Implementation of Harris Corner Detection and Mosaic Algorithm for Panoramic Image Stitching

1. INTRODUCTION

This report deals with camera calibration to obtain undistorted images to be used for Panoramic Photo Stitching. It also includes the implementation of Harris corner detection algorithm for feature detection and usage of Image mosaicing algorithm to get a panoramic image.

2. BACKGROUND

Image Mosaicing is termed as the process of combining multiple images into a single image to obtain a large field of view, which is not possible to get with a single image [1]. To create a Panorama, a set of images are required with overlapping field of view and then stitched together using these three steps: Image calibration, Image registration and Image blending [2]. In Image calibration, images are calibrated using the Extrinsic and Intrinsic parameters of the camera. Then the Image registration is done in which geometric relation between overlapping images are found so that they can be transformed for aligning with each other. Image registration generally includes feature detection, extraction and its matching [1]. Then Image blending is done to make the stitched images smoother at the seam positions. For Feature detection, the Harris Corner detection method is used which is invariant to image noise and transformations.

3. CAMERA CALIBRATION

Image calibration is done to minimize the difference between an ideal model of lens and the actual camera lens used. So, Camera calibration is done to estimate the parameters of lens and image sensor of camera and reprojection error. Camera parameters include intrinsic, extrinsic and distortion coefficients. These parameters are used to correct lens distortion and obtain undistorted images.

Intrinsic and extrinsic camera parameters are used to reconstruct the 3D structure of an image using the pixel coordinates on the image plane. The extrinsic parameters represent the location of camera in 3D plane with respect to a known world reference frame and intrinsic parameters represent the focal length and principal point of camera which link the pixel coordinates to the coordinates in camera reference frame [2].

The reprojection error measures the distance between the reprojection of an estimated model and its corresponding true model.

3.1. Estimation of Intrinsic and Extrinsic Parameter

To find the camera parameters, Caltech Camera Toolbox is used for calibration based on 20 images of planar checkerboard. Fig. 1 shows the 20 images used for calibration. The images are of size 4000 pixels (width) x 3000 pixels (height) and taken from Samsung S22 mobile phone camera.

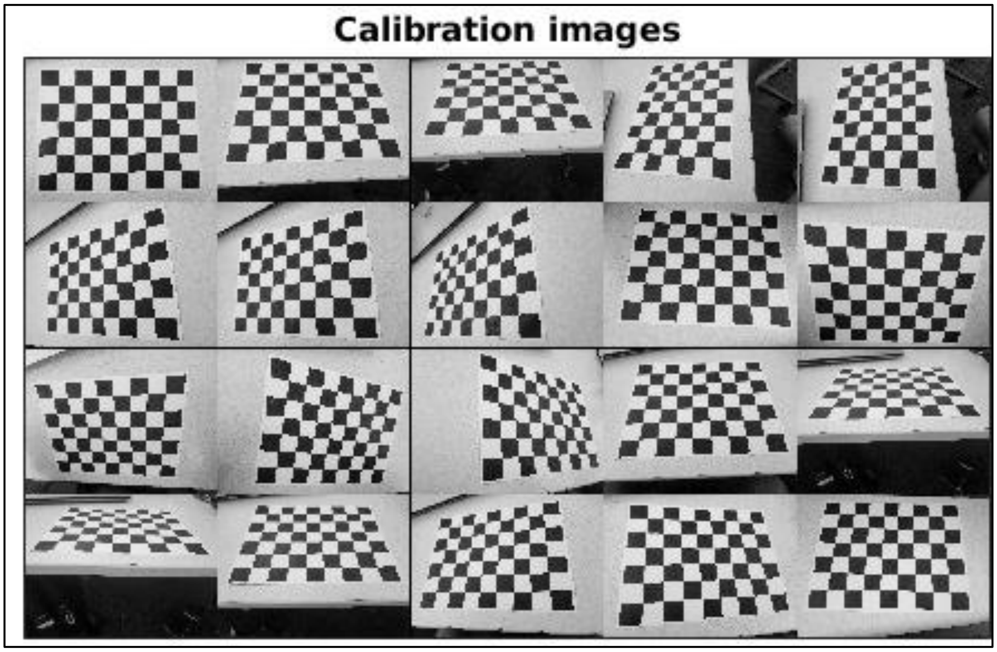

Fig. 1. Images used for calibration

After reading the images, manual corner selection is done to initialize the extraction of grid corners and then calibration is done to find the parameters and reprojection error.

After initial calibration, camera parameters (fig. 2) and reprojection error (fig. 3) is estimated.

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Calibration parameters after initialization:

Focal Length:          fc = [ 2831.24946   2831.24946 ]
Principal point:       cc = [ 1999.50000   1499.50000 ]
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: 20
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 = [ 2735.16099   2739.20473 ] +/- [ 14.39996   14.60057 ]
Principal point:       cc = [ 1947.94794   1524.99241 ] +/- [ 10.18784   9.44778 ]
Skew:             alpha_c = [ 0.00000 ] +/- [ 0.00000  ]   => angle of pixel axes = 90.00000 +/- 0.00000 degrees
Distortion:            kc = [ 0.06694   -0.09274   -0.00181   -0.00108  0.00000 ] +/- [ 0.01085   0.02790   0.00120   0.00157  0.00000 ]
Pixel error:          err = [ 1.92214   2.12294 ]

Note: The numerical errors are approximately three times the standard deviations (for reference).
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Fig. 2. Camera parameters after initial calibration

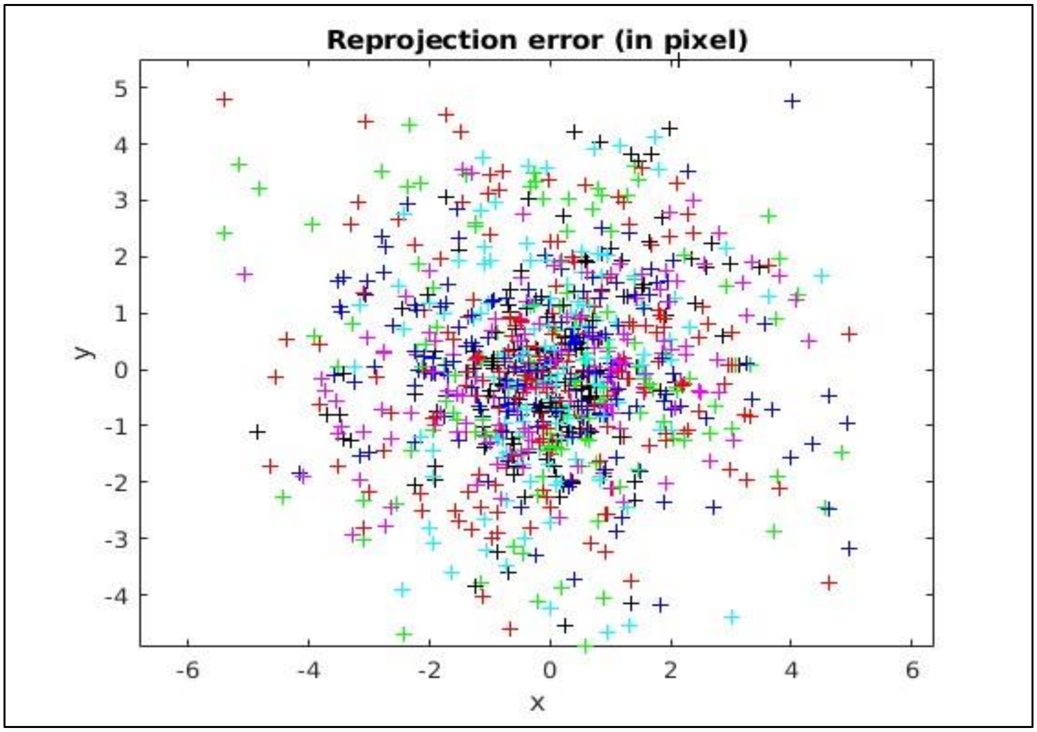

Fig. 3. Reprojection error after initial calibration

The reprojection error (in pixels) (1.92213, 2.12294) is quite large and while manual corner selection, the corners are not selected precisely for oblique images and thus contributing to large error. Now, image corners are again computed automatically using the Recompute corner option in toolbox and calibration is done.

After final calibration, the reprojection error is reduced considerably. Fig. 4 shows the camera parameters and fig. 5 show the reprojection error after final calibration.

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Main calibration optimization procedure - Number of images: 20
Gradient descent iterations: 1...2...3...4...5...6...7...8...9...10...11...12...13...14...15...16...17...done
Estimation of uncertainties...done


Calibration results after optimization (with uncertainties):

Focal Length:          fc = [ 2717.72150   2721.64567 ] +/- [ 9.88758   10.02714 ]
Principal point:       cc = [ 1939.27599   1519.96954 ] +/- [ 6.99062   6.48653 ]
Skew:             alpha_c = [ 0.00000 ] +/- [ 0.00000  ]   => angle of pixel axes = 90.00000 +/- 0.00000 degrees
Distortion:            kc = [ 0.07473   -0.09874   -0.00268   -0.00206  0.00000 ] +/- [ 0.00737   0.01876   0.00084   0.00109  0.00000 ]
Pixel error:          err = [ 1.41889   1.38290 ]

Note: The numerical errors are approximately three times the standard deviations (for reference).
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Fig. 4. Camera parameters after final calibration

The intrinsic parameters such as focal length, principal points and distortion coefficients is shown in fig. 4. The focal length and Principal points are measured in pixels.

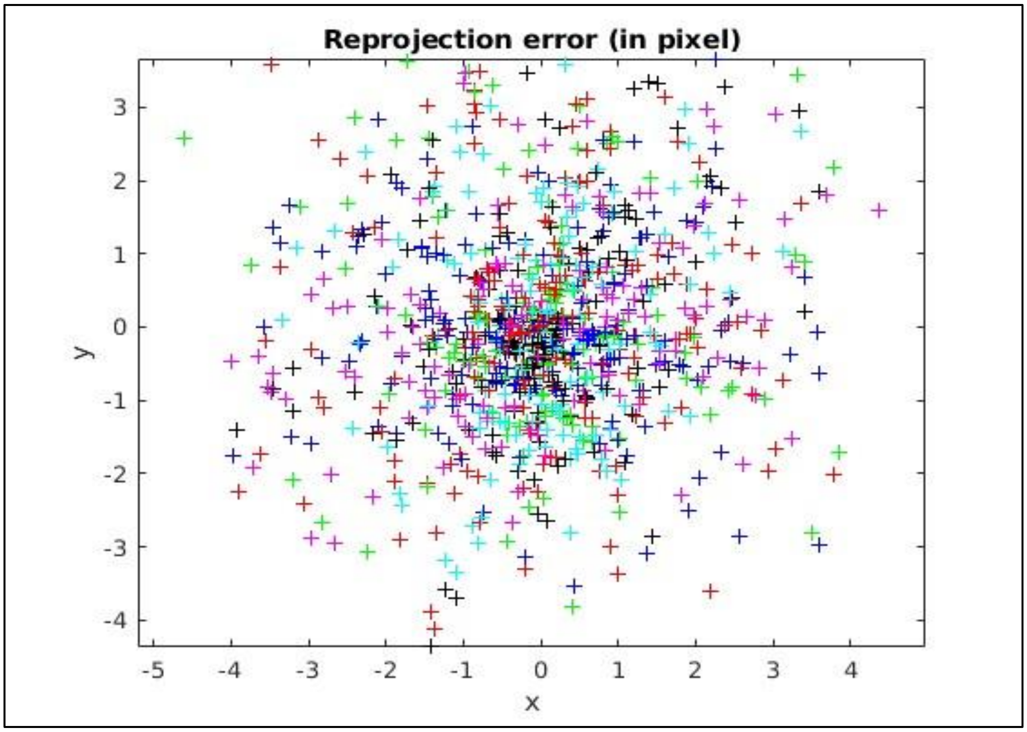
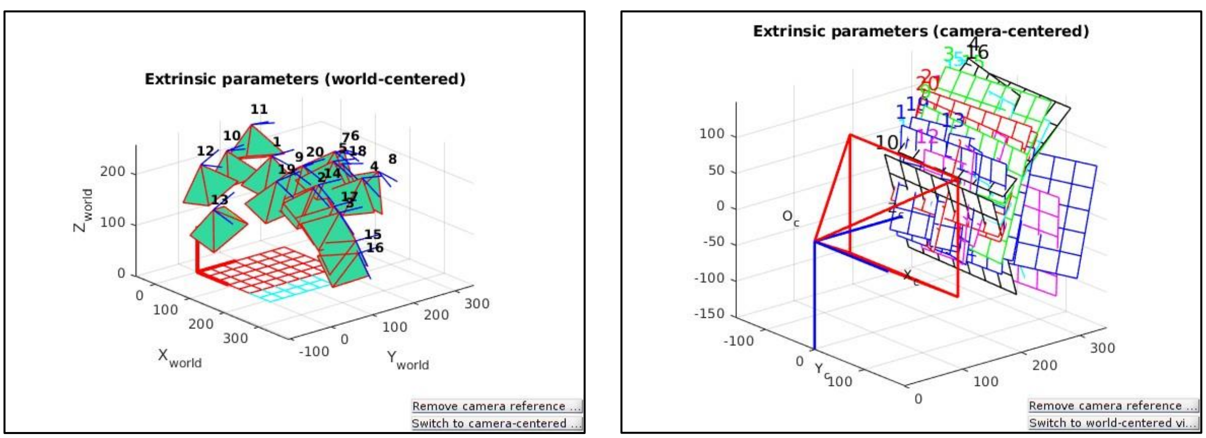


Fig. 5. Reprojection error after final calibration

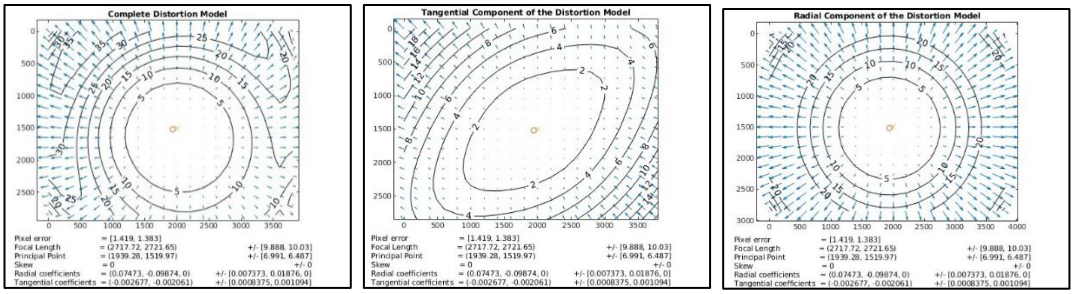
The reprojection error (in pixels) after final calibration is (1.41889, 1.38290). Since the original image is 4000x3000 (pixels), the pixel error of 1.4 is acceptable as this means that reprojected image point will be 1.4 pixels away from the true position in an array of pixels of 4000x3000.



(a) (b)

Fig. 6. Extrinsic parameters (a) Relative to World Frame (b) Relative to Camera frame

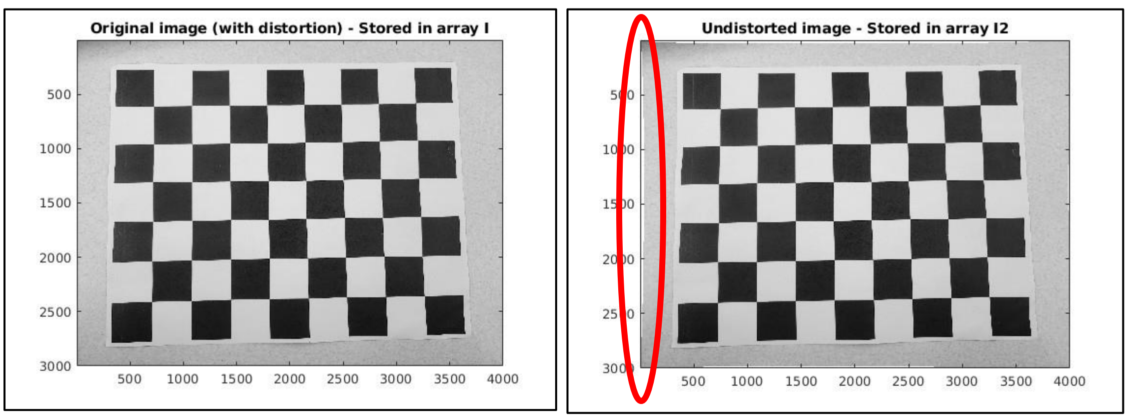
The Extrinsic parameters relative to the World reference frame and Camera reference frame are shown in fig. 6.



(a) (b) (c)

Fig. 7. (a) Complete Distortion Model (b) Tangential Component of Distortion Model (c) Radial Component of Distortion Model

Complete Distortion Model represents the impact of distortion on each pixel and each arrow depicts the overall displacement of each pixel induced by the lens distortion. Finally, using the calibration parameters, the images are undistorted. Fig. 8 shows the Uncalibrated and Calibrated image.



(a) (b)

Fig. 8. (a) Distorted Image before calibration (b) Undistorted Image after calibration (slight bulging at edges)

The images are taken from Samsung S22 camera, and the phone camera is already calibrated. So, it can be concluded that again calibrating the images can generate some sort of distortion due to over calibration and same can be seen from the Undistorted image after the calibration that the left and top edge are little bit bulged inwards. This will create an issue while stitching the images at the seam position.

To see the effect, both original images and calibrated images are used to create the Panorama.

4. IMAGE MOSAICING

For Image stitching, the most important step is Feature detection and extraction. For this, Harris Corner Detection algorithm is used. After Feature detection and extraction, Image blending is done to generate the panorama [3]. Several testings are done with different sets of images which are explained in detail in the sections below.

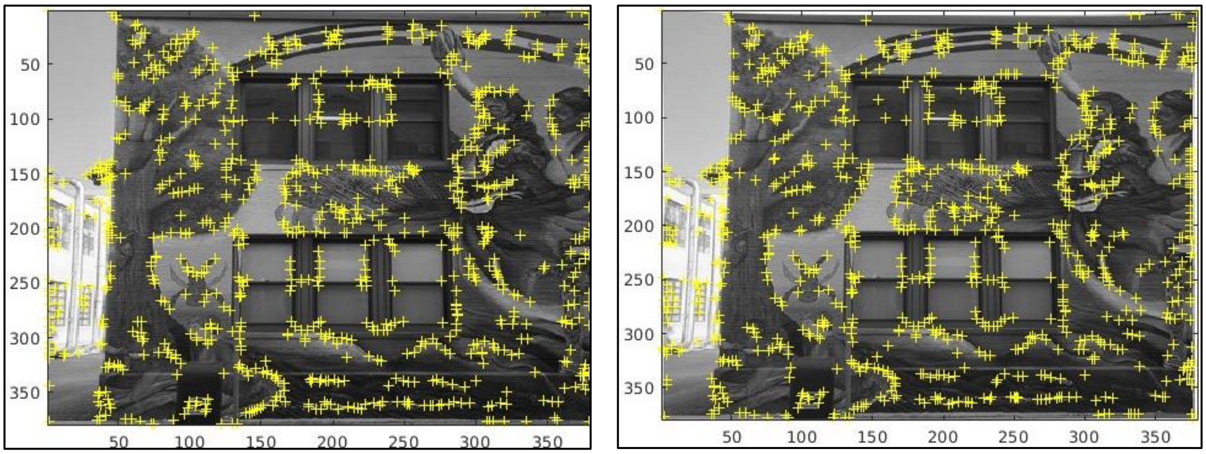
4.1. LSC Mosaic

For first set of tests, several overlapping images of Latino Students Center (LSC) building are taken. Fig. 9 shows the images of LSC building taken from phone camera. As already explained in section 3 that calibration of phone camera images produces slight distortion at the edges and to create the panorama, both Calibrated and Uncalibrated images are used. Fig. 10 shows the calibrated images of LSC building.

Fig. 9. Uncalibrated images of LSC building

Fig. 10. Calibrated images of LSC building

Now, after reading the images, Harris Corner Detector is used in algorithm to find the features in the images. Before using the Harris detector, Color image is converted to Grayscale image to find the features. In Harris detector, the number of features to be detected is kept 1000, tile size is kept [10 10] and threshold value is kept 1000. Fig. 11 shows the Harris corners in uncalibrated image(left) and calibrated image(right).



(a) (b)

Fig. 11. Harris corners detected in (a) uncalibrated image (b) calibrated image

After feature detection, features are extracted, and feature matching is done. Then, transformation matrix is calculated and finally stitching, and blending is done to generate the final panorama.

Fig. 12. Panoramic mosaic of LSC building (uncalibrated phone images used)

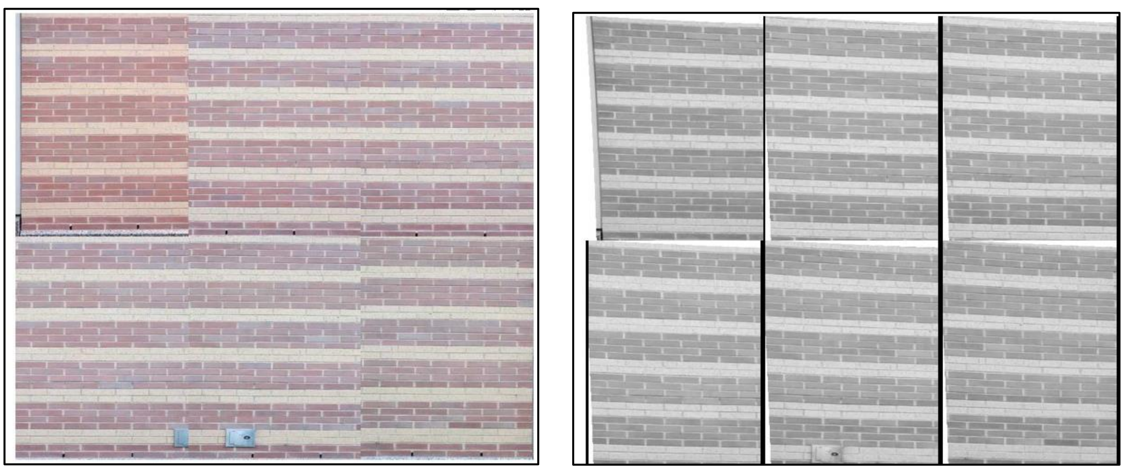
Fig. 13. Panoramic mosaic of LSC building (calibrated images used)

Fig. 12 and Fig. 13 shows the panorama of LSC building. In fig. 12, right most photo is not matched properly to the other images as pixel intensity of right most photo is low due to sun shining in the image and the LSC building image got dark as compared with other images. Also, it can be seen from the fig. 13 that edges are not properly aligned and the same is explained above i.e., due to over calibration.

But overall stitching is good. To generate a good quality panorama, 1000 features points are selected and for uniform distribution all over the image, tile size of [10 10] is selected. Also, to keep only stronger corner points, threshold value of 1000 is chosen so that weak corner points get eliminated and feature is matched only with the stronger corners.

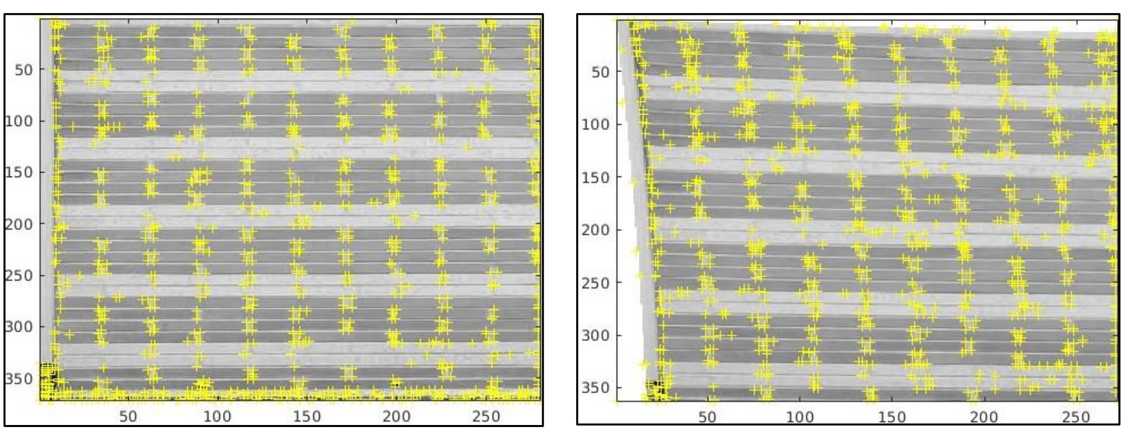
4.2. Brick Wall Mosaic

The second set of testing is done with Brick wall to observe the effectiveness of algorithm in generating a panorama of image sets repeating feature. For this, multiple overlapping images of brick wall are taken.



(a) (b)

Fig. 14. Brick image set (a) uncalibrated camera image (b) calibrated image



(a) (b)

Fig. 15. Harris corner detected (a) uncalibrated image (b) calibrated image

Since the brick wall has repeating features, the corners are detected almost at the seam position of brick where the intensity is changing from dark to light and light to dark. Number of feature points are kept 1000 and tile size of [1 1].

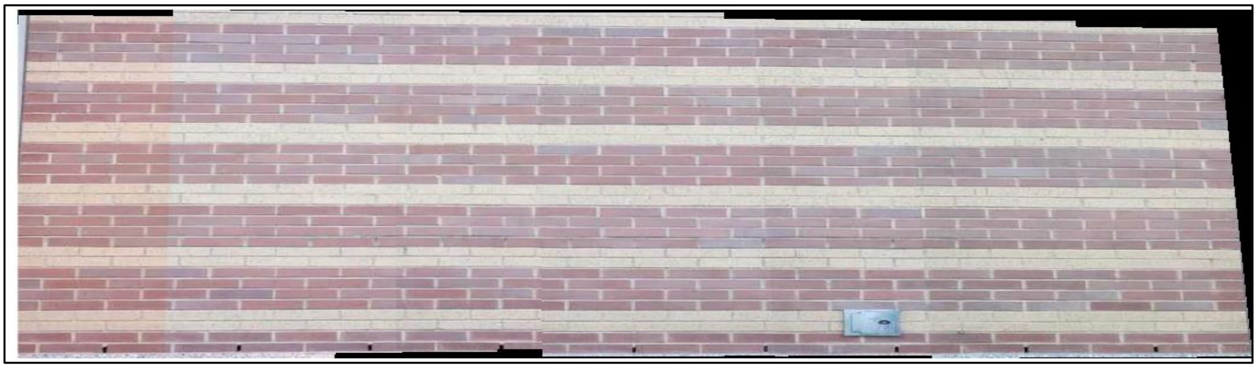


Fig. 16. Panoramic mosaic of brick wall with phone camera images

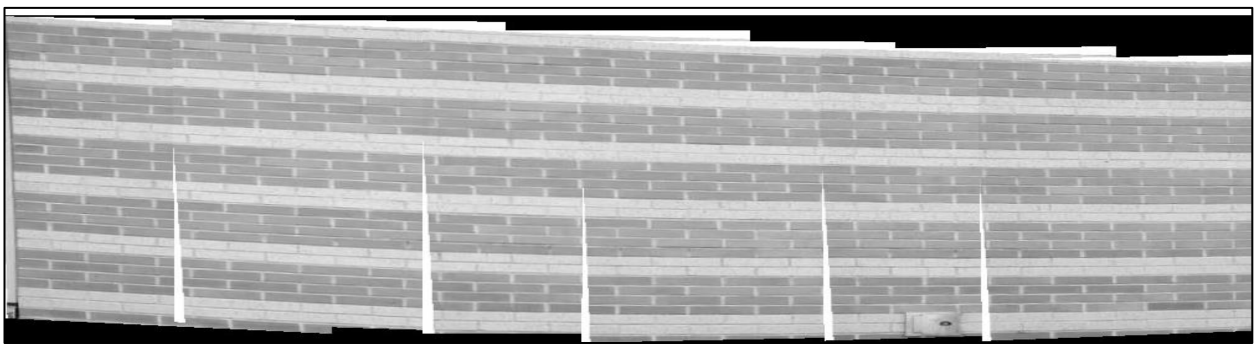


Fig. 17. Panoramic mosaic of brick wall with calibrated images

Fig. 16 and Fig. 17 shows the Panorama of brick wall. Due to edge distortion in calibrated image, there is problem of image stitching in fig. 17.

In LSC mosaic, there are unique features present in the images (same can be seen in the fig. 11) and the panorama is created easily by feature matching. But in Brick wall mosaic, there are similar features all over the image (can be seen in fig. 15) and there are no distinct features available which creates difficulty in feature matching. But by keeping the tile size [1 1], the performance of brick wall mosaic is made good, and the panorama of brick wall also has given a satisfactory result.

4.3. Mosaic with different overlap

For the third test, 2 sets of images of Ruggles station are taken, one with 50% overlap and the other with 15% overlap.

4.3.1. 50% overlap

The image set with 50% overlapping is shown in fig. 18 and fig. 19.

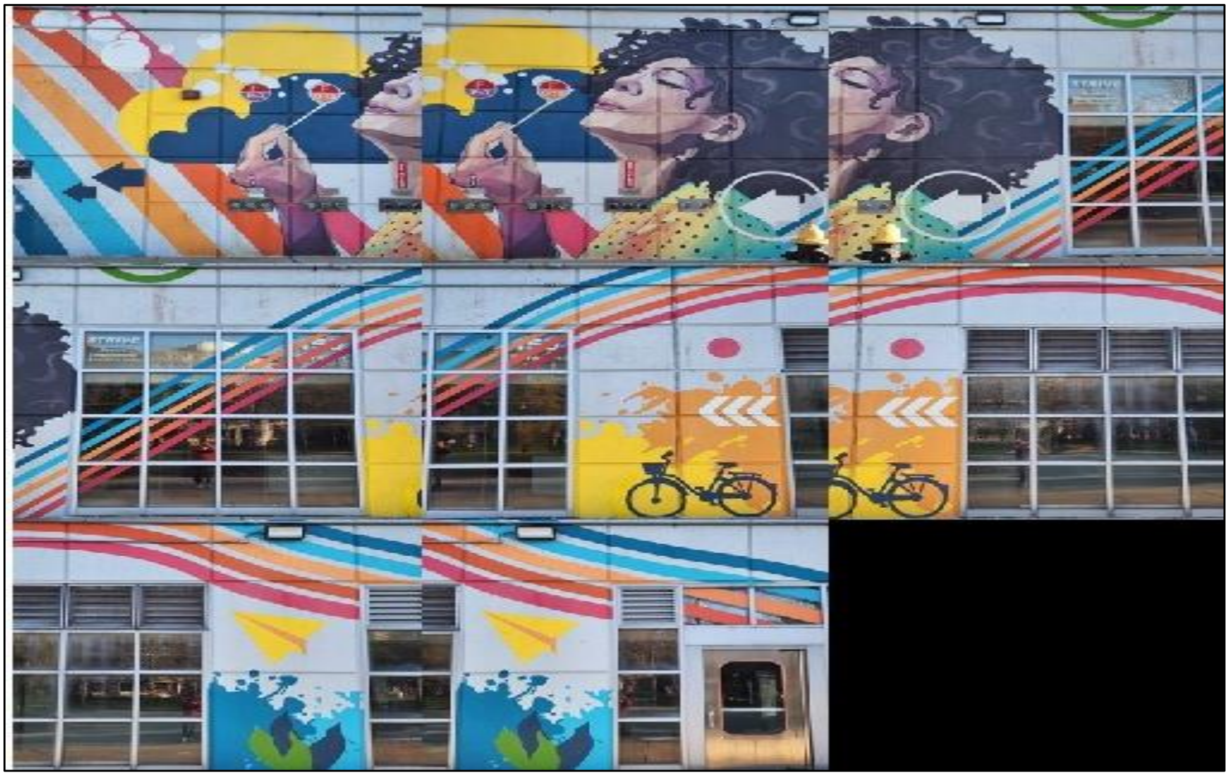


Fig. 18. 50% overlap of uncalibrated images

Fig. 19. 50% overlap of calibrated images

Since the overlap is 50%, so only 1000 features are selected and tile size is kept [10 10] to keep the distribution uniform in the image and threshold value is kept 1000 to select only the stronger corner points.

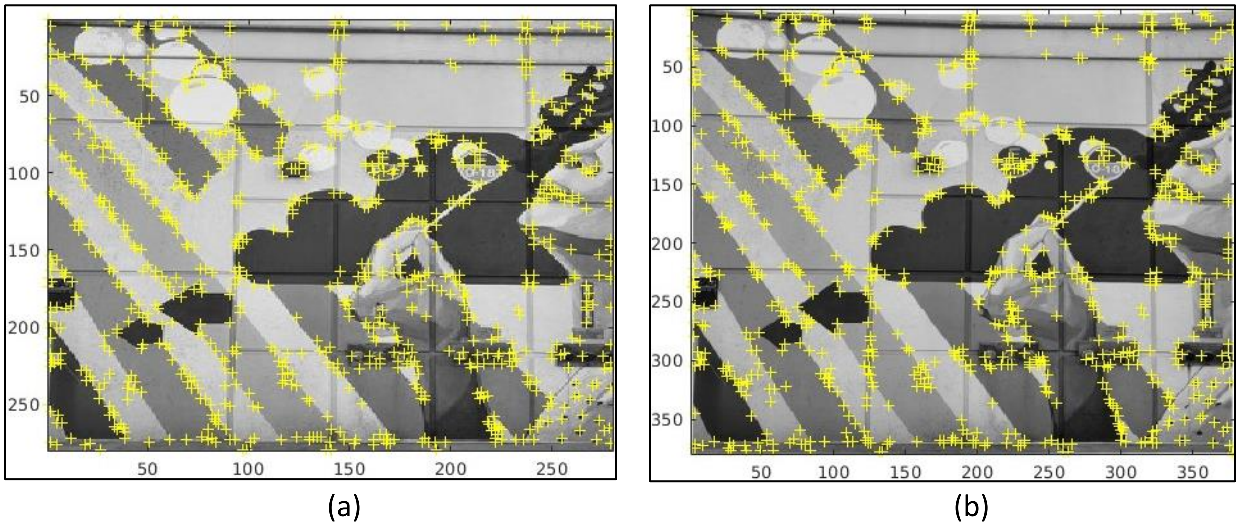


Fig. 20. Harris corner detected (a) uncalibrated images (b) calibrated images

Fig. 21. Panoramic mosaic with uncalibrated image of 50% overlap

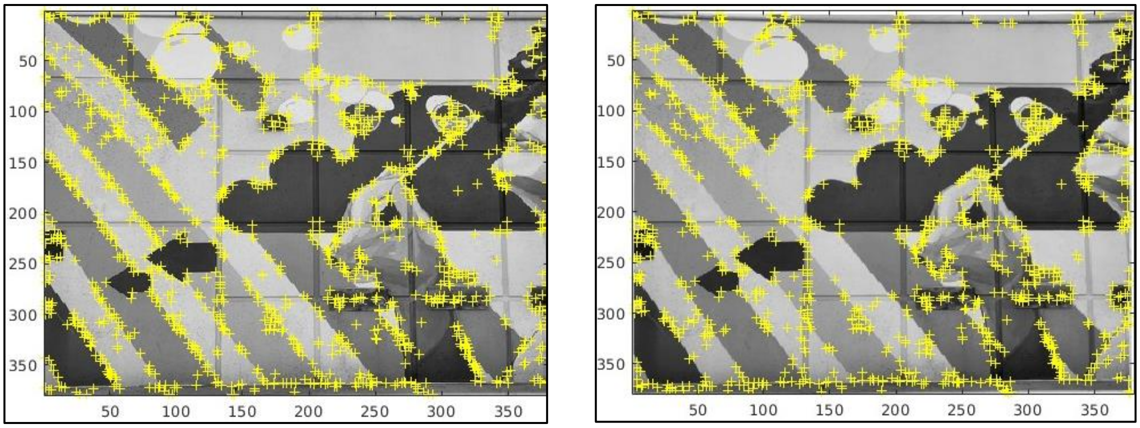
Fig. 22. Panoramic mosaic with calibrated image of 50% overlap

4.3.2. 15% overlap

The image set with 15% overlap is shown in fig. 23 and fig 24.

Fig. 23. 15% overlap of uncalibrated images

Fig. 24. 15% overlap of calibrated images



(a) (b)

Fig. 25. Harris corner detected (a) uncalibrated images (b) calibrated images

Fig. 26. Panoramic mosaic with uncalibrated image of 15% overlap

Fig. 27. Panoramic mosaic with calibrated image of 15% overlap

It is clearly seen from the panoramic view of fig. 21 and fig. 26 that images with overlap of 50% has performed well in generating the mosaic as more overlapping provides more matching of features and thus better stitching of images. In case of less overlap and with small distortion along edges for calibrated images, the panorama in fig. 27 has performed badly. Thus, it is certain that more overlap will provide better result for mosaic and even with presence of small distortion, less overlap images cannot be stitched properly.

For 50% overlapped images, number of features are kept to be 1000 but for 15% overlapped images, to get similar performance, number of features are kept 1500.

5. CONCLUSION

With the completion of three testings, it is concluded that to generate good panoramic image mosaic, following conditions should be met:

1. Images should be free of any distortion
2. Presence of unique features
3. Maximum possible overlap

REFERENCES

[1] Shreyas Mistry, Arpita Patel "Image Stitching using Harris Feature Detection", *International Research Journal of Engineering and Technology:* Vol. 03: Issue: 04| Apr-2016.

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[3] “Feature Based Panoramic Image Stitching” Accessed Nov. 28,2022. [Online.] Available: https://www.mathworks.com/help/vision/ug/feature-based-panoramic-image-stitching.html