Autonomous Navigation Behaviors for an Aerial Robotics Software Framework

Guillermo Echegoyen Blanco

2018

Technical University of Madrid

2018-07-19

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Overview

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1. Introduction
2. Problem Description
3. State of the Art
4. Implementation
5. Experiments
6. Conclusions
7. References

Introduction

Introduction

Autonomous Navigation

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

- Planning
- Localization
- Mapping

Introduction # Motivation

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.

Introduction # Objectives

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:

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Problem Description

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General purpose, modular software framework for aerial robotics.

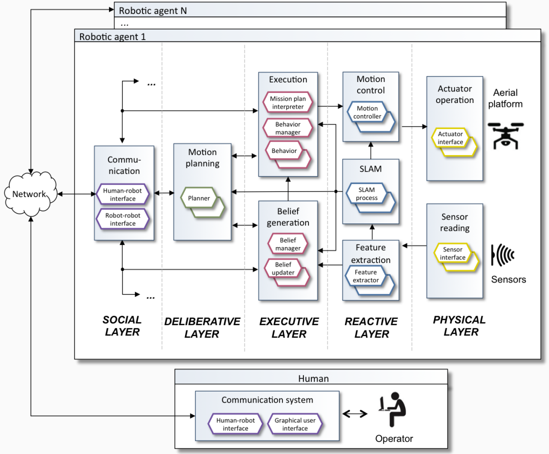

Figure 1: The Aerostack architecture

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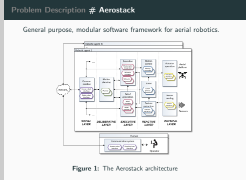
└─Problem Description
└─Aerostack
└─

Problem Description # Aerostack



Aerostack

Current version features:

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

Problem Description # Description

Aerostack

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

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.

Problem Description # Improvements

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

- A module to localize and map using **lidar** sensor.
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State of the Art

State of the Art

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.

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.

Bluetooth beacons are used in conferences and hotels to provide useful information.

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

State of the Art # SLAM

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

- EKF: classic, intractable
- Particle Filters: Currently in use, fast, does not escale well for big maps
- Graph Optimization: Currently in use, very fast
- Lidar: the one we will use, fast and escalable
- Visual: SOTA orb slam, very interesting, requires large dictionary of words

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

State of the Art # Lidar Slam

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

- Ray traces alignment as a Gauss-Newton minimization problem.
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- Navigation system: interpolates IMU with SLAM, giving 3D, 6DOF
- 2D SLAM

It handles 3D with 6DOF by using a navigator that interpolates the IMU with the SLAM data. As a hill climbing algorithm (gradient ascent), it can get stuck in local minima, therefore, multiresolution occupancy grid map is used. Each coarser map have half the resolution of the preceding one, like in CV image pyramid problem. Instead of downsampling, the maps are kept in memory and simultaneously updated with the pose estimates of the alignment process.

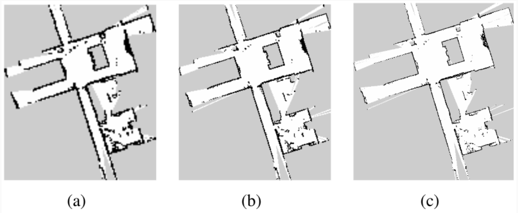
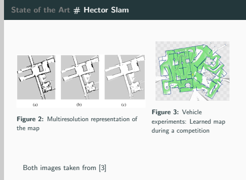


Figure 2: Multiresolution representation of the map

Figure 3: Vehicle experiments: Learned map during a competition

Both images taken from [3]



Lots of planning algorithms:

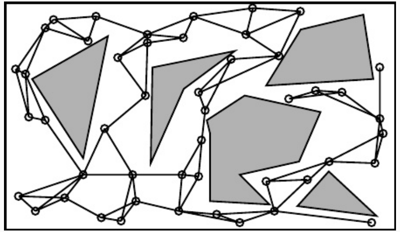


Figure 4: Probabilistic roadmaps (taken from [2])

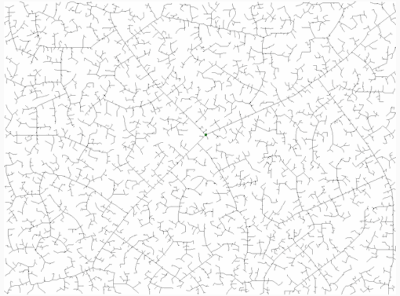
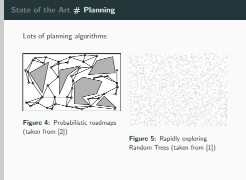
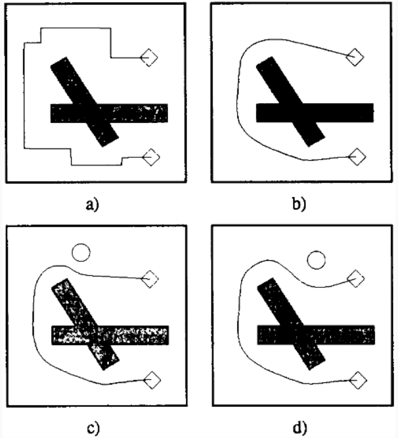


Figure 5: Rapidly exploring Random Trees (taken from [1])



ToDo := Comment algorithms and ?redo slide to include planners as text and figures as rows? Say something about both algorithms

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])

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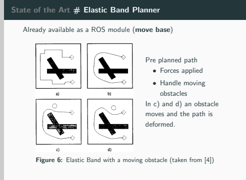
└State of the Art
 └Elastic Band Planner
  └State of the Art # Elastic Band Planner



Implementation

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Implementation # ROS

Robot Operating System. Widely used in robotics research.

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

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

- There is a master server which proxies messages from and to publishers subscribers
- Algorithms can be encapsulated inside an isolated process that acts as a pub or sub
- Provides modularity and testability

Implementation # Aerostack

Aerostack features:

- ROS node
- Robot processes.
- Behavior processes.

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- ROS node
- Robot processes.
- Behavior processes.

- ROS: Lowest level processes. Drivers & hardware.
- Robot process: Mid level process, general algorithms (like aruco recognition)
- Behavior: Highest level, algorithm monitor, useful to be coordinated.

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.

Implementation # Behavior System

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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 ↑)

Implementation # Navigation Interface

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Implementation # Implemented Behaviors

Implementing each behavior separately enables:

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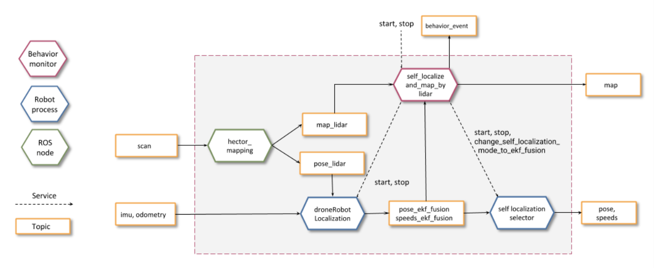
- Testability of components
- Separation of functionallity.

- This way a developer can use each module separately
- Enables fine control on Python missions
- Debugs each part separately

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
```



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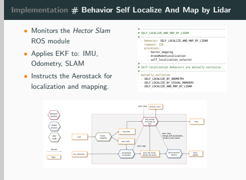
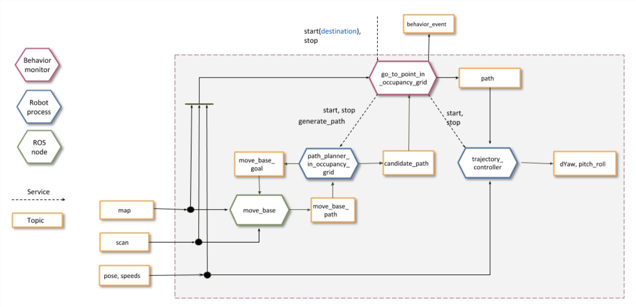
└Implementation
└Behavior Self Localize And Map by Lidar
└
Implementation # Behavior Self Localize And



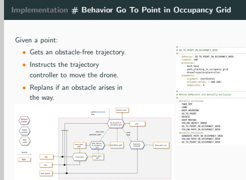
Given a point:

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




```yaml
#-----------------------------------------------------------
# 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
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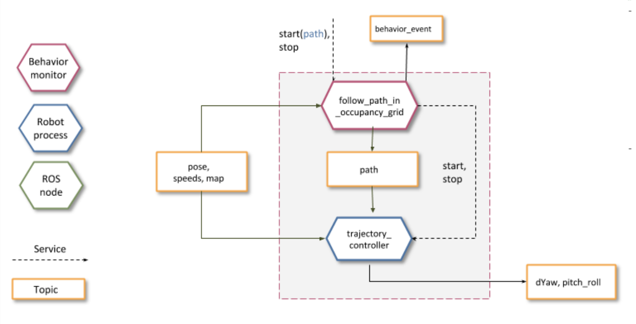

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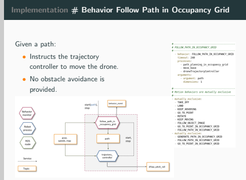
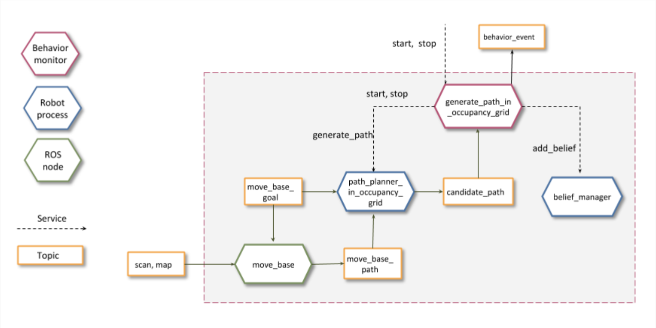
└Implementation
  └Behavior Follow Path in Occupancy Grid
    └
      Implementation # Behavior Follow Path in



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
```



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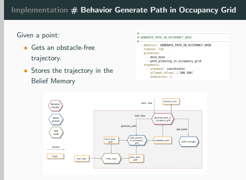
Autonomous Navigation Behaviors for an Aerial Robotics Software Framework
└Implementation
└Behavior Generate Path in Occupancy Grid
└Implementation # Behavior Generate Path in



Experiments

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Boiler inspection mission

Experiments
Boiler inspection mission
Autonomous Boiler Inspection
at Meirama Power Plant

Experiments # 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

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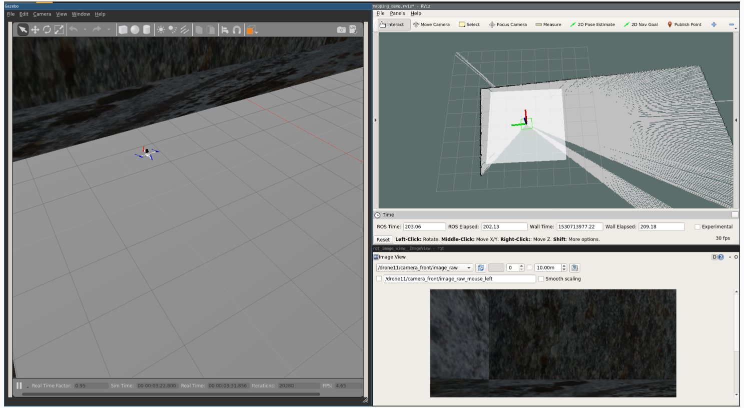

Figure 7: Simulated boiler environment

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└─Experiments
└─Simulated Experiment
└─
Experiments # Simulated Experiment

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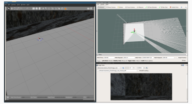

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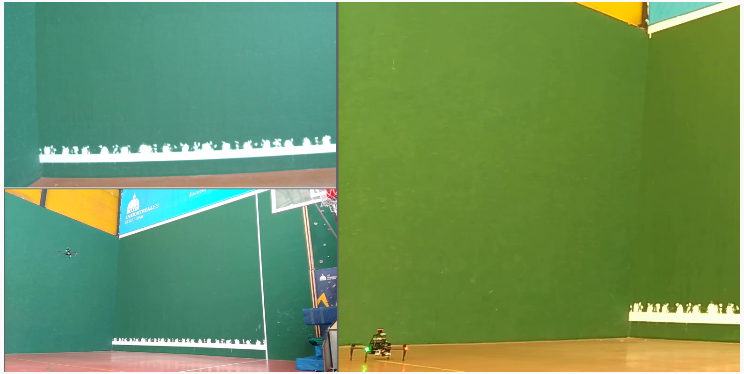

Figure 8: Real experiment on the Sports center (video)

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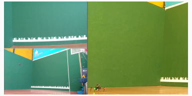
Autonomous Navigation Behaviors for an Aerial Robotics Software Framework
└─Experiments
  └─Real Experiment
    └─Experiments # Real Experiment



Simulation

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

Real Flight

Go to Point	16/18 (0.88%)	0.94 (± 0.23)	5.97 (± 1.38)

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Autonomous Navigation Behaviors for an Aerial Robotics Software Framework

└Experiments

└Data

└Experiments # Data

Experiments # Data

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Experiments # Discussion

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

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- Lower timeout
- Extend testing

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References

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References i

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