Autonomous Navigation Behaviors for an Aerial Robotics Software Framework

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Overview

Introduction

Autonomous Navigation

Move a drone through an automatically-generated, obstacle-free trajectory to a given point.

- Planning
- Localization
- Mapping

As a general goal we want to:

- Construct an indoor *Autonomous Navigation* interface inside Aerostack using a **lidar** sensor.

We propose the use of different state of the art algorithms following the Aerostack framework. The specific goals are:

- Contribute to the research community
- Test implementation suitable for real time aerial robotics applications.

Problem Description

General purpose, modular software framework for aerial robotics.

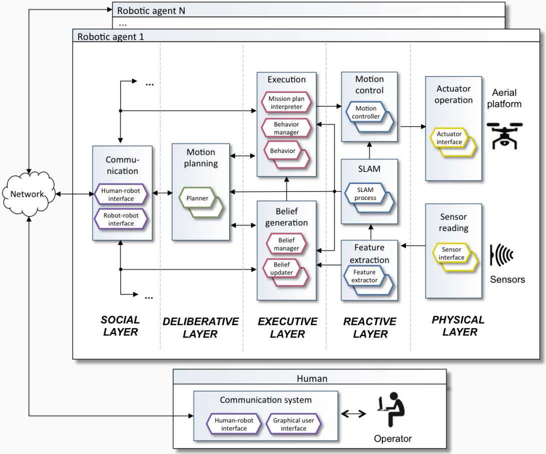


Figure 1: The Aerostack architecture

Aerostack

Current version features:

- Planner: 2D geometric.
- Localization: Odometry, Aruco (*requires preparation*)
- Mapping: Hardcoded in the robot.

Improvements

To provide an **autonomous**, **lidar** based navigation interface we propose:

- A module to localize and map using **lidar** sensor.
- A module to generate obstacle-free trajectories using that map.
- A module to follow a given trajectory.

State of the Art

Localization

Usually based on trilateration.

Outdoor Localization

External sources:

- GSM Antennas
- Satellites

Indoor Localization

Landmarks, beaconing (can provide more information)

- Bluetooth
- WiFi

In general, preparation of the environment is required.

With Simultaneous Localization and Mapping, the robot constructs a map and localizes inside it at the same time.

Does not require environment preparation.

- EKF Slam
- Particle Filters
- Graph Optimization
- Lidar Slam
- Visual Slam

Use a **lidar** sensor to do SLAM (Hector Slam [3]).

- Ray traces alignment as a Gauss-Newton minimization problem.
- Multi resolution occupancy grid map.
- Already available as ROS node.
- Suitable for real time
- Realiable enough

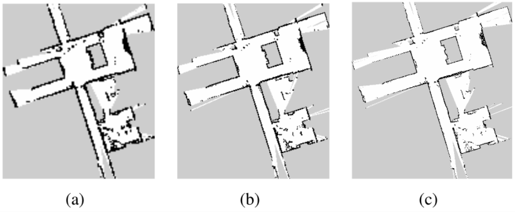


Figure 2: Multiresolution representation of the map

Figure 3: Vehicle experiments: Learned map during a competition

Both images taken from [3]

Lots of planning algorithms:

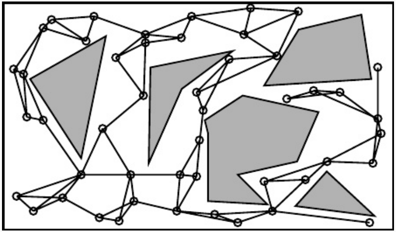


Figure 4: Probabilistic roadmaps (taken from [2])

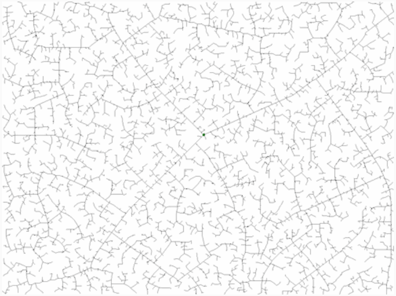
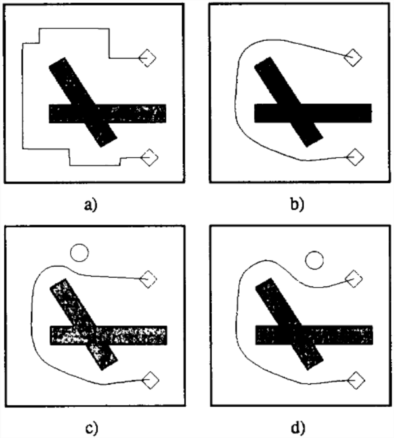


Figure 5: Rapidly exploring Random Trees (taken from [1])

Already available as a ROS module (**move base**)



Pre planned path

- Forces applied
- Handle moving obstacles

In c) and d) an obstacle moves and the path is deformed.

Figure 6: Elastic Band with a moving obstacle (taken from [4])

Implementation

Robot Operating System. Widely used in robotics research.

- Pub-Sub architecture (topics & services).
- Multiple programming languages (C, C++, Python...)
- Logic encapsulation

Aerostack features:

- ROS node
- Robot processes.
- Behavior processes.

Behavior System

The Behavior Manager coordinates the execution of all the behaviors. A behavior:

- Is the highest level abstraction component.
- Encapsulates an algorithm.
- Listens to *start* and *stop* events and emmits *error* events.
- Can have *exclusive constraints* and dependencies on other processes.

Navigation Interface

Therefore, the following components should be provided as behaviors or robots processes:

- Behavior to localize using lidar.
  - Behavior *Self Localize And Map by Lidar*
  - Hector Slam ROS module (monitored by ↑)
- Behavior to navigate the drone to a certain pose.
  - Behavior *Go To Point*
  - Behavior *Follow Path*
  - Behavior *Generate Path*
- Robot process to plan obstacle-free trajectories using lidar.
  - *Path planner* robot *process*
  - Move base ROS module (monitored by ↑)

 # Implemented Behaviors

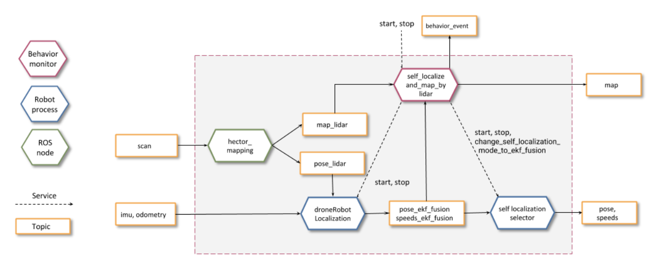
Implementing each behavior separately enables:

- Different, granular control over functionallity
- Testability of components
- Separation of functionallity.

Implementation # Behavior Self Localize And Map by Lidar

- Monitors the *Hector Slam* ROS module
- Applies EKF to: IMU, Odometry, SLAM
- Instructs the Aerostack for localization and mapping.

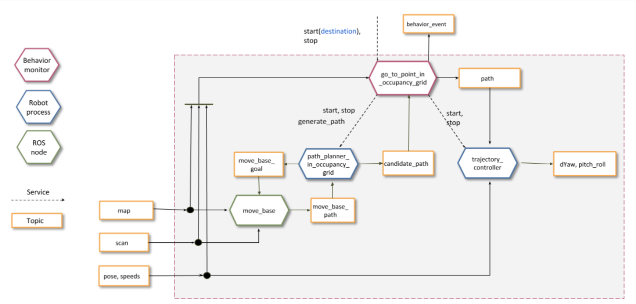
```
#-----------------------------------------------------------
# SELF_LOCALIZE_AND_MAP_BY_LIDAR
#-----------------------------------------------------------
  - behavior: SELF_LOCALIZE_AND_MAP_BY_LIDAR
    timeout: 120
    processes:
      - hector_mapping
      - droneRobotLocalization
      - self_localization_selector
#-----------------------------------------------------------
# Self-localization behaviors are mutually exclusive
#-----------------------------------------------------------
- mutually_exclusive:
  - SELF_LOCALIZE_BY_ODOMETRY
  - SELF_LOCALIZE_BY_VISUAL_MARKERS
  - SELF_LOCALIZE_AND_MAP_BY_LIDAR
```



Behavior Go To Point in Occupancy Grid

Given a point:

- Gets an obstacle-free trajectory.
- Instructs the trajectory controller to move the drone.
- Replans if an obstacle arises in the way.

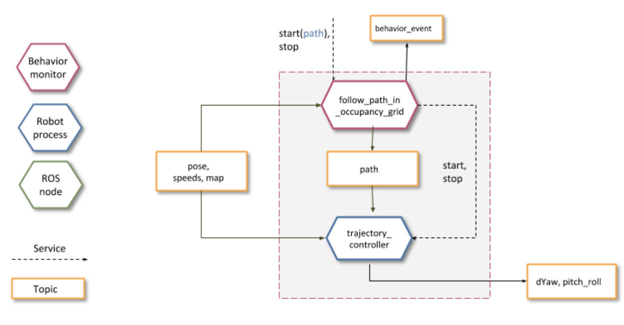



```
#------------------------------------------------------------
# GO_TO_POINT_IN_OCCUPANCY_GRID
#------------------------------------------------------------
  - behavior: GO_TO_POINT_IN_OCCUPANCY_GRID
    timeout: 240
    processes:
      - move_base
      - path_planning_in_occupancy_grid
      - droneTrajectoryController
    arguments:
      - argument: coordinates
        allowed_values: [-100,100]
        dimensions: 4

#------------------------------------------------------------
# Motion behaviors are mutually exclusive
#------------------------------------------------------------
- mutually_exclusive:
  - TAKE_OFF
  - LAND
  - KEEP_HOVERING
  - GO_TO_POINT
  - ROTATE
  - KEEP_MOVING
  - FOLLOW_OBJECT_IMAGE
  - GO_TO_POINT_IN_OCCUPANCY_GRID
  - FOLLOW_PATH_IN_OCCUPANCY_GRID
- mutually_exclusive:
  - GENERATE_PATH_IN_OCCUPANCY_GRID
  - FOLLOW_PATH_IN_OCCUPANCY_GRID
  - GO_TO_POINT_IN_OCCUPANCY_GRID
```

Given a path:

- Instructs the trajectory controller to move the drone.
- No obstacle avoidance is provided.

```
#-----------------------------------------------
# FOLLOW_PATH_IN_OCCUPANCY_GRID
#-----------------------------------------------
  - behavior: FOLLOW_PATH_IN_OCCUPANCY_GRID
    timeout: 240
    processes:
      - path_planning_in_occupancy_grid
      - move_base
      - droneTrajectoryController
    arguments:
      - argument: path
        dimensions: 1

#-----------------------------------------------
# Motion behaviors are mutually exclusive
#-----------------------------------------------
- mutually_exclusive:
  - TAKE_OFF
  - LAND
  - KEEP_HOVERING
  - GO_TO_POINT
  - ROTATE
  - KEEP_MOVING
  - FOLLOW_OBJECT_IMAGE
  - GO_TO_POINT_IN_OCCUPANCY_GRID
  - FOLLOW_PATH_IN_OCCUPANCY_GRID
- mutually_exclusive:
  - GENERATE_PATH_IN_OCCUPANCY_GRID
  - FOLLOW_PATH_IN_OCCUPANCY_GRID
  - GO_TO_POINT_IN_OCCUPANCY_GRID
```

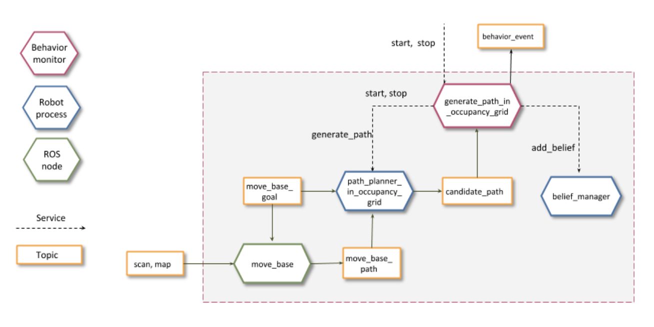


Implementation # Behavior Generate Path in Occupancy Grid

Given a point:

- Gets an obstacle-free trajectory.
- Stores the trajectory in the Belief Memory

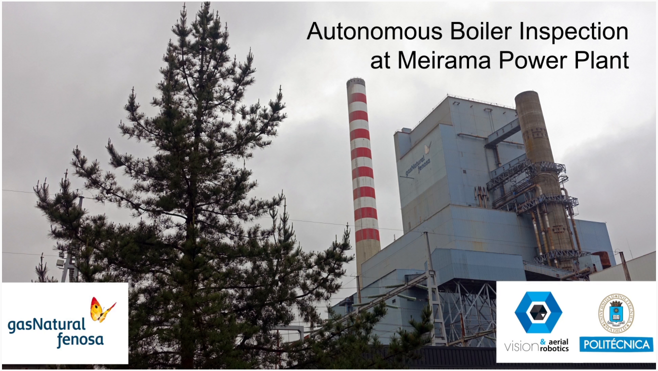
```
#-----------------------------------------------
# GENERATE_PATH_IN_OCCUPANCY_GRID
#-----------------------------------------------
  - behavior: GENERATE_PATH_IN_OCCUPANCY_GRID
    timeout: 120
    processes:
      - move_base
      - path_planning_in_occupancy_grid
    arguments:
      - argument: coordinates
        allowed_values: [-100,100]
        dimensions: 3
```



Experiments

Experiments

Boiler inspection mission



Experiment Details

Boiler mission both in simulation and real flight:

Simulation

- Gazebo + RotorS simulator
- Hummingbird Drone
- 16x16x57 - WxDxH mts

Real Flight

- Sports Center
- DJI 100 Matrice Drone
- 10x25x14 - WxDxH mts

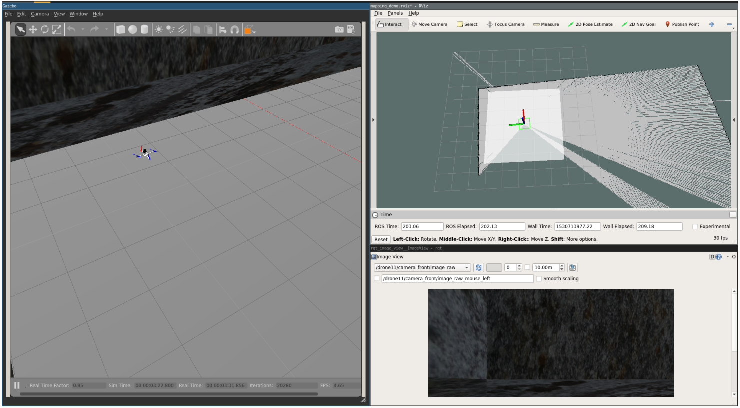


Figure 7: Simulated boiler environment

Experiments # Real Experiment

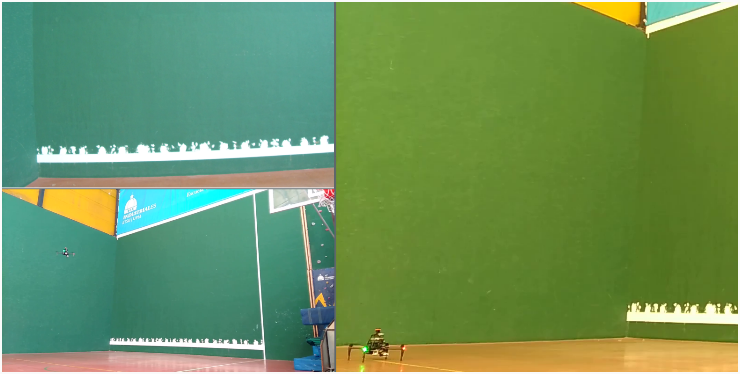


Figure 8: Real experiment on the Sports center (video)

Simulation

#	Correct	Avg. Total Point	Avg. Time
Go to Point	41/60 (0.68%)	1.82 ($\pm$ 0.52)	11.43 ($\pm$ 3.12)
Follow Path	39/60 (0.65%)	1.97 ($\pm$ 0.59)	12.21 ($\pm$ 3.58)
Generate Path	60/60 (100%)	0.20 ($\pm$ 0.00)	1.20 ($\pm$ 0.01)

Real Flight

Go to Point	16/18 (0.88%)	0.94 ($\pm$ 0.23)	5.97 ($\pm$ 1.38)

- Much room for improvement
- Localization is not accurate enough (lots of timeouts)
- Real flight is more stable & fast
- Simulation is more tested

Conclusions

Conclusions

With . . .

- Improve Localization
- Lower timeout
- Extend testing

. . . an **autonomous navigation can be achieved**.

References

References

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