```
import numpy as np
import cv2
import scipy.io
import os
from numpy.linalg import norm
from matplotlib import pyplot as plt
from numpy.linalg import det
from numpy.linalg import inv
from scipy.linalg import rq
from numpy.linalg import svd
import matplotlib.pyplot as plt
import numpy as np
import math
import random
import sys
from scipy import ndimage, spatial
from tqdm.notebook import tqdm, trange

import torch
import torch.nn as nn
import torch.optim as optim
from torch.optim import lr_scheduler
from torch.autograd import Variable
import torchvision
from torchvision import datasets, models, transforms
from torch.utils.data import Dataset, DataLoader, ConcatDataset
from skimage import io, transform,data
from torchvision import transforms, utils
import numpy as np
import math
import glob
import matplotlib.pyplot as plt
import time
import os
import copy
import sklearn.svm
import cv2
from matplotlib import pyplot as plt
import numpy as np
from os.path import exists
import pandas as pd
import PIL
import random
from google.colab import drive
from sklearn.metrics.cluster import completeness_score
from sklearn.cluster import KMeans
from tqdm import tqdm, tqdm_notebook
from functools import partial
from torchsummary import summary
from torchvision.datasets import ImageFolder
from torch.utils.data.sampler import SubsetRandomSampler

#cuda_output = !ldconfig -p|grep cudart.so|sed -e 's/.*\.\([0-9]*\)\.\([0-9]*\)$/cu\1\2/'
#accelerator = cuda_output[0] if exists('/dev/nvidia0') else 'cpu'

#print("Accelerator type = ",accelerator)
#print("Pytorch verision: ", torch.__version__)
```

```
from google.colab import drive

# This will prompt for authorization.
drive.mount('/content/drive')
```

```
     Drive already mounted at /content/drive; to attempt to forcibly remount, call drive.mount("/content/drive", force_remount=True).
```

```
#!pip install ipython-autotime

#%load_ext autotime
```

```
!pip install opencv-python==3.4.2.17
!pip install opencv-contrib-python==3.4.2.17
```

```
     Requirement already satisfied: opencv-python==3.4.2.17 in /usr/local/lib/python3.7/dist-packages (3.4.2.17)
     Requirement already satisfied: numpy>=1.14.5 in /usr/local/lib/python3.7/dist-packages (from opencv-python==3.4.2.17) (1.19.5)
     Requirement already satisfied: opencv-contrib-python==3.4.2.17 in /usr/local/lib/python3.7/dist-packages (3.4.2.17)
     Requirement already satisfied: numpy>=1.14.5 in /usr/local/lib/python3.7/dist-packages (from opencv-contrib-python==3.4.2.17) (1.19.5)
```

```
#!pip install opencv-python==4.4.0.44
#!pip install opencv-contrib-python==4.4.0.44
```

```


class Image:
    def __init__(self, img, position):

        self.img = img
        self.position = position

inlier_matchset = []
def features_matching(a,keypointlength,threshold):
  #threshold=0.2
  bestmatch=np.empty((keypointlength),dtype= np.int16)
  img1index=np.empty((keypointlength),dtype=np.int16)
  distance=np.empty((keypointlength))
  index=0
  for j in range(0,keypointlength):
    #For a descriptor fa in Ia, take the two closest descriptors fb1 and fb2 in Ib
    x=a[j]
    listx=x.tolist()
    x.sort()
    minval1=x[0]                                # min
    minval2=x[1]                                # 2nd min
    itemindex1 = listx.index(minval1)           #index of min val
    itemindex2 = listx.index(minval2)           #index of second min value
    ratio=minval1/minval2                       #Ratio Test

    if ratio<threshold:
      #Low distance ratio: fb1 can be a good match
      bestmatch[index]=itemindex1
      distance[index]=minval1
      img1index[index]=j
      index=index+1
  return  [cv2.DMatch(img1index[i],bestmatch[i].astype(int),distance[i]) for i in range(0,index)]



def compute_Homography(im1_pts,im2_pts):
  """
  im1_pts and im2_pts are 2×n matrices with
  4 point correspondences from the two images
  """
  num_matches=len(im1_pts)
  num_rows = 2 * num_matches
  num_cols = 9
  A_matrix_shape = (num_rows,num_cols)
  A = np.zeros(A_matrix_shape)
  a_index = 0
  for i in range(0,num_matches):
    (a_x, a_y) = im1_pts[i]
    (b_x, b_y) = im2_pts[i]
    row1 = [a_x, a_y, 1, 0, 0, 0, -b_x*a_x, -b_x*a_y, -b_x] # First row
    row2 = [0, 0, 0, a_x, a_y, 1, -b_y*a_x, -b_y*a_y, -b_y] # Second row

    # place the rows in the matrix
    A[a_index] = row1
    A[a_index+1] = row2

    a_index += 2

  U, s, Vt = np.linalg.svd(A)

  #s is a 1-D array of singular values sorted in descending order
  #U, Vt are unitary matrices
  #Rows of Vt are the eigenvectors of A^TA.
  #Columns of U are the eigenvectors of AA^T.
  H = np.eye(3)
  H = Vt[-1].reshape(3,3) # take the last row of the Vt matrix
  return H


def displayplot(img,title):

  plt.figure(figsize=(15,15))
  plt.title(title)
  plt.imshow(cv2.cvtColor(img, cv2.COLOR_BGR2RGB))
  plt.show()
```

```
def get_inliers(f1, f2, matches, H, RANSACthresh):

  inlier_indices = []
  for i in range(len(matches)):
    queryInd = matches[i].queryIdx
    trainInd = matches[i].trainIdx

    #queryInd = matches[i][0]
    #trainInd = matches[i][1]

    queryPoint = np.array([f1[queryInd].pt[0],  f1[queryInd].pt[1], 1]).T
    trans_query = H.dot(queryPoint)


    comp1 = [trans_query[0]/trans_query[2], trans_query[1]/trans_query[2]] # normalize with respect to z
    comp2 = np.array(f2[trainInd].pt)[:2]


    if(np.linalg.norm(comp1-comp2) <= RANSACthresh): # check against threshold
```

```
      inlier_indices.append(i)
  return inlier_indices


def RANSAC_alg(f1, f2, matches, nRANSAC, RANSACthresh):


    minMatches = 4
    nBest = 0
    best_inliers = []
    H_estimate = np.eye(3,3)
    global inlier_matchset
    inlier_matchset=[]
    for iteration in range(nRANSAC):

        #Choose a minimal set of feature matches.
        matchSample = random.sample(matches, minMatches)

        #Estimate the Homography implied by these matches
        im1_pts=np.empty((minMatches,2))
        im2_pts=np.empty((minMatches,2))
        for i in range(0,minMatches):
          m = matchSample[i]
          im1_pts[i] = f1[m.queryIdx].pt
          im2_pts[i] = f2[m.trainIdx].pt
          #im1_pts[i] = f1[m[0]].pt
          #im2_pts[i] = f2[m[1]].pt

        H_estimate=compute_Homography(im1_pts,im2_pts)


        # Calculate the inliers for the H
        inliers = get_inliers(f1, f2, matches, H_estimate, RANSACthresh)

        # if the number of inliers is higher than previous iterations, update the best estimates
        if len(inliers) > nBest:
            nBest= len(inliers)
            best_inliers = inliers

    print("Number of best inliers",len(best_inliers))
    for i in range(len(best_inliers)):
      inlier_matchset.append(matches[best_inliers[i]])

    # compute a homography given this set of matches
    im1_pts=np.empty((len(best_inliers),2))
    im2_pts=np.empty((len(best_inliers),2))
    for i in range(0,len(best_inliers)):
      m = inlier_matchset[i]
      im1_pts[i] = f1[m.queryIdx].pt
      im2_pts[i] = f2[m.trainIdx].pt
      #im1_pts[i] = f1[m[0]].pt
      #im2_pts[i] = f2[m[1]].pt

    M=compute_Homography(im1_pts,im2_pts)
    return M, best_inliers
```

```
files_all=[]
```

```
files_all = []
for file in os.listdir("/content/drive/My Drive/Uni_img"):
    if file.endswith(".JPG"):
      files_all.append(file)


files_all.sort()
folder_path = '/content/drive/My Drive/Uni_img/'

centre_file = folder_path + files_all[15]
left_files_path_rev = []
right_files_path = []

for file in files_all[:31]:
  left_files_path_rev.append(folder_path + file)

left_files_path = left_files_path_rev[::-1]

for file in files_all[30:61]:
  right_files_path.append(folder_path + file)
```

```
from PIL.ExifTags import TAGS
from PIL.ExifTags import GPSTAGS
from PIL import Image
def get_exif(filename):
    image = Image.open(filename)
    image.verify()
    return image._getexif()

def get_labeled_exif(exif):
    labeled = {}
    for (key, val) in exif.items():
        labeled[TAGS.get(key)] = val

    return labeled


def get_geotagging(exif):
    if not exif:
        raise ValueError("No EXIF metadata found")

    geotagging = {}
    for (idx, tag) in TAGS.items():
        if tag == 'GPSInfo':
            if idx not in exif:
                raise ValueError("No EXIF geotagging found")

            for (key, val) in GPSTAGS.items():
                if key in exif[idx]:
                    geotagging[val] = exif[idx][key]
    return geotagging

def get_decimal_from_dms(dms, ref):

    degrees = dms[0][0] / dms[0][1]
    minutes = dms[1][0] / dms[1][1] / 60.0
    seconds = dms[2][0] / dms[2][1] / 3600.0

    if ref in ['S', 'W']:
        degrees = -degrees
        minutes = -minutes
        seconds = -seconds

    return round(degrees + minutes + seconds, 5)

def get_coordinates(geotags):
    lat = get_decimal_from_dms(geotags['GPSLatitude'], geotags['GPSLatitudeRef'])

    lon = get_decimal_from_dms(geotags['GPSLongitude'], geotags['GPSLongitudeRef'])

    return (lat,lon)
```

```
gridsize = 8
clahe = cv2.createCLAHE(clipLimit=2.0,tileGridSize=(gridsize,gridsize))

images_left_bgr = []
images_right_bgr = []

images_left = []
images_right = []

for file in tqdm(left_files_path):
  left_image_sat= cv2.imread(file)
  lab = cv2.cvtColor(left_image_sat, cv2.COLOR_BGR2LAB)
  lab[...,0] = clahe.apply(lab[...,0])
  left_image_sat = cv2.cvtColor(lab, cv2.COLOR_LAB2BGR)
  left_img = cv2.resize(left_image_sat,None,fx=0.35, fy=0.35, interpolation = cv2.INTER_CUBIC)
  images_left.append(cv2.cvtColor(left_img, cv2.COLOR_BGR2GRAY).astype('float32')/255.)
  images_left_bgr.append(left_img)


for file in tqdm(right_files_path):
  right_image_sat= cv2.imread(file)
  lab = cv2.cvtColor(right_image_sat, cv2.COLOR_BGR2LAB)
  lab[...,0] = clahe.apply(lab[...,0])
  right_image_sat = cv2.cvtColor(lab, cv2.COLOR_LAB2BGR)
  right_img = cv2.resize(right_image_sat,None,fx=0.35,fy=0.35, interpolation = cv2.INTER_CUBIC)
  images_right.append(cv2.cvtColor(right_img, cv2.COLOR_BGR2GRAY).astype('float32')/255.)
  images_right_bgr.append(right_img)
```

```
100%|██████████| 31/31 [00:23<00:00,  1.31it/s]
100%|██████████| 31/31 [00:23<00:00,  1.31it/s]
```

```
images_left_bgr_no_enhance = []
images_right_bgr_no_enhance = []


for file in tqdm(left_files_path):
  left_image_sat= cv2.imread(file)
  left_img = cv2.resize(left_image_sat,None,fx=0.35, fy=0.35, interpolation = cv2.INTER_CUBIC)
  images_left_bgr_no_enhance.append(left_img)


for file in tqdm(right_files_path):
  right_image_sat= cv2.imread(file)
  right_img = cv2.resize(right_image_sat,None,fx=0.35,fy=0.35, interpolation = cv2.INTER_CUBIC)
  images_right_bgr_no_enhance.append(right_img)
```

```
100%|██████████| 31/31 [00:11<00:00,  2.59it/s]
100%|██████████| 31/31 [00:12<00:00,  2.57it/s]
```

```
Threshl=60;
Octaves=8;
#PatternScales=1.0f;
brisk = cv2.BRISK_create(Threshl,Octaves)


keypoints_all_left_brisk = []
descriptors_all_left_brisk = []
points_all_left_brisk=[]

keypoints_all_right_brisk = []
descriptors_all_right_brisk = []
points_all_right_brisk=[]

for imgs in tqdm(images_left_bgr):
  kpt = brisk.detect(imgs,None)
  kpt,descrip =  brisk.compute(imgs, kpt)
  keypoints_all_left_brisk.append(kpt)
  descriptors_all_left_brisk.append(descrip)
  points_all_left_brisk.append(np.asarray([[p.pt[0], p.pt[1]] for p in kpt]))

for imgs in tqdm(images_right_bgr):
  kpt = brisk.detect(imgs,None)
  kpt,descrip =  brisk.compute(imgs, kpt)
  keypoints_all_right_brisk.append(kpt)
  descriptors_all_right_brisk.append(descrip)
  points_all_right_brisk.append(np.asarray([[p.pt[0], p.pt[1]] for p in kpt]))
```

```
100%|██████████| 31/31 [00:31<00:00,  1.02s/it]
100%|██████████| 31/31 [00:30<00:00,  1.02it/s]
```

```
orb = cv2.ORB_create(5000)


keypoints_all_left_orb = []
descriptors_all_left_orb = []
points_all_left_orb=[]

keypoints_all_right_orb = []
descriptors_all_right_orb = []
points_all_right_orb=[]

for imgs in tqdm(images_left_bgr):
  kpt = orb.detect(imgs,None)
  kpt,descrip =  orb.compute(imgs, kpt)
  keypoints_all_left_orb.append(kpt)
  descriptors_all_left_orb.append(descrip)
  points_all_left_orb.append(np.asarray([[p.pt[0], p.pt[1]] for p in kpt]))

for imgs in tqdm(images_right_bgr):
  kpt = orb.detect(imgs,None)
  kpt,descrip =  orb.compute(imgs, kpt)
  keypoints_all_right_orb.append(kpt)
  descriptors_all_right_orb.append(descrip)
  points_all_right_orb.append(np.asarray([[p.pt[0], p.pt[1]] for p in kpt]))
```

```
    100%|██████████| 31/31 [00:04<00:00,  6.75it/s]
    100%|██████████| 31/31 [00:04<00:00,  7.24it/s]time: 8.89 s (started: 2021-06-15 15:24:25 +00:00)
```

```
kaze = cv2.KAZE_create()


keypoints_all_left_kaze = []
descriptors_all_left_kaze = []
points_all_left_kaze=[]

keypoints_all_right_kaze = []
descriptors_all_right_kaze = []
points_all_right_kaze=[]

for imgs in tqdm(images_left_bgr):
  kpt = kaze.detect(imgs,None)
  kpt,descrip =  kaze.compute(imgs, kpt)
  keypoints_all_left_kaze.append(kpt)
  descriptors_all_left_kaze.append(descrip)
  points_all_left_kaze.append(np.asarray([[p.pt[0], p.pt[1]] for p in kpt]))

for imgs in tqdm(images_right_bgr):
  kpt = kaze.detect(imgs,None)
  kpt,descrip =  kaze.compute(imgs, kpt)
  keypoints_all_right_kaze.append(kpt)
  descriptors_all_right_kaze.append(descrip)
  points_all_right_kaze.append(np.asarray([[p.pt[0], p.pt[1]] for p in kpt]))
```

```
    100%|██████████| 31/31 [02:27<00:00,  4.76s/it]
    100%|██████████| 31/31 [02:26<00:00,  4.71s/it]time: 4min 53s (started: 2021-06-15 15:24:34 +00:00)
```

```
tqdm = partial(tqdm, position=0, leave=True)
```

```
    time: 1.19 ms (started: 2021-06-15 15:51:44 +00:00)
```

```
akaze = cv2.AKAZE_create()


keypoints_all_left_akaze = []
descriptors_all_left_akaze = []
points_all_left_akaze=[]

keypoints_all_right_akaze = []
descriptors_all_right_akaze = []
points_all_right_akaze=[]

for imgs in tqdm(images_left_bgr):
  kpt = akaze.detect(imgs,None)
  kpt,descrip =  akaze.compute(imgs, kpt)
  keypoints_all_left_akaze.append(kpt)
  descriptors_all_left_akaze.append(descrip)
  points_all_left_akaze.append(np.asarray([[p.pt[0], p.pt[1]] for p in kpt]))

for imgs in tqdm(images_right_bgr):
  kpt = akaze.detect(imgs,None)
  kpt,descrip =  akaze.compute(imgs, kpt)
  keypoints_all_right_akaze.append(kpt)
  descriptors_all_right_akaze.append(descrip)
  points_all_right_akaze.append(np.asarray([[p.pt[0], p.pt[1]] for p in kpt]))
```

```
    100%|██████████| 31/31 [00:26<00:00,  1.16it/s]
    100%|██████████| 31/31 [00:25<00:00,  1.20it/s]time: 52.5 s (started: 2021-06-15 15:29:28 +00:00)
```

```
star = cv2.xfeatures2d.StarDetector_create()
brief = cv2.xfeatures2d.BriefDescriptorExtractor_create()

keypoints_all_left_star = []
descriptors_all_left_brief = []
points_all_left_star=[]

keypoints_all_right_star = []
descriptors_all_right_brief = []
points_all_right_star=[]

for imgs in tqdm(images_left_bgr):
  kpt = star.detect(imgs,None)
  kpt,descrip =  brief.compute(imgs, kpt)
  keypoints_all_left_star.append(kpt)
  descriptors_all_left_brief.append(descrip)
  points_all_left_star.append(np.asarray([[p.pt[0], p.pt[1]] for p in kpt]))

for imgs in tqdm(images_right_bgr):
  kpt = star.detect(imgs,None)
  kpt,descrip =  brief.compute(imgs, kpt)
  keypoints_all_right_star.append(kpt)
  descriptors_all_right_brief.append(descrip)
  points_all_right_star.append(np.asarray([[p.pt[0], p.pt[1]] for p in kpt]))
```

```
    100%|██████████| 31/31 [00:04<00:00,  6.20it/s]
    100%|██████████| 31/31 [00:04<00:00,  6.39it/s]time: 9.88 s (started: 2021-06-15 15:30:21 +00:00)
```

```
sift = cv2.xfeatures2d.SIFT_create()
keypoints_all_left_sift = []
descriptors_all_left_sift = []
points_all_left_sift=[]

keypoints_all_right_sift = []
descriptors_all_right_sift = []
points_all_right_sift=[]

for imgs in tqdm(images_left_bgr):
  kpt = sift.detect(imgs,None)
  kpt,descrip =  sift.compute(imgs, kpt)
  keypoints_all_left_sift.append(kpt)
  descriptors_all_left_sift.append(descrip)
  points_all_left_sift.append(np.asarray([[p.pt[0], p.pt[1]] for p in kpt]))

for imgs in tqdm(images_right_bgr):
  kpt = sift.detect(imgs,None)
  kpt,descrip =  sift.compute(imgs, kpt)
  keypoints_all_right_sift.append(kpt)
  descriptors_all_right_sift.append(descrip)
  points_all_right_sift.append(np.asarray([[p.pt[0], p.pt[1]] for p in kpt]))
```

```
    100%|██████████| 31/31 [01:01<00:00,  1.99s/it]
    100%|██████████| 31/31 [00:59<00:00,  1.92s/it]
```

```
surf  = cv2.xfeatures2d.SURF_create()
keypoints_all_left_surf = []
descriptors_all_left_surf = []
points_all_left_surf=[]

keypoints_all_right_surf = []
descriptors_all_right_surf = []
points_all_right_surf=[]

for imgs in tqdm(images_left_bgr):
  kpt = surf.detect(imgs,None)
  kpt,descrip =  surf.compute(imgs, kpt)
  keypoints_all_left_surf.append(kpt)
  descriptors_all_left_surf.append(descrip)
  points_all_left_surf.append(np.asarray([[p.pt[0], p.pt[1]] for p in kpt]))

for imgs in tqdm(images_right_bgr):
  kpt = surf.detect(imgs,None)
  kpt,descrip =  surf.compute(imgs, kpt)
  keypoints_all_right_surf.append(kpt)
  descriptors_all_right_surf.append(descrip)
  points_all_right_surf.append(np.asarray([[p.pt[0], p.pt[1]] for p in kpt]))
```

```
100%|██████████| 31/31 [02:17<00:00,  4.43s/it]
100%|██████████| 31/31 [02:18<00:00,  4.47s/it]
```

```
class RootSIFT:
  def __init__(self):
    # initialize the SIFT feature extractor
    #self.extractor = cv2.DescriptorExtractor_create("SIFT")
    self.sift = cv2.xfeatures2d.SIFT_create()

  def compute(self, image, kps, eps=1e-7):
    # compute SIFT descriptors
    (kps, descs) = self.sift.compute(image, kps)

    # if there are no keypoints or descriptors, return an empty tuple
    if len(kps) == 0:
      return ([], None)

    # apply the Hellinger kernel by first L1-normalizing, taking the
    # square-root, and then L2-normalizing
    descs /= (np.linalg.norm(descs, axis=0, ord=2) + eps)
    descs /= (descs.sum(axis=0) + eps)
    descs = np.sqrt(descs)
    #descs /= (np.linalg.norm(descs, axis=0, ord=2) + eps)

    # return a tuple of the keypoints and descriptors
    return (kps, descs)
```

```
time: 7.07 ms (started: 2021-06-15 15:36:05 +00:00)
```

```
sift = cv2.xfeatures2d.SIFT_create()
rootsift = RootSIFT()
keypoints_all_left_rootsift = []
descriptors_all_left_rootsift = []
points_all_left_rootsift=[]

keypoints_all_right_rootsift = []
```

```
descriptors_all_right_rootsift = []
points_all_right_rootsift=[]

for imgs in tqdm(images_left_bgr):
  kpt = sift.detect(imgs,None)
  kpt,descrip =  rootsift.compute(imgs, kpt)
  keypoints_all_left_rootsift.append(kpt)
  descriptors_all_left_rootsift.append(descrip)
  points_all_left_rootsift.append(np.asarray([[p.pt[0], p.pt[1]] for p in kpt]))

for imgs in tqdm(images_right_bgr):
  kpt = sift.detect(imgs,None)
  kpt,descrip =  rootsift.compute(imgs, kpt)
  keypoints_all_right_rootsift.append(kpt)
  descriptors_all_right_rootsift.append(descrip)
  points_all_right_rootsift.append(np.asarray([[p.pt[0], p.pt[1]] for p in kpt]))
```

```
100%|██████████| 31/31 [00:52<00:00,  1.68s/it]
  3%|▌         | 1/31 [00:01<00:57,  1.91s/it]
```

```
!git clone https://github.com/magicleap/SuperPointPretrainedNetwork.git
```

```
weights_path = 'SuperPointPretrainedNetwork/superpoint_v1.pth'

cuda = 'True'
```

```
def to_kpts(pts, size=1):
  return [cv2.KeyPoint(pt[0], pt[1], size) for pt in pts]
```

```
import numpy as np
import torch
import torch.nn as nn
import torch.nn.functional as F

torch.cuda.empty_cache()

class SuperPointNet(nn.Module):
    def __init__(self):
        super(SuperPointNet, self).__init__()
        self.relu = nn.ReLU(inplace=True)
        self.pool = nn.MaxPool2d(kernel_size=2, stride=2)
        c1, c2, c3, c4, c5, d1 = 64, 64, 128, 128, 256, 256
        # Shared Encoder.
        self.conv1a = nn.Conv2d(1, c1, kernel_size=3, stride=1, padding=1)
        self.conv1b = nn.Conv2d(c1, c1, kernel_size=3, stride=1, padding=1)
        self.conv2a = nn.Conv2d(c1, c2, kernel_size=3, stride=1, padding=1)
        self.conv2b = nn.Conv2d(c2, c2, kernel_size=3, stride=1, padding=1)
        self.conv3a = nn.Conv2d(c2, c3, kernel_size=3, stride=1, padding=1)
        self.conv3b = nn.Conv2d(c3, c3, kernel_size=3, stride=1, padding=1)
        self.conv4a = nn.Conv2d(c3, c4, kernel_size=3, stride=1, padding=1)
        self.conv4b = nn.Conv2d(c4, c4, kernel_size=3, stride=1, padding=1)
        # Detector Head.
        self.convPa = nn.Conv2d(c4, c5, kernel_size=3, stride=1, padding=1)
        self.convPb = nn.Conv2d(c5, 65, kernel_size=1, stride=1, padding=0)
        # Descriptor Head.
        self.convDa = nn.Conv2d(c4, c5, kernel_size=3, stride=1, padding=1)
        self.convDb = nn.Conv2d(c5, d1, kernel_size=1, stride=1, padding=0)

    def forward(self, x):
```

```
    def forward(self, x):

        # Shared Encoder.
        x = self.relu(self.conv1a(x))
        x = self.relu(self.conv1b(x))
        x = self.pool(x)
        x = self.relu(self.conv2a(x))
        x = self.relu(self.conv2b(x))
        x = self.pool(x)
        x = self.relu(self.conv3a(x))
        x = self.relu(self.conv3b(x))
        x = self.pool(x)
        x = self.relu(self.conv4a(x))
        x = self.relu(self.conv4b(x))
        # Detector Head.
        cPa = self.relu(self.convPa(x))
        semi = self.convPb(cPa)
        # Descriptor Head.
        cDa = self.relu(self.convDa(x))
        desc = self.convDb(cDa)
        dn = torch.norm(desc, p=2, dim=1) # Compute the norm.
        desc = desc.div(torch.unsqueeze(dn, 1)) # Divide by norm to normalize.
        return semi, desc


class SuperPointFrontend(object):
    def __init__(self, weights_path, nms_dist, conf_thresh, nn_thresh,cuda=True):
        self.name = 'SuperPoint'
        self.cuda = cuda
        self.nms_dist = nms_dist
        self.conf_thresh = conf_thresh
        self.nn_thresh = nn_thresh # L2 descriptor distance for good match.
        self.cell = 8 # Size of each output cell. Keep this fixed.
        self.border_remove = 4 # Remove points this close to the border.

        # Load the network in inference mode.
        self.net = SuperPointNet()
        if cuda:
          # Train on GPU, deploy on GPU.
            self.net.load_state_dict(torch.load(weights_path))
            self.net = self.net.cuda()
        else:
          # Train on GPU, deploy on CPU.
            self.net.load_state_dict(torch.load(weights_path, map_location=lambda storage, loc: storage))
        self.net.eval()

    def nms_fast(self, in_corners, H, W, dist_thresh):

        grid = np.zeros((H, W)).astype(int) # Track NMS data.
        inds = np.zeros((H, W)).astype(int) # Store indices of points.
        # Sort by confidence and round to nearest int.
        inds1 = np.argsort(-in_corners[2,:])
        corners = in_corners[:,inds1]
        rcorners = corners[:2,:].round().astype(int) # Rounded corners.
        # Check for edge case of 0 or 1 corners.
        if rcorners.shape[1] == 0:
            return np.zeros((3,0)).astype(int), np.zeros(0).astype(int)
        if rcorners.shape[1] == 1:
            out = np.vstack((rcorners, in_corners[2])).reshape(3,1)
            return out, np.zeros((1)).astype(int)
        # Initialize the grid.
        for i, rc in enumerate(rcorners.T):
            grid[rcorners[1,i], rcorners[0,i]] = 1
            inds[rcorners[1,i], rcorners[0,i]] = i
        # Pad the border of the grid, so that we can NMS points near the border.
        pad = dist_thresh
        grid = np.pad(grid, ((pad,pad), (pad,pad)), mode='constant')
        # Iterate through points, highest to lowest conf, suppress neighborhood.
        count = 0
        for i, rc in enumerate(rcorners.T):
          # Account for top and left padding.
            pt = (rc[0]+pad, rc[1]+pad)
            if grid[pt[1], pt[0]] == 1: # If not yet suppressed.
                grid[pt[1]-pad:pt[1]+pad+1, pt[0]-pad:pt[0]+pad+1] = 0
                grid[pt[1], pt[0]] = -1
                count += 1
        # Get all surviving -1's and return sorted array of remaining corners.
        keepy, keepx = np.where(grid==-1)
        keepy, keepx = keepy - pad, keepx - pad
        inds_keep = inds[keepy, keepx]
        out = corners[:, inds_keep]
        values = out[-1, :]
        inds2 = np.argsort(-values)
        out = out[:, inds2]
        out_inds = inds1[inds_keep[inds2]]
        return out, out_inds

    def run(self, img):
        assert img.ndim == 2 #Image must be grayscale.
        assert img.dtype == np.float32 #Image must be float32.
        H, W = img.shape[0], img.shape[1]
        inp = img.copy()
        inp = (inp.reshape(1, H, W))
        inp = torch.from_numpy(inp)
        inp = torch.autograd.Variable(inp).view(1, 1, H, W)
        if self.cuda:
            inp = inp.cuda()
        # Forward pass of network.
        outs = self.net.forward(inp)
        semi, coarse_desc = outs[0], outs[1]
        # Convert pytorch -> numpy.
        semi = semi.data.cpu().numpy().squeeze()

        # --- Process points.
        dense = np.exp(semi) # Softmax.
        dense = dense / (np.sum(dense, axis=0)+.00001) # Should sum to 1.
        nodust = dense[:-1, :, :]
        # Reshape to get full resolution heatmap.
        Hc = int(H / self.cell)
        Wc = int(W / self.cell)
        nodust = np.transpose(nodust, [1, 2, 0])
        heatmap = np.reshape(nodust, [Hc, Wc, self.cell, self.cell])
        heatmap = np.transpose(heatmap, [0, 2, 1, 3])
        heatmap = np.reshape(heatmap, [Hc*self.cell, Wc*self.cell])
        prob_map = heatmap/np.sum(np.sum(heatmap))

        return heatmap, coarse_desc


    def key_pt_sampling(self, img, heat_map, coarse_desc, sampled):

        H, W = img.shape[0], img.shape[1]
        xs, ys = np.where(heat_map >= self.conf_thresh) # Confidence threshold.
        if len(xs) == 0:
            return np.zeros((3, 0)), None, None
        print("number of pts selected :", len(xs))


        pts = np.zeros((3, len(xs))) # Populate point data sized 3xN.
        pts[0, :] = ys
        pts[1, :] = xs
        pts[2, :] = heat_map[xs, ys]
        pts, _ = self.nms_fast(pts, H, W, dist_thresh=self.nms_dist) # Apply NMS.
        inds = np.argsort(pts[2,:])
        pts = pts[:,inds[::-1]] # Sort by confidence.
        bord = self.border_remove
        toremoveW = np.logical_or(pts[0, :] < bord, pts[0, :] >= (W-bord))
        toremoveH = np.logical_or(pts[1, :] < bord, pts[1, :] >= (H-bord))
        toremove = np.logical_or(toremoveW, toremoveH)
        pts = pts[:, ~toremove]
        pts = pts[:,0:sampled] #we take 2000 keypoints with highest probability from heatmap for our benchmark

        # --- Process descriptor.
        D = coarse_desc.shape[1]
        if pts.shape[1] == 0:
            desc = np.zeros((D, 0))
        else:
          # Interpolate into descriptor map using 2D point locations.
            samp_pts = torch.from_numpy(pts[:2, :].copy())
            samp_pts[0, :] = (samp_pts[0, :] / (float(W)/2.)) - 1.
            samp_pts[1, :] = (samp_pts[1, :] / (float(H)/2.)) - 1.
            samp_pts = samp_pts.transpose(0, 1).contiguous()
            samp_pts = samp_pts.view(1, 1, -1, 2)
            samp_pts = samp_pts.float()
            if self.cuda:
                samp_pts = samp_pts.cuda()
            desc = nn.functional.grid_sample(coarse_desc, samp_pts)
            desc = desc.data.cpu().numpy().reshape(D, -1)
            desc /= np.linalg.norm(desc, axis=0)[np.newaxis, :]


        return pts, desc
```

```
print('Loading pre-trained network.')
# This class runs the SuperPoint network and processes its outputs.
fe = SuperPointFrontend(weights_path=weights_path,nms_dist = 3,conf_thresh = 0.01,nn_thresh=0.5)
print('Successfully loaded pre-trained network.')
```

```
keypoints_all_left_superpoint = []
descriptors_all_left_superpoint = []
points_all_left_superpoint=[]

keypoints_all_right_superpoint = []
descriptors_all_right_superpoint = []
points_all_right_superpoint=[]

tqdm = partial(tqdm, position=0, leave=True)

for lfpth in tqdm(images_left):
  heatmap1, coarse_desc1 = fe.run(lfpth)
  pts_1, desc_1 = fe.key_pt_sampling(lfpth, heatmap1, coarse_desc1, 80000) #Getting keypoints and descriptors for 1st image
  keypoints_all_left_superpoint.append(to_kpts(pts_1.T))
  descriptors_all_left_superpoint.append(desc_1.T)
  points_all_left_superpoint.append(pts_1.T)


for rfpth in tqdm(images_right):
  heatmap1, coarse_desc1 = fe.run(rfpth)
  pts_1, desc_1 = fe.key_pt_sampling(rfpth, heatmap1, coarse_desc1, 80000) #Getting keypoints and descriptors for 1st image

  keypoints_all_right_superpoint.append(to_kpts(pts_1.T))
  descriptors_all_right_superpoint.append(desc_1.T)
  points_all_right_superpoint.append(pts_1.T)
```

```
      0%|          | 0/31 [00:00<?, ?it/s]number of pts selected : 54389
    /usr/local/lib/python3.7/dist-packages/torch/nn/functional.py:3829: UserWarning: Default grid_sample and affine_grid behavior has changed to align_corners=False since 1.3.0. Please specify align_corners=True if the old behavior is desired.
      "Default grid_sample and affine_grid behavior has changed "
      6%|▋         | 2/31 [00:00<00:10,  2.81it/s]number of pts selected : 41692
     10%|▉         | 3/31 [00:00<00:09,  2.97it/s]number of pts selected : 46009
     13%|█▎        | 4/31 [00:01<00:08,  3.12it/s]number of pts selected : 45884
     16%|█▌        | 5/31 [00:01<00:08,  3.23it/s]number of pts selected : 45234
    number of pts selected : 52587
     19%|█▉        | 6/31 [00:01<00:07,  3.21it/s]number of pts selected : 53105
     23%|██▎       | 7/31 [00:02<00:07,  3.19it/s]number of pts selected : 66782
     26%|██▌       | 8/31 [00:02<00:07,  3.02it/s]number of pts selected : 65203
     29%|██▉       | 9/31 [00:02<00:07,  2.93it/s]number of pts selected : 67908
     32%|███▏      | 10/31 [00:03<00:07,  2.85it/s]number of pts selected : 65236
     35%|███▌      | 11/31 [00:03<00:07,  2.84it/s]number of pts selected : 66288
     39%|███▊      | 12/31 [00:03<00:06,  2.82it/s]number of pts selected : 67292
     42%|████▏     | 13/31 [00:04<00:06,  2.79it/s]number of pts selected : 74482
     45%|████▌     | 14/31 [00:04<00:06,  2.73it/s]number of pts selected : 80466
     48%|████▊     | 15/31 [00:05<00:06,  2.64it/s]number of pts selected : 79406
     52%|█████▏    | 16/31 [00:05<00:05,  2.60it/s]number of pts selected : 77186
     55%|█████▍    | 17/31 [00:05<00:05,  2.59it/s]number of pts selected : 78522
     58%|█████▊    | 18/31 [00:06<00:05,  2.56it/s]number of pts selected : 76461
     61%|██████▏   | 19/31 [00:06<00:04,  2.56it/s]number of pts selected : 75079
     65%|██████▍   | 20/31 [00:07<00:04,  2.56it/s]number of pts selected : 74653
     68%|██████▊   | 21/31 [00:07<00:03,  2.53it/s]number of pts selected : 72241
     71%|███████   | 22/31 [00:07<00:03,  2.56it/s]number of pts selected : 76421
     74%|███████▍  | 23/31 [00:08<00:03,  2.56it/s]number of pts selected : 76524
     77%|███████▋  | 24/31 [00:08<00:02,  2.55it/s]number of pts selected : 77484
     81%|████████  | 25/31 [00:09<00:02,  2.53it/s]number of pts selected : 76790
     84%|████████▍ | 26/31 [00:09<00:01,  2.53it/s]number of pts selected : 72526
     87%|████████▋ | 27/31 [00:09<00:01,  2.56it/s]number of pts selected : 74990
     90%|█████████ | 28/31 [00:10<00:01,  2.55it/s]number of pts selected : 73152
     94%|█████████▎| 29/31 [00:10<00:00,  2.57it/s]number of pts selected : 75194
     97%|█████████▋| 30/31 [00:11<00:00,  2.57it/s]number of pts selected : 72677
    100%|██████████| 31/31 [00:11<00:00,  2.72it/s]
      0%|          | 0/31 [00:00<?, ?it/s]number of pts selected : 54389
      3%|▎         | 1/31 [00:00<00:09,  3.16it/s]number of pts selected : 57668
      6%|▋         | 2/31 [00:00<00:09,  3.11it/s]number of pts selected : 72511
     10%|▉         | 3/31 [00:01<00:09,  2.95it/s]number of pts selected : 80589
     13%|█▎        | 4/31 [00:01<00:09,  2.79it/s]number of pts selected : 81288
     16%|█▌        | 5/31 [00:01<00:09,  2.67it/s]number of pts selected : 80120
     19%|█▉        | 6/31 [00:02<00:09,  2.56it/s]number of pts selected : 68019
     23%|██▎       | 7/31 [00:02<00:09,  2.60it/s]number of pts selected : 70150
     26%|██▌       | 8/31 [00:03<00:08,  2.63it/s]number of pts selected : 67211
     29%|██▉       | 9/31 [00:03<00:08,  2.68it/s]number of pts selected : 67542
     32%|███▏      | 10/31 [00:03<00:07,  2.71it/s]number of pts selected : 60955
     35%|███▌      | 11/31 [00:04<00:07,  2.79it/s]number of pts selected : 66493
     39%|███▊      | 12/31 [00:04<00:06,  2.81it/s]number of pts selected : 67367
     42%|████▏     | 13/31 [00:04<00:06,  2.78it/s]number of pts selected : 66701
     45%|████▌     | 14/31 [00:05<00:06,  2.77it/s]number of pts selected : 73340
     48%|████▊     | 15/31 [00:05<00:05,  2.71it/s]number of pts selected : 78344
     52%|█████▏    | 16/31 [00:05<00:05,  2.64it/s]number of pts selected : 82778
     55%|█████▍    | 17/31 [00:06<00:05,  2.56it/s]number of pts selected : 84116
     58%|█████▊    | 18/31 [00:06<00:05,  2.50it/s]number of pts selected : 78771
     61%|██████▏   | 19/31 [00:07<00:04,  2.50it/s]number of pts selected : 80455
```

```
 65%|██████▌   | 20/31 [00:07<00:04,  2.48it/s]number of pts selected : 68537
 68%|██████▊   | 21/31 [00:07<00:03,  2.54it/s]number of pts selected : 70715
 71%|███████   | 22/31 [00:08<00:03,  2.57it/s]number of pts selected : 55142
 74%|███████▍  | 23/31 [00:08<00:02,  2.69it/s]number of pts selected : 62314
```

```
def compute_homography_fast(matched_pts1, matched_pts2,thresh=4):
    #matched_pts1 = cv2.KeyPoint_convert(matched_kp1)
    #matched_pts2 = cv2.KeyPoint_convert(matched_kp2)

    # Estimate the homography between the matches using RANSAC
    H, inliers = cv2.findHomography(matched_pts1,
                                    matched_pts2,
                                    cv2.RANSAC, ransacReprojThreshold =thresh)
    inliers = inliers.flatten()
    return H, inliers
```

```
def compute_homography_fast_other(matched_pts1, matched_pts2):
    #matched_pts1 = cv2.KeyPoint_convert(matched_kp1)
    #matched_pts2 = cv2.KeyPoint_convert(matched_kp2)

    # Estimate the homography between the matches using RANSAC
    H, inliers = cv2.findHomography(matched_pts1,
                                    matched_pts2,
                                    0)
    inliers = inliers.flatten()
    return H, inliers
```

```


def get_Hmatrix(imgs,keypts,pts,descripts,ratio=0.8,thresh=4,disp=False):
  FLANN_INDEX_KDTREE = 2
  index_params = dict(algorithm=FLANN_INDEX_KDTREE, trees=5)
  search_params = dict(checks=50)
  flann = cv2.FlannBasedMatcher(index_params, search_params)
  #flann = cv2.BFMatcher()

  lff1 = np.float32(descripts[0])
  lff = np.float32(descripts[1])


  matches_lf1_lf = flann.knnMatch(lff1, lff, k=2)

  print("\nNumber of matches",len(matches_lf1_lf))

  matches_4 = []
  ratio = ratio
  # loop over the raw matches
  for m in matches_lf1_lf:
    # ensure the distance is within a certain ratio of each
    # other (i.e. Lowe’s ratio test)
    if len(m) == 2 and m[0].distance < m[1].distance * ratio:
        #matches_1.append((m[0].trainIdx, m[0].queryIdx))
        matches_4.append(m[0])

  print("Number of matches After Lowe's Ratio",len(matches_4))

  matches_idx = np.array([m.queryIdx for m in matches_4])
  imm1_pts = np.array([keypts[0][idx].pt for idx in matches_idx])
  matches_idx = np.array([m.trainIdx for m in matches_4])
  imm2_pts = np.array([keypts[1][idx].pt for idx in matches_idx])
  '''
  # Estimate homography 1
  #Compute H1
  # Estimate homography 1
  #Compute H1
  imm1_pts=np.empty((len(matches_4),2))
  imm2_pts=np.empty((len(matches_4),2))
  for i in range(0,len(matches_4)):
    m = matches_4[i]
    (a_x, a_y) = keypts[0][m.queryIdx].pt
    (b_x, b_y) = keypts[1][m.trainIdx].pt
    imm1_pts[i]=(a_x, a_y)
    imm2_pts[i]=(b_x, b_y)
  H=compute_Homography(imm1_pts,imm2_pts)
  #Robustly estimate Homography 1 using RANSAC
  Hn, best_inliers=RANSAC_alg(keypts[0] ,keypts[1], matches_4,  nRANSAC=1000, RANSACthresh=6)
  '''


  Hn,inliers = compute_homography_fast(imm1_pts,imm2_pts,thresh)
  inlier_matchset = np.array(matches_4)[inliers.astype(bool)].tolist()
  print("Number of Robust matches",len(inlier_matchset))
  print("\n")
  '''
  if len(inlier_matchset)<50:
    matches_4 = []
    ratio = 0.67
    # loop over the raw matches
    for m in matches_lf1_lf:
      # ensure the distance is within a certain ratio of each
      # other (i.e. Lowe’s ratio test)
      if len(m) == 2 and m[0].distance < m[1].distance * ratio:
          #matches_1.append((m[0].trainIdx, m[0].queryIdx))
          matches_4.append(m[0])
    print("Number of matches After Lowe's Ratio New",len(matches_4))

    matches_idx = np.array([m.queryIdx for m in matches_4])
    imm1_pts = np.array([keypts[0][idx].pt for idx in matches_idx])
    matches_idx = np.array([m.trainIdx for m in matches_4])
    imm2_pts = np.array([keypts[1][idx].pt for idx in matches_idx])
    Hn,inliers = compute_homography_fast_other(imm1_pts,imm2_pts)
    inlier_matchset = np.array(matches_4)[inliers.astype(bool)].tolist()
    print("Number of Robust matches New",len(inlier_matchset))
    print("\n")
    '''
  #H=compute_Homography(imm1_pts,imm2_pts)
  #Robustly estimate Homography 1 using RANSAC
  #Hn=RANSAC_alg(keypts[0] ,keypts[1], matches_4,  nRANSAC=1500, RANSACthresh=6)

  #global inlier_matchset

  if disp==True:
    dispimg1=cv2.drawMatches(imgs[0], keypts[0], imgs[1], keypts[1], inlier_matchset, None,flags=2)
    displayplot(dispimg1,'Robust Matching between Reference Image and Right Image ')

  return Hn/Hn[2,2], len(matches_lf1_lf), len(inlier_matchset)
```

```
from functools import partial
from tqdm import tqdm
tqdm = partial(tqdm, position=0, leave=True)
```

```
print(left_files_path)
```

```
['/content/drive/My Drive/Uni_img/IX-11-01917_0004_0031.JPG', '/content/drive/My Drive/Uni_img/IX-11-01917_0004_0030.JPG', '/content/drive/My Drive/Uni_img/IX-11-01917_0004_0029.JPG', '/content/drive/My Drive/Uni_img/IX-11-01917_0004_0028.JP
time: 927 µs (started: 2021-06-15 15:38:15 +00:00)
```

```
print(right_files_path)
```

```
['/content/drive/My Drive/Uni_img/IX-11-01917_0004_0031.JPG', '/content/drive/My Drive/Uni_img/IX-11-01917_0004_0032.JPG', '/content/drive/My Drive/Uni_img/IX-11-01917_0004_0033.JPG', '/content/drive/My Drive/Uni_img/IX-11-01917_0004_0034.JP
time: 940 µs (started: 2021-06-15 15:38:15 +00:00)
```

```
H_left_brisk = []
H_right_brisk = []

num_matches_brisk = []
num_good_matches_brisk = []

for j in tqdm(range(len(images_left))):
  if j==len(images_left)-1:
    break

  H_a,matches,gd_matches = get_Hmatrix(images_left_bgr[j:j+2][::-1],keypoints_all_left_brisk[j:j+2][::-1],points_all_left_brisk[j:j+2][::-1],descriptors_all_left_brisk[j:j+2][::-1],0.9,6)
  H_left_brisk.append(H_a)
  num_matches_brisk.append(matches)
  num_good_matches_brisk.append(gd_matches)

for j in tqdm(range(len(images_right))):
  if j==len(images_right)-1:
    break

  H_a,matches,gd_matches = get_Hmatrix(images_right_bgr[j:j+2][::-1],keypoints_all_right_brisk[j:j+2][::-1],points_all_right_brisk[j:j+2][::-1],descriptors_all_right_brisk[j:j+2][::-1],0.9,6)
  H_right_brisk.append(H_a)
  #num_matches.append(matches)
  #num_good_matches.append(gd_matches)
```

```
 29%|███       | 9/31 [00:27<01:03,  2.91s/it]
Number of matches 32135

Number of matches After Lowe's Ratio 6514
Number of Robust matches 2288


 32%|███       | 10/31 [00:30<00:58,  2.80s/it]
Number of matches 31427
Number of matches After Lowe's Ratio 6334
Number of Robust matches 2106


 35%|███      | 11/31 [00:32<00:53,  2.68s/it]
Number of matches 31280
Number of matches After Lowe's Ratio 6835
Number of Robust matches 2660


 39%|████      | 12/31 [00:34<00:50,  2.64s/it]
Number of matches 33078
Number of matches After Lowe's Ratio 8182
Number of Robust matches 3707


 42%|████      | 13/31 [00:37<00:47,  2.61s/it]
 42%|████▎     | 13/31 [00:37<00:47,  2.61s/it]
Number of matches 32047
Number of matches After Lowe's Ratio 7506
Number of Robust matches 3385


 45%|████▌     | 14/31 [00:40<00:43,  2.58s/it]
Number of matches 30911
Number of matches After Lowe's Ratio 7058
Number of Robust matches 2971


 48%|████▊     | 15/31 [00:42<00:41,  2.61s/it]
Number of matches 34839
Number of matches After Lowe's Ratio 8066
Number of Robust matches 3305


 52%|█████▏    | 16/31 [00:45<00:42,  2.80s/it]
Number of matches 37547
Number of matches After Lowe's Ratio 8142
Number of Robust matches 3305


 55%|█████▍    | 17/31 [00:49<00:41,  2.97s/it]
Number of matches 37734
Number of matches After Lowe's Ratio 9155
Number of Robust matches 4514


 58%|█████▊    | 18/31 [00:52<00:39,  3.02s/it]
Number of matches 32146
Number of matches After Lowe's Ratio 6856
Number of Robust matches 3068
```

```
H_left_sift = []
H_right_sift = []

num_matches_sift = []
num_good_matches_sift = []

for j in tqdm(range(len(images_left))):
  if j==len(images_left)-1:
    break

  H_a,matches,gd_matches = get_Hmatrix(images_left_bgr[j:j+2][::-1],keypoints_all_left_sift[j:j+2][::-1],points_all_left_sift[j:j+2][::-1],descriptors_all_left_sift[j:j+2][::-1],0.5)
  H_left_sift.append(H_a)
  num_matches_sift.append(matches)
  num_good_matches_sift.append(gd_matches)

for j in tqdm(range(len(images_right))):
  if j==len(images_right)-1:
    break

  H_a,matches,gd_matches = get_Hmatrix(images_right_bgr[j:j+2][::-1],keypoints_all_right_sift[j:j+2][::-1],points_all_right_sift[j:j+2][::-1],descriptors_all_right_sift[j:j+2][::-1],0.5)
  H_right_sift.append(H_a)
  #num_matches.append(matches)
  #num_good_matches.append(gd_matches)
```

```
Number of Robust matches 1397


 29%|██▉       | 9/31 [00:41<01:35,  4.32s/it]
Number of matches 32208
Number of matches After Lowe's Ratio 1620
Number of Robust matches 1283
```

```
 32%|███       | 10/31 [00:46<01:29,  4.26s/it]
Number of matches 29913
Number of matches After Lowe's Ratio 1946
Number of Robust matches 1643


 35%|███▌      | 11/31 [00:49<01:21,  4.08s/it]
Number of matches 28182
Number of matches After Lowe's Ratio 2441
Number of Robust matches 2112


 39%|███▊      | 12/31 [00:52<01:12,  3.83s/it]
Number of matches 27052
Number of matches After Lowe's Ratio 3134
Number of Robust matches 2634


 42%|████▏     | 13/31 [00:56<01:05,  3.63s/it]
Number of matches 26581
Number of matches After Lowe's Ratio 2774
Number of Robust matches 2419


 45%|████▌     | 14/31 [00:59<00:58,  3.44s/it]
Number of matches 25919
Number of matches After Lowe's Ratio 1958
Number of Robust matches 1745


 48%|████▊     | 15/31 [01:02<00:52,  3.31s/it]
Number of matches 27099
Number of matches After Lowe's Ratio 2111
Number of Robust matches 1695


 52%|█████▏    | 16/31 [01:05<00:49,  3.31s/it]
Number of matches 27282
Number of matches After Lowe's Ratio 1658
Number of Robust matches 1540


 55%|█████▍    | 17/31 [01:08<00:45,  3.28s/it]
Number of matches 27592
Number of matches After Lowe's Ratio 2370

Number of Robust matches 1920


 58%|█████▊    | 18/31 [01:11<00:41,  3.22s/it]
Number of matches 24162
Number of matches After Lowe's Ratio 1363
```

```
H_left_orb = []
H_right_orb = []

num_matches_orb = []
num_good_matches_orb = []

for j in tqdm(range(len(images_left))):
  if j==len(images_left)-1:
    break

  H_a,matches,gd_matches = get_Hmatrix(images_left_bgr[j:j+2][::-1],keypoints_all_left_orb[j:j+2][::-1],points_all_left_orb[j:j+2][::-1],descriptors_all_left_orb[j:j+2][::-1])
  H_left_orb.append(H_a)
  num_matches_orb.append(matches)
  num_good_matches_orb.append(gd_matches)
```

```
for j in tqdm(range(len(images_right))):
  if j==len(images_right)-1:
    break

  H_a,matches,gd_matches = get_Hmatrix(images_right_bgr[j:j+2][::-1],keypoints_all_right_orb[j:j+2][::-1],points_all_right_orb[j:j+2][::-1],descriptors_all_right_orb[j:j+2][::-1])
  H_right_orb.append(H_a)
  #num_matches.append(matches)
  #num_good_matches.append(gd_matches)
```

```
H_left_kaze = []
H_right_kaze = []

num_matches_kaze = []
num_good_matches_kaze = []

for j in tqdm(range(len(images_left))):
  if j==len(images_left)-1:
    break

  H_a,matches,gd_matches = get_Hmatrix(images_left_bgr[j:j+2][::-1],keypoints_all_left_kaze[j:j+2][::-1],points_all_left_kaze[j:j+2][::-1],descriptors_all_left_kaze[j:j+2][::-1])
  H_left_kaze.append(H_a)
  num_matches_kaze.append(matches)
  num_good_matches_kaze.append(gd_matches)

for j in tqdm(range(len(images_right))):
  if j==len(images_right)-1:
    break

  H_a,matches,gd_matches = get_Hmatrix(images_right_bgr[j:j+2][::-1],keypoints_all_right_kaze[j:j+2][::-1],points_all_right_kaze[j:j+2][::-1],descriptors_all_right_kaze[j:j+2][::-1])
  H_right_kaze.append(H_a)
  #num_matches.append(matches)
  #num_good_matches.append(gd_matches)
```

```
H_left_akaze = []
H_right_akaze = []

num_matches_akaze = []
num_good_matches_akaze = []

for j in tqdm(range(len(images_left))):
  if j==len(images_left)-1:
    break

  H_a,matches,gd_matches = get_Hmatrix(images_left_bgr[j:j+2][::-1],keypoints_all_left_akaze[j:j+2][::-1],points_all_left_akaze[j:j+2][::-1],descriptors_all_left_akaze[j:j+2][::-1])
  H_left_akaze.append(H_a)
  num_matches_akaze.append(matches)
  num_good_matches_akaze.append(gd_matches)

for j in tqdm(range(len(images_right))):
  if j==len(images_right)-1:
    break

  H_a,matches,gd_matches = get_Hmatrix(images_right_bgr[j:j+2][::-1],keypoints_all_right_akaze[j:j+2][::-1],points_all_right_akaze[j:j+2][::-1],descriptors_all_right_akaze[j:j+2][::-1])
  H_right_akaze.append(H_a)
  #num_matches.append(matches)
  #num_good_matches.append(gd_matches)
```

```
H_left_brief = []
```

```
H_right_brief = []

num_matches_brief = []
num_good_matches_brief = []

for j in tqdm(range(len(images_left))):
  if j==len(images_left)-1:
    break

  H_a,matches,gd_matches = get_Hmatrix(images_left_bgr[j:j+2][::-1],keypoints_all_left_star[j:j+2][::-1],points_all_left_star[j:j+2][::-1],descriptors_all_left_brief[j:j+2][::-1])
  H_left_brief.append(H_a)
  num_matches_brief.append(matches)
  num_good_matches_brief.append(gd_matches)

for j in tqdm(range(len(images_right))):
  if j==len(images_right)-1:
    break

  H_a,matches,gd_matches = get_Hmatrix(images_right_bgr[j:j+2][::-1],keypoints_all_right_star[j:j+2][::-1],points_all_right_star[j:j+2][::-1],descriptors_all_right_brief[j:j+2][::-1])
  H_right_brief.append(H_a)
  #num_matches.append(matches)
  #num_good_matches.append(gd_matches)
```

```
H_left_surf = []
H_right_surf = []

num_matches_surf = []
num_good_matches_surf = []

for j in tqdm(range(len(images_left))):
  if j==len(images_left)-1:
    break

  H_a,matches,gd_matches = get_Hmatrix(images_left_bgr[j:j+2][::-1],keypoints_all_left_surf[j:j+2][::-1],points_all_left_surf[j:j+2][::-1],descriptors_all_left_surf[j:j+2][::-1],0.5)
  H_left_surf.append(H_a)
  num_matches_surf.append(matches)
  num_good_matches_surf.append(gd_matches)

for j in tqdm(range(len(images_right))):
  if j==len(images_right)-1:
    break

  H_a,matches,gd_matches = get_Hmatrix(images_right_bgr[j:j+2][::-1],keypoints_all_right_surf[j:j+2][::-1],points_all_right_surf[j:j+2][::-1],descriptors_all_right_surf[j:j+2][::-1],0.5)
  H_right_surf.append(H_a)
  #num_matches.append(matches)
  #num_good_matches.append(gd_matches)
```

```
    Number of Robust matches 515


     29%|███       | 9/31 [00:40<01:38,  4.46s/it]
    Number of matches 38137
    Number of matches After Lowe's Ratio 1246
    Number of Robust matches 1026


     32%|███       | 10/31 [00:44<01:34,  4.50s/it]
    Number of matches 38678
    Number of matches After Lowe's Ratio 902
    Number of Robust matches 805


     35%|███      | 11/31 [00:49<01:29,  4.47s/it]
    Number of matches 37766
```

```
  Number of matches 37760
  Number of matches After Lowe's Ratio 1471
  Number of Robust matches 1265


   39%|███▉      | 12/31 [00:53<01:24,  4.44s/it]
  Number of matches 38222
  Number of matches After Lowe's Ratio 2218
  Number of Robust matches 1959


   42%|████▏     | 13/31 [00:58<01:20,  4.48s/it]
  Number of matches 38270
  Number of matches After Lowe's Ratio 2048
  Number of Robust matches 1592


   45%|████▌     | 14/31 [01:02<01:15,  4.43s/it]
  Number of matches 38049
  Number of matches After Lowe's Ratio 1334
  Number of Robust matches 1263


   48%|████▊     | 15/31 [01:06<01:11,  4.46s/it]
  Number of matches 37650
  Number of matches After Lowe's Ratio 1163
  Number of Robust matches 1000


   52%|█████▏    | 16/31 [01:11<01:06,  4.45s/it]
  Number of matches 38907
  Number of matches After Lowe's Ratio 1190
  Number of Robust matches 1027


   55%|█████▍    | 17/31 [01:15<01:01,  4.40s/it]
  Number of matches 37406
  Number of matches After Lowe's Ratio 1257
  Number of Robust matches 1134


   58%|█████▊    | 18/31 [01:19<00:56,  4.33s/it]
  Number of matches 34700
  Number of matches After Lowe's Ratio 637
  Number of Robust matches 472
```

```
H_left_rootsift = []
H_right_rootsift = []

num_matches_rootsift = []
num_good_matches_rootsift = []

for j in tqdm(range(len(images_left))):
  if j==len(images_left)-1:
    break

  H_a,matches,gd_matches = get_Hmatrix(images_left_bgr[j:j+2][::-1],keypoints_all_left_rootsift[j:j+2][::-1],points_all_left_rootsift[j:j+2][::-1],descriptors_all_left_rootsift[j:j+2][::-1])
  H_left_rootsift.append(H_a)
  num_matches_rootsift.append(matches)
  num_good_matches_rootsift.append(gd_matches)

for j in tqdm(range(len(images_right))):
  if j==len(images_right)-1:
    break

  H_a,matches,gd_matches = get_Hmatrix(images_right_bgr[j:j+2][::-1],keypoints_all_right_rootsift[j:j+2][::-1],points_all_right_rootsift[j:j+2][::-1],descriptors_all_right_rootsift[j:j+2][::-1])
  H_right_rootsift.append(H_a)
  #num_matches.append(matches)
  #num_good_matches.append(gd_matches)
```

```
H_left_superpoint = []
H_right_superpoint = []

num_matches_superpoint = []
num_good_matches_superpoint = []

for j in tqdm(range(len(images_left))):
  if j==len(images_left)-1:
    break

  H_a,matches,gd_matches = get_Hmatrix(images_left_bgr[j:j+2][::-1],keypoints_all_left_superpoint[j:j+2][::-1],points_all_left_superpoint[j:j+2][::-1],descriptors_all_left_superpoint[j:j+2][::-1])
  H_left_superpoint.append(H_a)
  num_matches_superpoint.append(matches)
  num_good_matches_superpoint.append(gd_matches)

for j in tqdm(range(len(images_right))):
  if j==len(images_right)-1:
    break

  H_a,matches,gd_matches = get_Hmatrix(images_right_bgr[j:j+2][::-1],keypoints_all_right_superpoint[j:j+2][::-1],points_all_right_superpoint[j:j+2][::-1],descriptors_all_right_superpoint[j:j+2][::-1])
  H_right_superpoint.append(H_a)
  #num_matches.append(matches)
  #num_good_matches.append(gd_matches)
```

```
def warpnImages(images_left, images_right,H_left,H_right):
    #img1-centre,img2-left,img3-right

    h, w = images_left[0].shape[:2]

    pts_left = []
    pts_right = []

    pts_centre = np.float32([[0, 0], [0, h], [w, h], [w, 0]]).reshape(-1, 1, 2)

    for j in range(len(H_left)):
      pts = np.float32([[0, 0], [0, h], [w, h], [w, 0]]).reshape(-1, 1, 2)
      pts_left.append(pts)

    for j in range(len(H_right)):
      pts = np.float32([[0, 0], [0, h], [w, h], [w, 0]]).reshape(-1, 1, 2)
      pts_right.append(pts)

    pts_left_transformed=[]
    pts_right_transformed=[]



    for j,pts in enumerate(pts_left):
      if j==0:
        H_trans = H_left[j]
      else:
        H_trans = H_trans@H_left[j]
      pts_ = cv2.perspectiveTransform(pts, H_trans)
      pts_left_transformed.append(pts_)

    for j,pts in enumerate(pts_right):
      if j==0:
        H_trans = H_right[j]
      else:
        H_trans = H_trans@H_right[j]
      pts_ = cv2.perspectiveTransform(pts, H_trans)
      pts_right_transformed.append(pts_)


    print('Step1:Done')


    #pts = np.concatenate((pts1, pts2_), axis=0)

    pts_concat = np.concatenate((pts_centre,np.concatenate(np.array(pts_left_transformed),axis=0),np.concatenate(np.array(pts_right_transformed),axis=0)), axis=0)

    [xmin, ymin] = np.int32(pts_concat.min(axis=0).ravel() - 0.5)
    [xmax, ymax] = np.int32(pts_concat.max(axis=0).ravel() + 0.5)
    t = [-xmin, -ymin]
    Ht = np.array([[1, 0, t[0]], [0, 1, t[1]], [0, 0, 1]])  # translate

    print('Step2:Done')


    return xmax,xmin,ymax,ymin,t,h,w,Ht
```

```
def final_steps_left(images_left,images_right,H_left,H_right,xmax,xmin,ymax,ymin,t,h,w,Ht):

    warp_imgs_left = []


    for j,H in enumerate(H_left):
      if j==0:
        H_trans = Ht@H
      else:
        H_trans = H_trans@H
      result = cv2.warpPerspective(images_left[j+1], H_trans, (xmax-xmin, ymax-ymin))

      if j==0:
        result[t[1]:h+t[1], t[0]:w+t[0]] = images_left[0]

      warp_imgs_left.append(result)

    print('Step31:Done')

    return warp_imgs_left

def final_steps_right(images_left,images_right,H_left,H_right,xmax,xmin,ymax,ymin,t,h,w,Ht):

    warp_imgs_right = []

    for j,H in enumerate(H_right):
      if j==0:
        H_trans = Ht@H
      else:
        H_trans = H_trans@H
      result = cv2.warpPerspective(images_right[j+1], H_trans, (xmax-xmin, ymax-ymin))

      warp_imgs_right.append(result)

    print('Step32:Done')
    return warp_imgs_right

def final_steps_union(warp_imgs_left,warp_imgs_right):
    #Union

    warp_images_all = warp_imgs_left + warp_imgs_right

    warp_img_init = warp_images_all[0]



    #warp_final_all=[]

    for j,warp_img in enumerate(warp_images_all):
      if j==len(warp_images_all)-1:
        break
      black_pixels = np.where((warp_img_init[:, :, 0] == 0) & (warp_img_init[:, :, 1] == 0) & (warp_img_init[:, :, 2] == 0))

      warp_img_init[black_pixels] = warp_images_all[j+1][black_pixels]

      #warp_final = np.maximum(warp_img_init,warp_images_all[j+1])
      #warp_img_init = warp_final
      #warp_final_all.append(warp_final)

    print('Step4:Done')


    return warp_img_init
```

```
def final_steps_left_union(images_left,H_left,xmax,xmin,ymax,ymin,t,h,w,Ht):



    for j,H in enumerate(H_left):
      if j==0:
        H_trans = Ht@H
      else:
        H_trans = H_trans@H
      result = cv2.warpPerspective(images_left[j+1], H_trans, (xmax-xmin, ymax-ymin))
      warp_img_init_curr = result

      if j==0:
        result[t[1]:h+t[1], t[0]:w+t[0]] = images_left[0]
        warp_img_init_prev = result
        continue

      black_pixels = np.where((warp_img_init_prev[:, :, 0] == 0) & (warp_img_init_prev[:, :, 1] == 0) & (warp_img_init_prev[:, :, 2] == 0))

      warp_img_init_prev[black_pixels] = warp_img_init_curr[black_pixels]

    print('Step31:Done')

    return warp_img_init_prev

def final_steps_right_union(warp_img_prev,images_right,H_right,xmax,xmin,ymax,ymin,t,h,w,Ht):

    for j,H in enumerate(H_right):
      if j==0:
        H_trans = Ht@H
      else:
        H_trans = H_trans@H
      result = cv2.warpPerspective(images_right[j+1], H_trans, (xmax-xmin, ymax-ymin))
      warp_img_init_curr = result

      black_pixels = np.where((warp_img_prev[:, :, 0] == 0) & (warp_img_prev[:, :, 1] == 0) & (warp_img_prev[:, :, 2] == 0))

      warp_img_prev[black_pixels] = warp_img_init_curr[black_pixels]

    print('Step32:Done')

    return warp_img_prev
```

```
print(left_files_path)
```

```
print(right_files_path)
```

```
xmax,xmin,ymax,ymin,t,h,w,Ht = warpnImages(images_left_bgr_no_enhance, images_right_bgr_no_enhance,H_left_brisk,H_right_brisk)
```

```
Step1:Done
Step2:Done
```

```
warp_imgs_left = final_steps_left_union(images_left_bgr_no_enhance,H_left_brisk,xmax,xmin,ymax,ymin,t,h,w,Ht)
```

```
Step31:Done
```

```
warp_imgs_all_brisk = final_steps_right_union(warp_imgs_left, images_right_bgr_no_enhance,H_right_brisk,xmax,xmin,ymax,ymin,t,h,w,Ht)
```

```
Step32:Done
```

```
fig,ax =plt.subplots()
fig.set_size_inches(20,20)
ax.imshow(cv2.cvtColor(warp_imgs_all_brisk , cv2.COLOR_BGR2RGB))
ax.set_title('61-Images Mosaic-BRISK')
```

```
xmax,xmin,ymax,ymin,t,h,w,Ht = warpnImages(images_left_bgr_no_enhance, images_right_bgr_no_enhance,H_left_sift,H_right_sift)
```

```
Step1:Done
Step2:Done
```

```
warp_imgs_left = final_steps_left_union(images_left_bgr_no_enhance,H_left_sift,xmax,xmin,ymax,ymin,t,h,w,Ht)
```

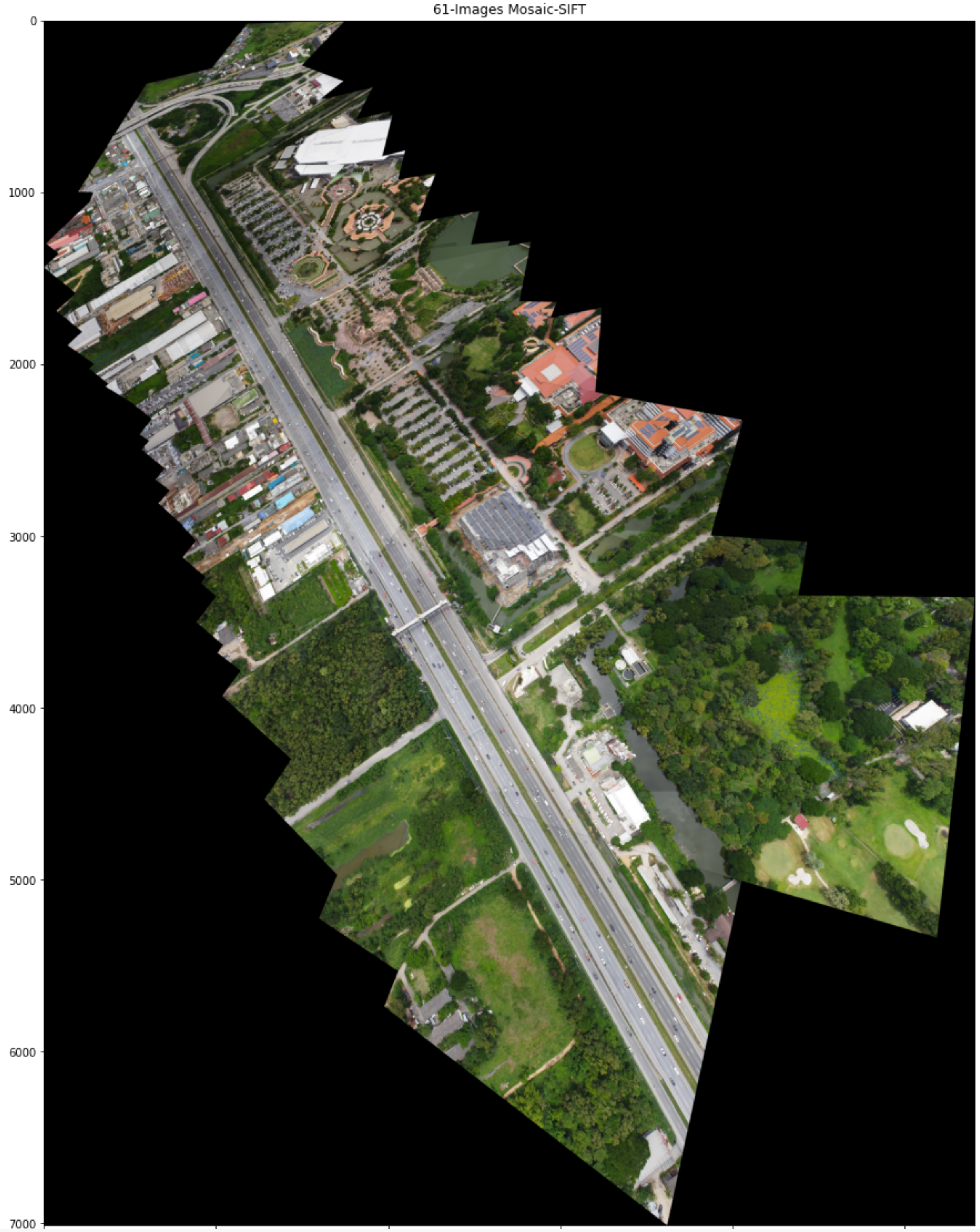
```
Step31:Done
```

```
warp_imgs_all_sift = final_steps_right_union(warp_imgs_left,images_right_bgr_no_enhance,H_right_sift,xmax,xmin,ymax,ymin,t,h,w,Ht)
```

```
Step32:Done
```

```
fig,ax =plt.subplots()
fig.set_size_inches(20,20)
ax.imshow(cv2.cvtColor(warp_imgs_all_sift , cv2.COLOR_BGR2RGB))
ax.set_title('61-Images Mosaic-SIFT')
```

```
Text(0.5, 1.0, '61-Images Mosaic-SIFT')
```



```
fig.savefig('drive/MyDrive/61.png',dpi=300)
```

```
xmax,xmin,ymax,ymin,t,h,w,Ht = warpnImages(images_left_bgr_no_enhance, images_right_bgr_no_enhance,H_left_rootsift,H_right_rootsift)
```

```
    Step1:Done
    Step2:Done
    time: 2.82 ms (started: 2021-06-15 15:10:58 +00:00)
```

```
warp_imgs_left = final_steps_left_union(images_left_bgr_no_enhance,H_left_rootsift,xmax,xmin,ymax,ymin,t,h,w,Ht)
```

```
    Step31:Done
    time: 41.1 s (started: 2021-06-15 15:10:58 +00:00)
```

```
warp_imgs_all_rootsift = final_steps_right_union(warp_imgs_left,images_right_bgr_no_enhance,H_right_rootsift,xmax,xmin,ymax,ymin,t,h,w,Ht)
```

```
    Step32:Done
    time: 36.7 s (started: 2021-06-15 15:11:39 +00:00)
```

```
xmax,xmin,ymax,ymin,t,h,w,Ht = warpnImages(images_left_bgr_no_enhance, images_right_bgr_no_enhance,H_left_orb,H_right_orb)
```

```
    Step1:Done
    Step2:Done
    time: 3.51 ms (started: 2021-06-15 15:12:16 +00:00)
```

```
warp_imgs_left = final_steps_left_union(images_left_bgr_no_enhance,H_left_orb,xmax,xmin,ymax,ymin,t,h,w,Ht)
```

```
warp_imgs_all_orb = final_steps_right_union(warp_imgs_left,images_right_bgr_no_enhance,H_right_orb,xmax,xmin,ymax,ymin,t,h,w,Ht)
```

```
xmax,xmin,ymax,ymin,t,h,w,Ht = warpnImages(images_left_bgr_no_enhance, images_right_bgr_no_enhance,H_left_kaze,H_right_kaze)
```

```
warp_imgs_left = final_steps_left_union(images_left_bgr_no_enhance,H_left_kaze,xmax,xmin,ymax,ymin,t,h,w,Ht)
```

```
warp_imgs_all_kaze = final_steps_right_union(warp_imgs_left,images_right_bgr_no_enhance,H_right_kaze,xmax,xmin,ymax,ymin,t,h,w,Ht)
```

```
xmax,xmin,ymax,ymin,t,h,w,Ht = warpnImages(images_left_bgr_no_enhance, images_right_bgr_no_enhance,H_left_akaze,H_right_akaze)
```

```
warp_imgs_left = final_steps_left_union(images_left_bgr_no_enhance,H_left_akaze,xmax,xmin,ymax,ymin,t,h,w,Ht)
```

```
warp_imgs_all_akaze = final_steps_right_union(warp_imgs_left,images_right_bgr_no_enhance,H_right_akaze,xmax,xmin,ymax,ymin,t,h,w,Ht)
```

```
xmax,xmin,ymax,ymin,t,h,w,Ht = warpnImages(images_left_bgr_no_enhance, images_right_bgr_no_enhance,H_left_surf,H_right_surf)
```

```
warp_imgs_left = final_steps_left_union(images_left_bgr_no_enhance,H_left_surf,xmax,xmin,ymax,ymin,t,h,w,Ht)
```

```
warp_imgs_all_surf = final_steps_right_union(warp_imgs_left,images_right_bgr_no_enhance,H_right_surf,xmax,xmin,ymax,ymin,t,h,w,Ht)
```

```
xmax,xmin,ymax,ymin,t,h,w,Ht = warpnImages(images_left_bgr_no_enhance, images_right_bgr_no_enhance,H_left_brief,H_right_brief)
```

```
warp_imgs_left = final_steps_left_union(images_left_bgr_no_enhance,H_left_brief,xmax,xmin,ymax,ymin,t,h,w,Ht)
```

```
warp_imgs_all_brief = final_steps_right_union(warp_imgs_left,images_right_bgr_no_enhance,H_right_brief,xmax,xmin,ymax,ymin,t,h,w,Ht)
```

```
xmax,xmin,ymax,ymin,t,h,w,Ht = warpnImages(images_left_bgr_no_enhance, images_right_bgr_no_enhance,H_left_superpoint,H_right_superpoint)
```

```
warp_imgs_left = final_steps_left_union(images_left_bgr_no_enhance,H_left_superpoint,xmax,xmin,ymax,ymin,t,h,w,Ht)
```

```
warp_imgs_all_superpoint = final_steps_right_union(warp_imgs_left,images_right_bgr_no_enhance,H_right_superpoint,xmax,xmin,ymax,ymin,t,h,w,Ht)
```

```
plt.figure(figsize = (25,25))

plt.imshow(cv2.cvtColor(warp_imgs_all , cv2.COLOR_BGR2RGB))
plt.title('61-Images Mosaic-SIFT')
```

```
plt.savefig('drive/MyDrive/61Images_Mosaic_sift.png',dpi=300)
plt.show()
```

```
     <Figure size 432x288 with 0 Axes>
     time: 254 ms (started: 2021-06-15 13:02:01 +00:00)
```

```
plt.show()
```

```
     time: 745 µs (started: 2021-06-15 13:02:33 +00:00)
```

✓ 4m 29s completed at 8:14 PM