Q1-Final

March 1, 2020

```
In [1]: import numpy as np
        import cv2
        import matplotlib.pyplot as plt
        import random
        from glob import glob
        import time

        # get_ipython().magic('matplotlib inline')
```

```
In [2]: def construct_H_matrix(x, xs):
            '''
                Construct the correspondance matrix for estimating Homography

                Keyword Arguments:
                    x  -- Image points from the First image
                    xs -- Image points from the Second Image

                Return Values:
                    A  -- Constructed correspondance matrix
            '''
            A = np.zeros((0, 9))
            for i in range(len(x)):
                a = np.array([
                    [x[i][0], x[i][1], 1, 0, 0, 0, -xs[i][0]*x[i][0], -xs[i][0]*x[i][1], -xs[i][
                    [0, 0, 0, x[i][0], x[i][1], 1, -xs[i][1]*x[i][0], -xs[i][1]*x[i][1], -xs[i][
                    ])
                A = np.concatenate((A, a))
            return A
```

```
In [3]: def transform_points(H, x):
            '''
                Given homography transforms points into the homography frame of reference

                Keyword Arguments:
                    H  -- 3*3 homography matrix
                    x  -- N*2 Points to be transformed

                Return Values:
                    xs  -- N*3 Transformed Points
            '''
            # Convert points into homogeneous coordinates
            x_homogeneous = np.concatenate((x, np.ones((len(x), 1))), axis=1)

            # Calculate the transformed points and normalize them
            xs = H @ x_homogeneous.T
            xs[0, :] = xs[0, :] / xs[2, :]
            xs[1, :] = xs[1, :] / xs[2, :]
            xs[2, :] = xs[2, :] / xs[2, :]
            xs = xs.T

            return xs
```

```
In [4]: def calculate_transformation_error(H, x, xs):
            '''
                Calculate the transformation error between the transformed points and the ground

                Keyword Arguments:
                    H                     -- 3*3 homography matrix
                    x                     -- N*2 points to be transformed
                    xs                    -- N*2 ground truth points

                Return Values:
                    transformation_error  -- Return the L2 norm of the error
            '''
            # Convert points into homogeneous coordinates
            xs_homogeneous = np.concatenate((xs, np.ones((len(xs), 1))), axis=1)

            # Calculate the projected points
            transformed_coords = transform_points(H, x)

            # Calculate the projection error
            transformation_error =  np.linalg.norm(xs_homogeneous - transformed_coords, axis=1)

            return transformation_error
```

0.1 RANSAC

- For better estimation of the homography matrix, we perform RANSAC and try to get the homography matrix with maximum inliers.
- We calculate the inliers based on the transformation error, which is required to be below a certain preset threshold that we choose.

```
In [5]: def RANSAC(img_coords_1, img_coords_2, num_points, max_iterations=30000, thresh=0.1):
            '''
                Get the best estimate of the Homography Matrix using RANSAC
```

```
        Keyword Arguments:
            img_coords_1   -- Coordinates of the first image after matching
            img_coords_2   -- Coordinates of the first image after matching
            num_points     -- Number of matched points
            max_iterations -- Maximum Number of iterations to run RANSAC for (default=20
            thresh         -- Threshold to compute inliers (default=0.1)

        Return Values:
            H              -- Estimated Homography matrix using RANSAC
    '''
    min_transform_error = 999999999
    max_inliers = -999999999

    # Best estimate of Projection matrix by far
    _H = np.zeros((3, 3))

    inliers = []

    for i in range(max_iterations):

        # Randomly select 4 world points and the corresponding image points
        idx = random.sample(range(0, num_points), 4)
        x  = img_coords_1[idx]
        xs = img_coords_2[idx]

        # Perform DLT and get the Transformation Matrix
        H = DLT(x, xs)

        # Calculate projection error
        transformation_error = calculate_transformation_error(H, img_coords_1, img_coord


        inliers = np.sum(transformation_error<thresh)

        if inliers > max_inliers:
            max_inliers = inliers
            _H = H

        # Repeat for a maximum number of iterations

    return _H
```

0.2 Estimating the Homography Matrix

- To estimate the homography matrix we perform a DLT like estimation
- $x_2 = H_{21} \cdot x_1$

- $$\begin{bmatrix} wx_{21} \\ wx_{22} \\ w \end{bmatrix} = \begin{bmatrix} h_1 & h_2 & h_3 \\ h_4 & h_5 & h_6 \\ h_7 & h_8 & h_9 \end{bmatrix} \cdot \begin{bmatrix} x_{11} \\ x_{12} \\ 1 \end{bmatrix} \tag{1}$$

- We take the SVD of the correspondance matrix which we define in the following way

- $\begin{bmatrix} x_1 & y_1 & 1 & 0 & 0 & 0 & -x_2x_1 & -x_2y_1 & -x_2 \\ 0 & 0 & 0 & x_1 & y_1 & 1 & -y_2x_1 & -y_2y_1 & -y_2 \end{bmatrix}$

- We require at least 4 points in order to estimate the homography matrix as it has 8 degrees of freedom. The ninth degree is removed due to scale ambiguity.

- We minimize the error, by taking the eigen vector corresponding to the smallest eigen value and reshape that to be our homography matrix

```
In [6]: def DLT(x, xs):
            '''
                Estimate Homography matrix using DLT

                Keyword Arguments:
                    x  -- Image points from the First image
                    xs -- Image points from the Second image

                Return Values:
                    A  -- Estimated Homography Matrix
            '''
            # Construct the DLT Matrix
            A = construct_H_matrix(x, xs)


            # Perform SVD on the Matrix
            U, s, Vh = np.linalg.svd(A.T @ A)

            # Extract the 9th row and Normalize it
            A = Vh[-1, :] / Vh[-1, -1]

            # Reshape the row and get the projection matrix
            A = A.reshape(3, 3)

            return A
```

```
In [7]: def find_matching_points(image1, image2, num_points=500):
            '''
                Find matching points between two images using SIFT

                Keyword Arguments:
                    image1   -- Image 1
                    image2   -- Image 2
                    num_points -- Maximum number of features
                Return Values:
                    x  -- Image points from the First image
                    xs -- Image points from the Second image
            '''
            # Initiate sift detector
            orb = cv2.xfeatures2d.SIFT_create(nfeatures=num_points)
        #     orb = cv2.ORB_create()

            # Create BF Matcher
            # bf = cv2.BFMatcher(cv2.NORM_HAMMING, crossCheck=True)
            bf = cv2.BFMatcher(cv2.NORM_L1, crossCheck=True)

            # Find keypoints and descriptors
            kp1, desc1 = orb.detectAndCompute(image1, None)
            kp2, desc2 = orb.detectAndCompute(image2, None)

            # Match descriptors
            matches = bf.match(desc1, desc2)

            # Sort the matches in the order of their distance
            matches = sorted(matches, key = lambda x:x.distance)[:80]

            # Draw first 10 matches.
            img3 = cv2.drawMatches(image1, kp1, image2, kp2, matches, None, flags=2)

            plt.imshow(img3),plt.show()

            if len(matches) >= 4:
                x = np.array([ kp1[m.queryIdx].pt for m in matches ])#.reshape(-1,1,2)
                xs = np.array([ kp2[m.trainIdx].pt for m in matches ])#.reshape(-1,1,2)
            return x, xs
```

```
In [8]: def warp_image(image_1, image_2, H):
            '''
                Warp image_2 to image_1 frame

                Keyword Arguments:
                    image_1  -- Image to warp to
                    image_2  -- Image to be warped
                    H        -- 3*3 homography matrix

                Return Values:
                    im_out  -- Warped image
            '''
            im_out = cv2.warpPerspective(image_2, H, (image_1.shape[1] + image_2.shape[1], image
            return im_out
```

```
In [9]: def crop_image(image, tolerence=0):
    '''
        Crop out black spaces from images by contouring

        Keyword Arguments:
            image  -- Image to be cropped

        Return Values:
            crop  -- Cropped image
    '''
    mask = image > tolerence
    if image.ndim==3:
        mask = mask.any(2)
    mask0,mask1 = mask.any(0),mask.any(1)
    return image[np.ix_(mask1,mask0)]
```

0.3 Image Stitching / Mosaicing

- In order to perform image stitching, we compute the homography between two images using RANSAC.
- After having computed the homography, we transform the second image in the first images reference frame.
- Then, we superimpose both the transformed and the first image in order to create the resultant stitched image.
- In order to stitch multiple images together, we take the resultant image we obtained from the above step and repeat the algorithm
- It is beneficial to perform the process with the resultant immage as we get more keypoints which matching a new image and thus relieving us to provide the images in a certain order.

```
In [10]: def stitch_images(images):
             '''
                 Given a set of images, perform image mosaicing and stitch the images.

                 Keyword Arguments:
                     images  -- Set of images of be stitched

                 Return Values:
                     A  -- Stitched Image
             '''
             result = images[0]
             for i in range(len(images)-1):
                 x, xs = find_matching_points(result, images[i+1])
                 H = RANSAC(xs, x, len(xs))
                 dst1 = warp_image(result, images[i+1], H)

                 resultant = np.zeros(dst1.shape).astype('uint8')
                 resultant[0:result.shape[0], 0:result.shape[1], :] = result[:,:,:]
                 mask = resultant<=0
                 resultant[mask] = dst1[mask]
```

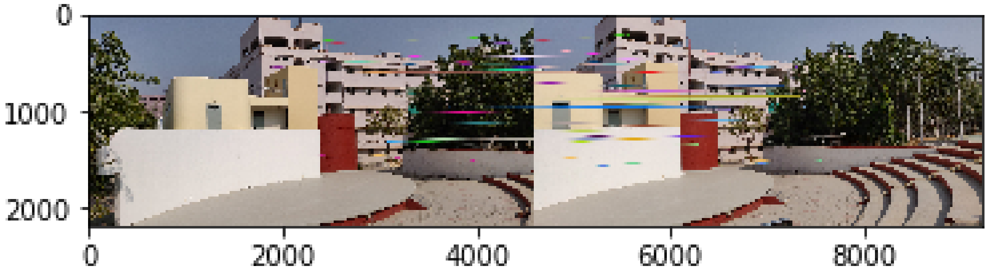
```
            result = crop_image(resultant)

            plt.imshow(result)
            plt.show()
        return result
```

0.3.1 Question 1 : Find matches between two partially overlapped images using any feature detector and descriptor

```
In [11]: image_files = sorted(glob('./image_mosaicing/img1/*'))
         images = []
         for im in image_files:
             images.append(cv2.cvtColor(cv2.imread(im), cv2.COLOR_BGR2RGB))

         x, xs = find_matching_points(images[1], images[2])
```



0.3.2 Question 2 : Estimate homography matrix between two images robustly using RANSAC

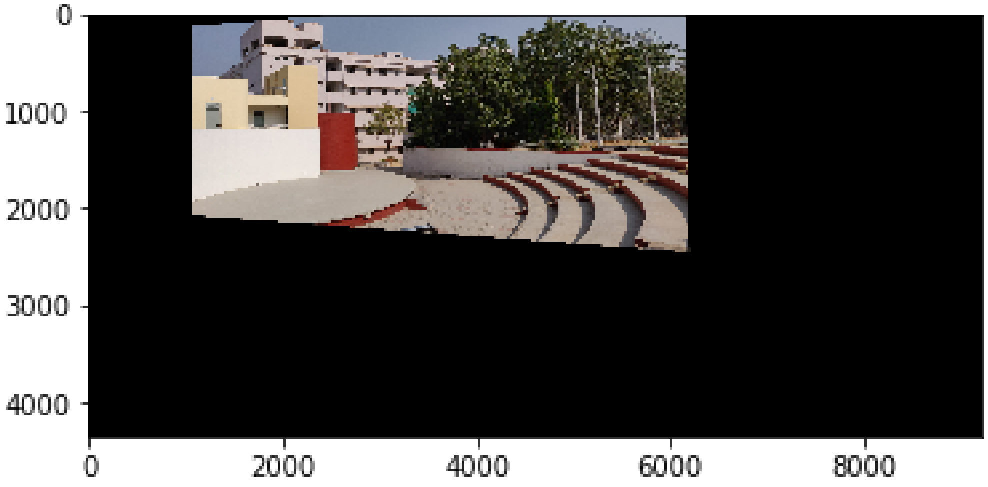
```
In [12]: H = RANSAC(xs, x, len(xs))
         print("Estimated Homography Matrix:\n",H)
```

```
Estimated Homography Matrix:
 [[ 7.19710665e-01 -1.27012982e-02  1.07937023e+03]
 [-7.09968288e-02  8.79695938e-01  1.45898122e+02]
 [-6.17983387e-05 -5.15009841e-06  1.00000000e+00]]
```

0.3.3 Question 3 : Transform one of the images to the others reference frame homography matrix

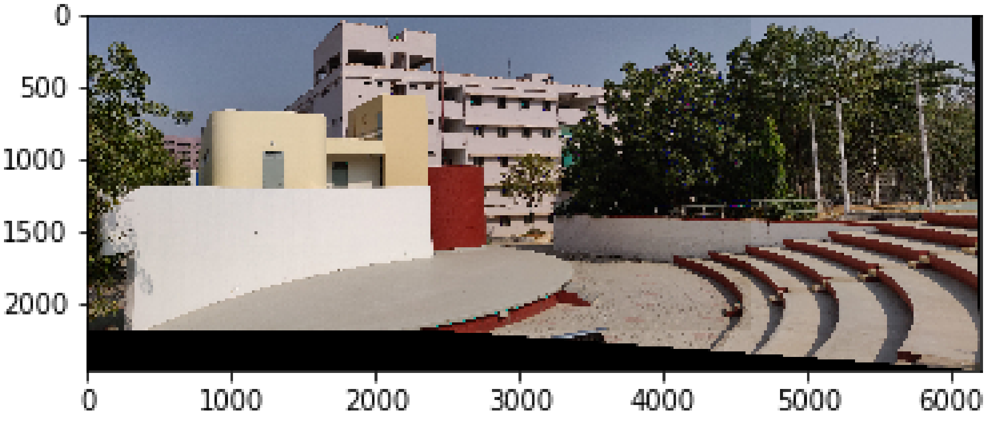
```
In [13]: dst1 = warp_image(images[1], images[2], H)
         print("Warped Image")
         plt.imshow(dst1)
         plt.show()
```

```
Warped Image
```



0.3.4 Question 4 : Stitch the two images together

```
In [14]: resultant = np.zeros(dst1.shape).astype('uint8')
         resultant[0:images[1].shape[0], 0:images[1].shape[1], :] = images[1][:,:,:]
         mask = resultant<=0
         resultant[mask] = dst1[mask]
         resultant = crop_image(resultant)
         plt.imshow(resultant)
         plt.show()
```

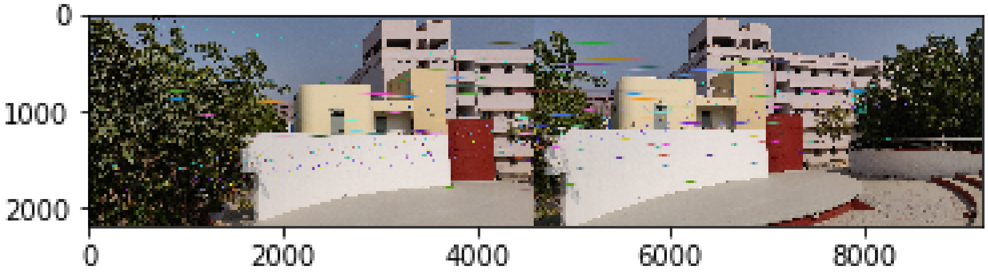


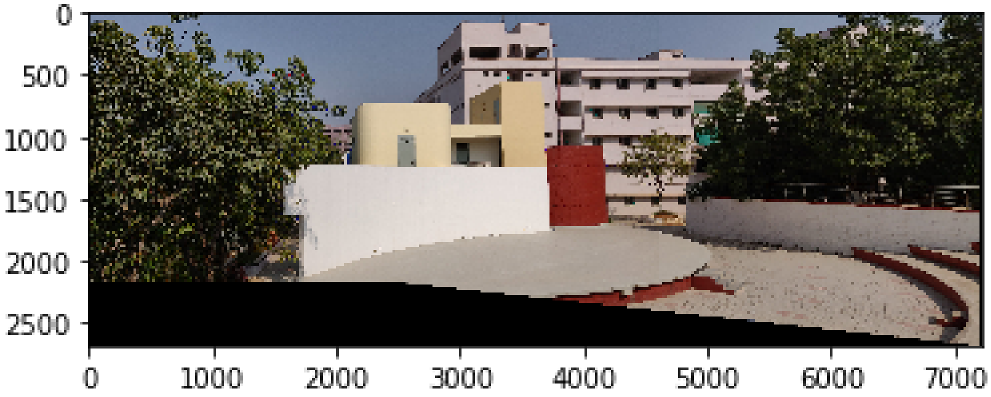
0.3.5 Question 5 : Stitch multiple images together

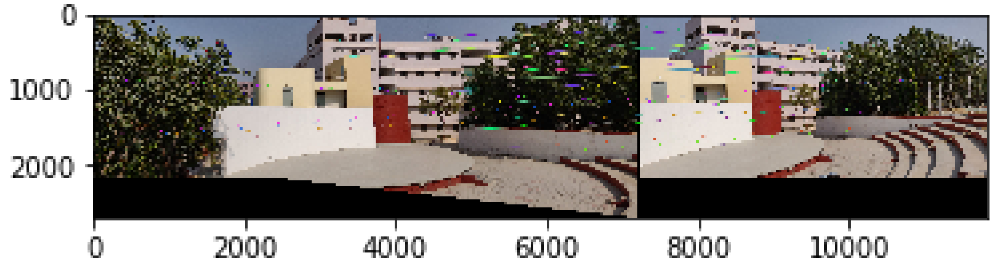
```
In [17]: image_dirs = sorted(glob('./image_mosaicing/*'))
         stitched_images = []
         for direc in image_dirs:
             print(direc)
             image_files = sorted(glob(direc+'/*'))
             images = []
             for im in image_files:
                 images.append(cv2.cvtColor(cv2.imread(im), cv2.COLOR_BGR2RGB))

             stitched_images.append(stitch_images(images))
```

```
./image_mosaicing/img1
```



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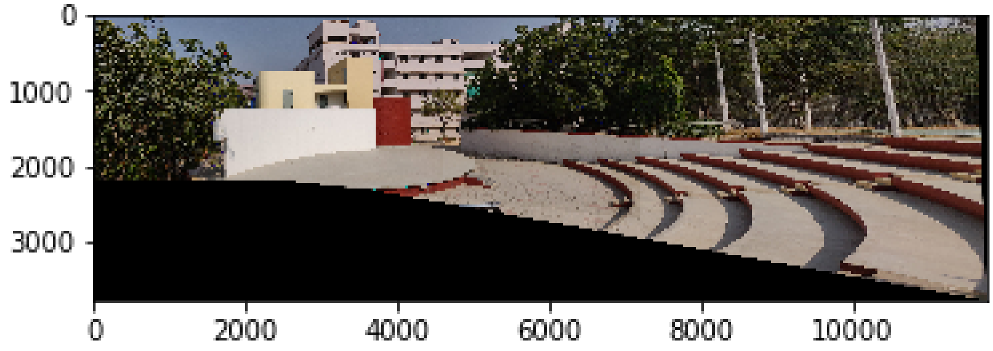
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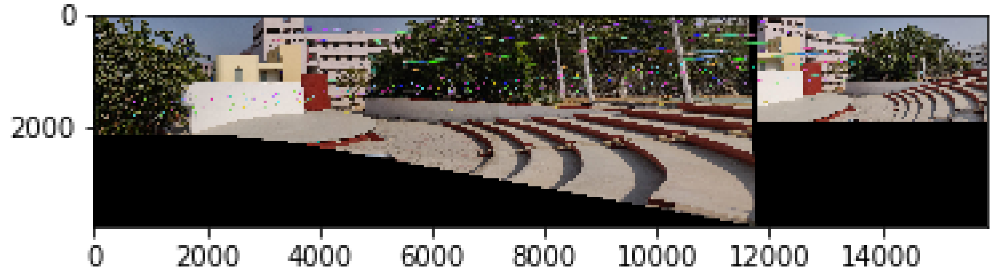
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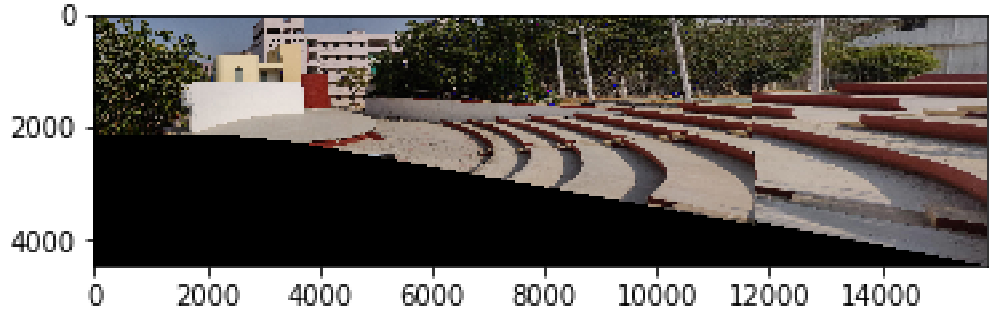
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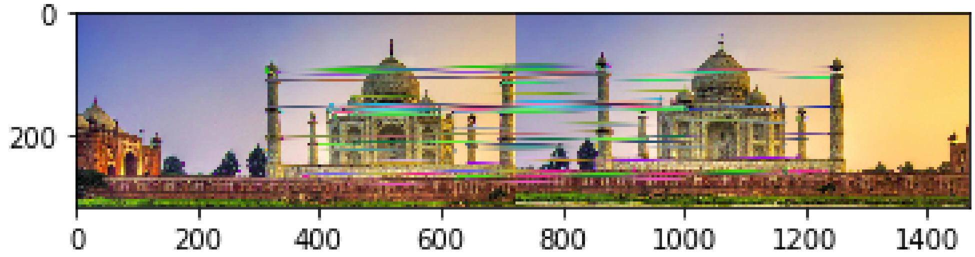
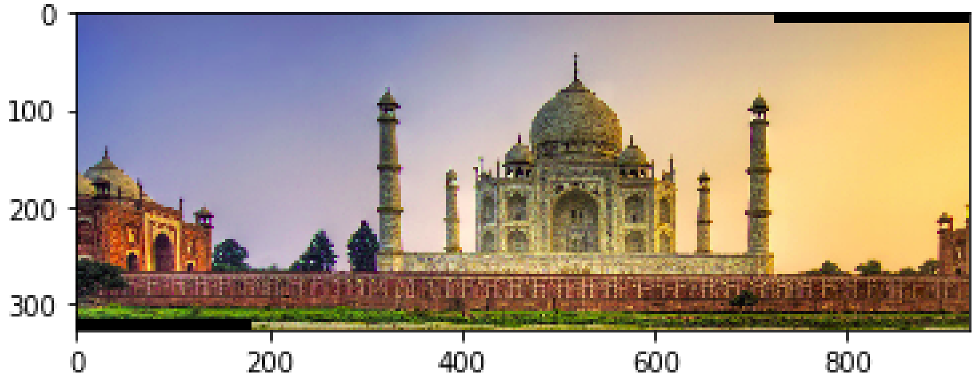
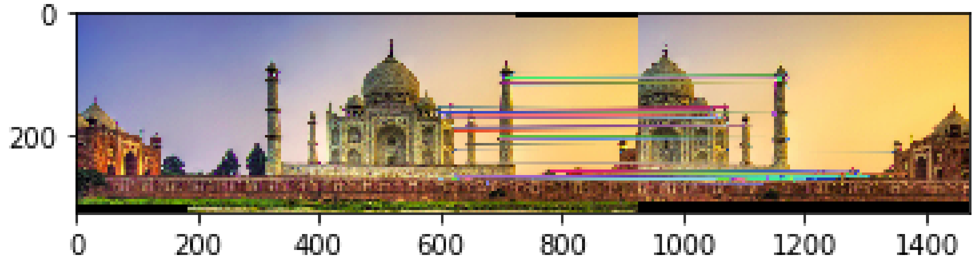
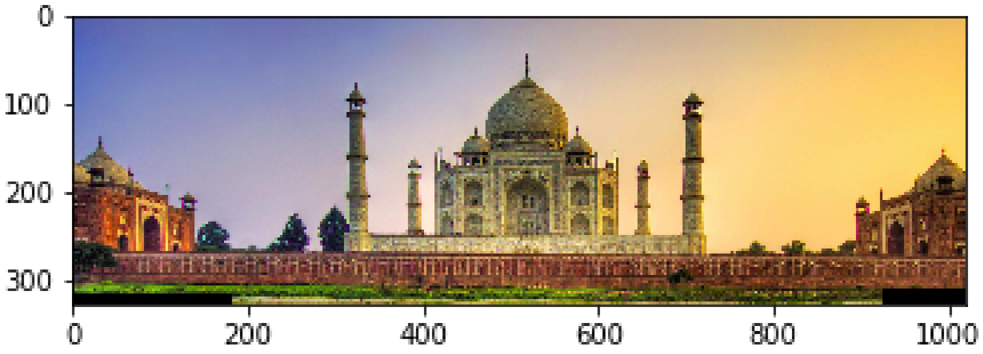
```
./image_mosaicing/img2
```





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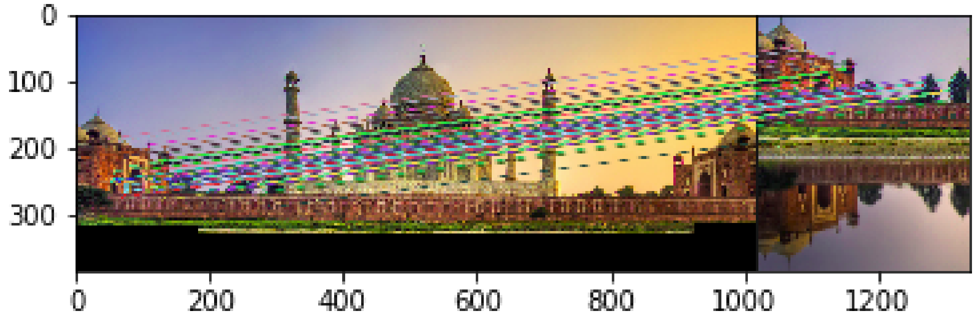
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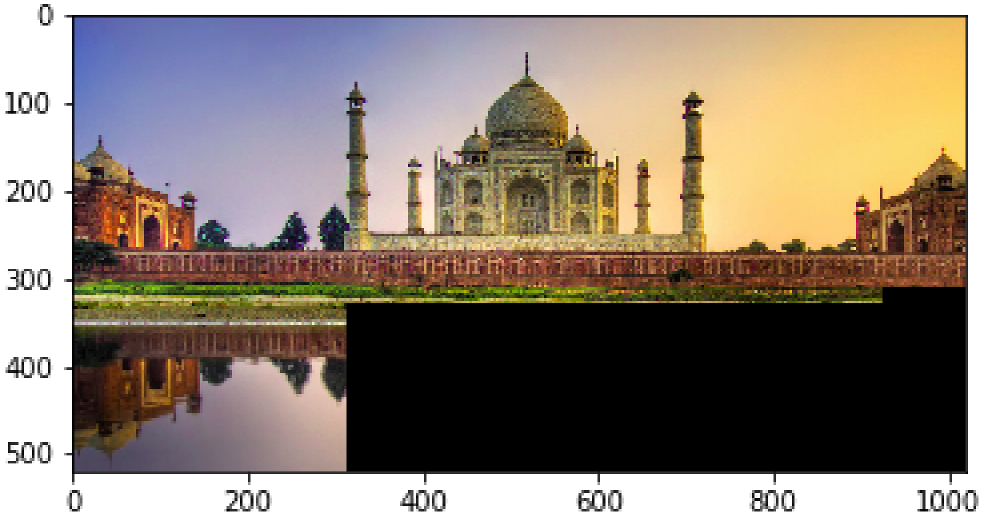
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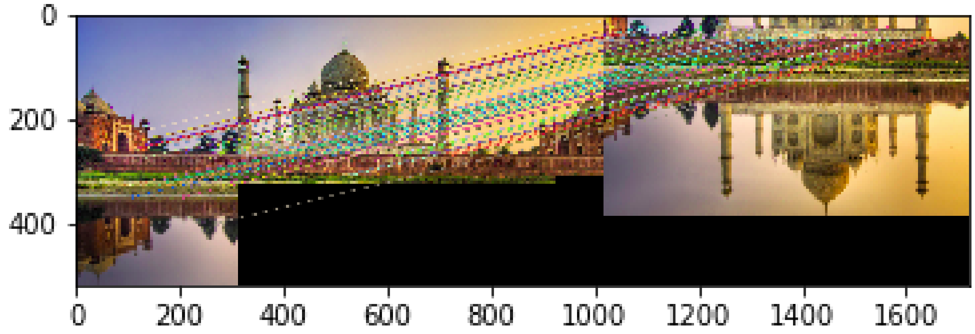
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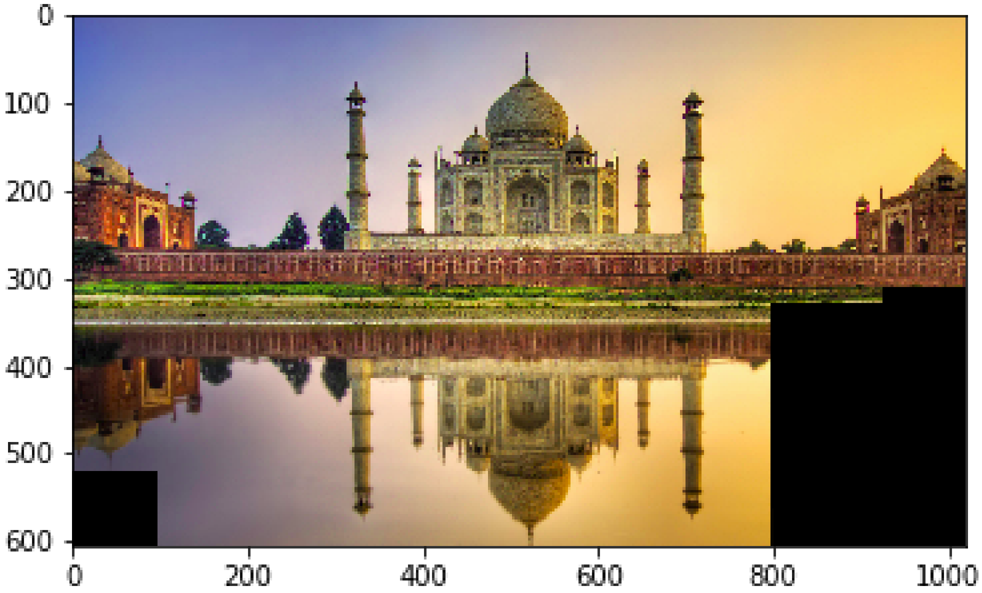
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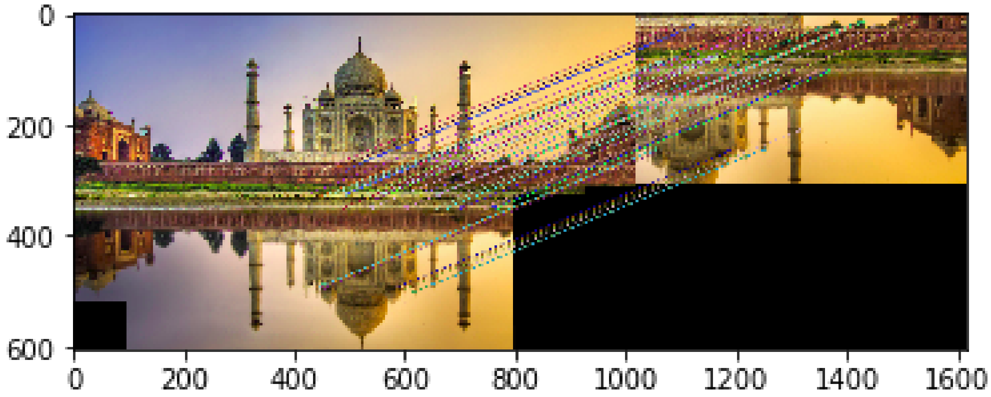
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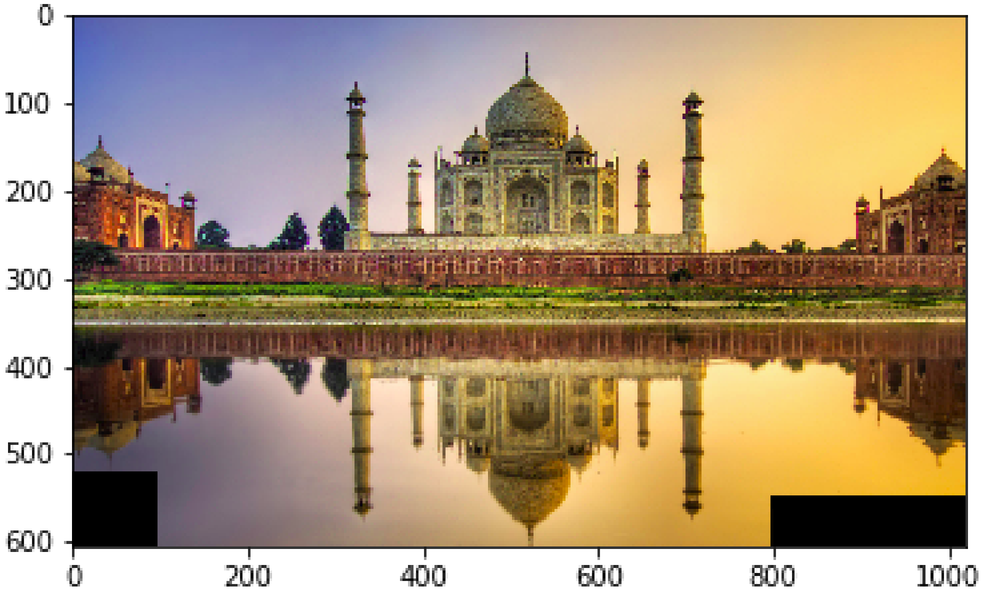
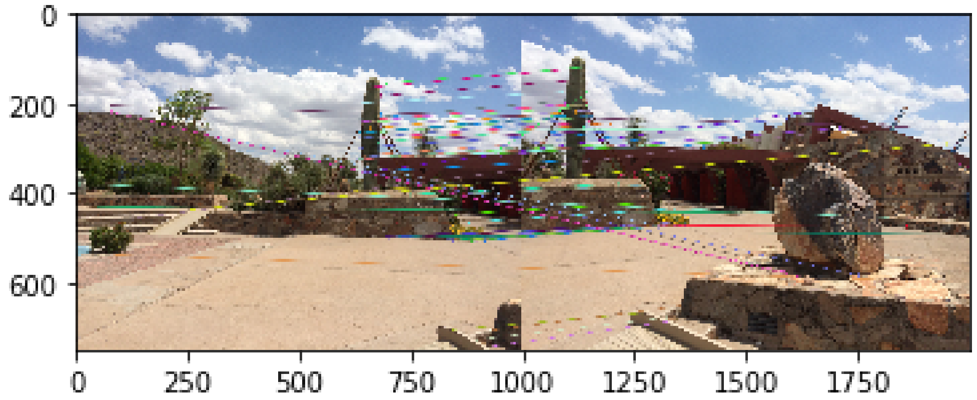
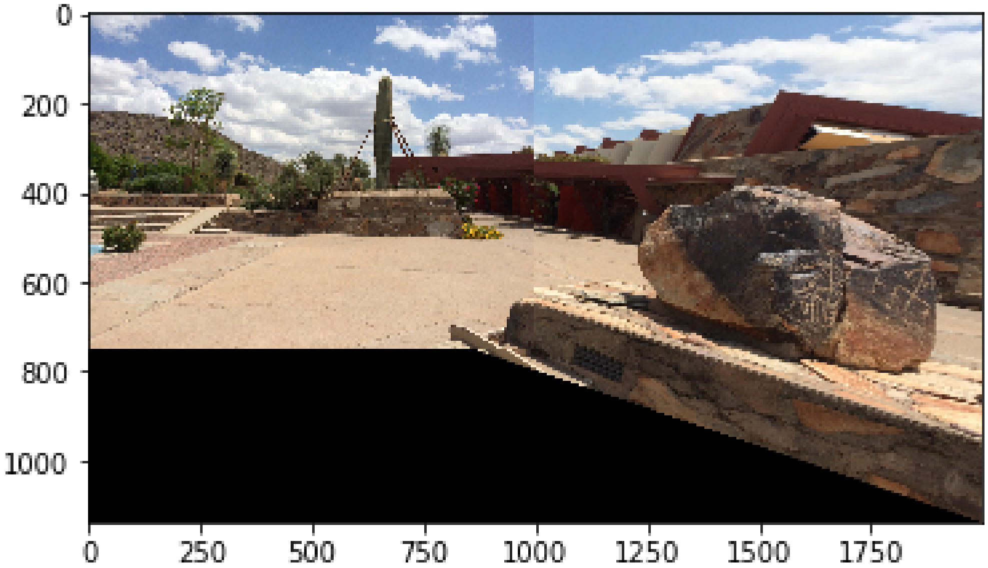


```
./image_mosaicing/img3
```





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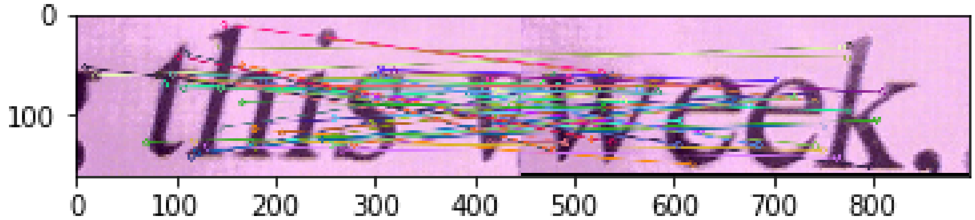

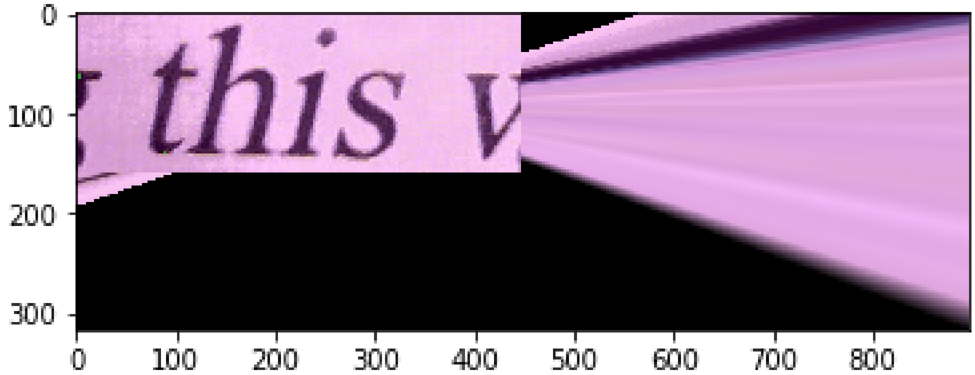

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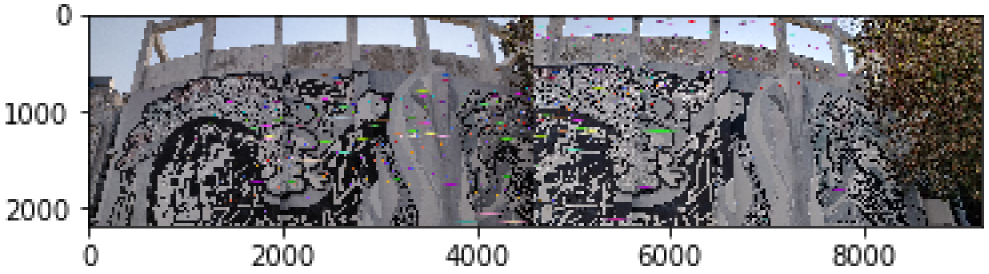

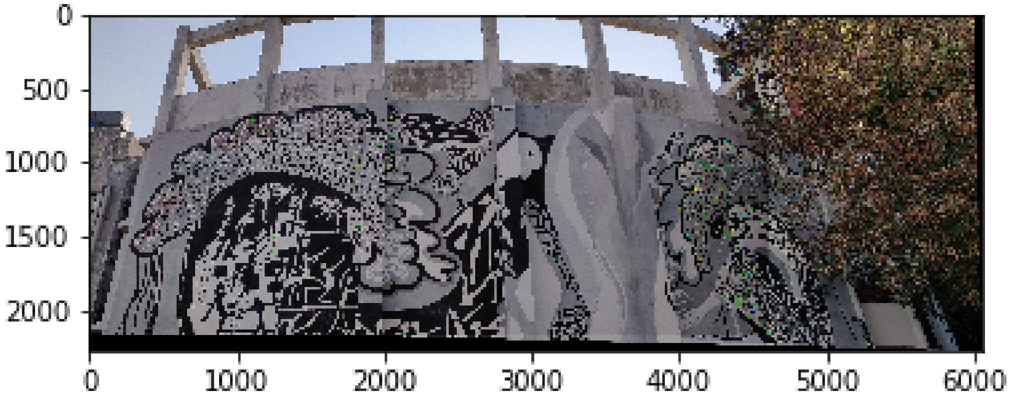

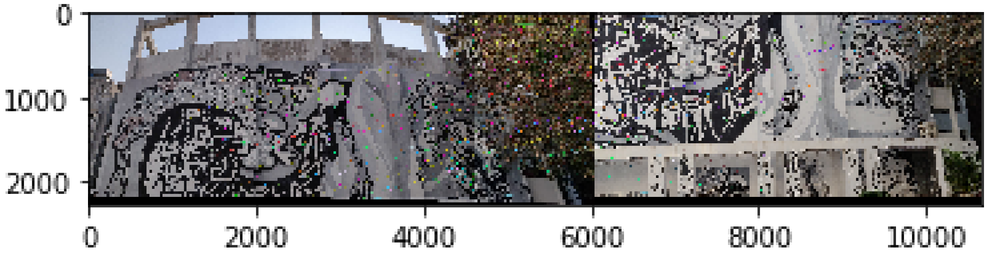

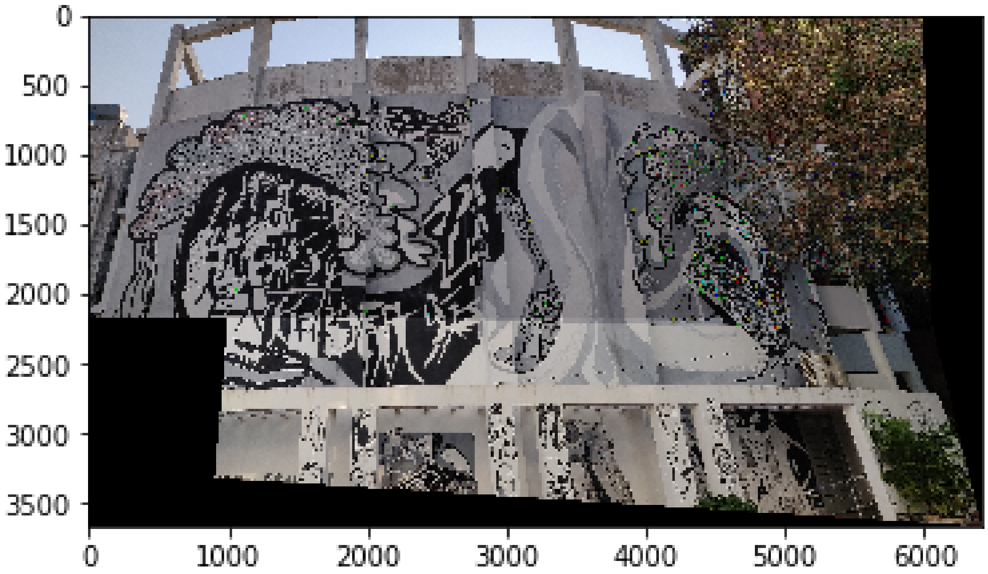
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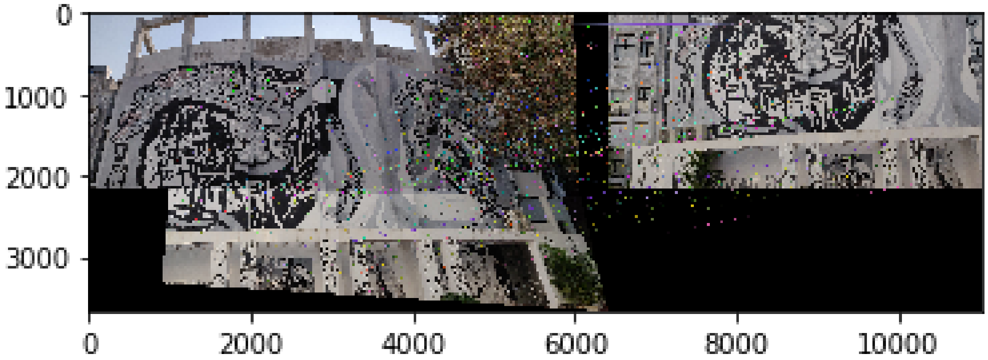
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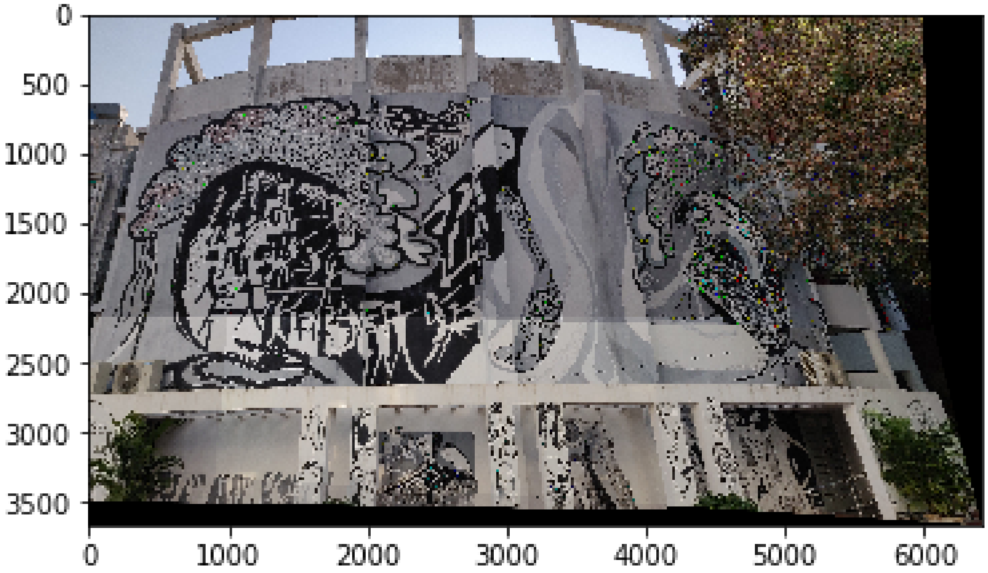

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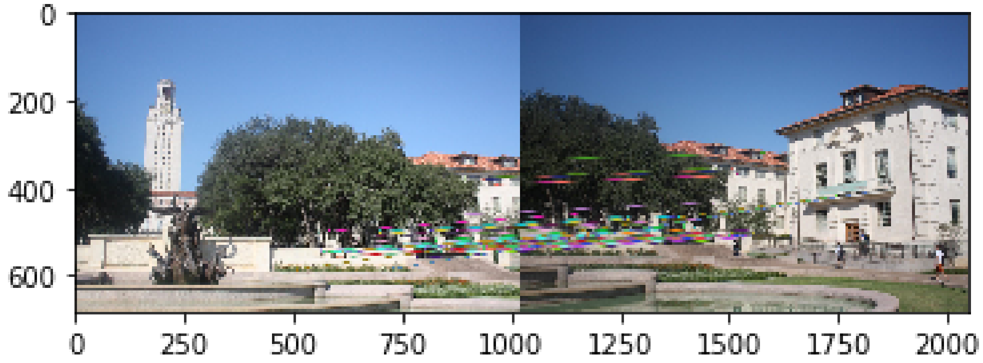

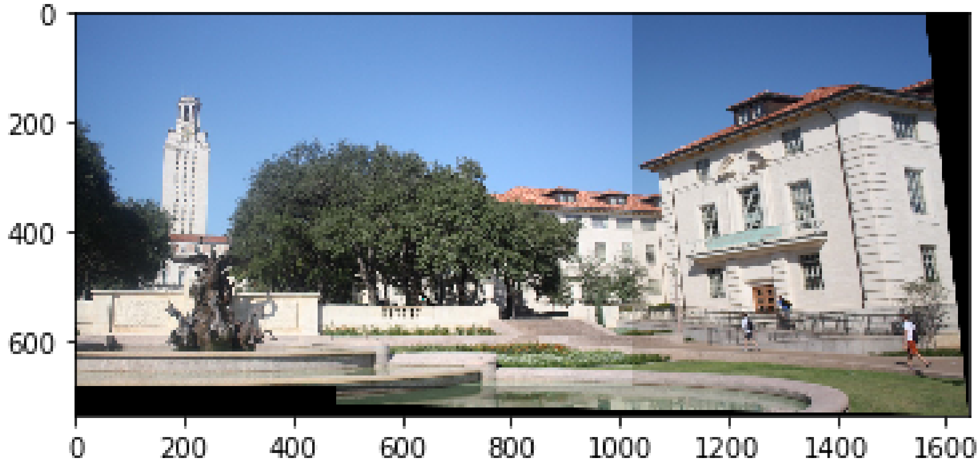

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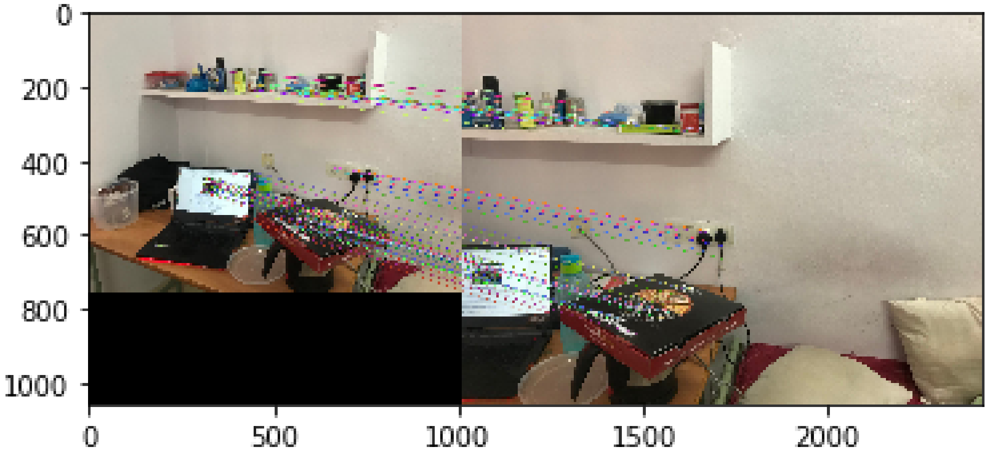

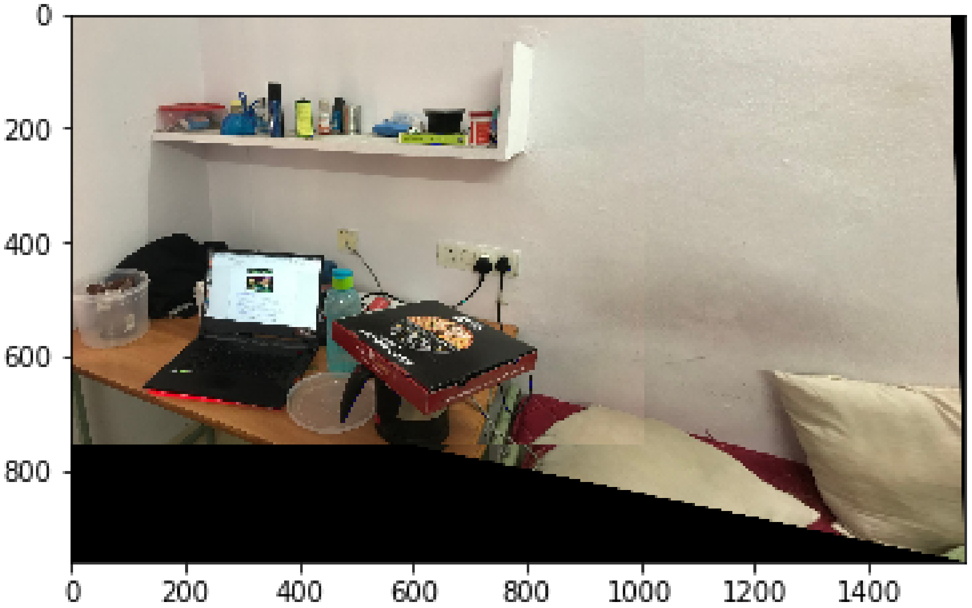
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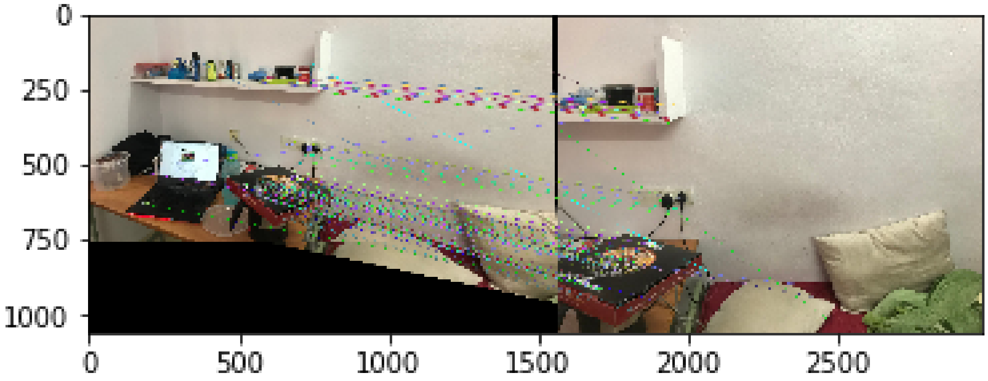
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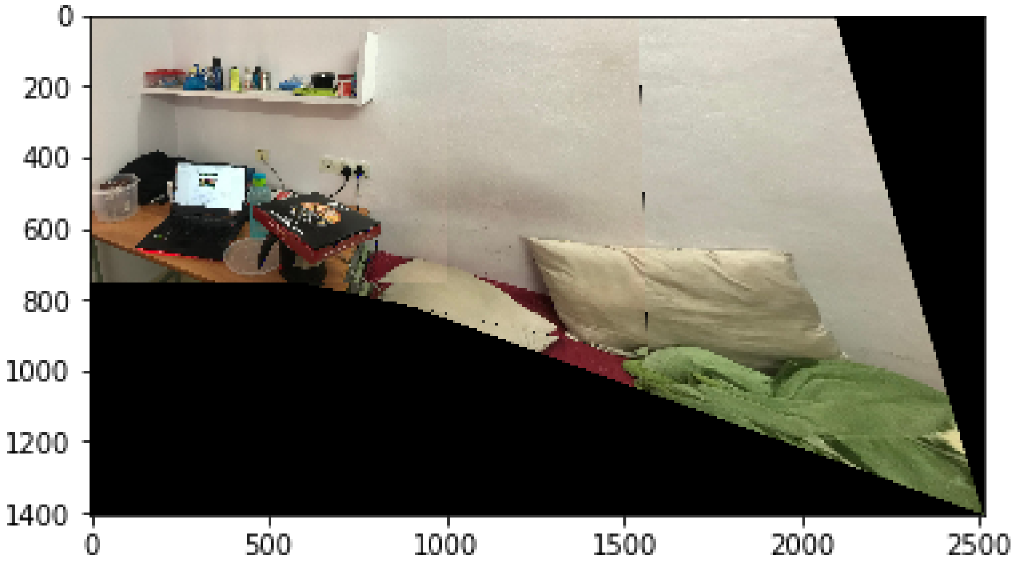
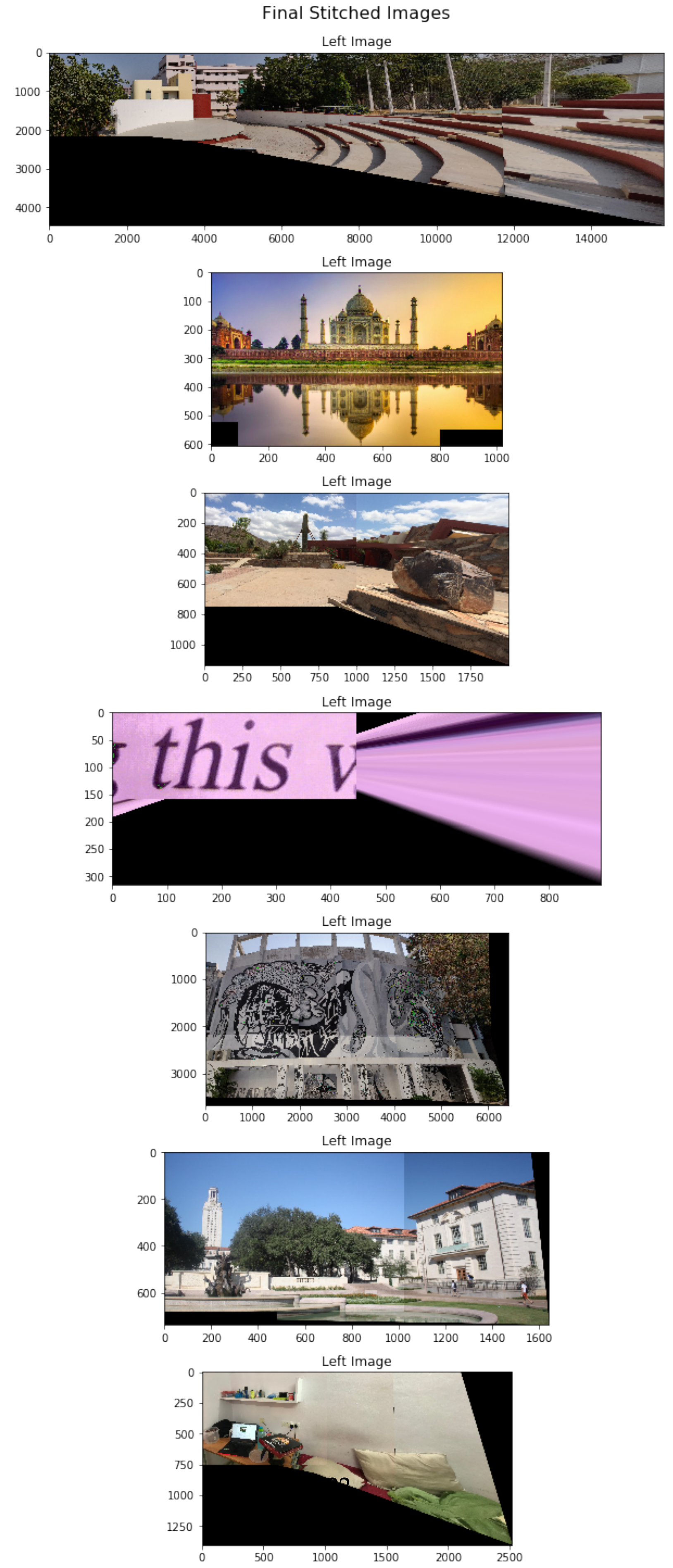


```
In [18]: fig3 = plt.figure(constrained_layout=True,figsize=(20, 20))
         gs = fig3.add_gridspec(7,1)
         for i in range(len(stitched_images)):
             f3_ax1 = fig3.add_subplot(gs[i])
             f3_ax1.set_title('Left Image')
             plt.imshow(stitched_images[i])
         fig3.suptitle('Final Stitched Images', fontsize=16)
         plt.show()
```


Final Stitched Images
Left Image
0
1000
2000
3000
4000
0
2000
4000
6000
8000
10000
12000
14000
Left Image
0
100
200
300
400
500
600
0
200
400
600
800
1000
Left Image
0
200
400
600
800
1000
0
250
500
750
1000
1250
1500
1750
Left Image
0
50
100
150
200
250
300
0
100
200
300
400
500
600
700
800
Left Image
0
1000
2000
3000
0
1000
2000
3000
4000
5000
6000
Left Image
0
200
400
600
0
200
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600
800
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1200
1400
1600
Left Image
0
250
500
750
1000
1250
0
500
1000
1500
2000
2500