CSL7650 Autonomous Systems

Programming assignment Report

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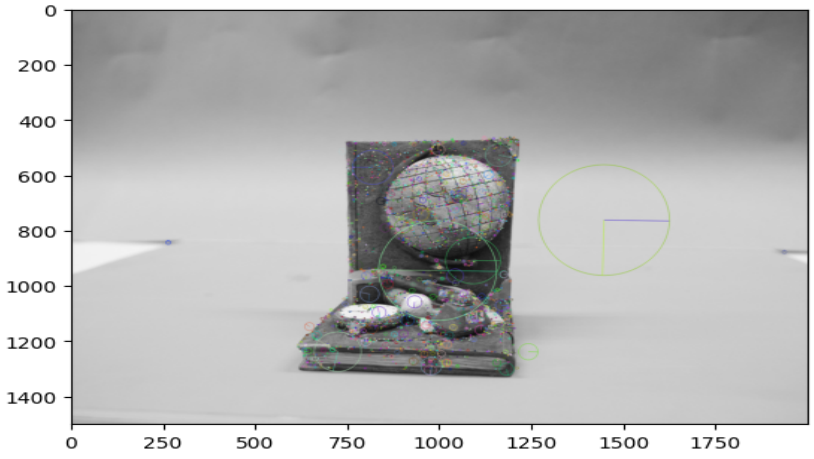
Camera Calibration

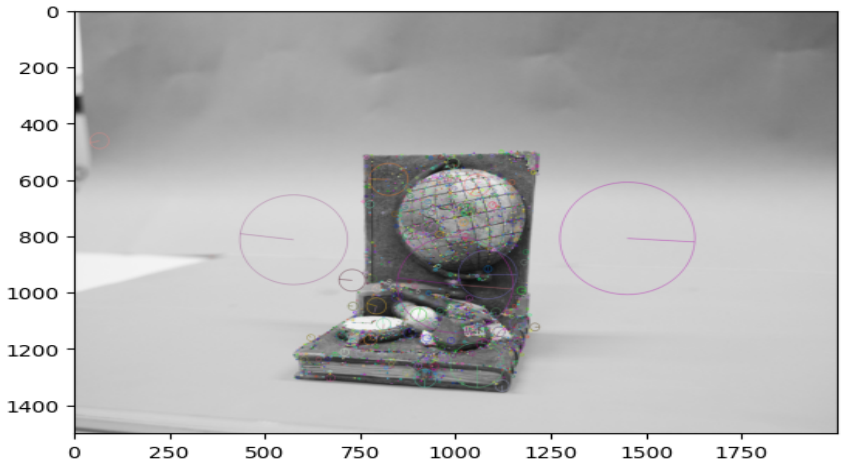
Camera calibration involves various stages whose results have been depicted here.We have extracted out the key points from two camera poses of the same image. By the use of these poses we have extracted the extrinsic camera properties which includes essential matrix,

➔ Ground Truth Correspondences

Here for finding the Ground truth Correspondences via Key points we have used the two feature detectors SIFT (Scale Invariant Feature Transform) and ORB () feature detector.

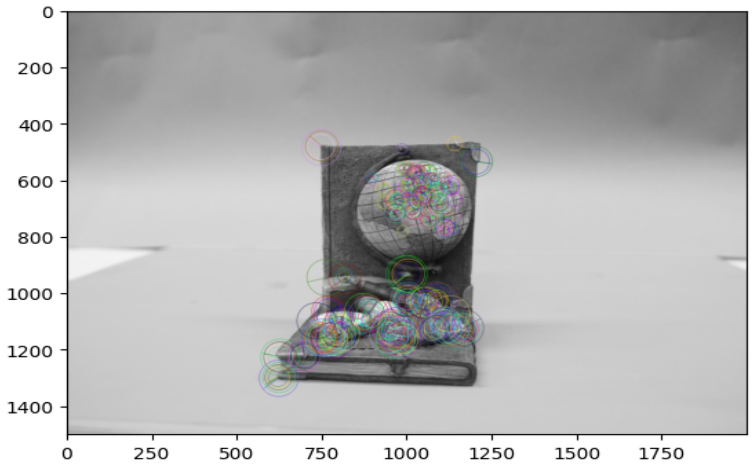
Key Points used by the SIFT feature detector on image 1 and image 2 are :

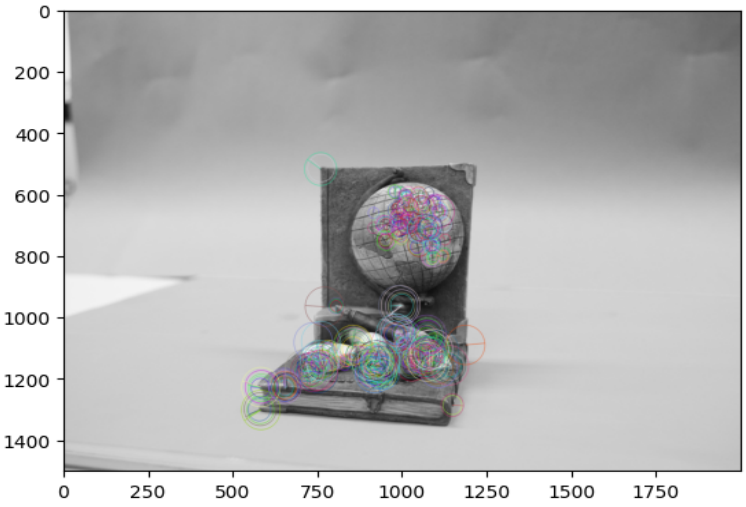




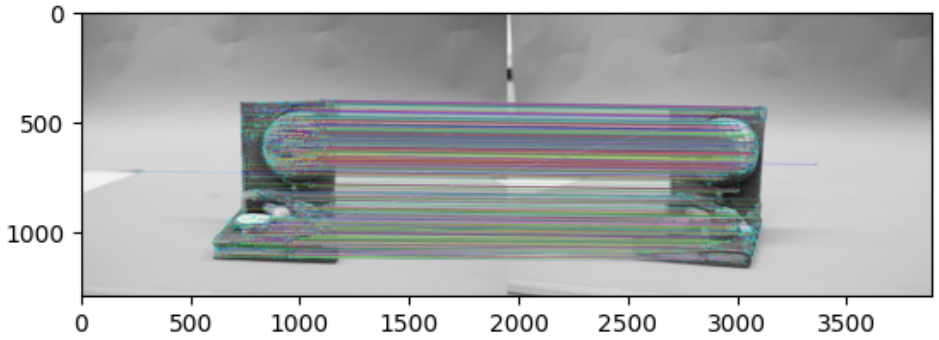
The Circular markings made on the above gray scale images depict the key points of the images .

Similarly we have also extracted the key points using the ORB feature detector.

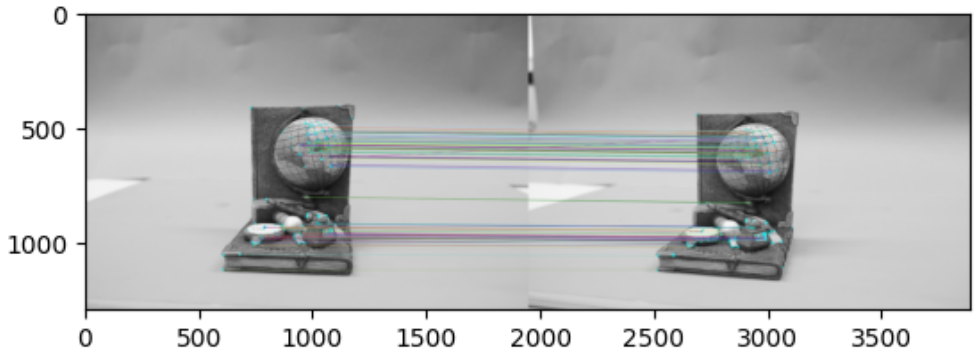




The above shown images and the circular markings on them are the key points of each of the two images given as input.
After finding the correspondences from each of the feature detector ,
We have found out the number of good matches for the both feature detectors -:



SIFT points matching (1272 correspondences found)



ORB points matching (117 correspondences found)

➔ Essential Matrix

Essential matrix is the product of the translation and rotation matrix. It is computed with the equation y'E x = 0 where y' is the y transpose with the multiple correspondences we have found E as shown below
Essential matrix -:

```
[[-0.00757833  0.12840393  0.09556399]  [[ 0.01432569 -0.11319563 -0.12980625]
 [-0.06482389  0.02040652 -0.69775494]   [ 0.03097322 -0.02756708  0.69450243]
 [-0.08552341  0.68950089  0.01078301]]  [ 0.11640156 -0.68731958 -0.01101947]]
```

SIFT Essential matrix ORB Essential Matrix

Shapes of the 2d pixels from each feature coordinates in the image planes are :

```
Shapes of the Pixel points of image1 and Image 2 respectively(SIFT_feature)  :  (1272, 1, 2) (1272, 1, 2)
Shapes of the Pixel points of image1 and Image 2 respectively(ORB_feature)  :  (117, 1, 2) (117, 1, 2)
```

➔ Decomposition of Essential matrix

The Essential matrix is composed of [t]x R so on Decomposition we have retrieved the Rotation and translation matrices for both the feature extractor that is SIFT and ORB
Rotation Matrices :

```
[[ 0.99541556 -0.01188257  0.09490344]
 [ 0.00922662  0.99955474  0.02837576]
 [-0.09519836 -0.02737003  0.99508198]]
```

SIFT

```
[[ 0.99200548 -0.01773207  0.12494279]
 [ 0.01293737  0.99915223  0.03908265]
 [-0.12552989 -0.03715377  0.99139389]]
```

ORB

Translation Matrices :

```
[[-0.97398411]
[-0.13053337]
[ 0.18524576]]
```

SIFT

```
[[-0.96967197]
[-0.1785894 ]
[ 0.16685952]]
```

ORB

The method used here for the decomposition is the QR decomposition.

[R | t] for SIFT :

```
[[ 0.99541556 -0.01188257  0.09490344 -0.97398411]
 [ 0.00922662  0.99955474  0.02837576 -0.13053337]
 [-0.09519836 -0.02737003  0.99508198  0.18524576]]
```

[R | t] for ORB :

```
[[ 0.99200548 -0.01773207  0.12494279 -0.96967197]
[ 0.01293737  0.99915223  0.03908265 -0.1785894 ]
[-0.12552989 -0.03715377  0.99139389  0.16685952]]
```

➔ 3D points extraction via Triangulation theorem

From the 2d correspondences we can find the 3d points using the camera calibration equation using the triangulation theorem.
Below is the result of the triangulation theorem with the both of the feature detector the Pi is calculated here SIFT have (4 , 1272) size where there are normalized so 4th row has 1 as its value and ORB has (4 , 117) size .

SIFT -:

```
[[1.1909398e+00 1.1834239e+00 1.1845342e+00 1.1912988e+00 1.2060223e+00
  1.1814338e+00 1.1324747e+00 1.1314408e+00 1.1950358e+00 1.2012560e+00
  1.1898530e+00 1.1934446e+00 1.1970673e+00 1.1896806e+00 1.0833751e+00
  1.1830916e+00 1.2059479e+00 1.2051119e+00 1.1963143e+00 1.1747341e+00
  1.2045070e+00 1.0787779e+00 1.1869465e+00 1.2015171e+00 1.0820101e+00
  1.0909575e+00 1.1945724e+00 1.1821157e+00 1.0613389e+00 1.1916449e+00
  1.0878725e+00 1.0736783e+00 1.2049937e+00 1.1315261e+00 1.2043326e+00
  1.1334068e+00 1.1965230e+00 1.0871100e+00 1.1102571e+00 1.2053866e+00
  1.1877887e+00 1.2092268e+00 1.1942443e+00 1.1829220e+00 1.1915013e+00
  1.1338509e+00 1.1831464e+00 1.1946213e+00 1.1834008e+00 1.2051802e+00
  1.1961442e+00 1.1944929e+00 1.0839145e+00 1.1858736e+00 1.1948357e+00
  1.1954385e+00 1.1857632e+00 1.1817560e+00 1.1035240e+00 1.1834877e+00
  1.2022905e+00 1.1831506e+00 1.1888829e+00 1.1314918e+00 1.1916093e+00
  1.0732682e+00 1.0748558e+00 1.1944302e+00 1.2044474e+00 1.1829269e+00
  1.1827136e+00 1.2053335e+00 1.0612580e+00 1.1910348e+00 1.2002749e+00
  1.1944604e+00 1.1847737e+00 1.1944281e+00 1.1914600e+00 1.2042646e+00
  1.1831963e+00 1.1955549e+00 1.1269268e+00 1.1932120e+00 1.1900070e+00
  1.1315784e+00 1.1957520e+00 1.1913484e+00 1.1886103e+00 1.1336381e+00
  1.1294013e+00 1.1099701e+00 1.1268867e+00 1.0607125e+00 1.1052126e+00
  1.0644540e+00 1.1039503e+00 1.0723389e+00 1.0864295e+00 1.1918415e+00
  1.1833066e+00 1.1467867e+00 1.0650003e+00 1.0762950e+00 1.1466191e+00
  1.1920104e+00 1.1270400e+00 1.1945503e+00 1.1027914e+00 1.1467394e+00
  1.0598391e+00 1.1049372e+00 1.0326517e+00 1.1455084e+00 1.1465220e+00
  9.9327177e-01 1.1025265e+00]
 [4.8853067e-01 5.1481831e-01 5.1098263e-01 4.8732838e-01 4.3802196e-01
  5.1859987e-01 6.8084747e-01 6.8436408e-01 4.7382653e-01 4.5449084e-01
  4.9268788e-01 4.7915688e-01 4.6906281e-01 4.9340841e-01 8.4623057e-01
  5.1474673e-01 4.3925616e-01 4.4025150e-01 4.7060364e-01 5.4336661e-01
  4.4188198e-01 8.6172152e-01 5.0050282e-01 4.5264640e-01 8.5074425e-01
  8.2061660e-01 4.7545013e-01 5.1715219e-01 9.1991395e-01 4.8435539e-01
  8.3113074e-01 8.7883568e-01 4.4047990e-01 6.8329734e-01 4.4466949e-01
  6.7764109e-01 4.6988070e-01 8.3405894e-01 7.5562936e-01 4.4005474e-01
  4.9773911e-01 4.2676991e-01 4.7643188e-01 5.1546186e-01 4.8667082e-01
  6.7549431e-01 5.1454240e-01 4.7627962e-01 5.1486558e-01 4.4195807e-01
  4.7206199e-01 4.7655147e-01 8.4439063e-01 5.0581664e-01 4.7656867e-01
  4.7363171e-01 5.0619406e-01 5.1929355e-01 7.7871180e-01 5.1458520e-01
  4.5098296e-01 5.1451474e-01 4.9402198e-01 6.8342119e-01 4.8566154e-01
  8.8022202e-01 8.7493837e-01 4.7678092e-01 4.4330823e-01 5.1546836e-01
  5.1436925e-01 4.4023302e-01 9.2051339e-01 4.8824692e-01 4.5589614e-01
  4.7683451e-01 5.1014805e-01 4.7599599e-01 4.8743713e-01 4.4391832e-01
  5.1434916e-01 4.7327092e-01 6.9872844e-01 4.8099703e-01 4.9177468e-01
  6.8331158e-01 4.7337630e-01 4.8720840e-01 4.9578768e-01 6.7606723e-01
  6.9047016e-01 7.5658125e-01 6.9888580e-01 9.2232382e-01 7.7233797e-01
  9.0950131e-01 7.7647114e-01 8.8334715e-01 8.3667666e-01 4.8490000e-01
  5.1239902e-01 6.3465393e-01 9.0767026e-01 8.7025189e-01 6.3524729e-01
  4.8434731e-01 6.9838238e-01 4.7562695e-01 7.8143215e-01 6.3482612e-01
  9.2529136e-01 7.7328038e-01 1.0158576e+00 6.3902605e-01 6.3555908e-01
  1.1473837e+00 7.8229976e-01]
```

```
 [1.0942779e-03 1.1551714e-03 1.1484124e-03 1.0944251e-03 1.0919934e-03
  1.0025339e-03 9.4352977e-04 9.4763911e-04 1.0417580e-03 1.1181976e-03
  1.1213523e-03 1.0419554e-03 1.1463644e-03 1.1289162e-03 1.0580193e-03
  1.0931320e-03 1.1416493e-03 1.0499653e-03 1.0966856e-03 1.1304498e-03
  1.0451153e-03 1.0718154e-03 1.0210359e-03 1.0685350e-03 1.0559082e-03
  1.0310956e-03 1.0455482e-03 1.0475779e-03 1.0861488e-03 1.0149573e-03
  1.0486904e-03 1.0820657e-03 1.0413368e-03 9.0009504e-04 1.1419539e-03
  9.3787402e-04 1.0955320e-03 1.0927108e-03 9.8329841e-04 1.0873325e-03
  1.0240106e-03 1.0655867e-03 1.0389102e-03 1.1008129e-03 1.0949038e-03
  8.9704315e-04 1.0922332e-03 1.0973625e-03 1.1536649e-03 1.1480405e-03
  1.1426180e-03 1.0892152e-03 1.0544105e-03 1.1123890e-03 1.1491347e-03
  1.1018303e-03 1.1126944e-03 1.0973997e-03 1.0228980e-03 1.1539216e-03
  1.1110926e-03 1.0917311e-03 1.0209430e-03 9.0086862e-04 1.0609562e-03
  1.0832854e-03 1.0831050e-03 1.0901233e-03 1.0925519e-03 1.1019981e-03
  1.0050938e-03 1.0871178e-03 1.1078171e-03 1.0957147e-03 1.0210878e-03
  1.0980762e-03 1.1468029e-03 1.0485302e-03 1.1273799e-03 1.0924307e-03
  1.0912727e-03 1.1029257e-03 9.0637442e-04 1.0975607e-03 1.1006941e-03
  9.1212109e-04 1.1420659e-03 1.0964980e-03 1.0660989e-03 8.8874652e-04
  9.0609695e-04 9.8285638e-04 9.0762228e-04 1.1080158e-03 9.7948266e-04
  1.0823078e-03 9.7372360e-04 1.0857348e-03 1.0929659e-03 1.0619523e-03
  1.0056932e-03 1.0174024e-03 1.0821411e-03 1.0893816e-03 1.0185126e-03
  1.0622918e-03 9.0773887e-04 1.0508616e-03 1.0403077e-03 1.0178515e-03
  1.1104039e-03 9.8032074e-04 1.1257521e-03 1.0239390e-03 1.0190287e-03
  1.1601103e-03 1.0400579e-03]
 [1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00
  1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00
  1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00
  1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00
  1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00
  1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00
  1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00
  1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00
  1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00
  1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00
  1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00
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  1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00
  1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00
  1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00
  1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00
  1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00
  1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00
  1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00 1.0000000e+00
  1.0000000e+00 1.0000000e+00]]
```

ORB -:

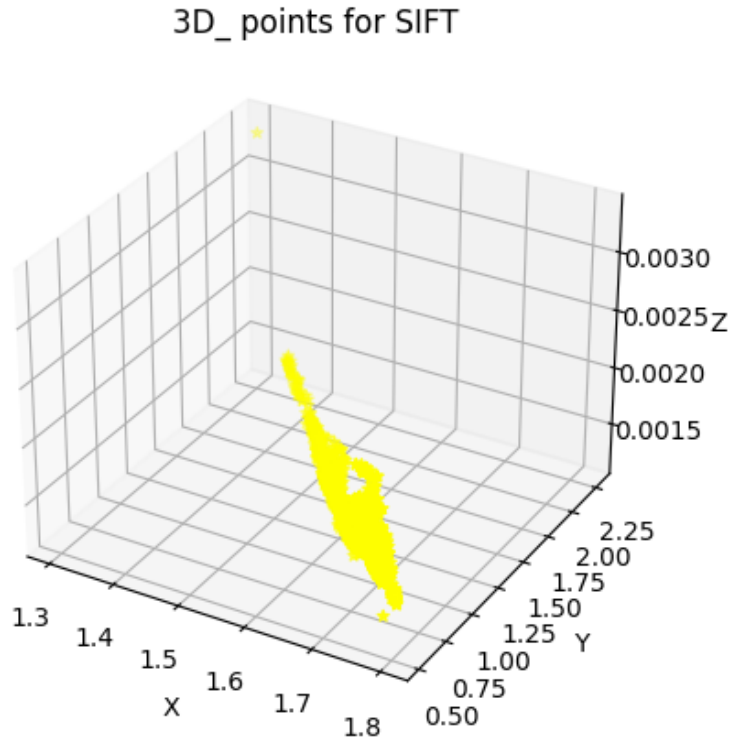
```
[[1.3014356e+00 1.4241210e+00 1.4232554e+00 ... 1.8018502e+00
  1.7858362e+00 1.7615552e+00]
 [2.2717941e+00 1.8314029e+00 1.8342013e+00 ... 5.2929544e-01
  5.8436126e-01 6.6337049e-01]
 [3.3356480e-03 1.8930814e-03 1.8711928e-03 ... 1.5067469e-03
  1.4793325e-03 1.2082362e-03]
 [1.0000000e+00 1.0000000e+00 1.0000000e+00 ... 1.0000000e+00
  1.0000000e+00 1.0000000e+00]]
```

….. Represents too many elements in the middle as its size is 117.

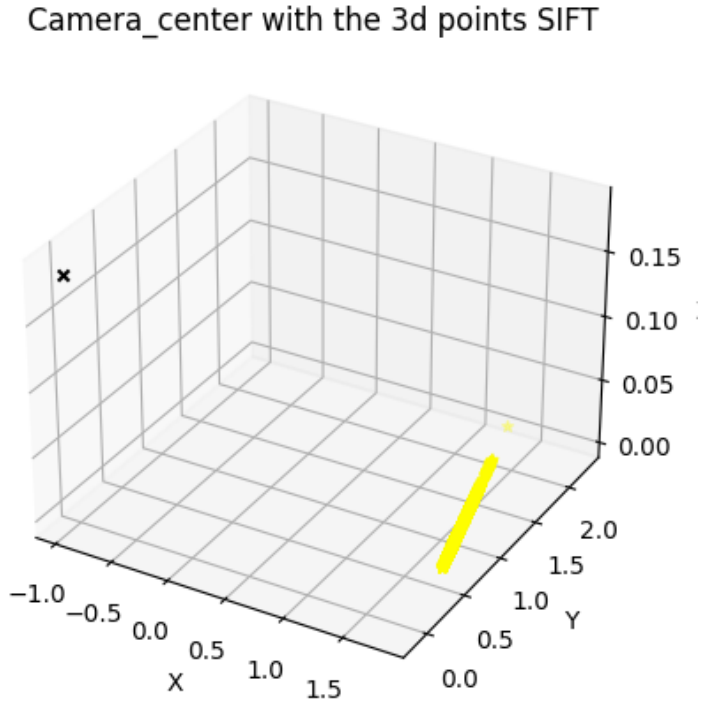
➔ 3D points and Camera Center Plot

As here we have used the two feature extractor so we have plotted the curves individually for the 3d points and simultaneously for the camera center and the corresponding 3d points. The plots represents the corresponding 3d points which we have extracted using the triangulation theorem as mentioned above.

❖ 3d points plot SIFT feature extractor -:

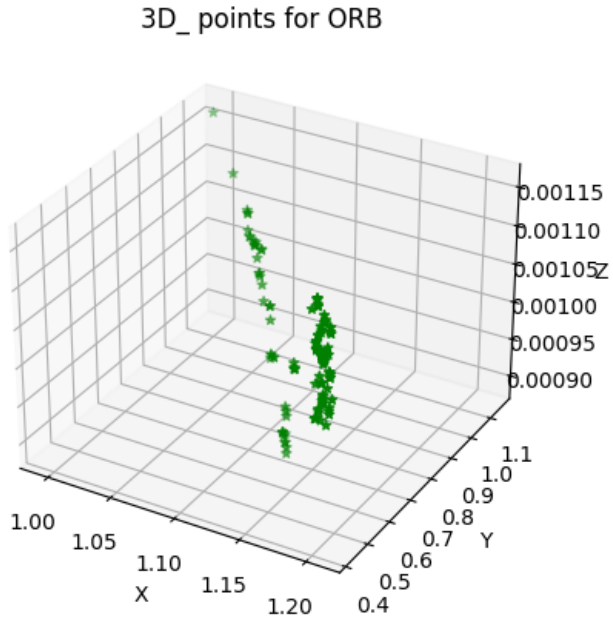


3d points with the camera center marked in the black color in the below graph.

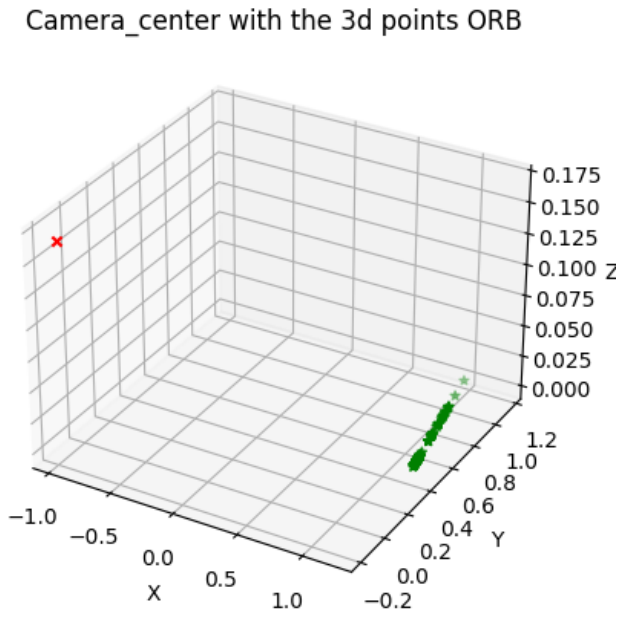


The black cross is the camera center T and yellow ones are the points, they are scaled accor.

❖ 3d points plot SIFT feature extractor -:



3d points with the camera center marked in the red color in the below graph.



The Red cross is the camera center T and yellow ones are the points, they are scaled accor.