



# Development and testing of methods for drones control

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## **Acronyms**

**CPP** Coverage Path Planning

**GCS** Ground Control Station

**QGC** QGroundControl

**ROS** Robot Operating System

**SITL** Software-In-The-Loop

**UAV** Unmanned Aerial Vehicle

**WSL** Windows Subsystem for Linux

# 1 Introduction

The project is officially called (italian) *Sviluppo e sperimentazione di metodologie di controllo per droni* and it lies in the field of agricultural robots. The aim of these months will be the implementation of a real drone which is able to move in a area and take informations autonomously through some device mounted on the robot (thermal imager). The project can be splitted in two main parallel directions:

- Navigation (path planner, control schemes, etc.)
- Implementation (drone construction, autopilot selection, etc.)

## 2 Navigation

To successfully cover the area of interest the quadcopter has to navigate following a certain logic and take into account different factors such as the shape and the dimension of the area, presence of obstacles, vehicle used and so on. There is a class of algorithm called Coverage Path Planning (CPP) which is well suited for this aim.

### 2.1 Coverage Path Planning

Given an area of interest the CPP problem consist of planning a path which covers the entire target environment considering the vehicle's motion restriction and sensor's characteristics, while avoiding passing over obstacles [1]. These algorithms can be classified into two main categories: offline and online [2]. Offline algorithms need a previous knowledge of the search area, online algorithm instead are based on real-time data acquisition.

Another classification is based on the decomposition method thaat can be classified in:

- Cellular decomposition
  - Exact decomposition
  - Approximate decomposition
- No decomposition

Cellular decomposition methods are based in dividing the surface into cells: in the exact decomposition the workspace is splitted in sub-areas whose re-union exactly occupied the target area [1]. In the approximate decomposition the area is usally divided using a grid where the size of the squares is typically determined for example by the footprint of the camera mounted on the robot. In no decomposition techniques, as the name suggest, isn't applied any type of decomposition. Taking in to account the aim of the project, i.e. the Unmanned Aerial Vehicle (UAV) has to collect data in different positions of an area, the best solution is the approximate decomposition technique beacuse we don't need to cover every centimetre of the area (like an autonomous lawn mower), we need to determine the amount of waypoints that guarantees an exhaustive data collection compared to the target area.

## 3 Implementation

The implementation step is the physical construction of the UAV, this involves the selection of all the elements, both hardware (e.g. platform and its components) and software (e.g. autopilot flight stack).

### 3.1 Autopilot selection

Autopilot selection is made by evaluating possible pros and cons which every autopilot flight stack brings with it. Three possible solution were evaluated:

1. INAV [3]
2. PX4 [4]
3. Agilicious [5]

There are a lot of reason which can determine the choice of one solution instead of another, a preliminary evaluation is made considering the informations available on the web (official documentation and other sources). These parameters have been accounted:

- configuration
- missions definition
- future developments

*Configuration* denotes the level of complexity needed to configure flight controller for the first flight, *missions definition* takes into account how to define missions, and *future development* indicates compatibility with other framework, software and so on.

INAV's configuration seems easy as PX4, the main difference is the guide: for INAV you can follow some videos on Youtube at this [link](#), for PX4 it's necessary to follow sections from [Basic Assembly](#) to [Flying](#) in the official documentation. Agilicious doesn't have a section related to the configuration steps for the first real flight like the above mentioned.

INAV provide a Ground Control Station (GCS) which is capable of define only waypoints which the UAV has to visit, as shown for example [here](#). PX4 typically use QGroundControl (QGC) as GCS<sup>1</sup>, here different missions can be defined and it is worth to note that there is also survey missions which seems particularly suited with the aim of this project. Agilicious doesn't not provide a GCS for missions definition, but it has a module called [reference](#) which implements different ways of generating reference trajectories.

I wasn't able to find any documentation regarding interfacing between INAV and Robot Operating System (ROS), PX4 has a subsection dedicated to [ROS communication with PX4](#). In addition PX4 has a MATLAB package called UAV Toolbox Support Package for PX4 Autopilots [6]. Agilicious has a very good structure for future developments beacause you can change controller or estimator by simply modify a `yaml` file. It's not provided a way to integrate GPS measurements. An interface for ROS called [agiros](#) is provided. Both PX4 and Agilicious docs propose a simulator.

In conclusion the better idea should be to try the autopilot in this order: PX4, Agilicious, INAV.

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<sup>1</sup>QGC supports only PX4 and Ardupilot

## 3.2 PX4 configuration

Before first flight PX4 Autopilot needs some steps to follow to configure the autopilot, this one are documented in PX4 documentation's section called [Standard Configuration](#). The procedure is quite straightforward but some problems may arise during these steps.

### Troubleshooting

#### Firmware version

QGC provides an automatic way to flash the latest firmware<sup>2</sup>, however all version 13 express same problem with our specific hardware. More specifically the problem is related to the Wi-Fi module because with the firmware version v1.13.x the autopilot is unable to connect with QGC. So I found that version v1.12.3<sup>3</sup> fixes this problem.

#### Autotune

Having downgraded to the version v1.12.3 determined the impossibility to use the autotune procedure because this is available from v1.13.0.

## 3.3 Optitrack configuration

After some outside experiments (in which human pilot successfully drove the quadcopter) we decided to take the next flight test in an indoor scenario; this because an indoor environment is safer if compared to the outdoor one in terms of damage caused by the drone's crashing.

Before flying, the communication between Optitrack and flight controller needs to be configured, we can think the Optitrack as the indoor counterpart of the GPS. To configure the Optitrack with PX4 there is also a dedicated section named [Using Vision or Motion Capture Systems for Position Estimation](#), this one provides all the necessary steps to configure the communication. Please note that there is also a [dedicated subsection](#) for Optitrack system.

### Troubleshooting

#### Parameters

Having used an older firmware version, some parameters<sup>4</sup> have been replaced with others; these ones are listed in the table below. The first column shows the actual name of the parameters the second column shows the counterpart on the firmware version used in this project.

PX4 docs naming	v1.12.3 naming
EKF2_EV_CTRL	EKF2_AID_MASK
EKF2_HGT_REF	EKF2_HGT_MODE
EKF2_GPS_CTRL	EKF2_AID_MASK

Another set of parameters are the ones used for the preflight check, Disabling these prevents the drone from checking the correct operation of the corresponding sensors:

- SYS\_HAS\_BARO

---

<sup>2</sup>At the time of writing this report, i.e. September 2023, the last stable release is v1.13.3.

<sup>3</sup>Firmware releases available [here](#).

<sup>4</sup>Full parameter list [here](#).

- SYS\_HAS\_GPS
- SYS\_HAS\_MAG

## 4 Simulation

To test some CPP algorithms is worth to implement an environment which allows to drive a drone autonomously in a safe way, without any risk of collision. PX4 offers different simulators which allow to develop Software-In-The-Loop (SITL) simulation [7]. More in details, in the section named *MAVROS Offboard control example (Python)* [8] there is a useful example on how to setup PX4, Gazebo and MAVROS to run a simulation.

To implement a complete pipeline which allows to develop CPP algorithms, simulate the quadcopter and analyse the result MATLAB has been employed beside the simulator structure which exploit PX4, Gazebo and MAVROS, mentioned above. MATLAB is used to determine the area, develop the CPP algorithms and pass the waypoint to the simulator. After the simulation phase, which is executed in Gazebo environment the results are visualized and analysed in MATLAB again.

MATLAB is executed in Windows environment, while PX4 software stack, Gazebo and of course ROS are executed in Windows Subsystem for Linux (WSL) environment (more specifically in Ubuntu 20.04).

### 4.1 MATLAB code

There are two main files called `main.m` and `WSL_connection.m`; the first one deals with the definition of the target area by the user, the execution of the CPP algorithm and consequently the determination of waypoints in space. The second one is devoted to establish the connection with WSL to send the waypoint calculated in the `main.m` file.

#### Main.m code

As mentioned previously the `main.m` code is responsible for determining the area of interest and the waypoint calculation. The first section allows the user to select an area by specifying the latitude and longitude as shown in 1. After the selection procedure the area is converted in local coordinate expressed in meters. This further step is needed because waypoints will be calculated based on robot's footprint.

```

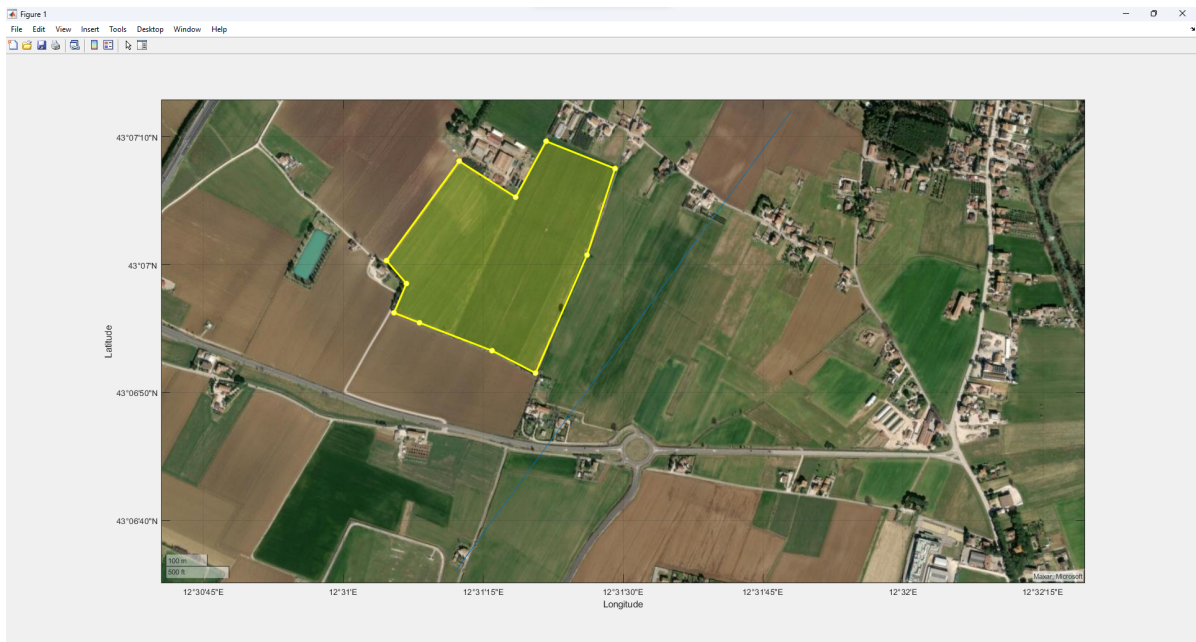
5 %% create target area
6
7 basemap = "satellite";
8 geobasemap(basemap)
9 longitude = 43.116118
10 latitude = 12.525492
11 [long_LowLim, longUpLim] = roundNumber_2digits(longitude);
12 [lat_LowLim, latUpLim] = roundNumber_2digits(latitude);
13 geoplot([long_LowLim, longUpLim], [lat_LowLim, latUpLim])
14 set(gcf, 'WindowState', 'maximized');
15
16 target_area = drawpolygon("Color", 'y') % 1 column = latitude, 2 column =
    longitude
17
18 target_area = polyshape(target_area.Position(:,2), target_area.Position(:,1)
    )

```

```

19 close
20
21 figure
22 plot(target_area)
23 title('Target area')
24 xlabel('Longitude')
25 ylabel('Latitude')
26 grid on
27
28
29 target_area_verticesMeters = latLonToMeters(target_area);
30 target_area_meters = polyshape(target_area_verticesMeters(:,2),
    target_area_verticesMeters(:,1));
31
32 figure
33 plot(target_area_meters)
34 title('Target area (local coordinates in meters)')

```



**Figure 1:** Target area selection.

The next section is devoted to the application of the CPP algorithm to the selected area, it returns a 2D or 3D waypoints, these last ones will be passed to the simulator through the `WSL_connection.m` file.

```

39 %% CPP algorithm
40
41 target_area_meters = polyshape([0 2 2 0], [0 0 2 2]) % only for test
42
43 robot_footprint = polyshape([0 1 1 0], [0 0 1 1]);
44 waypoint = calculateWaypoint(target_area_meters, robot_footprint); % CPP
    algorithm
45
46 figure
47 plot(target_area_meters, 'FaceColor', 'g')

```

```

48 hold on
49 scatter(waypoint(:, 1), waypoint(:, 2), '*r')
50 title('Target area waypoints')
51 xlabel('X (m)')
52 ylabel('Y (m)')
53 grid on
54 axis equal
55
56 figure
57 plot(target_area_meters, 'FaceColor', 'g')
58 hold on
59 scatter(waypoint(:, 1), waypoint(:, 2), '*r')
60 title('Target area waypoints and robot footprint')
61 xlabel('X (m)')
62 ylabel('Y (m)')
63 grid on
64 axis equal
65
66 for i = 1 : size(waypoint, 1)
67
68     actual_footprint = moveFootprint(waypoint(i, 1), waypoint(i,2),
69     robot_footprint);
70     plot(actual_footprint, 'FaceColor', 'y')
71 end
72
73 ref_height = transpose(ones(1, size(waypoint, 1))*1); %% add reference
74 waypoint3D = [waypoint, ref_height] % waypoints in 3D space

```

## WSL\_connection.m code

This script is responsible for the connection with WSL, which means that allows MATLAB to interact with the rostopic executed on WSL, it automatically recovers the ip addresses needed <sup>5</sup>.

```

1 %% connect to WSL
2
3 % get ip addresses needed to communicate with WSL
4
5 [~, ipAdd_wsl] = system('wsl ip -4 addr show eth0 | findstr "inet"');
6
7 ipAdd_wsl = regexp(ipAdd_wsl, '\d+\.\d+\.\d+\.\d+', 'match');
8 ipAdd_wsl = ipAdd_wsl(1)
9
10 [~, ipAdd_windows] = system('ipconfig | findstr /C:"vEthernet (WSL)" /C:"
11 IPv4"', '-echo');
12 ipAdd_windows = regexp(ipAdd_windows, '172.\d+\.\d+\.\d+', 'match')

```

<sup>5</sup>This code is tested in Windows system, to recover the addresses through Windows terminal and ubuntu shell type the following commands:

- In Ubuntu shell type \$ ifconfig and look for the address named iner under eth0. This is the variable named ipAdd\_wsl.
- In Windows terminal type \$ ip config and look for IPv4 address under Ethernet Card vEthernet (WSL). This is the variable named ipAdd\_Windows.



```

13
14 % wsl ip address -> $ ifconfig -> eth0, inet
15 string_ROS_MASTER_URI = strcat('http://', ipAdd_wsl, ':11311')
16 setenv('ROS_MASTER_URI', string_ROS_MASTER_URI)
17
18 % wsl ip on windows -> $ ipconfig -> Scheda Ethernet vEthernet (WSL),
    indirizzo IPV4
19 setenv('ROS_IP', ipAdd_windows)
20
21 roscinit
22
23 rostopic list

```

In addition, the second section is responsible of instantiating a new node which publish the waypoint list<sup>6</sup> in the topic named /MATLAB\_waypoint.

```

26 %% publish waypoint
27
28 % publisher
29 waypoint_pub = rospublisher('/MATLAB_waypoint', 'geometry_msgs/PoseArray')
30
31
32 % create message
33 waypointList_msg = rosmessage('geometry_msgs/PoseArray');
34
35 for i = 1:length(waypoint3D)
36     waypoint = rosmessage('geometry_msgs/Pose');
37     waypoint.Position.X = waypoint3D(i,1); % Set the x-coordinate
38     waypoint.Position.Y = waypoint3D(i,2); % Set the y-coordinate
39     waypoint.Position.Z = waypoint3D(i,3); % Set the z-coordinate
40     waypoint.Orientation.W = 1.0;
41
42     % Add the Pose message to the PoseArray
43     waypointList_msg.Poses = [waypointList_msg.Poses; waypoint];
44
45 end
46
47 send(waypoint_pub, waypointList_msg); % send this message only one time

```

## 4.2 WSL environment

WSL is used to run the simulations, it exploits the PX4 autopilot with Gazebo and MAVROS. First of all the following components need to be installed:

- PX4 autopilot folder, downloadable by following the section named [Ubuntu Development Environment](#).
- ROS and MAVROS<sup>7</sup>

The idea behind the simulation is to use MAVROS to drive in off-board mode a simulated quadcopter in Gazebo using the waypoint calculated in MATLAB. As a result, we need a across that is capable of subscribing to the topic named /MATLAB\_waypoint to recover the waypoint list. By

<sup>6</sup>The code assumes that there is a matrix variable named `waypoint3D`, with dimensions  $N \times 3$ , where  $N$  represents the number of waypoint and the columns are the *xyz* coordinates in the space.

<sup>7</sup>The installation of ROS and MAVROS is not covered in this guide.

following PX4 documentation sections named [MAVROS Offboard control example \(Python\)](#) is easy to understand how to develop a new ROS package<sup>8</sup>. The file implemented to create the rosnode is called `waypoint_manager.py`.

## Waypoint\_manager.py

The code should be easily readable by the user, for more details contact the author.

```
1  #!/usr/bin/env python3
2
3  import rospy
4  from geometry_msgs.msg import PoseStamped, Point, PoseArray
5  from mavros_msgs.msg import State
6  from mavros_msgs.srv import CommandBool, CommandBoolRequest, SetMode,
   SetModeRequest
7  from math import dist
8
9
10 current_state = State()
11
12 waypoint_index = 0
13 waypointList = []
14 waypointReceived = False # flag to check if waypoint list is received
15 nextWaypoint = [0, 0, 0]
16
17
18
19 def state_cb(msg):
20     global current_state
21     current_state = msg
22
23
24 def buildWPArray(data):
25     for index in range(len(data.poses)):
26         waypointList.append([data.poses[index].position.x, data.poses[index].
           position.y, data.poses[index].position.z])
27
28
29 def getNextWP(currentPosition, threshold):
30
31     global waypoint_index
32     global waypointList
33     global nextWaypoint
34
35     try:
36         currentWaypoint = waypointList[waypoint_index]
37         nextWaypoint = currentWaypoint
38
39         if dist(currentPosition, currentWaypoint) < threshold: # compute
           euclidean 3D distance
40             waypoint_index += 1
41             nextWaypoint = waypointList[waypoint_index]
42             rospy.loginfo('Next waypoint: ' + str(nextWaypoint))
43
```

---

<sup>8</sup> `catkin_make` can be used instead of `catkin build`, for more details take a look at ROS documentation section named [Creating a ROS Package](#).

```

44     except IndexError:
45         pass
46
47
48     return nextWaypoint
49
50
51
52     def WP_callback(data):
53
54         if waypointReceived:
55
56             targetWP = getNextWP([data.pose.position.x,
57                                   data.pose.position.y,
58                                   data.pose.position.z], threshold=.2)
59
60
61
62             # Create a PoseStamped message
63             pose_msg = PoseStamped()
64             pose_msg.header.stamp = rospy.Time.now()
65             pose_msg.pose.position.x = targetWP[0]
66             pose_msg.pose.position.y = targetWP[1]
67             pose_msg.pose.position.z = targetWP[2]
68             pose_msg.pose.orientation.x = 0.0
69             pose_msg.pose.orientation.y = 0.0
70             pose_msg.pose.orientation.z = 0.0
71             pose_msg.pose.orientation.w = 0.0
72
73             currentWaypoint_pub.publish(pose_msg)
74
75         else:
76             # rospy.loginfo('Waiting for waypoint')
77
78     if __name__ == '__main__':
79
80         try:
81
82             rospy.init_node('waypoint_manager')
83
84             # subscribers
85             state_sub = rospy.Subscriber("mavros/state", State, callback = state_cb)
86             position_sub = rospy.Subscriber('mavros/local_position/pose',
87                                             PoseStamped, callback = WP_callback)
88
89             # publisher
90             currentWaypoint_pub = rospy.Publisher('/mavros/setpoint_position/local',
91                                                  PoseStamped, queue_size=10)
92
93
94             rospy.wait_for_service("/mavros/cmd/arming")
95             arming_client = rospy.ServiceProxy("mavros/cmd/arming", CommandBool)
96
97             rospy.wait_for_service("/mavros/set_mode")
98             set_mode_client = rospy.ServiceProxy("mavros/set_mode", SetMode)
99
100            waypointMessage = rospy.wait_for_message("/MATLAB_waypoint", PoseArray)

```

```

99     buildWPArray(waypointMessage)
100     rospy.loginfo("Waypoint list: " + str(waypointList))
101     waypointReceived = True
102
103
104     # Setpoint publishing MUST be faster than 2Hz
105     rate = rospy.Rate(20)
106
107     # Wait for Flight Controller connection
108     while(not rospy.is_shutdown() and not current_state.connected):
109         rate.sleep()
110
111     offb_set_mode = SetModeRequest()
112     offb_set_mode.custom_mode = 'OFFBOARD'
113
114     arm_cmd = CommandBoolRequest()
115     arm_cmd.value = True
116
117     last_req = rospy.Time.now()
118
119     while(not rospy.is_shutdown()):
120         if(current_state.mode != "OFFBOARD" and (rospy.Time.now() - last_req)
121 > rospy.Duration(5.0)):
122             if(set_mode_client.call(offb_set_mode).mode_sent == True):
123                 rospy.loginfo("OFFBOARD enabled")
124
125                 last_req = rospy.Time.now()
126
127             else:
128                 if(not current_state.armed and (rospy.Time.now() - last_req) > rospy
129 .Duration(5.0)):
130                     if(arming_client.call(arm_cmd).success == True):
131                         rospy.loginfo("Vehicle armed")
132
133                         last_req = rospy.Time.now()
134
135                     rate.sleep()
136
137     rospy.spin()
138
139 except rospy.ROSInterruptException:
140     rospy.logwarn("Node Interrupted")

```

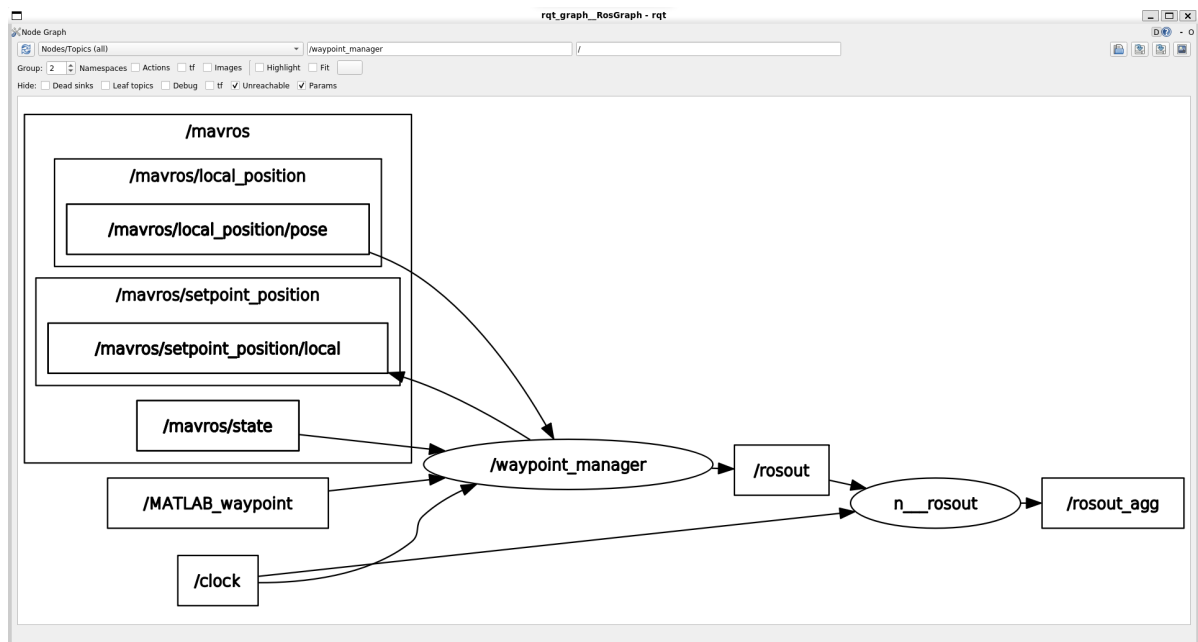
### 4.3 Execute simulation

Is recommendable to don't use a .launch, launch all the files from different terminal. These are the steps to successfully run the simulation:

1. Run main.m file to calculate the waypoints
2. On the first terminal run the command `$ roslaunch PX4-Autopilot/launch/mavros_posix_sitl.launch` to launch the PX4 autopilot and Gazebo environment
3. On the second terminal run the command `$ rosrn offboard_py waypoint_manager.py` to launch the waypoint\_manager node

4. Run `WSL_connection.m` to send the waypoint list to the `waypoint_manager` node

After this the situation should look like the one depicted in Figure 2.



**Figure 2:** Node and topic view focused on `waypoint_manager` node.

## References

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