Group Meeting Report

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2019.10.09

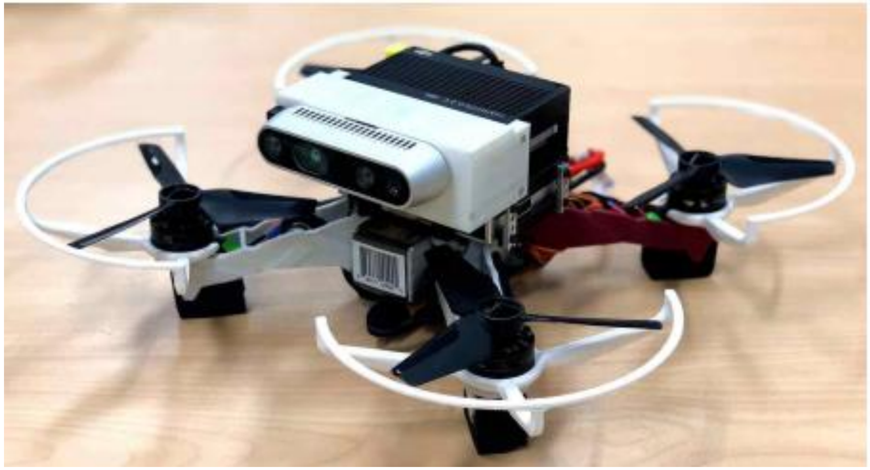
上海交通大學
SHANGHAI JIAO TONG UNIVERSITY

Quadrotor Omnidirectional Obstacle Avoidance with a Swiveling RGB-D Camera

Background

Unidirectional Obstacle Avoidance

2015 MIT

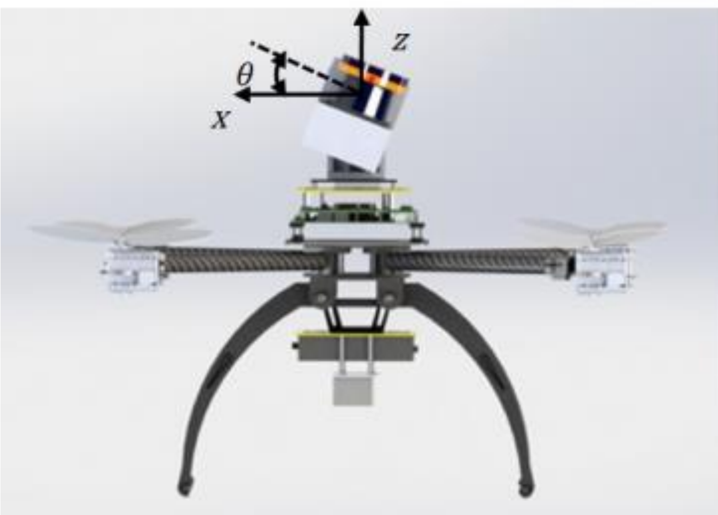


2019 港科大

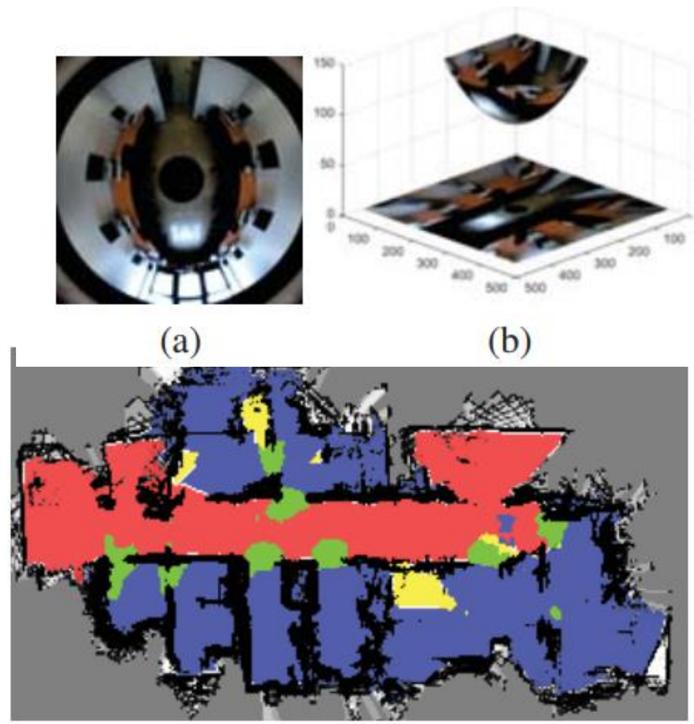
Background

Omnidirectional Obstacle Avoidance

Pre-condition: Omnidirectional Perception



2016 National University of Singapore



2018 Universidad EAFIT Colombia

Background

Omnidirectional Obstacle Avoidance

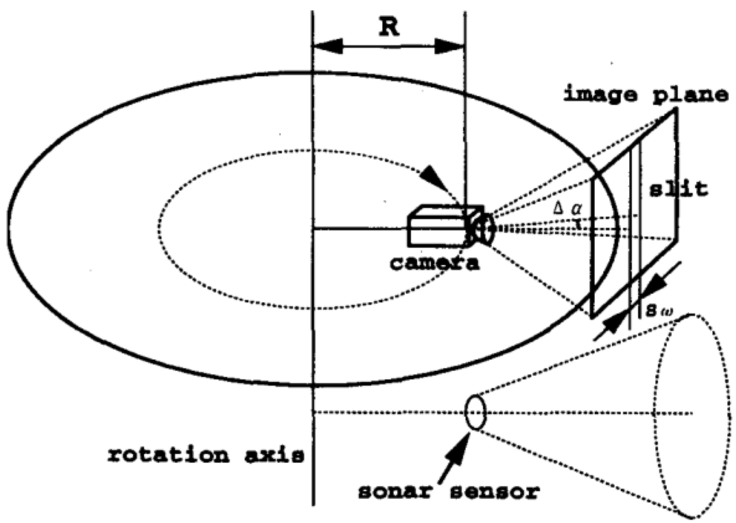
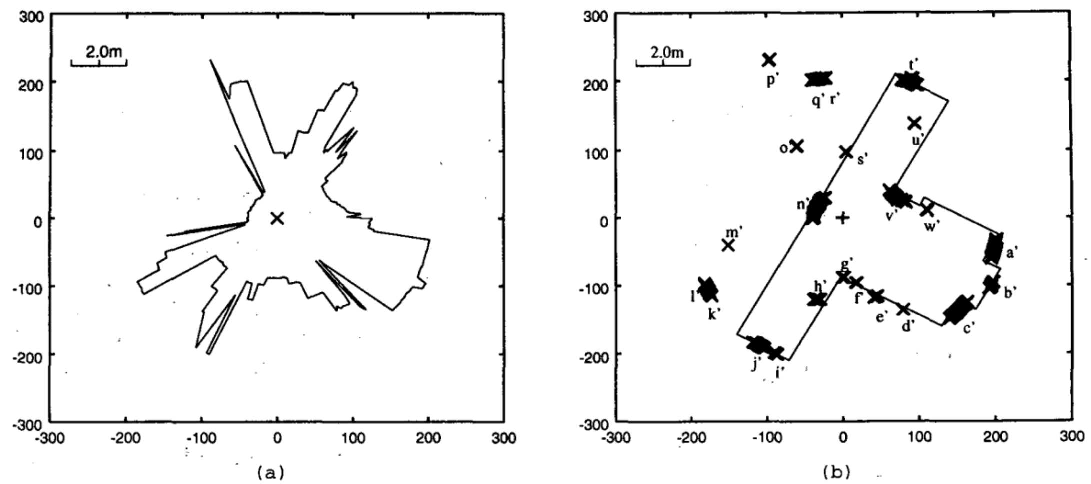


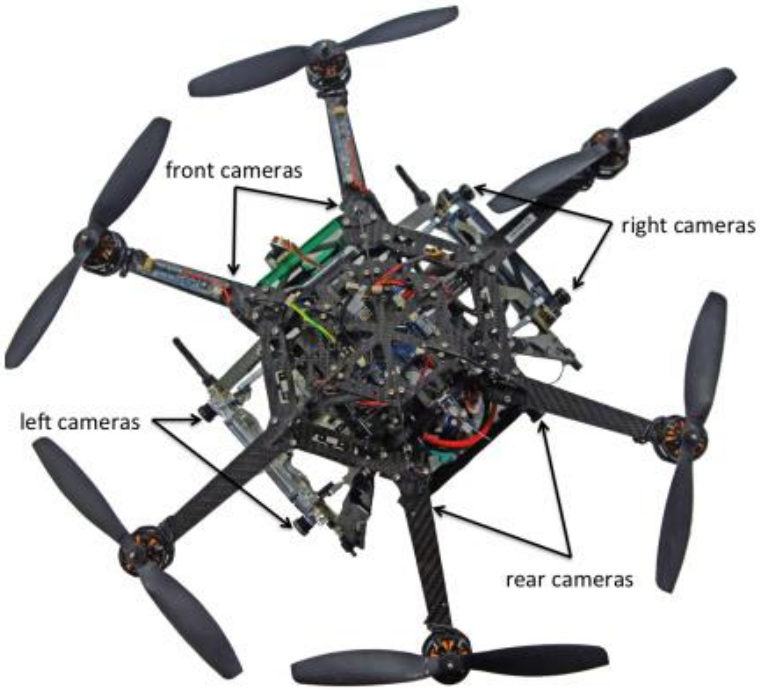
Figure 1: A camera and a sonar are mounted on a robot and rotate together.



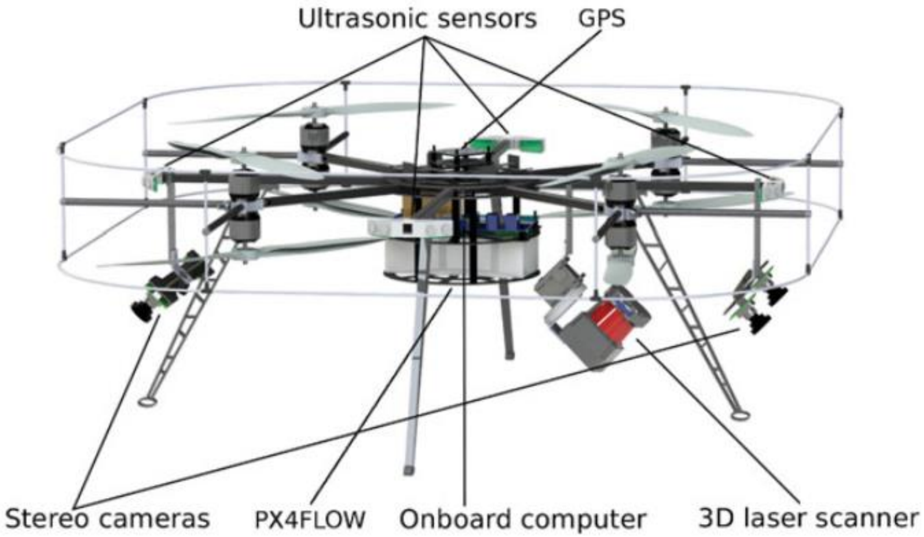
1999 Hiroshima City University

Background

Omnidirectional Obstacle Avoidance



2015 ETHZ



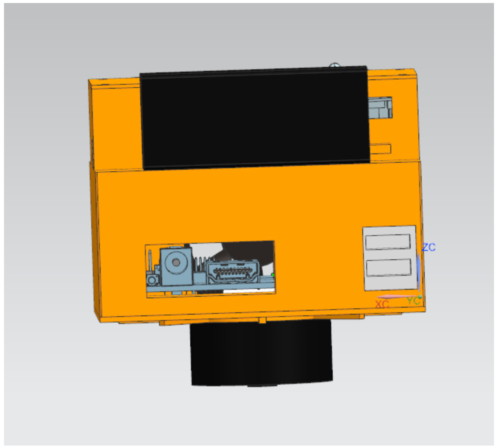
2015 University of Bonn

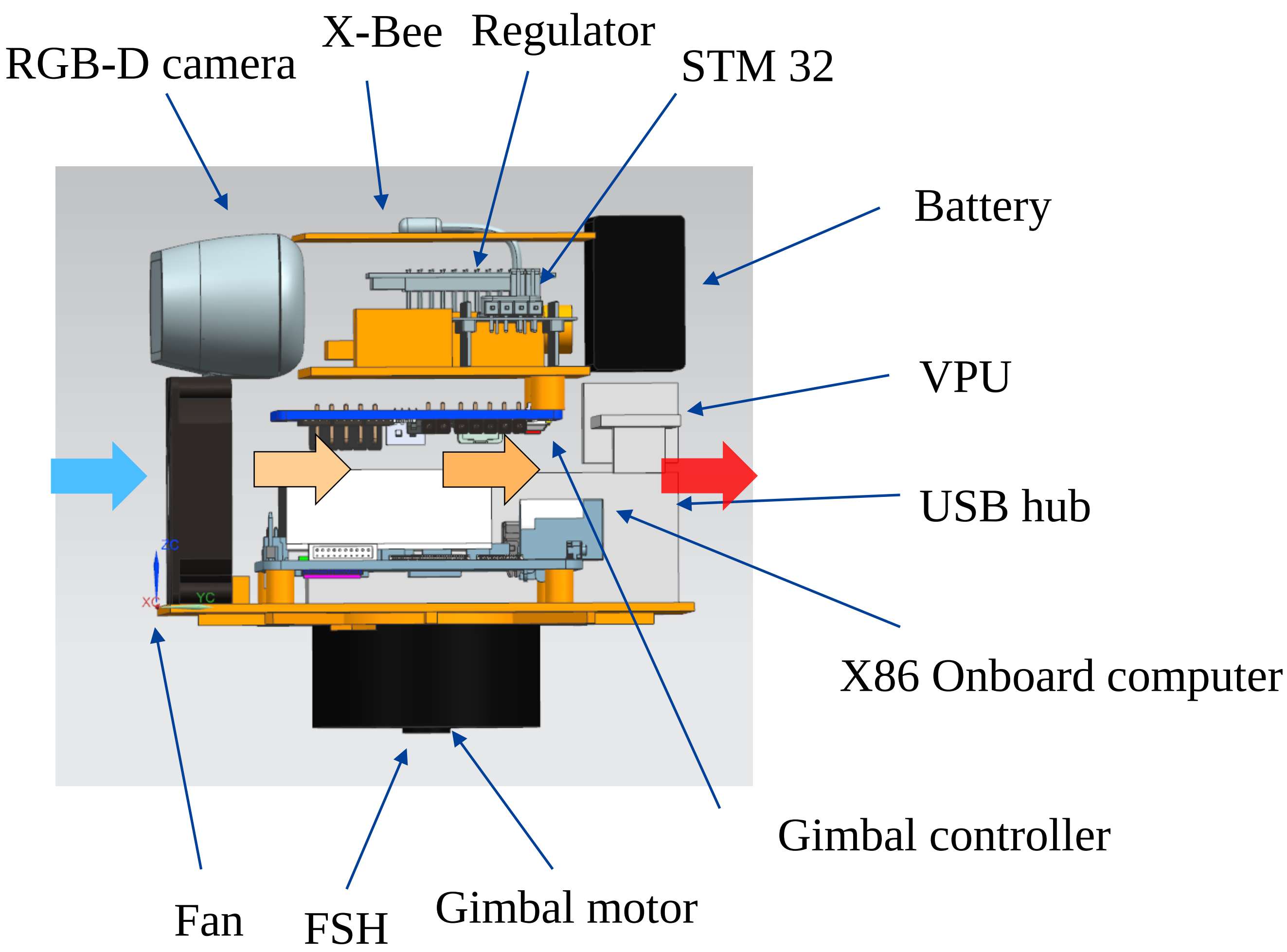
Background

Animals

Mechanical Design

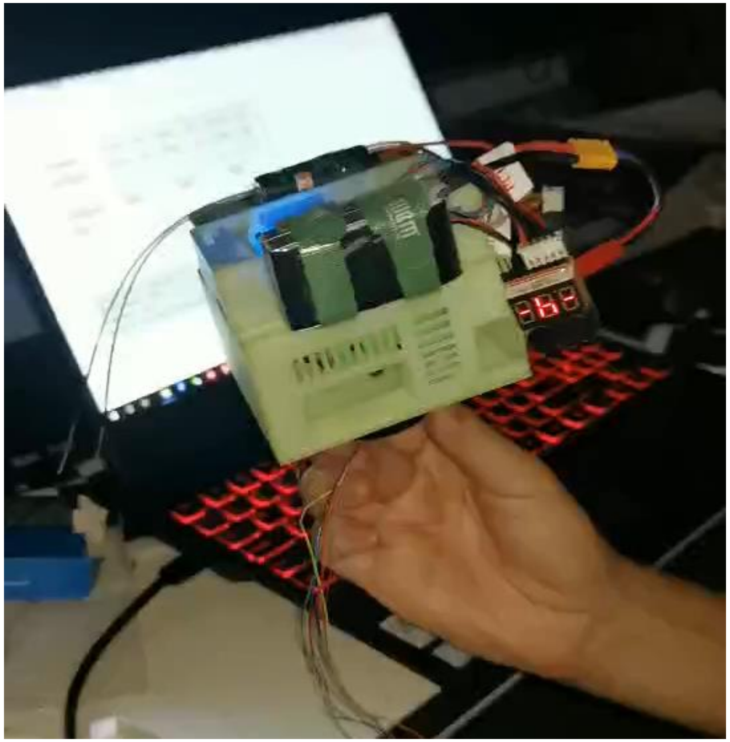
Swiveling Head





Mechanical Design

Swiveling Head



Advantages:

- Free and continuous rotation
- Multi-platform Adaptability

Disadvantages:

- Heavy
- Slow

Mechanical Design

Swiveling Eyes

RGB-D camera

Servo motor with encoder

Advantages:

- Light and fast

Disadvantages:

- Limited rotation range

Dynamic Property

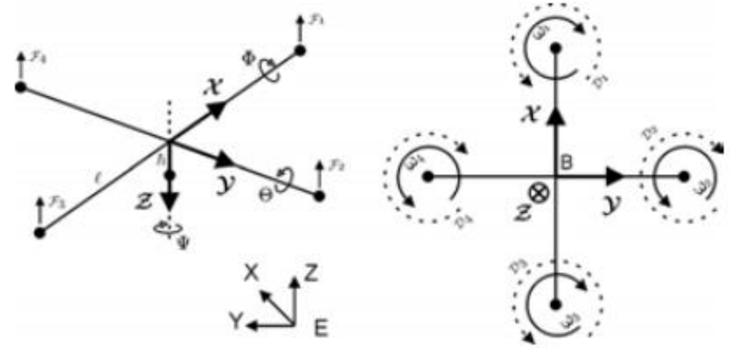
State Vector of attitude is

$$X = \begin{bmatrix} \phi & \dot{\phi} & \theta & \dot{\theta} & \psi & \dot{\psi} \end{bmatrix}^T \tag{1}$$

Denote

$$\begin{cases} U_1 = b(\Omega_1^2 + \Omega_2^2 + \Omega_3^2 + \Omega_4^2) \\ U_2 = b(-\Omega_2^2 + \Omega_4^2) \\ U_3 = b(\Omega_1^2 - \Omega_3^2) \\ U_4 = d(-\Omega_1^2 + \Omega_2^2 - \Omega_3^2 + \Omega_4^2) \end{cases} \tag{2}$$

$$\begin{cases} a_1 = (I_{yy} - I_{zz})/I_{xx} \\ a_2 = J_r/I_{xx} \\ a_3 = (I_{zz} - I_{xx})/I_{yy} \\ a_4 = J_r/I_{yy} \\ a_5 = (I_{xx} - I_{yy})/I_{zz} \\ b_1 = l/I_{xx} \\ b_2 = l/I_{yy} \\ b_3 = 1/I_{zz} \end{cases} \tag{3}$$



$$\dot{X} = \begin{pmatrix} \dot{\phi} \\ \dot{\theta}\dot{\psi}a_1 + \dot{\theta}a_2\Omega_r + b_1U_2 \\ \dot{\theta} \\ \dot{\phi}\dot{\psi}a_3 - \dot{\phi}a_4\Omega_r + b_2U_3 \\ \dot{\psi} \\ \dot{\theta}\dot{\phi}a_5 + b_3U_4 \end{pmatrix} \tag{4}$$

$$M = \ddot{\xi} I_{head} = \ddot{\psi} I_{zz} = U_4 + \dot{\theta}\dot{\phi}(I_{xx} - I_{yy}) \approx U_4 \tag{5}$$

Camera Rotation Planning

Multi-objective Problem

- Current target moving direction of the quadrotor should be in the view field of the camera. *(ft)*
- Current velocity direction of the quadrotor should be in the view field of the camera. *(fv)*
- keep the rotation of the camera smoothly. *(fs)*

$$min \quad F(x) = [f_t(x), f_v(x), f_s(x)]^T \tag{6}$$

Camera Rotation Planning

Multi-objective Problem

$$f_t(x) = G(x-\kappa) \cdot H(\kappa) \tag{7}$$

$$G(x) = \begin{cases} 0, & if \ |x| \leq \frac{\theta_h}{2} \\ x^2, & otherwise \end{cases} \tag{8}$$

$$f_v(x) = G(x-\xi) \cdot H(\xi) \tag{9}$$

$$f_s(x) = (x - x_l)^2 \tag{10}$$

$$\boxed{F(x) = \lambda_1 f_t(x) + \lambda_2 f_v(x) + \lambda_3 f_s(x) \quad (11)}$$

θ_h	Horizontal view angle of the camera
κ	Current target moving direction of the quadrotor
ξ	Current velocity direction of the quadrotor
$H(x)$	Update extent function given by the mapping part
x_l	The last planned rotation angle of the camera
λ_{i}	Weighting coefficients

Camera Rotation Planning

Problem Solving

To find the optimized solution $\hat{x}$, the direction angle is discretized with a **resolution of δ** and $\hat{x}$ is searched through enumeration.

- Case 1: If the camera can rotate freely, the searching domain is

$$\{x_0 - \pi, x_0 - \pi + \delta, x_0 - \pi + 2\delta, \ldots, x_0 + \pi - \delta\}$$

- Case 2： If the camera has a limited rotation range satisfies $x_{min} < -\pi - \delta$ and $x_{max} > \pi + \delta$, the searching domain is

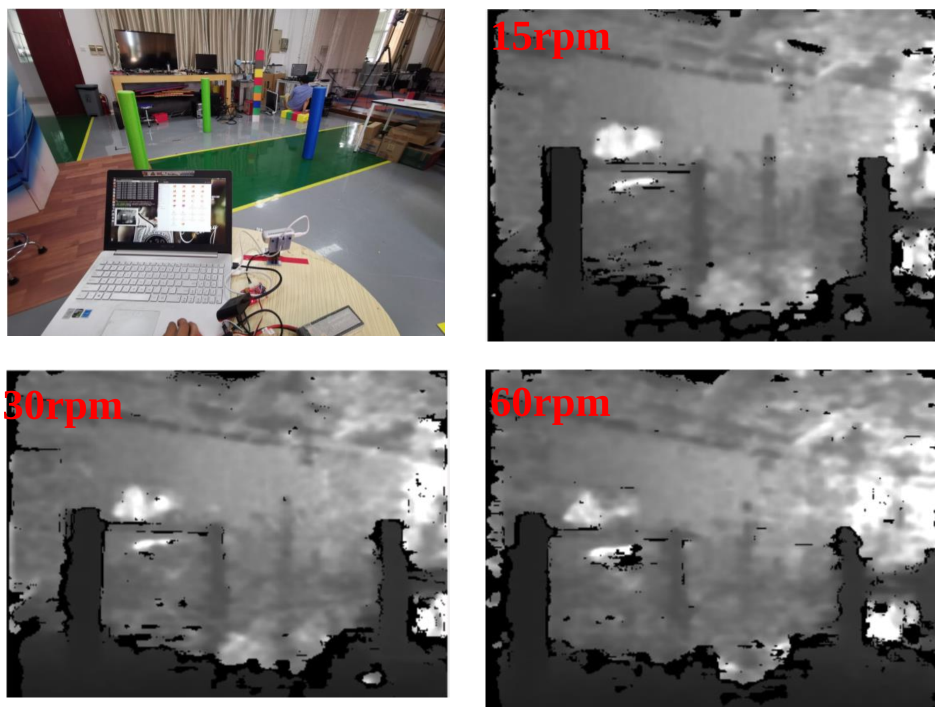
$$\{-\pi - \delta, -\pi, -\pi + \delta, \ldots, \pi + \delta\}$$

(Margin δ is required to avoid unnecessary large rotation)

Camera Rotation Planning

Setpoint Generation

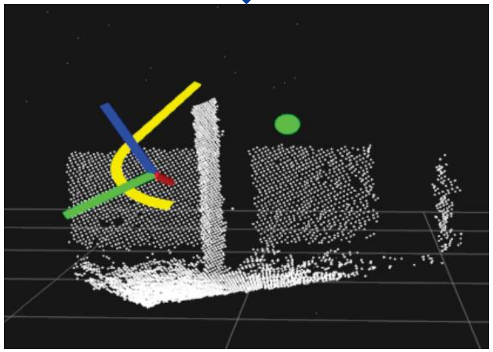
Constant angular acceleration planning with angular velocity limitation, where $\ddot{x}$ is given by the dynamic characteristics of the quadrotor and angular velocity limitation $\dot{x}_{max}$ is given by the motion blur of the depth image.



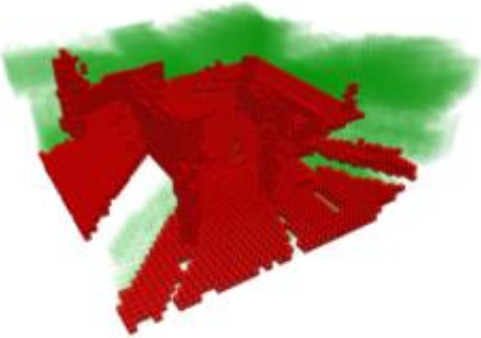
Local Mapping

Local occupancy map

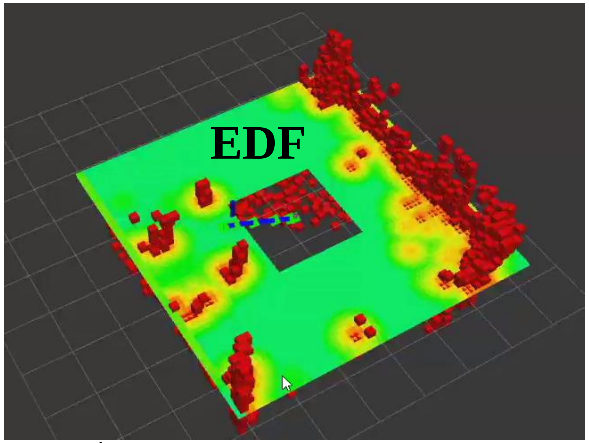
Transformed Pointcloud



Map building

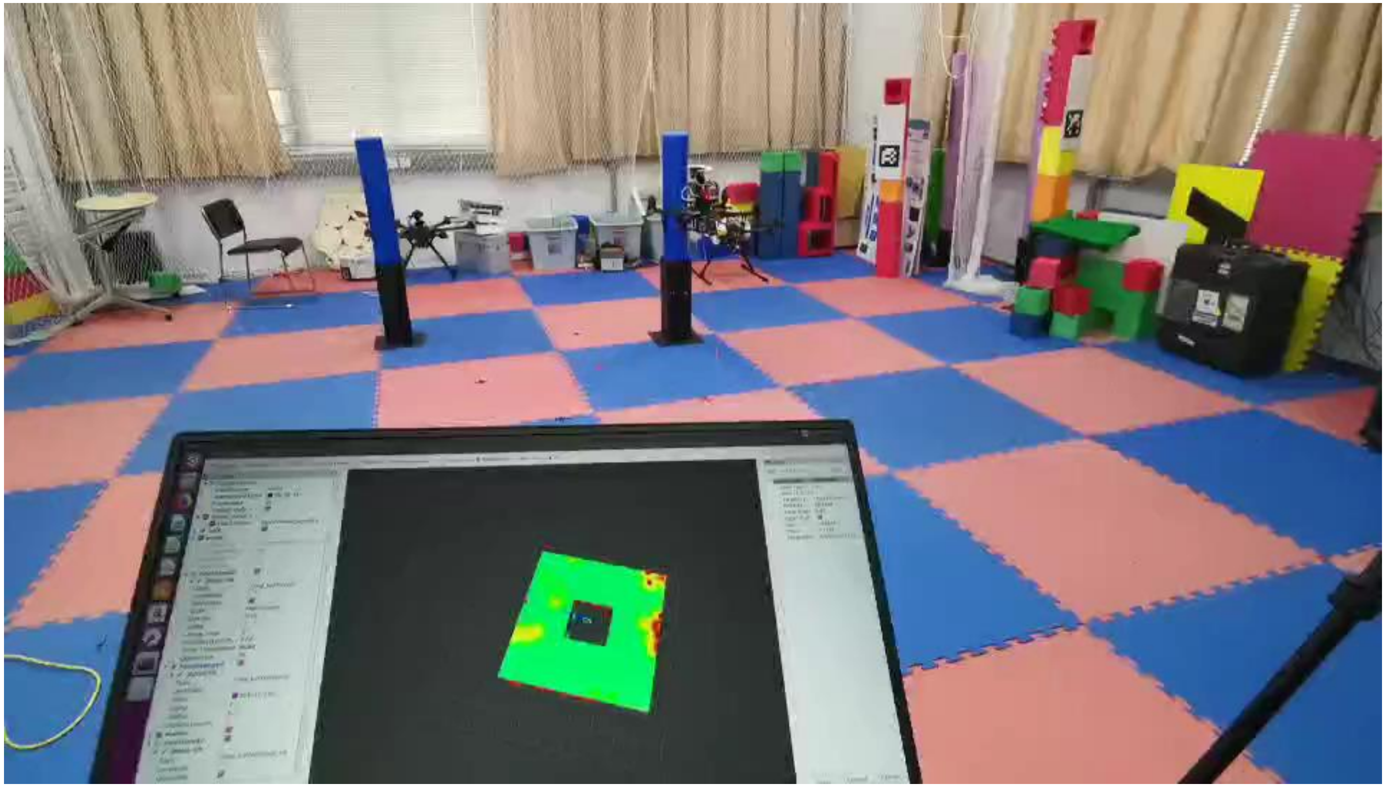


Dynamic sensing ability enhancing



Local Mapping

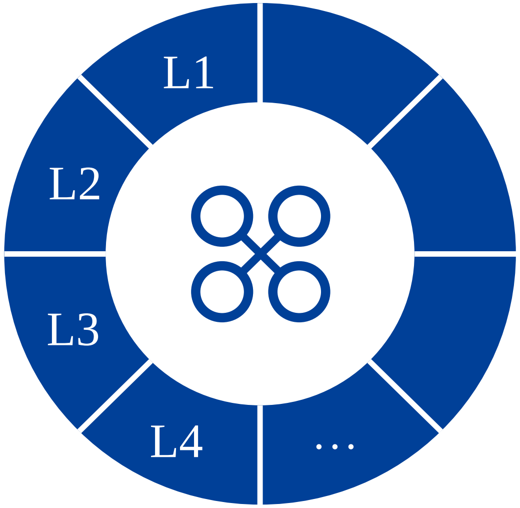
Local occupancy map



Local Mapping

Update extent map

One-dimension buffer representing the fully updated probability of each direction with a resolution of δ



Denote the probability of one direction x to be fully updated at a discrete time t in log-odds notation $L(x|y_{1:t}) \in [0,1]$, given the measurement $y_{1:t}$. The update formula regarding current measurement yt can be expressed as:

$$L(x|y_{1:t}) = max(min(L(x|y_{1:t-1}) + L(x|y_t), l_{max}), l_{min})$$

where L(x|yt) is calculated by:

$$L(x|y_t) = -\frac{2\varepsilon_1}{d} v_{hrzt,x}\ \Delta t - \frac{2\varepsilon_2}{d} v_{vtc,x}\ \Delta t + l(x)$$

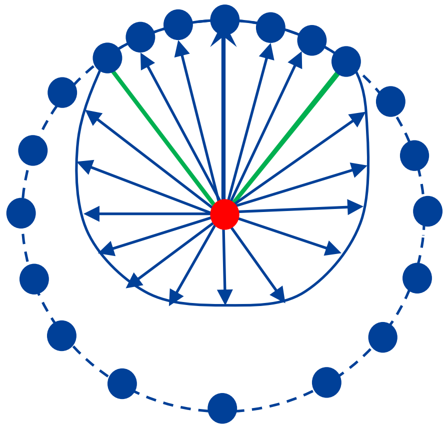
$$l(x) = \begin{cases} l_{hit}, & if\ |x - x_0| \le \frac{\theta_h}{2} \\ l_{miss}, & otherwise \end{cases}$$

* $H(x)$ is simply to query the update extent map.

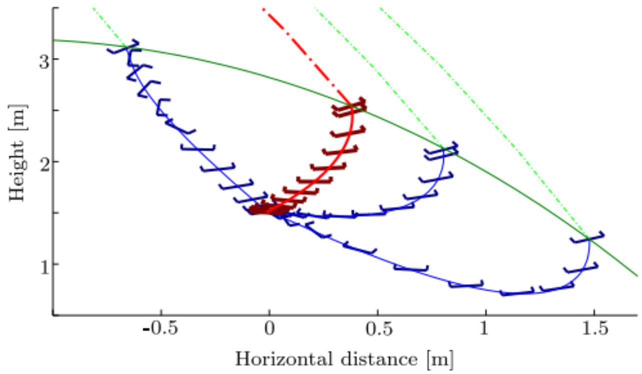
Quadrotor Path Planning

Motion Primitives → Trajectory Generation → Collision Checking

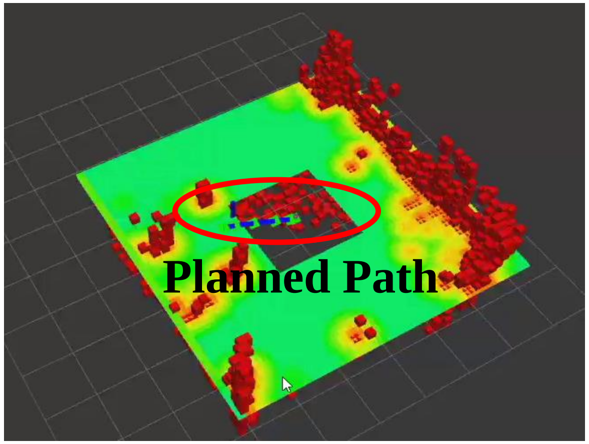
State Based Sample



Optimal Jerk Trajectory



Query in EDF



Test Video

Future Works

- Use a proper criteria to evaluation the motion blur in depth image.
- Test with RTK GPS in outdoor environment for high- speed obstacle avoidance

谢谢！