RoboND Map My World Robot

Kevin James

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Abstract

Simultaneous Localization and Mapping (SLAM) is conducted using the *rtabmap* package in ROS. This project takes two gazebo environments without maps and uses an exploring robot with SLAM to discover the occupancy grid and map while simultaneously localizing. The goal was to demonstrate loop closures showing that the algorithm is able to recognize locations that it has encountered previously.

Introduction

Robots often operate in *a priori* unknown environments. When this is the case, if it wishes to operate effectively, a robot must both map its environment and localize itself within the environment. This is the domain of SLAM (Simultaneous Localization and Mapping) algorithms. The problem is complicated by the robot's need to know its relative location during the mapping process in order to construct an accurate map. The robot does not know its location but its control inputs enable computation of where it should be relative to where it started. Since the effect of controls is statistical, the estimated location accumulates error over time. Additional information is needed to close the loop and correct the error. One solution uses optical feature recognition and distance. Of course, since the map is not known in advance, a camera collects data as the robot explores and later correlates images with previously seen features. Distance to detected objects can be determined using an RGBD camera or LIDAR.

Background

This project uses *rtabmap*, an implementation of GraphSLAM that solves the *full* SLAM problem: it recovers the entire path and map, as opposed to *online* SLAM algorithms that estimate only the current pose and the map. The graph constructed by the algorithm links nodes with edges corresponding to the robot's *motion* and corresponding to *features* sensed in the environment from specific poses. *Motion* between poses has expected value given the control inputs, and noise. Feature detection has both noise and the requirement to associate known features using *loop closure*. Graph edges between poses and features both constrain the solution, and minimizing the set of constraints produces the most likely actual path and map.

GraphSLAM improves on FastSLAM, which uses a particle filter and Extended Kalman Filter. Each particle contains a hypothetical pose and map. EKF is used for feature association, and feature measurements determine the particle weights. Since particles are expensive, some work on FastSLAM has involved reducing the number of particles, but this reduction may result in no particle that accurately estimates the pose and map.

Scene and Robot Configuration

The robot used to scout the environments is the *udacitybot* from the previous project, updated with an RGBD camera. The robot also maintains its Hokuyo laser range sensor. The customized gazebo world is based on a gazebo cafe model. Added to this open-roof building model are multiple objects that are intended to be differentiable so that the robot can establish non-aliasing correspondences during the localization and mapping process.

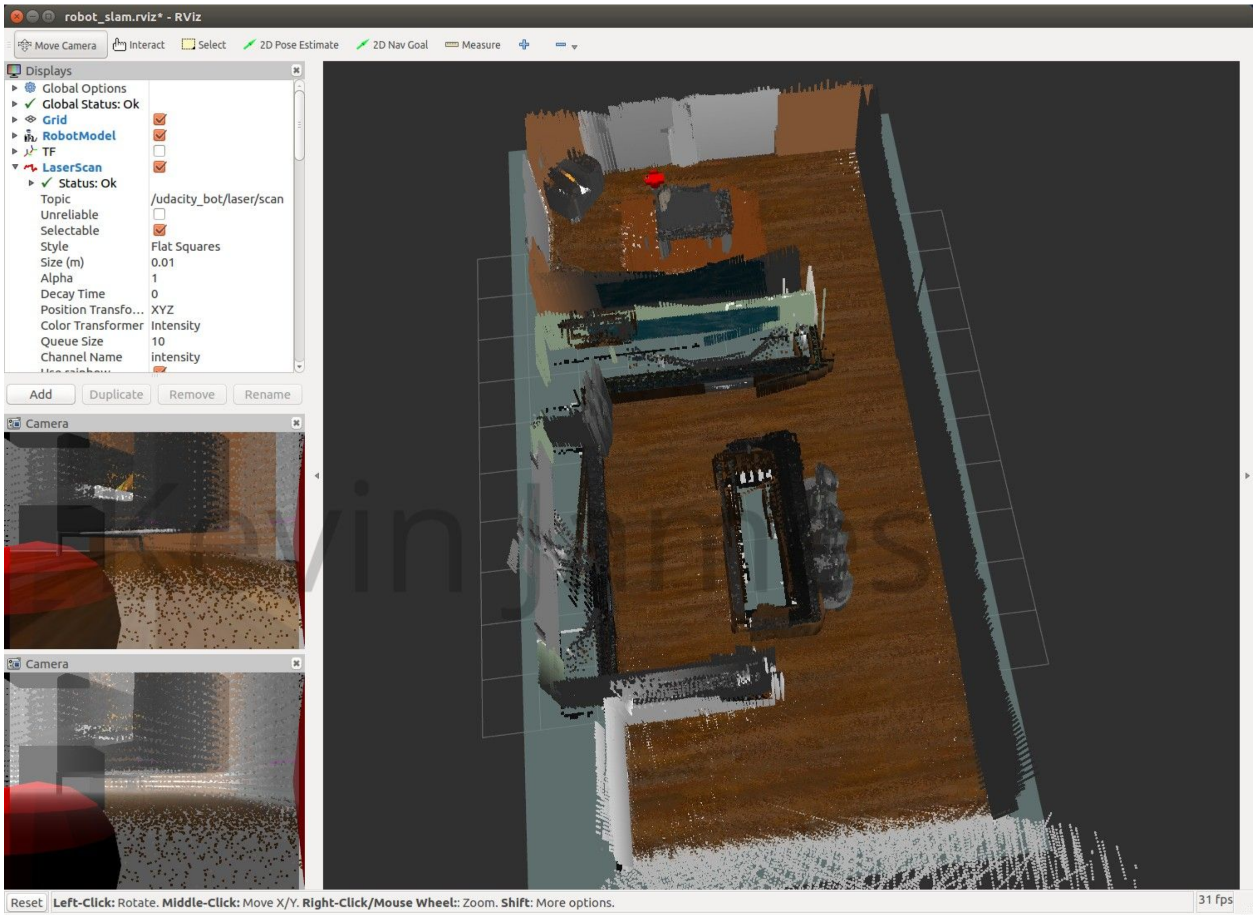
The package structure for launching the world and robot in ROS are derived from the previous project. Added are the launch files for mapping and teleop. The basic files were provided for the project, but some topic name changes were required to connect the laser and camera sensors and TF frames correctly.

Results

Kitchen Dining World

Shown below are images of the Udacity world mapping, occupancy grid, path, and loop closure. Note that images may have been generated from different explorations of the environment.

The image below shows the 3D map of the world in rviz. Following is the map and path shown by the *rtabmap* visualizer.

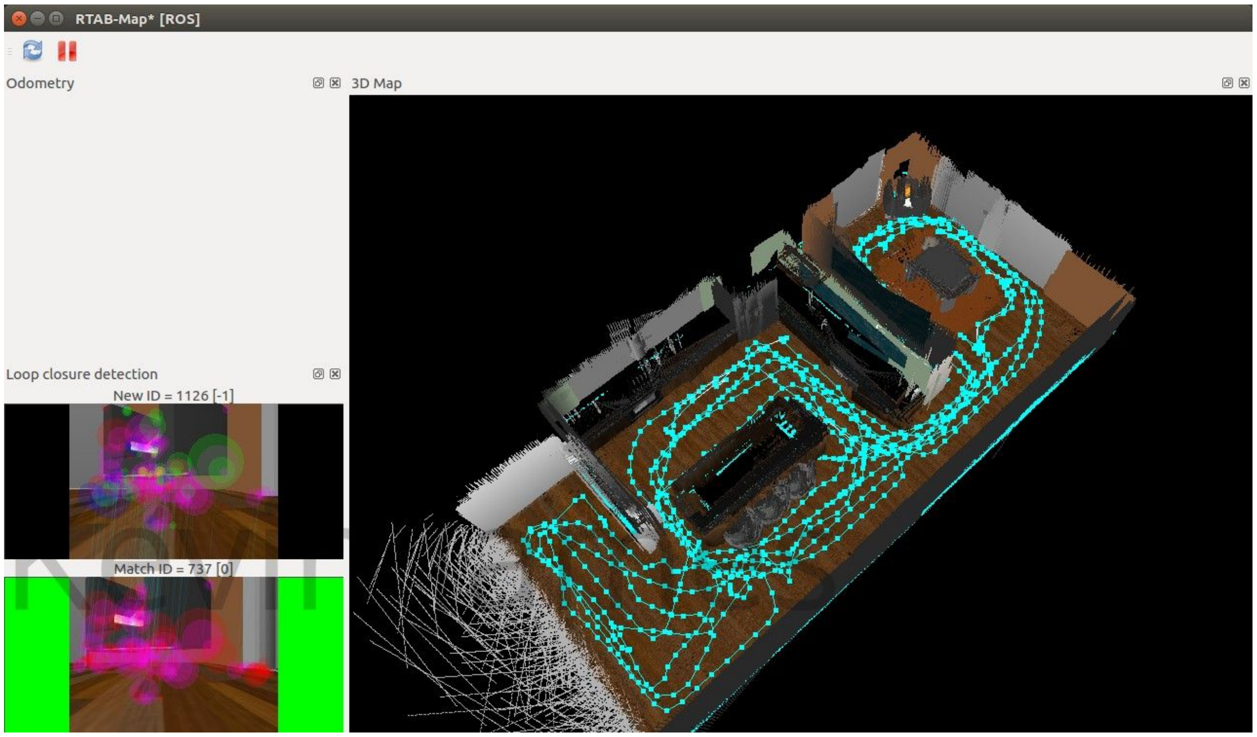


Global Options
✓ Global Status: Ok
Grid ✓
RobotModel ✓
TF
LaserScan ✓
✓ Status: Ok

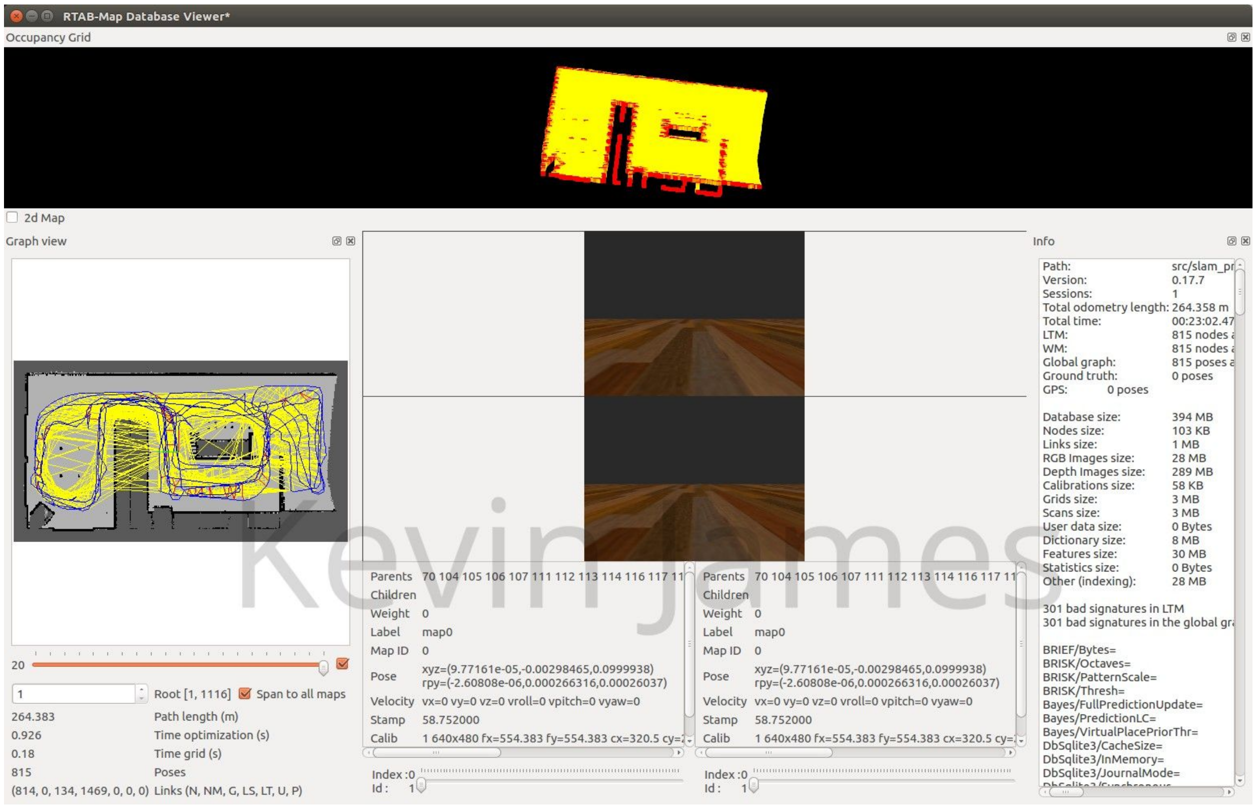
Topic	/udacity_bot/laser/scan
Unreliable	
Selectable	✓
Style	Flat Squares
Size (m)	0.01
Alpha	1
Decay Time	0
Position Transfo…	XYZ
Color Transformer	Intensity
Queue Size	10
Channel Name	intensity

Left-Click: Rotate. **Middle-Click:** Move X/Y. **Right-Click/Mouse Wheel:**: Zoom. **Shift**: More options.

31 fps



The occupancy grid and graph view are shown in *rtabmap-databaseViewer*.



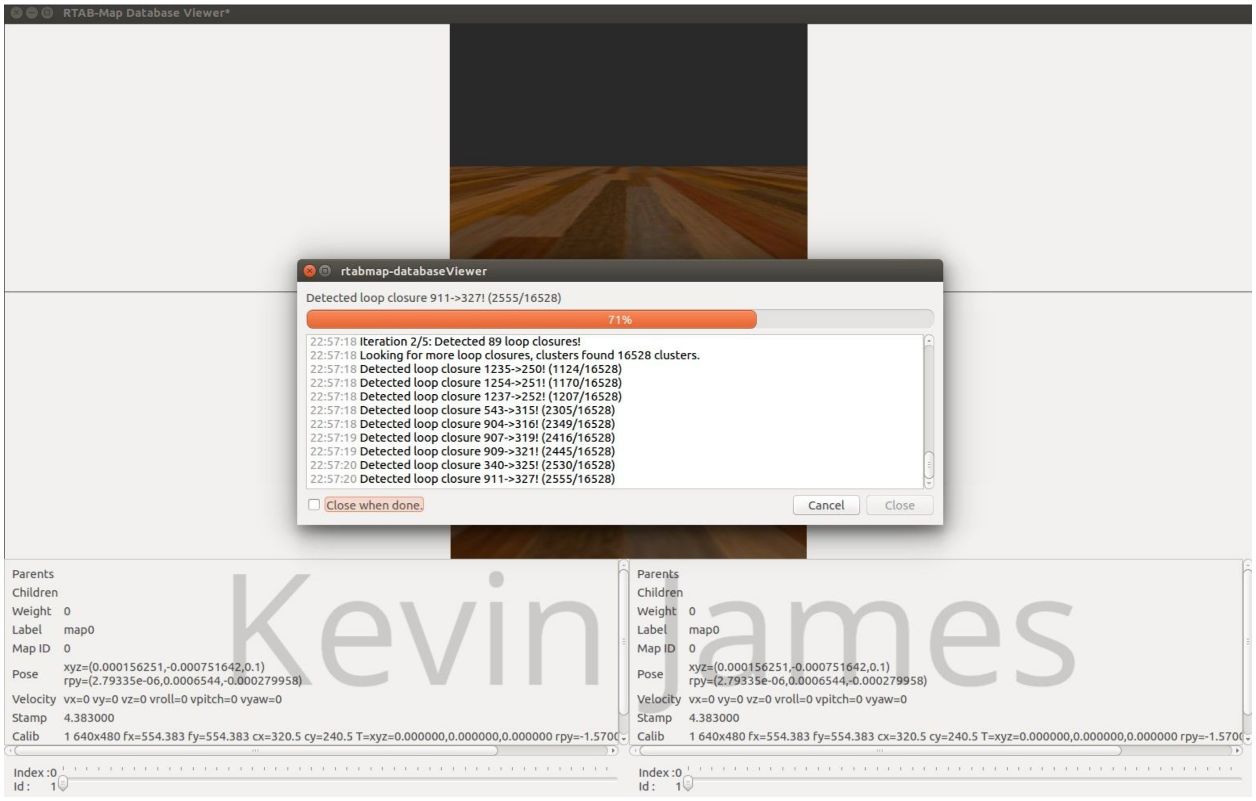
```
264.383                       Path length (m)
0.926                         Time optimization (s)
0.18                          Time grid (s)
815                           Poses
(814, 0, 134, 1469, 0, 0, 0)  Links (N, NM, G, LS, LT, U, P)
```

```
Parents   70 104 105 106 107 111 112 113 114 116 117 11
Children
Weight    0
Label     map0
Map ID    0
Pose      xyz=(9.77161e-05,-0.00298465,0.0999938)
          rpy=(-2.60808e-06,0.000266316,0.00026037)
Velocity  vx=0 vy=0 vz=0 vroll=0 vpitch=0 vyaw=0
Stamp     58.752000
Calib     1 640x480 fx=554.383 fy=554.383 cx=320.5 cy=
Index :0
Id :    1
```

```
Parents   70 104 105 106 107 111 112 113 114 116 117 11
Children
Weight    0
Label     map0
Map ID    0
Pose      xyz=(9.77161e-05,-0.00298465,0.0999938)
          rpy=(-2.60808e-06,0.000266316,0.00026037)
Velocity  vx=0 vy=0 vz=0 vroll=0 vpitch=0 vyaw=0
Stamp     58.752000
Calib     1 640x480 fx=554.383 fy=554.383 cx=320.5 cy=
Index :0
Id :    1
```

```
Path:                    src/slam_pr
Version:                 0.17.7
Sessions:                1
Total odometry length:   264.358 m
Total time:              00:23:02.47
LTM:                     815 nodes a
WM:                      815 nodes a
Global graph:            815 poses a
Ground truth:            0 poses
GPS:          0 poses

Database size:           394 MB
Nodes size:              103 KB
Links size:              1 MB
RGB Images size:         28 MB
Depth Images size:       289 MB
Calibrations size:       58 KB
Grids size:              3 MB
Scans size:              3 MB
User data size:          0 Bytes
Dictionary size:         8 MB
Features size:           30 MB
Statistics size:         0 Bytes
Other (indexing):        28 MB

301 bad signatures in LTM
301 bad signatures in the global gr

BRIEF/Bytes=
BRISK/Octaves=
BRISK/PatternScale=
BRISK/Thresh=
Bayes/FullPredictionUpdate=
Bayes/PredictionLC=
Bayes/VirtualPlacePriorThr=
DbSqlite3/CacheSize=
DbSqlite3/InMemory=
DbSqlite3/JournalMode=
```

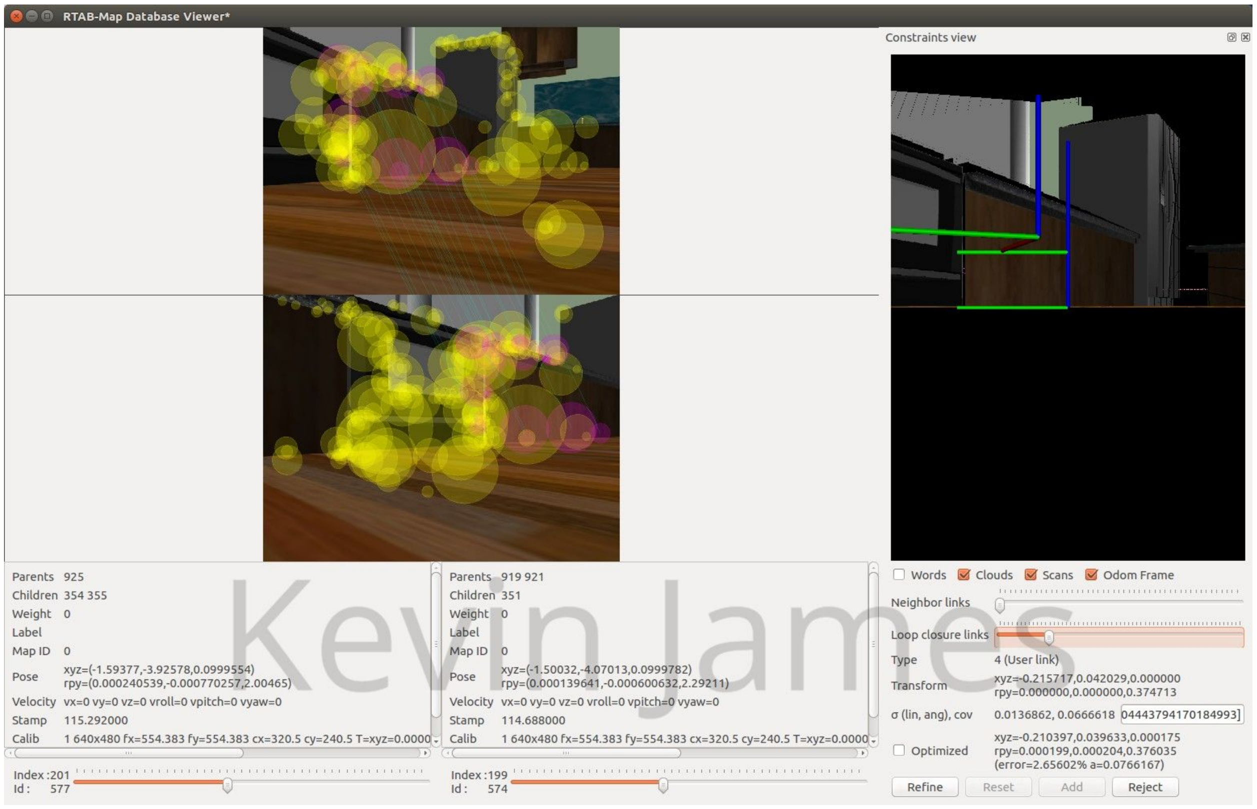
The following images show loop closures detected in *rtabmap-databaseViewer*.



```
Detected loop closure 911->327! (2555/16528)

22:57:18 Iteration 2/5: Detected 89 loop closures!
22:57:18 Looking for more loop closures, clusters found 16528 clusters.
22:57:18 Detected loop closure 1235->250! (1124/16528)
22:57:18 Detected loop closure 1254->251! (1170/16528)
22:57:18 Detected loop closure 1237->252! (1207/16528)
22:57:18 Detected loop closure 543->315! (2305/16528)
22:57:18 Detected loop closure 904->316! (2349/16528)
22:57:19 Detected loop closure 907->319! (2416/16528)
22:57:19 Detected loop closure 909->321! (2445/16528)
22:57:20 Detected loop closure 340->325! (2530/16528)
22:57:20 Detected loop closure 911->327! (2555/16528)
```

```
Parents
Children
Weight   0
Label    map0
Map ID   0
Pose     xyz=(0.000156251,-0.000751642,0.1)
         rpy=(2.79335e-06,0.0006544,-0.000279958)
Velocity vx=0 vy=0 vz=0 vroll=0 vpitch=0 vyaw=0
Stamp    4.383000
Calib    1 640x480 fx=554.383 fy=554.383 cx=320.5 cy=240.5 T=xyz=0.000000,0.000000,0.000000 rpy=-1.570

Index :0
Id :   1
```

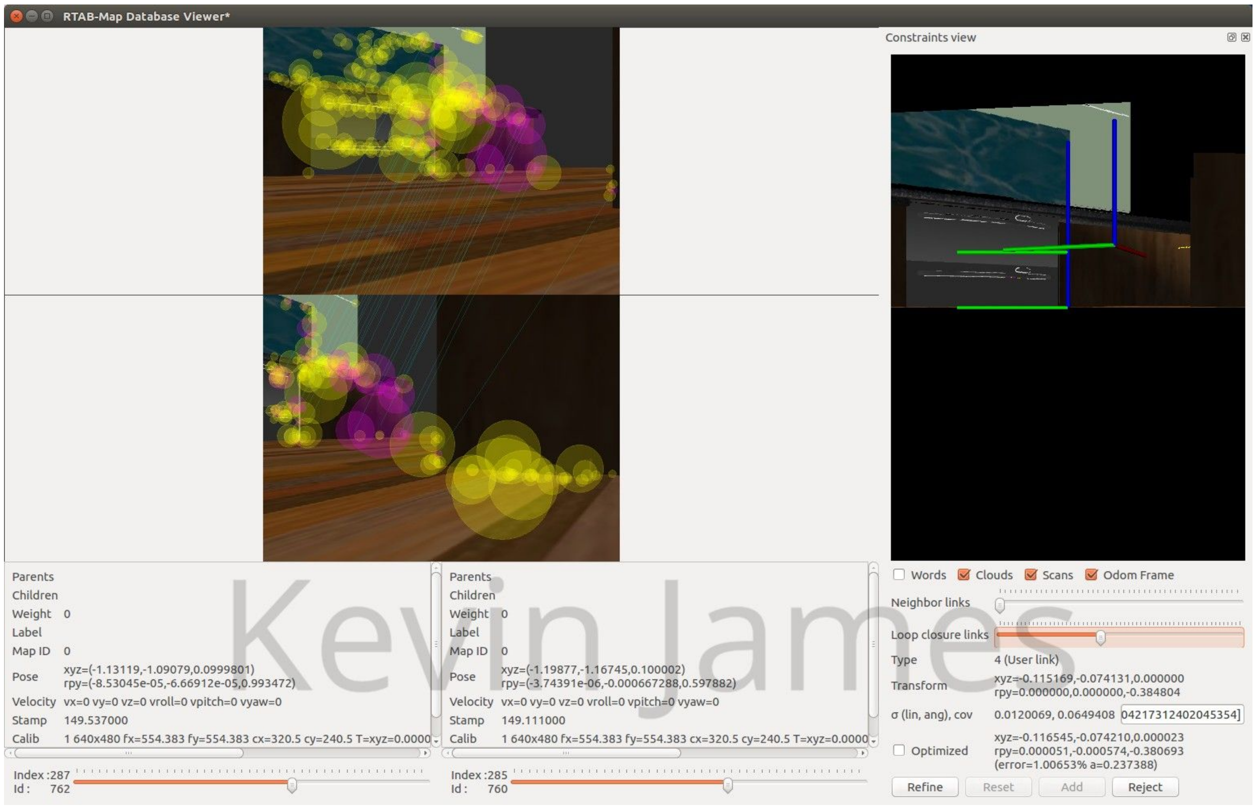
```
Parents
Children
Weight   0
Label    map0
Map ID   0
Pose     xyz=(0.000156251,-0.000751642,0.1)
         rpy=(2.79335e-06,0.0006544,-0.000279958)
Velocity vx=0 vy=0 vz=0 vroll=0 vpitch=0 vyaw=0
Stamp    4.383000
Calib    1 640x480 fx=554.383 fy=554.383 cx=320.5 cy=240.5 T=xyz=0.000000,0.000000,0.000000 rpy=-1.570

Index :0
Id :   1
```



```
Parents   925
Children  354 355
Weight    0
Label
Map ID    0
Pose      xyz=(-1.59377,-3.92578,0.0999554)
          rpy=(0.000240539,-0.000770257,2.00465)
Velocity  vx=0 vy=0 vz=0 vroll=0 vpitch=0 vyaw=0
Stamp     115.292000
Calib     1 640x480 fx=554.383 fy=554.383 cx=320.5 cy=240.5 T=xyz=0.0000
Index :201
Id :   577
```

```
Parents   919 921
Children  351
Weight    0
Label
Map ID    0
Pose      xyz=(-1.50032,-4.07013,0.0999782)
          rpy=(0.000139641,-0.000600632,2.29211)
Velocity  vx=0 vy=0 vz=0 vroll=0 vpitch=0 vyaw=0
Stamp     114.688000
Calib     1 640x480 fx=554.383 fy=554.383 cx=320.5 cy=240.5 T=xyz=0.0000
Index :199
Id :   574
```

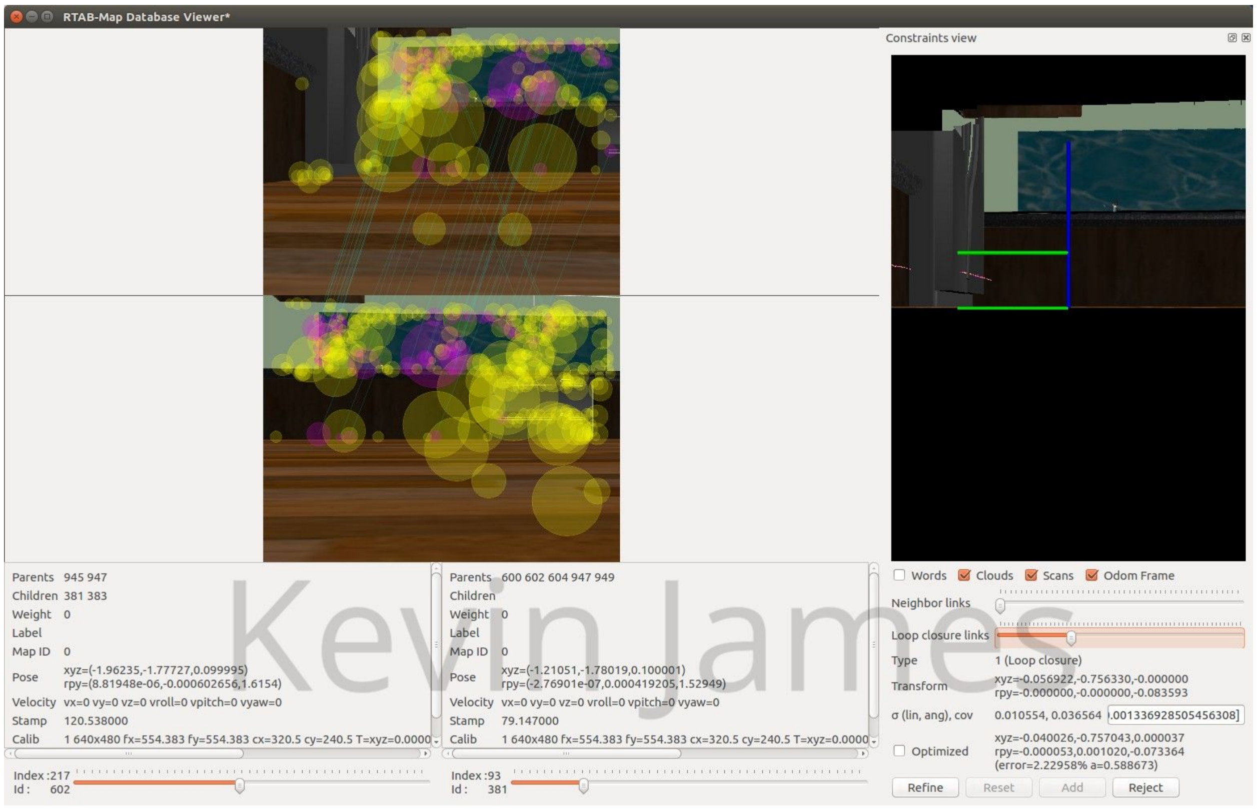
```
Type                 4 (User link)
Transform            xyz=-0.215717,0.042029,0.000000
                     rpy=0.000000,0.000000,0.374713
σ (lin, ang), cov    0.0136862, 0.0666618  04443794170184993]
Optimized            xyz=-0.210397,0.039633,0.000175
                     rpy=0.000199,0.000204,0.376035
                     (error=2.65602% a=0.0766167)
```



```
Parents
Children
Weight    0
Label
Map ID    0
Pose      xyz=(-1.13119,-1.09079,0.0999801)
          rpy=(-8.53045e-05,-6.66912e-05,0.993472)
Velocity  vx=0 vy=0 vz=0 vroll=0 vpitch=0 vyaw=0
Stamp     149.537000
Calib     1 640x480 fx=554.383 fy=554.383 cx=320.5 cy=240.5 T=xyz=0.0000
Index :287
Id :   762
```

```
Parents
Children
Weight    0
Label
Map ID    0
Pose      xyz=(-1.19877,-1.16745,0.100002)
          rpy=(-3.74391e-06,-0.000667288,0.597882)
Velocity  vx=0 vy=0 vz=0 vroll=0 vpitch=0 vyaw=0
Stamp     149.111000
Calib     1 640x480 fx=554.383 fy=554.383 cx=320.5 cy=240.5 T=xyz=0.0000
Index :285
Id :   760
```

```
Type                 4 (User link)
Transform            xyz=-0.115169,-0.074131,0.000000
                     rpy=0.000000,0.000000,-0.384804
σ (lin, ang), cov    0.0120069, 0.0649408  04217312402045354]
Optimized            xyz=-0.116545,-0.074210,0.000023
                     rpy=0.000051,-0.000574,-0.380693
                     (error=1.00653% a=0.237388)
```



```
Parents   945 947
Children  381 383
Weight    0
Label
Map ID    0
Pose      xyz=(-1.96235,-1.77727,0.099995)
          rpy=(8.81948e-06,-0.000602656,1.6154)
Velocity  vx=0 vy=0 vz=0 vroll=0 vpitch=0 vyaw=0
Stamp     120.538000
Calib     1 640x480 fx=554.383 fy=554.383 cx=320.5 cy=240.5 T=xyz=0.0000
Index :217
Id :   602
```

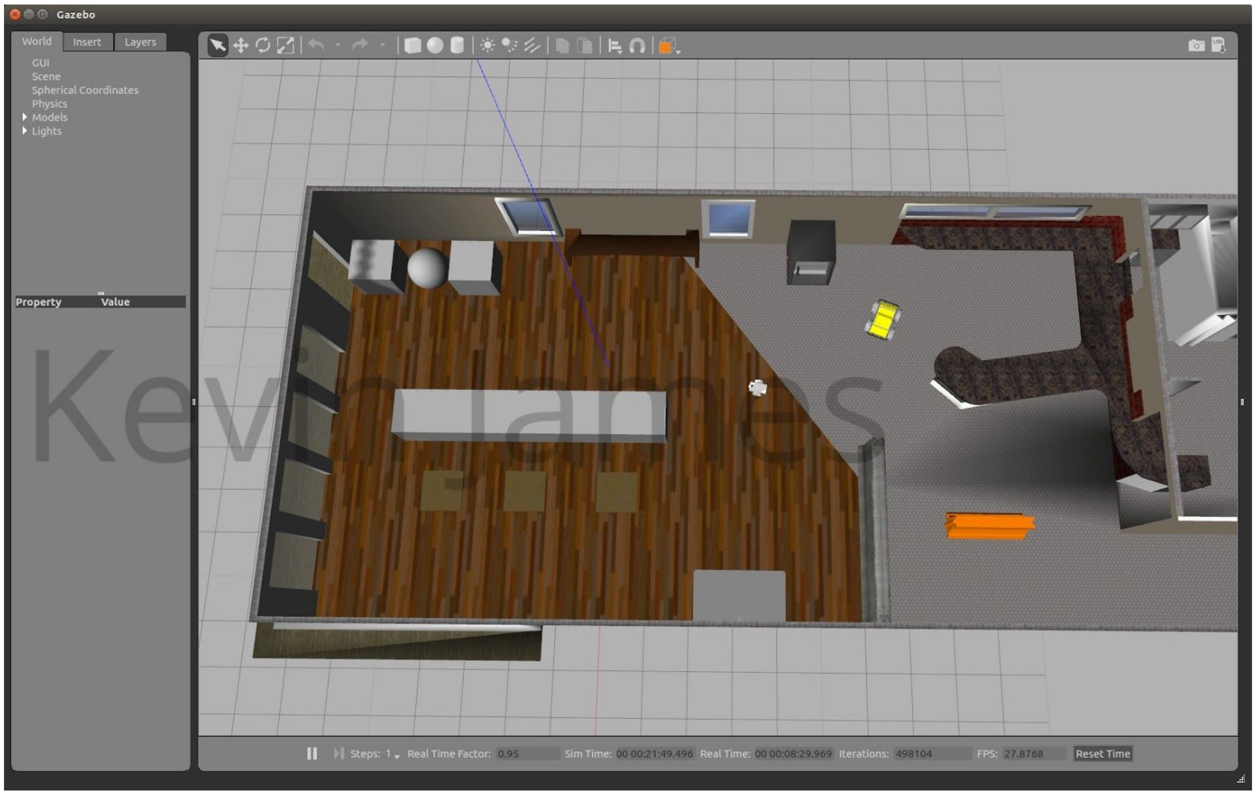
```
Parents   600 602 604 947 949
Children
Weight    0
Label
Map ID    0
Pose      xyz=(-1.21051,-1.78019,0.100001)
          rpy=(-2.76901e-07,0.000419205,1.52949)
Velocity  vx=0 vy=0 vz=0 vroll=0 vpitch=0 vyaw=0
Stamp     79.147000
Calib     1 640x480 fx=554.383 fy=554.383 cx=320.5 cy=240.5 T=xyz=0.0000
Index :93
Id :   381
```

```
Type               1 (Loop closure)
Transform          xyz=-0.056922,-0.756330,-0.000000
                   rpy=-0.000000,-0.000000,-0.083593
σ (lin, ang), cov  0.010554, 0.036564  .001336928505456308]
Optimized          xyz=-0.040026,-0.757043,0.000037
                   rpy=-0.000053,0.001020,-0.073364
                   (error=2.22958% a=0.588673)
```

Custom World

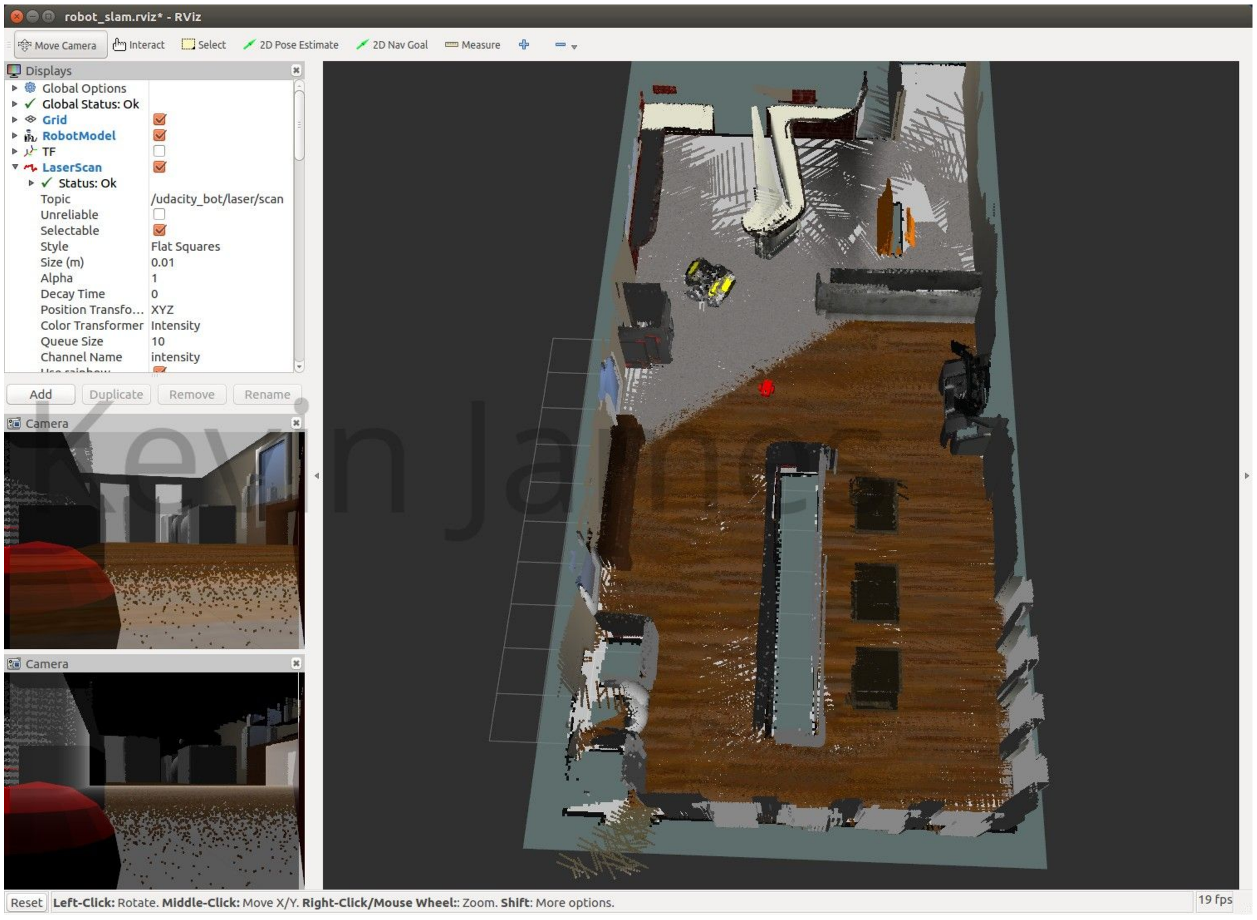
The images below show results for the customized world. Rtabmap_viz is used to show the loop closures because in this case Reg/Strategy = 2 (ICP and Visual) was required to get good correlation results. With Reg/Strategy = 0 (Visual) the map was severely corrupted and the algorithm was clearly unable to get consistent localization.

The custom gazebo world is shown in the following image.



Steps: 1 Real Time Factor: 0.95 Sim Time: 00 00:21:49.496 Real Time: 00 00:08:29.969 Iterations: 498104 FPS: 27.8768

3D map for the custom world is shown in rviz in the following image.

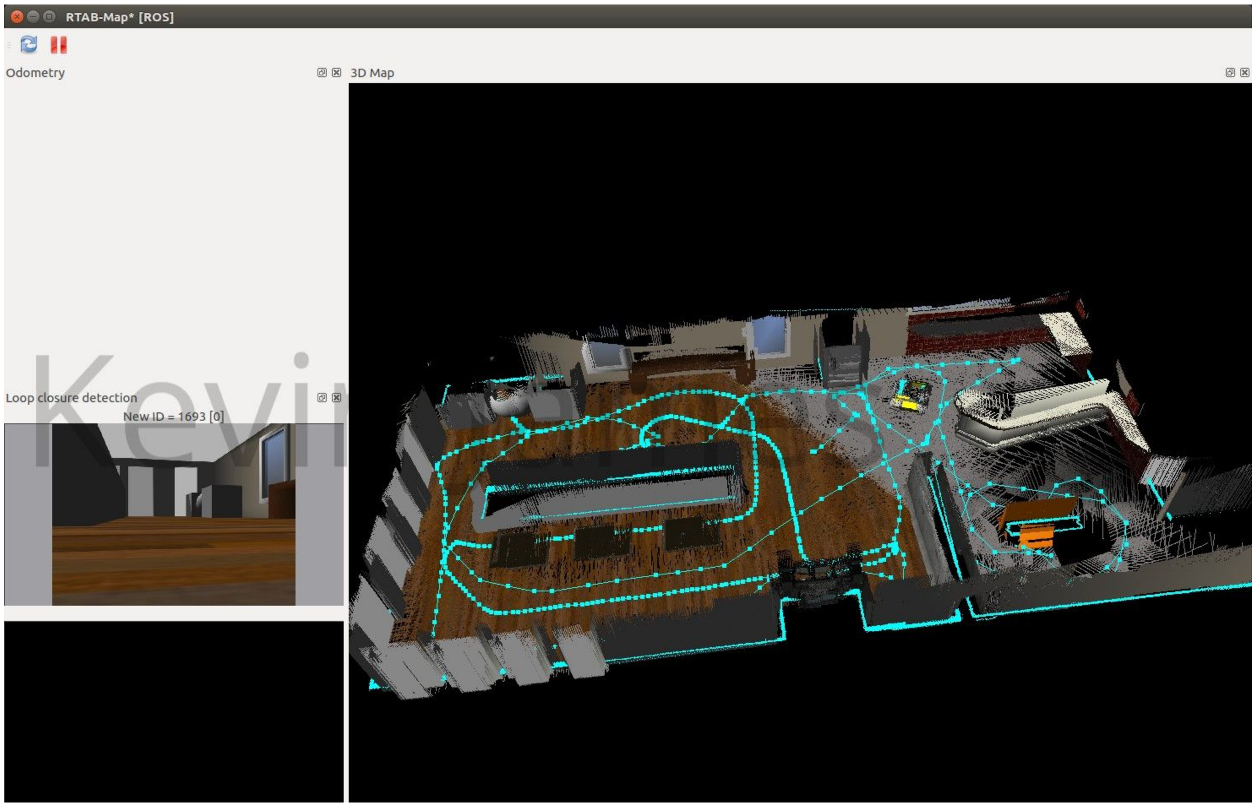


Global Options
Global Status: Ok
Grid ✓
RobotModel ✓
TF ☐
LaserScan ✓
Status: Ok

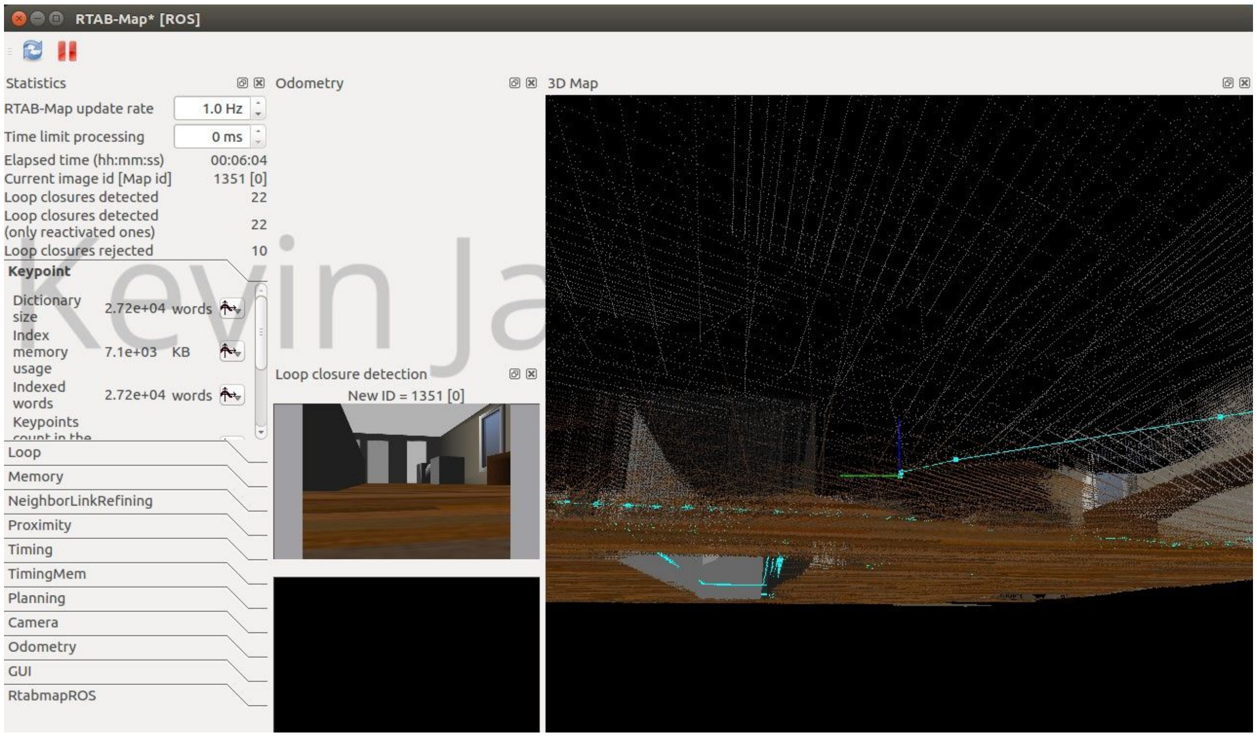
Topic	/udacity_bot/laser/scan
Unreliable	☐
Selectable	✓
Style	Flat Squares
Size (m)	0.01
Alpha	1
Decay Time	0
Position Transfo...	XYZ
Color Transformer	Intensity
Queue Size	10
Channel Name	intensity

Left-Click: Rotate. **Middle-Click:** Move X/Y. **Right-Click/Mouse Wheel:**: Zoom. **Shift**: More options.

The path is shown in *rtabmap_viz* below.



Statistics column slows *Loop closures detected* (22).



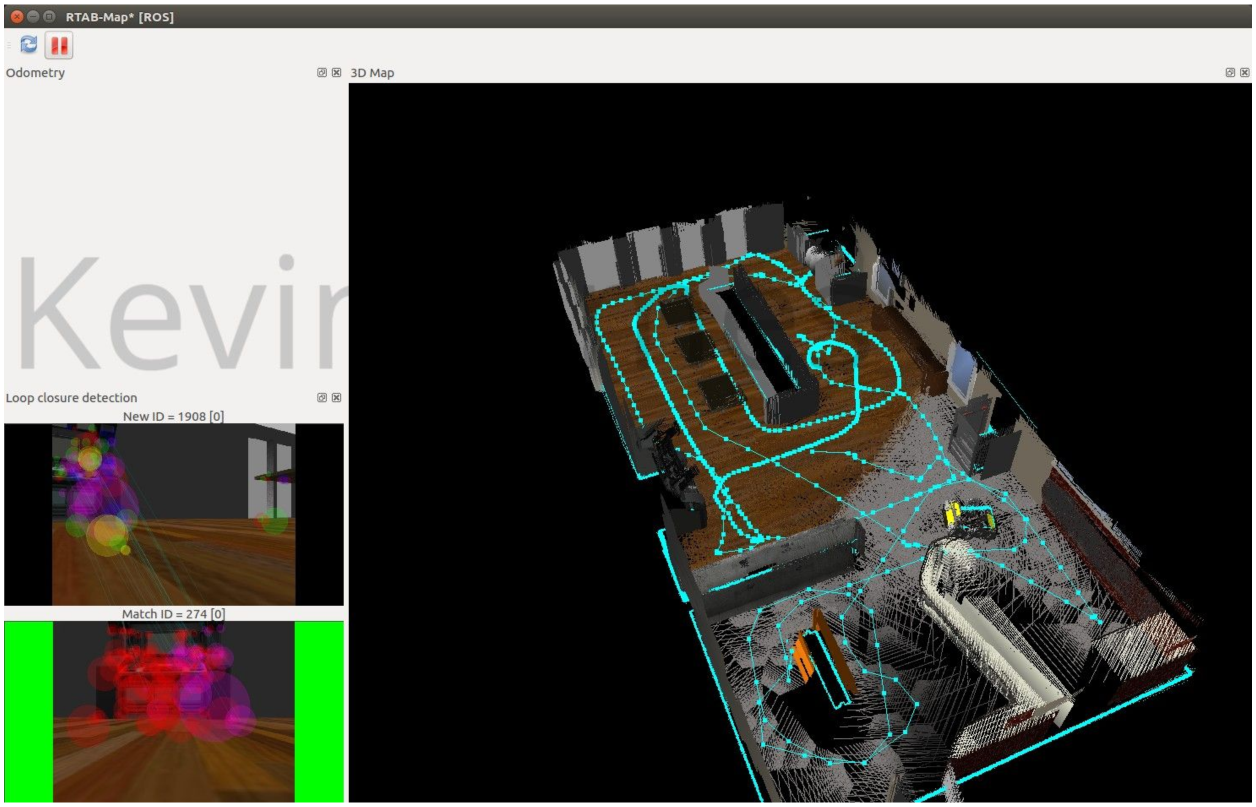
RTAB-Map update rate	1.0 Hz
Time limit processing	0 ms
Elapsed time (hh:mm:ss)	00:06:04
Current image id [Map id]	1351 [0]
Loop closures detected	22
Loop closures detected (only reactivated ones)	22
Loop closures rejected	10

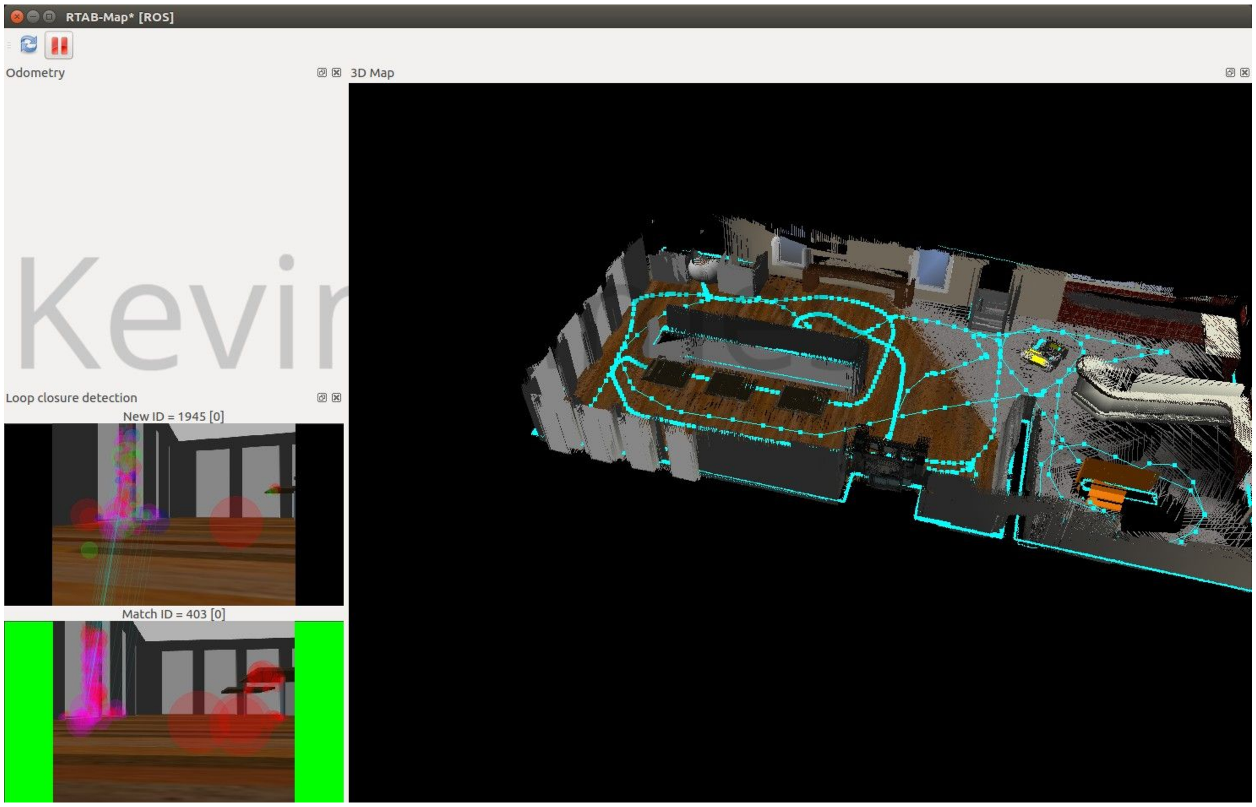
Keypoint

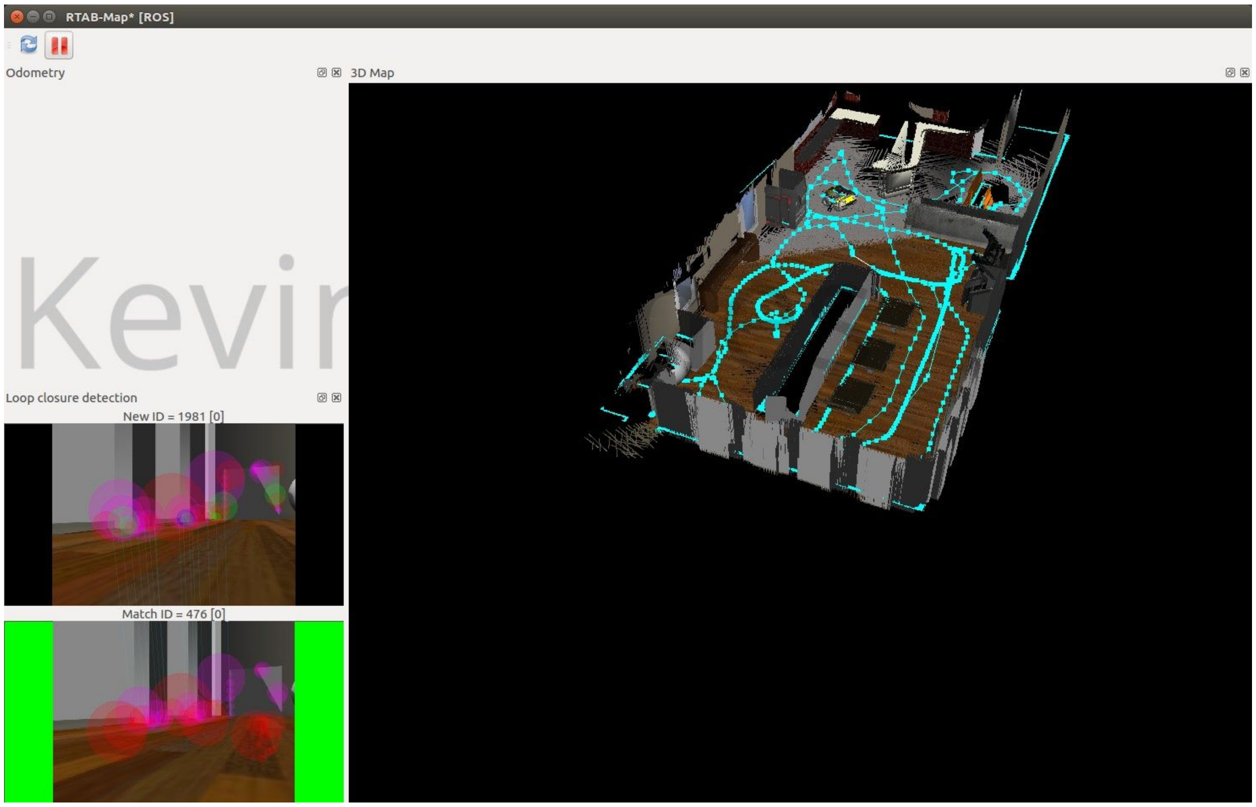
Dictionary size	2.72e+04 words
Index memory usage	7.1e+03 KB
Indexed words	2.72e+04 words
Keypoints count in the	

Loop
Memory
NeighborLinkRefining
Proximity
Timing
TimingMem
Planning
Camera
Odometry
GUI
RtabmapROS

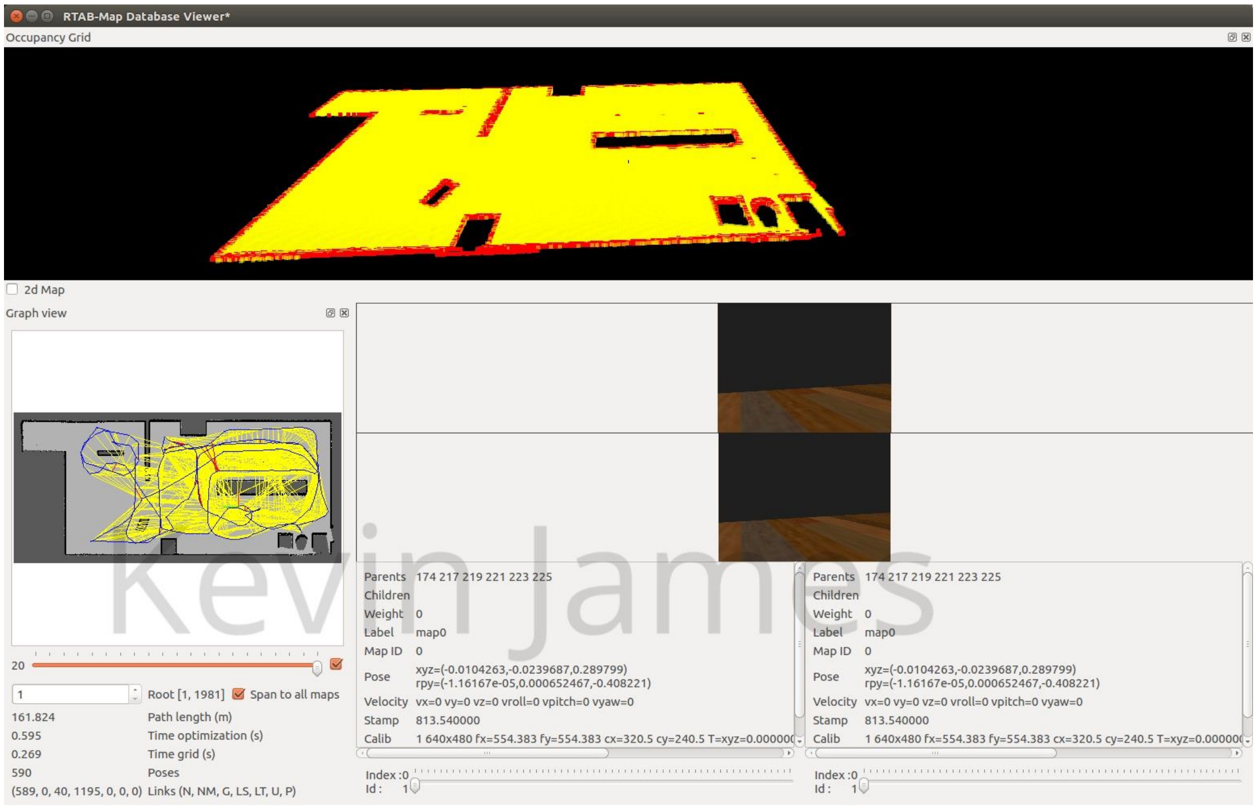
The following three images show loop closures detected live on *rtabmap_viz*.


RTAB-Map* [ROS]
Odometry
3D Map
Kevin
Loop closure detection
New ID = 1908 [0]
Match ID = 274 [0]


RTAB-Map* [ROS]
Odometry
3D Map
Kevin
Loop closure detection
New ID = 1945 [0]
Match ID = 403 [0]



Custom world occupancy grid is shown in *rtabmap-databaseViewer* below.



```
20
1                  Root [1, 1981]   Span to all maps
161.824            Path length (m)
0.595              Time optimization (s)
0.269              Time grid (s)
590                Poses
(589, 0, 40, 1195, 0, 0, 0) Links (N, NM, G, LS, LT, U, P)
```

```
Parents   174 217 219 221 223 225
Children
Weight    0
Label     map0
Map ID    0
Pose      xyz=(-0.0104263,-0.0239687,0.289799)
          rpy=(-1.16167e-05,0.000652467,-0.408221)
Velocity  vx=0 vy=0 vz=0 vroll=0 vpitch=0 vyaw=0
Stamp     813.540000
Calib     1 640x480 fx=554.383 fy=554.383 cx=320.5 cy=240.5 T=xyz=0.000000
Index :0
Id :    1
```

```
Parents   174 217 219 221 223 225
Children
Weight    0
Label     map0
Map ID    0
Pose      xyz=(-0.0104263,-0.0239687,0.289799)
          rpy=(-1.16167e-05,0.000652467,-0.408221)
Velocity  vx=0 vy=0 vz=0 vroll=0 vpitch=0 vyaw=0
Stamp     813.540000
Calib     1 640x480 fx=554.383 fy=554.383 cx=320.5 cy=240.5 T=xyz=0.000000
Index :0
Id :    1
```

Discussion

There were four problems encountered on this project. First was likely caused by a missed setup step. Laser scans were not detected on the Udacity world unless the sensor orientation was incorrect. Absence of laser scans resulted in poor map quality. While attempting to observe loop closures, **Reg/Strategy** rtabmap param was changed to 1 (ICP) to make use of the laser scan. It later turned out that ICP is not supported in *rtabmap-databaseViewer* as 0 loop closures were reported (http://official-rtab-map-forum.67519.x6.nabble.com/Cannot-detect-more-loop-closures-offline-td4777.html). Setting this parameter to 2 (ICP and Visual) produced good maps, but attempting to detect loop closures caused the database viewer to crash. Thus, loop closures shown in the database viewer for the Udacity world used Visual only (0).

Creating the custom world involved some learning about gazebo. First issue was that only some of the objects are static, and others can be moved by contact with the robot, or apparently can just shift around for no reason. Mapping performance was mediocre with the world shifting. The final issue was probably due to inadequate visually distinctive features in the custom world. Mapping performance was quite bad using Visual loop closure. Changing this parameter back to ICP and Visual resulted in marked improvement, and this setting was used for the results presented. Because the parameter setting crashes the database viewer, loop closures were shown in the visualizer instead.

Aside from the problems mentioned, *rtabmap* produced good occupancy grids and 3D maps with modest required number of passes through the environment.

Future Work

The next step here is clear enough: deploy on a real robot and see how *rtabmap* performs in a real-world environment. Running on the Jetson TX2 board is likely to require some parameter tuning to reduce computational load.