Gliding Pitch Control Model of Bionic Flying Squirrel Robot

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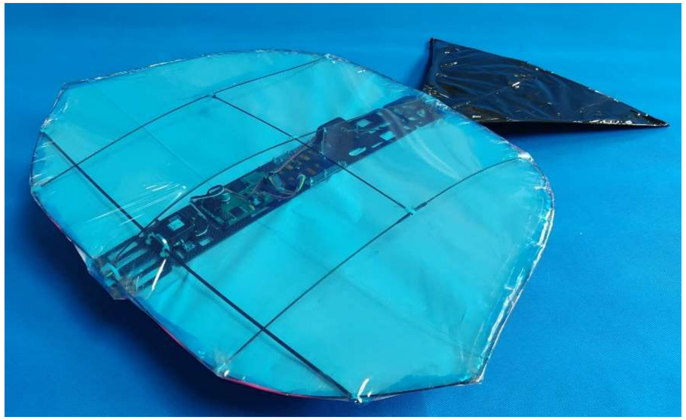
Flying squirrel


Bionic flying squirrel robot

Outline

1. Introduction
2. Mathematical and control model
3. Simulation and experiments
4. Conclusions and prospects

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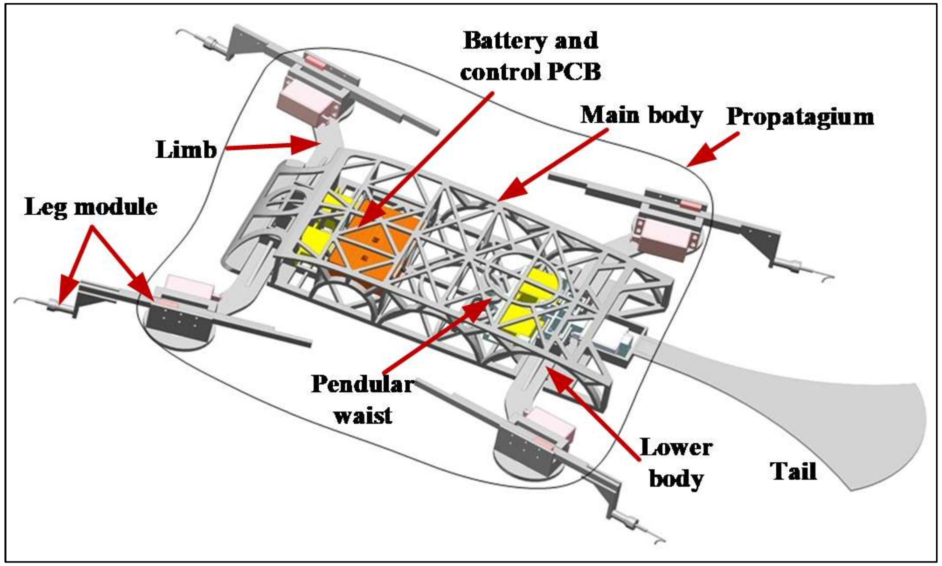
Flying Squirrel

- Has abilities of climbing and gliding
- Mobile space:2D-3D
- Transfer rapidly in 3D space
- Low noise and energy consumption

Bionic flying squirrel robot (BSR)

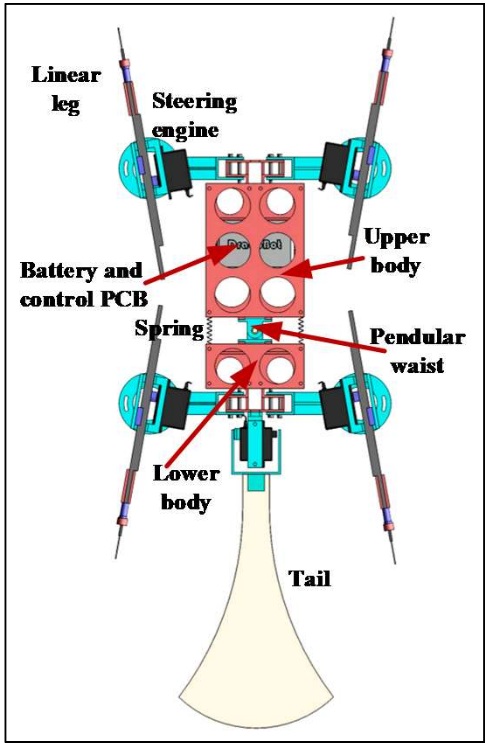
- BSR has nine degrees of freedom
- Four prismatic pairs in axial legs are used to climb
- Five revolute pairs in limbs and tail to glide



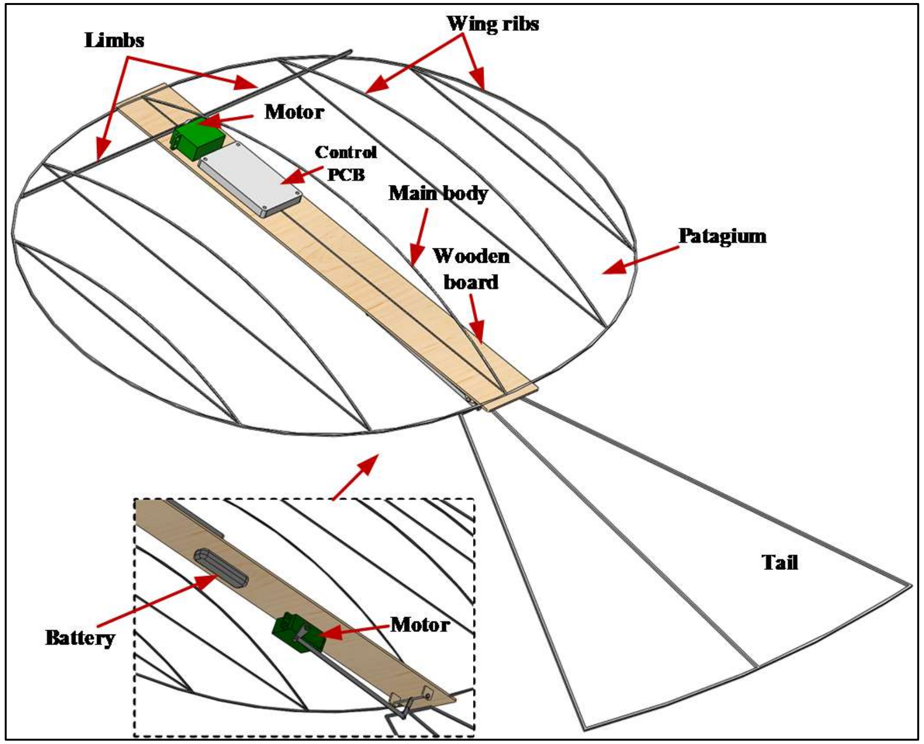
Bionic flying squirrel multi-mode robot

Bionic flying squirrel robot (BSR)

- BSR consists of two parts



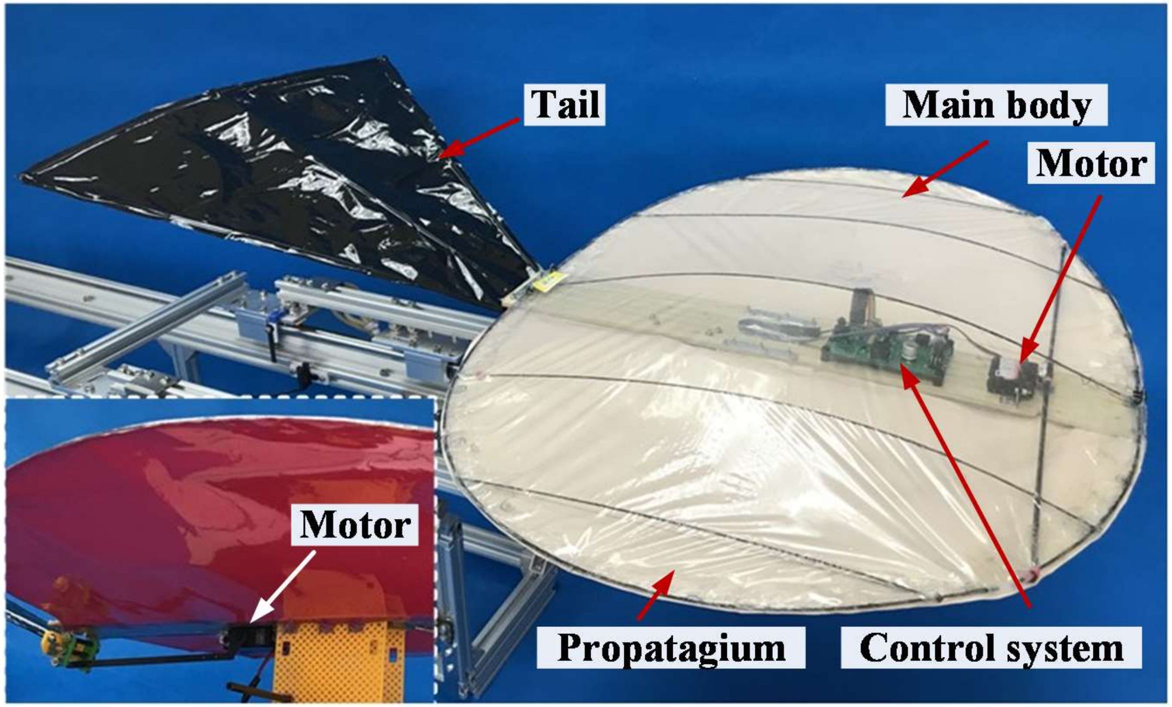
Wall-climbing part of BSR



Gliding part of BSR

Bionic flying squirrel robot (BSR)

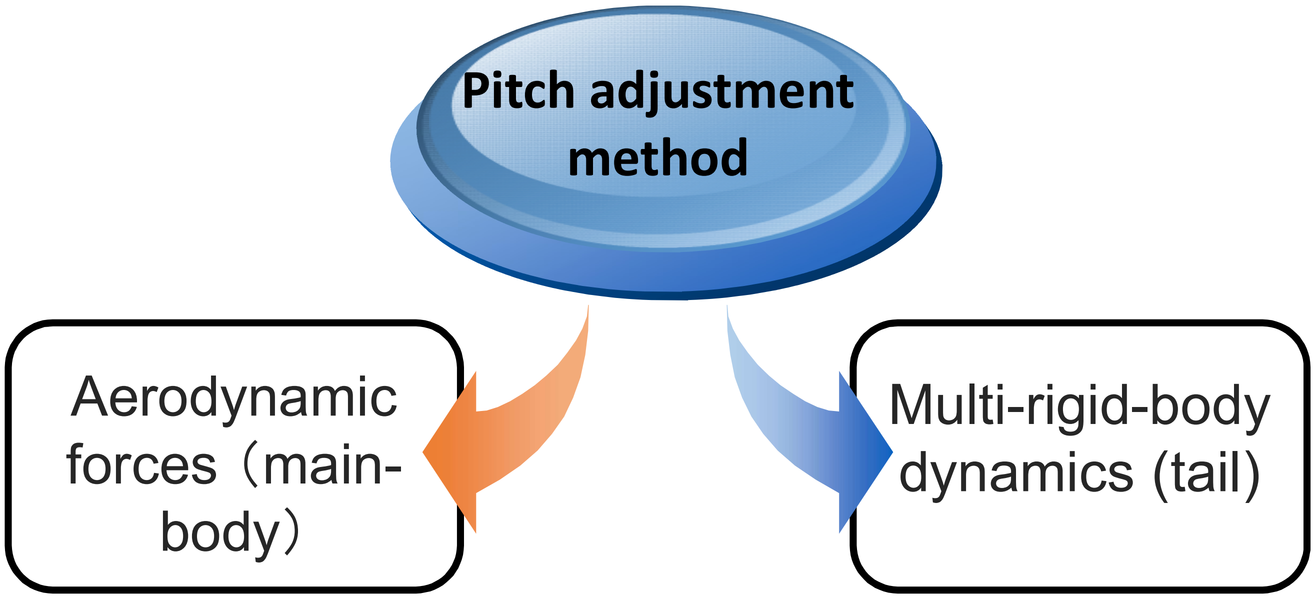
- Simplified gliding physical prototype of pitching motion adjustment.



- Tail's movement adjusts BSR's pitching motion.

Summary - Introduction to BSR

- BSR has abilities of climbing and gliding
- Key points: BSR's stability of the pitching motion



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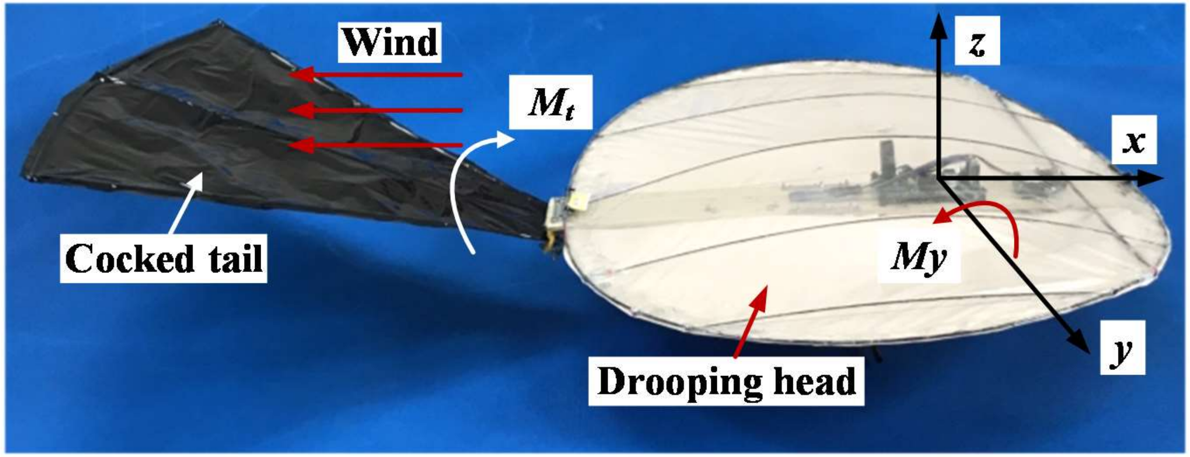
Basic theory of pitching motion

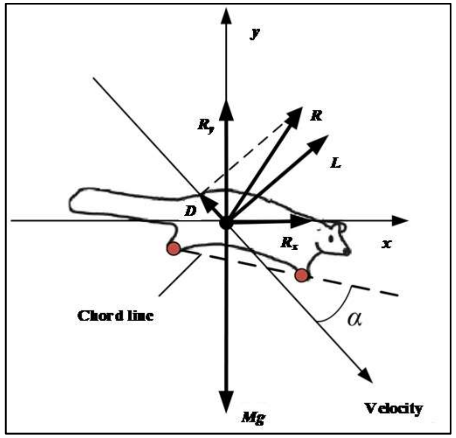
- Aerodynamic force produced by wind
- Additional moment of tail's rotation



Tail swings for pitch posture adjustment

- Aerodynamic forces and multi-rigid-body dynamics works together to adjust pitching motion

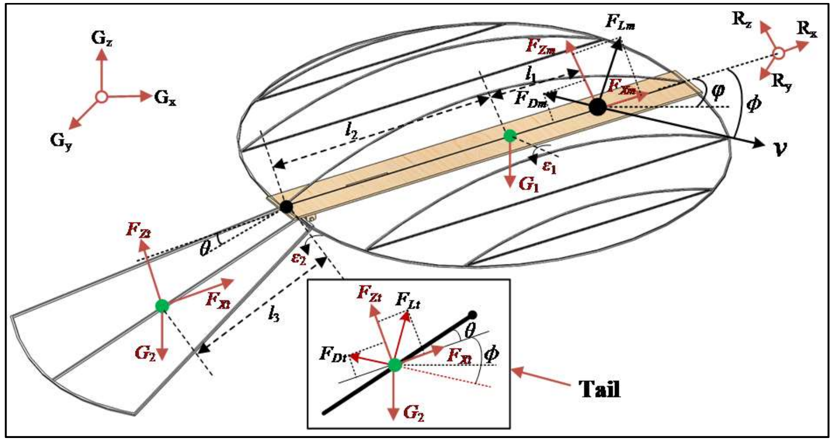
Mathematical model



Aerodynamic model

$$L = \frac{\rho C_L S v^2}{2}$$

$$D = \frac{\rho C_D S v^2}{2}$$



Simplified gliding mechanical model

$$\begin{cases} F_{Ab} = \begin{bmatrix} F_{Lm} & F_{Dm} \end{bmatrix}^T = \dfrac{\rho S_1 v^2}{2} \begin{bmatrix} C_{L1} & C_{D1} \end{bmatrix}^T \\ F_{At} = \begin{bmatrix} F_{Lt} & F_{Dt} \end{bmatrix}^T = \dfrac{\rho S_2 v^2}{2} \begin{bmatrix} C_{L2} & C_{D2} \end{bmatrix}^T \end{cases}$$

$$M_1 + J_t \varepsilon_2 = 0$$

The pitching moment at the center of the robot's mass could be got:

$$M = M_1 + F_{Zm} l_1 - F_{Zt}(l_3 \cos\theta + l_2) + F_{Xt} l_3 \sin\theta$$

Control model

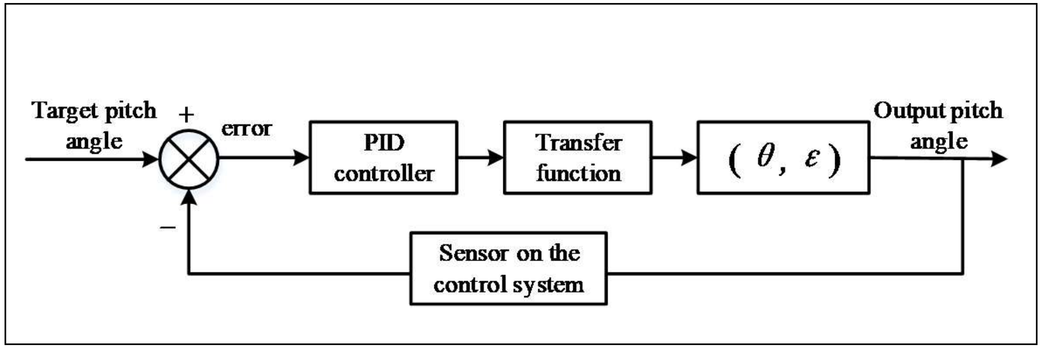
- When the pitching motion is in a stable state, M and the pitching torque generated by the aerodynamic torque should be 0

$$\boxed{F_{Zm} l_1 - F_{Zt}(l_3 \cos\theta + l_2) + F_{Xt} l_3 \sin\theta = 0} \longrightarrow \boxed{\theta = \arcsin\left(\frac{F_{Zt} l_2 - F_{Zm} l_1}{l_3 \| L_t \|_2}\right) + \gamma}$$

- When the pitch torque of main body and the pitch angular acceleration ε_1 is generated, Tail would swing to avoid instability.
- Tail's angular acceleration ε_2 :
- θ is the tail's target position, ε_2 is the process to get target θ .

$$\boxed{|\varepsilon_2| \geq \frac{J_m |\varepsilon_1|}{J_t}}$$

Control model



Gliding pitch control strategy of BSR

$$\theta = \arcsin\left(\frac{F_{Zt} l_2 - F_{Zm} l_1}{l_3 \| L_t \|_2}\right) + \gamma$$

$$|\varepsilon_2| \geq \frac{J_m |\varepsilon_1|}{J_t}$$

Tail's angle and angular acceleration

$$\frac{\varphi(s)}{\theta(s)} = \frac{Ks^2 + 1}{T^2 s^2 + 2\xi Ts}$$

Simplified open-loop transfer function of the system.

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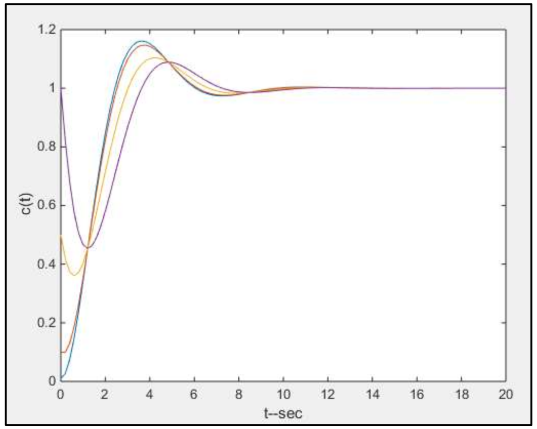
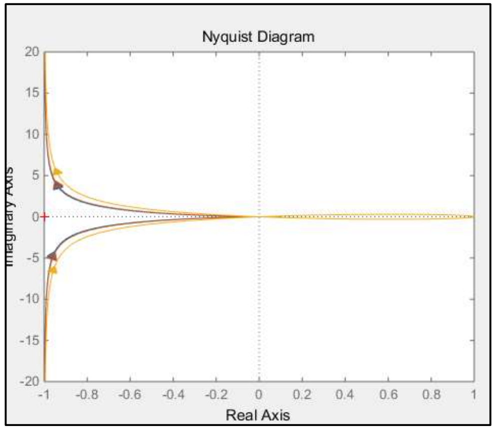
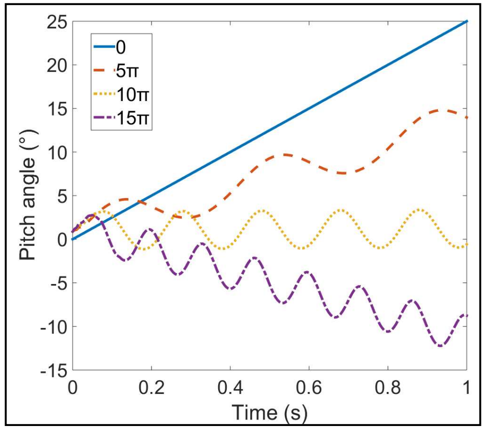
Simulation



Unit step function response



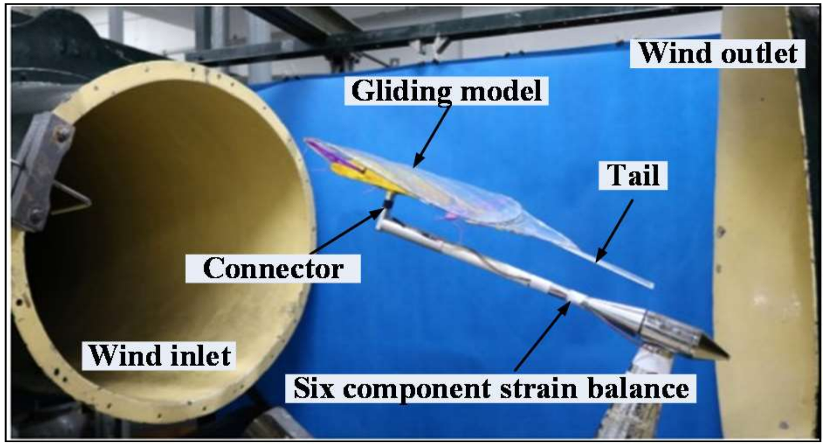
Nyquist diagram



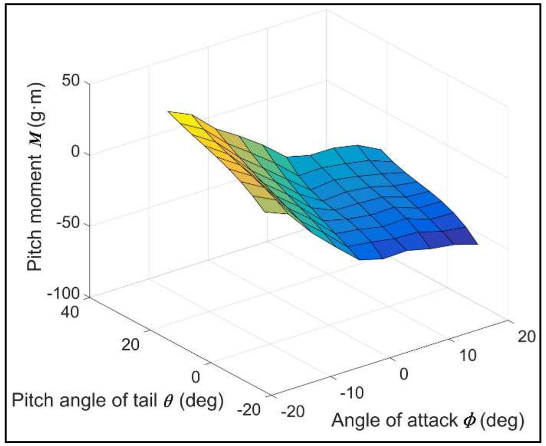
Main body's pitch angle with different angular frequency of tail

- The control system is stable.
- The additional torque generated by the tail's angular acceleration can adjust the pitch motion of the main body well.

Experiments



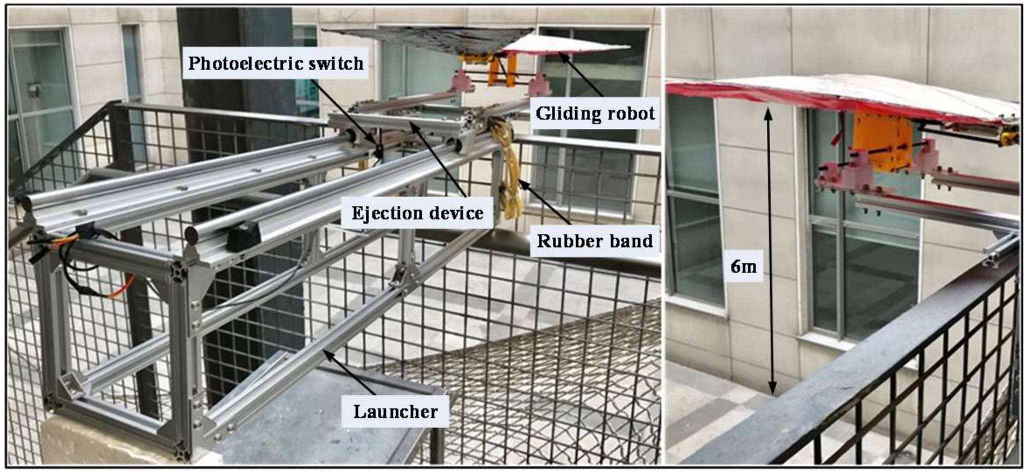
Wind tunnel experimental paltform



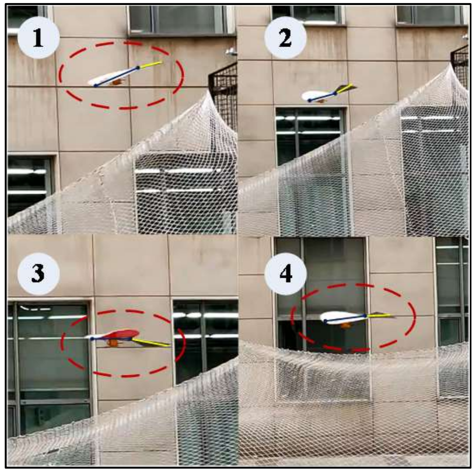
The pitch moments variation space of (φ, θ)

- The pitching moment exhibits a linear trend with θ and its variation changes obviously.
- Different pitch angle (θ) of tail leads to different aerodynamic moment of the robot at the same wind speed.

Experiments



The gliding experience platform

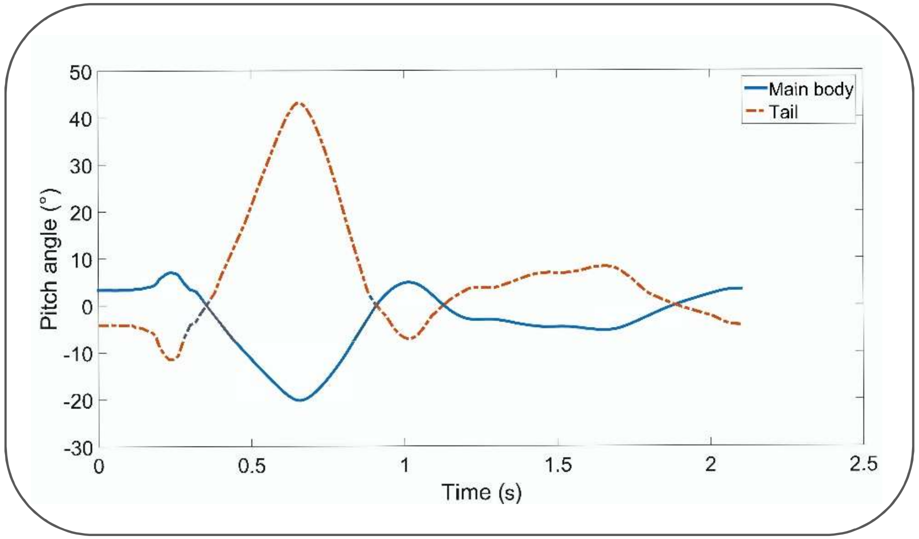


The tail swings up and down for pitch posture adjustment

- The platform consists of the launcher and ejection device.
- The tail swings up and down for pitch posture adjustment in the gliding process.

Experiments

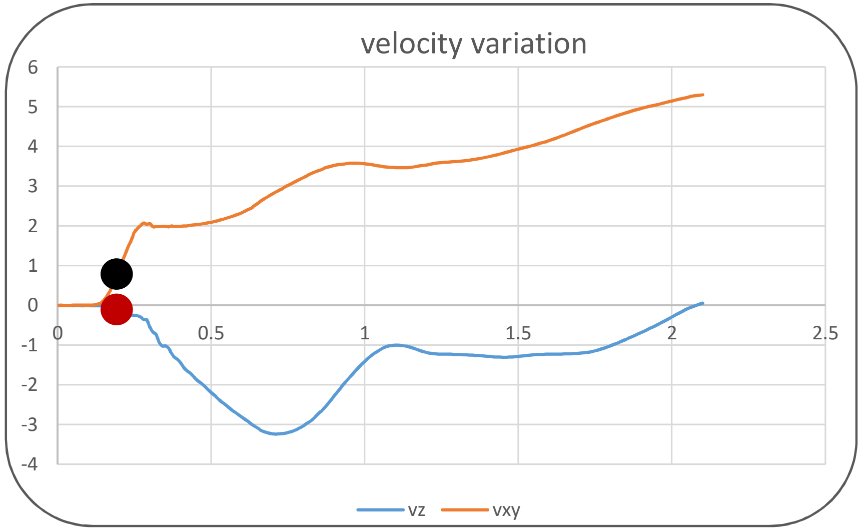
Field experiment



Tail and main body's pitch angle variation

The pitch angle variation of main body with tail's adjustment!

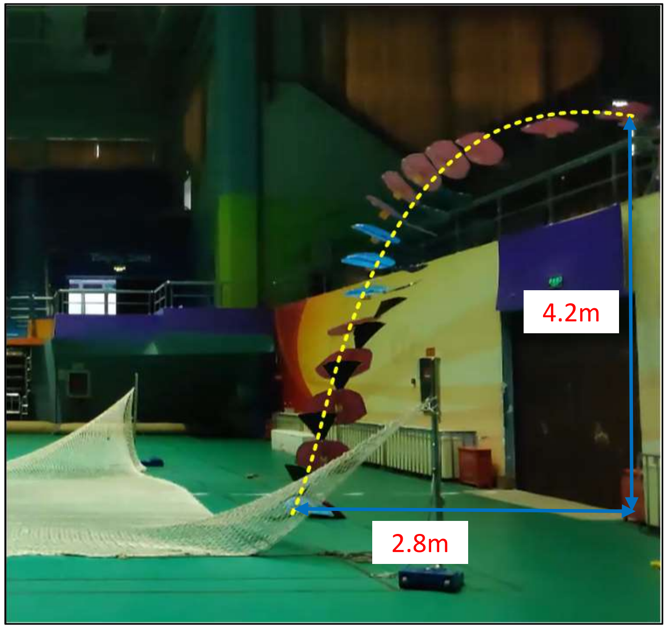
Experiments



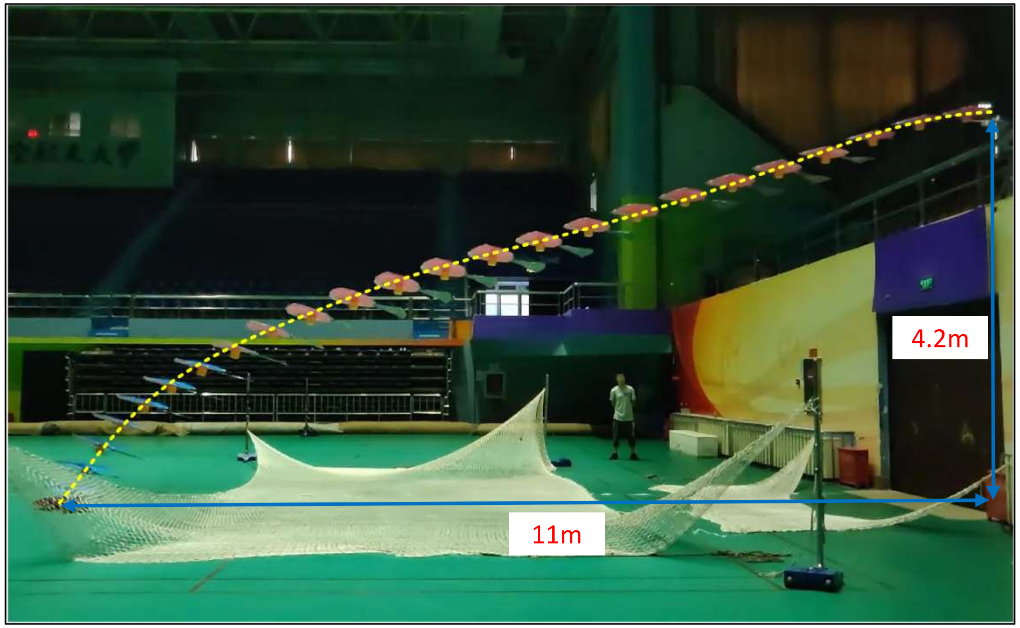
The velocity variation of main body with tail's motion !

Experiments

- Comparison of experimental results



Experiment without tail's adjustment



Experiment with tail's adjustment

- The robot glides more steadily and farther with tail's adjustment!

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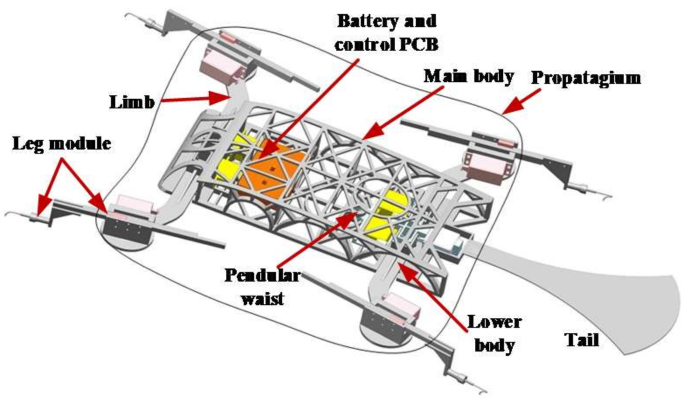
Conclusions and prospects

- The aerodynamic and additional torque generated by tail's pitch angle and angular acceleration can adjust the pitching stability of the robot during the stable glide stage with a control strategy.
- Yaw control model will be explored in the future.
- The combination and switching mode of climbing and gliding motion is a research direction.



Thank you very much!

Thanks for Listening