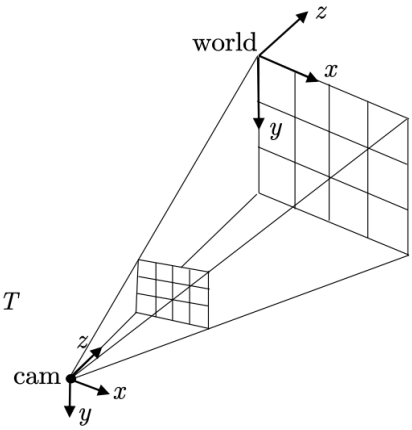
1. PnP 算法简单介绍

PnP(pespective-n-point) , 求解3D-2D点对运动的方法。在已知n个三维空间点坐标（相对于某个指定的坐标系A）及其二维投影位置的情况下，估计相机的位姿（即相机在坐标系A下的姿态）的方法。
PNP 的问题是一致的，不同的就是在已知3D-2D的点对的情况下，怎么求出相机的位姿或者说点对在相机坐标系下的姿态。常见的PNP问题的求解方法，有以下几种:

PnP算法大体分为直接法和优化法
常见的直接法包括：P3P、DLT、EPnP等
优化的算法包括：LHM、Only pos BA

PnP算法的指标主要包括：匹配点数、鲁棒性、速度、精度
P3P：3对匹配点，需要相机内参
DLT：不需要内参，4点法求出单映矩阵，DLT分解出K、R、T
EPnP：最小4个点，性价比高，精度较高，需要内参K
LHM：复杂度较高，具有全局凸性，收敛性好，精度高
（在object坐标系建立误差模型）



only－pos BA：复杂度高，需要初始解，精度高（在image坐标系建立误差模型）

- 直接线性变换DLT
- EPnP ： 利用已知的3d点，通过PCA选择4个控制点，建立新的局部坐标系，从而将3d坐标用新的控制点表示出来。然后，利用相机投影模型和2d点，转换到相机坐标系中，再在相机坐标系中建立和世界坐标系同样关系（每个点在相机坐标系和世界坐标系下控制点处的坐标一致）的4个控制点，求解出相机坐标系下的四个控制点的坐标，进而利用ICP求解pose。
- SDP
- P3P
- UPnP
- 非线性优化方法等.....

2. opencv 函数说明:

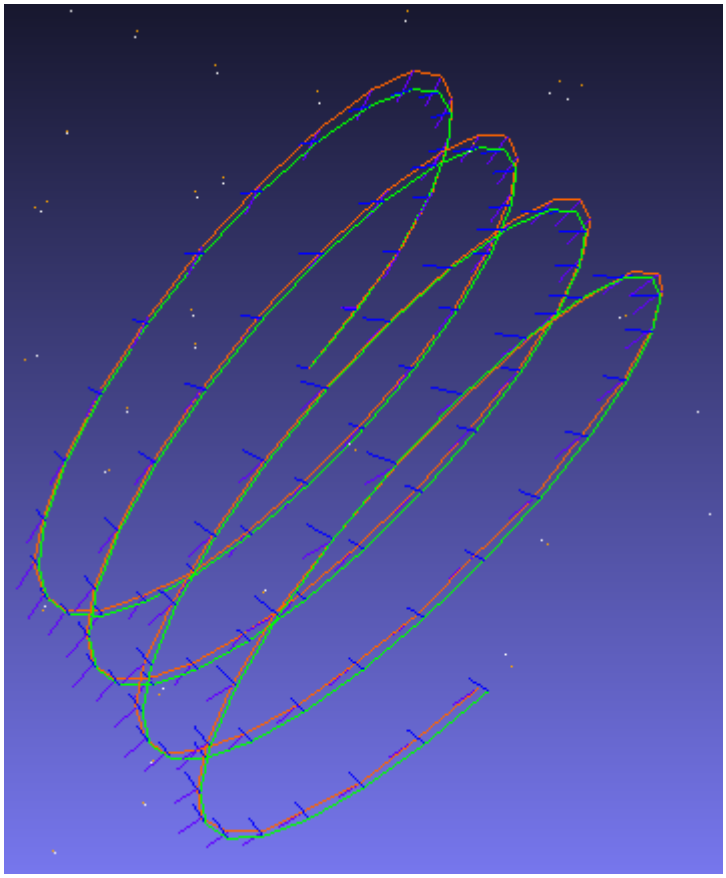
[solvePnPRansac by opencv doc]

```
bool solvePnPRansac(InputArray _opoints, InputArray _ipoints,
    InputArray _cameraMatrix, InputArray _distCoeffs,
    OutputArray _rvec, OutputArray _tvec, bool useExtrinsicGuess,
    int iterationsCount, float reprojectionError, double confidence,
    OutputArray _inliers, int flags)

参数说明：
objectPoints - 世界坐标系下的控制点的坐标，vector<Point3f>的数据类型在这里可以使用
imagePoints - 在图像坐标系下对应的控制点的坐标。vector<Point2f>在这里可以使用
cameraMatrix - 相机的内参矩阵
distCoeffs - 相机的畸变系数
rvec - 输出的旋转向量。使坐标点从世界坐标系旋转到相机坐标系
tvec - 输出的平移向量。使坐标点从世界坐标系平移到相机坐标系
flags - 默认使用CV_ITERATIV迭代法
     SOLVEPNP_ITERATIVE(此方案，最小模型用的EPNP，内点选出之后用了一个迭代)；
```

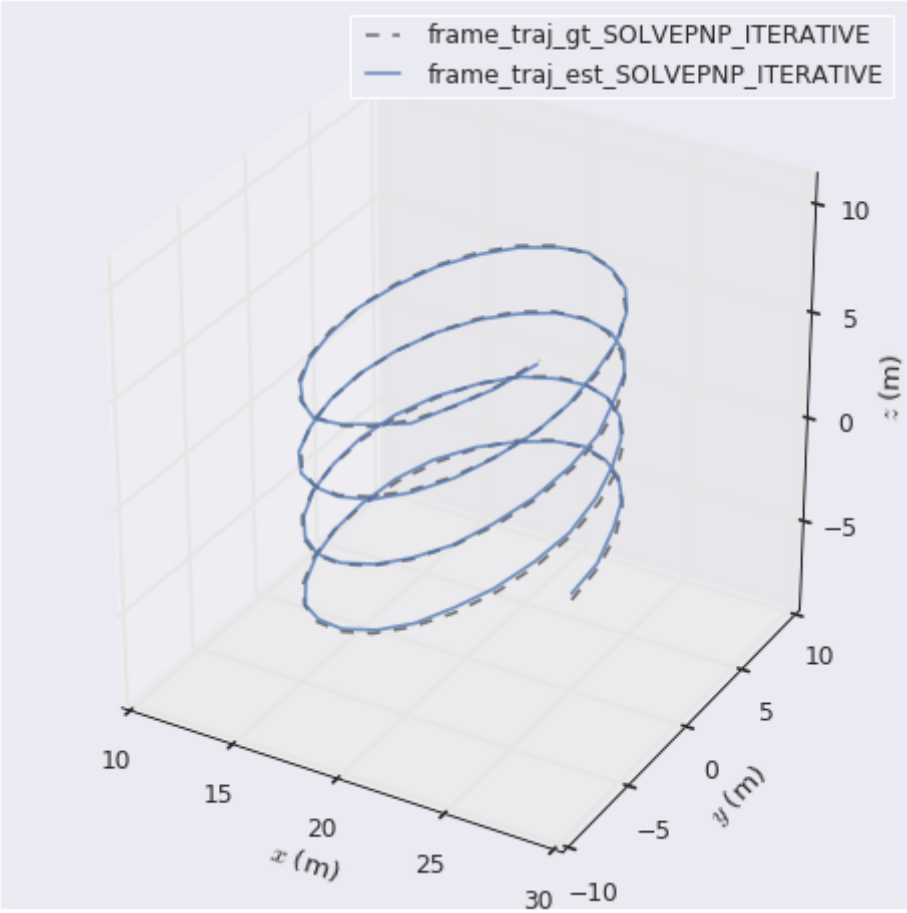
```
SOLVE_P3P(P3P只用在最小模型上，内点选出之后用了一个EPNP)
SOLVE_AP3P(AP3P只用在最小模型上，内点选出之后用了一个EPNP)
SOLVE_EPnP(最小模型上&内点选出之后都采用了EPNP)
```

3. 实验数据与结果分析

3.0. SOLVEPNP_ITERATIVE



```
 evo_traj tum frame_traj_est_SOLVEPNP_ITERATIVE.txt --
ref=frame_traj_gt_SOLVEPNP_ITERATIVE.txt -p --plot_mode xyz  --align --
correct_scale
```

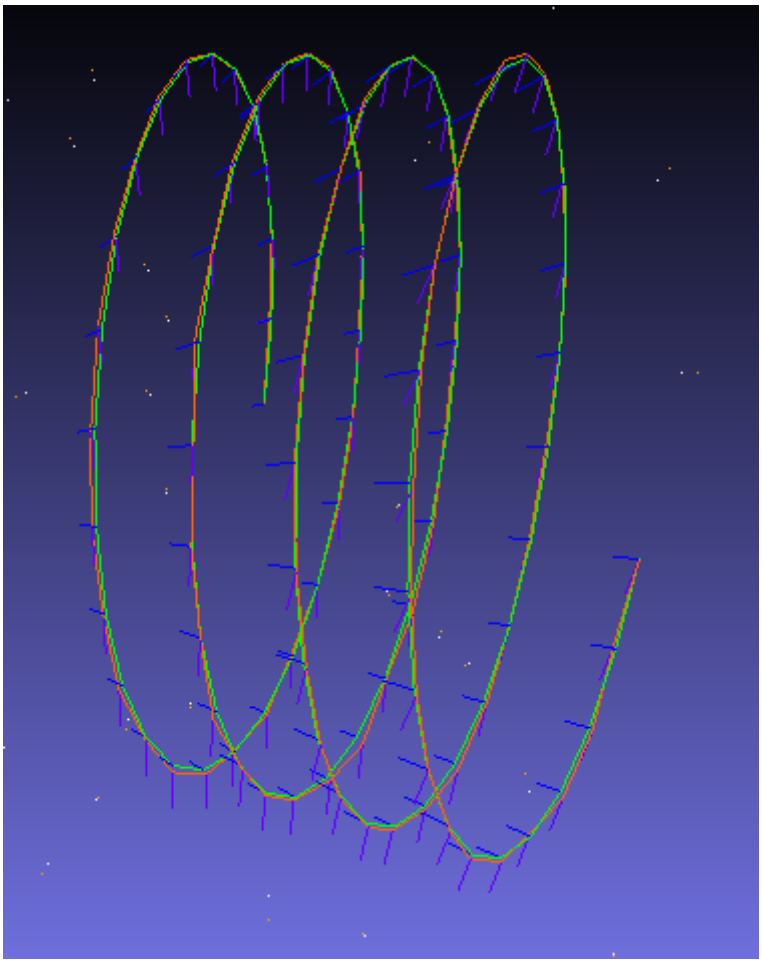



```
evo_ape tum frame_traj_est_SOLVEPNP_ITERATIVE.txt
frame_traj_gt_SOLVEPNP_ITERATIVE.txt  -va --plot --plot_mode xyz --save_results
SOLVEPNP_ITERATIVE_ape.zip
       max      0.434389
      mean      0.178372
    median      0.171207
       min      0.039869
      rmse      0.197632
       sse      3.749621
       std      0.085099
```

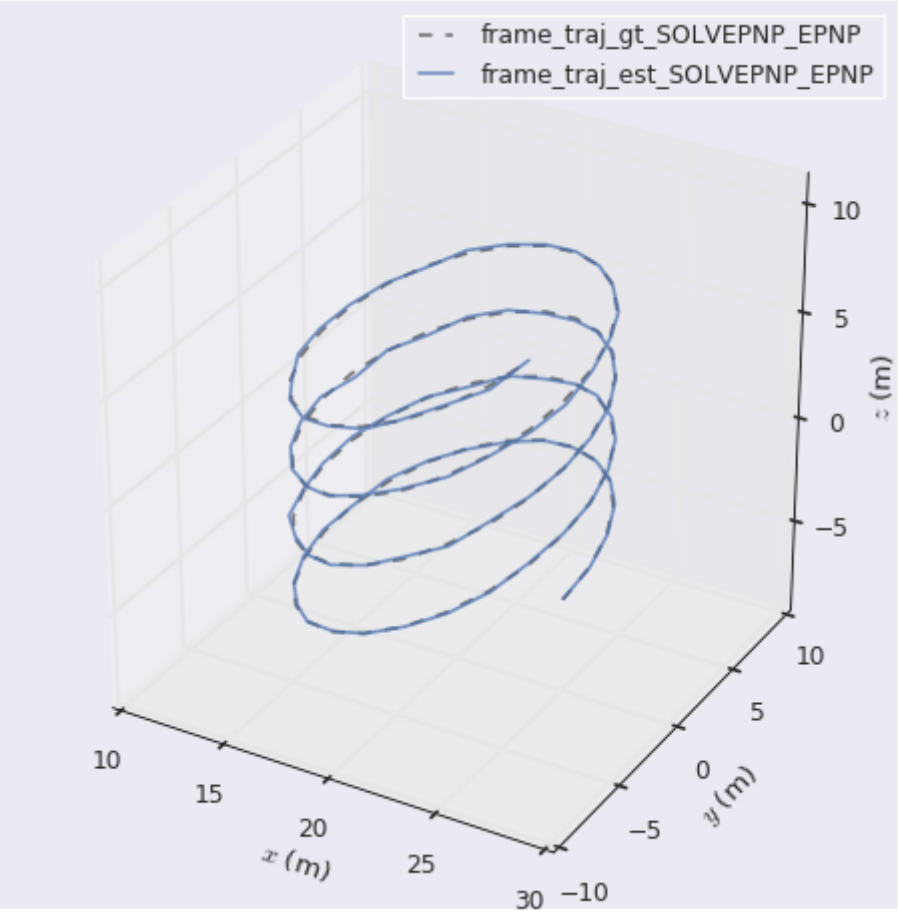
```
 evo_rpe tum frame_traj_est_SOLVEPNP_ITERATIVE.txt
frame_traj_gt_SOLVEPNP_ITERATIVE.txt  -va --plot --plot_mode xyz --save_results
SOLVEPNP_ITERATIVE_rpe.zip

       max      4.377182
      mean      2.601915
    median      2.644808
       min      0.074727
      rmse      2.779581
       sse      733.976471
       std      0.977806
```

```
evo_res SOLVEPNP_ITERATIVE_ape.zip -p --save_table SOLVEPNP_ITERATIVE_table.csv


                           max      mean    median        min      rmse  \
frame_traj_gt_SOL...  0.434389  0.178372  0.171207  0.0398691  0.197632

                          sse       std
frame_traj_gt_SOL...  3.74962  0.0850991
```

3.1. SOLVEPNP_EPNP



```
 evo_traj tum frame_traj_est_SOLVEPNP_EPNP.txt --
ref=frame_traj_gt_SOLVEPNP_EPNP.txt -p --plot_mode xyz  --align --correct_scale
```

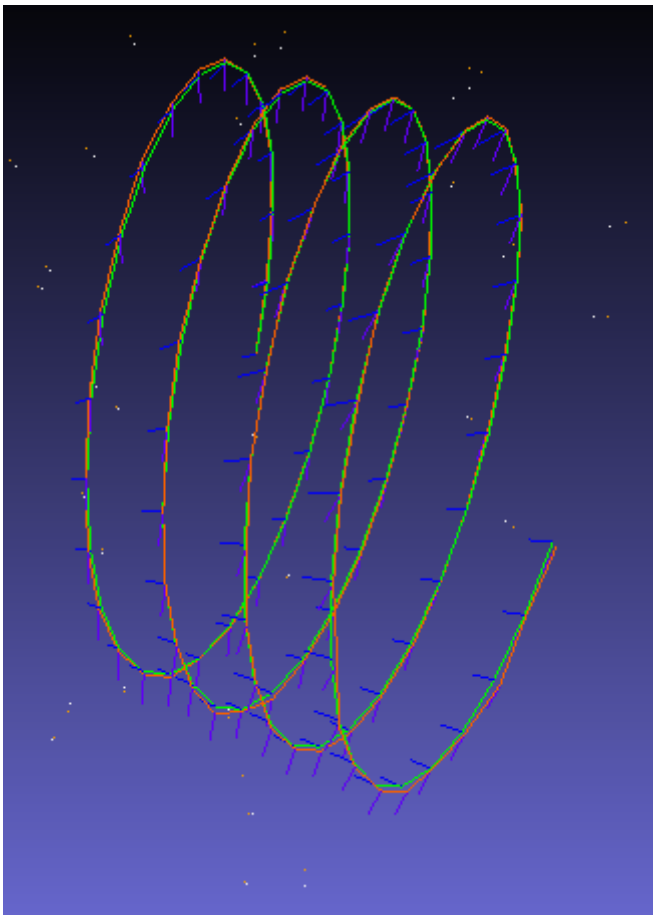



```
evo_ape tum frame_traj_est_SOLVEPNP_EPNP.txt frame_traj_gt_SOLVEPNP_EPNP.txt  -
va --plot --plot_mode xyz --save_results SOLVEPNP_EPNP_ape.zip
       max      0.242836
      mean      0.117471
    median      0.114078
       min      0.017015
      rmse      0.126450
       sse      1.534998
       std      0.046799
```

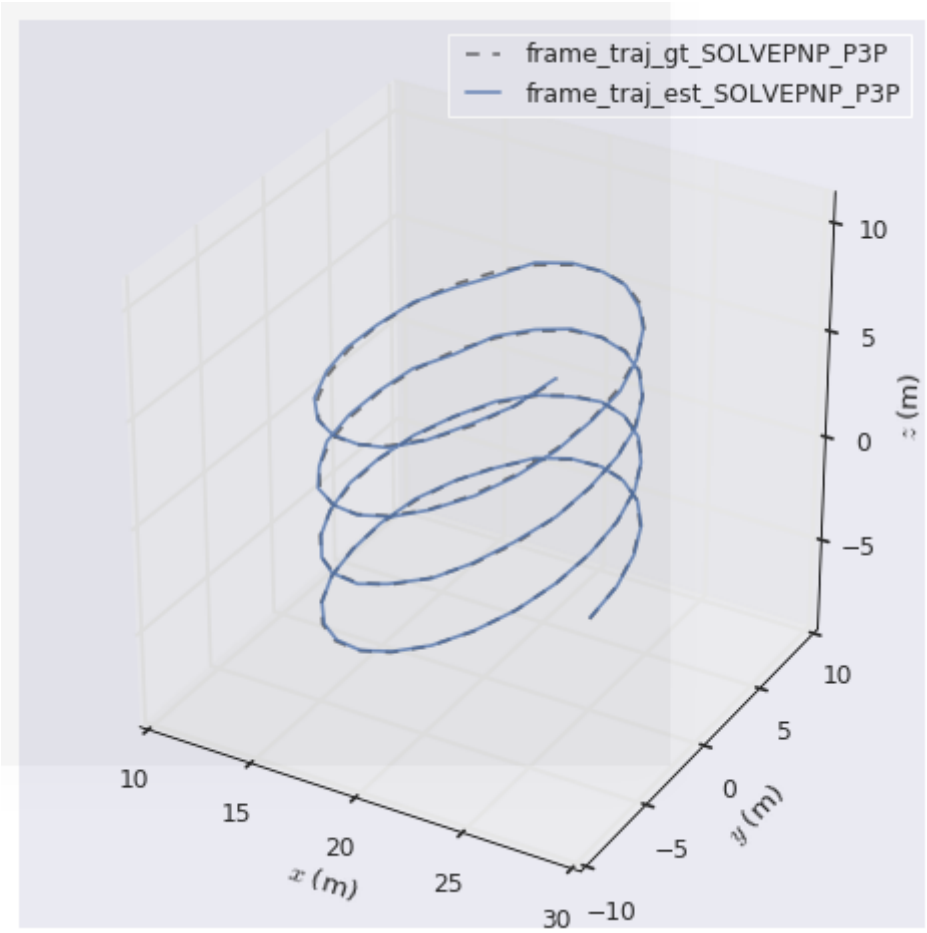
```
 evo_rpe tum frame_traj_est_SOLVEPNP_EPNP.txt frame_traj_gt_SOLVEPNP_EPNP.txt  -
va --plot --plot_mode xyz --save_results SOLVEPNP_EPNP_rpe.zip

       max      4.352881
      mean      2.587162
    median      2.637466
       min      0.074727
      rmse      2.763539
       sse      725.528841
       std      0.971461
```

```
evo_res SOLVEPNP_EPNP_ape.zip -p --save_table SOLVEPNP_EPNP_table.csv

                          max      mean    median        min     rmse    sse  \
frame_traj_gt_SOL...  0.242836  0.117471  0.114078  0.0170151  0.12645  1.535

                           std
frame_traj_gt_SOL...  0.0467992
```

3.2. SOLVEPNP_P3P



```
 evo_traj tum frame_traj_est_SOLVEPNP_P3P.txt --
ref=frame_traj_gt_SOLVEPNP_P3P.txt -p --plot_mode xyz  --align --correct_scale
```

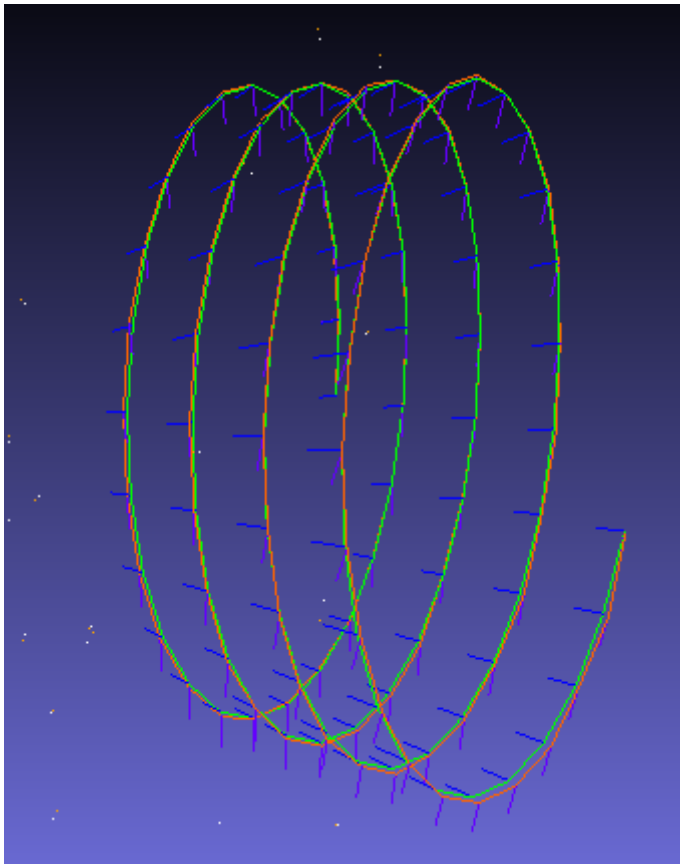


```
evo_ape tum frame_traj_est_SOLVEPNP_P3P.txt frame_traj_gt_SOLVEPNP_P3P.txt  -va
--plot --plot_mode xyz --save_results SOLVEPNP_P3P_ape.zip

       max      0.246748
      mean      0.116399
    median      0.108588
       min      0.040195
      rmse      0.124018
       sse      1.476530
       std      0.042799
```

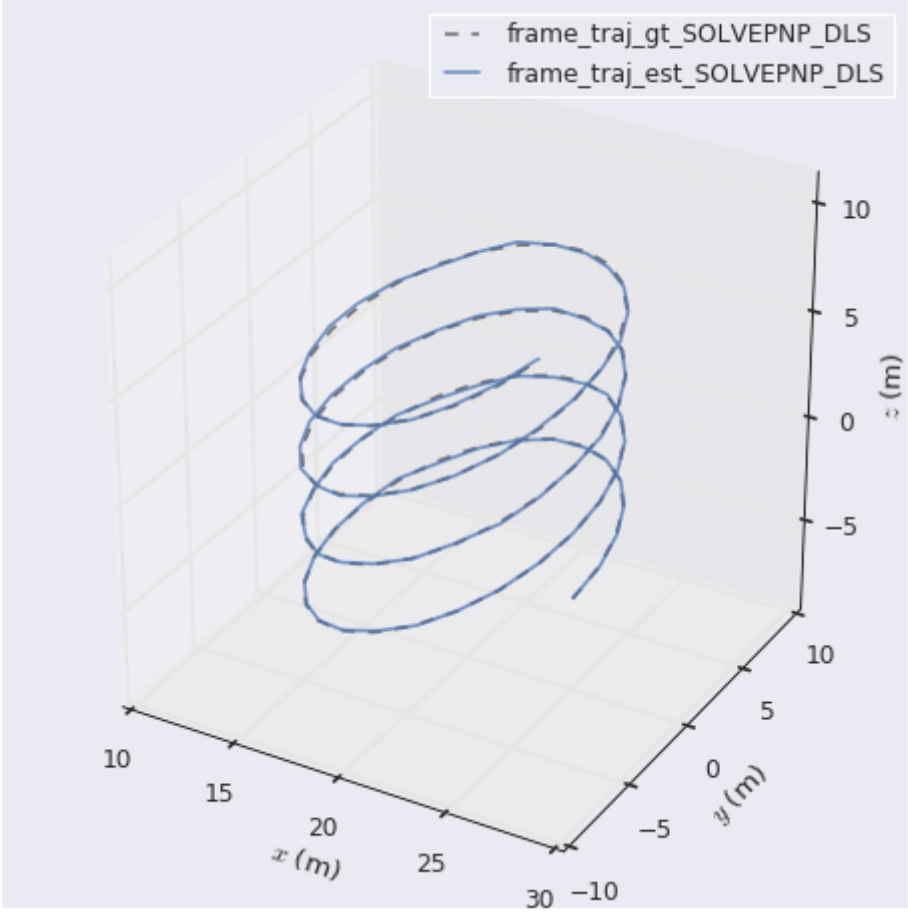
```
 evo_rpe tum frame_traj_est_SOLVEPNP_P3P.txt frame_traj_gt_SOLVEPNP_P3P.txt  -va
--plot --plot_mode xyz --save_results SOLVEPNP_P3P_rpe.zip
       max      4.376081
      mean      2.589348
    median      2.609933
       min      0.031821
      rmse      2.764878
       sse      726.232326
       std      0.969448
```

```
evo_res SOLVEPNP_P3P_ape.zip -p --save_table SOLVEPNP_P3P_table.csv

                          max      mean    median        min      rmse  \
frame_traj_gt_SOL...  0.246748  0.116399  0.108588  0.0401949  0.124018

                         sse        std
frame_traj_gt_SOL...  1.47653  0.0427988
```

3.3. SOLVEPNP_DLS



```
 evo_traj tum frame_traj_est_SOLVEPNP_DLS.txt --
ref=frame_traj_gt_SOLVEPNP_DLS.txt -p --plot_mode xyz  --align --correct_scale
```

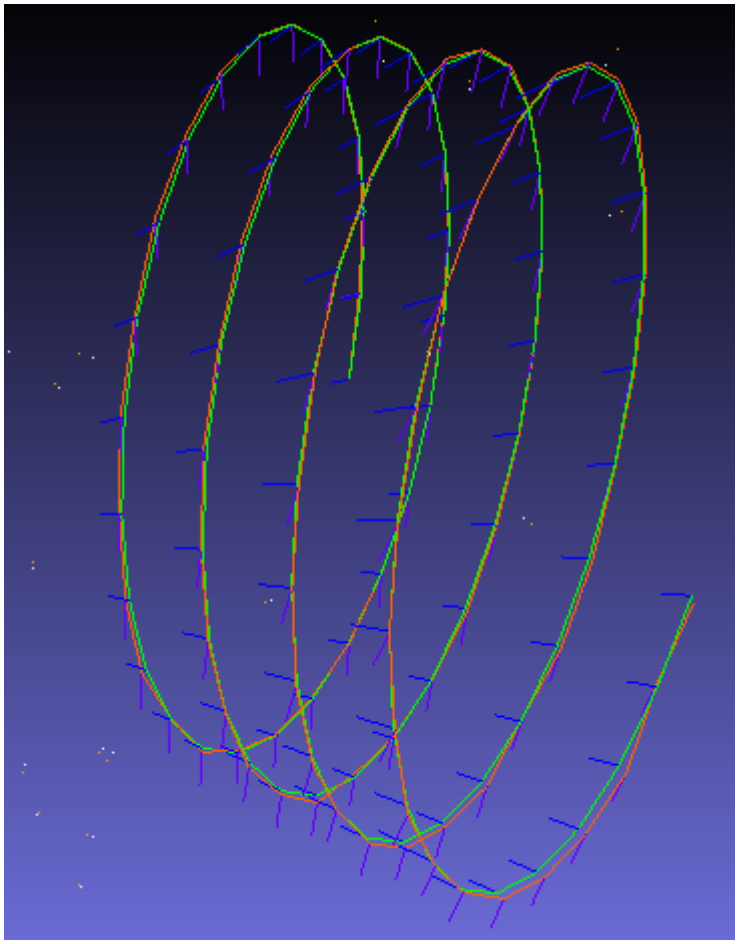


```
evo_ape tum frame_traj_est_SOLVEPNP_DLS.txt frame_traj_gt_SOLVEPNP_DLS.txt  -va
--plot --plot_mode xyz --save_results SOLVEPNP_DLS_ape.zip
       max      0.225975
      mean      0.113513
    median      0.106261
       min      0.035635
      rmse      0.122289
       sse      1.435645
       std      0.045492
```

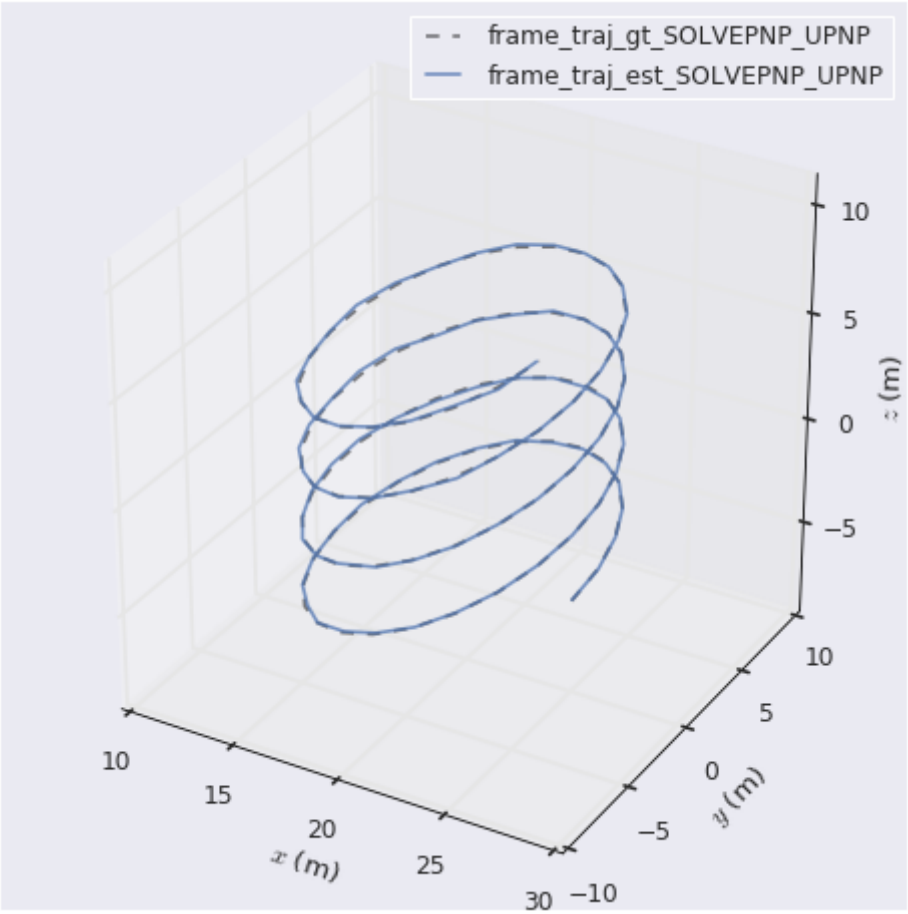
```
 evo_rpe tum frame_traj_est_SOLVEPNP_DLS.txt frame_traj_gt_SOLVEPNP_DLS.txt  -va
--plot --plot_mode xyz --save_results SOLVEPNP_DLS_rpe.zip
       max      4.333318
      mean      2.583120
    median      2.601981
       min      0.017241
      rmse      2.759503
       sse      723.411568
       std      0.970746
```

```
evo_res SOLVEPNP_DLS_ape.zip -p --save_table SOLVEPNP_DLS_table.csv

                          max      mean    median        min      rmse  \
frame_traj_gt_SOL...  0.225975  0.113513  0.106261  0.0356351  0.122289

                         sse        std
frame_traj_gt_SOL...  1.43565  0.0454917
```

3.4. SOLVEPNP_UPNP



```
 evo_traj tum frame_traj_est_SOLVEPNP_UPNP.txt --
ref=frame_traj_gt_SOLVEPNP_UPNP.txt -p --plot_mode xyz  --align --correct_scale
```

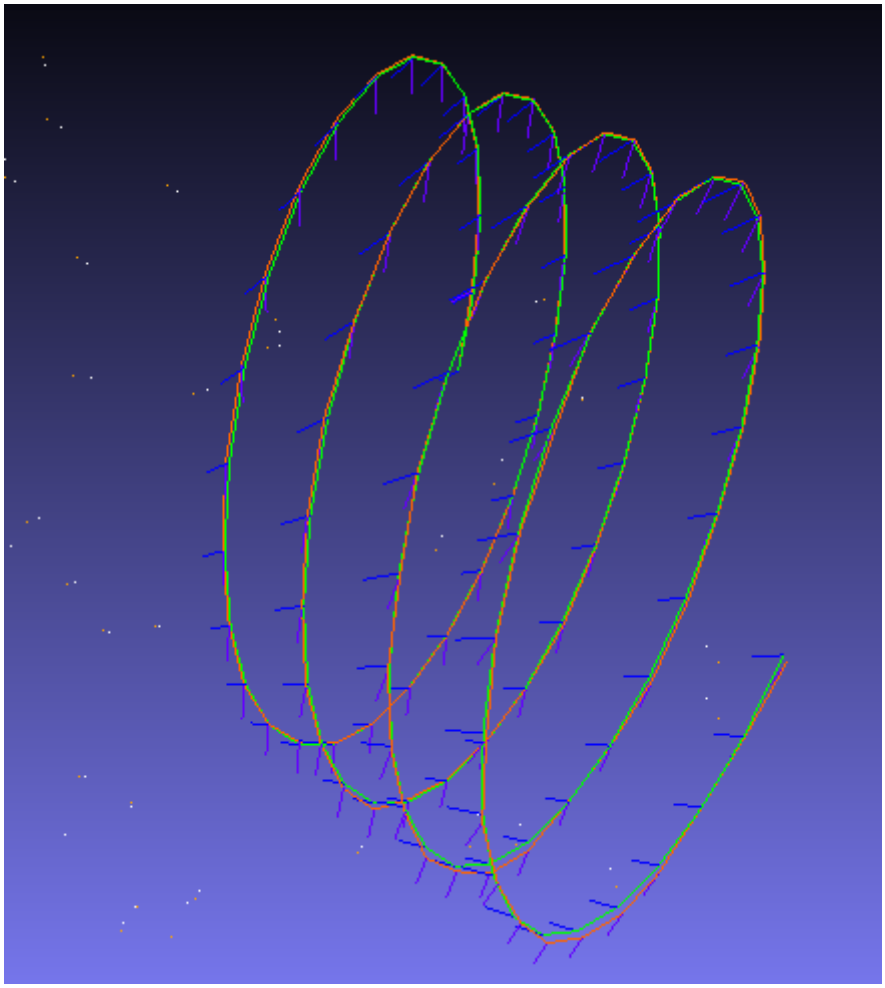


```
evo_ape tum frame_traj_est_SOLVEPNP_UPNP.txt frame_traj_gt_SOLVEPNP_UPNP.txt  -
va --plot --plot_mode xyz --save_results SOLVEPNP_UPNP_ape.zip
       max      0.218468
      mean      0.106990
    median      0.094463
       min      0.033494
      rmse      0.115861
       sse      1.288688
       std      0.044462
```

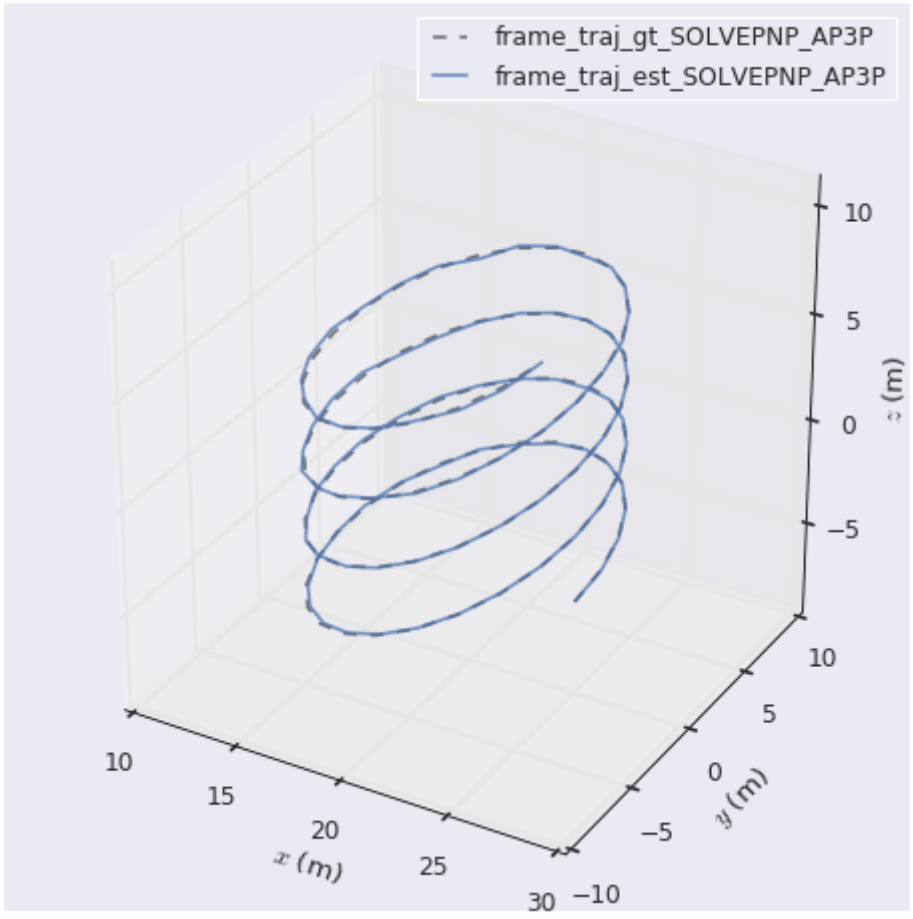
```
 evo_rpe tum frame_traj_est_SOLVEPNP_UPNP.txt frame_traj_gt_SOLVEPNP_UPNP.txt  -
va --plot --plot_mode xyz --save_results SOLVEPNP_UPNP_rpe.zip
       max      4.361522
      mean      2.585335
    median      2.631826
       min      0.016013
      rmse      2.760945
       sse      724.167897
       std      0.968950
```

```
evo_res SOLVEPNP_UPNP_ape.zip -p --save_table SOLVEPNP_UPNP_table.csv
                           max     mean     median        min      rmse  \
frame_traj_gt_SOL...  0.218468  0.10699  0.0944627  0.0334936  0.115861

                          sse        std
frame_traj_gt_SOL...  1.28869  0.0444622
```

3.5. SOLVEPNP_AP3P



```
 evo_traj tum frame_traj_est_SOLVEPNP_AP3P.txt --
ref=frame_traj_gt_SOLVEPNP_AP3P.txt -p --plot_mode xyz  --align --correct_scale
```

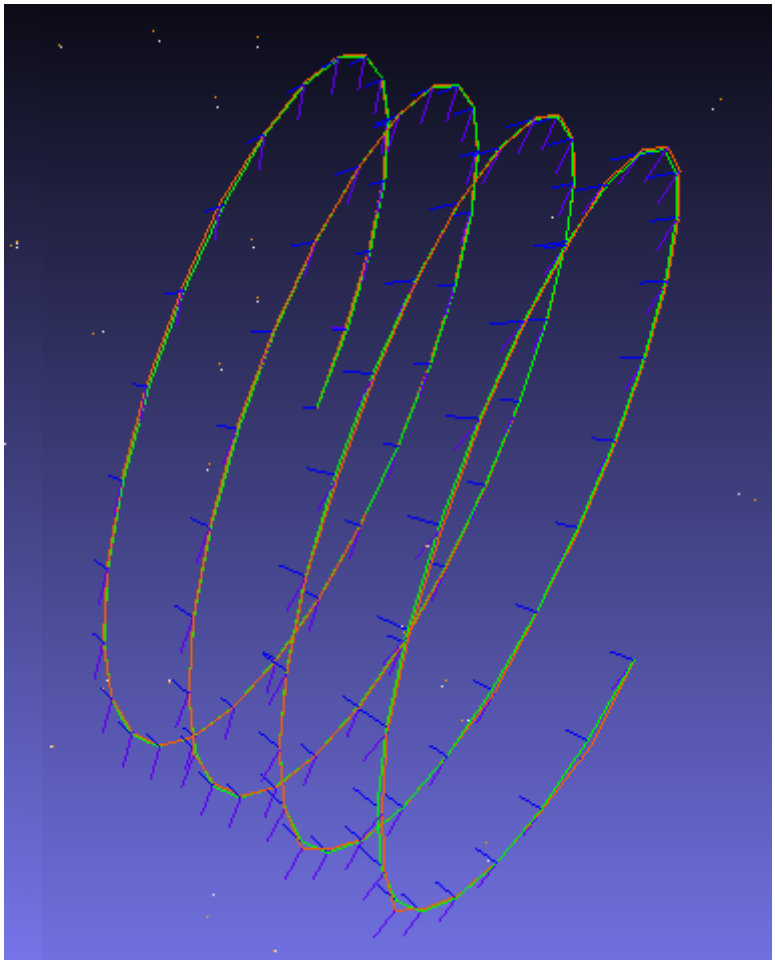


```
evo_ape tum frame_traj_est_SOLVEPNP_AP3P.txt frame_traj_gt_SOLVEPNP_AP3P.txt  -
va --plot --plot_mode xyz --save_results SOLVEPNP_AP3P_ape.zip
       max      0.236128
      mean      0.105609
    median      0.097849
       min      0.034734
      rmse      0.116205
       sse      1.296356
       std      0.048481
```

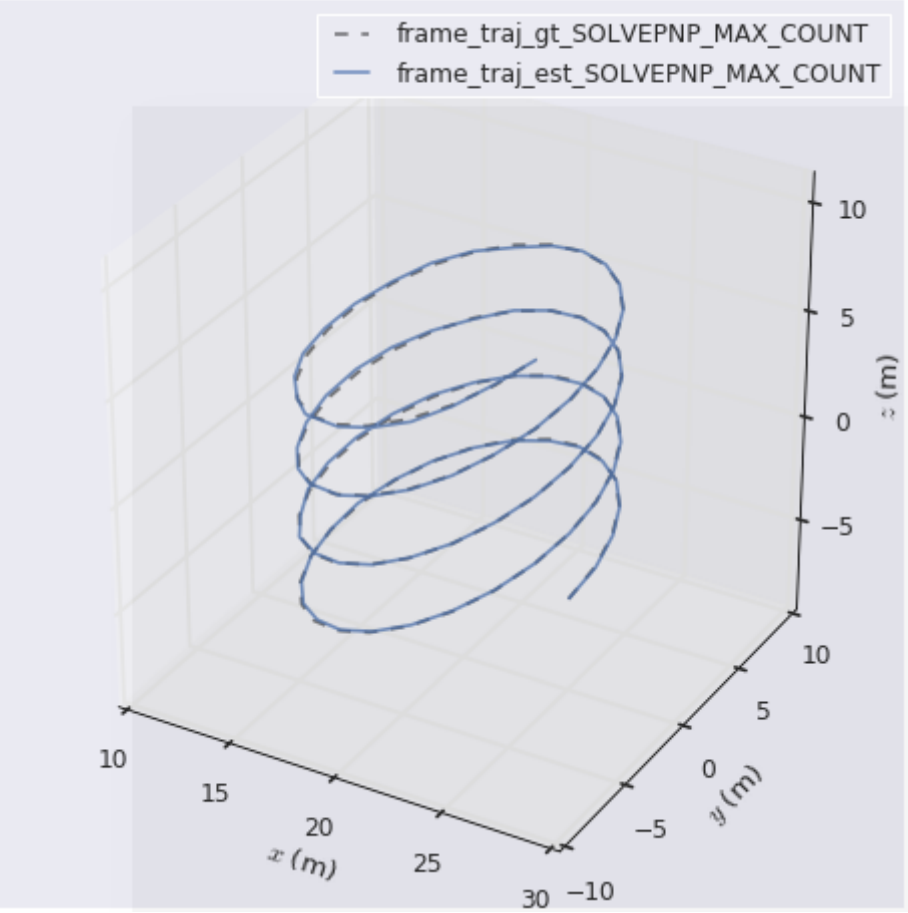
```
 evo_rpe tum frame_traj_est_SOLVEPNP_AP3P.txt frame_traj_gt_SOLVEPNP_AP3P.txt  -
va --plot --plot_mode xyz --save_results SOLVEPNP_AP3P_rpe.zip

       max      4.316022
      mean      2.581949
    median      2.619087
       min      0.016013
      rmse      2.758708
       sse      722.994698
       std      0.971603
```

```
evo_res SOLVEPNP_AP3P_ape.zip -p --save_table SOLVEPNP_AP3P_table.csv

                          max      mean     median       min      rmse  \
frame_traj_gt_SOL...  0.236128  0.105609  0.0978492  0.034734  0.116205

                         sse        std
frame_traj_gt_SOL...  1.29636  0.0484811
```

3.6. SOLVEPNP_MAX_COUNT



```
 evo_traj tum frame_traj_est_SOLVEPNP_MAX_COUNT.txt --
ref=frame_traj_gt_SOLVEPNP_MAX_COUNT.txt -p --plot_mode xyz  --align --
correct_scale
```




```
evo_ape tum frame_traj_est_SOLVEPNP_MAX_COUNT.txt
frame_traj_gt_SOLVEPNP_MAX_COUNT.txt  -va --plot --plot_mode xyz --save_results
SOLVEPNP_MAX_COUNT_ape.zip
       max      0.262875
      mean      0.090947
    median      0.078453
       min      0.025371
      rmse      0.101519
       sse      0.989395
       std      0.045109
```

```
 evo_rpe tum frame_traj_est_SOLVEPNP_MAX_COUNT.txt
frame_traj_gt_SOLVEPNP_MAX_COUNT.txt  -va --plot --plot_mode xyz --save_results
SOLVEPNP_MAX_COUNT_rpe.zip
       max      4.313694
      mean      2.582501
    median      2.616074
       min      0.016013
      rmse      2.758629
       sse      722.953111
       std      0.969907
```

```
evo_res SOLVEPNP_MAX_COUNT_ape.zip -p --save_table SOLVEPNP_MAX_COUNT_table.csv

                           max       mean     median        min      rmse  \
frame_traj_gt_SOL...  0.262875  0.0909472  0.0784525  0.0253707  0.101519

                           sse        std
frame_traj_gt_SOL...  0.989395  0.0451088
```

3.7 结果分析

```
method: 0~6 依次代表以下方法：
SOLVEPNP_ITERATIVE
SOLVEPNP_EPNP
SOLVEPNP_P3P
SOLVEPNP_DLS
SOLVEPNP_UPNP
SOLVEPNP_AP3P
SOLVEPNP_MAX_COUNT
```

evo_ape(计算绝对位姿误差)

param	**0**	**1**	**2**	**3**	**4**	**5**	**6**
max	0.434389	0.242836	0.246748	0.225975	**0.218468**	0.236128	0.262875
mean	0.178372	0.117471	0.116399	0.113513	0.10699	0.105609	**0.090947**
median	0.171207	0.114078	0.108588	0.106261	0.094463	0.097849	**0.078453**
min	0.039869	**0.017015**	0.040195	0.035635	0.033494	0.034734	0.025371
rmse	0.197632	0.12645	0.124018	0.122289	0.115861	0.116205	**0.101519**
sse	3.749621	1.534998	1.47653	1.435645	1.288688	1.296356	**0.989395**
std	0.085099	0.046799	**0.042799**	0.045492	0.044462	0.048481	0.045109

evo_rpe(计算相对位姿误差)

param	**0**	**1**	**2**	**3**	**4**	**5**	**6**
max	4.377182	4.352881	4.376081	4.333318	4.361522	4.316022	**4.313694**
mean	2.601915	2.587162	2.589348	2.58312	2.585335	**2.581949**	2.582501
median	2.644808	2.637466	2.609933	**2.601981**	2.631826	2.619087	2.616074
min	0.074727	0.074727	0.031821	0.017241	**0.016013**	**0.016013**	**0.016013**
rmse	2.779581	2.763539	2.764878	2.759503	2.760945	2.758708	2.758629
sse	733.976471	725.528841	726.232326	723.411568	724.167897	722.994698	**722.953111**
std	0.977806	0.971461	0.969448	0.970746	**0.96895**	0.971603	0.969907

evo_res(结果比较)

	max	mean	median	min	rmse	sse	std
0	0.434389	0.178372	0.171207	0.0398691	0.197632	3.74962	0.0850991
1	0.242836	0.117471	0.114078	**0.0170151**	0.12645	1.535	0.0467992
2	0.246748	0.116399	0.108588	0.0401949	0.124018	1.47653	**0.0427988**
3	0.225975	0.113513	0.106261	0.0356351	0.122289	1.43565	0.0454917
4	**0.218468**	0.10699	0.0944627	0.0334936	0.115861	1.28869	0.0444622
5	0.236128	0.105609	0.0978492	0.034734	0.116205	1.29636	0.0484811
6	0.262875	**0.0909472**	**0.0784525**	0.0253707	**0.101519**	**0.989395**	0.0451088

整个轨迹估计时间消耗（ms）, 基本都在4 sec左右

param	0	1	2	3	4	5	6
time	5704151	6099984	5622415	4662723	4643438	5104300	**4497043**

综合比较， SOLVEPNP_MAX_COUNT 方法估计的精度更加准确可靠，整体方法比对相差不大.

> 1）一般VO看RPE，有闭环的SLAM系统ATE RPE都要看；
> 2）RPE反映了VO局部轨迹的精度情况，相当于是只使用某个轨迹点附近的一段轨迹计算误差，ATE则是使用全部长度的轨迹真值计算误差。
> 3）VO不带闭环，跑久了之后轨迹不可避免有漂移，如果计算ATE误差的话，相比那些有闭环的系统误差就太大了，并不是很公平，所以VO和带闭环的SLAM的话只比较RPE是相对公平的

4. 注意点

1. solvePnPRansac 求得的R.t 为 相机的世界坐标在相机坐标系下的表示。
2. solvePnPRansac参数列表(带缺省较多)，运用网上例子调用出错。 下回注意check opencv的api手册