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1 from google.colab import drive
2 drive.mount('/content/drive')
```

Go to this URL in a browser: https://accounts.google.com/o/oauth2/auth?client_id=947318989803-6bn6qk8qdgf4n4g3pfee6491hc0brc

Enter your authorization code:

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Mounted at /content/drive

```
1 !pip uninstall opencv-python
2 !pip uninstall opencv-contrib-python
3 !pip install opencv-python==3.4.2.16
4 !pip install opencv-contrib-python==3.4.2.16
```

Uninstalling opencv-python-3.4.7.28:

Would remove:

```
/usr/local/lib/python3.6/dist-packages/cv2/*
/usr/local/lib/python3.6/dist-packages/opencv_python-3.4.7.28.dist-info/*
```

Would not remove (might be manually added):

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/usr/local/lib/python3.6/dist-packages/cv2/.libs/libQtCore-9549151f.so.4.8.7
/usr/local/lib/python3.6/dist-packages/cv2/.libs/libQtGui-6d0f14dd.so.4.8.7
/usr/local/lib/python3.6/dist-packages/cv2/.libs/libavcodec-eac15e48.so.58.21.104
/usr/local/lib/python3.6/dist-packages/cv2/.libs/libavformat-b6bcbe33.so.58.17.101
/usr/local/lib/python3.6/dist-packages/cv2/.libs/libavutil-e1b1a17d.so.56.18.102
/usr/local/lib/python3.6/dist-packages/cv2/.libs/libswresample-b4363bfa.so.3.2.100
/usr/local/lib/python3.6/dist-packages/cv2/.libs/libswscale-15b3fdc6.so.5.2.100
/usr/local/lib/python3.6/dist-packages/cv2/.libs/libvpx-81a43c0a.so.5.0.0
```

Proceed (y/n)? y

Successfully uninstalled opencv-python-3.4.7.28

Uninstalling opencv-contrib-python-3.4.3.18:

Would remove:

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/usr/local/lib/python3.6/dist-packages/cv2/.libs/libQtCore-9549151f.so.4.8.7
/usr/local/lib/python3.6/dist-packages/cv2/.libs/libQtGui-6d0f14dd.so.4.8.7
/usr/local/lib/python3.6/dist-packages/cv2/.libs/libavcodec-eac15e48.so.58.21.104
/usr/local/lib/python3.6/dist-packages/cv2/.libs/libavformat-b6bcbe33.so.58.17.101
/usr/local/lib/python3.6/dist-packages/cv2/.libs/libavutil-e1b1a17d.so.56.18.102
/usr/local/lib/python3.6/dist-packages/cv2/.libs/libswresample-b4363bfa.so.3.2.100
/usr/local/lib/python3.6/dist-packages/cv2/.libs/libswscale-15b3fdc6.so.5.2.100
/usr/local/lib/python3.6/dist-packages/cv2/.libs/libvpx-81a43c0a.so.5.0.0
/usr/local/lib/python3.6/dist-packages/opencv_contrib_python-3.4.3.18.dist-info/*
```

Proceed (y/n)? y

Successfully uninstalled opencv-contrib-python-3.4.3.18

Collecting opencv-python==3.4.2.16

Downloading https://files.pythonhosted.org/packages/fa/7d/5042b668a8ed41d2a80b8c172f5efcd572e3c046c75ae029407e19b7fc68/opencv-python-3.4.2.16-cp36-cp37m-linux_x86_64.whl 25.0MB 40.3MB/s

Requirement already satisfied: numpy>=1.11.3 in /usr/local/lib/python3.6/dist-packages (from opencv-python==3.4.2.16) (1.17.0)

ERROR: albumations 0.1.12 has requirement imgaug<0.2.7,>=0.2.5, but you'll have imgaug 0.2.9 which is incompatible.

Installing collected packages: opencv-python

Successfully installed opencv-python-3.4.2.16

Collecting opencv-contrib-python==3.4.2.16

Downloading https://files.pythonhosted.org/packages/08/f1/66330f4042c4fb3b2d77a159db8e8916d9cdecc29bc8c1f56bc7f8a9bec9/opencv-contrib-python-3.4.2.16-cp36-cp37m-linux_x86_64.whl 30.6MB 38.5MB/s

Requirement already satisfied: numpy>=1.11.3 in /usr/local/lib/python3.6/dist-packages (from opencv-contrib-python==3.4.2.16)

Installing collected packages: opencv-contrib-python

Successfully installed opencv-contrib-python-3.4.2.16

Question 1

NC would perform better.

Reason: We first list the matching cost functions for both SSD and NC methods.

$$SSD(\text{patch}_l, \text{patch}_r) = \sum_x \sum_y (I_{\text{patch}_l}(x, y) - I_{\text{patch}_r}(x, y))^2 \quad NC(\text{patch}_l, \text{patch}_r) = \frac{\sum_x \sum_y (I_{\text{patch}_l}(x, y) \cdot I_{\text{patch}_r}(x, y))}{\|I_{\text{patch}_l}\| \cdot \|I_{\text{patch}_r}\|}$$

From cost functions we could observe that the cost function for SSD method depends on the difference among pixels in two images, resulting changes on exposure time might impact the disparity image. In contrast, the cost function for NC method has no dependence on the difference among pixels in two images, so an alteration in exposure time would not directly impact the disparity image. Hence, the NC method for cost function would perform better.

Question 2

(a)

```
1 import sys
2 import cv2 as cv
3 from matplotlib import pyplot as plt
4 import numpy as np
5 import time
6 import cmath
```

```

7 from matplotlib import pyplot as plt
8 from mpl_toolkits.mplot3d import Axes3D
9 import random

1 def loadRange(path):
2     with open(path,'r') as fp:
3         lines=fp.readline()
4         data_list=[i.strip() for i in lines.split(' ')]
5         return int(float(data_list[1])),int(float(data_list[3])),int(float(data_li

1 def loadParameters(path):
2     with open(path,'r') as fp:
3         lines=fp.readlines()
4         f=float([str.strip() for str in lines[0].split(' ')] [1])
5         px=float([str.strip() for str in lines[1].split(' ')] [1])
6         py=float([str.strip() for str in lines[2].split(' ')] [1])
7         baseline=float([str.strip() for str in lines[3].split(' ')] [1])
8     return f,px,py,baseline

1 def SSD(left_image,right_image,patch_size):
2     path_range='/content/drive/My Drive/Colab Notebooks/A4/000020.txt'
3     xmin,xmax,ymin,ymax=loadRange(path_range)
4     path_allcalib='/content/drive/My Drive/Colab Notebooks/A4/000020_allcalib.txt'
5     f,px,py,baseline=loadParameters(path_allcalib)
6     maxoffset=79
7     middlepatch=int((patch_size-1)/2)
8     ssd_right_patch_image=np.zeros((int(ymax)-int(ymin)+1,int(xmax)-int(xmin)+
9     ssd_depth_image=np.zeros((int(ymax)-int(ymin)+1,int(xmax)-int(xmin)+1),np.
10    for y in range(ymin,ymax):
11        for x in range(xmin,xmax):
12            min_SSD_cost=100000000
13            best_disparity=0
14            for offset in range(maxoffset):
15                ssd_temp=0
16                for u in range(-middlepatch,middlepatch):
17                    for v in range (-middlepatch,middlepatch):
18                        ssd_temp+=pow(int(left_image[y+v,x+u])-int(right_image[y+v
19                    if ssd_temp < min_SSD_cost:
20                        min_SSD_cost=ssd_temp
21                        best_disparity= offset
22            if best_disparity!=0:
23                depth=int((f*baseline)/best_disparity)
24                ssd_depth_image[y-ymin,x-xmin]=best_disparity
25                ssd_right_patch_image[y-ymin,x-xmin]=right_image[y,x-best_dispar
26    cv.imwrite('/content/drive/My Drive/Colab Notebooks/A4/SSD_rightPatchImage.png
27    cv.imwrite('/content/drive/My Drive/Colab Notebooks/A4/SSD_depthImage.png', ss
28    return ssd_depth_image,ssd_right_patch_image
29

30 def NC(left_image,right_image,patch_size):
31     path_range='/content/drive/My Drive/Colab Notebooks/A4/000020.txt'
32     xmin,xmax,ymin,ymax=loadRange(path_range)
33     path_calib='/content/drive/My Drive/Colab Notebooks/A4/000020_allcalib.txt'
34     f,px,py,baseline=loadParameters(path_calib)
35     max_disparity=79
36     middle_patch=int((patch_size-1)/2)
37     nc_right_patch_image=np.zeros((int(ymax)-int(ymin)+1,int(xmax)-int(xmin)+1
38     nc_depth_image=np.zeros((int(ymax)-int(ymin)+1,int(xmax)-int(xmin)+1),np.u
39     for y in range(ymin,ymax):
40         for x in range(xmin,xmax):
41             maxNC=0
42             best_disparity=0
43             for offset in range(max_disparity):
44                 nc_temp=0
45                 norm1=0
46                 norm2=0
47                 for u in range(-middle_patch,middle_patch):
48                     for v in range (-middle_patch,middle_patch):
49                         nc_temp+=int(left_image[y+v,x+u])*int(right_image[y+v,x+u-
50                         norm1+=int(left_image[y+v,x+u])*int(left_image[y+v,x+u])
51                         norm2+=int(right_image[y+v,x+u-offset])*int(right_image[y+
52                 nc_temp=nc_temp/((norm1**0.5)*(norm2**0.5))
53                 if nc_temp>maxNC:
54                     maxNC=nc_temp
55                     best_disparity= offset
56             if best_disparity!=0:
57                 depth=int((f*baseline)/best_disparity)
58                 nc_depth_image[y-ymin,x-xmin]=best_disparity
59                 nc_right_patch_image[y-ymin,x-xmin]=right_image[y,x-best_dispari
60    cv.imwrite('/content/drive/My Drive/Colab Notebooks/A4/NC_rightPatchImage.png'
61    cv.imwrite('/content/drive/My Drive/Colab Notebooks/A4/NC_depthImage.png',nc_d
62    return nc_depth_image, nc_right_patch_image
63

64 if __name__ == "__main__":
65     left_image = cv.imread('/content/drive/My Drive/Colab Notebooks/A4/000020_left
66     right_image = cv.imread('/content/drive/My Drive/Colab Notebooks/A4/000020_rig

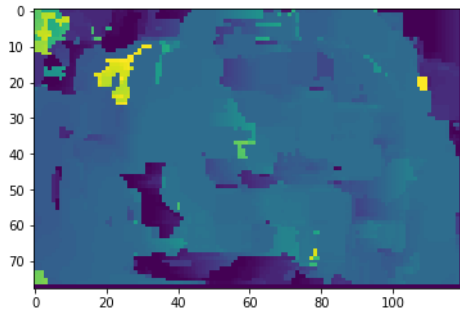
```

```

67  ssd_depth_image, ssd_right_patch_image = SSD(left_image, right_image, 9)
68  nc_depth_image, nc_right_patch_image = NC(left_image, right_image, 9)
69  print("BELOW IS THE SSD DEPTH IMAGE")
70  plt.imshow(ssd_depth_image)
71  plt.show()
72  print("=====")
73  print("BELOW IS THE SSD RIGHT PATCH IMAGE")
74  plt.imshow(ssd_right_patch_image)
75  plt.show()
76  print("=====")
77  print("BELOW IS THE NC DEPTH IMAGE")
78  plt.imshow(nc_depth_image)
79  plt.show()
80  print("=====")
81  print("BELOW IS THE NC RIGHT PATCH IMAGE")
82  plt.imshow(nc_right_patch_image)
83  plt.show()

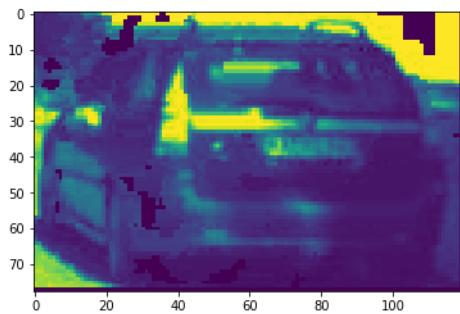
```

BELOW IS THE SSD DEPTH IMAGE



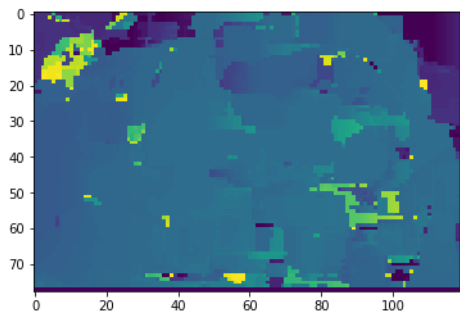
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BELOW IS THE SSD RIGHT PATCH IMAGE



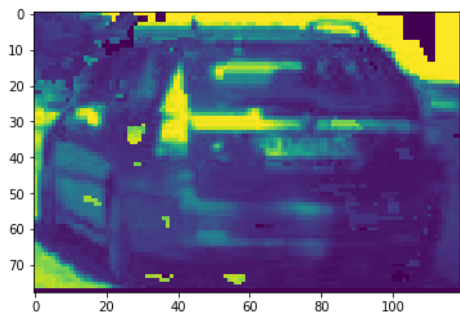
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BELOW IS THE NC DEPTH IMAGE



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BELOW IS THE NC RIGHT PATCH IMAGE



patch size: 9

sampling method: For every pixel in the bounding box, loop through all pixels within its corresponding patch and determine the minimum matching cost and best disparity for such pixel.

matching cost function: $SSD(\text{patch}_l, \text{patch}_r) = \sum_x \sum_y (I_{\text{patch}_l}(x, y) - I_{\text{patch}_r}(x, y))^2$

$$NC(\text{patch}_l, \text{patch}_r) = \frac{\sum_x \sum_y (I_{\text{patch}_l}(x,y) \cdot I_{\text{patch}_r}(x,y))}{\|I_{\text{patch}_l}\| \cdot \|I_{\text{patch}_r}\|}$$

From the graph above we could state that there are some outlier points.

▼ (b)

```
1 %cd '/content/drive/My Drive/Colab Notebooks/A4/PSMNet'
```

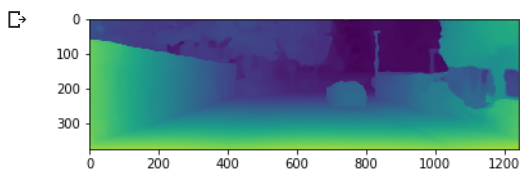
```
↳ /content/drive/My Drive/Colab Notebooks/A4/PSMNet
```

```
1 !ls
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```
↳ dataloader  finetune.py  main.py  README.md  submission.py  utils
   dataset    LICENSE    models  run.sh    Test_img.py
```

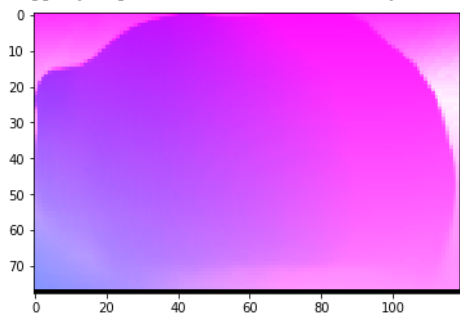
```
1 !python Test_img.py --loadmodel pretrained_model_KITTI2012.tar --leftimg ../000020
```

```
1 disparity_image = cv.imread("/content/drive/My Drive/Colab Notebooks/A4/PSMNet/dis
2 plt.imshow(disparity_image)
3 plt.show()
```



```
1 def loadDisparityImageFromModel(path):
2     path_range='/content/drive/My Drive/Colab Notebooks/A4/000020.txt'
3     xmin,xmax,ymin,ymax=loadRange(path_range)
4     path_allcalib='/content/drive/My Drive/Colab Notebooks/A4/000020_allcalib.txt'
5     f,px,py,baseline=loadParameters(path_allcalib)
6     model_disparity_image=cv.imread(path,0)
7     model_depth_image=np.zeros([int(ymax)-int(ymin)+1,int(xmax)-int(xmin)+1,3])
8     for row in range(ymin,ymax):
9         for col in range(xmin,xmax):
10             depth=(f*baseline)/model_disparity_image[row,col]
11             model_depth_image[row-ymin,col-xmin,2]=depth
12             model_depth_image[row-ymin,col-xmin,0]=(col-px)*depth/f
13             model_depth_image[row-ymin,col-xmin,1]=(row-py)*depth/f
14     return model_depth_image
15
16 if __name__=="__main__":
17     model_depth_image = loadDisparityImageFromModel('/content/drive/My Drive/Colab
18     plt.imshow(model_depth_image)
19     plt.show()
20     cv.imwrite('/content/drive/My Drive/Colab Notebooks/A4/model_depth_image.png',
```

```
↳ Clipping input data to the valid range for imshow with RGB data ([0..1] for floats or [0..255] for integers).
```



I choose PSMNet. Using pretrained model could increase the result of the disparity image both in terms of image quality and running speed. The resulting disparity image I got has many outliers and could hardly distinguish the shape of a car, but the disparity image calculated by PSMNet looks super clean and smooth and has barely any outliers, and we could easily tell the shape of a car from it. The running time for my algorithm to execute with patch size as 9 is roughly around 1.5 minutes, but the running time for the pretrained PSMNet model takes only few seconds, so the running speed for using pretrained PSMNet is way faster.

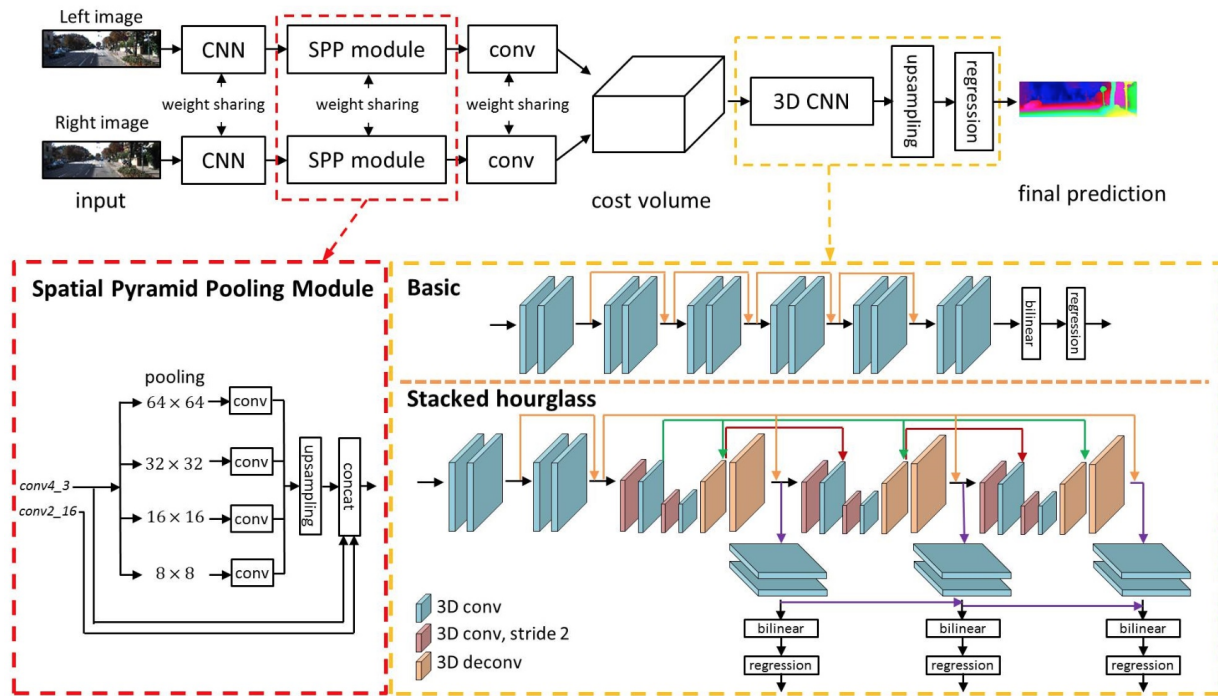
▼ (c)

The model I choose is PSMNet.

Github link: <https://github.com/JiaRenChang/PSMNet/blob/master/README.md>

Paper link: http://openaccess.thecvf.com/content_cvpr_2018/papers/Chang_Pyramid_Stereo_Matching_CVPR_2018_paper.pdf

Structure:



From the structure we know the input images are the left and right stereo images, and the PSMNet use two weight sharing pipelines to handle these two input images. Each pipeline consists of a CNN feature map calculation, a SPP module for feature collection, and a convolutional layer for feature fusion. Then the PSMNet form a 4D cost volume, and a 3D CNN cost volume for regularization and disparity regression, then we could get the resulting image.

▼ (d)

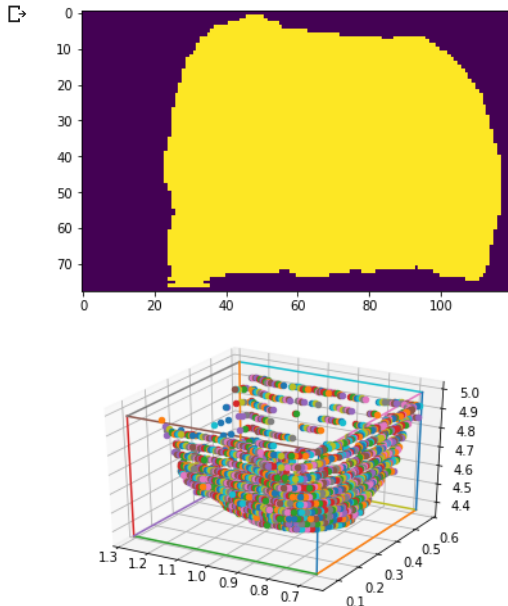
```
1 def checkBorders(x,y,image,path_size):
2     if x==0 and y==0:
3         return x,y,x+1+(path_size-1)/2,y+1+(path_size-1)/2
4     elif x==0 and y==(image.shape)[0]-1:
5         return x,y-(path_size-1)/2,y
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```

3 ax=fig.gca(projection='3d')
4 ax.xaxis.set_ticks_position('top')
5 ax.invert_xaxis()
6 for y in range(model_depth_image.shape[0]):
7     for x in range(model_depth_image.shape[1]):
8         if model_depth_image[y,x,0]>min_3D_location[0] and model_depth_image[y
9             ax.scatter3D(model_depth_image[y,x,0],model_depth_image[y,x,1],mod
10 ax.plot([min_3D_location[0],min_3D_location[0]],[min_3D_location[1],min_3D_loc
11 ax.plot([min_3D_location[0],min_3D_location[0]],[min_3D_location[1],max_3D_loc
12 ax.plot([min_3D_location[0],max_3D_location[0]],[min_3D_location[1],min_3D_loc
13 ax.plot([max_3D_location[0],max_3D_location[0]],[min_3D_location[1],min_3D_loc
14 ax.plot([max_3D_location[0],max_3D_location[0]],[min_3D_location[1],max_3D_loc
15 ax.plot([min_3D_location[0],max_3D_location[0]],[min_3D_location[1],min_3D_loc
16 ax.plot([min_3D_location[0],min_3D_location[0]],[min_3D_location[1],max_3D_loc
17 ax.plot([max_3D_location[0],max_3D_location[0]],[min_3D_location[1],max_3D_loc
18 ax.plot([min_3D_location[0],max_3D_location[0]],[max_3D_location[1],max_3D_loc
19 ax.plot([min_3D_location[0],max_3D_location[0]],[max_3D_location[1],max_3D_loc
20 ax.plot([min_3D_location[0],min_3D_location[0]],[max_3D_location[1],max_3D_loc
21 ax.plot([max_3D_location[0],max_3D_location[0]],[max_3D_location[1],max_3D_loc
22
23 plt.savefig('/content/drive/My Drive/Colab Notebooks/A4/3dBox.png', dpi=fig.dp
24 plt.show()

1 if __name__ == "__main__":
2     model_depth_image = loadDisparityImageFromModel('/content/drive/My Drive/Colab
3     is_car_part_image,min_3d_location,max_3d_location = get2dBox(model_depth_image
4     plt.imshow(is_car_part_image)
5     plt.show()
6     cv.imwrite('/content/drive/My Drive/Colab Notebooks/A4/2dBox.png', model_depth
7     get3dBox(model_depth_image,min_3d_location,max_3d_location)

```



The classification threshold for distance I choose is 0.6.

Question 3

(a)

```

1 img1 = cv.imread('/content/drive/My Drive/Colab Notebooks/A4/I1_original.jpg', cv.
2 img1 = cv.resize(img1, (int(img1.shape[0]* 0.3), int(img1.shape[0]* 0.3)))
3 cv.imwrite('/content/drive/My Drive/Colab Notebooks/A4/I1.jpg', img1)
4
5 img2 = cv.imread('/content/drive/My Drive/Colab Notebooks/A4/I2_original.jpg', cv.
6 img2 = cv.resize(img2, (int(img2.shape[0]* 0.3), int(img2.shape[0]* 0.3)))
7 cv.imwrite('/content/drive/My Drive/Colab Notebooks/A4/I2.jpg', img2)
8
9 img3 = cv.imread('/content/drive/My Drive/Colab Notebooks/A4/I3_original.jpg', cv.
10 img3 = cv.resize(img3, (int(img3.shape[0]* 0.3), int(img3.shape[0]* 0.3)))
11 cv.imwrite('/content/drive/My Drive/Colab Notebooks/A4/I3.jpg', img3)

1 def mySIFT(img1_path, img2_path):
2     img1 = cv.imread(img1_path, cv.IMREAD_GRAYSCALE)
3     img2 = cv.imread(img2_path, cv.IMREAD_GRAYSCALE)
4
5     sift = cv.xfeatures2d.SIFT_create()

```

```

5     cv.imshow(img3, img3)
6
7     kp1, des1 = sift.detectAndCompute(img1, None)
8     kp2, des2 = sift.detectAndCompute(img2, None)
9
10    bf = cv.BFMatcher()
11    matches = bf.knnMatch(des1, des2, k=2)
12    goodMatches = []
13    for m, n in matches:
14        if m.distance < 0.6*n.distance:
15            goodMatches.append([m])
16
17    all_pairs = cv.drawMatchesKnn(img1, kp1, img2,
18                                kp2, goodMatches, None, flags=2)
19    plt.imshow(all_pairs)
20    plt.show()
21
22    if (img2_path == '/content/drive/My Drive/Colab Notebooks/A4/I2.jpg'):
23        cv.imwrite('/content/drive/My Drive/Colab Notebooks/A4/I1_I2_all_pairs.png')
24    else:
25        cv.imwrite('/content/drive/My Drive/Colab Notebooks/A4/I1_I3_all_pairs.png')
26
27    new_matches, pts1, pts2 = pick8Points(img1.shape[1], img1.shape[0], goodMatches)
28
29    img3 = np.concatenate((img1, img2), axis=1)
30    img3 = cv.cvtColor(img3, cv.COLOR_GRAY2RGB)
31
32    for i in range(len(pts1)):
33        l_pt = pts1[i]
34        r_pt = pts2[i]
35        r, g, b = random.randint(100, 255), random.randint(100, 255), random.randint(100, 255)
36        cv.circle(img3, (int(l_pt[0]), int(l_pt[1])), 10, (r + 30, g + 30, b + 30))
37        cv.circle(img3, (int(r_pt[0] + img1.shape[0]), int(r_pt[1])), 10, (r + 30, g + 30, b + 30))
38        cv.line(img3, (int(l_pt[0]), int(l_pt[1])), (int(r_pt[0] + img1.shape[0]), int(r_pt[1])), 2, (r, g, b))
39
40    plt.imshow(img3)
41    plt.show()
42
43    if (img2_path == '/content/drive/My Drive/Colab Notebooks/A4/I2.jpg'):
44        cv.imwrite('/content/drive/My Drive/Colab Notebooks/A4/I1_I2_8_pairs.png')
45    else:
46        cv.imwrite('/content/drive/My Drive/Colab Notebooks/A4/I1_I3_8_pairs.png')
47
48
49    return pts1, pts2
50
51

```

```

1 def pick8Points(img_width, img_height, matches, kp1, kp2):
2     pts1 = [(-1, -1) for i in range(8)]
3     pts2 = [(-1, -1) for i in range(8)]
4     dis = [10000 for i in range(8)]
5     new_matches = [matches[0] for i in range(8)]
6
7     backup1 = []
8     backup2 = []
9     backupm = []
10
11    col_span = img_width // 3
12    row_span = img_height // 3
13    for m in matches:
14        pt1 = kp1[m[0].queryIdx].pt
15        pt2 = kp2[m[0].trainIdx].pt
16
17        i = -1
18        if pt1[0] < col_span and pt1[1] < row_span and m[0].distance < dis[0]:
19            i = 0
20        elif pt1[0] >= col_span and pt1[0] < 2 * col_span and pt1[1] < row_span and m[0].distance < dis[1]:
21            i = 1
22        elif pt1[0] >= 2 * col_span and pt1[1] < row_span and m[0].distance < dis[2]:
23            i = 2
24        elif pt1[0] < col_span and pt1[1] < 2 * row_span and pt1[1] >= row_span and m[0].distance < dis[3]:
25            i = 3
26        elif pt1[0] >= 2 * col_span and pt1[1] < 2 * row_span and pt1[1] >= row_span and m[0].distance < dis[4]:
27            i = 4
28        elif pt1[0] < col_span and pt1[1] >= 2 * row_span and m[0].distance < dis[5]:
29            i = 5
30        elif pt1[0] >= col_span and pt1[0] < 2 * col_span and pt1[1] >= 2 * row_span and m[0].distance < dis[6]:
31            i = 6
32        elif pt1[0] >= 2 * col_span and pt1[1] >= 2 * row_span and m[0].distance < dis[7]:
33            i = 7
34
35    if i > -1:
36        if pts1[i] != (-1, -1):
37            backup1.append(pts1[i])
38            backup2.append(pts2[i])
39            backupm.append(matches[i])
40
41    pts1[i] = (-1, -1)
42    pts2[i] = (-1, -1)
43    new_matches[i] = matches[i]
44
45    return pts1, pts2, new_matches

```

```

39         backupm.append(new_matches[i])
40         pts1[i] = pt1
41         pts2[i] = pt2
42         new_matches[i] = m
43     else:
44         backup1.append(pt1)
45         backup2.append(pt2)
46         backupm.append(m)
47
48     bounder = (col_span * col_span + row_span * row_span) / 4
49     j = 0
50     for i in range(8):
51         if pts1[i] == (-1, -1) and len(backup1) > j:
52             flag = True
53             for l in range(j, len(backup1)):
54                 flag = True
55                 for k in range(8):
56                     dist = (backup1[l][0] - pts1[k][0]) * (backup1[l][0] - pts1[k]
57                     if i != k and dist < bounder:
58                         flag = False
59                         break
60             if flag:
61                 j = l
62                 break
63
64         if flag:
65             pts1[i] = backup1[j]
66             pts2[i] = backup2[j]
67             new_matches[i] = backupm[j]
68             j += 1
69
70     j = 0
71     for i in range(8):
72         if (pts1[i] == (-1, -1)):
73             flag = True
74             for l in range(j, len(backup1)):
75                 flag = True
76                 for k in range(8):
77                     if i != k and (pts1[k] == backup1[l]):
78                         flag = False
79                         break
80             if flag:
81                 j = l
82                 break
83         if flag:
84             pts1[i] = backup1[j]
85             pts2[i] = backup2[j]
86             new_matches[i] = backupm[j]
87             j += 1
88
89     return new_matches, np.array(pts1), np.array(pts2)

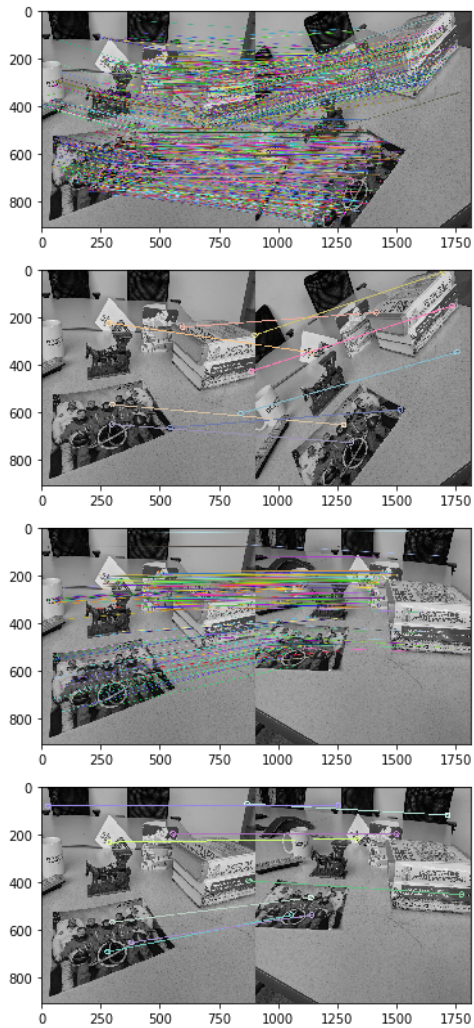
```

```

1 pts1, pts2 = mySIFT('/content/drive/My Drive/Colab Notebooks/A4/I1.jpg', '/content
2 pts3, pts4 = mySIFT('/content/drive/My Drive/Colab Notebooks/A4/I1.jpg', '/content

```





▼ (b)

```

1 def calFundamental(pts1, pts2):
2     A = np.zeros(shape=(len(pts1), 9))
3     for i in range(len(pts1)):
4         x_l, y_l = pts1[i][0], pts1[i][1]
5         x_r, y_r = pts2[i][0], pts2[i][1]
6         A[i][0] = x_l * x_r
7         A[i][1] = x_r * y_l
8         A[i][2] = x_r
9         A[i][3] = y_r * x_l
10        A[i][4] = y_r * y_l
11        A[i][5] = y_r
12        A[i][6] = x_l
13        A[i][7] = y_l
14        A[i][8] = 1
15    u, s, vh = np.linalg.svd(A)
16    f = vh[-1].reshape(3, 3)
17    u, s, vh = np.linalg.svd(f)
18    s[-1] = 0
19    s = np.diag(s)
20    f = np.dot(np.dot(u, s), vh)
21    return f

1 F_12 = calFundamental(pts1, pts2)
2 F_13 = calFundamental(pts3, pts4)
3 print("F12: \n", F_12)
4 print("F13: \n", F_13)

F12:
[[ 1.91616168e-06 -2.89116255e-06  3.18358143e-03]
 [ 2.90072679e-06  1.10083829e-06 -2.26825705e-03]
 [-4.80837972e-03  3.08203777e-04  9.99980752e-01]]
F13:
[[ 1.61805847e-06  2.55363434e-05 -2.50181584e-03]
 [-2.14897962e-05  1.85874050e-05 -7.58600594e-03]
 [ 1.72634938e-03 -4.91644465e-03  9.99954519e-01]]

```

▼ (c)

```

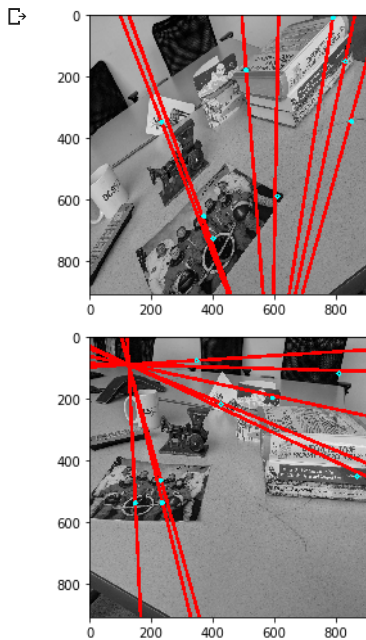
1 def plotEpipolarLines(img_path, F, pts1, pts2):
2     img_gray = cv.imread(img_path, cv.IMREAD_GRAYSCALE)
3     img = cv.cvtColor(img_gray, cv.COLOR_GRAY2RGB)
4     lines1 = cv.computeCorrespondEpilines(pts1, 1, F)
5
6     for line in lines1:
7         cv.line(img,
8                 (0, int(-line[0, 2]/line[0, 1])),
9                 (img_gray.shape[1], -int((line[0, 2] + line[0, 0] * img_gray.shape[1]))
10                (255, 0, 0), thickness = 10)
11
12     for pt in pts2:
13         cv.circle(img, (int(pt[0]), int(pt[1])), 5, (0, 255, 255), thickness=5)
14
15     plt.imshow(img)
16     plt.show()
17     if (img_path == '/content/drive/My Drive/Colab Notebooks/A4/I2.jpg'):
18         cv.imwrite('/content/drive/My Drive/Colab Notebooks/A4/I2-epipolar_lines.p
19         cv.imwrite('/content/drive/My Drive/Colab Notebooks/A4/I3-epipolar_lines.png',

```

```

1 lotEpipolarLines('/content/drive/My Drive/Colab Notebooks/A4/I2.jpg', F_12, pts1,
2 lotEpipolarLines('/content/drive/My Drive/Colab Notebooks/A4/I3.jpg', F_13, pts3,

```



▼ (d)

```

1 def rectifyAndPlot(img1_path, img2_path, F, pts1, pts2, openCV_F=False):
2     img1_gray = cv.imread(img1_path, cv.IMREAD_GRAYSCALE)
3     img2_gray = cv.imread(img2_path, cv.IMREAD_GRAYSCALE)
4
5     ret_bool, rectmat1, rectmat2 = cv.stereoRectifyUncalibrated(pts1, pts2, F, (im
6     print(rectmat1)
7     rectmat1_inv = np.linalg.inv(rectmat1)
8     rectmat2 = rectmat1_inv.dot(rectmat2)
9     dst2 = cv.warpPerspective(img2_gray, rectmat2, (img1_gray.shape[1], img1_gray.
10    out = np.concatenate([img1_gray, dst2], axis=1)
11    plt.imshow(out)
12    plt.show()
13    if (img2_path == '/content/drive/My Drive/Colab Notebooks/A4/I2.jpg'):
14        if (openCV_F == True):
15            cv.imwrite('/content/drive/My Drive/Colab Notebooks/A4/I1-I2-openCV-re
16        else:
17            cv.imwrite('/content/drive/My Drive/Colab Notebooks/A4/I1-I2-rectify.p
18    else:
19        if (openCV_F == True):
20            cv.imwrite('/content/drive/My Drive/Colab Notebooks/A4/I1-I3-openCV-re
21        else:
22            cv.imwrite('/content/drive/My Drive/Colab Notebooks/A4/I1-I3-rectify.p

```

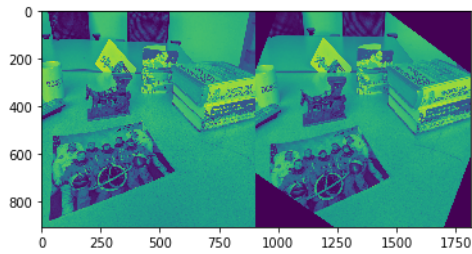
```

1 rectifyAndPlot('/content/drive/My Drive/Colab Notebooks/A4/I1.jpg', '/content/driv
2 rectifyAndPlot('/content/drive/My Drive/Colab Notebooks/A4/I1.jpg', '/content/driv

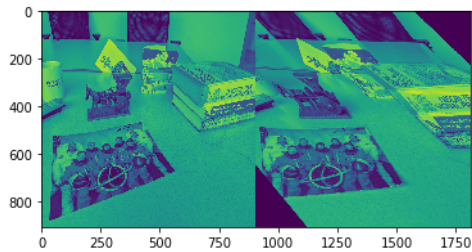
```



```
[[ 1.03142301e-03 -1.82574642e-03 -1.72634294e+00]
 [ 3.35398455e-03  3.18772983e-03 -5.10043180e+00]
 [-2.39578401e-06  5.13826460e-06 -5.95168059e-03]]
```



```
[[ 4.86036467e-03  1.38772484e-03 -1.30469529e+00]
 [-7.34003596e-05  5.75986504e-03 -6.75786227e-01]
 [ 4.95067411e-06  2.09440131e-06  1.02015166e-03]]
```



▼ (e)

```
1 openCV_F12 = cv.findFundamentalMat(pts1, pts2, cv.FM_8POINT)
2 print("OPEN CV F_12: \n", openCV_F12[0])
3 print("MY CALCULATED F_12: \n", F_12)
4 print("=====")
5 openCV_F13 = cv.findFundamentalMat(pts3, pts4, cv.FM_8POINT)
6 print("OPEN CV F_13: \n", openCV_F13[0])
7 print("MY CALCULATED F_13: \n", F_13)
```

```
OPEN CV F_12:
[[ 1.90587129e-06 -2.89110790e-06  3.17155415e-03]
 [ 2.86370616e-06  1.12828749e-06 -2.27099964e-03]
 [-4.78379273e-03  2.87896549e-04  1.00000000e+00]]
MY CALCULATED F_12:
[[ 1.91616168e-06 -2.89116255e-06  3.18358143e-03]
 [ 2.90072679e-06  1.10083829e-06 -2.26825705e-03]
 [-4.80837972e-03  3.08203777e-04  9.99980752e-01]]
=====
OPEN CV F_13:
[[ 1.95670625e-06  2.49076773e-05 -2.47726386e-03]
 [-2.08148786e-05  1.81326008e-05 -7.45669999e-03]
 [ 1.66376147e-03 -4.83196726e-03  1.00000000e+00]]
MY CALCULATED F_13:
[[ 1.61805847e-06  2.55363434e-05 -2.50181584e-03]
 [-2.14897962e-05  1.85874050e-05 -7.58600594e-03]
 [ 1.72634938e-03 -4.91644465e-03  9.99954519e-01]]
```

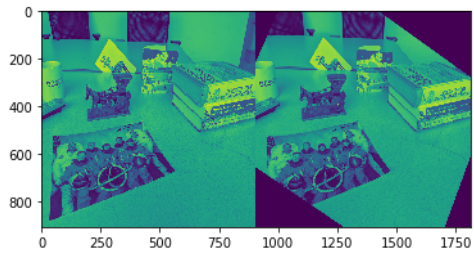
The fundamental matrix I got is quite similar to the fundamental matrix calculated by OpenCV. There might still exist some number differences for some entries, but the scales for all entries are the same, so the fundamental matrix I calculated is acceptable.

▼ (e)

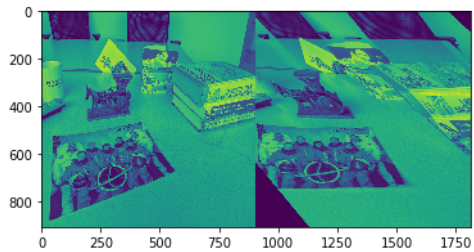
```
1 rectifyAndPlot('/content/drive/My Drive/Colab Notebooks/A4/I1.jpg', '/content/drive/My Drive/Colab Notebooks/A4/I2.jpg')
2 rectifyAndPlot('/content/drive/My Drive/Colab Notebooks/A4/I1.jpg', '/content/drive/My Drive/Colab Notebooks/A4/I2.jpg')
```

✖

```
[ [ 1.14342925e-03 -2.11303518e-03 -1.70434693e+00 ]
[ 3.36241906e-03 3.20109352e-03 -5.07909219e+00 ]
[-2.34471875e-06 5.14260218e-06 -5.94086948e-03 ]]
```



```
[ [ 4.52792851e-03 1.62200552e-03 -1.31936571e+00 ]
[ 3.01505395e-05 5.65388670e-03 -6.67565134e-01 ]
[ 4.95112096e-06 2.03780209e-06 1.01521181e-03 ]]
```



Compare with the rectification effects got by myself, the rectification effects calculated by OpenCV might has some minor improvements, but since the fundamental matrix I got are pretty similar to the fundamental matrix calculated by OpenCV, the resulting images for rectification are pretty much the same.