

# Autonomous Navigation Behaviors for an Aerial Robotics Software Framework

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2018



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Autonomous Navigation Behaviors  
for an  
Aerial Robotics Software Framework

1. Introduction

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5. Experiments

6. Conclusions

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## └ Overview

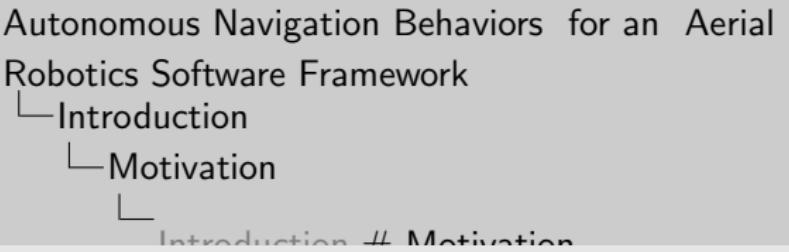
## Introduction

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## Autonomous Navigation

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

- Planning
- Localization
- Mapping



# 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:

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

## Autonomous Navigation Behaviors for an Aerial Robotics Software Framework

### └ Introduction

### └ Objectives

### └ Introduction # Objectives

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Introduction # Objectives

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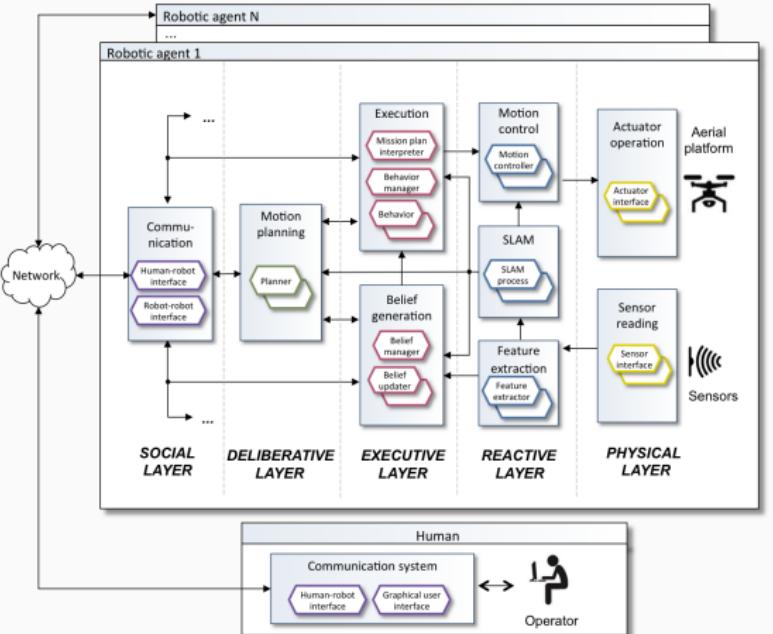
- Contribute to the research community
- Test implementation suitable for real time aerial robotics applications.

## Problem Description

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## Problem Description # Aerostack

General purpose, modular software framework for aerial robotics.



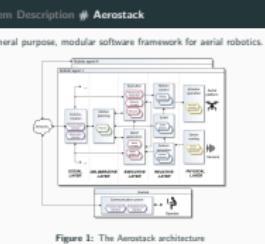
**Figure 1:** The Aerostack architecture

# Autonomous Navigation Behaviors for an Aerial Robotics Software Framework —Problem Description

## Aerostack

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## Problem Description # Aerostack

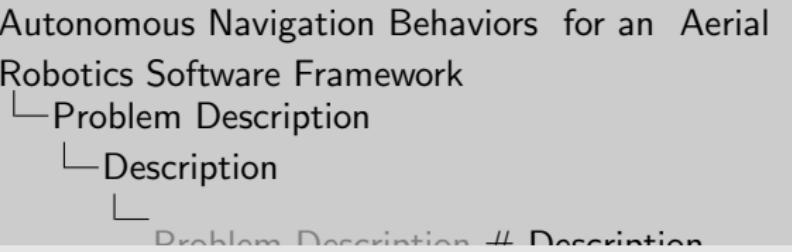


## Problem Description # Description

### Aerostack

Current version features:

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



Problem Description	# Description
<b>Aerostack</b>	<p>Current version features:</p> <ul style="list-style-type: none"><li>● Planner: 2D geometric.</li><li>● Localization: Odometry, Aruco (<i>requires preparation</i>)</li><li>● Mapping: Hardcoded in the robot.</li></ul>

## Problem Description # 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.

## Autonomous Navigation Behaviors for an Aerial Robotics Software Framework

### Problem Description

### Improvements

### Problem Description # Improvements

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Problem Description # 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.
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## State of the Art

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└ State of the Art

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Usually based on trilateration.

**Outdoor Localization**

External sources:

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.

# Autonomous Navigation Behaviors for an Aerial Robotics Software Framework

## State of the Art

### Localization

#### State of the Art # Localization

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

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## 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

## Autonomous Navigation Behaviors for an Aerial Robotics Software Framework

### State of the Art

#### SLAM

##### State of the Art # SLAM

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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 scale well for big maps
- Graph Optimization: Currently in use, very fast
- Lidar: the one we will use, fast and scalable
- Visual: SOTA orb slam, very interesting, requires large dictionary of words

## 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.
- Multi resolution occupancy grid map.
- Already available as ROS node.
- Suitable for real time
- Reliable enough

## Autonomous Navigation Behaviors for an Aerial Robotics Software Framework

### State of the Art

#### Lidar Slam

##### State of the Art # Lidar Slam

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State of the Art # Lidar Slam

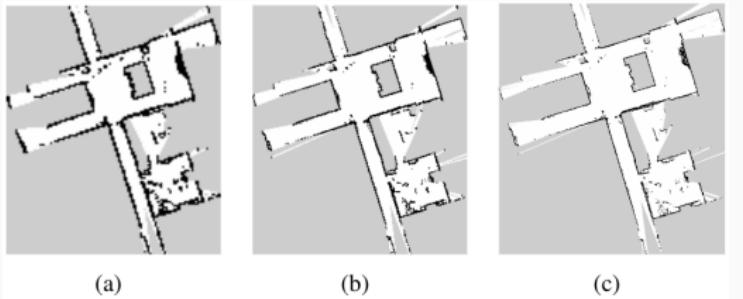
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- Navigation system: interpolates IMU with SLAM, giving 3D, 6DOF
- 2D SLAM

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.

# State of the Art # Hector Slam



**Figure 2:** Multiresolution representation of the map



**Figure 3:** Vehicle experiments: Learned map during a competition

Both images taken from [3]

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└ State of the Art  
  └ Hector Slam  
    └ State of the Art # Hector Slam

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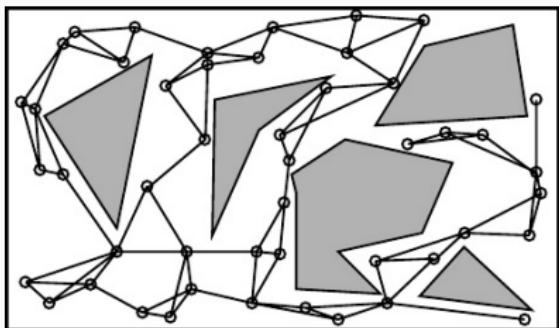
Both images taken from [3]

Figure 2: Multiresolution representation of the map

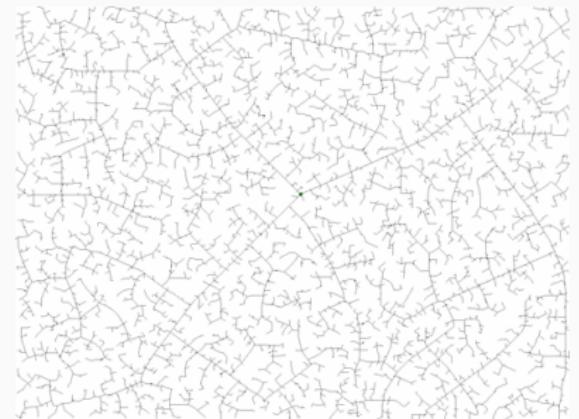
Figure 3: Vehicle experiments: Learned map during a competition

# State of the Art # Planning

Lots of planning algorithms:



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



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

## Autonomous Navigation Behaviors for an Aerial Robotics Software Framework

### State of the Art

#### Planning

##### State of the Art # Planning

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State of the Art # Planning

Lots of planning algorithms:



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

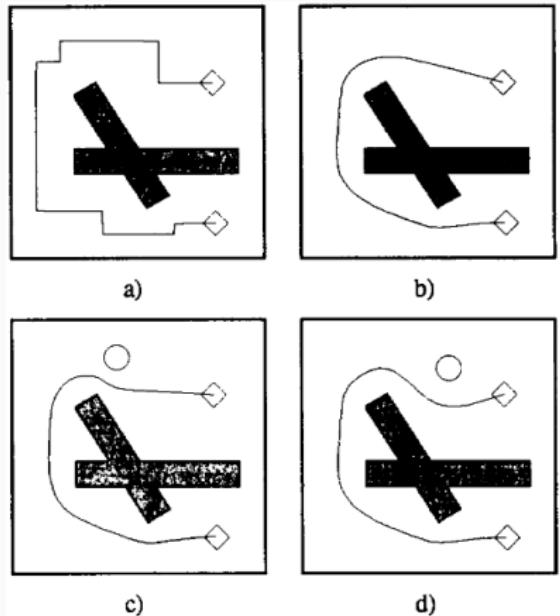


Figure 5: Rapidly exploring  
Random Trees (taken from [1])

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

# State of the Art # Elastic Band Planner

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])

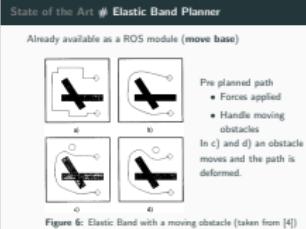
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└ State of the Art

└ Elastic Band Planner

└ State of the Art # Elastic Band Planner

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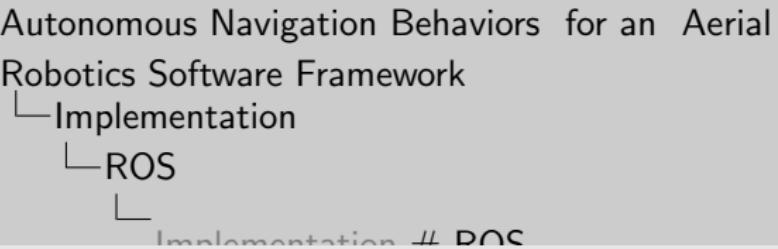
## Implementation

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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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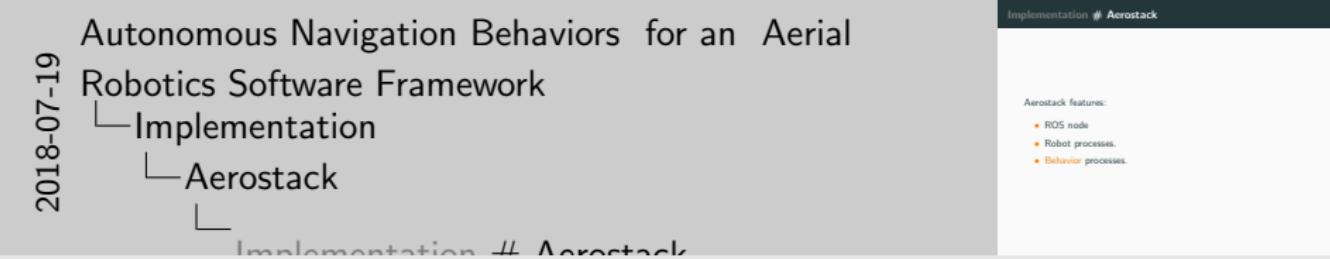
Implementation # ROS

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# Implementation # Aerostack

Aerostack features:

- ROS node
- Robot processes.
- Behavior processes.



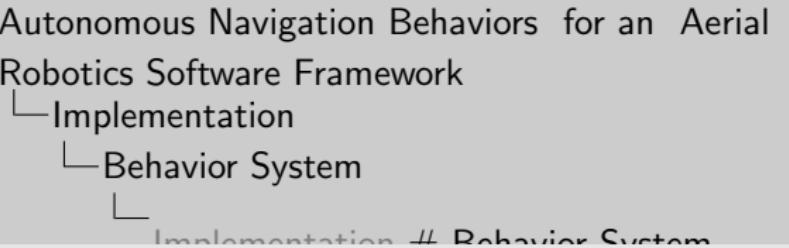
- ROS: Lowest level processes. Drivers & hardware.
- Robot process: Mid level process, general algorithms (like aruco recognition)
- Behavior: Highest level, algorithm monitor, useful to be coordinated.

# Implementation # 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 emits *error* events.
- Can have *exclusive constraints* and dependencies on other processes.

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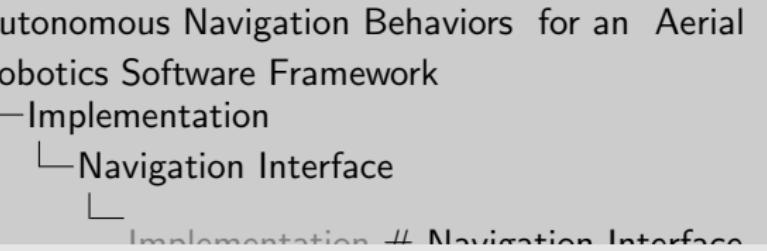
Implementation # Behavior System

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## Implementation # 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 ↑)



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  - Move base ROS module (monitored by ↑)

## Implementation # Implemented Behaviors

Implementing each behavior separately enables:

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

## Autonomous Navigation Behaviors for an Aerial Robotics Software Framework

### Implementation

#### Implemented Behaviors

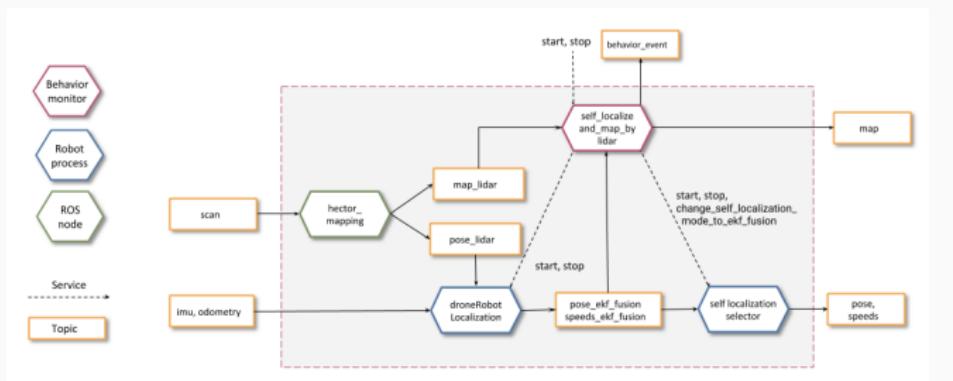
##### Implementation # Implemented Behaviors

- Implementing each behavior separately enables:
- Different, granular control over functionality
  - Testability of components
  - Separation of functionality.

# 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
```



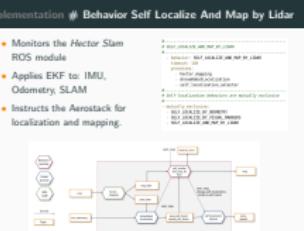
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## Autonomous Navigation Behaviors for an Aerial Robotics Software Framework

### Implementation

#### Behavior Self Localize And Map by Lidar

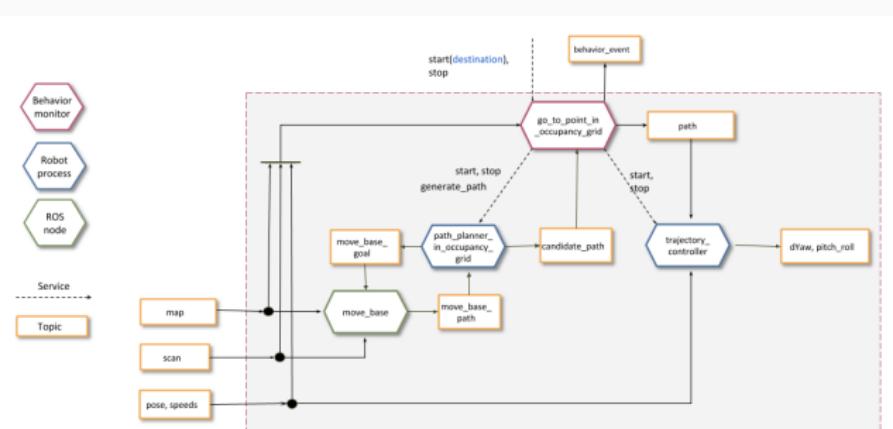
##### Implementation # Behavior Self Localize And



# Implementation # 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

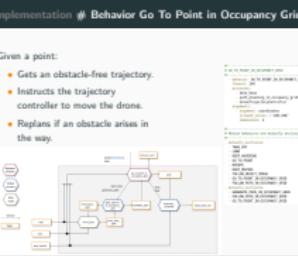
#-----#
# Motion behaviors are mutually exclusive
#-----
- mutually_exclusive:
  - TAKE_OFF
  - LAND
  - KEEP_HOVERING
  - GO_TO_POINT
  - ROTATE
  - KEEP_MOVING
  - FOLLOW_OBJECT_IMAGE
  - GO_TO_POINT_IN_OCCUPANCY_GRID
  - FOLLOW_PATH_IN_OCCUPANCY_GRID
  - mutually_exclusive:
    - GENERATE_PATH_IN_OCCUPANCY_GRID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

Autonomous Navigation Behaviors for an Aerial Robotics Software Framework  
└ Implementation

└ Behavior Go To Point in Occupancy Grid

└ Implementation # Behavior Go To Point in

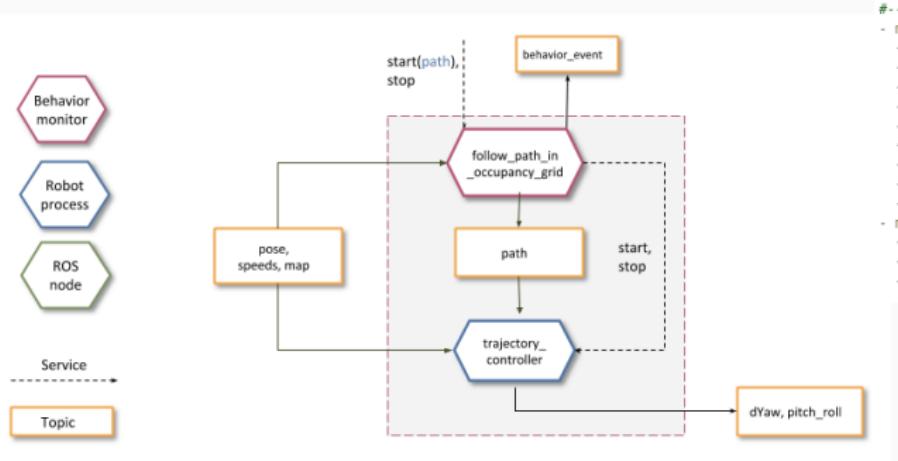
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# Implementation # Behavior Follow Path in Occupancy Grid

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  
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  - GO_TO_POINT_IN_OCCUPANCY_GRID
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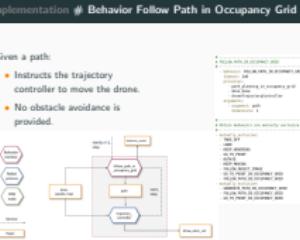
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# Autonomous Navigation Behaviors for an Aerial Robotics Software Framework

## Implementation

### Behavior Follow Path in Occupancy Grid

#### Implementation # Behavior Follow Path in

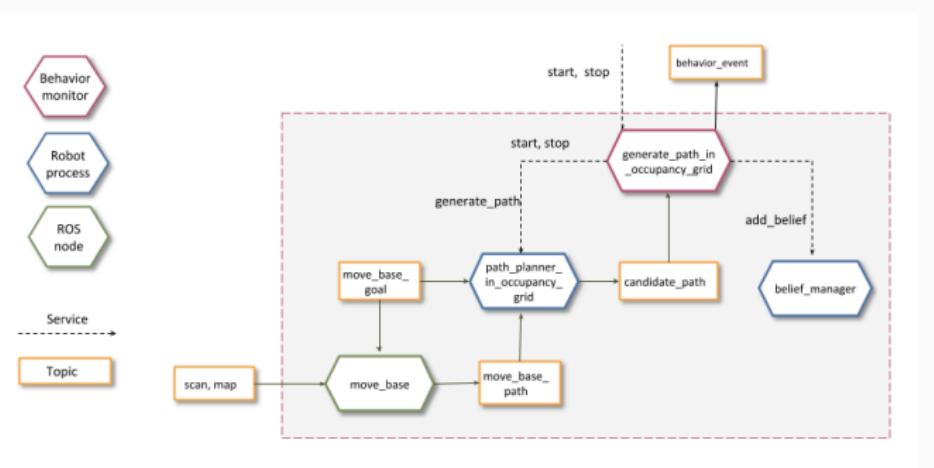


# Implementation # Behavior Generate Path in Occupancy Grid

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
```



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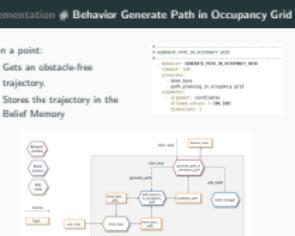
## Autonomous Navigation Behaviors for an Aerial Robotics Software Framework

- Implementation
  - Behavior Generate Path in Occupancy Grid

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### Behavior Generate Path in Occupancy Grid

#### Implementation # Behavior Generate Path in

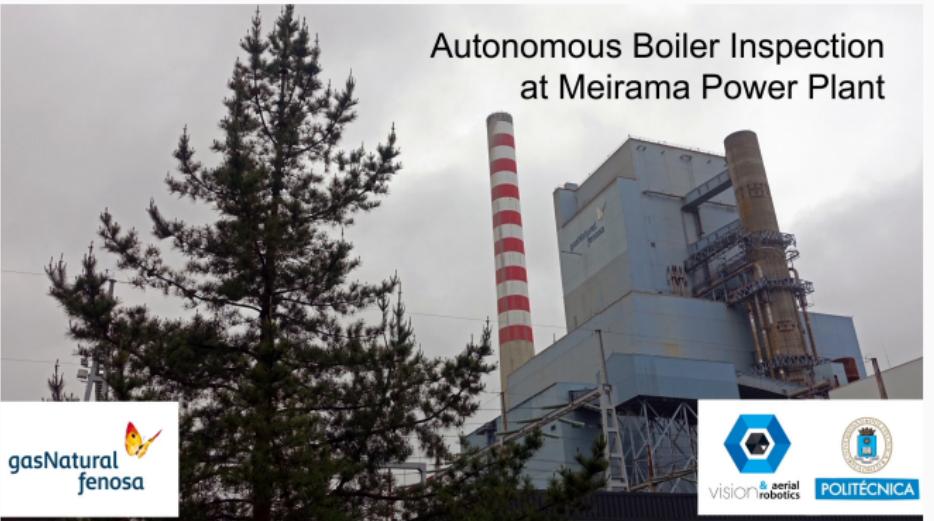


## Experiments

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# Experiments

## Boiler inspection mission



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└ Experiments

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└ Experiments



# 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

# Autonomous Navigation Behaviors for an Aerial Robotics Software Framework

## Experiments

### Experiment Details

#### Experiments # Experiment Details

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Experiments # Experiment Details

Boiler mission both in simulation and real flight:

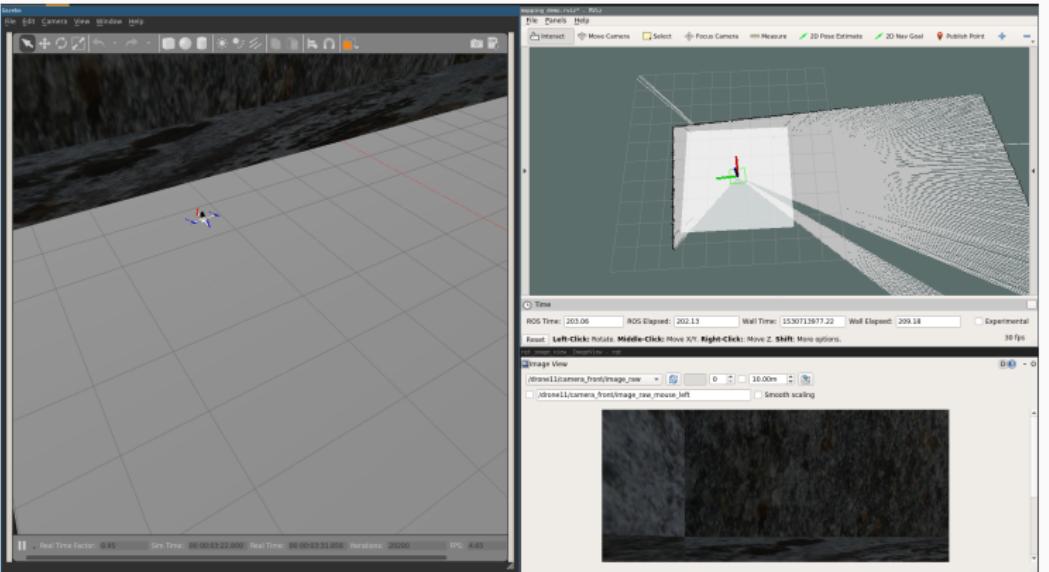
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- Sports Center
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# Experiments # Simulated Experiment



**Figure 7:** Simulated boiler environment

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└ Experiments  
  └ Simulated Experiment  
    └ Experiments # Simulated Experiment

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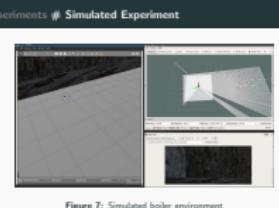
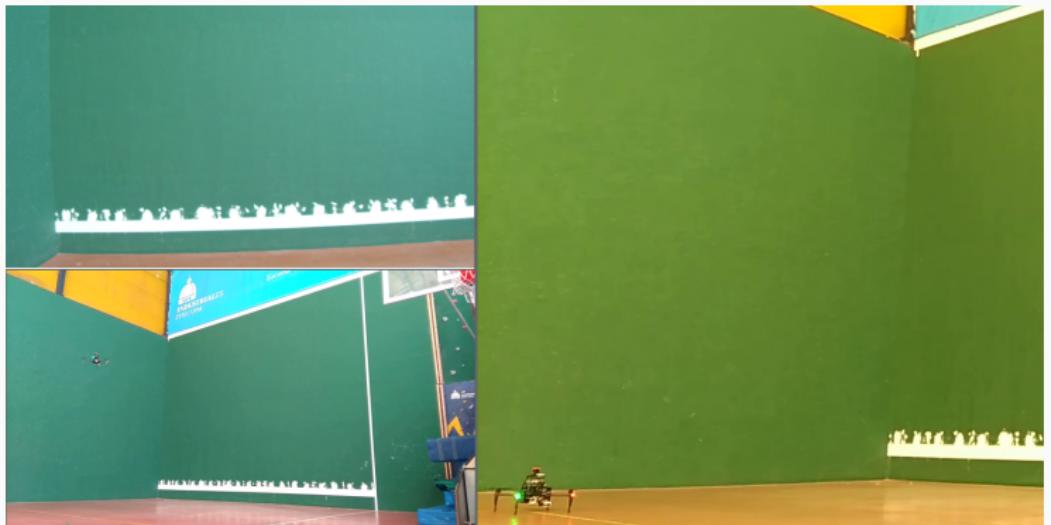


Figure 7: Simulated boiler environment

## Experiments # Real Experiment



**Figure 8:** Real experiment on the Sports center ([video](#))

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└ Experiments

  └ Real Experiment

    └ [Experiments II Real Experiment](#)

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Experiments # Real Experiment



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

## Experiments # Data

*Simulation (10 tests, 6 points each)*

#	Correct	Avg. Total Point	Avg. Time
Go to Point	41/60 (68%)	1.82 ( $\pm$ 0.52)	11.43 ( $\pm$ 3.12)
Follow Path	39/60 (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 (3 tests, 6 points each)*

Go to Point	16/18 (88%)	0.94 ( $\pm$ 0.23)	5.97 ( $\pm$ 1.38)
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## Autonomous Navigation Behaviors for an Aerial Robotics Software Framework

### Experiments

#### Data

##### Experiments # Data

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Experiments # Data			
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Real Flight (3 tests, 6 points each)			
#	Correct	Avg. Total Point	Avg. Time
Go to Point	16/18 (88%)	0.94 ( $\pm$ 0.23)	5.97 ( $\pm$ 1.38)

- Simulation has more tests
- EKF Localization worse in simulation
- Time adds up because of timeouts (bad loc)

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

## Autonomous Navigation Behaviors for an Aerial Robotics Software Framework

### └ Experiments

#### └ Discussion

└ Experiments # Discussion

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

## Conclusions

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# Conclusions

With ...

- Improve Localization
- Lower timeout
- Extend testing

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

## Autonomous Navigation Behaviors for an Aerial Robotics Software Framework

### └ Conclusions

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### └ Conclusions

Conclusions

With ...

- Improve Localization
- Lower timeout
- Extend testing

... an autonomous navigation can be achieved.

# Autonomous Navigation Behaviors for an Aerial Robotics Software Framework

## Conclusions

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Questions?

## References

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## References

-  By Javed Hossain - Own work, CC BY-SA 3.0. *Rapidly Exploring Random Trees* image Wikimedia Commons. [Online; accessed 10-July-2018]. 2018. URL: [https://upload.wikimedia.org/wikipedia/commons/6/62/Rapidly-exploring\\_Random\\_Tree\\_%28RRT%29\\_500x373.gif](https://upload.wikimedia.org/wikipedia/commons/6/62/Rapidly-exploring_Random_Tree_%28RRT%29_500x373.gif).
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