FINNDRONE
TAMPERE UNIVERSITY

ICRA 2022 DodgeDrone Challenge

Tampere University *is one of the most multidisciplinary universities in Finland. We bring together research and education in a vast range of technologies. The Automation Technology and Mechanical Engineering unit conducts research and offers education in automation, hydraulics, machine design, product development, mechatronics, robotics, control, and systems theory, industrial informatics, and production engineering.*

FINNDRONE TEAM

FinnDrone *is an active team consisting of motivated, curious, and creative M.Sc. and Ph.D. students whose research interests mostly focus on Control, Robotics, Vision, and Learning-based methods. The group is under supervision of Prof. Reza Ghabcheloo.*

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FinnDrone is pleased to participate in the ICRA 2022 DodgeDrone Challenge. Taking advantage of state-of-the-art methods in the fields of control and vision, FinnDrone achieved the Fifth rank in the State-Based competition as its first experience of participating in this challenge.

DODGEDRONE CHALLENGE

DodgeDrone *Challenge.*

https://uzh-rpg.github.io/icra2022-dodgedrone/

DodgeDrone competition was a fun and creative way to develop our team’s knowledge in the control of an agile drone in a highly dynamic environment. In this challenge, drones should fly as fast as possible while avoiding collision with both static and dynamic spherical obstacles.

STATE-BASED CONTROL STRATEGY

The employed control strategy can be divided into two different layers: High-Level, and Low-Level Controller. As is shown in Figure 1, the drone states are measured and along with the obstacles' information are fed to the High-Level Control. In this block, the desired velocity commands and yaw rate will be calculated and fed to the next layer as inputs. And finally, propulsion commands will be produced in the Low-Level Control block to feed the drone.

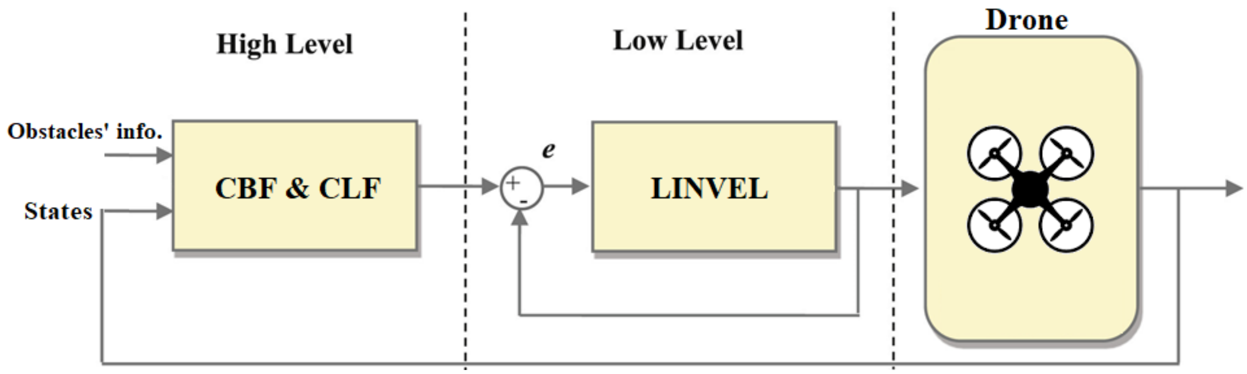

Figure 1 *Structure of Control Scheme*

High-Level Controller

In this control level, we aim to generate the desired linear velocity and yaw rate so that not only leads to stability but also guarantees safety in a highly dynamic environment. To this end, consider the following closed-loop non-linear dynamic system:

$$\dot{\boldsymbol{x}} = f(\boldsymbol{x}, \boldsymbol{u}) \tag{1}$$

where $\boldsymbol{x} \in \mathbb{X} \subseteq \mathbb{R}^n$ is state vector, and $\boldsymbol{u} \in \mathbb{U} \subseteq \mathbb{R}^m$ is control input.

Let's define a closed time-variant safe set $C(t)$ as below:

$$C(t) = \{\boldsymbol{x} \in \mathbb{X} | h_i(\boldsymbol{x}, t) \geq 0\} \tag{2}$$

where $h_i(\boldsymbol{x}, t)\colon \mathbb{X} \times \mathbb{R}^+ \rightarrow \mathbb{R}$ are smooth and continuously differentiable functions which satisfy the following conditions for all $i \in \{1,2, \dots, N\}$:

$$\begin{gathered} \partial C_i(t) = \{\boldsymbol{x} \in \mathbb{X} | h_i(\boldsymbol{x}, t) = 0\} \\ Int\big(C_i(t)\big) = \{\boldsymbol{x} \in \mathbb{X} | h_i(\boldsymbol{x}, t) > 0\} \end{gathered} \tag{3}$$

where $C_i(t)$ are individual safe sets around each unsafe set $\mathbb{X}_i^u$. Obviously, the final safe set for the control system (1) that is valid for all previous conditions, would be the intersection of all individual safe sets $C_i(t)$:

$$C(t) = C_1(t) \cap C_2(t) \dots C_N(t) \tag{4}$$

It is mathematically proven that the following condition is necessary and sufficient to make time-variant safe set $C(t)$ forward invariant [1]:

$$\dot{h}_i(\boldsymbol{x}, t) = \frac{\partial h_i(x,t)}{\partial x} f(\boldsymbol{x}, \boldsymbol{u}) + \frac{\partial h_i(x,t)}{\partial t} \geq -\alpha_i\big(h_i(\boldsymbol{x}, t)\big) \text{ for all } (\boldsymbol{x}, t) \in C(t) \times [t_0, t_1] \tag{5}$$

where $\alpha_i(.)$ is a class κ function that can be defined based on the density of the environment.

In an environment with dynamic spherical obstacles, the following $h_i(\boldsymbol{x}, t)$ would be a valid candidate for the time-variant Control Barrier Function.

$$h_i(\boldsymbol{x}, t) = \left(\boldsymbol{x} - \boldsymbol{x}_{o_i}(t)\right)^T \left(\boldsymbol{x} - \boldsymbol{x}_{o_i}(t)\right) - r_{o_i}^2 \tag{6}$$

To have a stable flight inside the bounding box toward X-direction, we defined a quadratic Control Lyapunov Function as below:

$$V(\boldsymbol{x}) = \frac{1}{2}\boldsymbol{x}_{\boldsymbol{e}}^{\boldsymbol{T}}\boldsymbol{x}_{\boldsymbol{e}} \tag{7}$$

where $\boldsymbol{x}_{\boldsymbol{e}} = \boldsymbol{x} - \boldsymbol{x}_{\boldsymbol{g}}$, and $\boldsymbol{x}_{\boldsymbol{g}}$ is the nearest point on the midline of the bounding box.

The stability can be guaranteed as far as the controller satisfy the following condition.

$$\dot{V}(\boldsymbol{x}, \boldsymbol{u}) < \gamma(V) \tag{8}$$

To find the linear desired velocity as control command, the following linear programming optimization problem should be solved in each time-step:

$$\begin{gathered} \max \dot{x} - \delta \\ \text{subject to:} \\ \dot{h}_i(\boldsymbol{x}, t) \geq -\alpha_i\left(h_i(\boldsymbol{x}, t)\right) \text{ for all } i \in \{1,2, \dots, N\} \\ \dot{V}(\boldsymbol{x}, \boldsymbol{u}) < \gamma(V) + \delta \\ \boldsymbol{u}_{\boldsymbol{lb}} < \boldsymbol{u} < \boldsymbol{u}_{\boldsymbol{ub}} \end{gathered} \tag{9}$$

where $\boldsymbol{u}$ can be defined as vector of linear velocity $\boldsymbol{u} = [\dot{x}, \dot{y}, \dot{z}]^T$, and δ is relaxation parameter.

To maintain the camera view in the velocity vector direction, the heading of drone should be controlled based on the yaw feedback. To this end, a PID controller generates the desired yaw rate in each time-step.

Low-Level Controller

In the Low-Level Controller block, the LINVEL control algorithm has been used. This control method receives linear velocity and yaw rate as input from the High-Level Control block and produces the propulsion commands as outputs [2].

REFERENCE

[1] Prajna, Stephen, and Ali Jadbabaie. "Safety verification of hybrid systems using barrier certificates." *International Workshop on Hybrid Systems: Computation and Control*. Springer, Berlin, Heidelberg, 2004.

[2] Valavanis, Kimon P., ed. "Advances in unmanned aerial vehicles: state of the art and the road to autonomy." (2008).