Test of Three Slam Frameworks

1. Introduction

We have test three slam frameworks including ***hdl_graph_slam***, ***LeGO_LOAM***, and ***lidarslam_ros2***. First, a brief introduction to the three frameworks.

The first framework is ***hdl_graph_slam***. It is an open source **ROS** package for real-time 6DOF SLAM using a 3D LIDAR. It is based on 3D Graph SLAM with NDT scan matching-based odometry estimation and loop detection. It also supports several graph constraints, such as GPS, IMU acceleration (gravity vector), IMU orientation (magnetic sensor), and floor plane (detected in a point cloud).
The github address: **https://github.com/koide3/hdl_graph_slam**

The second framework is ***LeGO_LOAM***. This framework is designed as a lightweight and ground optimized lidar odometry and mapping (LeGO-LOAM) system for ROS compatible UGVs. The system takes in point cloud from a Velodyne VLP-16 Lidar (palced horizontally) and optional IMU data as inputs. It outputs 6D pose estimation in real-time.
The github address: **https://github.com/RobustFieldAutonomyLabT/LeGO-LOAM**
The third framework is ***lidarslam_ros2***. It is designed by a Japanese scholar **Ryohei Sasaki** who is very kind man. It is a ros2 slam package of the frontend using OpenMP-boosted gicp/ndt scan matching and the backend using graph-based slam. Its process map uses threads and Future (this is the standard library of cpp) to update asynchronously with scan matching compared to ***hdl_graph_slam***.
The github address: **https://github.com/rsasaki0109/lidarslam_ros2**

2. Test

We test the three slam frameworks using 16/32/64 line lidar dataset on two types of hardware. This test records and compares the cpu/memory usage and trajectory offset of the three frameworks. We have shown specific values and figures to help you better understand this test.
The most figures are drawn by the evo tools. Currently I have not found the way using evo tools to process the message in ROS2. So I make a screen capture for lidarslam_ros2 instead. As a result there is missing some information than the other two frameworks.
The trajectories and offset on axis of frameworks are shown separately for datasets without ground truth. For those datasets with ground truth, we directly show the error map and ape values.
Since there are no graphical display on the cloud server, we cannot get the trajectory only the cpu/memory usage.

(1) 16 line dataset

The first dataset we used is NSH indoor outdoor dataset. You can download it from

https://doc-0c-44-docs.googleusercontent.com/docs/securesc/7m9cafd7us0kjfjq79u1lg4a08m1h2qd/nv2h7blpte85qeo19v1hn1bb9rd46f04/1598539050000/10637983609117326248/07574466021164400993/1s05tBQOLNEDDurlg48KiUWxCp-YqYyGH?e=download&authuser=0&nonce=40t1ej7u573dk&user=07574466021164400993&hash=mrju6o8hkuefb65fo1eb0vaupl2vuk2k.

Since we did not find the 16 line dataset with ground truth, it is unable to test the trajectory offset.

[1] on cloud server with Xeon 6266C-16U 32G

a. specific values

See Appendix 1.

b. figures

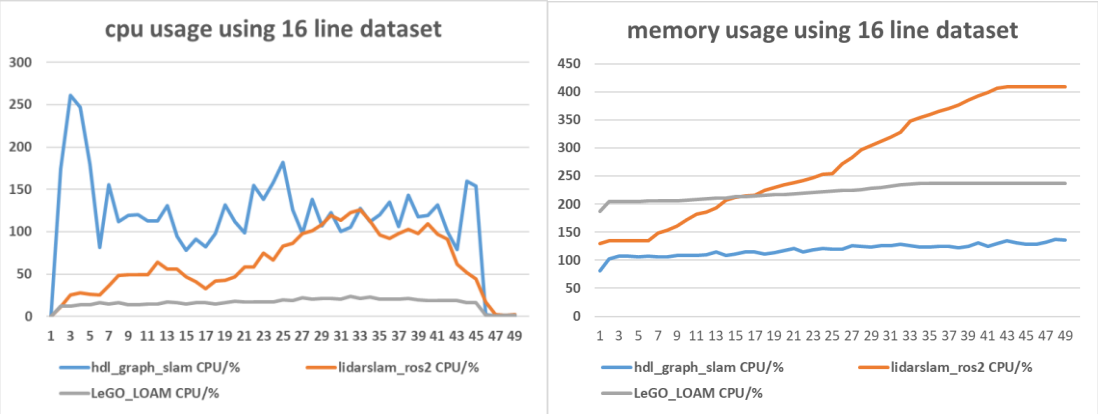
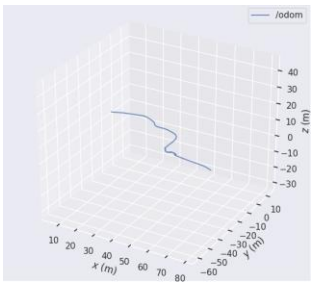
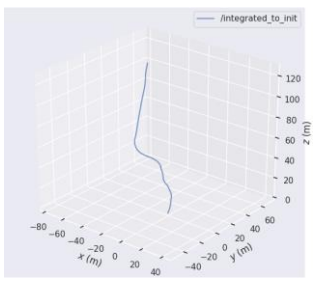
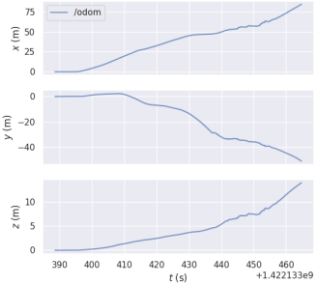
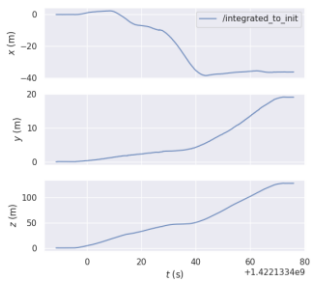
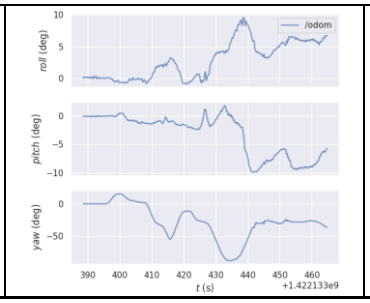
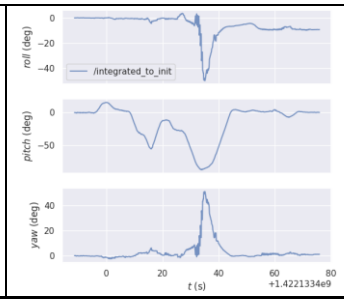


Figure 1 cpu/memory usage using 16 line dataset on cloud server

Table 1 trajectories using 16 line dataset on cloud server

dataset	ush_indoor_outdoor.bag		
framework	hdl_graph_slam	LeGO_LOAM	lidarslam_ros2
trajectory			There are no graphical display on cloud server.
xyz view			

rpy view			

From the figures and tables above, we find that the **hdl_graph_slam** takes up more cpu resource and less memory resource than the other two frameworks. Its slam ability looks like better.

[2] on pc with i7-1065G7-1U 8G

a. specific values

****See Appendix 2.****

b. figures

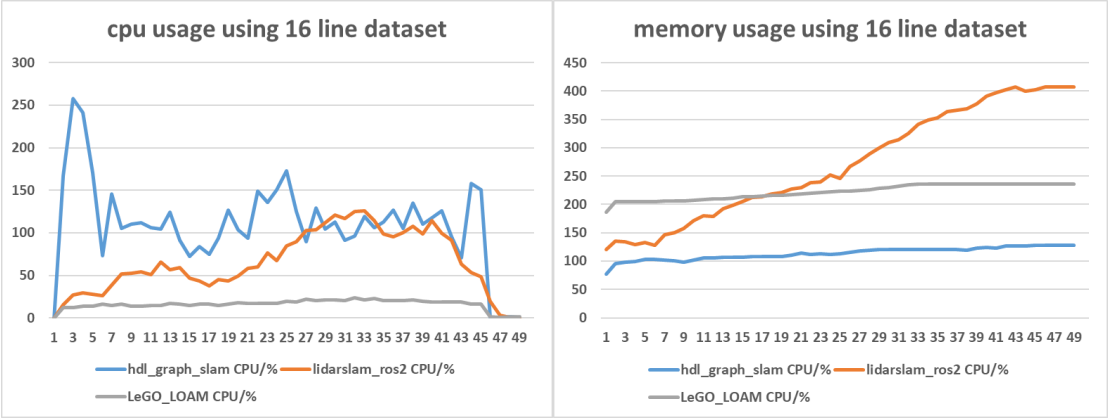
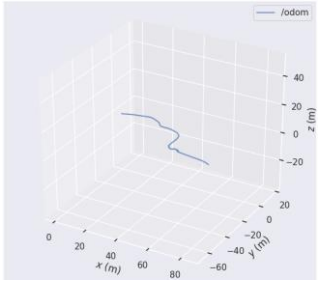
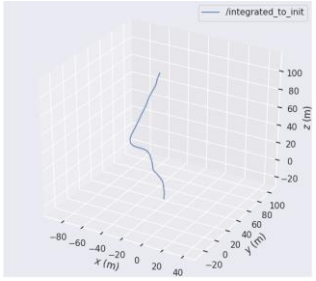
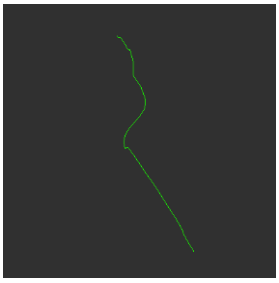
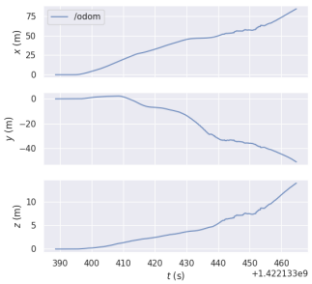
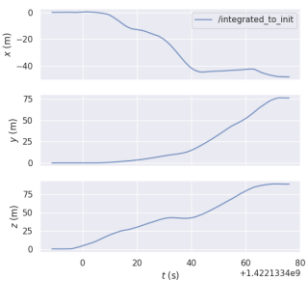
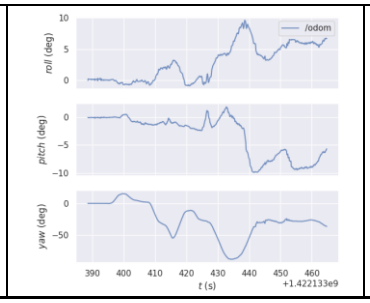
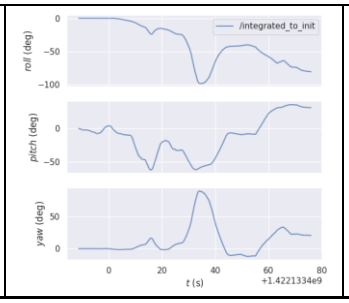


Figure 2 cpu/memory usage using 16 line dataset on pc

Table 2 trajectories using 16 line dataset on pc

dataset	ush_indoor_outdoor.bag		
framework	hdl_graph_slam	LeGO_LOAM	lidarslam_ros2
trajectory			
xyz view			

rpy view			

From the figures and table above, we found the same truth as the cloud server.

(2) 32 line dataset

The first dataset we used here is an indoor dataset **hdl_501.bag** which you can download from **http://www.aisl.cs.tut.ac.jp/databases/hdl_graph_slam/hdl_501.bag.tar.gz**. You can see it from Figure 3.

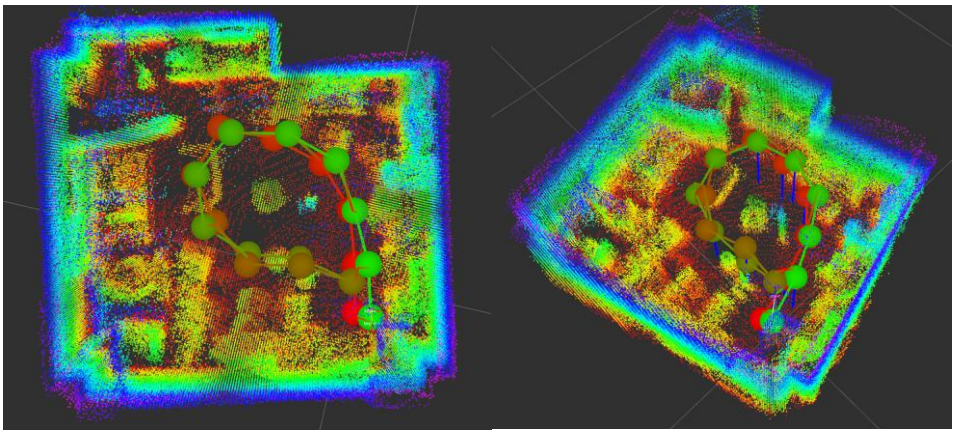


Figure 3 hdl_501.bag

The second dataset we used here is a outdoor dataset **hdl_400.bag** which you can download from **http://www.aisl.cs.tut.ac.jp/databases/hdl_graph_slam/hdl_400.bag.tar.gz**. You can see it from Figure 4.

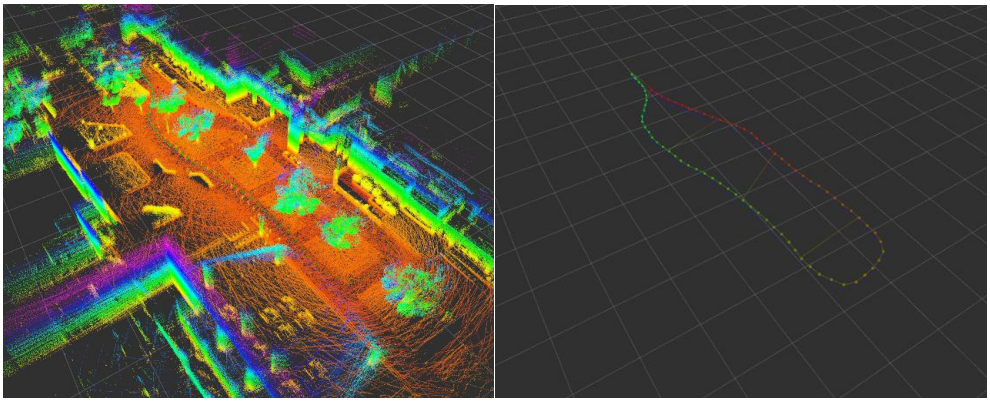


Figure 4 hdl_400.bag

[1] on cloud server with Xeon 6266C-16U 32G

a. specific values

****See Appendix 3&4.****

b. figures

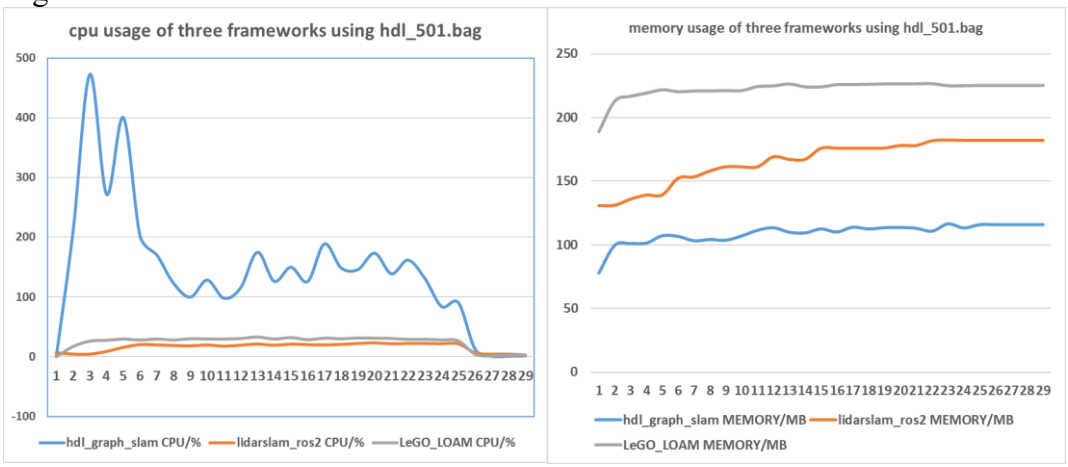


Figure 5 cpu/memory usage using hdl_501.bag

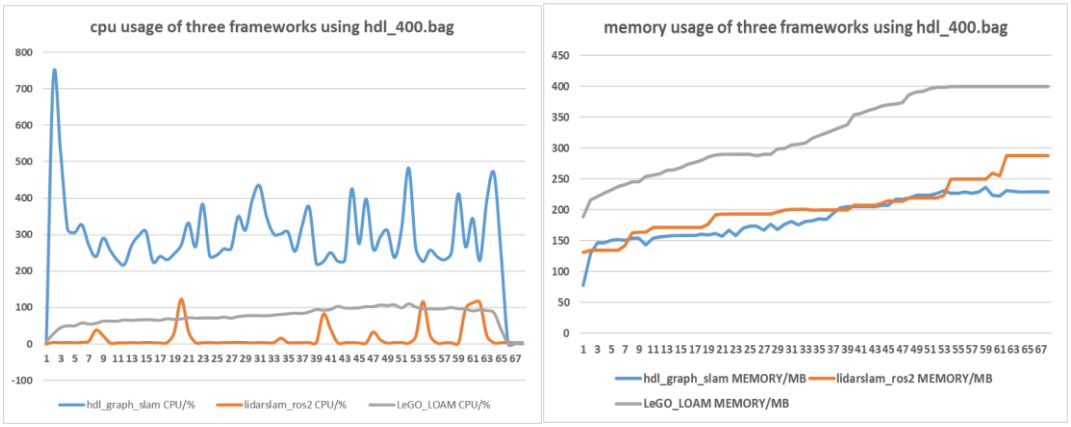
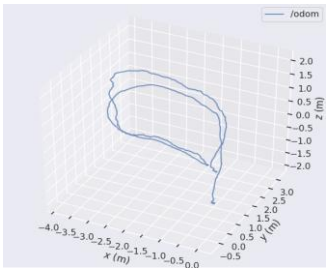
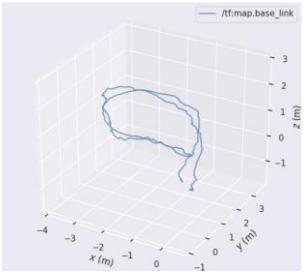
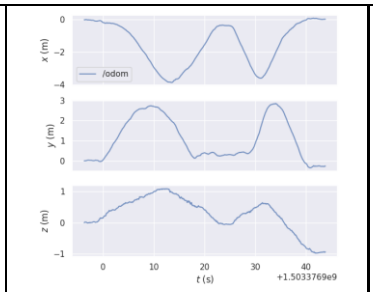
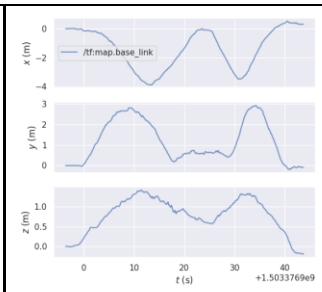
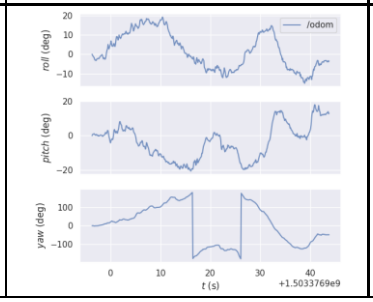
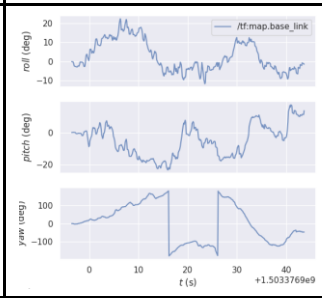
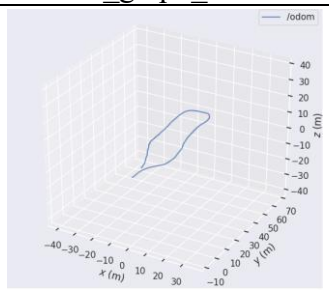
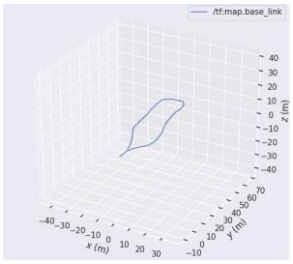
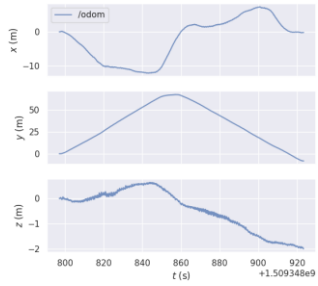
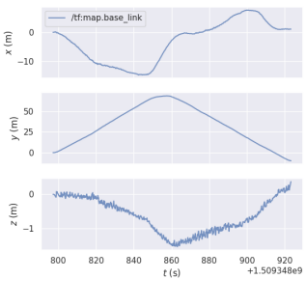
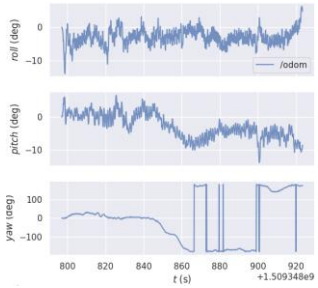
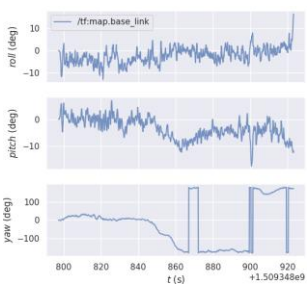


Figure 6 cpu/memory usage using hdl_400.bag

Table 3 trajectories using 32 line dataset on cloud server

dataset	hdl_501.bag		
framework	hdl_graph_slam	LeGO_LOAM	lidarslam_ros2
trajectory			**There are no graphical display on cloud server.**

xyz view			
rpy view			

dataset	hdl_400.bag		
framework	hdl_graph_slam	LeGO_LOAM	lidarslam_ros2
trajectory			**There are no graphical display on cloud server.**
xyz view			
rpy view			

From the figures and table above, we found the same truth as the test using 16 line dataset.

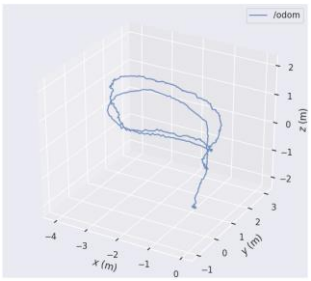
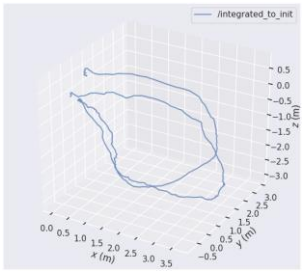
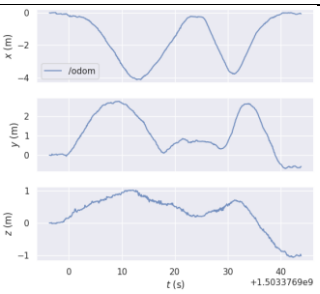
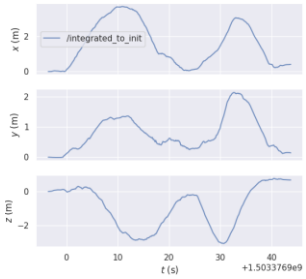
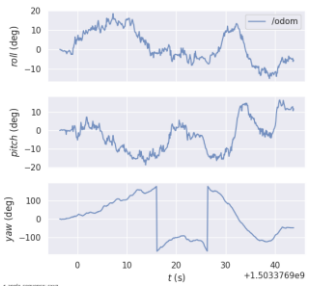
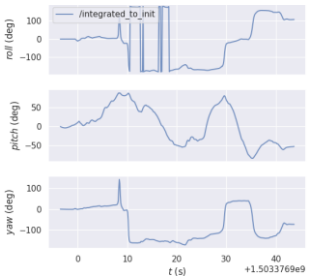
[2] on pc with i7-1065G7-1U 8G

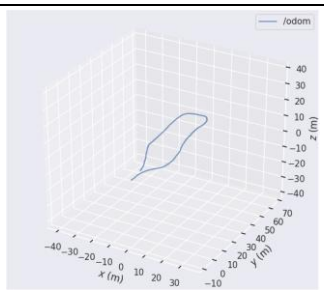
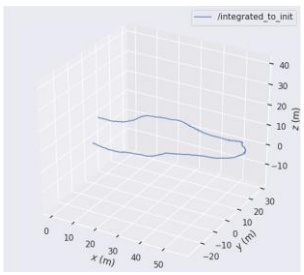
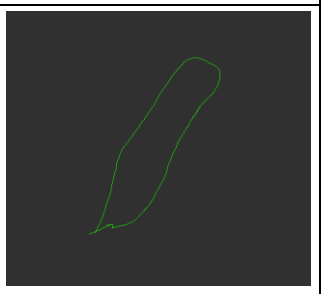
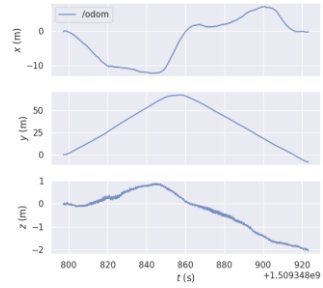
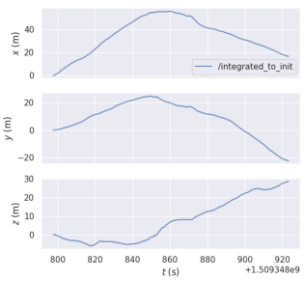
a. specific values

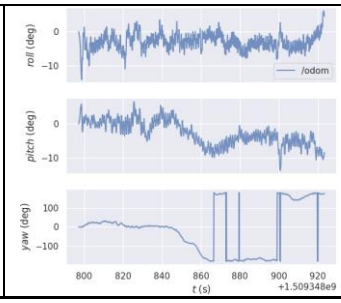
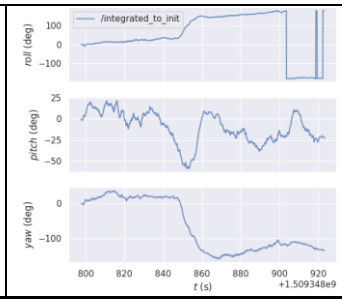
****See Appendix 5&6.****

b. figures

Table 4 trajectories using 32 line dataset on pc

dataset	hdl_501.bag		
framework	hdl_graph_slam	LeGO_LOAM	lidarslam_ros2
trajectory			
xyz view			
rpy view			

dataset	hdl_400.bag		
framework	hdl_graph_slam	LeGO_LOAM	lidarslam_ros2
trajectory			
xyz view			

rpy view			

The slam abilities of frameworks look worse than them in cloud server.

(3) 64 line dataset

The dataset we used here is 10.bag of the KITTI dataset.

[1] on cloud server with Xeon 6266C-16U 32G

a. specific values

****See Appendix 7.****

b. figures

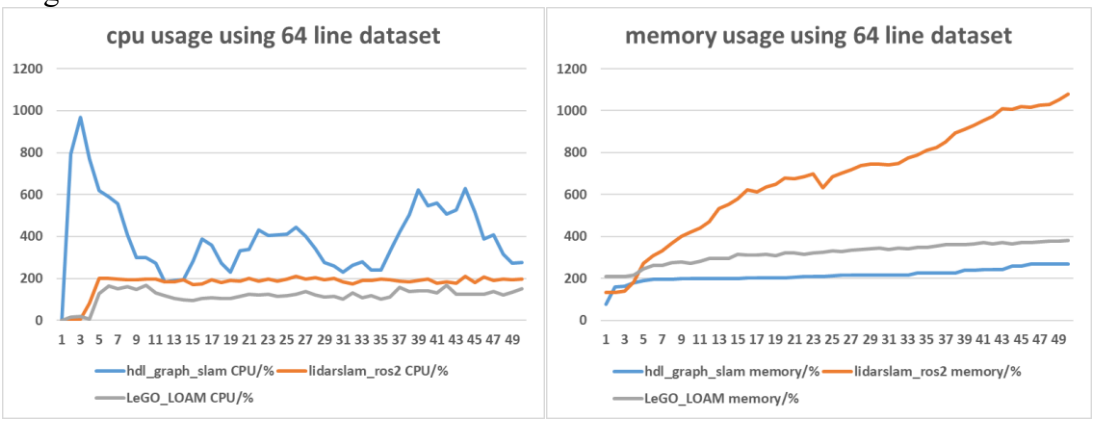
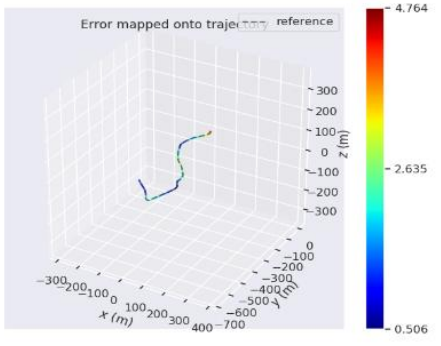
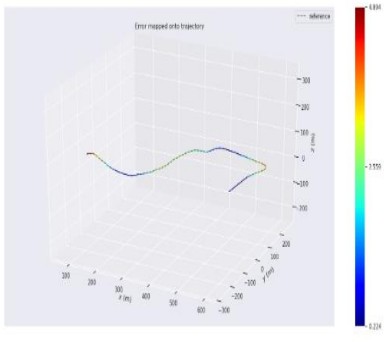
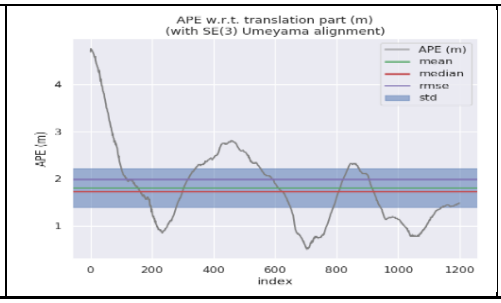
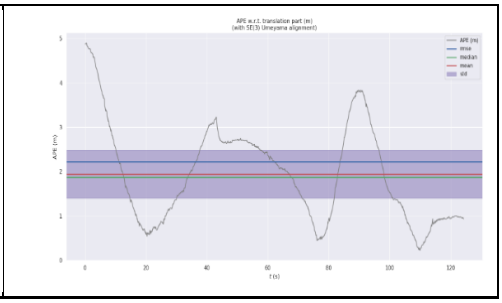


Figure 9 cpu/memory usage using 10.bag

Table 5 trajectories using 64 line dataset on cloud server

dataset	10.bag	
framework	hdl_graph_slam	LeGO_LOAM
error map		

ape graph		

[2] on pc with core i7-1065G7-1U 8G

a. specific values

****See Appendix 8.****

b. figures

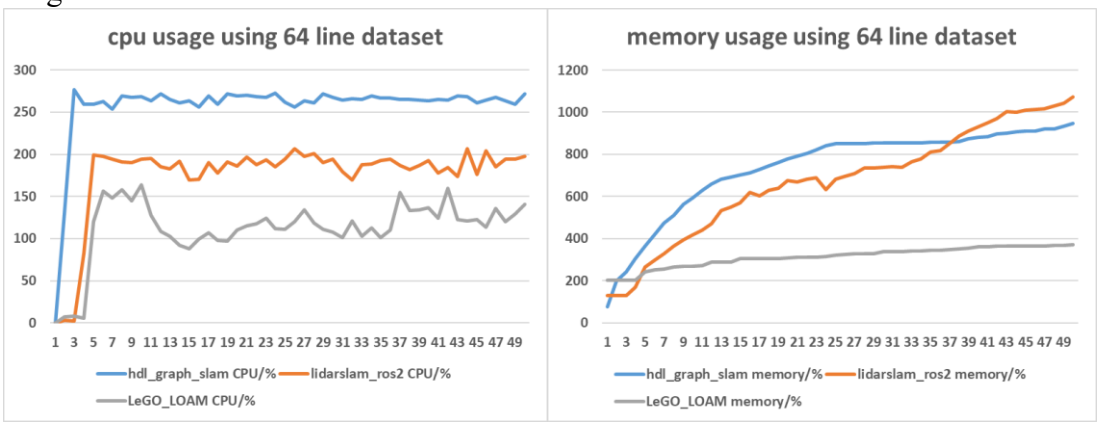
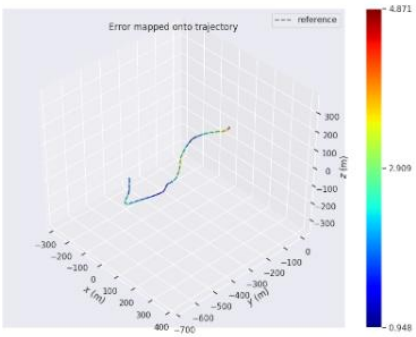
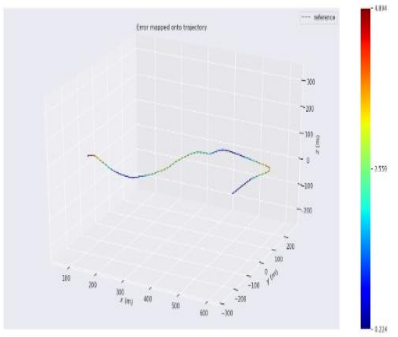
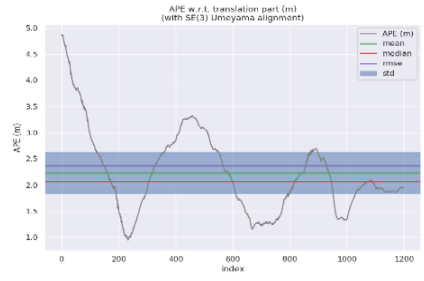
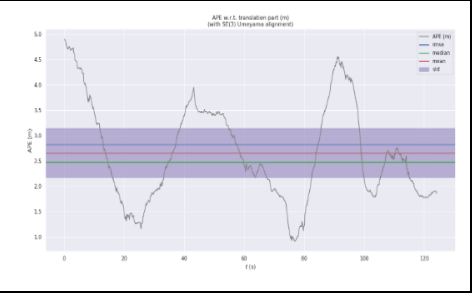


Figure 10 cpu/memory usage using 10.bag

Table 6 trajectories using 64 line dataset on pc

dataset	10.bag	
framework	hdl_graph_slam	LeGO_LOAM
error map		
ape graph		

From the figures and table abstained from cloud server and pc, we found that the **hdl_graph_slam** and **LeGO_LOAM** both have good slam ability. The lidarslam_ros2 cannot draw the correct trajectory after long time parameter adjustment. This lidarslam_ros2 have few adjustable parameters. The best trajectory in the parameter adjustment process is shown in the following figure.

Figure 11 the best trajectory using kitti dataset

3. Conclusion

From the test I get the following conclusion. The ***hdl_graph_slam*** and ***LeGO_LOAM*** both have good slam ability for 16/32/64 line lidar dataset. The hdl_graph_slam prefer using more cpu resources for calculation while the ***LeGO_LOAM*** prefer using more memory resources. The third framework lidarslam_ros2 which I think is not a proven framework. The author of it is a Japanese scholar named Ryohei Sasaki which is a good person. I learned that the framework is similar to ***hdl_graph_slam*** and add asynchronous update function after his helping and teaching. It has few adjustable parameters which make it have poor slam ability than other frameworks.

4. Appendix

(1) Appendix 1

nsh_indoor_outdoor.bag					
hdl_graph_slam		lidarslam_ros2		LeGO_LOAM	
CPU/%	MEMORY/MB	CPU/%	MEMORY/MB	CPU/%	MEMORY/MB
0	80.86442	0	129.2539	0	186.8672
174.7	102.2109	11.5	135.1328	12	204.3203
261.1	107.4431	25.5	135.1367	12.5	204.3203
246.8	107.07	27.5	135.1367	13.5	204.3203
179.3	106.4328	26.4	135.1367	13.5	204.3203
81.3	107.6917	25.5	135.1367	16.5	205.2031

155.3	106.4692	36.5	148.9844	14.5	205.9688
112.1	105.6954	48.5	154.0039	16	205.7656
119.5	108.0051	49	161.4375	14	206.2891
120.3	107.9954	49.5	172.2305	14	207.5742
112.8	108.9762	49	182.25	14.5	208.0898
112.6	109.1891	64.5	185.2656	14.5	209.4375
130.9	114.1818	56	193.8789	17.5	210.4609
94.3	108.6987	55.7	207.0313	16.5	210.9766
78.3	110.8889	46.5	211.5039	14.5	213.2969
91.5	114.9448	41	215.0547	16.5	213.8125
82	114.6814	33	215.3867	16.5	215.1016
97.9	110.4518	41.5	223.9141	15	215.875
131.5	112.9701	43	229.7148	16.5	216.6484
112	117.5352	47	234.1055	18	217.2734
98.5	120.4763	58	238.7773	17.5	218.0469
154.8	114.359	58.2	242.332	17.5	219.5898
138.1	118.768	74.5	247.5117	17	220.8789
158.4	120.7236	67	253.3008	17	221.9102
181.6	120.3446	83.5	254.8047	20	223.3398
126.2	119.6871	86	272.1523	19	223.8555
97.8	126.2268	98	283.4297	22.5	224.8867
138.6	124.942	101	296.4688	20.4	226.1758
107.2	123.2339	108.5	303.8008	21.5	228.4961
122.3	125.4137	119	311.1719	21	230.043
100.7	125.5262	114	319.5156	20.5	232.1133
105.4	128.164	122.4	328.5781	24	234.1758
128	125.7233	126	347.4258	21.4	235.4648
111.9	123.4537	113	354.1914	23	236.4961
120.5	124.025	96.5	359.0781	20.5	236.4961
134.9	125.0503	92	365.4531	20.5	236.4961
106.5	125.2174	98	370.2539	20.4	236.4961
143.3	122.5138	103	376.8672	21	236.4961
117.8	125.1362	98	385.0586	19.5	236.4961
119.6	131.1668	109.5	392.9766	19	236.4961
131.4	124.4358	97	399.293	19	236.4961
100.2	130.131	91	405.9063	18.5	236.4961
78.6	134.1132	62	408.4453	18.5	236.4961
159.9	131.3734	51.5	408.4453	16.5	236.4961
154	128.7551	44.3	408.4453	16.5	236.4961
2	129.0495	17.5	408.4453	1.5	236.4961
1	131.9742	2.5	408.4453	1	236.4961
1	137.2302	1.5	408.4453	1.5	236.4961
1	136.1493	2	408.4453	1.5	236.4961

(2) Appendix 2

nsh_indoor_outdoor.bag					
hdl_graph_slam		lidarslam_ros2		LeGO_LOAM	
CPU/%	MEMORY/MB	CPU/%	MEMORY/MB	CPU/%	MEMORY/MB
0	77.07422	0	120.1408	0	186.8672
167.5	95.22266	15.9	134.7768	12	204.3203
257.5	98.05469	27	134.0624	12.5	204.3203
241.5	99.08594	29.4	128.6824	13.5	204.3203
170.6	102.6719	28.1	132.8094	13.5	204.3203
73	103.2773	25.9	127.6456	16.5	205.2031
146	102.457	38.8	146.2697	14.5	205.9688
105	100.7383	51.9	150.1141	16	205.7656
110	98.50391	53	157.6813	14	206.2891
112	102.3281	54.2	171.5789	14	207.5742
106	105.9805	51.1	180.5884	14.5	208.0898
104.5	105.0273	65.8	179.1809	14.5	209.4375
124.5	106.6953	56.8	192.1774	17.5	210.4609
91.5	106.3359	58.8	199.1009	16.5	210.9766
72.5	106.3359	47	205.2033	14.5	213.2969
83.6	107.8828	43.9	212.0066	16.5	213.8125
74.5	108.1406	37.6	213.653	16.5	215.1016
94	108.1406	45.1	218.8662	15	215.875
127	108.3984	43.7	221.0668	16.5	216.6484
103.5	110.4609	49	227.6904	18	217.2734
93.5	114.0703	58.7	229.9987	17.5	218.0469
148.8	111.9805	60.4	238.2309	17.5	219.5898
135.5	113.5273	76.2	240.1861	17	220.8789
151	111.8984	67.4	251.8254	17	221.9102
173	112.7031	84.4	245.5701	20	223.3398
125	115.4844	90	266.9869	19	223.8555
89.6	117.4766	102.8	276.9203	22.5	224.8867
129.5	118.6797	103.6	289.6538	20.4	226.1758
104.5	120.2266	111.7	299.2934	21.5	228.4961
112.5	120.2266	120.8	309.3204	21	230.043
91.5	120.2266	116.9	314.7211	20.5	232.1133
96.5	120.7383	124.9	325.2748	24	234.1758
119.5	120.7383	126.2	341.7159	21.4	235.4648
106.5	120.7383	114.2	348.5569	23	236.4961
113	120.9961	99	352.2864	20.5	236.4961
126.5	120.9961	95.4	363.9393	20.5	236.4961
105.5	120.9961	100.4	366.3348	20.4	236.4961

134.8	118.8984	107.6	368.7357	21	236.4961
110	123.2813	99.1	378.0112	19.5	236.4961
118	123.9258	114.2	391.6818	19	236.4961
126	122.4766	100	396.7675	19	236.4961
95.5	127.1172	91.6	402.2645	18.5	236.4961
71.1	127.1172	63.7	406.9241	18.5	236.4961
158	127.1172	53.6	399.4503	16.5	236.4961
151	127.6289	48.2	401.8069	16.5	236.4961
1	127.6289	19.8	406.9962	1.5	236.4961
1	127.6289	3	406.8318	1	236.4961
1.5	127.6289	1	407.2353	1.5	236.4961
1	127.6289	1	407.6989	1.5	236.4961

(3) Appendix 3

hdl_501.bag					
hdl_graph_slam		lidarslam_ros2		LeGO_LOAM	
CPU/%	MEMORY/MB	CPU/%	MEMORY/MB	CPU/%	MEMORY/MB
0	77.98438	6.7	130.9961	0	188.7461
210.4	99.57031	4.5	131.2539	17	212.8672
472.5	100.9336	4.5	136.1172	26	216.6797
271.5	101.2891	9	139.2461	27.4	219.2109
400	107.0156	15.9	139.4336	29.5	221.8281
201.5	106.4844	20.5	152.4023	28	220.3516
170	103.0781	20	153.4297	29.5	220.9258
122.4	104.0781	19	158.0977	28	220.9258
99.5	103.4688	18.5	161.2773	30	221.25
128	106.8438	19.9	161.2461	29.5	221.2109
97.5	111.2305	18	161.2461	29.5	224.4023
115	113.25	19.5	169.0938	30.4	224.9063
174.6	109.7266	21.5	167.1406	33	226.4336
126	109.2227	19.5	167.1406	29.5	224.1797
149.5	112.3242	21.4	175.7969	32	224.1445
125.5	109.9336	20.5	175.7969	28.5	225.9492
188.5	113.6484	20	175.7969	31	225.9961
148.3	112.2773	21	175.7969	30	226.207
145.5	113.3242	22.5	175.9453	31.4	226.4922
173	113.4648	23.4	177.9219	31	226.5664
138.5	112.8633	22	177.9219	30.5	226.5938
161.5	110.5781	22.5	181.6328	29	226.6875
130.5	116.25	22.5	182.2266	29	225.0703
83.6	113.0781	22	181.9609	28	225.0703
90	115.6563	21.9	181.9609	26.5	225.3242
12	115.6563	6.5	181.9609	4	225.3242

0.5	115.6563	4.5	181.9609	1.5	225.3242
0.5	115.6563	4.5	181.9609	2.5	225.3242
1	115.6563	3	181.9609	2.5	225.3242

(4) Appendix 4

hdl_400.bag					
hdl_graph_slam		lidarslam_ros2		LeGO_LOAM	
CPU/%	MEMORY/MB	CPU/%	MEMORY/MB	CPU/%	MEMORY/MB
0	77.91406	0	130.8203	6.7	188.7422
733	129.6367	4.5	134.1992	27.9	216.0859
529	146.8086	3.5	134.1992	44.9	221.9414
314	146.7813	4.5	134.1992	50	226.4258
305.5	151.2734	3.5	134.1992	50	232.6094
327	151.4609	4.5	134.1992	58	237.4688
270	150.3945	8	142.5508	54.8	241.3359
239.5	153.7617	38.5	163.2852	56.9	245.4609
290.5	153.9141	22.5	163.457	62.9	245.6406
256.7	143.793	2.5	163.457	63	253.6211
229.5	154.5547	3	171.7422	62.9	256.4805
218	156.1016	3	171.7422	66.3	259.0039
270.5	157.3008	4	171.7422	65	263.8984
297	158.0742	3	171.7422	66.4	265.1914
309	158.5898	4.5	171.7422	67	268.2813
225.5	158.5898	3.5	171.7422	66.5	273.3984
240.5	158.5898	3	171.7422	65.3	277.3047
231	160.6523	4	171.7422	69.5	280.3555
247.5	159.9492	31.5	176.8008	67.8	285.5039
272.1	161.6641	123.5	191.8125	69	289.3711
332	157.332	34.8	193.6172	72.5	289.8867
266.5	166.7109	4	193.6172	71.3	289.8867
384	158.832	3.5	193.6172	71.5	289.8867
241.5	170.832	4	193.6172	71.9	289.8867
243.8	173.3008	3	193.6172	71.5	289.8867
261	173.8281	4	193.6172	74	288.1484
262	166.793	4	193.6172	71.3	289.6914
350	176.8906	4	193.6172	75.5	289.6914
312	168.4492	4	196.5781	77.8	298.7148
396.5	177.4727	3	200.0781	78	299.7461
434.3	181.3594	4	200.8633	78	305.1602
348.5	175.9414	3.5	200.8633	77.7	306.4492
302	181.3555	3.5	200.8633	79.5	307.9961
302	182.2344	16	199.4883	81.4	316.5039
307.5	185.8438	4	199.4883	83	320.8867

254	184.2891	3.5	199.4883	85	325.2695
324.4	194.5703	3.5	199.4883	84	329.6523
375	203.0781	4	199.4883	88.2	333.5195
221	204.9258	4	199.4883	94.8	337.9023
226	204.9688	82.5	207.2891	93	353.5898
250.7	204.9688	41.3	207.2891	95	356.6836
227	205.0273	3.5	207.2891	103.5	360.8086
230	205.2109	3.5	207.2891	99.1	363.3828
426	207.1445	4	210.2031	98.4	368.2813
275	207.1445	3	214.5625	99.5	370.8594
398	216.8086	2.5	213.6641	102.9	371.6328
260.5	217.0664	33	213.6641	103	373.6953
293.5	219.6445	11.5	219.8242	107.5	386.8438
311	223.5117	2.5	219.8242	106	391.2266
237	223.5117	4	219.8242	107.9	392
316.4	223.5117	4	219.8242	99.5	396.125
483	226.8633	2.5	219.8242	110.5	398.9609
263	231.2227	21.5	224.207	102	398.9609
226	227.3984	116.5	250.0117	97	399.2188
257.5	227.1406	24.5	250.0117	97	399.2188
239.5	229.6172	2.5	250.0117	96.6	399.2188
230.8	226.6563	3	250.0117	97.4	399.2188
250	229.2344	3.5	250.0117	100.5	399.2188
412.5	236.9648	3	250.0117	97	399.2188
266.5	223.8477	96.5	260.0352	96.5	399.2188
344.5	223.0352	113	254.7539	91	399.2188
228.9	231.2227	114	287.8672	94	399.2188
395.5	230.1992	23	287.8672	92	399.2188
468.5	228.7148	3.5	287.8672	86	399.2188
246.5	228.7148	3.5	287.8672	40	399.4766
0	228.7148	4	287.8672	2	399.4766
1	228.7148	3.5	287.8672	2	399.4766
0	228.7148	4	287.8672	3	399.4766

(5) Appendix 5

hdl_501.bag					
hdl_graph_slam		lidarslam_ros2		LeGO_LOAM	
CPU/%	MEMORY/MB	CPU/%	MEMORY/MB	CPU/%	MEMORY/MB
6.7	77.35938	6.7	130.9961	0	188.7461
109	100.7617	4.5	131.2539	17	212.8672
122.4	107.1289	4.5	136.1172	26	216.6797
133.5	110.125	9	139.2461	27.4	219.2109
188.5	110.5	15.9	139.4336	29.5	221.8281

169	111.1367	20.5	152.4023	28	220.3516
188	111.9219	20	153.4297	29.5	220.9258
181.5	109.3164	19	158.0977	28	220.9258
186.6	111.8906	18.5	161.2773	30	221.25
170	112.9219	19.9	161.2461	29.5	221.2109
208.5	110.625	18	161.2461	29.5	224.4023
202.5	114.8398	19.5	169.0938	30.4	224.9063
208.5	114.6992	21.5	167.1406	33	226.4336
219	113.9531	19.5	167.1406	29.5	224.1797
143.5	112.7031	21.4	175.7969	32	224.1445
121.9	113.2188	20.5	175.7969	28.5	225.9492
156.5	116.2266	20	175.7969	31	225.9961
206.5	115.625	21	175.7969	30	226.207
175.6	113.7031	22.5	175.9453	31.4	226.4922
225	119.6172	23.4	177.9219	31	226.5664
213.9	112.9414	22	177.9219	30.5	226.5938
188	120.0039	22.5	181.6328	29	226.6875
137.5	116.4219	22.5	182.2266	29	225.0703
75	116.9375	22	181.9609	28	225.0703
111	116.9375	21.9	181.9609	26.5	225.3242
1	116.9375	6.5	181.9609	4	225.3242
1	116.9375	4.5	181.9609	1.5	225.3242
1.5	116.9375	4.5	181.9609	2.5	225.3242
1.5	116.9375	3	181.9609	2.5	225.3242

(6) Appendix 6

hdl_400.bag					
hdl_graph_slam		lidarslam_ros2		LeGO_LOAM	
CPU/%	MEMORY/MB	CPU/%	MEMORY/MB	CPU/%	MEMORY/MB
0	77.17188	0	127.6406	5.9	183.8064
122.5	135.6406	3.9	130.2817	26.8	207.1176
254	146.5273	2.4	126.764	42.2	214.5086
256.7	159.9336	4.1	125.9809	48.3	217.5711
257	168.4414	2	125.1246	49.5	227.004
262	177.75	3	133.1595	56.4	237.227
262.2	170.6563	7.1	142.1951	52.4	239.6161
263	175.293	38.4	157.285	54.1	236.641
263	184.0586	20.6	154.6551	60.2	238.544
263.5	190.5039	0.7	154.0145	61.9	251.6666
262.7	194.1133	1.1	163.2936	61.8	254.0544
259.5	203.1367	2.3	169.6886	63.4	252.9819
265.2	203.1367	2.2	171.6056	62.8	258.5346
263.5	203.1367	1.3	165.6285	64.2	261.6517

263	212.1602	2.7	166.3415	66	263.1567
261.2	219.6367	2	171.6081	63.8	268.7359
263	211.5234	1.3	166.8504	65.3	271.0572
263	214.0977	3.5	167.5611	69.2	272.8657
264.5	218.1406	29.7	173.352	67.6	279.0973
260.7	218.1406	123.3	189.4326	67.8	285.1476
264	222.7813	33	187.1941	71.3	287.4603
264	228.6914	2.7	187.1647	69.8	284.9329
266.5	232.5586	1.7	187.6501	70.6	288.8528
261.5	234.9023	3.1	183.9837	69	285.2836
260.2	237.2188	2.4	185.3095	70.3	280.037
266.5	254.4297	3.7	185.237	71.8	280.4141
261.2	265.8555	3.8	188.724	70.7	279.7159
265	280.9258	3.9	189.8375	73.1	285.9976
267.5	293.2148	2.5	195.394	77.2	289.5493
262.5	299.7227	1.9	196.4505	77	292.6497
263.5	309.9023	3.1	200.3305	77.7	298.9814
259.5	321.0742	2.3	199.7192	74.9	298.2344
263.2	328.9883	2.2	199.2654	78.4	301.5272
259.5	339.043	15	191.9863	79.1	309.3019
255	349.0039	2.4	194.3793	81.6	316.6698
261	349.7773	3	197.0641	84.3	322.3194
256	351.6406	2.2	191.8562	83.8	324.9117
260.2	353.4414	3.7	192.1193	87.4	331.8539
262	356.1445	4	197.2427	94.8	329.9862
264.5	358.7227	82.4	198.3733	91.4	352.4852
263	358.7227	39.4	203.741	92.6	355.7994
262.7	361.5586	2.4	202.7367	101.8	351.704
265	362.4961	1.6	199.5248	98.4	355.9083
267.5	362.4961	3	209.9819	98.1	362.7622
268.5	362.4961	1	213.5996	98.7	368.2811
267.5	362.4961	1.2	207.8675	102	369.1277
267.2	366.1055	32.5	204.7233	101.5	363.9116
268	373.0664	9.6	217.6073	106.5	376.0156
259.5	385.4414	1.3	218.0759	104.4	383.6986
264	397.625	3.9	214.7398	104.9	382.5274
254	417.8711	3.6	214.9291	97.5	393.3135
242.3	424.0313	0.9	215.5609	109.8	390.1581
246.5	425.5781	20.4	218.4621	99.2	394.1346
205	429.4453	115.2	242.1789	96	394.605
244	429.4453	23.8	240.7366	96.1	391.5763
245	429.4453	1.8	246.5657	94.1	397.2881
242.8	429.4453	2.6	249.2077	96.6	395.5651

250.5	429.4453	3.3	241.4347	97.7	392.1815
244.5	429.4453	2.4	245.7158	94.1	396.7373
241	388.4609	95.2	250.6474	95.5	389.959
252.7	398.418	112.2	251.4578	88.4	399.1755
247.5	398.4531	112.7	281.4793	92.1	389.9268
244	374.4336	21.7	287.1776	91.6	390.9947
249.5	376.1484	3.5	279.4748	83.1	393.3048
256.5	376.1484	3	278.9003	38.6	390.1401
266.7	354.4609	3.5	282.6857	3	398.4428
229	354.4609	4	280.5193	3	391.7327
158.5	354.4609	4	284.8671	3	394.4251

(7) Appendix 7

10.bag					
hdl_graph_slam		lidarslam_ros2		LeGO_LOAM	
CPU/%	MEMORY/MB	CPU/%	MEMORY/MB	CPU/%	MEMORY/MB
0	76.83203	0	128.5156	0	203.6797
130	197.6406	3.5	129.8047	7	203.6797
276.5	241.2188	2	129.8047	8	203.6797
259.5	305.9922	82	170.207	6	203.6797
259.7	362.9688	199	265.4492	120	242.4492
262.5	421.4922	198	296.4727	156.4	253.082
253.5	473.8281	194	328.5938	148	255.6563
269.5	510.9531	191	364.082	158	263.3555
268	564.0625	190	394.7891	145	268.8242
268.2	592.3555	194	417.9727	163.5	268.8242
263.5	630.5117	195	440.8086	128	272.0352
271.5	657.582	185	469.918	109	287.0859
265.5	682.0742	182.5	532.4102	103	288
261.5	691.6133	191.5	551.0781	92	288
263.7	701.9258	169.7	570.9414	88	304.9805
256	712.2969	170.5	617.6016	100	304.9805
269.5	727.7656	190.5	601.8125	106.9	306.0117
259.5	745.8125	177.5	627.9453	98	306.0117
271.5	762.5703	191.1	637.8516	97	306.0117
269.2	776.4922	186.5	673.8984	110	309.0898
270.5	790.9297	196.5	667.3555	115	309.8633
268.5	805.1094	187.5	681.3359	118	311.9219
268	820.5781	193.5	688.25	124	312.4375
272.5	839.6563	185.1	632.2461	112	313.9844
262	851.5156	194.5	681.8398	111	322.1875
256.5	851.5156	206.5	695.7617	120	323.2188
263.2	851.5156	197.5	709.7109	134	327.3438

261	851.5156	201	733.6406	118.8	328.1133
271.5	855.5156	190.5	735.4023	111	328.8867
267.5	855.5156	194.5	738.4609	108	336.8789
264.5	855.5156	179.5	741	101	336.8789
265.7	855.5156	169.7	739.2969	121	338.9414
265	855.5156	187.5	765.8867	103	339.7148
269	855.5469	189	778.9063	113	340.2305
266.5	856.5781	192.5	810.3984	100.9	342.8086
266.5	856.5781	194.5	816.6602	110	343.8398
265.2	856.5781	186.6	849.3711	155	349.2539
265.5	862.25	182.4	885.9375	133	351.0586
264	874.8828	187	909.2734	134	353.3789
263.5	880.0391	192.5	930.1445	137	360.3359
265.2	883.6484	178	951.0313	124	361.8828
264.5	896.2813	184.6	968.4727	160	363.4297
269.5	900.1484	174	1003.332	123	363.6875
268.5	907.8828	207	999.6484	121	363.6875
261.5	909.6875	176.5	1009.902	122.8	364.4609
264	909.6875	204	1013.188	114	364.4609
267.7	921.3242	185	1015.176	136	364.9727
263.5	921.3242	194	1030.539	120	367.5508
259.5	934.2422	194.5	1044.039	129	368.582
271.5	947.4414	197.5	1074.203	141	370.9023
266	955.9492	188.6	1085.41	129	373.2227
266.7	959.043	214.5	1095.23	127	379.4102
267.5	959.043	187	1112.941	98	380.4414
269.5	959.043	193	1120.469	108.9	380.4414
267.5	959.043	191.5	1138.422	109	392.043
265	959.043	191.5	1099.328	120	392.043
265.2	959.043	189.5	1193.43	152	395.1367
267	959.043	200.5	1125.762	105	395.9102
258.5	959.043	223	1217.488	97	396.4258
268.5	959.043	198	1160.992	105	401.582
270.5	959.1055	196	1176.992	112.9	401.582
261.7	959.1055	203.5	1196.887	155	410.8633
257.5	959.1055	187	1229.926	121	411.1211
264	959.1055	58	1246.168	116	412.9258
294	959.1055	84.6	1254.16	110	424.5938
279.5	959.1055	44.5	1221.824	99	425.1094
276	959.1055	3.5	1221.824	4	425.8828

(8) Appendix 8

10.bag

hdl_graph_slam		lidarslam_ros2		LeGO_LOAM	
CPU/%	MEMORY/MB	CPU/%	MEMORY/MB	CPU/%	MEMORY/MB
0	77.07422	0	131.1045	0	207.6876
794	158.668	5.1	131.2952	14.5	208.7392
967	160.8008	4.7	137.7249	17.8	209.4096
770.6	178.1797	82.1	181.3728	6.5	213.7907
618.5	188.2344	201.2	272.375	126.8	245.5416
590	195.1953	200.4	307.2832	164.4	262.0224
556.5	196.2266	196.2	330.2901	151.9	261.475
407	196.2266	193	367.2007	162.3	273.8038
299	197.2578	192.4	401.0411	147.8	277.4578
301	197.2578	197.7	421.2637	169	271.9618
272	197.5156	198	441.5996	131.6	280.1469
184.5	197.5156	185.1	469.9919	116.8	294.81
189.5	197.5156	185.2	532.947	104.4	293.7964
195	197.5156	193.6	553.2439	98.9	295.4094
284.5	198.2891	172.4	579.5708	96.1	313.2851
388	200.8672	172.8	623.6049	106.3	311.7053
358	201.3828	195.2	612.477	109.6	311.0309
272	201.3828	180.2	634.7976	104.1	316.126
229.9	201.3828	192.3	649.6305	104.9	306.7216
331.5	202.6719	186.7	677.3958	114.5	319.7371
340.5	206.0234	199.9	676.6128	124.8	320.8131
432	207.0547	187.6	685.4261	121.7	315.632
404	208.8555	198.1	697.8267	125.2	320.5678
407.5	209.3711	187.9	632.662	115.1	324.5809
411.5	212.4648	196.2	684.3644	117.2	330.1538
444	213.7539	209	702.7905	123.7	327.9568
400.5	215.043	198.6	716.9282	138.8	333.614
340.8	215.043	203.9	737.368	121.3	336.4183
277	215.043	195.2	745.3665	111.1	339.6615
259	215.043	199.1	745.2963	113.8	343.2644
231.5	215.043	183.2	741.1002	101.8	339.0367
264	215.043	174.2	748.3157	130.2	344.7212
279.1	215.043	191.4	774.029	108.7	341.1089
238.5	225.6563	191.3	787.4197	116.8	348.8226
241	225.7188	197.4	811.8704	101.2	346.3456
327.5	226.0625	195.1	824.3402	112.1	354.0297
421.5	226.0625	188.4	851.486	157.2	359.3929
504	226.6406	184.6	894.918	139.5	360.1453
623.5	239.7891	191.8	910.9625	141.2	359.388
548	239.7891	196.8	930.7658	142.2	363.372
561	242.8828	178.4	952.067	132.1	369.6419

507.5	242.9766	184.7	973.4592	167.1	363.834
528.5	242.9766	176.1	1009.857	124.2	371.4595
630.5	258.4414	210.8	1007.935	124	365.1561
517.5	258.4414	179.2	1020.148	125.1	369.88
388	267.1211	207.1	1016.43	123.3	370.4748
407	267.1211	189.4	1025.064	138	374.7516
314.5	267.1211	198.1	1030.554	122.6	378.4536
272	267.1211	195.6	1052.554	136	376.9083
277.5	267.1211	197.7	1079.748	149.9	379.2294
268.5	267.1211	192.2	1095.336	137.3	381.91
174.1	267.1563	216	1103.299	135.8	382.6473
194.5	267.1563	187.3	1114.559	105.9	385.6877
190.5	267.1563	193.8	1131.619	113.9	381.4005
309.5	267.1563	196.3	1146.653	118.7	396.7408
341	267.1563	192.4	1103.104	129.6	395.1551
370	267.1563	191.7	1198.491	155.9	404.6382
371.5	267.1563	203.4	1134.463	105.2	401.0337
272.5	267.1563	227.1	1219.832	105.8	404.6557
203.5	289.582	201.9	1163.725	111.9	404.3525
166	289.582	200.6	1181.431	113.4	412.1129
148.5	289.582	204.2	1201.441	157.6	421.4721
166	289.582	187.4	1237.668	128.3	411.7722
48	289.582	58.5	1248.799	119.4	419.8129
1	289.582	89.1	1263.242	118.3	431.1596
1	289.582	44.6	1226.517	101.7	434.3226
1	289.582	4.5	1270.155	4	430.2388