

Homework 3 Writeup

Analysis of RANSAC-based Image Alignment and Blending Approach

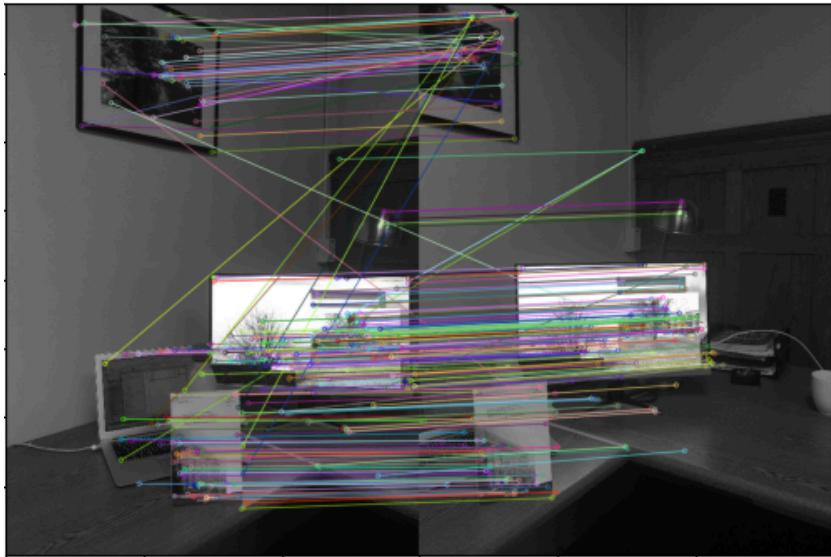
My approach to image alignment and similarity analysis relies on SIFT for keypoint extraction and RANSAC for computing both the fundamental matrix and homography. RANSAC is an estimation algorithm that excels in its ability to handle a large percentage of outliers. RANSAC makes minimal assumptions about data distribution, making it well-suited for real-world image analysis with its large amounts of "noise". However, RANSAC is computationally expensive due to its iterative nature, and there is no guarantee of finding the globally optimal transformation since it relies on random sampling. Additionally, the effectiveness of RANSAC is dependent on hyperparameters, such as the inlier threshold and confidence score, which must be tuned to prevent inaccurate fundamental matrix estimation or excessive rejection of matches. I resorted to using the defaults in both uses with values of 3 for RansacReprojThreshold and 0.99 as the confidence score.

To perform keypoint matching, I first used SIFT to extract keypoints, although computationally expensive and memory inefficient when compared to ORB, it is considered more accurate. This is because of its highly distinctive feature descriptors, resulting in extracted keypoints to be more unique and well-suited for matching across images. For keypoint matching, I used `bf.matchKnn()` which applies the brute-force matching algorithm with k-nearest neighbors. This approach compares descriptors from two images and finds the two closest matches for each descriptor. A ratio test is then applied using the condition `m.distance < 0.8 * n.distance`, based on David Lowe's ratio test. This test ensures that the best match is significantly better than the second-best match, reducing the likelihood of false matches caused by noise or repetition.

Once homography is computed, the next step was to build the mosaic. The blending starts with perspective warping, where one image is transformed into the coordinate space of the other using the estimated homography matrix. Overlapping regions are identified, and a linear averaging technique is applied where pixel values in the overlap region are averaged to "blend" the image. The current implementation uses a straightforward pixel-wise averaging formula: `I_blended = 0.5 * I_base + 0.5 * I_warped`. In terms of simplicity of implementation this would definitely be the strength of this blending algorithm. As a result you can tell where the images are overlapped via a visible seam. Those can be removed via more advanced blending techniques like Poisson blending.

Thresholds Applied

A minimum of 100 matches ensures sufficient correspondences for a semi-reliable RANSAC. Additionally, at least 5% of keypoints from each image must find a match to confirm significant overlap:



The two images above IMG2536.JPG and IMG2537.JPG had 667 and 610 keypoints extracted respectively using SIFT. Of which, 257 matched between the two resulting in keypoint match ratio of 0.3853 and 0.4213.

After fundamental matrix estimation, a minimum of 25 inliers and an inlier ratio of 30% are required to validate the transformation:



Of the initial 257 matched keypoints, after Fundamental Matrix estimation using RANSAC, 222 remain inliers.

The ratio of retained matching keypoints being 0.8638132295719845

Finally, homography validation ensures that the estimated transformation retains at least 30% of inliers:

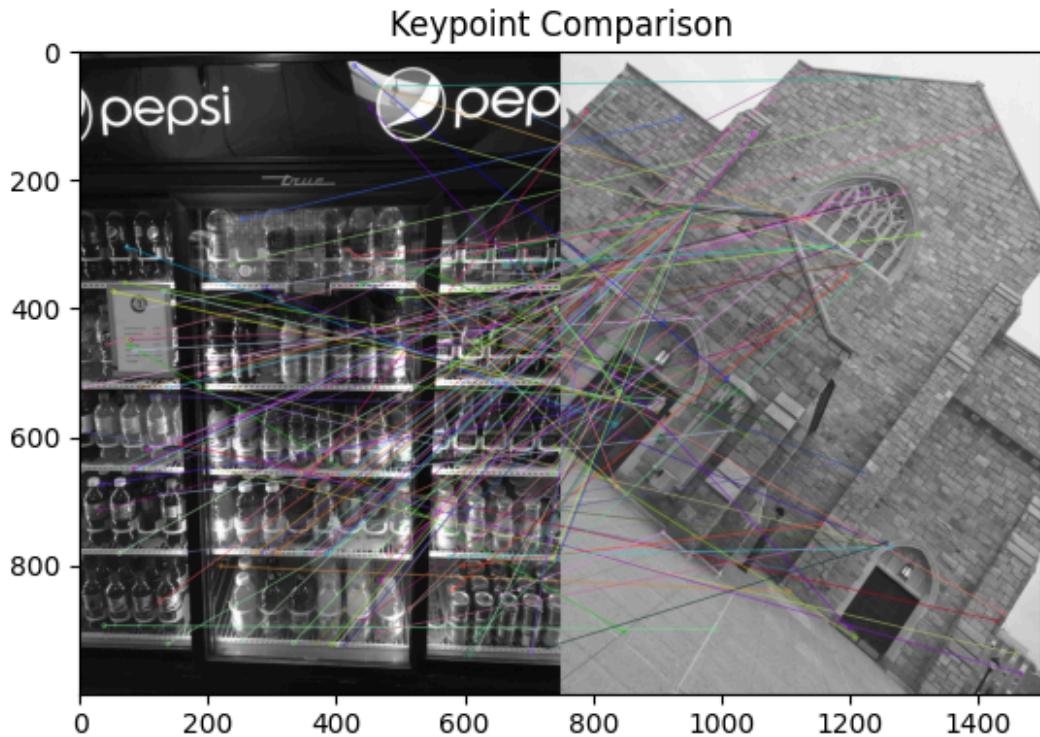


Of the 222 inliers using the fundamental matrix estimation, applying the homography estimations on top resulted in 188 remaining inliers.

The ratio of new inliers to fundamental matrix inliers: 0.8468468468468469

Overall, this approach effectively leverages RANSAC to filter out outliers and establish accurate feature correspondences. While RANSAC is computationally demanding, its robustness makes it superior to least squares estimation in the presence of noise. The use of `bf.matchKnn()` with Lowe's ratio test improves match reliability, while basic blending techniques provide a reasonable visual transition. Future improvements could involve adopting multi-band blending techniques or more advanced feature matching strategies to further enhance the quality of the final mosaic.

Usage on two images of different sets:



122 keypoints match out of 4707 and 4457 initial keypoints found. <2% match for both, did not pass threshold.

OUTPUT FROM EACH IMG DIRECTORY

```
hw3_align.py hw3_data/frear-park outfile.txt
```

Keypoint counts using SIFT

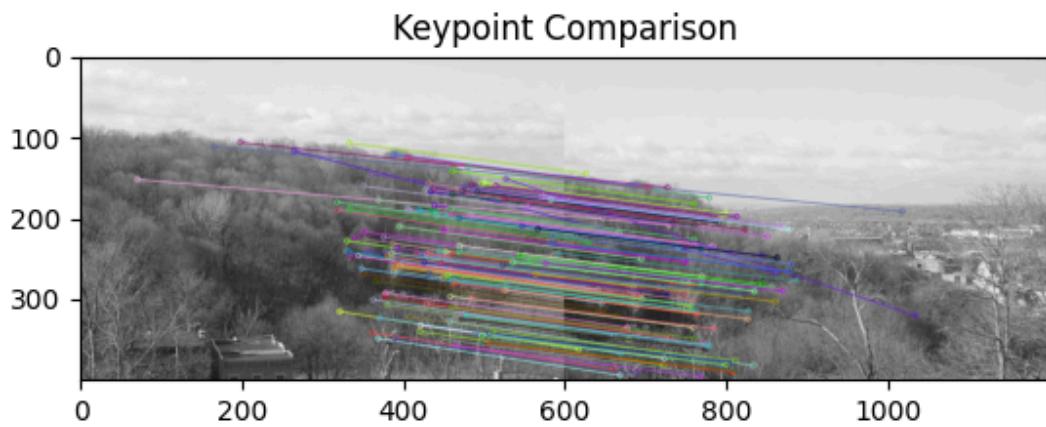
image1.JPG: 668

image2.JPG: 863

Matches between image1.JPG and image2.JPG: 152

Fraction of keypoints matched: 0.2275, 0.1761

Image of Keypoint Comparison:



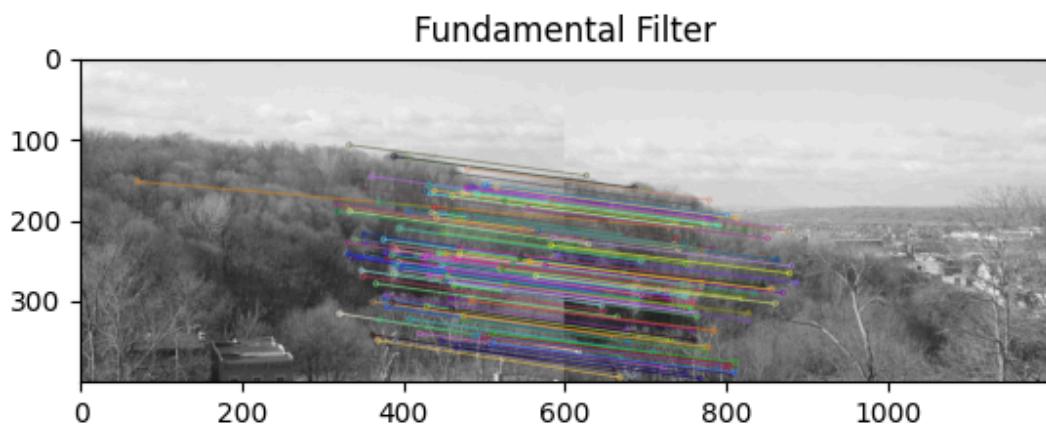
Passed threshold of matching keypoints

Amount of matching keypoints meets threshold

Inlier count between image1.JPG and image2.JPG: 147

Ratio of inliers to initial match: 0.9671052631578947

Image consistent with Fundamental Matrix:



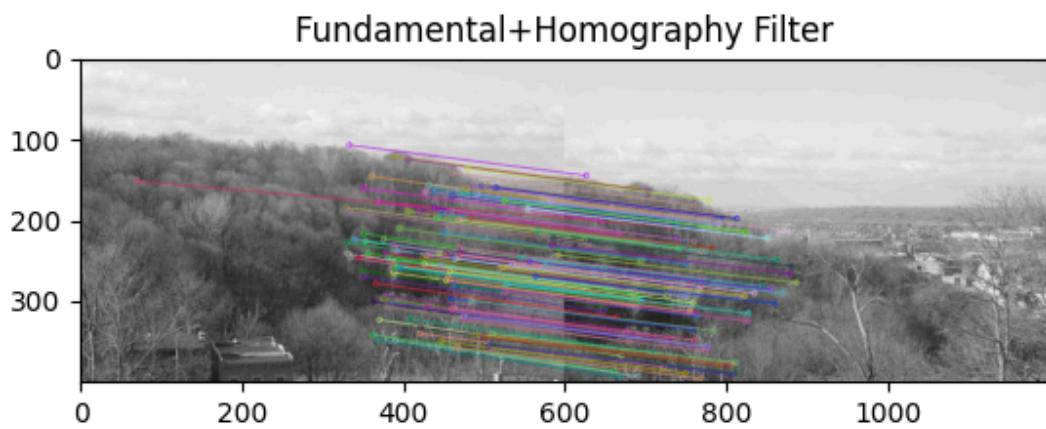
Passed threshold for inliers:

Contains enough inliers to be considered as matching images

New inlier count using homography between image1.JPG and image2.JPG: 142

Ratio of new inliers to fundamental matrix inliers: 0.9659863945578231

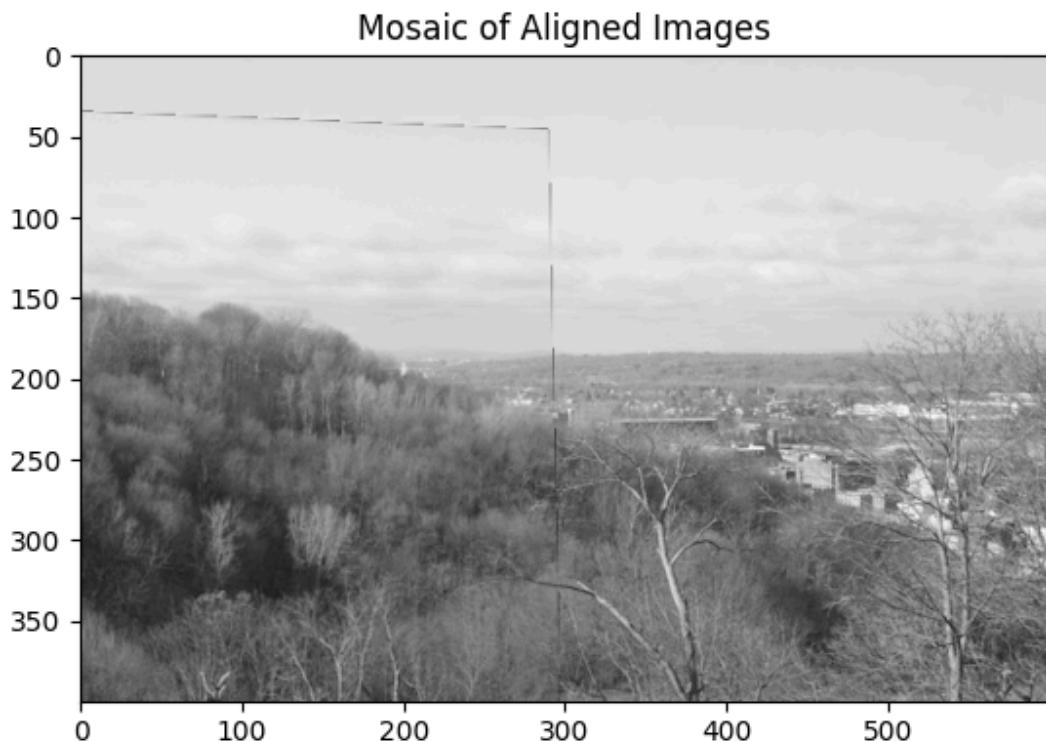
Image of new inliers consistent with Fundamental and Homography matrix:



Passed threshold for new inliers calculations:

Ratio and amount of new inliers computed by homography matrix is above threshold

Image of overlapping scenes:



`hw3_align.py hw3_data/office outfile.txt`

Keypoint counts using SIFT

IMG2536.JPG: 667

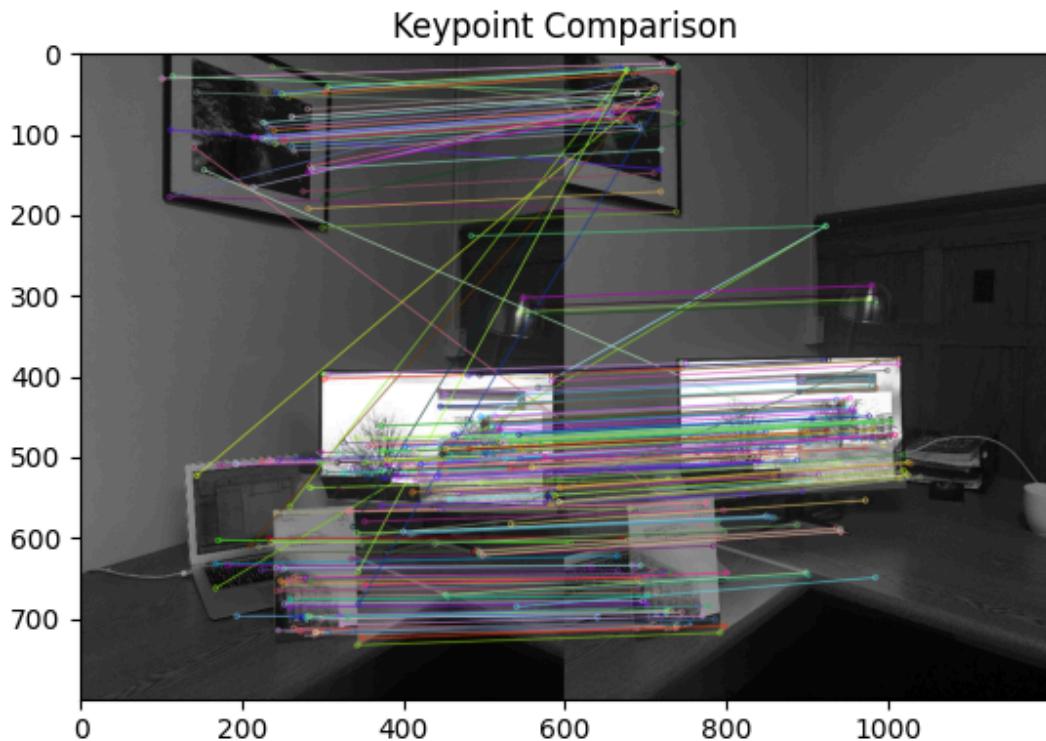
IMG2537.JPG: 610

IMG2538.JPG: 751

Matches between IMG2536.JPG and IMG2537.JPG: 257

Fraction of keypoints matched: 0.3853, 0.4213

Image of Keypoint Comparison:



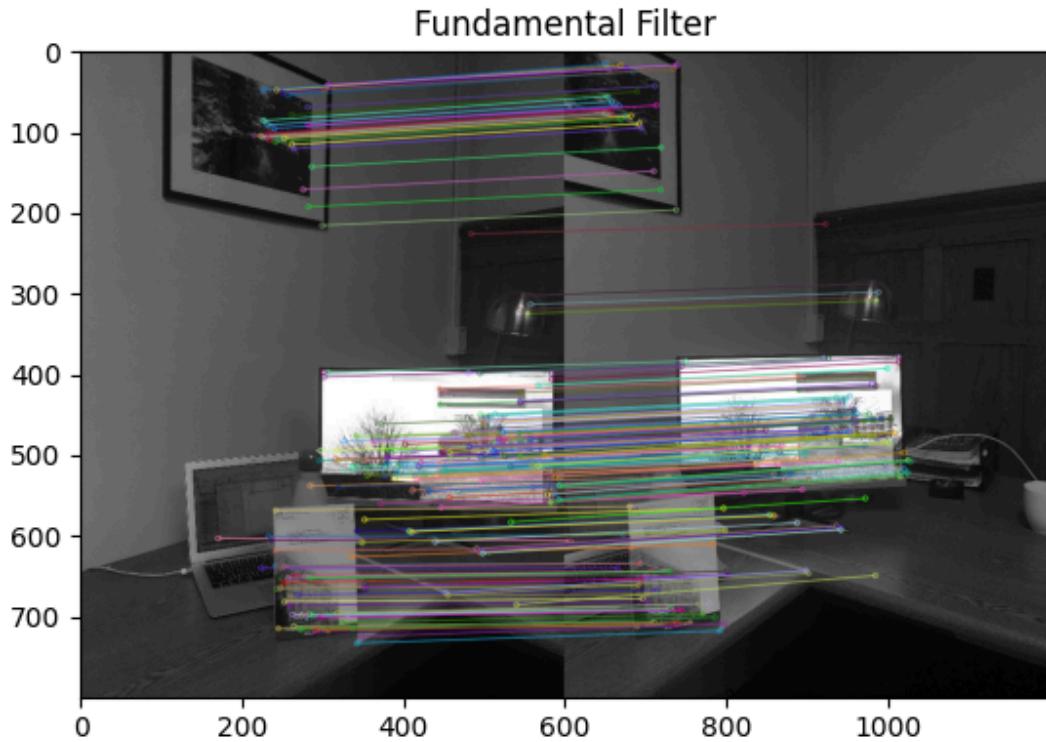
Passed threshold of matching keypoints

Amount of matching keypoints meets threshold

Inlier count between IMG2536.JPG and IMG2537.JPG: 222

Ratio of inliers to initial match: 0.8638132295719845

Image consistent with Fundamental Matrix:



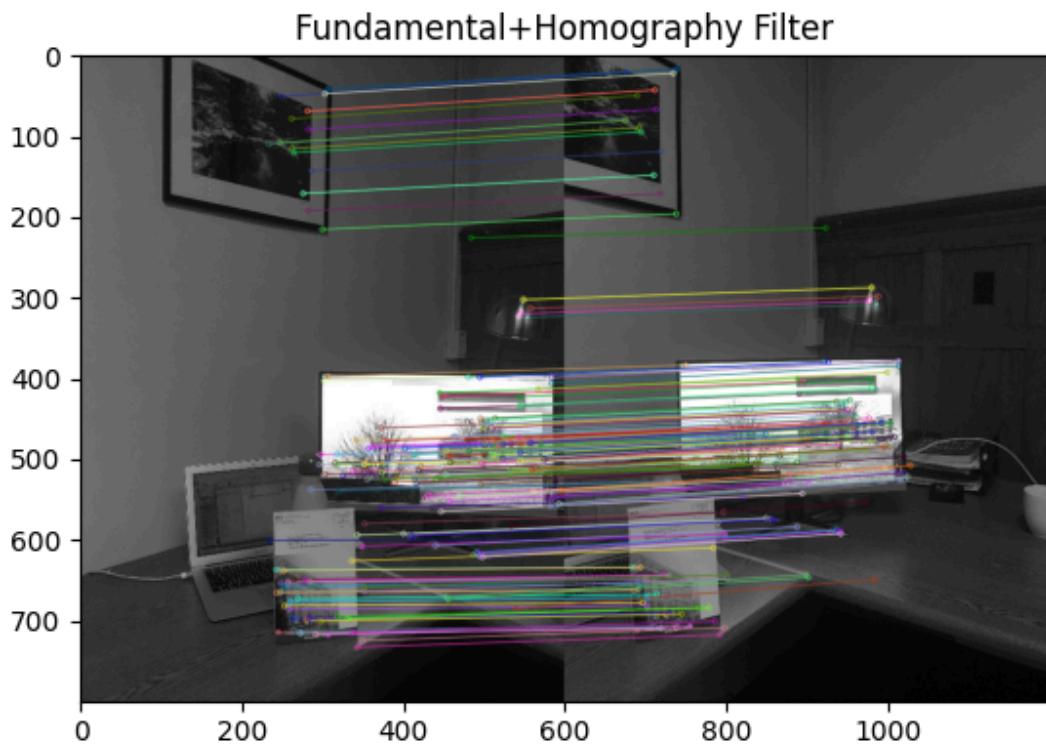
Passed threshold for inliers:

Contains enough inliers to be considered as matching images

New inlier count using homography between IMG2536.JPG and IMG2537.JPG: 188

Ratio of new inliers to fundamental matrix inliers: 0.8468468468469

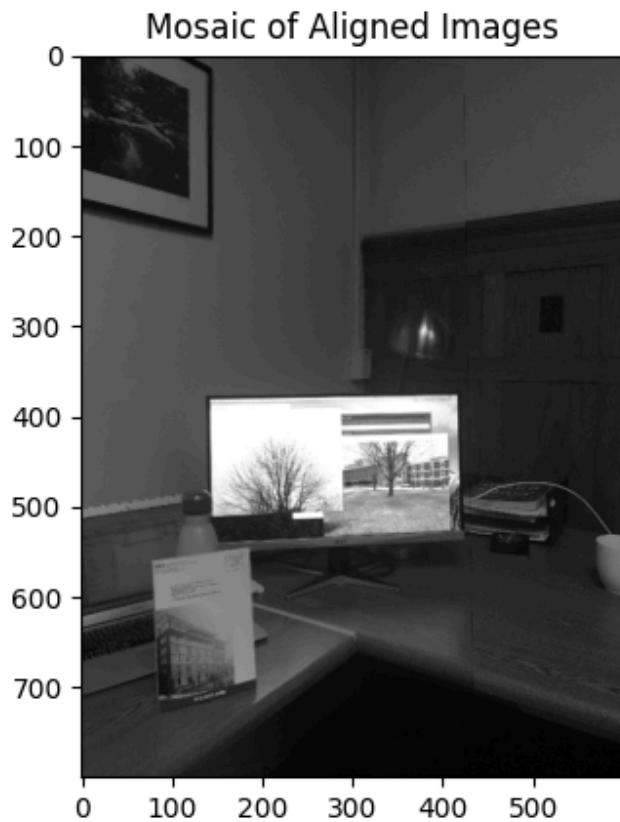
Image of new inliers consistent with Fundamental and Homography matrix:



Passed threshold for new inliers calculations:

Ratio and amount of new inliers computed by homography matrix is above threshold

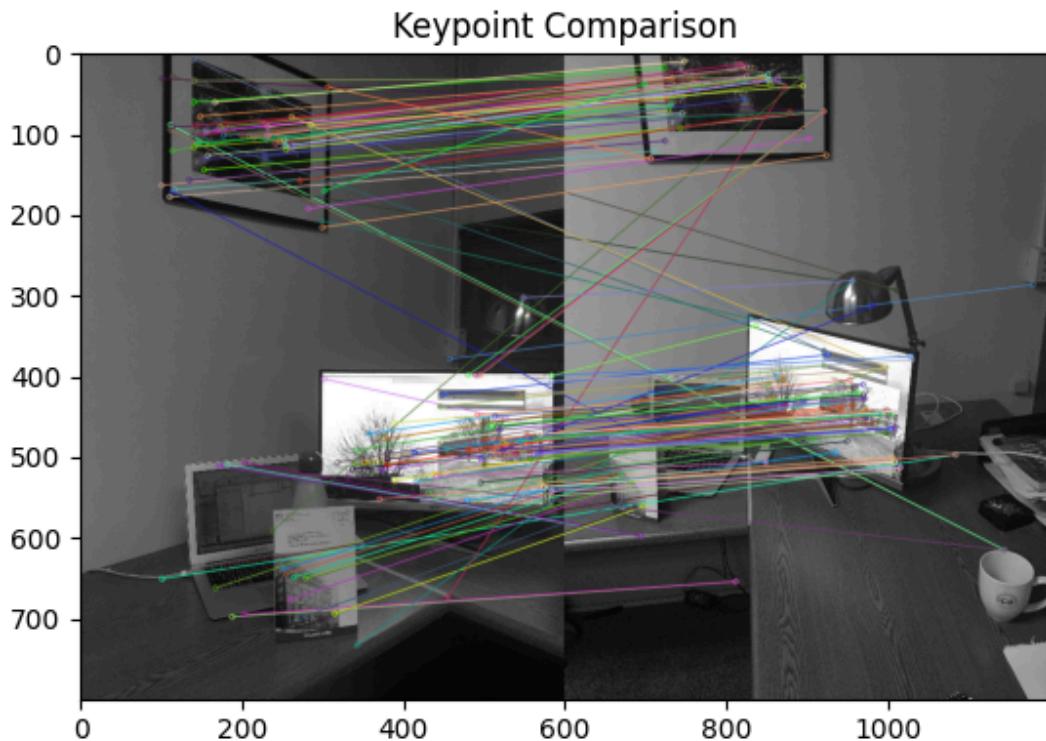
Image of overlapping scenes:



Matches between IMG2536.JPG and IMG2538.JPG: 153

Fraction of keypoints matched: 0.2294, 0.2037

Image of Keypoint Comparison:



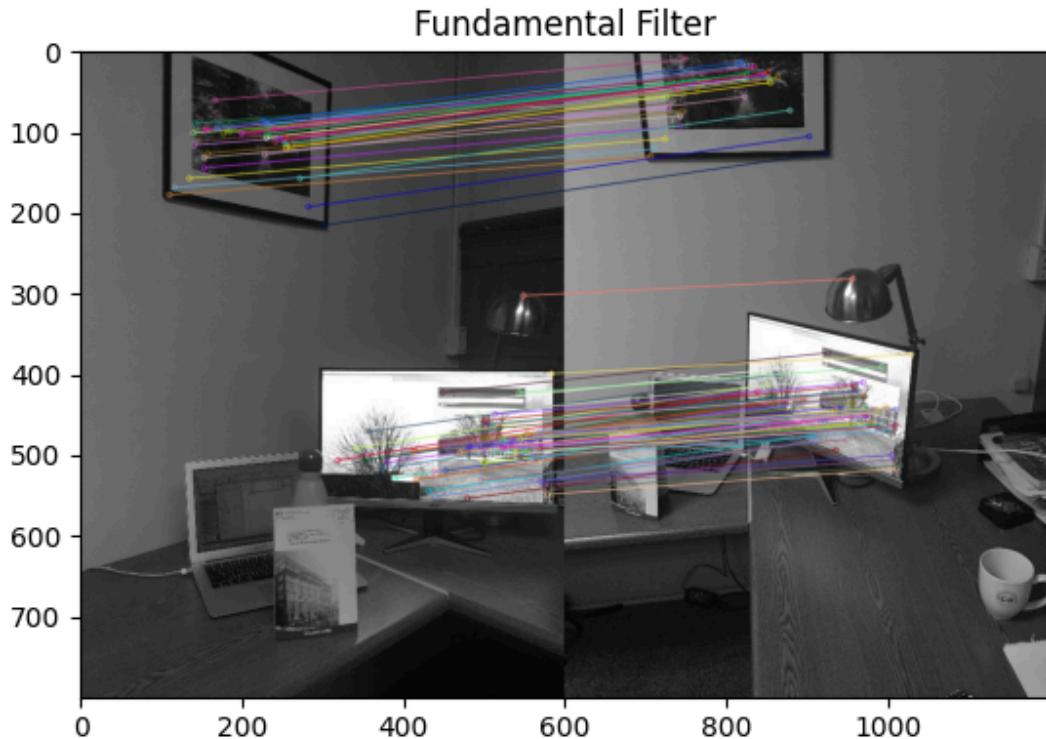
Passed threshold of matching keypoints

Amount of matching keypoints meets threshold

Inlier count between IMG2536.JPG and IMG2538.JPG: 95

Ratio of inliers to initial match: 0.6209150326797386

Image consistent with Fundamental Matrix:



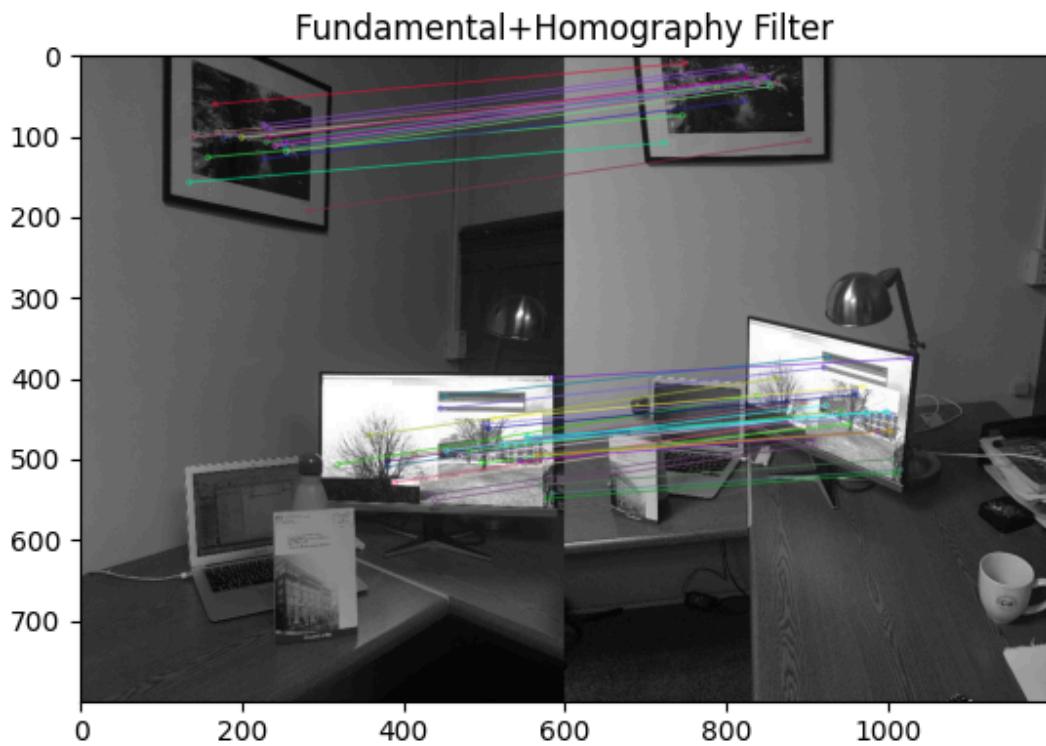
Passed threshold for inliers:

Contains enough inliers to be considered as matching images

New inlier count using homography between IMG2536.JPG and IMG2538.JPG: 48

Ratio of new inliers to fundamental matrix inliers: 0.5052631578947369

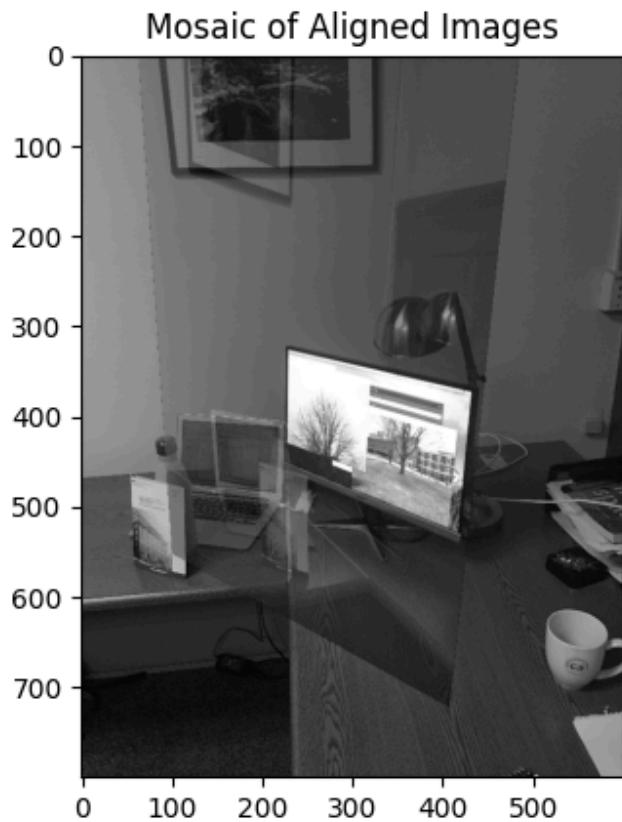
Image of new inliers consistent with Fundamental and Homography matrix:



Passed threshold for new inliers calculations:

Ratio and amount of new inliers computed by homography matrix is above threshold

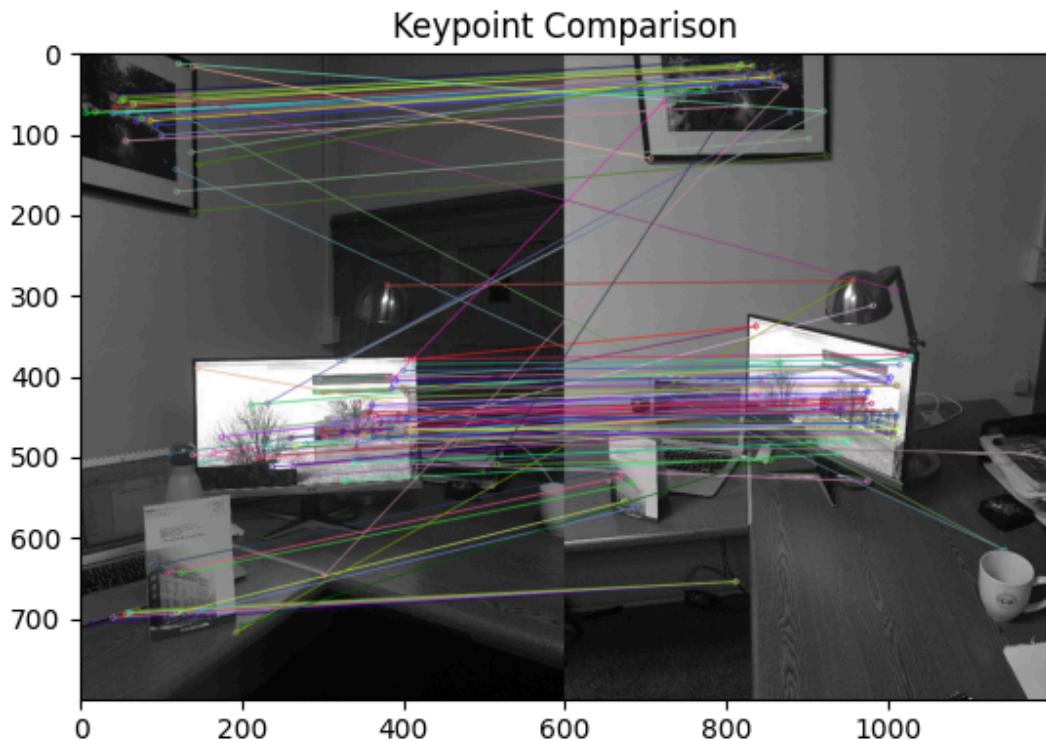
Image of overlapping scenes:



Matches between IMG2537.JPG and IMG2538.JPG: 121

Fraction of keypoints matched: 0.1984, 0.1611

Image of Keypoint Comparison:



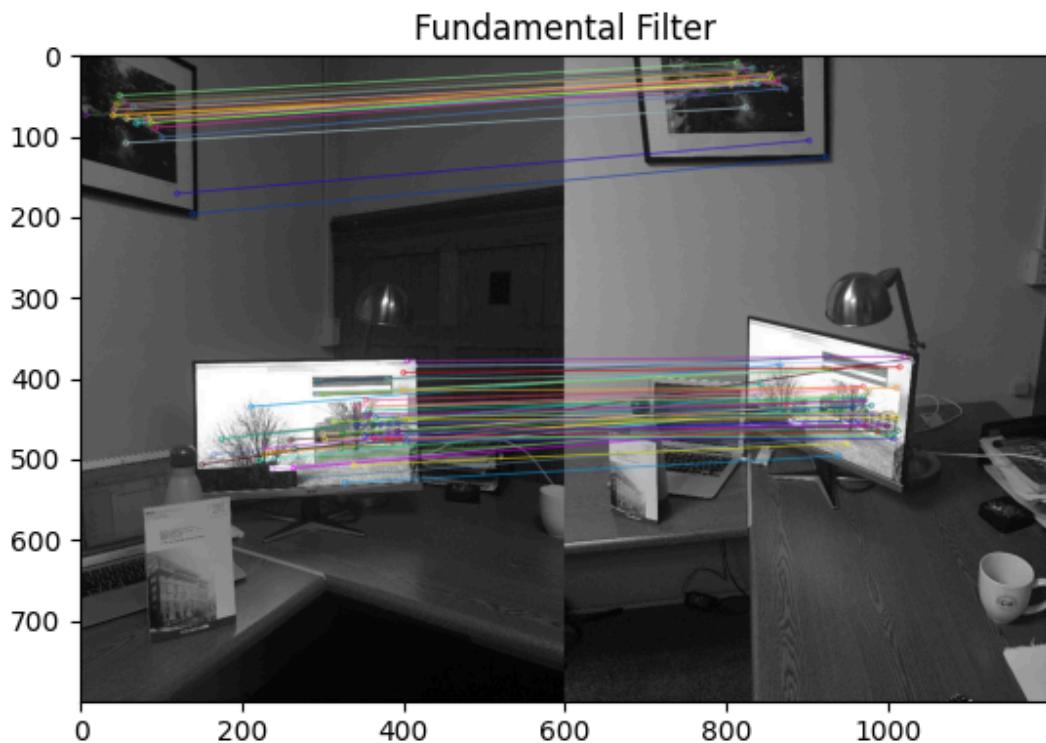
Passed threshold of matching keypoints

Amount of matching keypoints meets threshold

Inlier count between IMG2537.JPG and IMG2538.JPG: 78

Ratio of inliers to initial match: 0.6446280991735537

Image consistent with Fundamental Matrix:



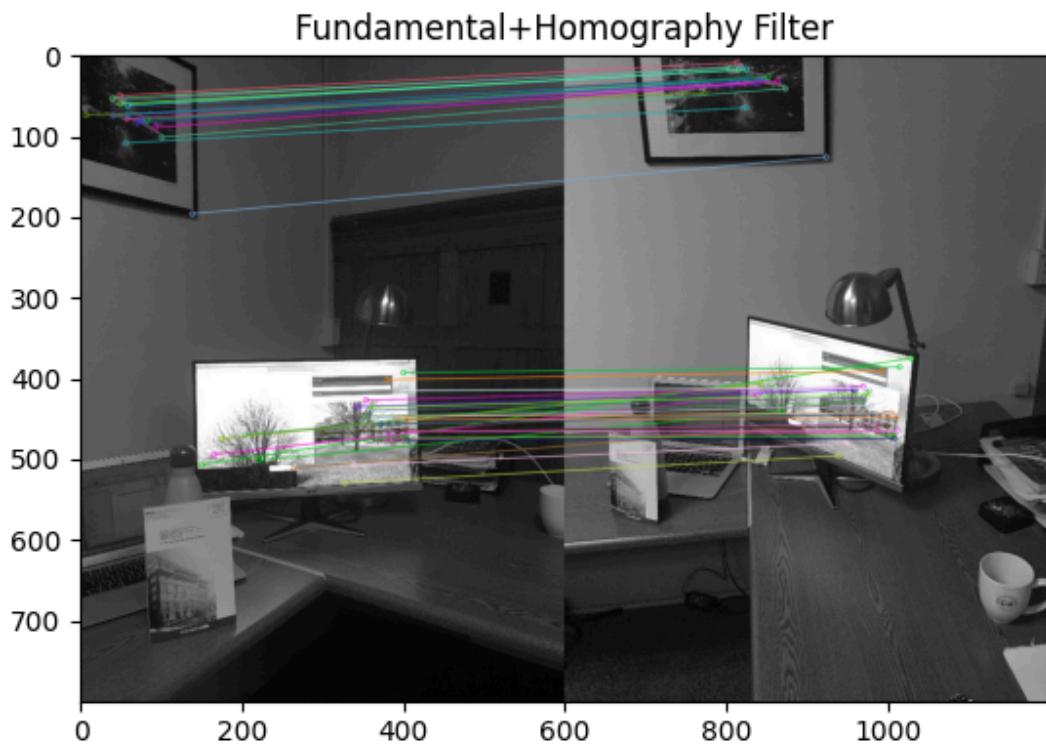
Passed threshold for inliers:

Contains enough inliers to be considered as matching images

New inlier count using homography between IMG2537.JPG and IMG2538.JPG: 47

Ratio of new inliers to fundamental matrix inliers: 0.6025641025641025

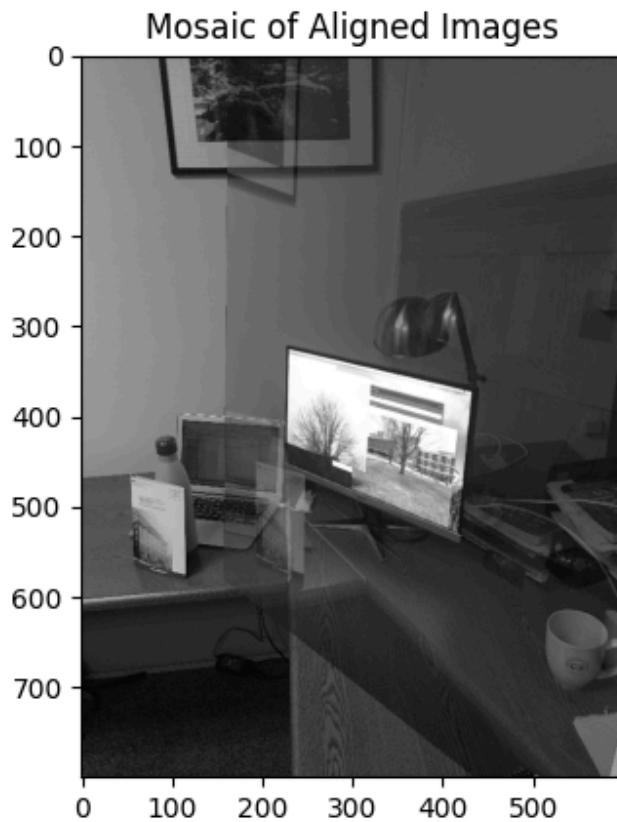
Image of new inliers consistent with Fundamental and Homography matrix:



Passed threshold for new inliers calculations:

Ratio and amount of new inliers computed by homography matrix is above threshold

Image of overlapping scenes:



`hw3_align.py hw3_data/drink-machine outfile.txt`

Keypoint counts using SIFT

image1.JPG: 3607

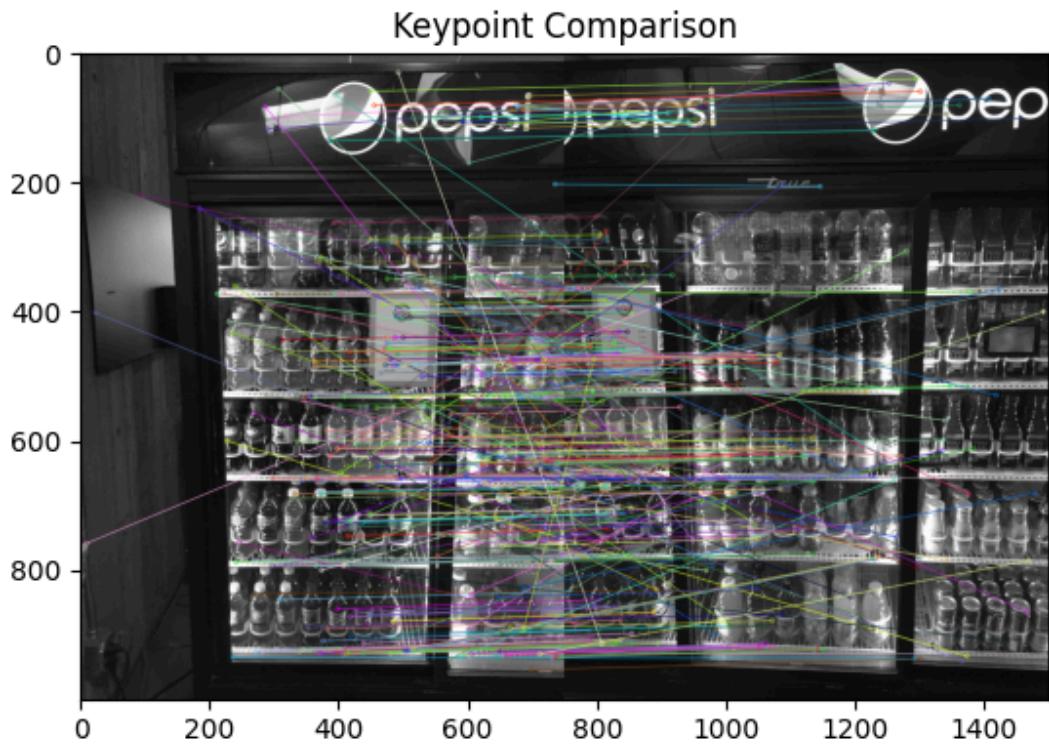
image2.JPG: 4707

image3.JPG: 3683

Matches between image1.JPG and image2.JPG: 315

Fraction of keypoints matched: 0.0873, 0.0669

Image of Keypoint Comparison:



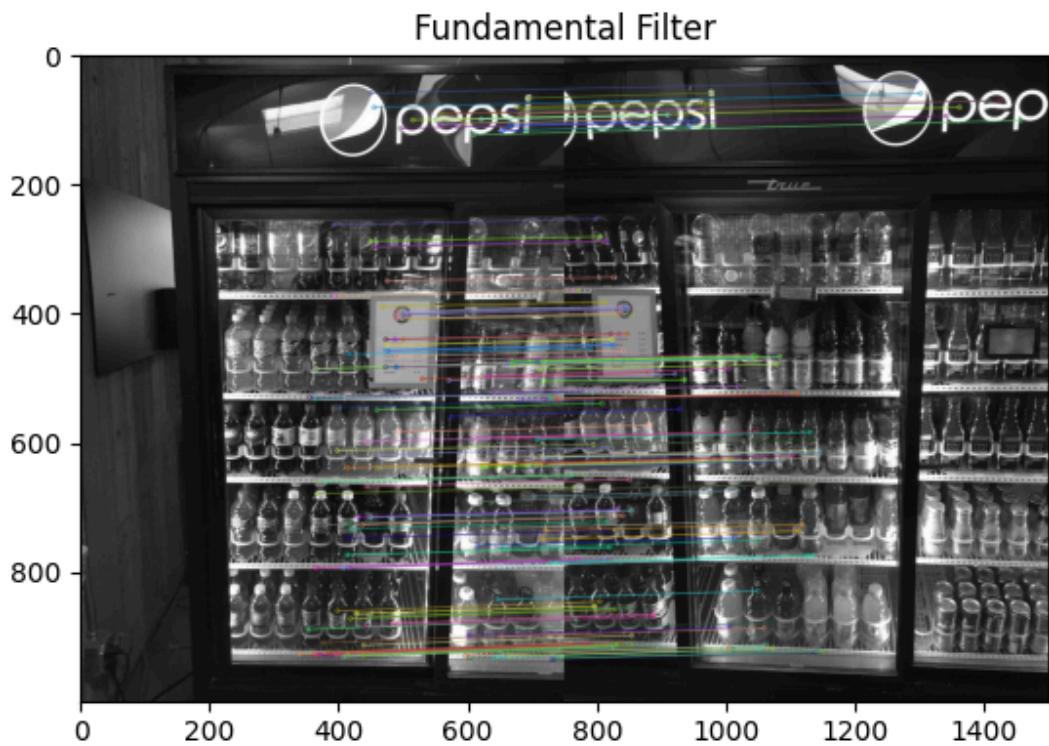
Passed threshold of matching keypoints

Amount of matching keypoints meets threshold

Inlier count between image1.JPG and image2.JPG: 172

Ratio of inliers to initial match: 0.546031746031746

Image consistent with Fundamental Matrix:



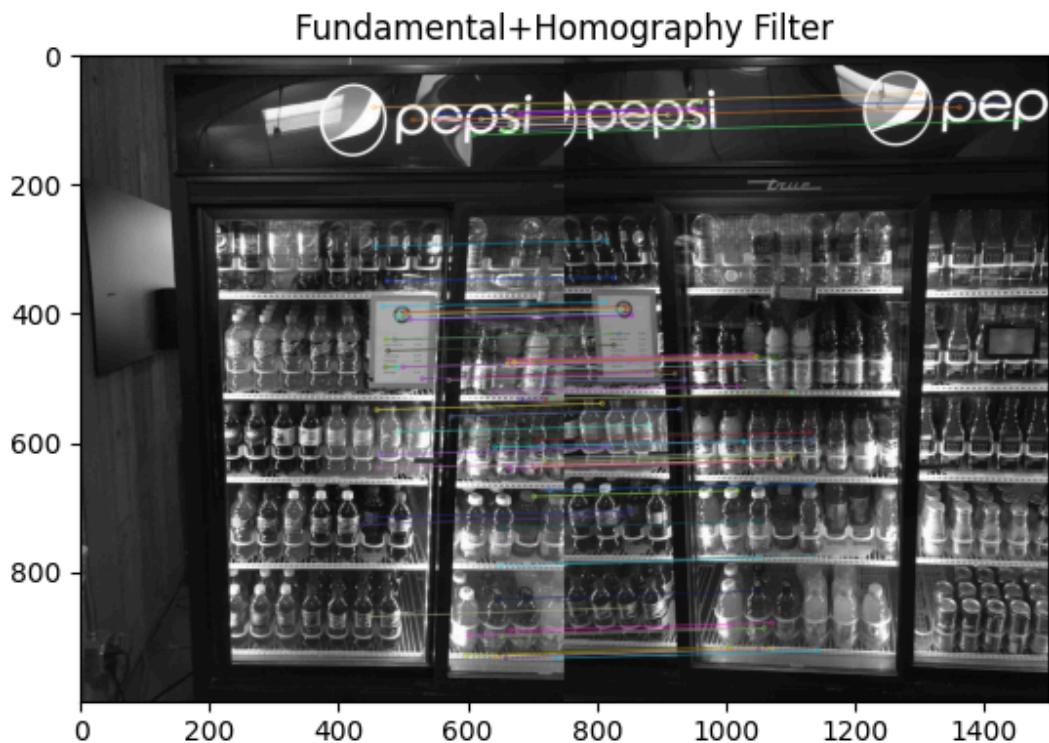
Passed threshold for inliers:

Contains enough inliers to be considered as matching images

New inlier count using homography between image1.JPG and image2.JPG: 85

Ratio of new inliers to fundamental matrix inliers: 0.4941860465116279

Image of new inliers consistent with Fundamental and Homography matrix:



Passed threshold for new inliers calculations:

Ratio and amount of new inliers computed by homography matrix is above threshold

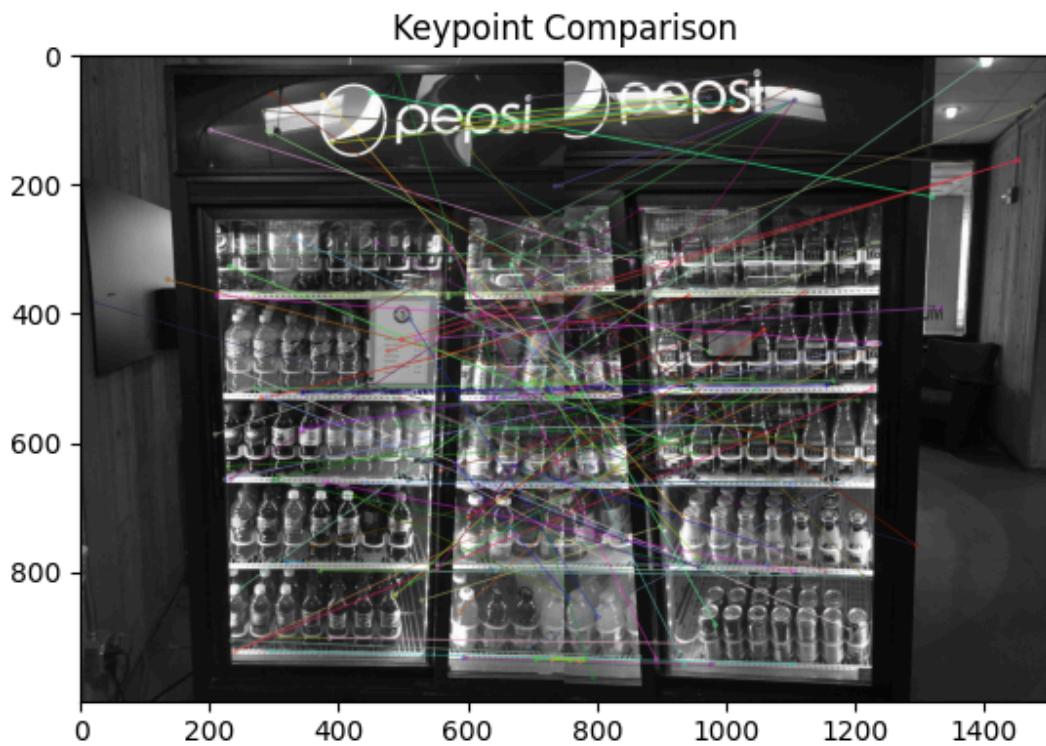
Image of overlapping scenes:



Matches between image1.JPG and image3.JPG: 122

Fraction of keypoints matched: 0.0338, 0.0331

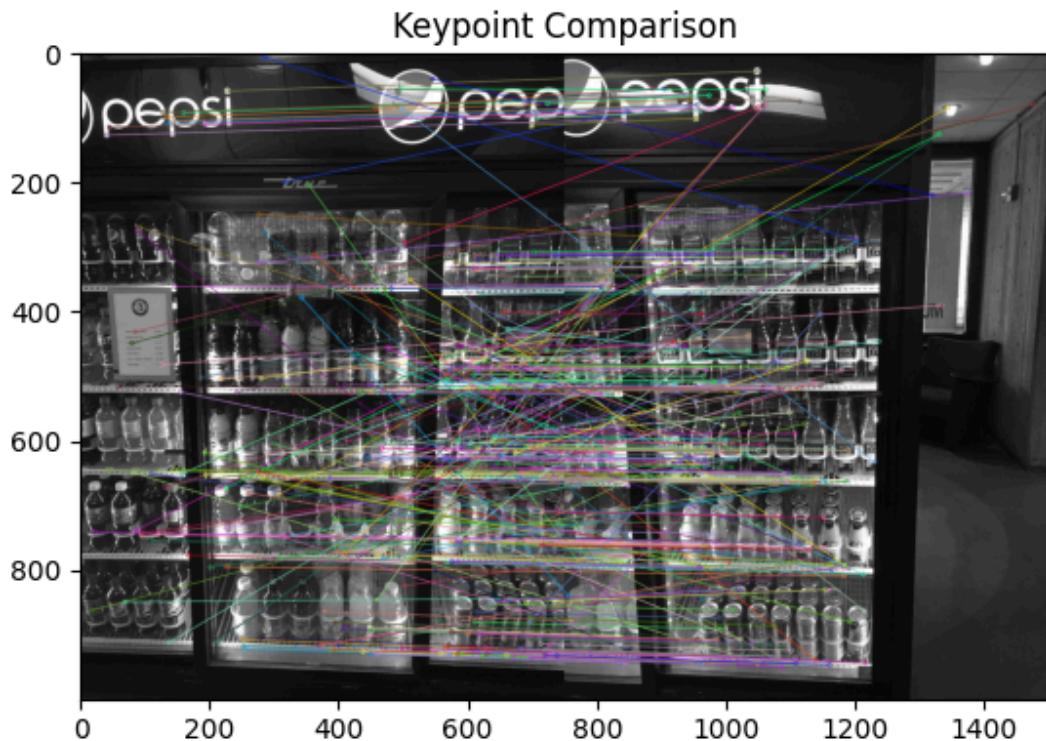
Image of Keypoint Comparison:



Failed threshold of matching keypoints
Too little matching keypoints

Matches between image2.JPG and image3.JPG: 368
Fraction of keypoints matched: 0.0782, 0.0999

Image of Keypoint Comparison:



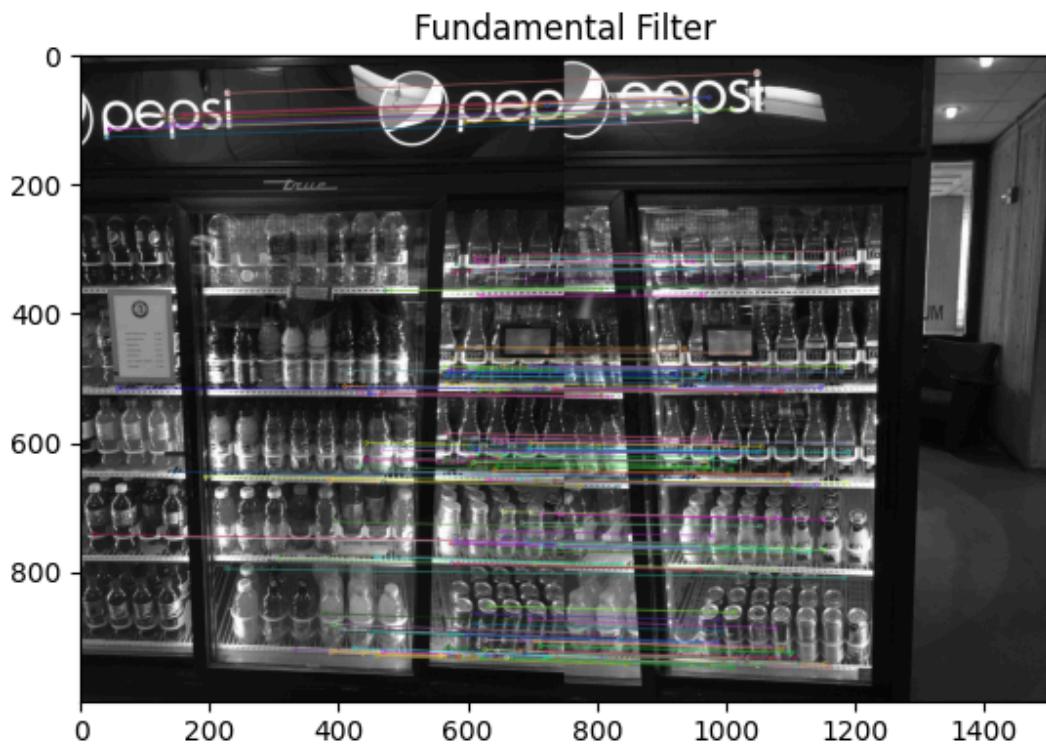
Passed threshold of matching keypoints

Amount of matching keypoints meets threshold

Inlier count between image2.JPG and image3.JPG: 224

Ratio of inliers to initial match: 0.6086956521739131

Image consistent with Fundamental Matrix:



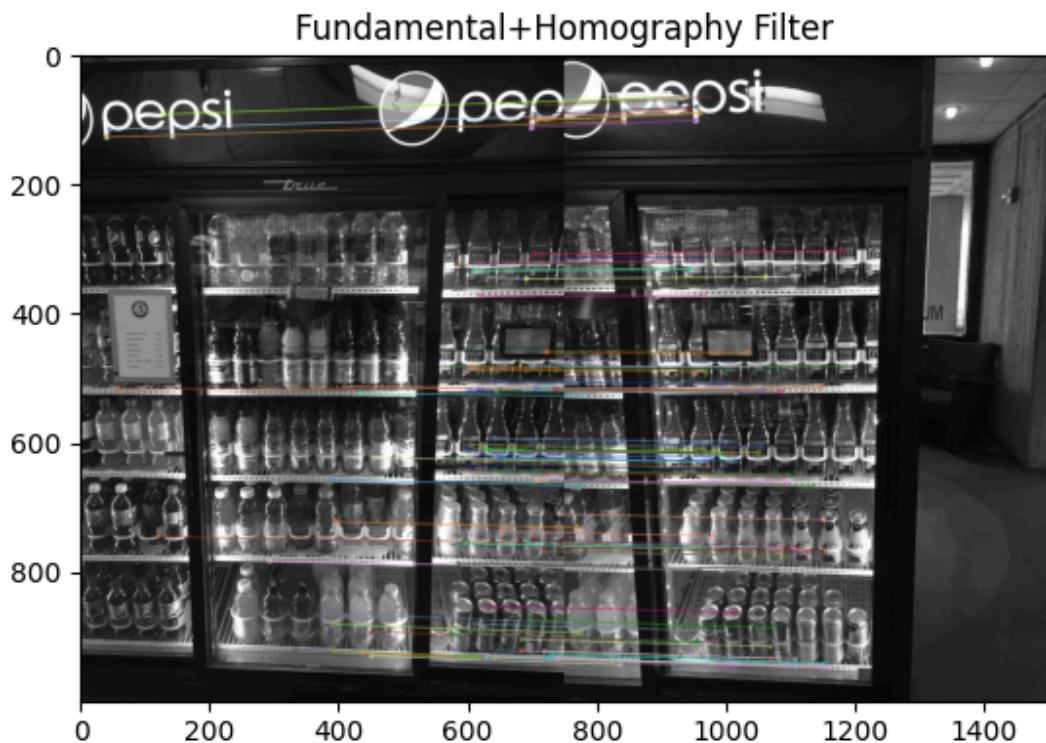
Passed threshold for inliers:

Contains enough inliers to be considered as matching images

New inlier count using homography between image2.JPG and image3.JPG: 112

Ratio of new inliers to fundamental matrix inliers: 0.5

Image of new inliers consistent with Fundamental and Homography matrix:



Passed threshold for new inliers calculations:

Ratio and amount of new inliers computed by homography matrix is above threshold

Image of overlapping scenes:



`hw3_align.py hw3_data/vcc-entrance outfile.txt`

Keypoint counts using SIFT

image1.JPG: 2337

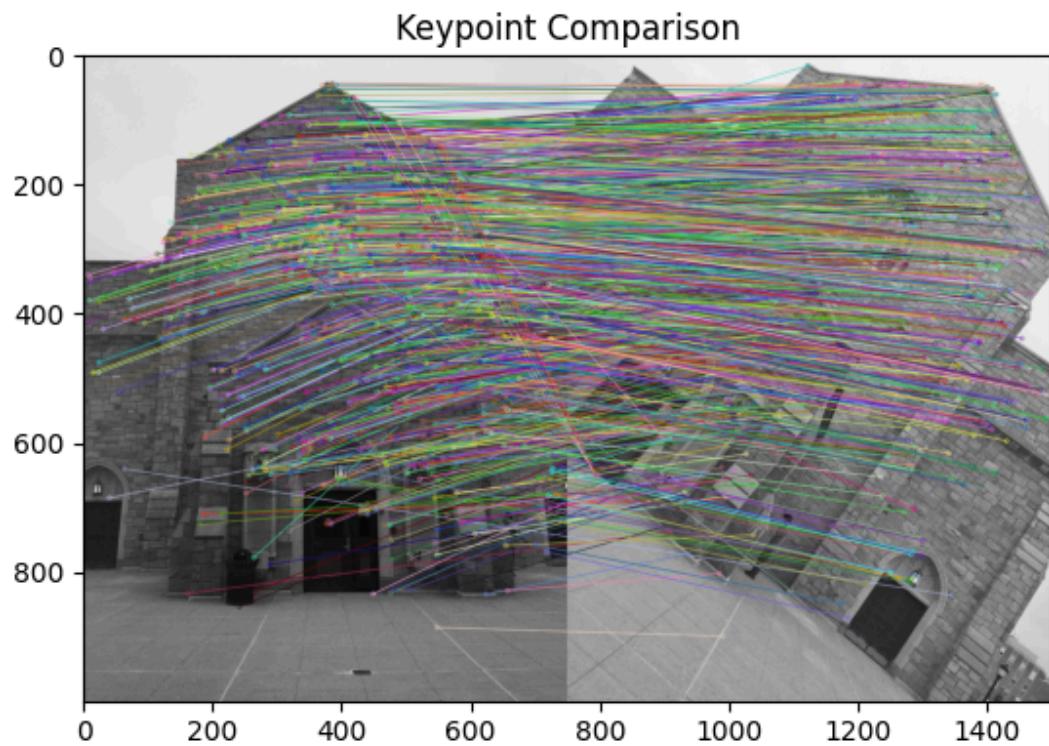
image2.JPG: 4457

image3.JPG: 491

Matches between image1.JPG and image2.JPG: 964

Fraction of keypoints matched: 0.4125, 0.2163

Image of Keypoint Comparison:



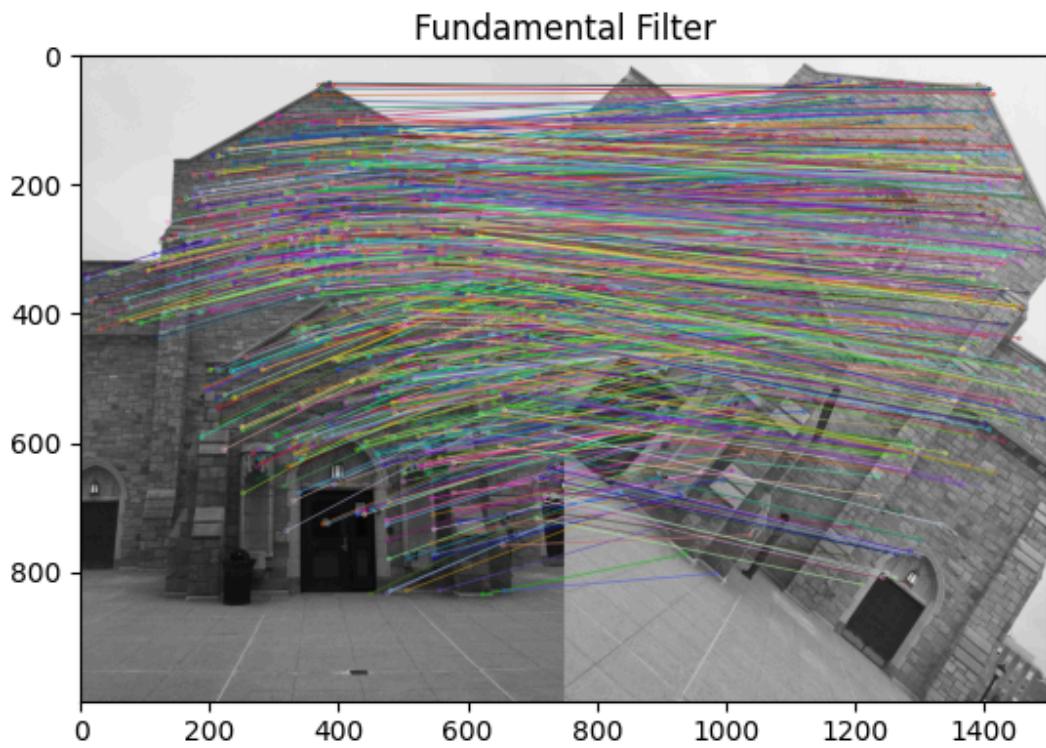
Passed threshold of matching keypoints

Amount of matching keypoints meets threshold

Inlier count between image1.JPG and image2.JPG: 881

Ratio of inliers to initial match: 0.9139004149377593

Image consistent with Fundamental Matrix:



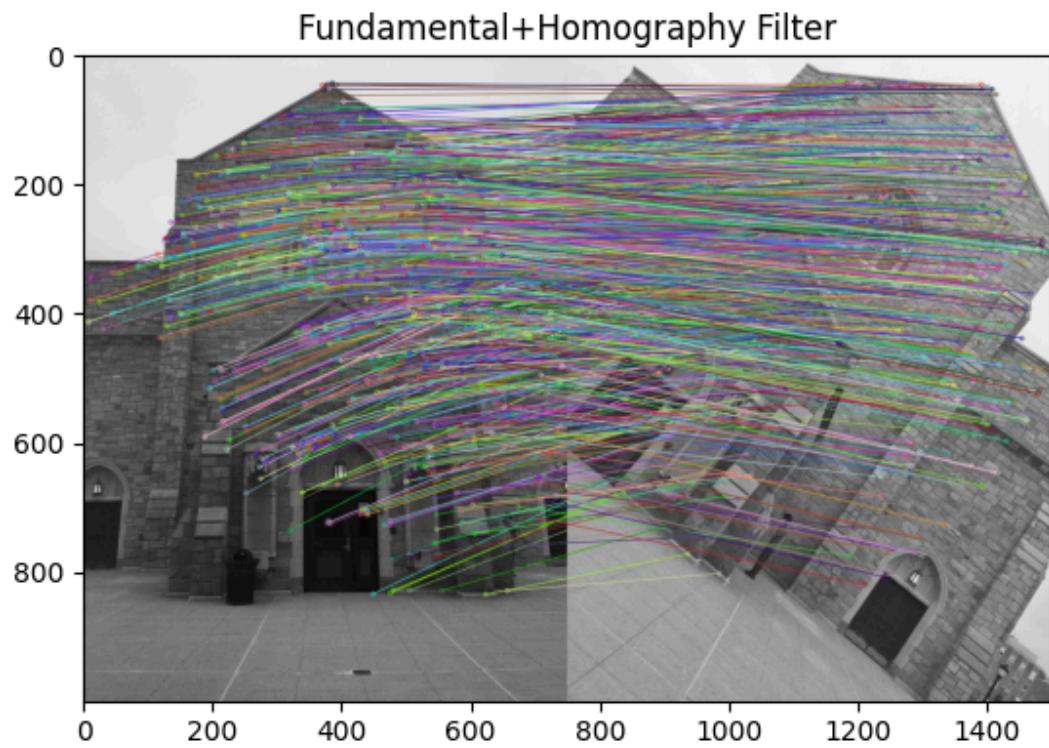
Passed threshold for inliers:

Contains enough inliers to be considered as matching images

New inlier count using homography between image1.JPG and image2.JPG: 802

Ratio of new inliers to fundamental matrix inliers: 0.9103291713961408

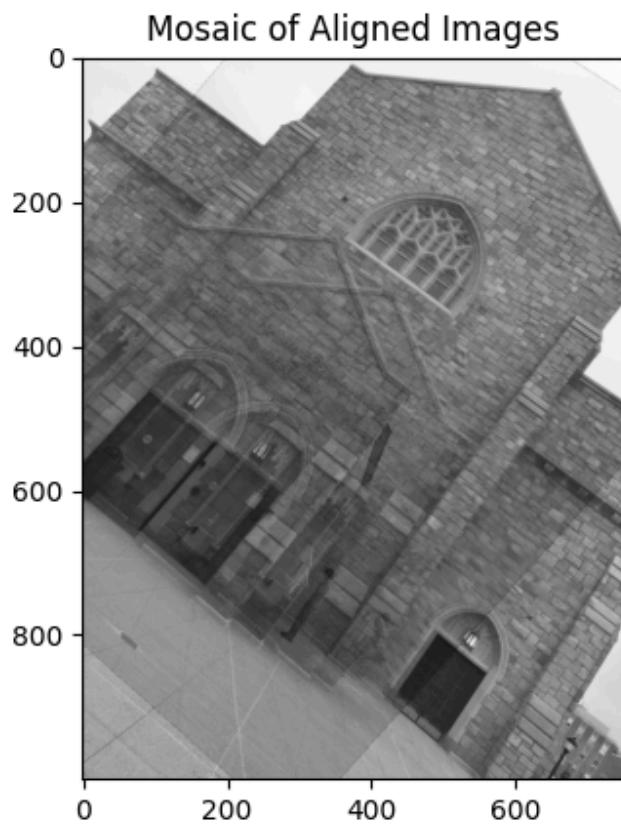
Image of new inliers consistent with Fundamental and Homography matrix:



Passed threshold for new inliers calculations:

Ratio and amount of new inliers computed by homography matrix is above threshold

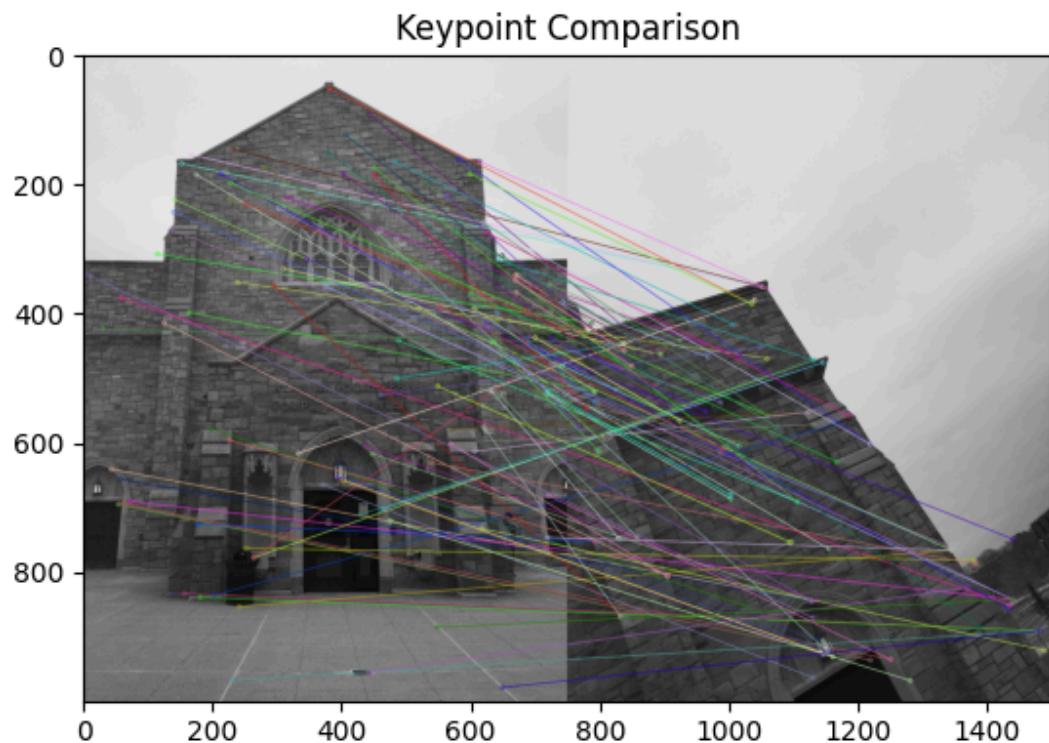
Image of overlapping scenes:



Matches between image1.JPG and image3.JPG: 125

Fraction of keypoints matched: 0.0535, 0.2546

Image of Keypoint Comparison:



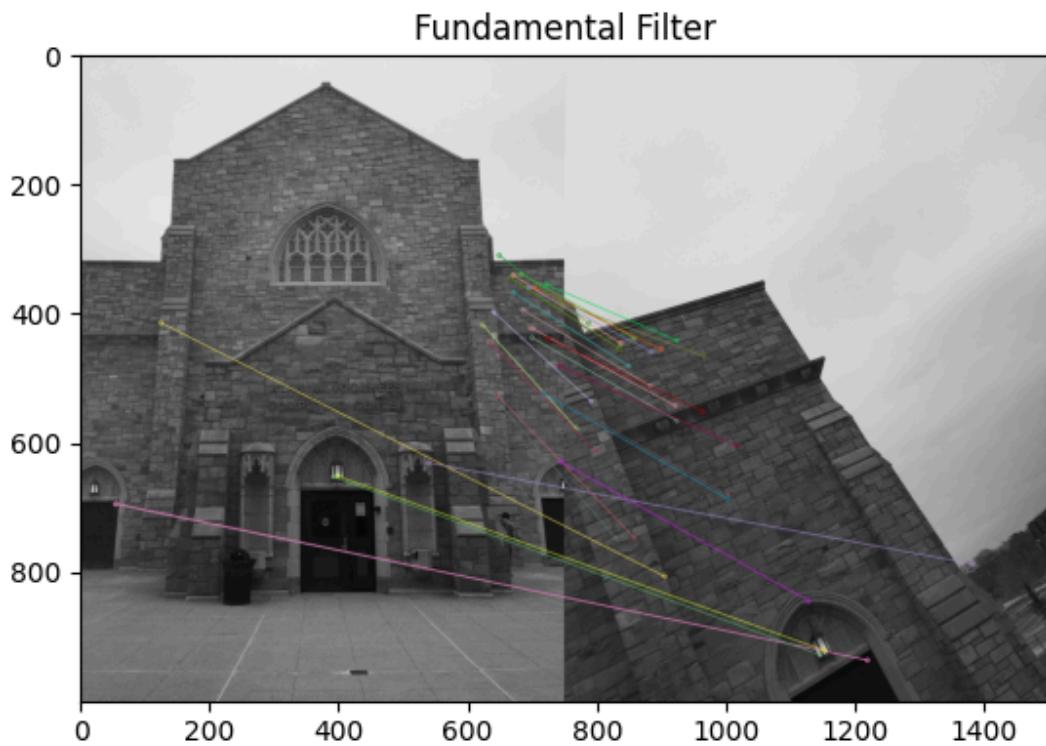
Passed threshold of matching keypoints

Amount of matching keypoints meets threshold

Inlier count between image1.JPG and image3.JPG: 34

Ratio of inliers to initial match: 0.272

Image consistent with Fundamental Matrix:



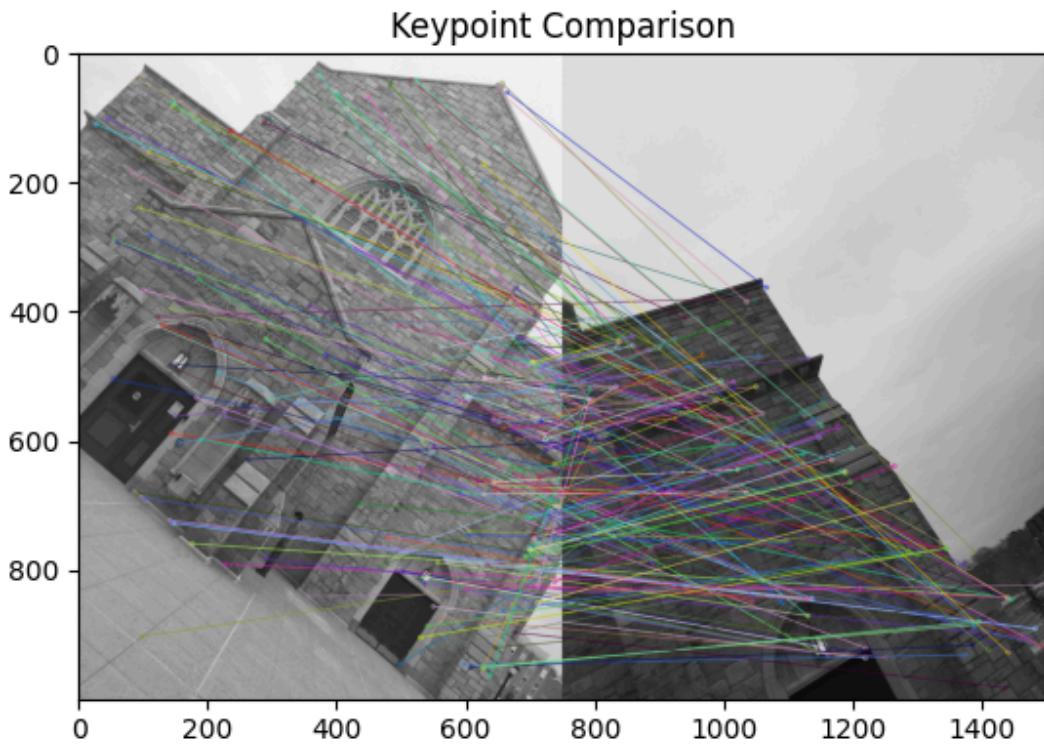
Failed threshold for inliers:

Too little inliers or too small of a ratio, images do not match

Matches between image2.JPG and image3.JPG: 202

Fraction of keypoints matched: 0.0453, 0.4114

Image of Keypoint Comparison:



Failed threshold of matching keypoints

Too little matching keypoints

`hw3_align.py hw3_data/tree_mrc outfile.txt`

Keypoint counts using SIFT

image4.JPG: 5475

image1.JPG: 6861

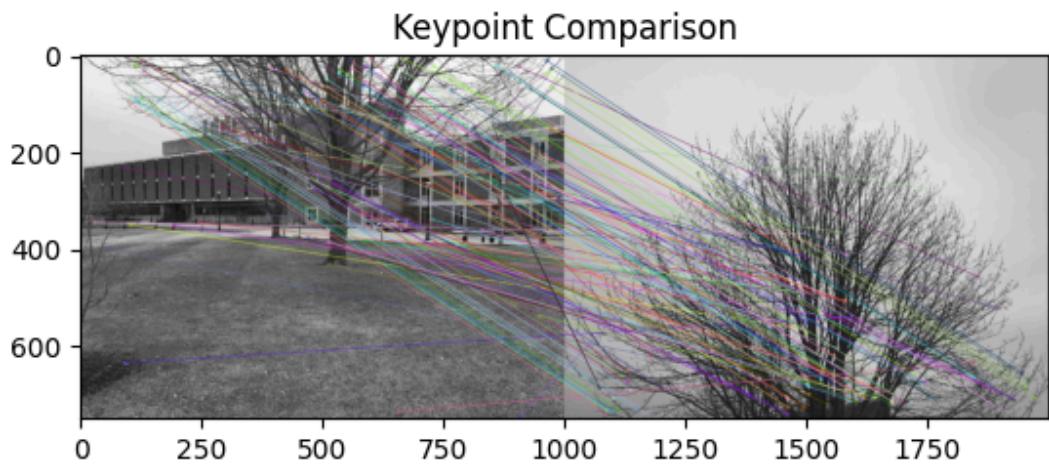
image2.JPG: 7277

image3.JPG: 5997

Matches between image4.JPG and image1.JPG: 127

Fraction of keypoints matched: 0.0232, 0.0185

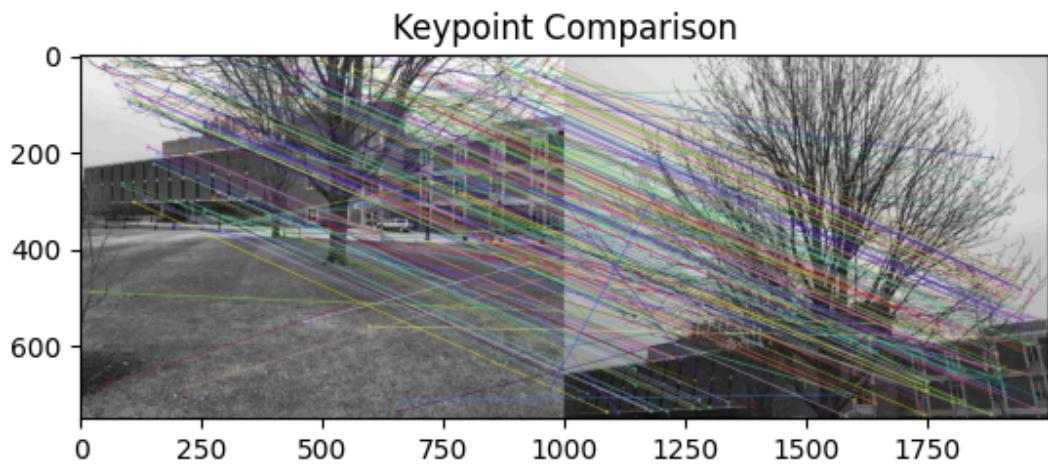
Image of Keypoint Comparison:



Failed threshold of matching keypoints
Too little matching keypoints

Matches between image4.JPG and image2.JPG: 260
Fraction of keypoints matched: 0.0475, 0.0357

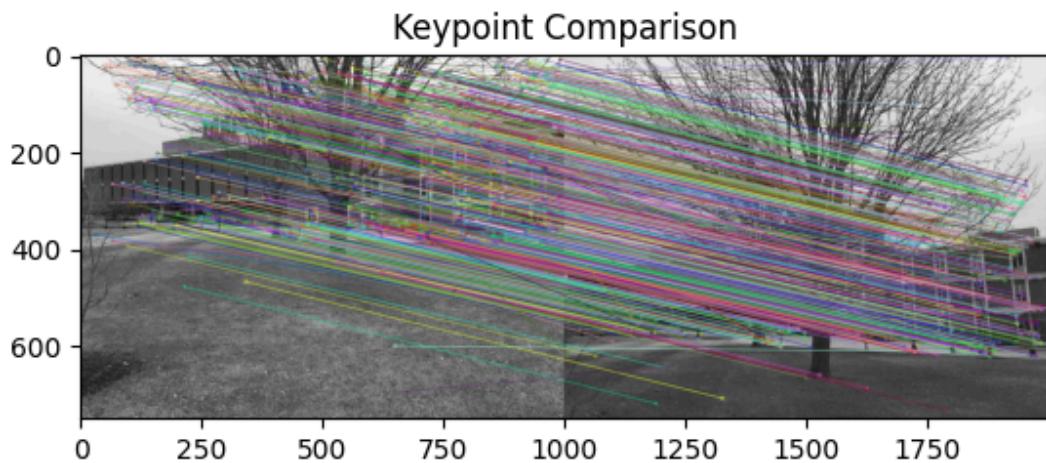
Image of Keypoint Comparison:



Failed threshold of matching keypoints
Too little matching keypoints

Matches between image4.JPG and image3.JPG: 675
Fraction of keypoints matched: 0.1233, 0.1126

Image of Keypoint Comparison:



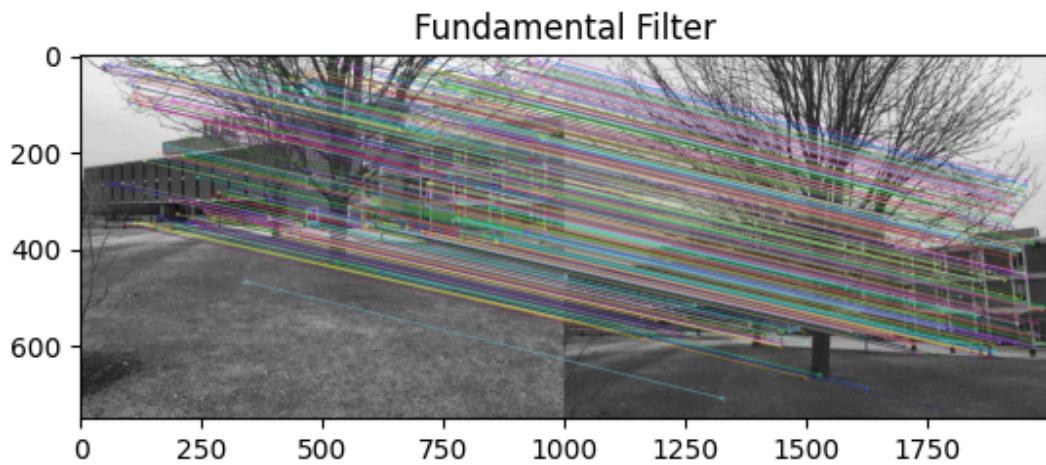
Passed threshold of matching keypoints

Amount of matching keypoints meets threshold

Inlier count between image4.JPG and image3.JPG: 582

Ratio of inliers to initial match: 0.8622222222222222

Image consistent with Fundamental Matrix:



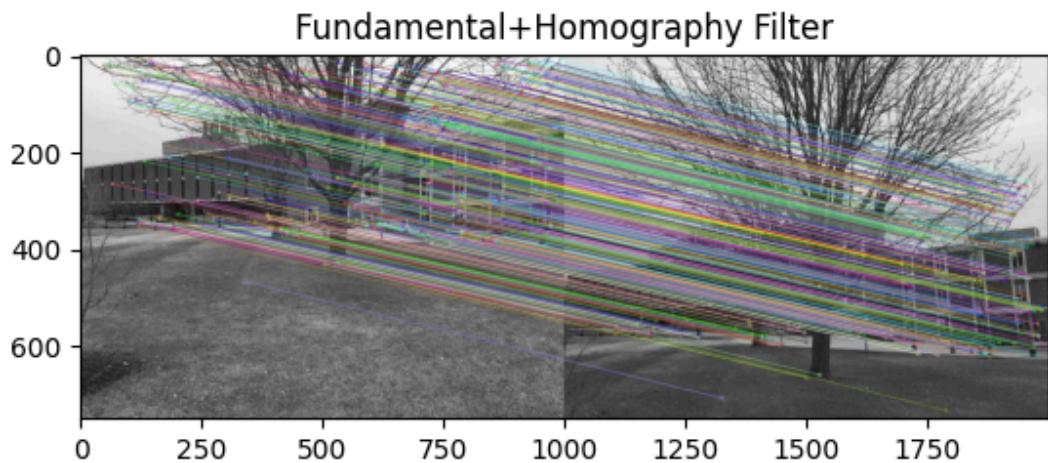
Passed threshold for inliers:

Contains enough inliers to be considered as matching images

New inlier count using homography between image4.JPG and image3.JPG: 500

Ratio of new inliers to fundamental matrix inliers: 0.8591065292096219

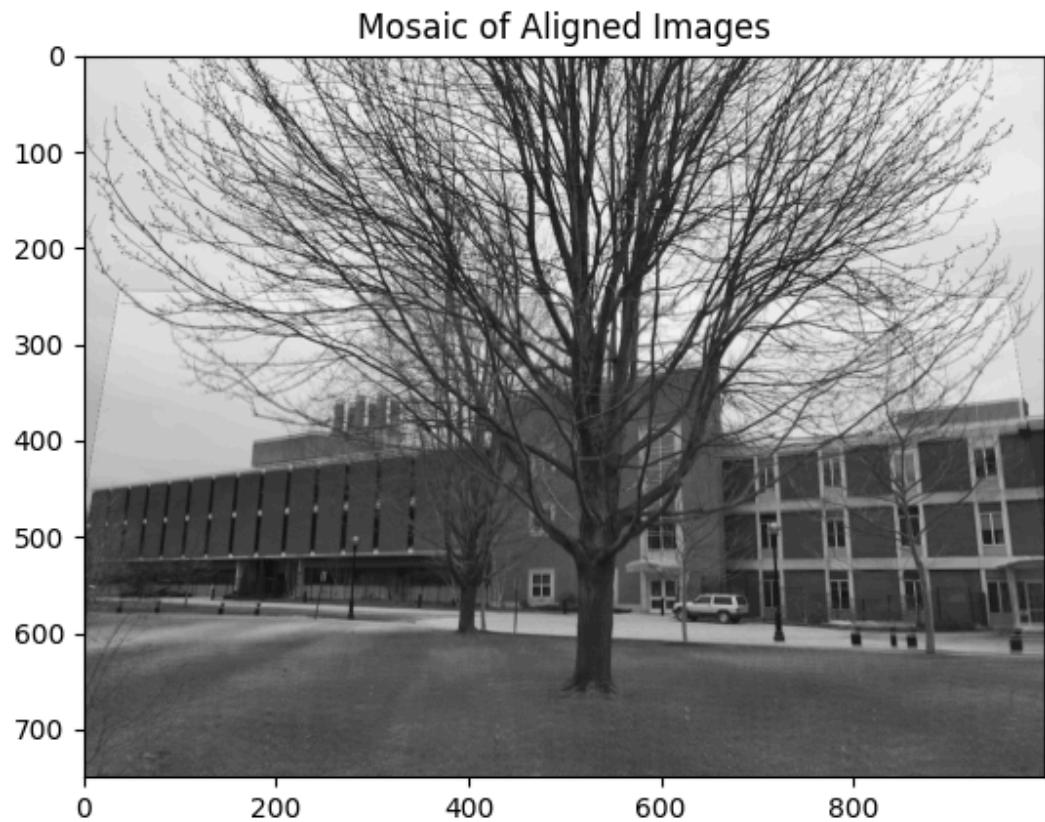
Image of new inliers consistent with Fundamental and Homography matrix:



Passed threshold for new inliers calculations:

Ratio and amount of new inliers computed by homography matrix is above threshold

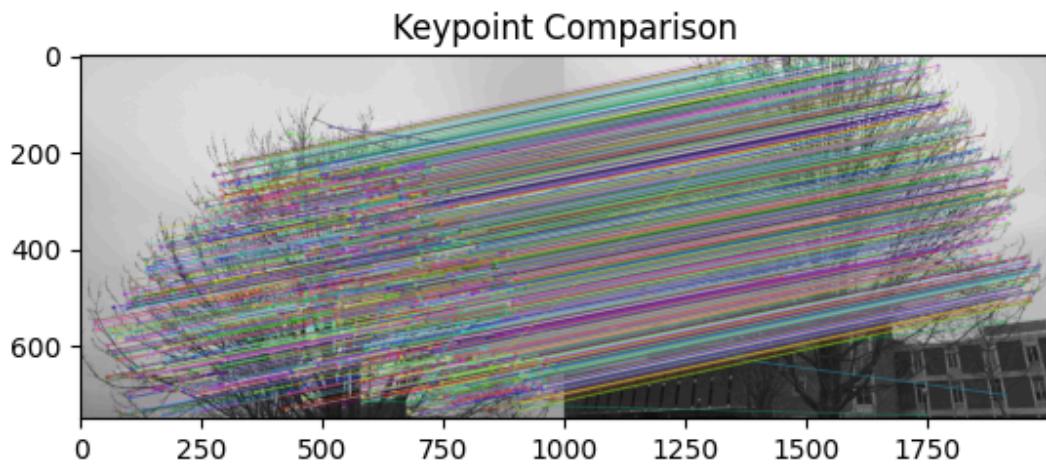
Image of overlapping scenes:



Matches between image1.JPG and image2.JPG: 1613

Fraction of keypoints matched: 0.2351, 0.2217

Image of Keypoint Comparison:



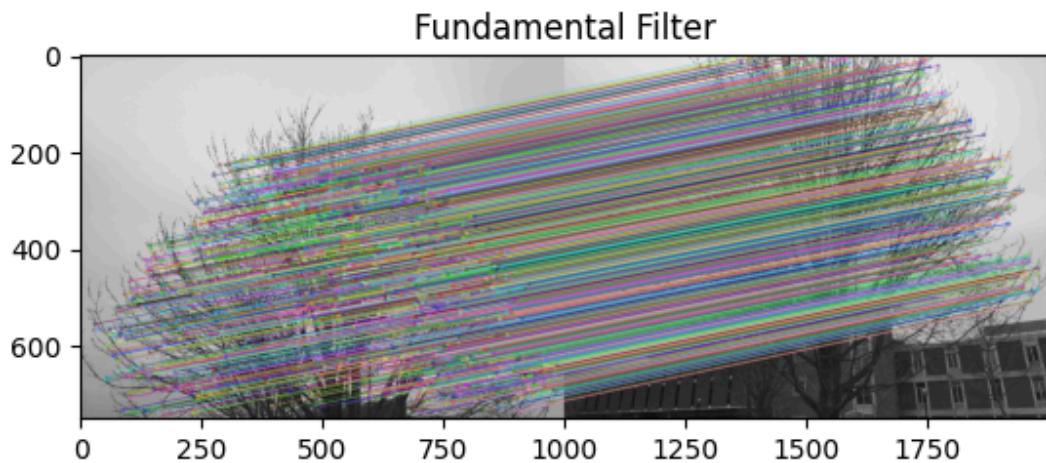
Passed threshold of matching keypoints

Amount of matching keypoints meets threshold

Inlier count between image1.JPG and image2.JPG: 1535

Ratio of inliers to initial match: 0.9516429014259145

Image consistent with Fundamental Matrix:



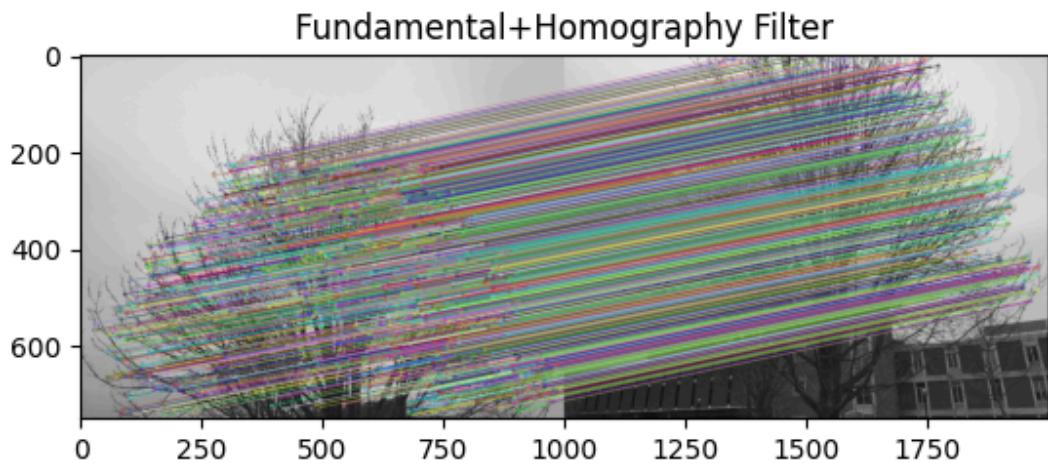
Passed threshold for inliers:

Contains enough inliers to be considered as matching images

New inlier count using homography between image1.JPG and image2.JPG: 1457

Ratio of new inliers to fundamental matrix inliers: 0.949185667752443

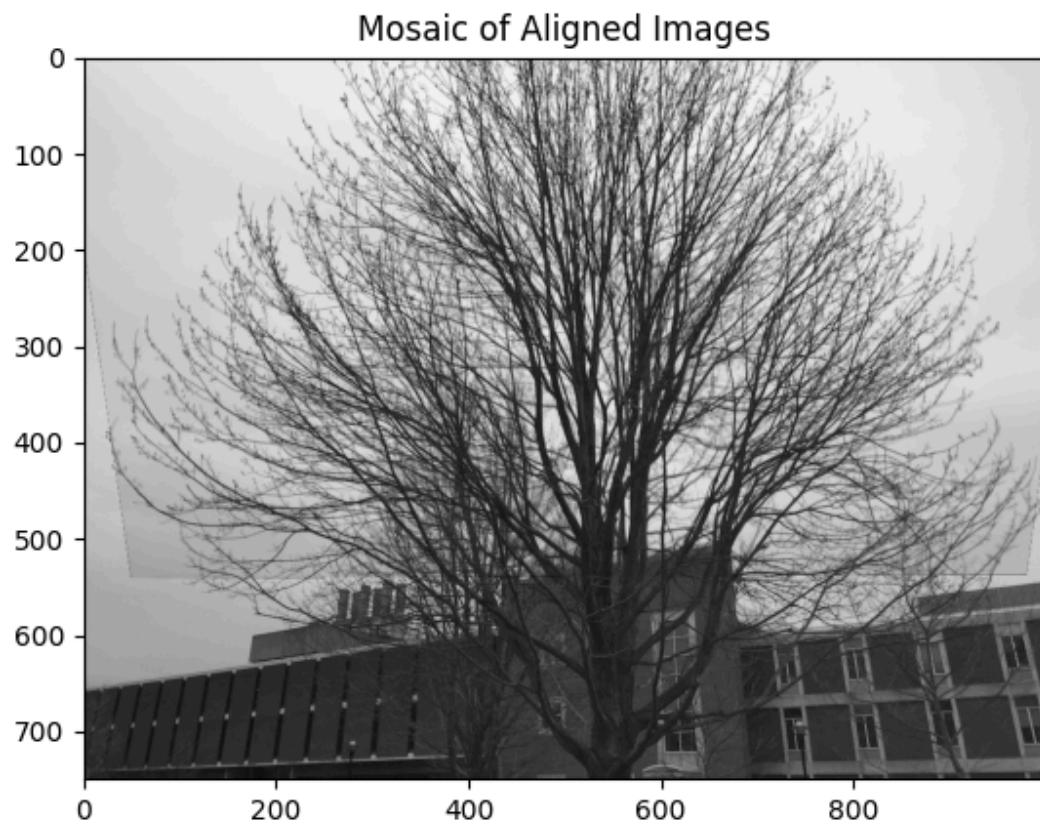
Image of new inliers consistent with Fundamental and Homography matrix:



Passed threshold for new inliers calculations:

Ratio and amount of new inliers computed by homography matrix is above threshold

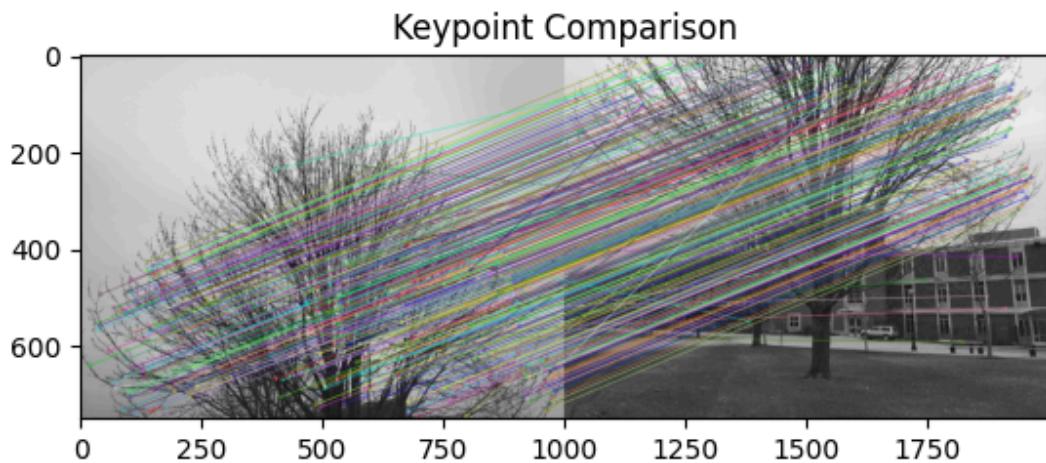
Image of overlapping scenes:



Matches between image1.JPG and image3.JPG: 505

Fraction of keypoints matched: 0.0736, 0.0842

Image of Keypoint Comparison:



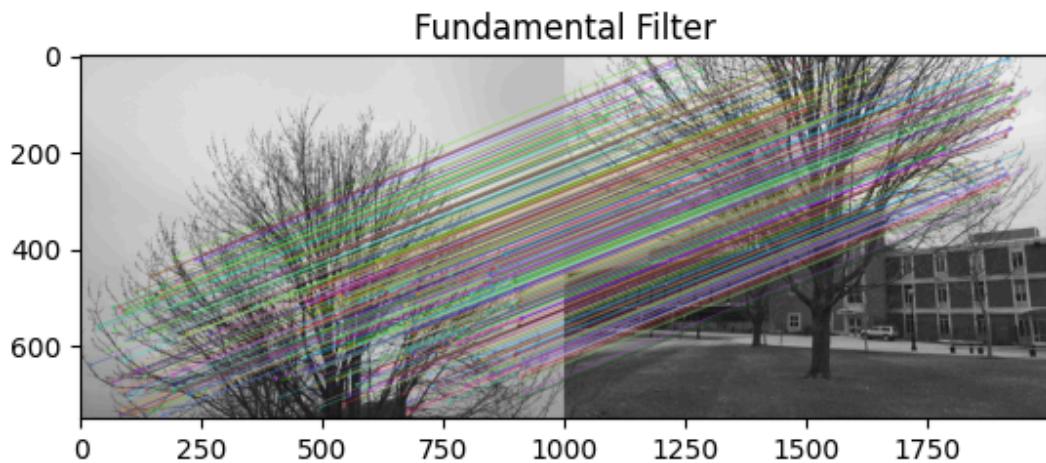
Passed threshold of matching keypoints

Amount of matching keypoints meets threshold

Inlier count between image1.JPG and image3.JPG: 400

Ratio of inliers to initial match: 0.7920792079207921

Image consistent with Fundamental Matrix:



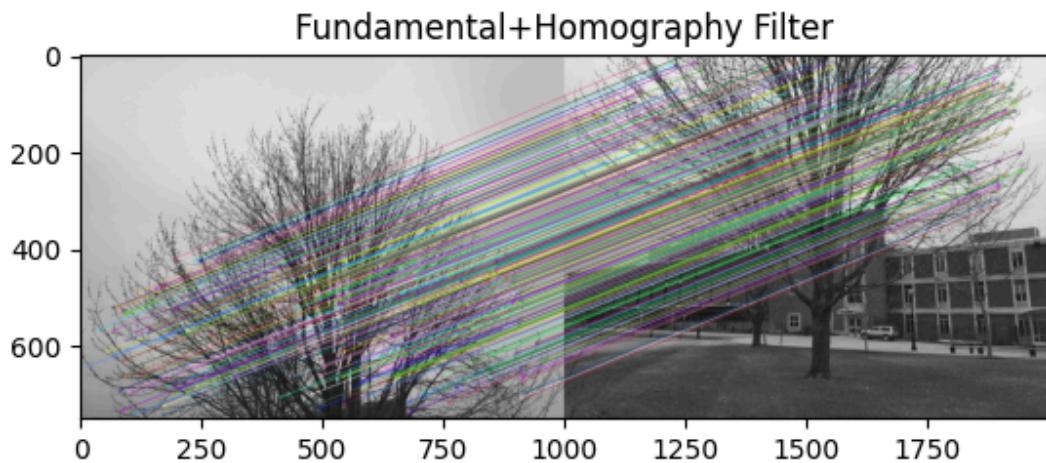
Passed threshold for inliers:

Contains enough inliers to be considered as matching images

New inlier count using homography between image1.JPG and image3.JPG: 329

Ratio of new inliers to fundamental matrix inliers: 0.8225

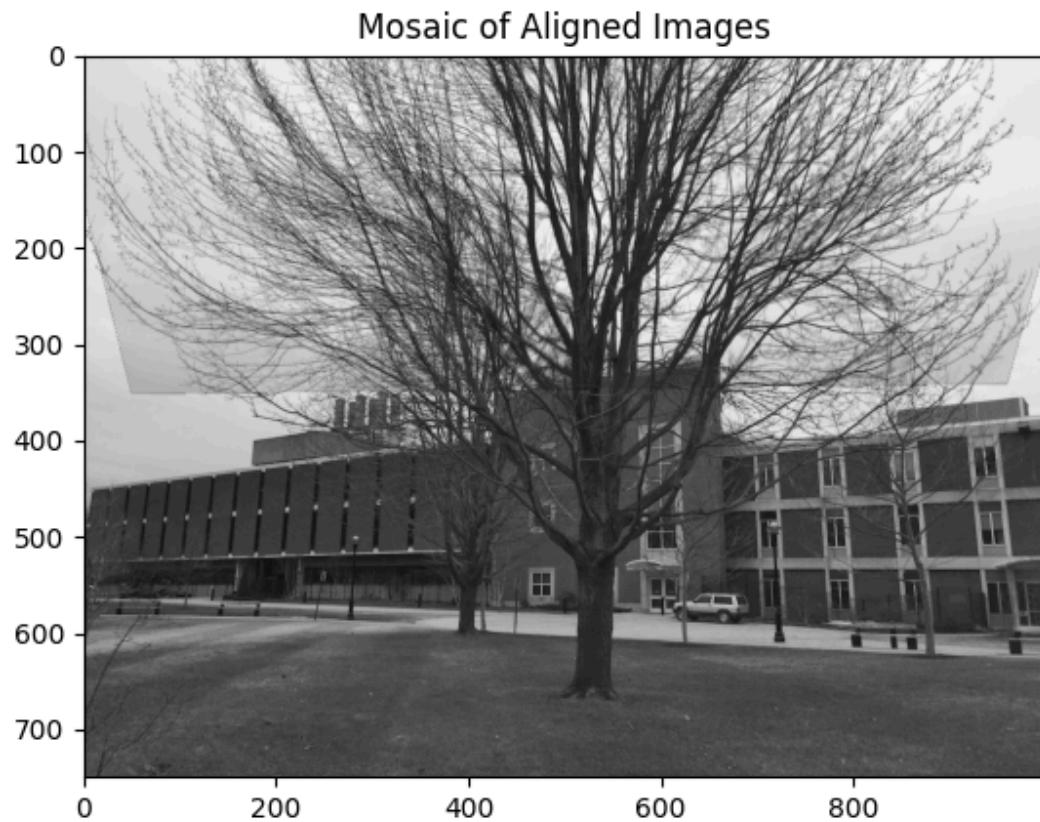
Image of new inliers consistent with Fundamental and Homography matrix:



Passed threshold for new inliers calculations:

Ratio and amount of new inliers computed by homography matrix is above threshold

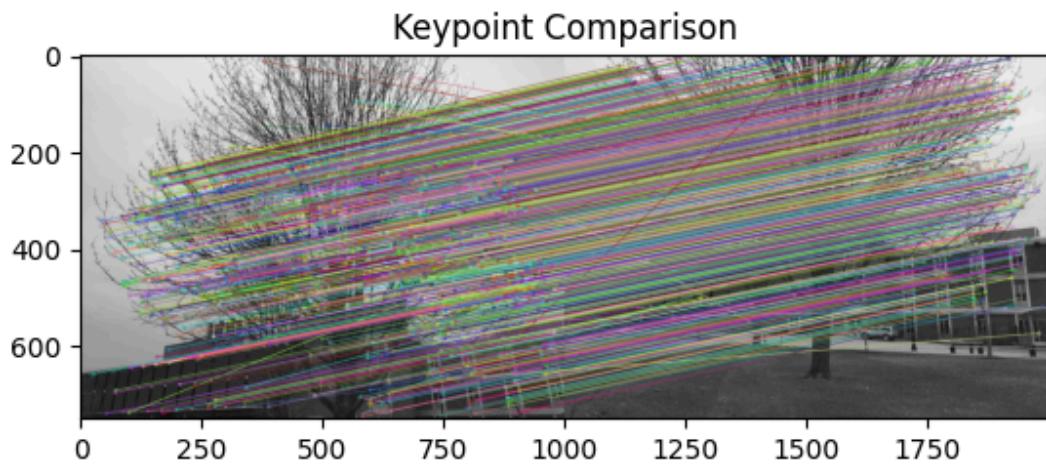
Image of overlapping scenes:



Matches between image2.JPG and image3.JPG: 1289

Fraction of keypoints matched: 0.1771, 0.2149

Image of Keypoint Comparison:



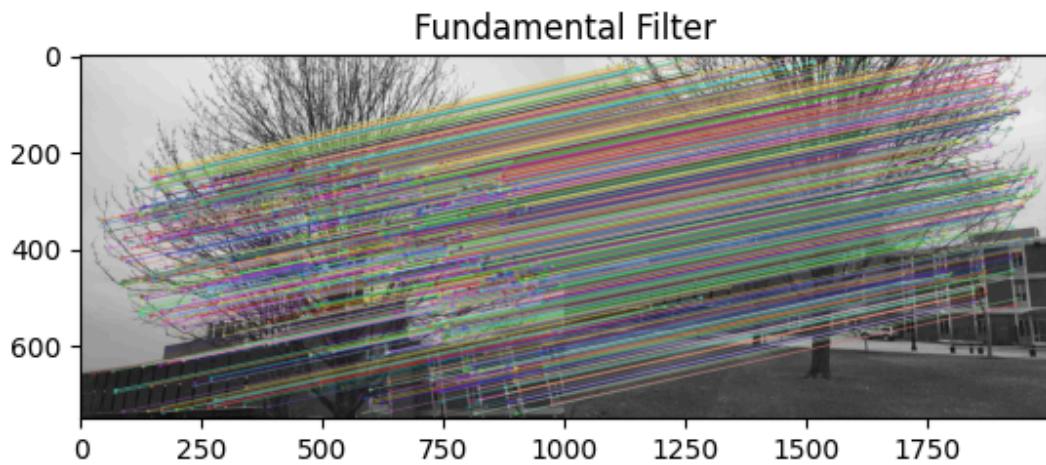
Passed threshold of matching keypoints

Amount of matching keypoints meets threshold

Inlier count between image2.JPG and image3.JPG: 1184

Ratio of inliers to initial match: 0.9185415050426687

Image consistent with Fundamental Matrix:



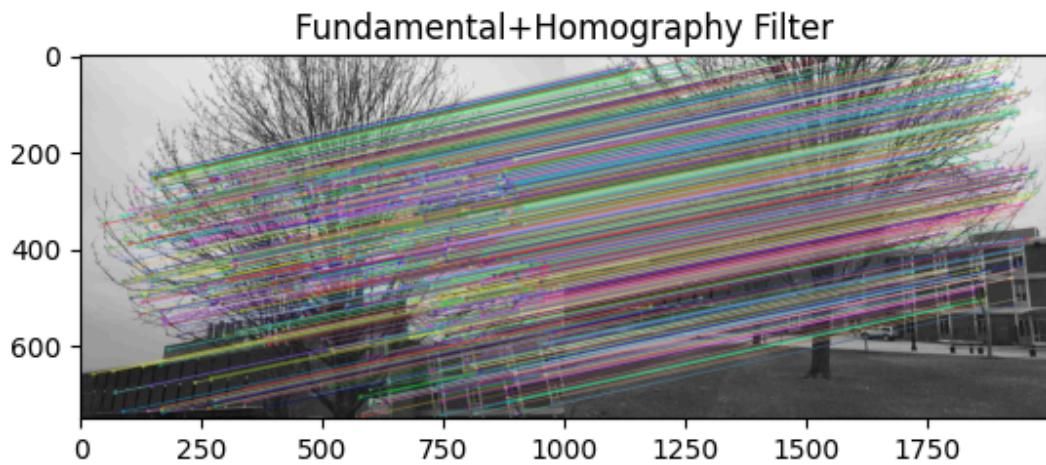
Passed threshold for inliers:

Contains enough inliers to be considered as matching images

New inlier count using homography between image2.JPG and image3.JPG: 1084

Ratio of new inliers to fundamental matrix inliers: 0.9155405405405406

Image of new inliers consistent with Fundamental and Homography matrix:



Passed threshold for new inliers calculations:

Ratio and amount of new inliers computed by homography matrix is above threshold

Image of overlapping scenes:

