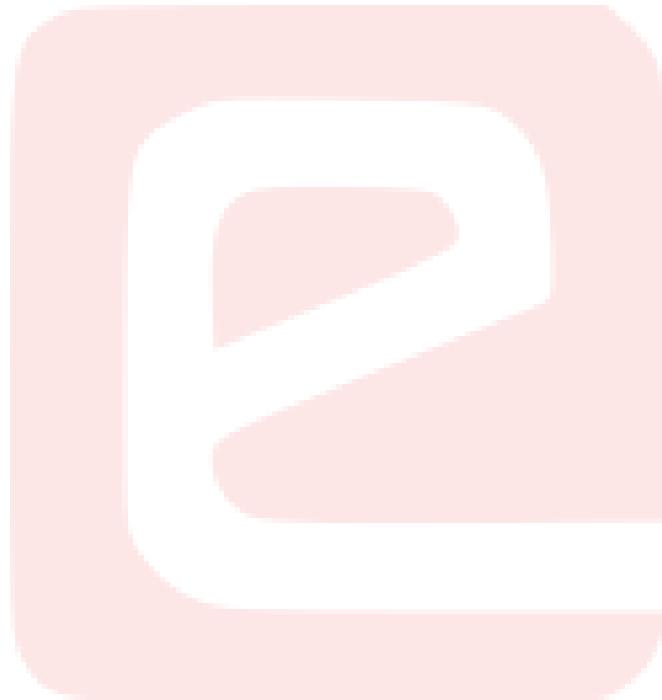


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INDOOR ENVIRONMENT MAPPING USING UAV



Rishabh Beri

Samaahita S Belavadi

Mentors: Simranjeet, Vamshi

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Indoor Environment Mapping Using UAV

Abstract

Research in the area of robotic indoor mapping has been active for a very long time. This project aims to solve the problem of autonomous mapping of an indoor environment using an unmanned aerial vehicle. The platform chosen to solve this problem is Robotics Operating System(ROS) and Gazebo simulator.

ROS is an open-source system for controlling robots using a PC. It has various libraries and packages that simplify the task of building a robotic software applications.

Gazebo is a simulator powered with a physics engine, which is used to simulate the real world. It enables setting of parameters like gravity, friction, inertia, etc. to replicate any real world scenario.

The package used for the map building process is RTAB-Map which runs an RGB-D Graph SLAM algorithm based on the global Bayesian loop closure detector.

In simulation, this problem was solved using an Intel Realsense R200 camera mounted on an AR Drone 2.0.

In the real world, we used a Kinect v1.0 camera mounted on a Firebird VI robot, which is controlled manually.

Completion status

- Completed autonomous mapping in simulation
- Interfaced Kinect camera with the PC
- Completed manual mapping in the real world
- Made tutorials on the various packages used in the project

1.1. HARDWARE COMPONENTS

1.1 Hardware Components

- Kinect v1.0 ([Specifications](#))
- Firebird VI (—— Add Specs ——)
- USB to RS-232 Converter ([Datasheet](#), [Buy](#))

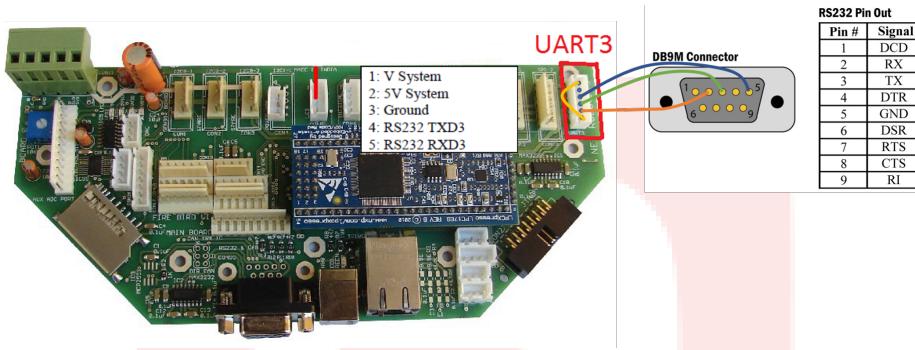


Figure 1.1: Circuit Diagram

1.2 Software used

- Ubuntu
 - Version - 14.04
- ROS
 - Version - Indigo
 - Installation:
`sudo apt-get install ros-indigo-desktop-full`
- Gazebo Simulator
 - Version - 7
 - Installation - Download and run [this](#) file to install gazebo7

1.3. THE MAPPING PROCESS

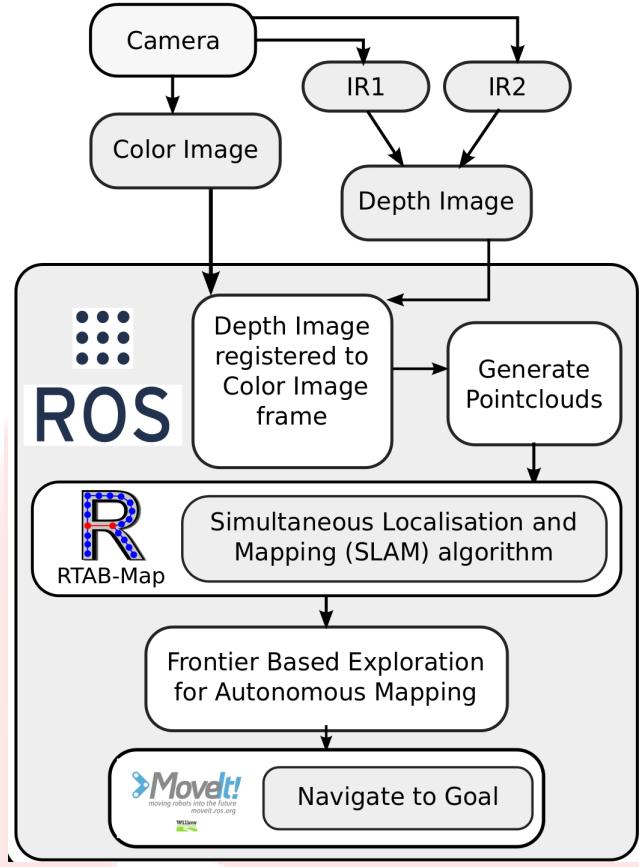


Figure 1.2: The mapping process

1.3 The Mapping Process

Packages Required

- `ardrone_simulator_gazebo7` - This package contains the models, drivers and plug-ins necessary to simulate the behaviour of an AR Drone in Gazebo7.
- `depth_image_proc` - This package is a part of the image pipeline package of ROS, and contains nodelets for processing depth images.
- `realsense_gazebo_plugin` - This package contains the models, drivers and plugins necessary to simulate the behaviour of an Intel Realsense R200 camera in Gazebo7.
- `move_it` - This package plans the path of the drone from it's current

1.3. THE MAPPING PROCESS

location to a goal point.

Initial Setup

- Including the drone and camera in gazebo
 - The model of the AR Drone is in the URDF format
 - But, the model of the Realsense camera is in SDF format
 - URDF and SDF formats are incompatible. Hence, one format has to be converted to the other
 - [This](#) tutorial explains the conversion process

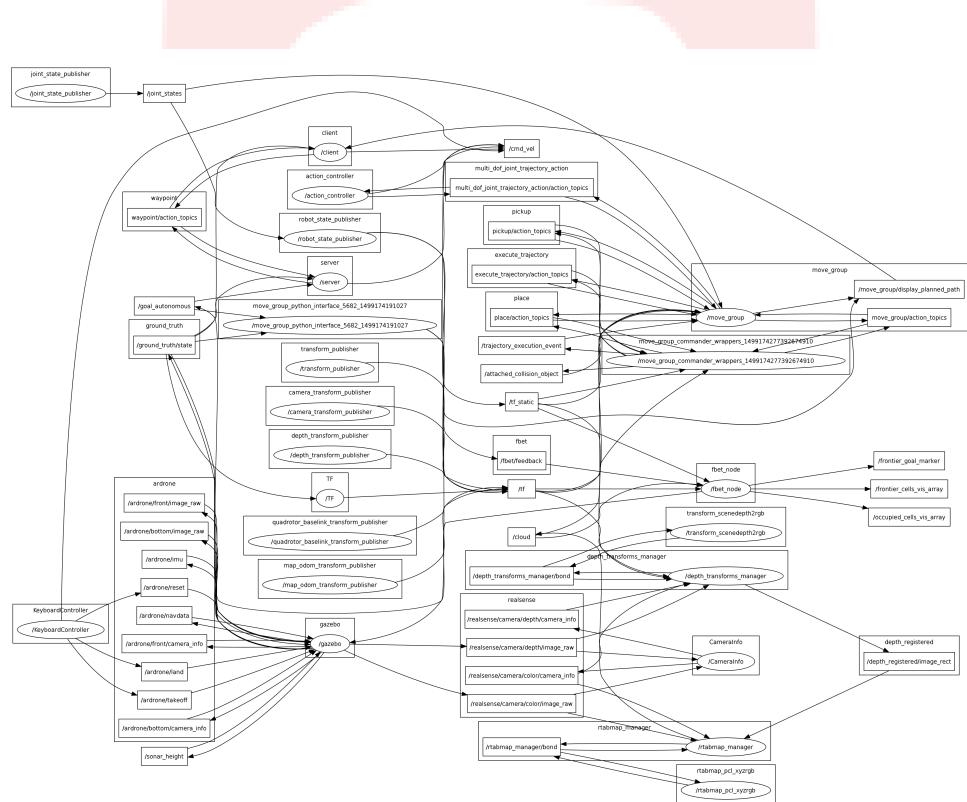


Figure 1.3: Output of the rqt_graph command showing how the nodes communicate with each other

Generation of Pointclouds

- Register(Project) the depth image to the frame of the colour image



1.3. THE MAPPING PROCESS

- The realsense camera publishes both RGB and Depth images
- But to generate an RGB-D pointcloud, the depth image and the colour image have to be in the same frame.
- The register nodelet of the depth_image_proc package is used for registering the depth image to the frame of the colour image
- Requirements:
 - * Meta-data of the RGB camera
 - * Meta-data of the depth camera
 - * Depth Image
 - * A transform between the frame of the depth camera and that of the colour camera
- The output of this nodelet is a registered depth image

- Create a pointcloud

- The point_cloud_xyzrgb nodelet of the rtabmap_ros package is used to generate a pointcloud which has 7 attributes - 3D coordinates, RGB-colour and depth.
- Requirements:
 - * RGB image
 - * Registered depth image
 - * Meta-data of the RGB camera
- The output of this nodelet is a pointcloud.

Map Building using RTAB-Map

- SLAM - Simultaneous Localization and Mapping

Simultaneous Localization and Mapping (SLAM), is the problem of building the map of an unknown environment incrementally, while simultaneously keeping track of a robot's location within the map.

The SLAM algorithm applied depends on the sensors used in the mapping process. These algorithms are broadly classified into landmark-based and raw-data algorithms. Landmark-based algorithms uniquely identify objects in the world, whose location is estimated using a sensor. Raw-data algorithms on the other hand, model the probability of estimating the correctness of an observation directly as a function of the location.

1.3. THE MAPPING PROCESS

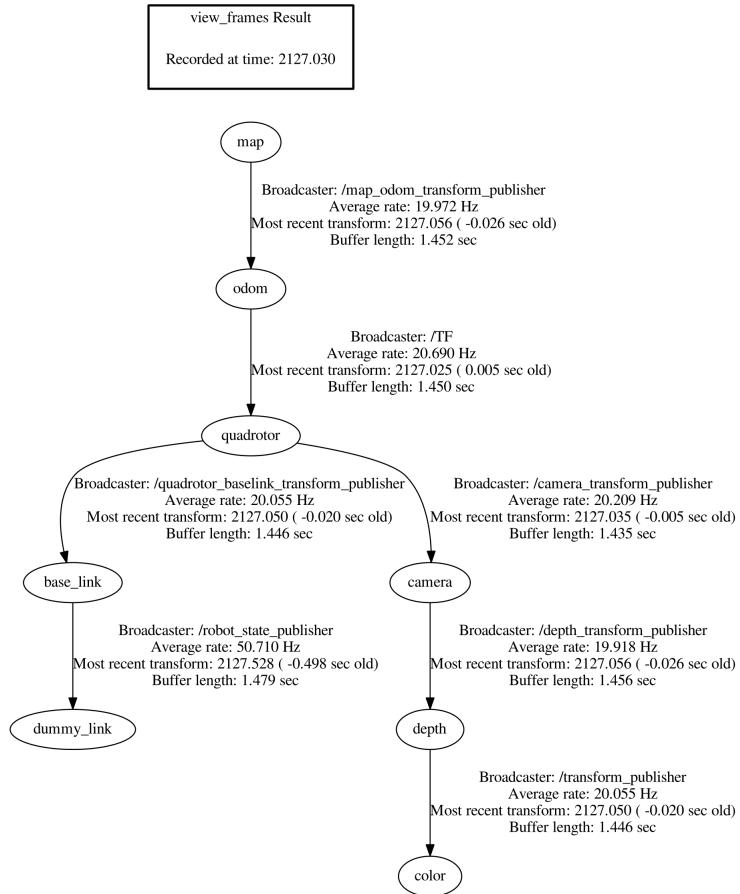


Figure 1.4: The tf tree generated during the mapping process

RTAB-Map is a RGB-D Graph SLAM approach based on the global Bayesian loop closure detector. Loop-Closure is the problem of identifying a previously visited location based on sensed features and updating the variables accordingly. The loop closure detector uses a bag-of-words approach to determinate how likely a new image comes from a previous location or a new location.

- The main node of the RTAB-Map package is rtabmap
- The map is incrementally built and optimized whenever a loop-closure is detected
- Requirements:



1.3. THE MAPPING PROCESS

- Odometry information
- RGB image
- Metadata of the RGB image
- Registered depth image
- Pointclouds
- The output of this node is an incrementally built map and information about the map
- There are various parameters that can be set to use the node for a wide variety of applications
- [This](#) tutorial explains how to use RTAB-Map for mapping

Autonomous Navigation - Frontier-Based Exploration Technique (FBET)

- Algorithm for Goal generation:
 1. Receive a Pointcloud
 2. Convert the Pointcloud to an Octomap
 3. Classify cells in the Octomap as free or occupied
 4. Find frontier cells
 - Frontier cells represent the boundary of known and unknown regions
 - A free cell is a frontier cell if it has one free cell and one unknown cell as its neighbour
 5. Cluster the frontier cells using the k-means clustering algorithm
 - The number of clusters 'k', depends upon the number of frontier cells
 - Since the camera has a limited field of view, we limit the number of frontier cells each cluster can accommodate
 6. Calculate the cost of each cluster. The cost function depends on:
 - Inverse of the cluster size - Cluster size represents the size of the unknown region
 - Distance between the drone and the centroid of the cluster
 7. The cluster with the minimum cost is chosen the optimal cluster



1.4. SOFTWARE AND CODE

8. The centroid of the optimal cluster is the new goal to navigate to

- Path planning
 - Package used - MoveIt
 - MoveIt is a ROS framework used for motion planning, control and navigation of robotic arms
 - By making a few changes, we can use it for planning the path of a quadrotor too
 - If it is not possible for MoveIt to generate a path to a goal(Goal is too close to an obstacle), then a feedback mechanism requests the FBET node for a new goal
- Navigating to the goal
 - Once a plan has been generated, we use actionlib server-client mechanism along with PID control to navigate through each waypoint of the goal
- [This](#) video explains the mapping process

1.4 Software and Code

[Github link](#) for the repository of code

- /ardrone_simulator_gazebo7/cvg_sim_gazebo/scripts/keyboard.py - Script to control the drone manually
- /ardrone_simulator_gazebo7/cvg_sim_gazebo/scripts/ardrone_get_odometry.py - Script to fetch pose of the drone from gazebo and publish tf
- /realsense_gazebo_plugin/scripts/pub_camera_info.py - Publish fake depth and color camera info for the simulated cameras
- /realsense_gazebo_plugin/scripts/server.py - Start the actionlib server to execute the waypoints from MoveIt!
- /realsense_gazebo_plugin/scripts/client.py - Start the actionlib client to execute the waypoints from MoveIt!
- /realsense_gazebo_plugin/scripts/send_goal.py - Start the script to send goals to MoveIt!



1.5. RESULTS AND DEMO

- /realsense_gazebo_plugin/launch/ardrone_realsense.launch - Launch Gazebo7 and load the simulated world
- /realsense_gazebo_plugin/launch/register.launch - Register the depth image to the color image frame
- /realsense_gazebo_plugin/launch/rtabmap_pcl.launch - Launch nodelet to convert depth and color image to pointcloud
- /realsense_gazebo_plugin/launch/fbet.launch - Launch the FBETServer
- /move_it/launch/moveit.launch - Launch the MoveIt! path planner
- /fbet/src/FBETServer.cpp - Code to find goals for autonomous navigation
- /bash_scripts/keyboard_mapping.sh - Bash script to launch all necessary packages required for the mapping process

1.5 Results and Demo

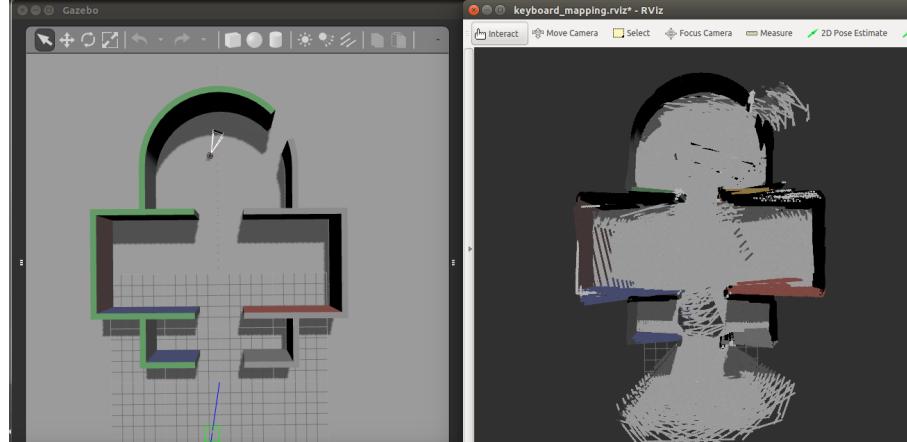


Figure 1.5: Result of manual mapping in simulation

[Demonstration video for manual mapping in simulation](#)

1.6. FUTURE WORK

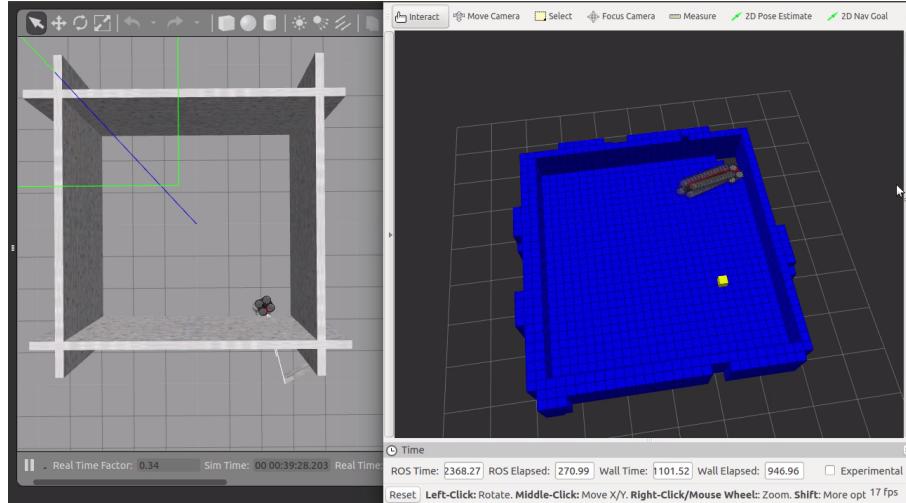


Figure 1.6: Result of autonomous mapping in simulation

[Demonstration video for autonomous mapping in simulation](#)



Figure 1.7: Final setup

1.6 Future Work

- Autonomous mapping of the real world using a Firebird VI robot or a quadcopter.
- Build a system comprising of two drones/robots where one of them maps the environment autonomously, while the other navigates autonomously in the generated map to perform a simple task.

1.7. TUTORIALS

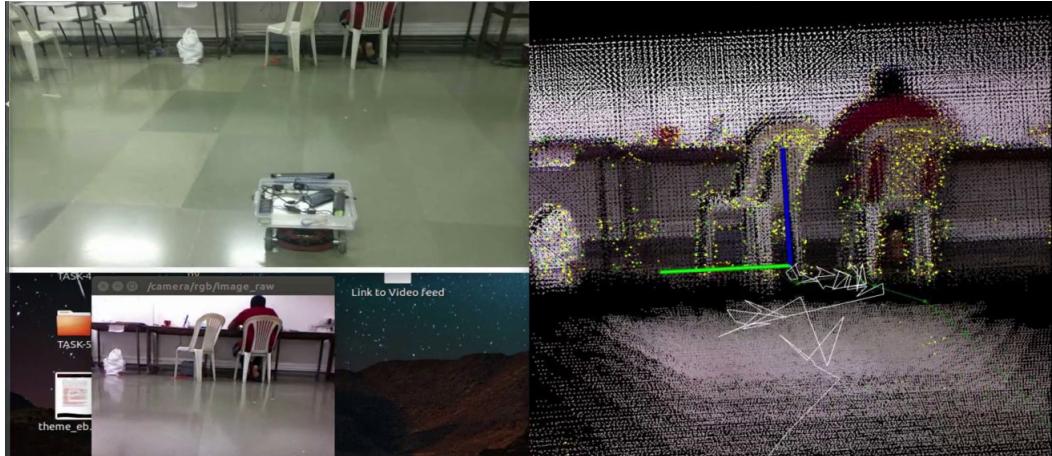


Figure 1.8: Result of manual mapping in the real world

[Demonstration video for manual mapping of the real world](#)

1.7 Tutorials

- Adding Realsense R200 camera to ARDrone in Gazebo7
- Landing Drone on ArUco marker
- OctoMap and RTAB-Map
- Using RTAB-Map for mapping with Kinect

1.8 Bug report and Challenges

- Issues:
 - The mass of the Realsense R200 camera was set to 1 gram in Gazebo. Setting it to a higher value increases the load on the drone, which causes a constant decrease in altitude.
 - When the drone goes very close to an obstacle in Gazebo, the camera is able to see through the obstacle and hence pointclouds which would be impossible to generate in the real world are generated in the simulated world.
 - Due to the numerous front-end and back-end processes running, the processor(i5 5th Gen Dual-Core) was overloaded. This created



1.8. BUG REPORT AND CHALLENGES

a huge delay between the generation of pointclouds and the map building process.

- The MoveIt package was developed for robotic arms. Hence, when using the package for a drone, the planned trajectories are overly complex.

- Failures:

- Due to compatibility issues with the RGB-D camera and the processor, the original idea of mapping with a drone in the real world had to be dropped. Hence, we used a Firebird VI robot for manual mapping.

- Challenges faced:

1. Problem: ROS comes pre-installed with Gazebo2, but the Realsense plugin works only with Gazebo7 and higher.
Solution: Replaced Gazebo2 with Gazebo7.
2. Setting the right values for the PID parameters
3. Problem: The Gazebo plug-in for Realsense camera does not publish camera metadata and calibration parameters(camera info)
Solution: Wrote a python script to publish camera info (obtained from the physical realsense camera) for depth and color cameras in sync with the image data
4. Problem: The default encoding of the depth image is mono16, which is not supported by the depth_image_proc nodelets
Solution: Changed the encoding of the depth image from mono16 to 16UC1 using the toCvShare function of the cv_bridge library
5. Problem: Register nodelet of depth_image_proc requires a transform from the depth image to the color image
Solution: Created a static_transform_publisher node to publish tf data (based on placement of the depth and color cameras in the SDF model of the realsense camera)
6. Problem: Choosing between the octomap package and rtabmap package of ROS to build a map
Solution: Octomaps require a localization process(e.g. hector_mapping) running in the background, whereas RTAB-Map runs a SLAM algorithm based on loop closure detection for localization and mapping. Hence we chose to use RTAB-Map to create a map of the environment



1.8. BUG REPORT AND CHALLENGES

7. Problem: Choosing an efficient algorithm for autonomous mapping

Solution: Two options were available - Wall following, and frontier-based exploration. We chose frontier-based exploration because, the wall following strategy was limited to only rectangular walls and does not perform well with obstacles in the map.

8. Problem: Choosing a good clustering technique for the frontier-based exploration algorithm

Solution: We chose the k-means clustering algorithm to cluster the frontier cells, because it is one of the most efficient clustering algorithms for big data sets and the clusters generated are of similar sizes

9. Problem: Choosing an optimal value of K in the k-means clustering algorithm

Solution: The efficiency of the entire algorithm depends on the value of K (number of clusters). A very low value of K would give us large clusters which would be useless given that the drone has a limited field of view. A large value of K would give us very small clusters, which would slow down the mapping process. Hence, we fixed an upper limit on the number of frontier cells each cluster can accommodate, and found the value of K.

Bibliography

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- [2] Labbe, M. and Michaud, F., *Appearance-Based Loop Closure Detection for Online Large-Scale and Long-Term Operation*, 2013
- [3] Cheng Zhu, Rong Ding, Mengxiang Lin, Yuanyuan Wu, *A 3D frontier-based exploration tool for MAVs*, 2015
- [4] [ROS Wiki](#)
- [5] [Gazebo simulator](#)
- [6] [RTAB-Map](#)
- [7] [MoveIt!](#)
- [8] [MoveIt for quadrotors](#)
- [9] [RS232 Connector](#)