

This is a programming assignment to implement a simplified version of structure from motion pipeline. We will focus on reconstructing from just a pair of calibrated camera images. The goal, given such a pair, is to reconstruct the 3-D positions of a set of matching points in the images and also to infer the camera extrinsic parameters. All results can be in a coordinate frame aligned with the first camera.

With five main parts:

1. Keypoint feature extraction and matchings: These steps are the same as in HW3 and you may reuse your code. However, filtering out weak matches may be more important for computing essential matrix than for homography.
2. findEssentialMat function computes the essential matrix, given a list of match points; it also can use RANSAC for robust matching (similar to findHomography).
3. recoverpose function decomposes essential matrix into rotation and translation components. It also selects among four possible solutions by considering reconstruction of matched points. If you choose to implement on your own, by following Algorithm 8.1 of the FP book, you will need to be careful to select the solution that puts the reconstructed points in front of the two cameras. The camera matrices can be easily constructed from the recovered rotation and translation parameters.
4. triangulatepoints may be used to compute intersections of rays, given matching points and camera matrices. As triangulation involves solving linear equations, it may be complicated to write on your own. Note that the results may be output in homogeneous coordinates which should be converted to regular coordinates for output. This function also expects normalized coordinates as input so you need to convert from image coordinates.
5. undistortpoints may be used to convert image coordinates to normalized coordinates. It is also easy to write this function on your own.

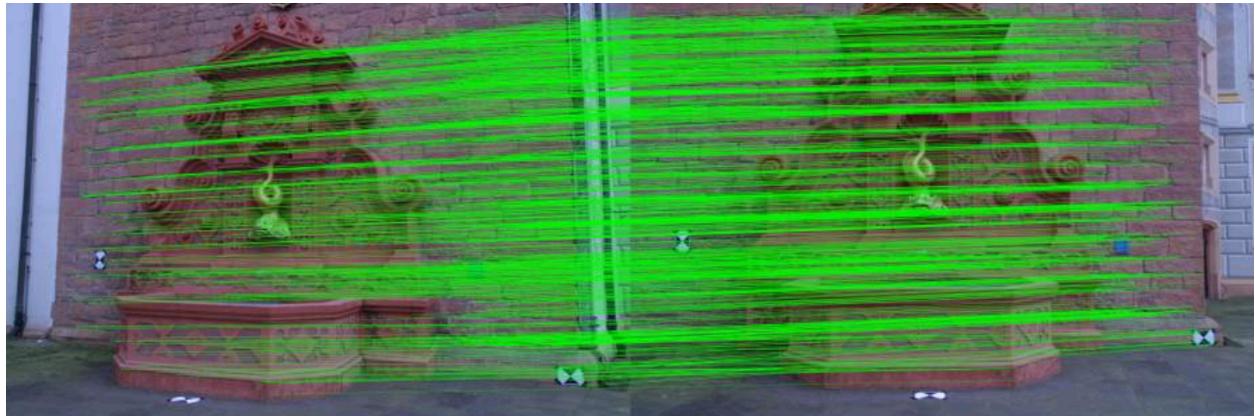
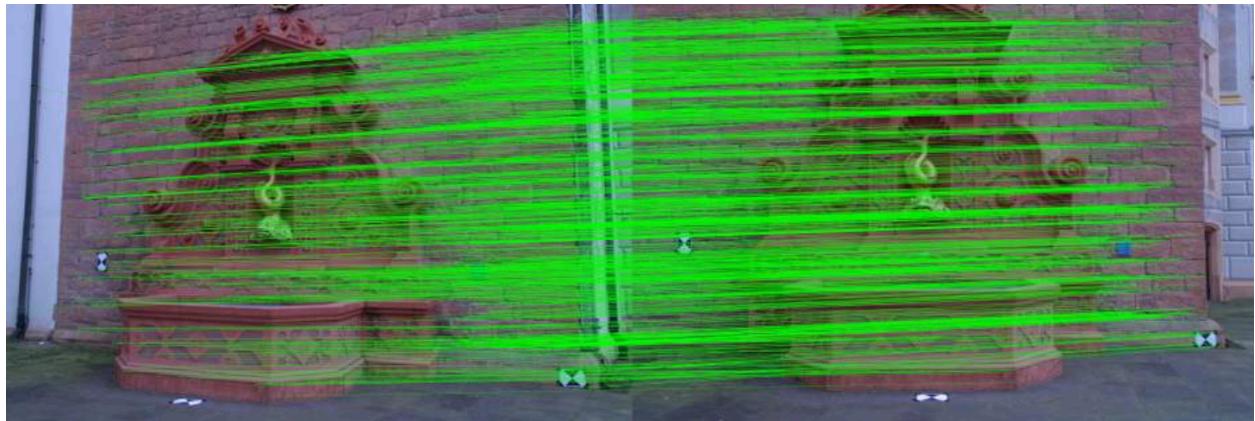
**Question 1: A brief description of the programs you write (include the source listing). Your program should be commented clearly.**

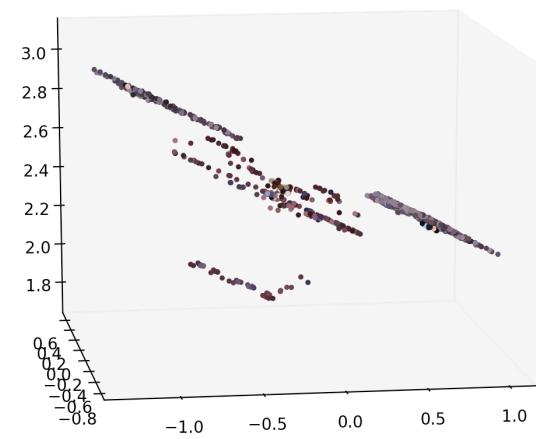
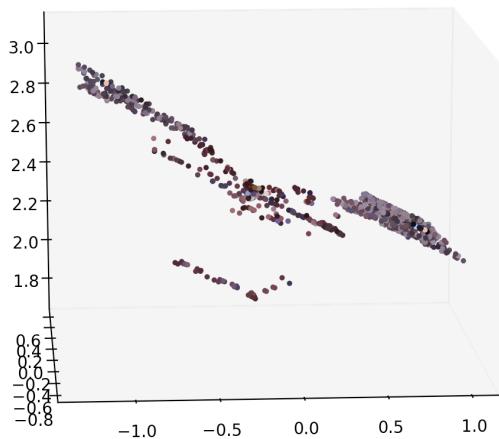
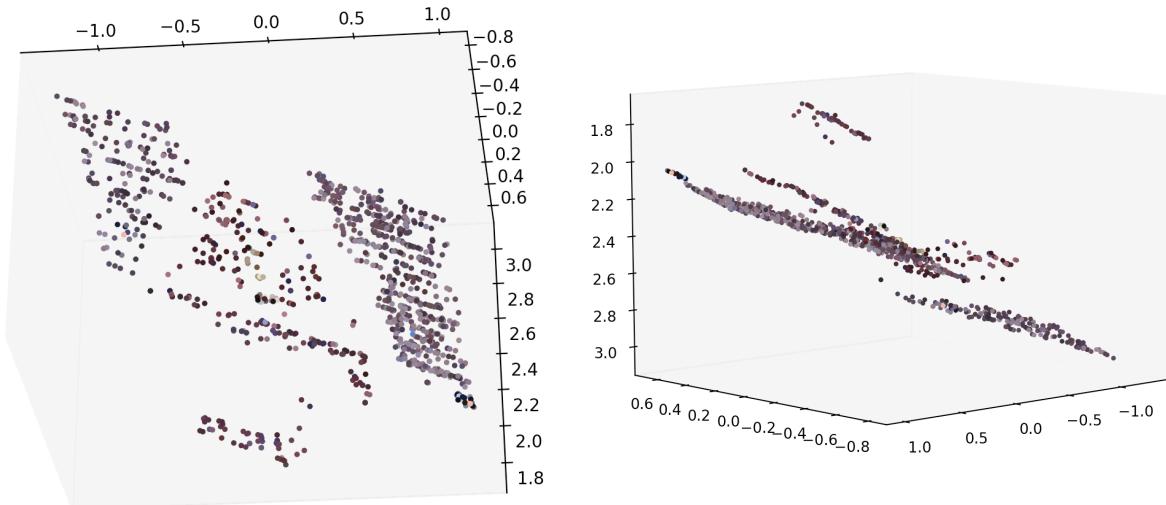
```
# screen the matches and record the screened matches
# screen the useful points
# read the images
# convert them to gray scale
# initiate the class and use BFMatcher with default params
# get the keypoints and descriptors
# draw keypoints on original images
# display the number of keypoints for each image
# KNN matches for k1 and k2
# get the point positions
# get the point colors
# convert BGR to RGB for display
# display the mathces before RANSAC but after screening
# draw the matches before RANSAC
# find the essential matrix
# decompose an essential matrix and verify possible pose hypotheses
# display the rotation matrix and translation vector
# draw the matches after RANSAC
# write it to disk
```

```
# compute the ideal point coordinates
# image camera matrix
# display the matrix
# reconstruct the 3D points
# display the shape an all points
# draw the 3D points
```

**Question 2: Show the results of intermediate steps. Use your judgment in how to display or record these results.**

Rotation matrix:	Intrinsic camera matrix:
$\begin{bmatrix} 0.9301538 & -0.02513059 & -0.36630911 \\ 0.00957989 & 0.99897638 & -0.04420881 \\ 0.36704514 & 0.03761179 & 0.92944242 \end{bmatrix}$	$\begin{bmatrix} 2760 & 0 & 1520 \\ 0 & 2760 & 1006 \\ 0 & 0 & 1 \end{bmatrix}$
Translation vector:	Extrinsic camera matrix:
$\begin{bmatrix} 0.99729284 \\ 0.01078151 \\ 0.07273756 \end{bmatrix}$	$\begin{bmatrix} 0.9301538 & -0.02513059 & -0.36630911 & 0.99729284 \\ 0.00957989 & 0.99897638 & -0.04420881 & 0.01078151 \\ 0.36704514 & 0.03761179 & 0.92944242 & 0.07273756 \end{bmatrix}$





### Question 3: An analysis of your test results: how well does the method work?

It shows even though we screened all matches, there are lots of outliers before RANSAC. And after RANSAC, there contains no outliers. This shows RANSAC can efficiently remove outliers from the image. The figures above shows both the point color and point positions in original image corresponding to the reconstructed cloud point. In these cloud point figures, it shows the correspondence between the blue box in the original image and the blue points in cloud at the same position. This tells my cloud points can indicate information in original image and it is a good result.

Points Location:

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 0.49578298 2.23128549]] [[ 0.70721367 0.49883356 2.2103316 ]]  
 [[ 0.81758465 0.50494749 2.16940217]] [[ 0.83522869 0.53383733  
 2.16120838]] [[ 0.98191013 0.58569282 2.05512771]] [[ 0.90067041  
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 [[ 0.98672148 0.63939017 2.04861415]] [[-0.2201576 -0.60749863

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[[ 0.54218518 -0.45445532 2.37101257]] [[ 0.54218518 -0.45445532  
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[[ 0.58937612 -0.0923892 2.31687408]] [[ 0.61413072 0.22422936  
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[[ 0.94235801 0.63053281 2.06303861]] [[ 0.9740409 0.62987867  
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[[-0.92590357 0.10085336 2.85307526]] [[-0.92590357 0.10085336  
2.85307526]] [[-0.34379263 0.37607173 2.35240999]] [[-0.34379263  
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[[ 0.94307997 0.59862384 2.07116567]] [[-0.28414508 -0.4409341  
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0.1457952 2.39979005]] [[-0.2049857 -0.07167903 2.44446848]]

```

import cv2
import numpy as np
from matplotlib import pyplot
from mpl_toolkits.mplot3d import Axes3D

# screen the matches and record the screened matches
def good_match(matches):
    good = []
    screen_matches = []
    match_inx = 0
    for m, n in matches:
        if m.distance < 0.7*n.distance:
            good.append(m)
            screen_matches.append(matches[match_inx])
        match_inx += 1
    return (match_inx, good, screen_matches)

# screen the useful points
def useful_points (mask, raw_points):
    '''Use mask to screen the useful points'''
    raw_size = raw_points.shape
    # print raw_size
    new_num = np.count_nonzero(mask)
    # print new_num
    screened_points = np.zeros((new_num, raw_size[1], raw_size[2]))
    # print screened_points.shape
    new_ind = 0
    for i in range(raw_size[0]):
        if mask[i] == 1:
            screened_points[new_ind, :, :] = raw_points[i, :, :]
            # print screened_points[new_ind, :, :], new_ind
            new_ind += 1
    return screened_points

# read the images
img1 = cv2.imread('/Users/YiyueZhang/Downloads/HW4_data/image1.jpg')
img2 = cv2.imread('/Users/YiyueZhang/Downloads/HW4_data/image2.jpg')

# convert them to gray scale
gray1 = cv2.cvtColor(img1, cv2.COLOR_BGR2GRAY)
gray2 = cv2.cvtColor(img2, cv2.COLOR_BGR2GRAY)

```

```

# initiate the class and use BFMatcher with default params
sift = cv2.xfeatures2d.SIFT_create()
bf = cv2.BFMatcher()

# get the keypoints and descriptors
k1, desc1 = sift.detectAndCompute(gray1, None)
k2, desc2 = sift.detectAndCompute(gray2, None)

# draw keypoints on original images
img_k1 = cv2.drawKeypoints(img1, k1, None, flags=cv2.DRAW_MATCHES_FLAGS_DRAW_RICH_KEYPOINTS)
img_k2 = cv2.drawKeypoints(img2, k2, None, flags=cv2.DRAW_MATCHES_FLAGS_DRAW_RICH_KEYPOINTS)

# display the number of keypoints for each image
print ('\n')
print ('# of keypoints in image1:', len(k1))
print ('# of keypoints in image2:', len(k2))
print ('\n')

# KNN matches for k1 and k2
matches = bf.knnMatch(desc1,desc2,k=2)
matches_len = len(matches)
(match_inx, good, screen_matches) = good_match(matches)

# get the point positions
point_pos = []
for m in good:
    point_pos.append(k1[m.queryIdx].pt)

# get the point colors
point_color = []
for pos in point_pos:
    point_color.append(img1[int(pos[1]), int(pos[0])])

# convert BGR to RGB for display
for i in point_color:
    tmp = i[0]
    i[0] = i[2]
    i[2] = tmp

# display the matches before RANSAC but after screening
print ("\n")
print ("Matches before RANSAC:")
print (len(screen_matches))
print ("\n")

```

```

# draw the matches before RANSAC
matches_before_RANSAC_param = dict(matchColor = (0,255,0), # draw matches in green color
                                     singlePointColor = None,
                                     flags = 2)
matches_before_RANSAC = cv2.drawMatches(img1, k1, img2, k2, good, None, **matches_before_RANSAC_param)
cv2.imwrite('match_before_RANSAC.png', matches_before_RANSAC)

# find the essential matrix
src_pts = np.float32([ k1[m.queryIdx].pt for m in good]).reshape(-1,1,2)
dst_pts = np.float32([ k2[m.trainIdx].pt for m in good]).reshape(-1,1,2)
ess_matrix, ess_mask = cv2.findEssentialMat(src_pts, dst_pts, focal=2760,
                                             pp=(1520, 1006), method=cv2.RANSAC, prob=0.999, threshold=1.0)

# decompose an essential matrix and verify possible pose hypotheses
_, rotat, trans, rp_mask = cv2.recoverPose(ess_matrix, src_pts, dst_pts,
                                           focal=2760, pp=(1520, 1006))

# display the rotation matrix and translation vector
print ("\nRotation matrix:")
print (rotat)
print ("\nTranslation vector:")
print (trans)
print ("\n")

# draw the matches after RANSAC
ess_mask_list = ess_mask.ravel().tolist()
rp_matches = dict(matchColor = (0,255,0), # draw matches in green color
                  singlePointColor = None,
                  matchesMask = ess_mask_list, # draw only inliers
                  flags = 2)
show_rp_match = cv2.drawMatches(img1, k1, img2, k2, good,
                                None, **rp_matches)

# write it to disk
cv2.imwrite('show_rp_match_01_02.png', show_rp_match)

# compute the ideal point coordinates
src_pts_screened = useful_points (mask=ess_mask, raw_points=src_pts)
dst_pts_screened = useful_points (mask=ess_mask, raw_points=dst_pts)
src_pts_normalized = cv2.undistortPoints(src_pts_screened, np.array([[2760, 0, 1520], [0, 2760, 1006], [0, 0, 1]]), None)
dst_pts_normalized = cv2.undistortPoints(dst_pts_screened, np.array([[2760, 0, 1520], [0, 2760, 1006], [0, 0, 1]]), None)

# write it to disk
cv2.imwrite('show_rp_match_01_02.png', show_rp_match)

# compute the ideal point coordinates
src_pts_screened = useful_points (mask=ess_mask, raw_points=src_pts)
dst_pts_screened = useful_points (mask=ess_mask, raw_points=dst_pts)
src_pts_normalized = cv2.undistortPoints(src_pts_screened, np.array([[2760, 0, 1520], [0, 2760, 1006], [0, 0, 1]]), None)
dst_pts_normalized = cv2.undistortPoints(dst_pts_screened, np.array([[2760, 0, 1520], [0, 2760, 1006], [0, 0, 1]]), None)

# image camera matrix
img1_cam_matrix = np.eye(4)[:,3]
img2_cam_matrix = np.array([[rotat[0, 0], rotat[0, 1], rotat[0, 2], trans[0]],
                           [rotat[1, 0], rotat[1, 1], rotat[1, 2], trans[1]],
                           [rotat[2, 0], rotat[2, 1], rotat[2, 2], trans[2]]])

# display the matrix
print ("\nIntrinsic camera matrix:")
print (np.array([[2760, 0, 1520], [0, 2760, 1006], [0, 0, 1]]))
print ("\nExtrinsic camera matrix:")
print (img2_cam_matrix)
print ('\n')

# reconstruct the 3D points
pts_3d_homo = cv2.triangulatePoints(img1_cam_matrix, img2_cam_matrix, src_pts_normalized, dst_pts_normalized)
pts_3d = cv2.convertPointsFromHomogeneous(np.transpose(pts_3d_homo))

# display the shape an all points
print ("Points shape:")
print (pts_3d.shape)
print ("\n")

print ("Points positions:")
for i in pts_3d:
    print (i)

# draw the 3D points
final_poin_color = []
for i in range(0, len(ess_mask_list)):
    if ess_mask_list[i] == 1:
        final_poin_color.append(point_color[i])

for i in final_poin_color:
    for j in i:
        float(j)

final_color = []
for i in final_poin_color:
    tmp1 = i[0]
    tmp2 = i[1]
    tmp3 = i[2]
    final_color.append(np.array([tmp1/255.0, tmp2/255.0, tmp3/255.0]))

fig = pyplot.figure()
ax = Axes3D(fig)

x_axis = pts_3d[:, :, 0].ravel().tolist()
y_axis = pts_3d[:, :, 1].ravel().tolist()
z_axis = pts_3d[:, :, 2].ravel().tolist()

ax.scatter(x_axis, y_axis, z_axis, s=5, depthshade=False, c=final_color)
ax.grid(False)

pyplot.show()

```