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In [1]: 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
```

```
In [2]: 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).
```

```
In [3]: 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=[0]
            minval2=[1]
            itemindex1 = listx.index(minval1) #min
            itemindex2 = listx.index(minval2) #index of second min value
            ratio=minval1/minval2 #Ratio Test

            if ratio
  


```
def compute_Homography(im1_pts,im2_pts):
 """
 im1_pts and im2_pts are 2xn 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_y*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()
```


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In [4]: def RANSAC_alg(f1, f2, matches, nRANSAC, RANSACthresh):
```

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    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][0]=m.pt[0]
            im1_pts[i][1]=m.pt[1]
            im2_pts[i][0]=m.pt[0]
            im2_pts[i][1]=m.pt[1]
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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

```

In [5]:

```

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 ImageBounds(img, H):

    h, w = img.shape[0], img.shape[1]
    p1 = np.dot(H, np.array([0, 0, 1]))
    p2 = np.dot(H, np.array([0, h - 1, 1]))
    p3 = np.dot(H, np.array([w - 1, 0, 1]))
    p4 = np.dot(H, np.array([w - 1, h - 1, 1]))
    x1 = p1[0] / p1[2]
    y1 = p1[1] / p1[2]
    x2 = p2[0] / p2[2]
    y2 = p2[1] / p2[2]
    x3 = p3[0] / p3[2]
    y3 = p3[1] / p3[2]
    x4 = p4[0] / p4[2]
    y4 = p4[1] / p4[2]
    minX = math.ceil(min(x1, x2, x3, x4))
    minY = math.ceil(min(y1, y2, y3, y4))
    maxX = math.ceil(max(x1, x2, x3, x4))
    maxY = math.ceil(max(y1, y2, y3, y4))

    return int(minX), int(minY), int(maxX), int(maxY)

def Populate_Images(img, accumulator, H, bw):

    h, w = img.shape[0], img.shape[1]
    minX, minY, maxX, maxY = ImageBounds(img, H)

    for i in range(minX, maxX + 1):
        for j in range(minY, maxY + 1):
            p = np.dot(np.linalg.inv(H), np.array([i, j, 1]))

            x = p[0]
            y = p[1]
            z = p[2]

            _x = int(x / z)
            _y = int(y / z)

            if _x < 0 or _x >= w - 1 or _y < 0 or _y >= h - 1:
                continue

            if img[_y, _x, 0] == 0 and img[_y, _x, 1] == 0 and img[_y, _x, 2] == 0:
                continue

            wt = 1.0

            if _x >= minX and _x < minX + bw:
                wt = float(_x - minX) / bw
            if _x <= maxX and _x > maxX - bw:
                wt = float(maxX - _x) / bw

            accumulator[j, i, 3] += wt

            for c in range(3):
                accumulator[j, i, c] += img[_y, _x, c] *wt

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In [6]:

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def Image_Stitch(Imagesall, blendWidth, accWidth, accHeight, translation):
    channels=3
    #width=720

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acc = np.zeros((accHeight, accWidth, channels + 1))
M = np.identity(3)
for count, i in enumerate(Imagesall):
    M = i.position
    img = i.img
    M_trans = translation.dot(M)
    Populate_Images(img, acc, M_trans, blendWidth)

height, width = acc.shape[0], acc.shape[1]

img = np.zeros((height, width, 3))
for i in range(height):
    for j in range(width):
        weights = acc[i, j, 3]
        if weights > 0:
            for c in range(3):
                img[i, j, c] = int(acc[i, j, c] / weights)

Imagefull = np.uint8(img)
M = np.identity(3)
for count, i in enumerate(Imagesall):
    if count != 0 and count != (len(Imagesall) - 1):
        continue
    M = i.position
    M_trans = translation.dot(M)
    p = np.array([0.5 * width, 0, 1])
    p = M_trans.dot(p)

    if count == 0:
        x_init, y_init = p[2] / p[0]
    if count == (len(Imagesall) - 1):
        x_final, y_final = p[2] / p[0]

A = np.identity(3)
croppedImage = cv2.warpPerspective(
    Imagefull, A, (accWidth, accHeight), flags=cv2.INTER_LINEAR
)
displayplot(croppedImage, 'Final Stitched Image')

```

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In [7]: files_all = os.listdir('/content/drive/My Drive/Aerial/')
files_all.sort()
folder_path = '/content/drive/My Drive/Aerial/'

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

for file in files_all[1:16]:
    left_files_path_rev.append(folder_path + file)

left_files_path = left_files_path_rev[::-1]

for file in files_all[15:30]:
    right_files_path.append(folder_path + file)

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In [8]: from PIL import Image, ExifTags
img = Image.open(f"{left_files_path[0]}")
exif = {ExifTags.TAGS[k]: v for k, v in img._getexif().items() if k in ExifTags.TAGS}
from PIL.ExifTags import TAGS

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

exif = get_exif(f"{left_files_path[0]}")
labeled = get_labeled_exif(exif)
print(labeled)
from PIL.ExifTags import GPSTAGS

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
all_files_path = left_files_path[::-1] + right_files_path[1:]
for file1 in all_files_path:
    exif = get_exif(f"{file1}")
    geotags = get_geotagging(exif)
    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'])

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fig, ax = plt.subplots()
fig.set_size_inches(20,10)
ax.set_xlabel('Latitude')
ax.set_ylabel('Longitude')
ax.set_xlim(100,101)
#ax.set_xlim(12,16)

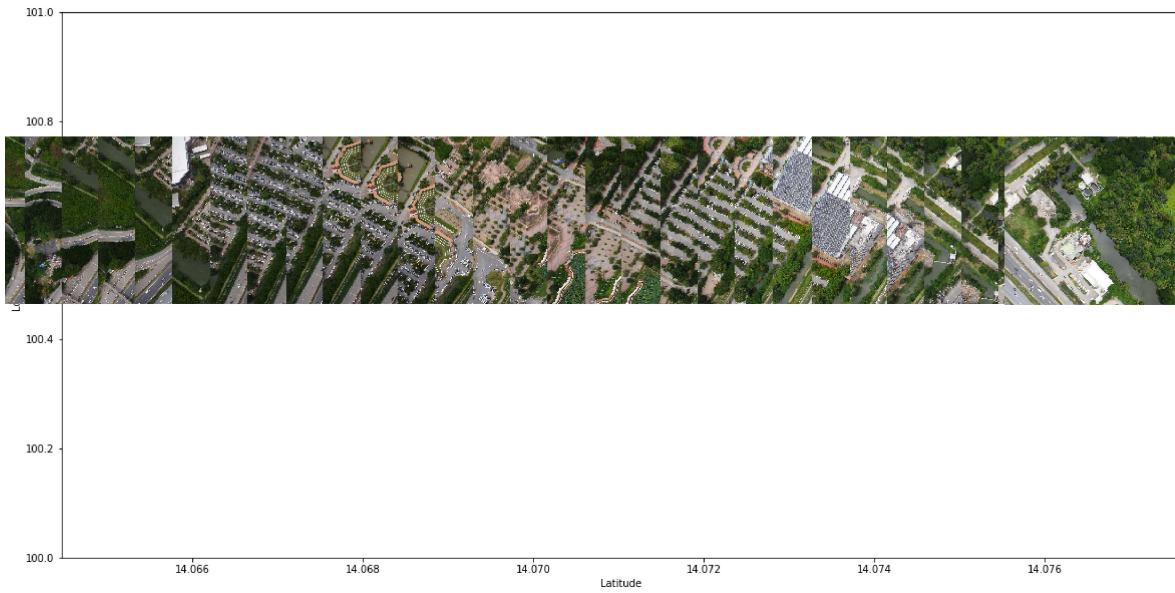
len1 = 50
ax.plot(np.array(all_geocoords)[:len1,0], np.array(all_geocoords)[:len1,1], linestyle='None')

def aerial_images_register(x, y, ax=None):
    ax = ax or plt.gca()
    for count, points in enumerate(zip(x,y)):
        lat,lon = points
        image = plt.imread(all_files_path[count])
        #print(ax.figure.dpi)
        im = OffsetImage(image, zoom=3/ax.figure.dpi)
        im.image.axes = ax
        ab = AnnotationBbox(im, (lat,lon), frameon=False, pad=0.0,)

        ax.add_artist(ab)

aerial_images_register(np.array(all_geocoords)[:len1,0], np.array(all_geocoords)[:len1,1], ax=ax)

```



```
In [10]: images_left = []
images_right = []

for file in tqdm(left_files_path):
    left_image_sat= cv2.imread(file)
    left_img = cv2.resize(left_image_sat,None,fx=0.30, fy=0.30, interpolation = cv2.INTER_CUBIC)
    images_left.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=0.30, fy=0.30, interpolation = cv2.INTER_CUBIC)
    images_right.append(right_img)
```

```
In [11]: #brisk = cv2.KAZE_create()
Threshl=60;
Octaves=6;
#PatternScales=1.0f;
brisk = cv2.BRISK_create(Threshl,Octaves)
#brisk = cv2.SIFT_create()
#brisk = cv2.AKAZE_create()

keypoints_all_left = []
descriptors_all_left = []
points_all_left=[]

keypoints_all_right = []
descriptors_all_right = []
points_all_right=[]

for imgs in tqdm(images_left):
    kpt = brisk.detect(imgs,None)
    kpt,descrip = brisk.compute(imgs, kpt)
    keypoints_all_left.append(kpt)
    descriptors_all_left.append(descrip)
    points_all_left.append(np.asarray([[p.pt[0], p.pt[1]] for p in kpt]))

for imgs in tqdm(images_right):
    kpt = brisk.detect(imgs,None)
    kpt,descrip = brisk.compute(imgs, kpt)
    keypoints_all_right.append(kpt)
    descriptors_all_right.append(descrip)
    points_all_right.append(np.asarray([[p.pt[0], p.pt[1]] for p in kpt]))
```

```
In [12]: def get_Hmatrix(imgs,keypts,pts,descripts,disp=True):
    #FLANN INDEX KDTREE = 1
    #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(len(matches_lf1_lf))

    matches_4 = []
    ratio = 0.8
    # 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",len(matches_4))

    # Estimate homography
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```

#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) = keypoints[0][m.queryIdx].pt
    (b_x, b_y) = keypoints[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=RANSAC_alg(keypts[0] ,keypts[1], matches_4, nRANSAC=1500, RANSACthresh=6)
global inlier_matchset

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

return Hn/Hn[2,2]

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In [13]:
H_left = []
H_right = []

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

    H_a = get_Hmatrix(images_left[j:j+2][::-1],keypoints_all_left[j:j+2][::-1],points_all_left[j:j+2][::-1],descriptors_all_left[j:j+2][::-1])
    H_left.append(H_a)

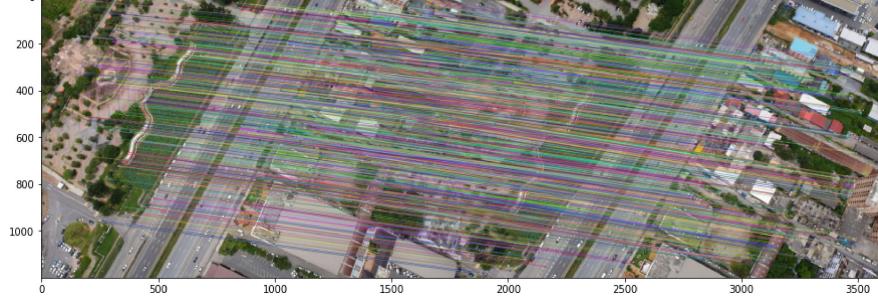
for j in tqdm(range(len(images_right))):
    if j==len(images_right)-1:
        break

    H_a = get_Hmatrix(images_right[j:j+2][::-1],keypoints_all_right[j:j+2][::-1],points_all_right[j:j+2][::-1],descriptors_all_right[j:j+2][::-1])
    H_right.append(H_a)

```

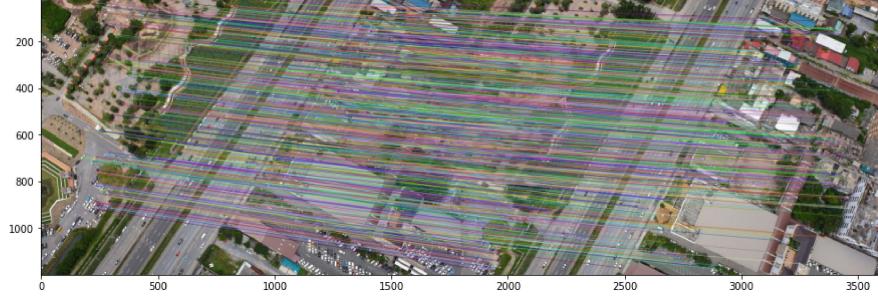
Number of matches 1643
Number of best inliers 1192

Robust Matching between Reference Image and Right Image



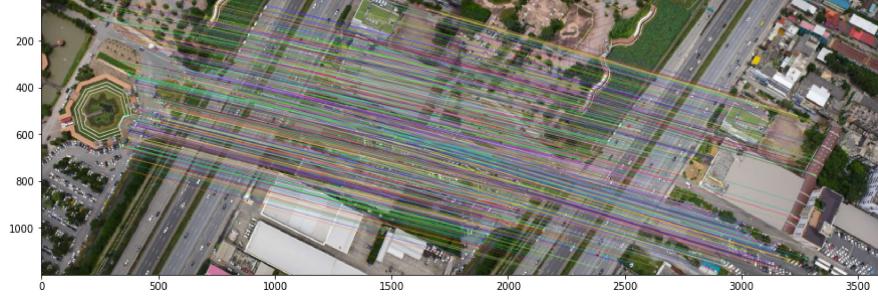
Number of matches 1565
Number of best inliers 1172

Robust Matching between Reference Image and Right Image

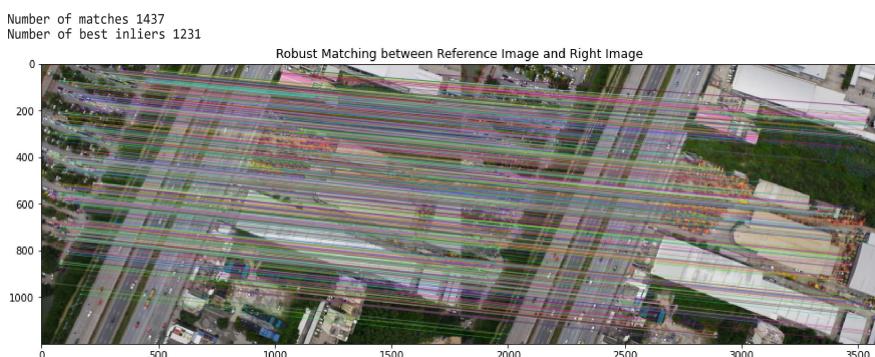
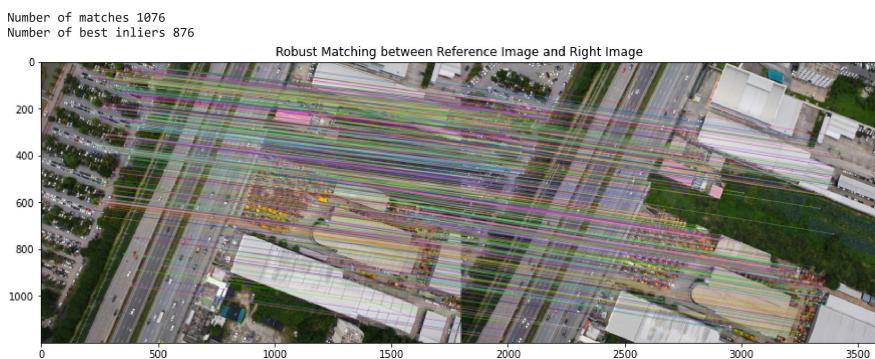
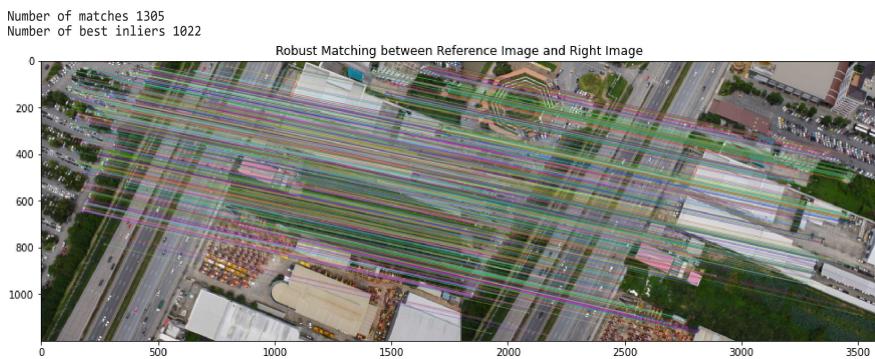
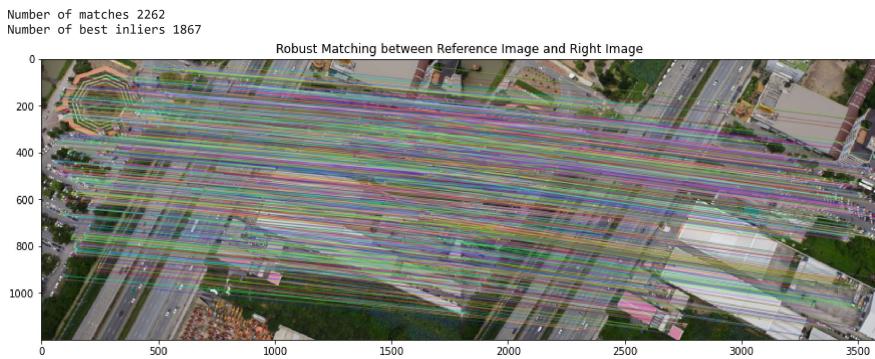
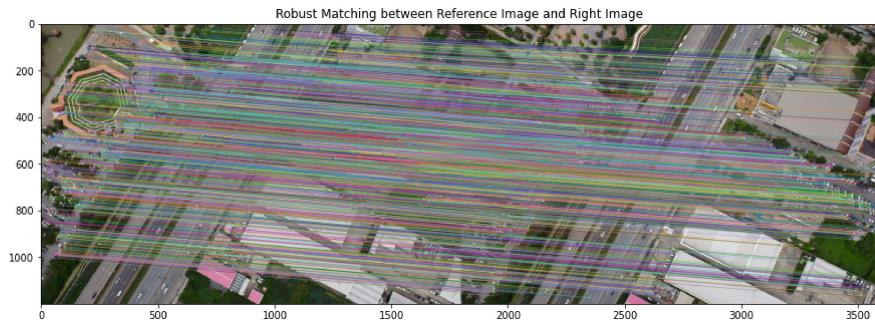


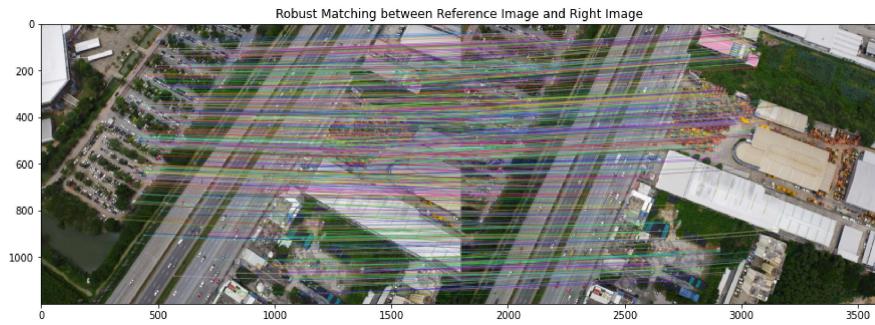
Number of matches 1306
Number of best inliers 947

Robust Matching between Reference Image and Right Image

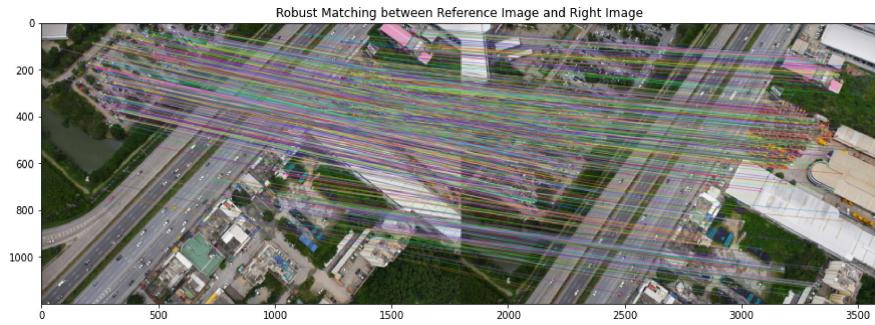


Number of matches 2382
Number of best inliers 1974

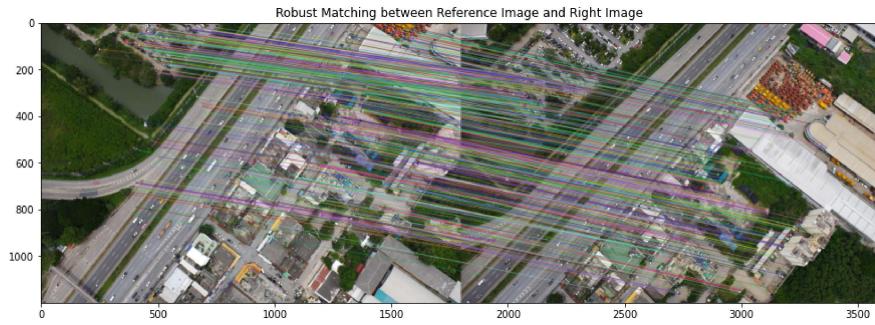




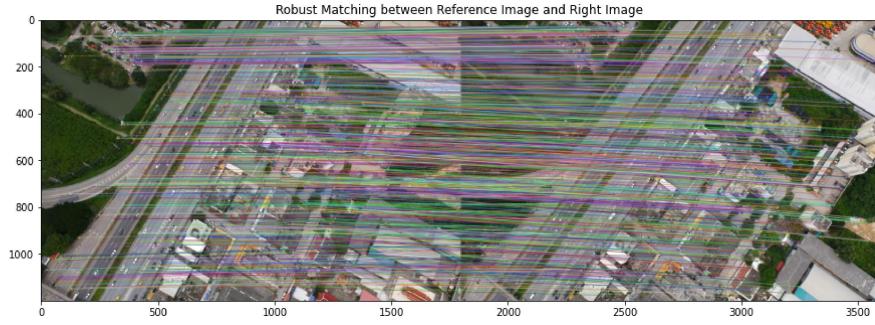
Number of matches 1277
Number of best inliers 1061



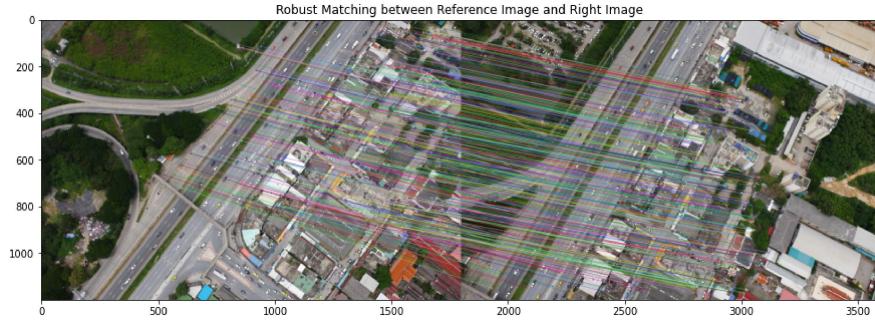
Number of matches 1003
Number of best inliers 646



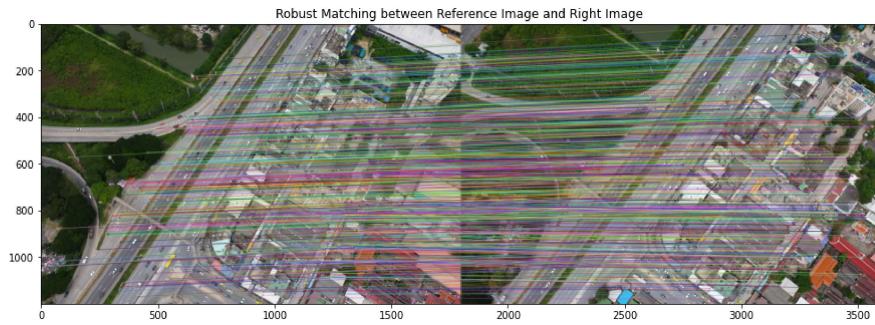
Number of matches 1614
Number of best inliers 1020



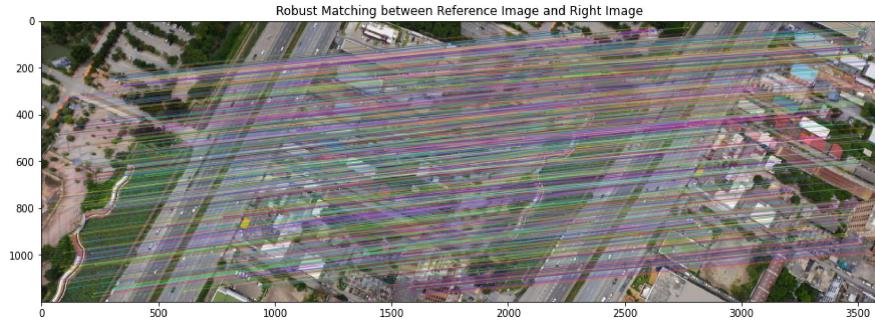
Number of matches 909
Number of best inliers 477



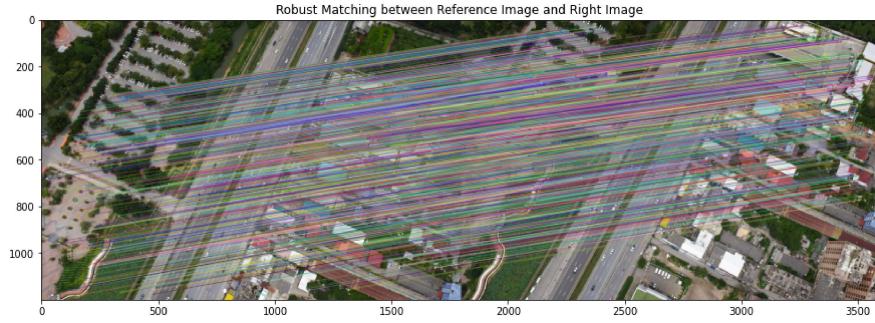
Number of matches 1388
Number of best inliers 825



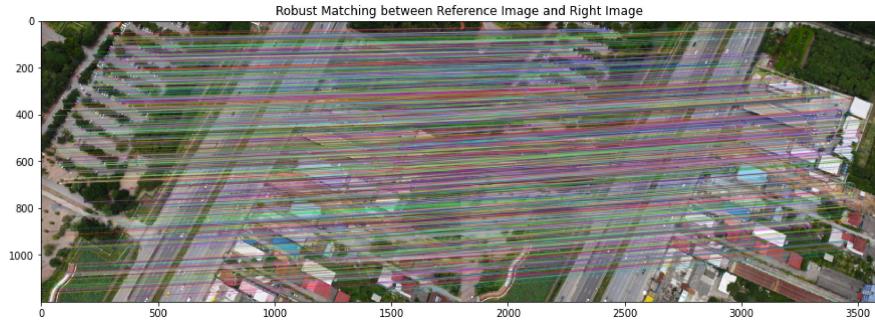
Number of matches 1731
Number of best inliers 1323



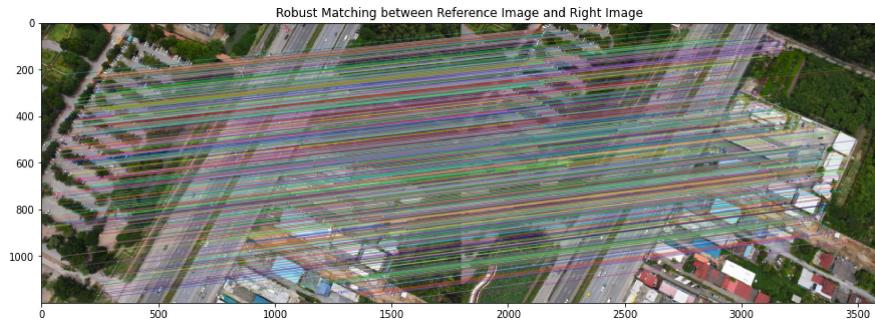
Number of matches 1609
Number of best inliers 1344



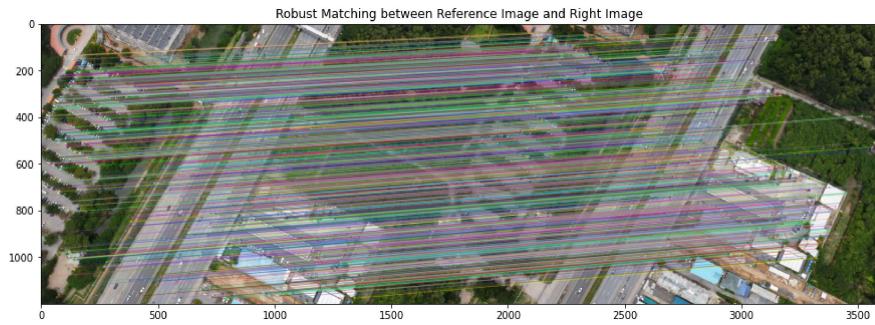
Number of matches 1830
Number of best inliers 1577



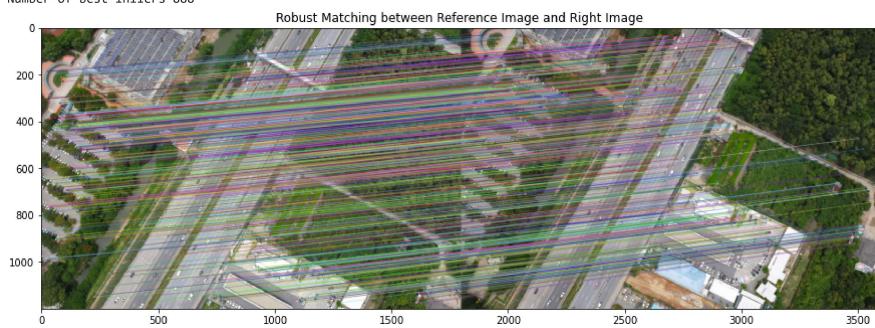
Number of matches 1781
Number of best inliers 1523



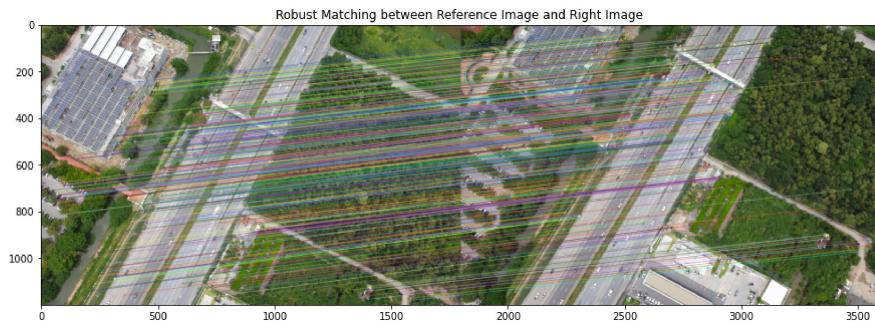
Number of matches 1549
Number of best inliers 1296



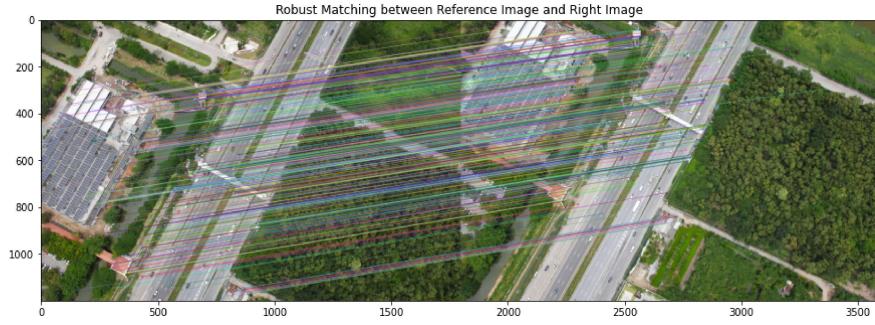
Number of matches 1190
Number of best inliers 888



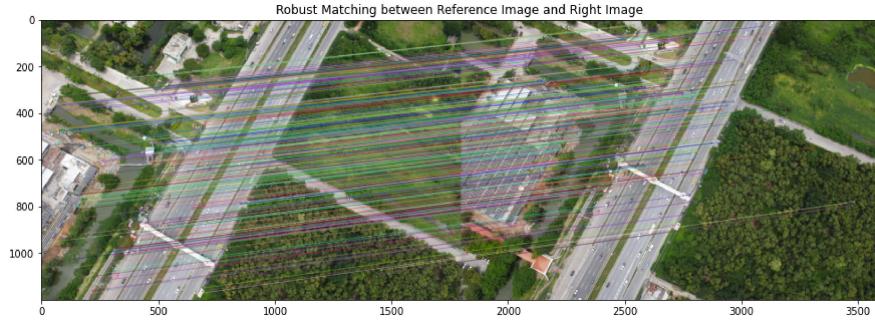
Number of matches 850
Number of best inliers 469



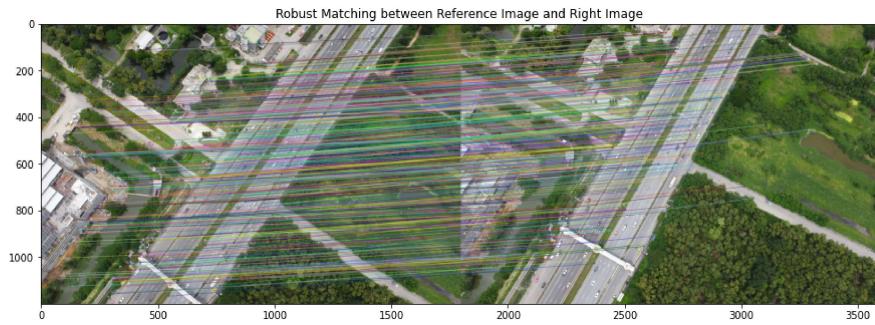
Number of matches 961
Number of best inliers 422



Number of matches 608
Number of best inliers 371

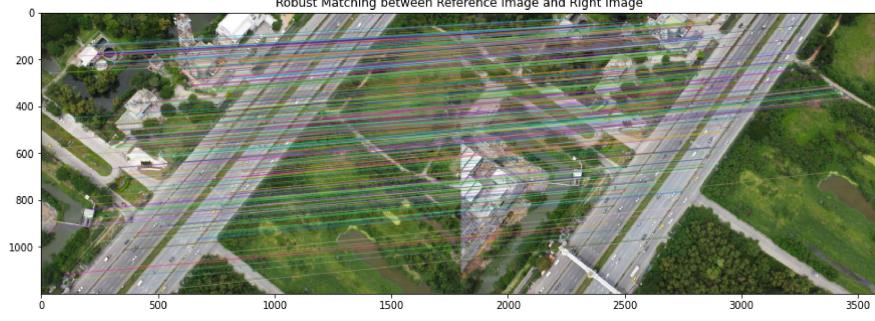


Number of matches 853
Number of best inliers 577



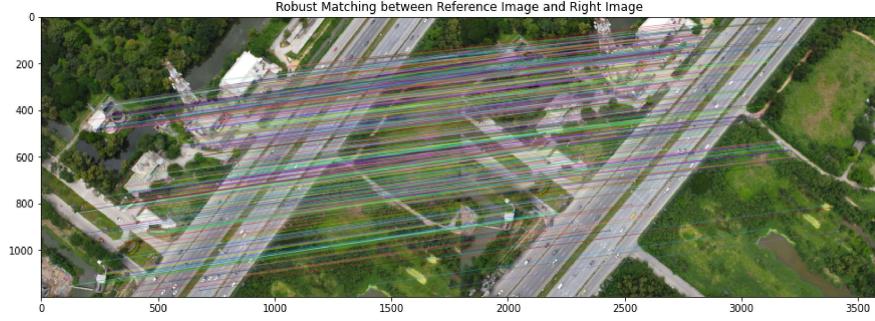
Number of matches 606

Number of best inliers 459



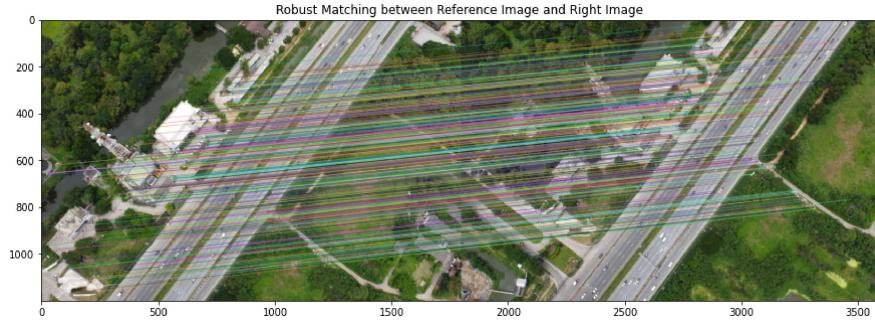
Number of matches 910

Number of best inliers 614



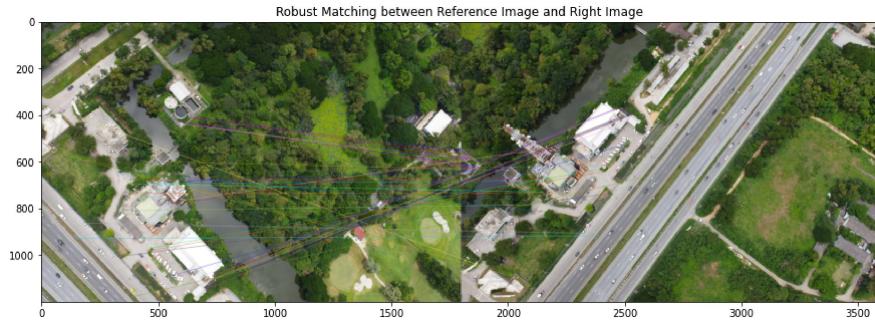
Number of matches 795

Number of best inliers 519



Number of matches 85

Number of best inliers 38



In [14]:

```
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_)

#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')

warp_imgs_left = []
warp_imgs_right = []

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)

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('Step3:Done')

#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
    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_final,warp_final_all

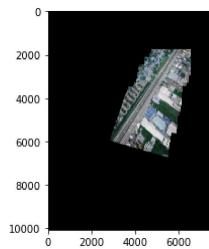
```

In [15]: combined_warp_n,warp_all = warpnImages(images_left, images_right,H_left,H_right)

Step2:Done
Step3:Done
Step4:Done

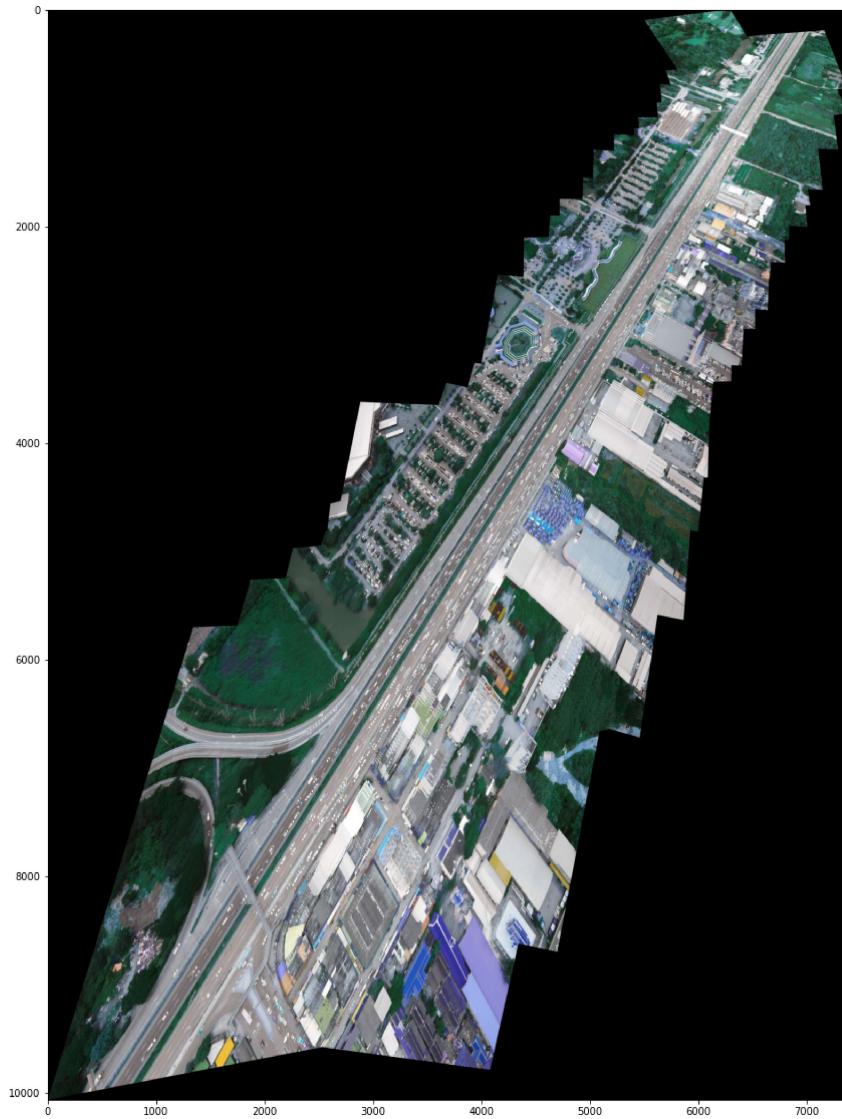
In [16]: plt.imshow(warp_all[6])

Out[16]: <matplotlib.image.AxesImage at 0x7fcbebbeda890>



```
In [17]: plt.figure(figsize = (25,20))
plt.imshow(combined_warp_n)
```

```
Out[17]: <matplotlib.image.AxesImage at 0x7fcbebbe326d0>
```



```
In [18]: combo_rgb = cv2.cvtColor(combined_warp_n, cv2.COLOR_BGR2RGB)
```

```
In [19]: plt.figure(figsize = (25,15))
```

```
plt.imshow(combo_rgb)
plt.title('30 Images Mosaic')
```

```
Out[19]: Text(0.5, 1.0, '10 Images Mosaic')
```

