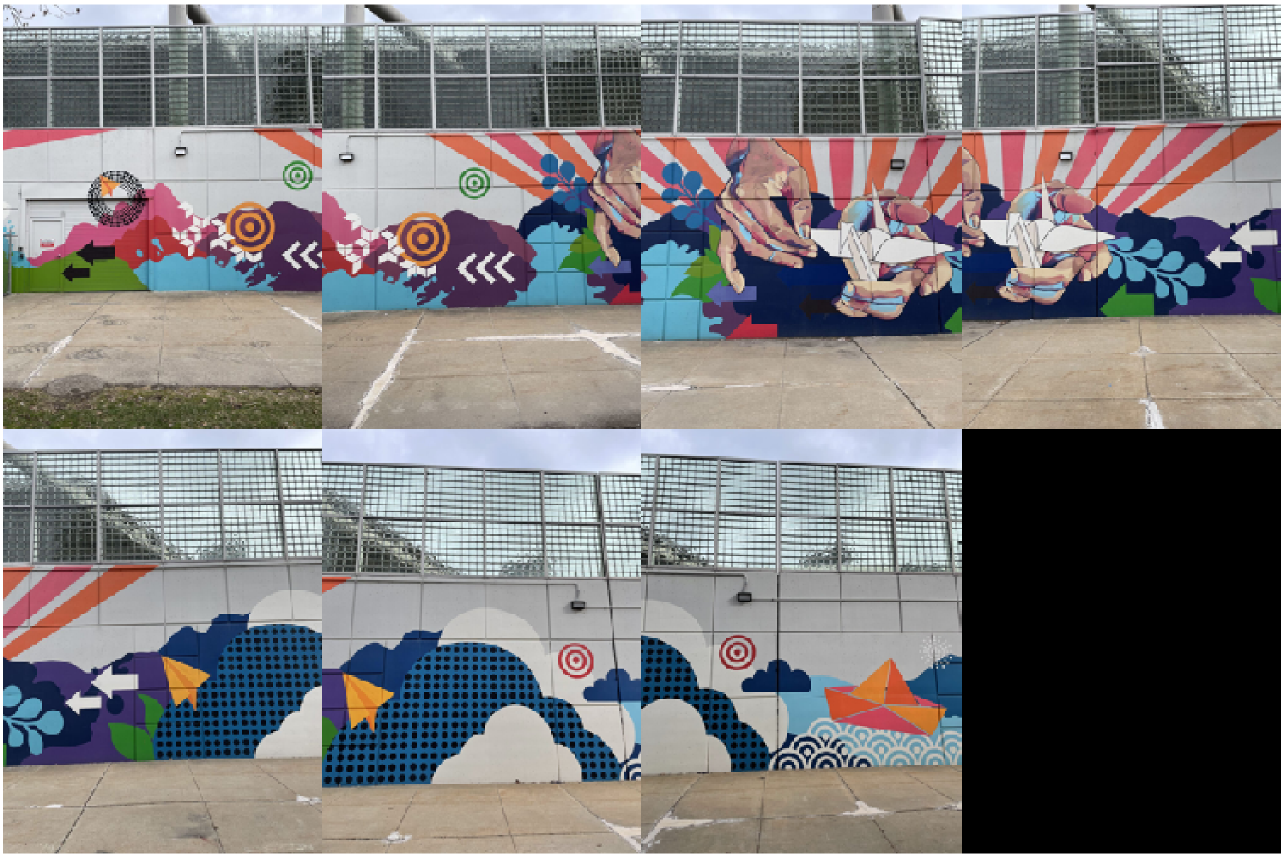
The features were distributed sufficiently across the image. The tile approach distributed the features across the image, which provided a non-maximal suppression effect to the features

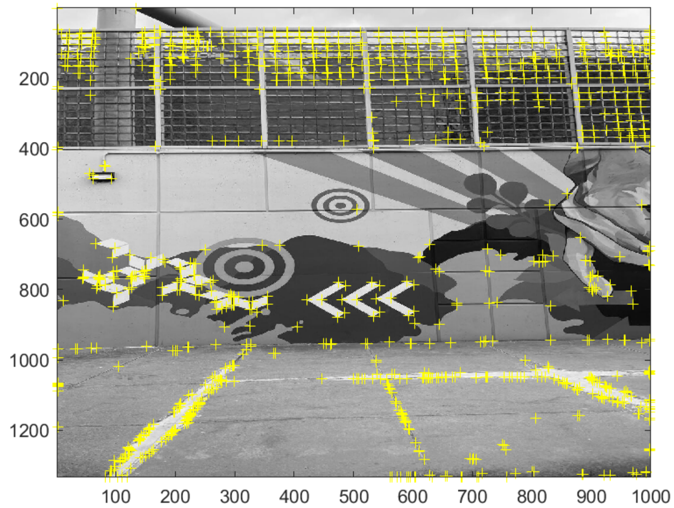


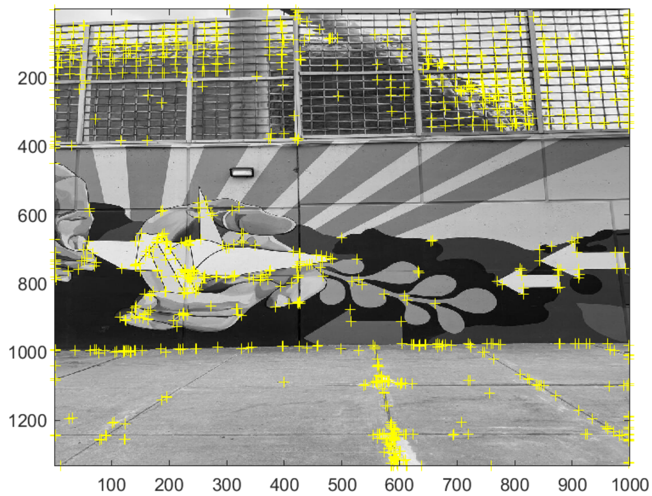
2.3 Ruggles Mural with 15% Overlapping

A set of 7 photos were captured at Ruggles with 15% overlapping. The overlap of these 7 image is considerably smaller than before. The parameters used for implementation of these part are the default ones. The Harris Corner Detector was set with 1,000 features, and ‘tile’ approach of 2 rows and 2 columns. The features were distributed sufficiently across the image. The tile approach distributed the features across the image, which provided a non-maximal suppression effect to the features.

By increasing the number of feature point, we can make the stiching more even distributed.



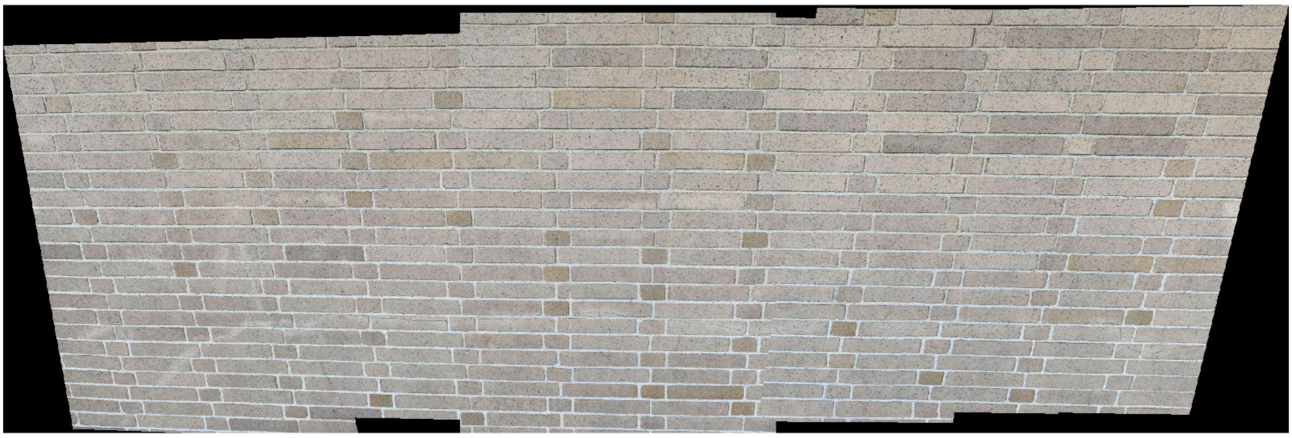


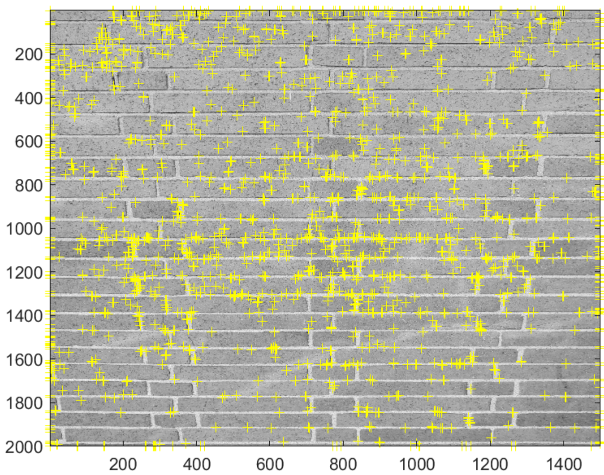


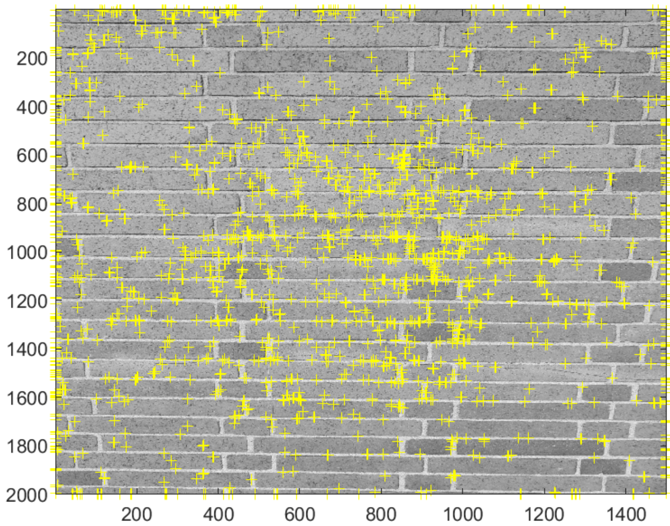
we can see a better panoramic mosaic than before. However, there is still mismatch of the last three images. If we compare the stiching done in 50% overlapping is much better than 15% overlapping, if we use harris corner detector with 1000 features. On 15% overlap, it shows a bad result of the mosaicking algorithm. Because many feature points are in the upper part of the image, which is all the repeatitive square pattern of the cage, it is hard to blend the images with proper order. This synchronisation of the pattern makes it hard to blend.

2.4 Cinder Wall Mosaic

A set of 6 overlapping photos of cinder block wall were captured at Cabot center with a similar orientation. There are some regular and repetitive patterns on the walls. The parameters used for implementation of these part are the default ones. The Harris Corner Detector was set with 1,800 features, and ‘tile’ approach of 2 rows and 2 columns. The tile approach distributed the features across the image, which provided a nonmaximal suppression effect to the features. Most of the features are located at the seam and corners of the block shown in Figures below . The features detected were distributed sufficiently well across the images. This is mainly because of the numerous distinct corners that can be observed in the image due to the brick designs. It is clearly visible in the result also where distortions are not visible clearly. They are more clear towards the borders, but are still quite well-aligned. If we compare cinder brick wall with other above experiments, we have used more harris features here because cinder block forms a repetitive pattern. And this repetitive pattern makes it hard to blend. As we increase the harris features we can see that stitching is quite perfect shown in final image







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4. References

https://www.mathworks.com/help/vision/ug/camera-calibration. html •
https://www.mathworks.com/help/vision/ug/feature-based-panoramic-image-stitching. html