Computer Vision, Fall 2022

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Exercise 5, return latest on Sunday 16.10.2022 at 23.59 via Moodle

Return the answer in PDF and Jupyter Notebook formats.

Ex 5.1. Camera matrix (4 p)

Using the focal length, principal point and skew coefficient values given in this template, and equations given in Lecture 6, slide 49, form the camera matrix P and compute image coordinates (x,y) for an object point X (0, 0, 1, 1) when the origin of the world coordinate frame is

- exactly 3 meters away from the camera center, i.e. t = (0, 0, 3), and the camera is completely aligned with the world coordinate axis
- exactly 5 meters away from the camera center, i.e. t = (0, 0, 5), and the camera is completely aligned with the world coordinate axis
- t = (0.5, 1, 3) and the camera otherwise aligned with the world coordinate axis but it has only turned 20 degrees to the left
- t = (15, 1, 3) and the camera otherwise aligned with the world coordinate axis but it has only turned 20 degrees to the left

Discuss the phenomena behind the results.

In [6]:

```
import numpy as np
import cv2 as cv
np.set_printoptions(suppress=True)

# Focal length
fc = [719.302047058490760, 718.392548175289110]

# Principal point
cc = [334.631234942930060, 256.166677783686790]

# Skew coefficient
alpha_c = 0.000000000000000


# Your solution here
#P = K*[R|t]
#R = rotation matrix
#t = translation vector
#K = intrinsic: a_x is focal_x, B_x is principal_x,
#s is skew coefficient

def get_R_matrix(angle):
    cos_t = np.cos(np.radians(angle))
    sin_t = np.sin(np.radians(angle))
    R = [[cos_t, 0, sin_t],
        [0, 1, 0],
        [-sin_t, 0, cos_t]]
    return np.array(R)

def get_Rt_matrix(angle, trans):
    R = get_R_matrix(angle)
    t = np.array([trans])
    Rt = np.concatenate((R, t.T), axis=1)
    return Rt

def compute_image_coords(obj_p, K, angle, trans):
    Rt = get_Rt_matrix(angle, trans)
    P = K @ Rt
    x_p = P @ obj_p
    x_p = x_p / x_p[2]
    return P, x_p[:2]

K = np.array([[fc[0], alpha_c, cc[0]],
            [0, fc[1], cc[1]],
            [0, 0, 1]])

obj_p = np.array([0, 0, 1, 1])
```

In [7]:

```
#1. t = (0, 0, 3):
P, img_c = compute_image_coords(obj_p, K, 0, [0, 0, 3])
print("1. Exactly 3 meters away from the camera center, i.e. t = (0, 0, 3), and the cam
era is completely aligned with the world coordinate axis")
print(f"Camera matrix P:\n{P}\nImage coords: {img_c}\n")

#2. t = (0, 0, 5)
P, img_c = compute_image_coords(obj_p, K, 0, [0, 0, 5])
print("2. Exactly 5 meters away from the camera center, i.e. t = (0, 0, 5), and the cam
era is completely aligned with the world coordinate axis")
print(f"Camera matrix P:\n{P}\nImage coords: {img_c}\n")

#3. t = (0,5, 1, 3), 20 degrees left
P, img_c = compute_image_coords(obj_p, K, -20, [0.5, 1, 3])
print("3. t = (0.5, 1, 3) and the camera otherwise aligned with the world coordinate ax
is but it has only turned 20 degrees to the left")
print(f"Camera matrix P:\n{P}\nImage coords: {img_c}\n")

#4. t = (15, 1, 3), 20 degrees left
P, img_c = compute_image_coords(obj_p, K, -20, [15, 1, 3])
print("4. t = (15, 1, 3) and the camera otherwise aligned with the world coordinate axi
s but it has only turned 20 degrees to the left")
print(f"Camera matrix P:\n{P}\nImage coords: {img_c}\n")
```

```
1. Exactly 3 meters away from the camera center, i.e. t = (0, 0, 3), and t
he camera is completely aligned with the world coordinate axis
Camera matrix P:
[[ 719.30204706    0.          334.63123494 1003.89370483]
 [   0.          718.39254818  256.16667778  768.50003335]
 [   0.            0.            1.            3.        ]]
Image coords: [334.63123494 256.16667778]

2. Exactly 5 meters away from the camera center, i.e. t = (0, 0, 5), and t
he camera is completely aligned with the world coordinate axis
Camera matrix P:
[[ 719.30204706    0.          334.63123494 1673.15617471]
 [   0.          718.39254818  256.16667778 1280.83338892]
 [   0.            0.            1.            5.        ]]
Image coords: [334.63123494 256.16667778]

3. t = (0.5, 1, 3) and the camera otherwise aligned with the world coordin
ate axis but it has only turned 20 degrees to the left
Camera matrix P:
[[ 790.37344867    0.           68.43471293 1363.54472836]
 [  87.61416385  718.39254818  240.7179368  1486.89258153]
 [   0.34202014    0.            0.93969262    3.        ]]
Image coords: [363.47491521 438.51403767]

4. t = (15, 1, 3) and the camera otherwise aligned with the world coordina
te axis but it has only turned 20 degrees to the left
Camera matrix P:
[[  790.37344867     0.            68.43471293 11793.42441071]
 [   87.61416385   718.39254818   240.7179368   1486.89258153]
 [    0.34202014     0.             0.93969262     3.        ]]
Image coords: [3010.85903531  438.51403767]
```

Matrices 1 and 2 have no rotation applied to them, hence the first columns of both these matrices are filled with zeroes. Note also that 1 and 2 have the same image co-ordinates due to the fact that the camera is centered exactly about the object points with the difference being a further distance for matrix 2, hence as you can imagine moving the camera further backwards does not affect image co-ordinates because it is dead centered about the image. Matrix 3 has been affected by the 20 degree rotation to the left as seen in the first column, with reasonable image co-ordinates in the bounds of the frame. Matrix 4 is much similar to 3 except for the last element in the first row being overly large. This causes out of bounds image co-ordinates, caused by the translation of 15 in the x direction.

Ex 5.2 Fundamental matrix (4 p)

Compute the fundamental matrix F for the images image1.jpg and image2.jpg using the normalized 8-point algorithm. You may use ready made functions for detecting and matching the features, but develop the algorithm for deriving matrix F by yourself. Where are the epipoles for both images? Report both F and the two epipoles.

In [194]:

```
import numpy as np
import cv2 as cv
from matplotlib import pyplot as plt
from numpy import *
```

Normalisation function for the points expects them in homogenous form hence the first 3 lines

In [195]:

```
def normalize2dpts(pts):
    N = pts.shape[0]
    pts = c_[ pts, np.ones(N) ]
    pts = pts.T

    if pts.shape[0]!=3:
        raise ShapeError('pts must be 3xN')

    finiteind = abs(pts[2]) > finfo(float).eps
    pts[0,finiteind] = pts[0,finiteind]/pts[2,finiteind]
    pts[1,finiteind] = pts[1,finiteind]/pts[2,finiteind]
    pts[2,finiteind] = 1

    # Centroid of finite points
    c = [mean(pts[0,finiteind]), mean(pts[1,finiteind])]

    # Shift origin to centroid.
    newp0 = pts[0,finiteind]-c[0]
    newp1 = pts[1,finiteind]-c[1]

    meandist = mean(sqrt(newp0**2 + newp1**2));

    scale = sqrt(2)/meandist;
    '''
    T = [scale   0   -scale*c(1)
         0     scale -scale*c(2)
         0       0      1      ];
    '''
    T = eye(3)
    T[0][0] = scale
    T[1][1] = scale
    T[0][2] = -scale*c[0]
    T[1][2] = -scale*c[1]
    newpts = dot(T, pts)
    return newpts, T
```

Then defining a function to generate the constraint matrix and finally to perform the 8 points algorithm for finding the fundamental matrix

In [187]:

```
def constraint_matrix(x1,x2):
    npts = x1.shape[1]
    # stack column by column
    A = np.c_[x2[0]*x1[0], x2[0]*x1[1], x2[0], x2[1]*x1[0], x2[1]*x1[1], x2[1], x1[0],
x1[1], np.ones((npts,1))]
    return A
```

In [188]:

```
def F_8point(x1, x2):
    x1, T1 = normalize2dpts(x1);
    x2, T2 = normalize2dpts(x2);

    A = constraint_matrix(x1,x2)
    (U, S, V) = np.linalg.svd(A)
    V = V.conj().T;
    F = V[:,8].reshape(3,3).copy()

    # recall that F should be of rank 2, do the lower-rank approximation by svd
    (U,D,V) = np.linalg.svd(F);
    F = np.dot(np.dot(U,np.diag([D[0], D[1], 0])),V);

    F = dot(dot(T2.T,F),T1);
    return F
```

Reading in the images and detecting features

In [189]:

```
img1 = cv.imread("image 1.jpg", 0)
img2 = cv.imread("image 2.jpg", 0)

sift = cv.SIFT_create()
# find the keypoints and descriptors with SIFT
kp1, des1 = sift.detectAndCompute(img1,None)
kp2, des2 = sift.detectAndCompute(img2,None)
# FLANN parameters
FLANN_INDEX_KDTREE = 1
index_params = dict(algorithm = FLANN_INDEX_KDTREE, trees = 5)
search_params = dict(checks=50)
flann = cv.FlannBasedMatcher(index_params,search_params)
matches = flann.knnMatch(des1,des2,k=2)
pts1 = []
pts2 = []
# ratio test as per Lowe's paper
for i,(m,n) in enumerate(matches):
    if m.distance < 0.8*n.distance:
        pts2.append(kp2[m.trainIdx].pt)
        pts1.append(kp1[m.queryIdx].pt)
```

Comparing my fundamental matrix to CV2's

In [196]:

```
pts1 = np.int32(pts1)
pts2 = np.int32(pts2)
my_F = F_8point(pts1, pts2)
cv2_F, mask = cv.findFundamentalMat(pts1,pts2,cv.FM_8POINT)
print(f"My 8 point F matrix: {my_F}\nCv2 F Matrix {cv2_F}")
```

```
My 8 point F matrix: [[ 0.00000031 -0.00001     0.00168318]
 [ 0.00001202 -0.00000293  0.00342895]
 [-0.00211107 -0.00537262  0.34403385]]
Cv2 F Matrix [[ 0.00000089 -0.00002908  0.00489249]
 [ 0.00003494 -0.00000851  0.00996691]
 [-0.00613623 -0.01561655  1.        ]]
```

Finally displaying the epipolar lines

In [200]:

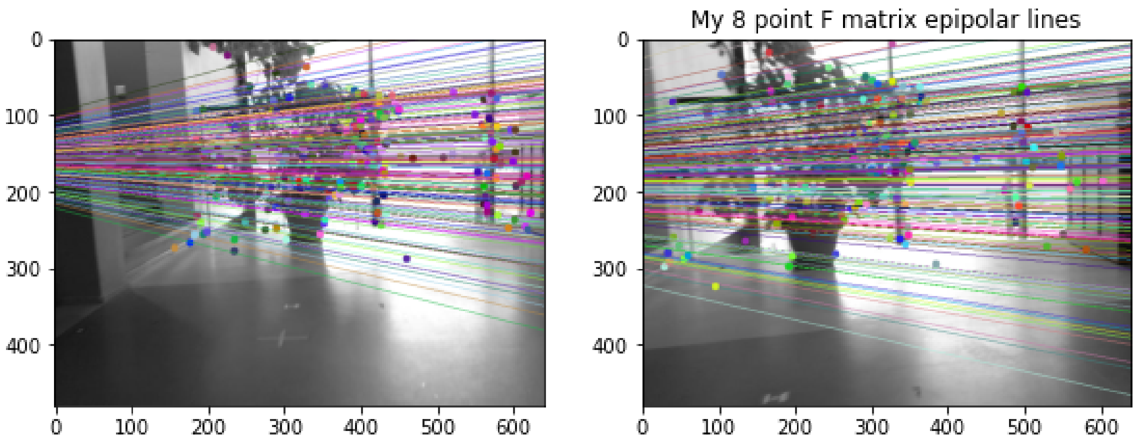
```
def drawlines(img1,img2,lines,pts1,pts2):
    ''' img1 - image on which we draw the epilines for the points in img2
        lines - corresponding epilines '''
    r,c = img1.shape
    img1 = cv.cvtColor(img1,cv.COLOR_GRAY2BGR)
    img2 = cv.cvtColor(img2,cv.COLOR_GRAY2BGR)
    for r,pt1,pt2 in zip(lines,pts1,pts2):
        color = tuple(np.random.randint(0,255,3).tolist())
        x0,y0 = map(int, [0, -r[2]/r[1] ])
        x1,y1 = map(int, [c, -(r[2]+r[0]*c)/r[1] ])
        img1 = cv.line(img1, (x0,y0), (x1,y1), color,1)
        img1 = cv.circle(img1,tuple(pt1),5,color,-1)
        img2 = cv.circle(img2,tuple(pt2),5,color,-1)
    return img1,img2
```

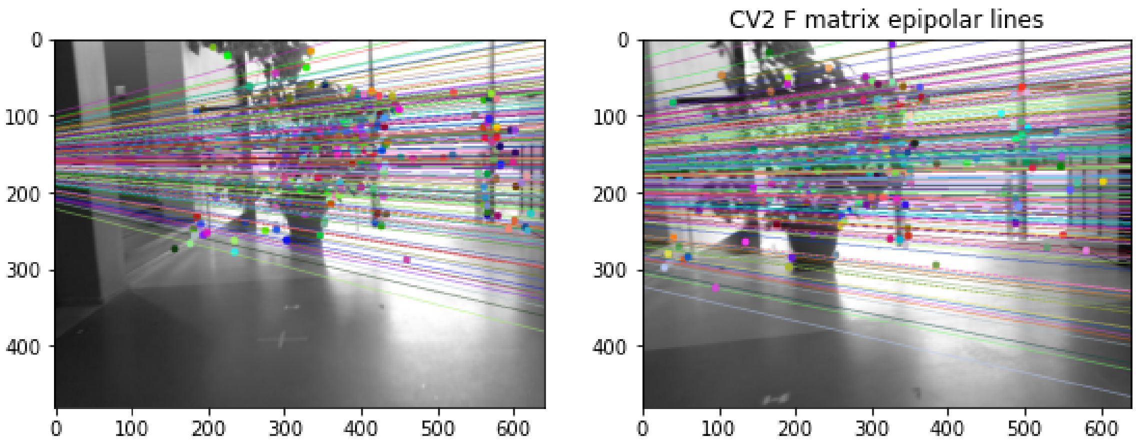
In [209]:

```
def display_epipolar_lines(F, title):
    lines1 = cv.computeCorrespondEpilines(pts2.reshape(-1,1,2), 2,F)
    #CHANGE THIS LINE TO ALTER THE NUMBER OF EPIPOLAR LINES DISPLAYED
    num_epipolar_lines = len(lines1)
    lines1 = lines1.reshape(-1,3)[:num_epipolar_lines]
    img5,img6 = drawlines(img1,img2,lines1,pts1,pts2)
    # Find epilines corresponding to points in left image (first image) and
    # drawing its lines on right image
    lines2 = cv.computeCorrespondEpilines(pts1.reshape(-1,1,2), 1,F)
    lines2 = lines2.reshape(-1,3)[:num_epipolar_lines]
    img3,img4 = drawlines(img2,img1,lines2,pts2,pts1)
    plt.figure(figsize=(10, 10))
    plt.subplot(121),plt.imshow(img5)
    plt.subplot(122),plt.imshow(img3)
    plt.title(title)
    plt.show()
```

In [210]:

```
display_epipolar_lines(my_F, "My 8 point F matrix epipolar lines")
display_epipolar_lines(cv2_F, "CV2 F matrix epipolar lines")
```





In [ ]:

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In [ ]:

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