Self-aware drone swarm for transportation

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1 Platforms

CVUT (2020)

2 Motion planning (Estimation, control, and planning)/Path planning

General definition The fundamental problem of motion planning is obtaining a collision-free path from start to goal for a robot that moves in a static and totally known environment that consists of one or many obstacles Mohanan and Salgoankar (2018)[1]. Motion planning, also **path planning** (also known as the navigation problem or the piano mover's problem) is computational problem to find a sequence of valid configurations that moves the object from the source to destination [1].

Approaches in static environment For wikipedia see [2] section Algorithms

Sampling-based The idea of the sampling-based planning is to random sample the configuration space C and classify the samples as free or non- free using collision detection. The free samples are stored in a roadmap and the nearest free samples are connected by edges. Then, the path in the roadmap corresponds to a motion in the workspace Spurny et al. (2019).

footnote [3].

- **Probabilistic Roadmaps (PRM)**: LaValle (1998) which is used in Spurny et al. (2019)
- **Rapidly Exploring Random Trees (RRT)**: Kavraki et al. (1996) which is used in Spurny et al. (2019) The basic RRT builds a configuration tree T rooted at at initial state q_{init} by sub-sequence adding of new reachable feasible configuration. In each iteration of the tree construction, a configuration qrand is randomly sampled from the whole configuration space C and its nearest neighbor $q_{near} \in T$ in the tree is found. The

[1] https://en.wikipedia.org/wiki/Motion_planning
[2] https://en.wikipedia.org/wiki/Motion_planning
[3] http://planning.cs.uiuc.edu/ch5.pdf

configuration q_{near} is then expanded using the motion model to obtain new configurations reachable from q_{near} . The new positions are obtained by applying control inputs to the motion model over time Δt. From these configurations, the nearest one towards q_{rand} is selected and added to the tree. The algorithm terminates if the goal configuration is approached within a given distance or if the maximum number of iterations is reached.

- Guided RRT: Vonasek et al. (2009) in which the guided path (a path that) The guiding path can be computed as a simple geometric path, e.g. using **Voronoi diagram** or **Triangular-based** methods.
- Transition-based RRT Spurny et al. (2019)[19]

LaValle (1998) which is used by It also uses Spurny et al. (2019)[15][16][17][18][19]

Approaches for dynamic environment Dynamic environment means obstacles movements etc Mohanan and Salgoankar (2018) is a survey and the list of the approaches are taken out of it. Masehian and Katebi (2007)

Artificial potential fields (APF) Based on force field idea where the goal is the attractor and the obstacles are repulsive forces Mohanan and Salgoankar (2018); Baydoun et al. (2019).

Accessibility graph (AG)

Configuration space (CS), state time space (STS)

Velocity based motion planning

A thousand more see Mohanan and Salgoankar (2018)

With a simple camera and an IMU Loianno et al. (2017)

Collision avoidance

In 3d environment Wang et al. (2015)

2.1 Trajectory Tracking / tracking control

Tagliabue et al. (2017) has used Kamel et al. (2016) and Kamel et al. (2017). see footnote [4]

Algorithms

[4] `https://www.researchgate.net/publication/320913735_Trajectory_tracking_in_quadrotor_platform_by_using_PD_controller_and_LQR_control_approach`

Using both a linear model predictive controller (MPC) and non-linear state feedback

PID control for disturbance rejection To make a drone follow its trajectory See footnote URL`https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8741829`

2.2 Disturbance rejection

In trajectory tracking See footnote [5]

2.3 Stability

Position and altitude control Nascimento and Saska (2019)

Quadrotors Quadrotors are underactuated systems by design, since they possess six degrees of freedom but only four actuating motors (lift-generating propellers). The system is categorized as inherently unstable in its open-loop operation due to the underactuated property but its stability can be achieved via closed-loop control[6]

2.4 State estimation

Definition to achieve state estimation and localization relative to a scene.

Approches/Algorithms It deals with techniques such as Kolman filter. See footnote [7].

UKF

2.4.1 Localization

Simultaneous Localization and Mapping (SLAM)

Visual-inertial Nikolic et al. (2014) Bloesch et al. (2015) See footnote [8]

With smart phones See footnote [9]

[5] `https://journals.sagepub.com/doi/abs/10.1177/0142331220909003`
[6] `https://www.researchgate.net/post/Why_are_quadrotors_inherently_unstable`
[7] `https://www.mdpi.com/2504-446X/3/1/19`
[8] `https://www.sciencedirect.com/science/article/pii/S2405896317302859`
[9] `https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6308659/#B5-sensors-18-04161`

2.5 General

Powers et al. (2015) Four forces of flight

- Thrust vs Drag (To move the drone forward)
- Lift vs Weight (To lift the drone up)

Six degrees of freedom

- **Pitch**: Orientation along the backward-forward axis
- **Roll**: Orientation along the left-right axis
- **Yaw**: Orientation along the up-down axis

Components of a drone

- **Telemetry module**: to receive back information from the drone

3 Auto pilot

Open source See URL[10]

Companies Such as Pixhawk auto pilot [11]

4 Sensors

Altitude meter http://downloads.hindawi.com/journals/mpe/2013/587098.pdf https://www.researchgate.net/publication/309486306_Altitude_Control_of_a_Quadcopter

For obstacle detection the such sensor may contribute https://www.dronezon.com/learn-about-drones-quadcopters/top-drones-with-obstacle-detection-collision-av

Exteroceptive sensors

- **Stereo Vision**:
- **Time-of-Flight**: https://en.wikipedia.org/wiki/Time-of-flight_camera
- **Lidar**:
- **Infra-red**:
- **ultra-sound(Sonar)**:
- **Monocular Vision**:

[10] https://px4.io/

[11] https://pixhawk.org/

Proprioceptive sensors https://3dinsider.com/drone-sensors/

Compass : Determines heading

GPS : Determines position based on GPS/GLONASS satellites

Power module : Power supply to flight controller

mmWave sensor

IMU : Inertial measurement unit https://en.wikipedia.org/wiki/Inertial_measurement_unit is composed of

- **Accelerometer**: Measures acceleration in all 3 axis
- **Gyroscope**: Measure angular rate in all 3 axis

MEMS inertial sensors See footnote for their application[12]

Force sensors : Such as this company [13] Always consider sensor fusions

5 Standards

Pixhawk Offers the reference standards. All aspects of mechanical and electrical specifications for creating interoperable drone system components See footnote URL[14] and this footnote to the standard documentation [15]

FMUv5x

6 Simulation

See footnote URL [16]

6.1 ROS

In quadcoptors each rotor is a joint[17].

[12] https://ieeexplore.ieee.org/document/4610859
[13] https://www.tekscan.com/products-solutions/embedded-force-sensors
[14] https://pixhawk.org/
[15] https://github.com/pixhawk/Pixhawk-Standards
[16] https://openuav.us/
[17] https://www.wilselby.com/research/ros-integration/3d-mapping-navigation/

6.2 PX4

Youtube channel [18]

Dronecode See footnote URL [19]

Existing vehicles See footnote URL [20]

Worlds See footnote URL [21]

Hardware in the Loop Simulation (HITL) See footnote URL [22]

Multi-Vehicle Simulation with Gazebo See footnote URL [23]

Simulator MAVLink API See footnote URL [24]

SITL Simulation Environment See footnote URL [25]

Airframes Reference See footnote URL [26]

MAVROS See footnote URL [27] provides communication driver for various autopilots with MAVLink communication protocol. Additional it provides UDP MAVLink bridge for ground control stations (e.g. QGroundControl). See footnote URL [28]

6.3 Multi-Vehicle Simulation

https://dev.px4.io/master/en/simulation/multi-vehicle-simulation.html

Multi-Vehicle Simulation with Gazebo See footnote URL [29]

6.4 MAVLink

MAVLink is a very lightweight, header-only message library for communication between drones and/or ground control stations. See footnote URL [30]

[18] https://www.youtube.com/c/PX4AutopilotProject/videos
[19] https://www.dronecode.org/
[20] https://dev.px4.io/master/en/simulation/gazebo_vehicles.html
[21] https://dev.px4.io/master/en/simulation/gazebo_worlds.html
[22] https://dev.px4.io/master/en/simulation/hitl.html
[23] https://dev.px4.io/master/en/simulation/multi_vehicle_simulation_gazebo.html
[24] https://dev.px4.io/v1.9.0/en/simulation/#simulator-mavlink-api
[25] https://dev.px4.io/v1.9.0/en/simulation/#sitl-simulation-environment
[26] https://dev.px4.io/v1.9.0/en/airframes/airframe_reference.html
[27] http://wiki.ros.org/mavros
[28] https://dev.px4.io/master/en/ros/mavros_installation.html
[29] https://dev.px4.io/master/en/simulation/multi-vehicle-simulation.html
[30] https://github.com/mavlink/mavlink

MavSDK The library provides a simple API for managing one or more vehicles, providing programmatic access to vehicle information and telemetry, and control over missions, movement and other operations. See footnote URL [31] and [32] and [33]

7 companies

Skynode

twins From where lake side buys its drones. See url in the footnote[34]

8 Models

clover See footnote URL [35] It is

SITL See footnote URL [36]

9 Social

People Follow the url `https://scholar.google.it/citations?view_op=search_authors\&hl=en\&mauthors=label:mavs` to see people interested in MAV.

giuseppe-loianno `https://engineering.nyu.edu/faculty/giuseppe-loianno` with thousands of citations in this field and he also is an expert in sensor fusion.

Byung Joon Lee https://scholar.google.it/citations?hl=en\&user=
aH-8urcAAAAJ\&view_op=list_works\&citft=1\&citft=2\&citft=3\&email_
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cB7gyf0kK5kTc-9fAw0SW7XCG85Kgabtzsa1v8VAX1PrdUUphy5gimBhXA

Vijay kumar Scholar `https://scholar.google.com/citations?hl=en\&user=FUOEBDUAAAAJ\&view_op=list_works\&sortby=pubdate`

[31] https://auterion.com/getting-started-with-mavsdk-python/
[32] https://www.youtube.com/watch?v=GXt-eXJ9vfg
[33] https://mavsdk.mavlink.io/develop/en/index.html
[34] https://pixhawk.org/products/
[35] https://coex.tech/clover
[36]

Daniel Mellinger https://scholar.google.com/citations?user=hI8nho4AAAAJ\&hl=en

References

M. Baydoun, D. Campo, D. Kanapram, L. Marcenaro, and C. S. Regazzoni. Prediction of multi-target dynamics using discrete descriptors: an interactive approach. 2019.

M. Bloesch, S. Omari, M. Hutter, and R. Siegwart. Robust visual inertial odometry using a direct ekf-based approach. In *2015 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pages 298–304, 2015.

MRS Felk CVUT. Micro aerial vehicles - platforms, 01 2020. URL http://mrs.felk.cvut.cz/research/micro-aerial-vehicles.

Mina Kamel, Michael Burri, and Roland Siegwart. Linear vs nonlinear MPC for trajectory tracking applied to rotary wing micro aerial vehicles. 2016.

Mina Samir Kamel, Thomas Stastny, Kostas Alexis, and Roland Siegwart. *Model Predictive Control for Trajectory Tracking of Unmanned Aerial Vehicles Using Robot Operating System.* 05 2017. doi: 10.1007/978-3-319-54927-9_1.

L. E. Kavraki, P. Svestka, J. . Latombe, and M. H. Overmars. Probabilistic roadmaps for path planning in high-dimensional configuration spaces. *IEEE Transactions on Robotics and Automation*, 12(4):566–580, 1996.

S. LaValle. Rapidly-exploring random trees : a new tool for path planning. 1998.

G. Loianno, C. Brunner, G. McGrath, and V. Kumar. Estimation, control, and planning for aggressive flight with a small quadrotor with a single camera and imu. *IEEE Robotics and Automation Letters*, pages 404–411, 2017.

E. Masehian and Yalda Katebi. Robot motion planning in dynamic environments with moving obstacles and target. *World Academy of Science, Engineering and Technology, International Journal of Computer, Electrical, Automation, Control and Information Engineering*, 1:1249–1254, 2007.

M. G. Mohanan and Ambuja Salgoankar. A survey of robotic motion planning in dynamic environments. *Robotics Auton. Syst.*, 100:171–185, 2018.

Tiago Nascimento and Martin Saska. Position and attitude control of multi-rotor aerial vehicles: A survey. 2019.

J. Nikolic, J. Rehder, M. Burri, P. Gohl, S. Leutenegger, P. T. Furgale, and R. Siegwart. A synchronized visual-inertial sensor system with fpga pre-processing for accurate real-time slam. pages 431–437, 2014.

Caitlin Powers, Daniel Mellinger, and Vijay Kumar. *Quadrotor Kinematics and Dynamics*. 2015.

V. Spurny, M. Petrlik, V. Vonasek, and M. Saska. Cooperative transport of large objects by a pair of unmanned aerial systems using sampling-based motion planning. In *2019 24th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA)*, pages 955–962, 2019.

Andrea Tagliabue, Mina Kamel, Roland Siegwart, and Juan I. Nieto. Robust collaborative object transportation using multiple mavs. 2017.

Vojtech Vonasek, Jan Faigl, Tomáš Krajník, and Libor Přeučil. *RRT-path – A Guided Rapidly Exploring Random Tree*. 2009.

Honglun Wang, Wentao Lyu, Peng Yao, Xiao Liang, and Chang Liu. Three-dimensional path planning for unmanned aerial vehicle based on interfered fluid dynamical system. 2015.