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The Seventh
INTERNATIONAL CONFERENCE ON
TETHERS in SPACE

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Detumbling Control of An Underactuated Tethered Satellite System

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Contents.

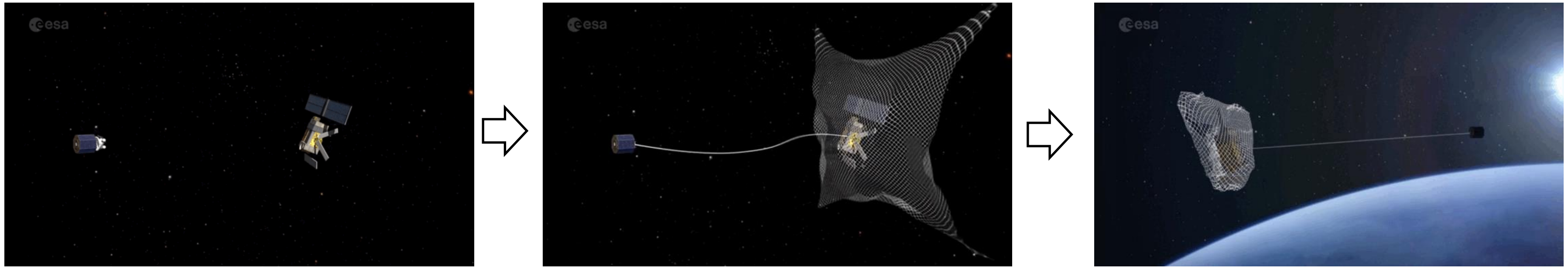
Background

- Active Debris Removal (ADR) Mission

Deployment phase → Capture phase → Post-capture phase

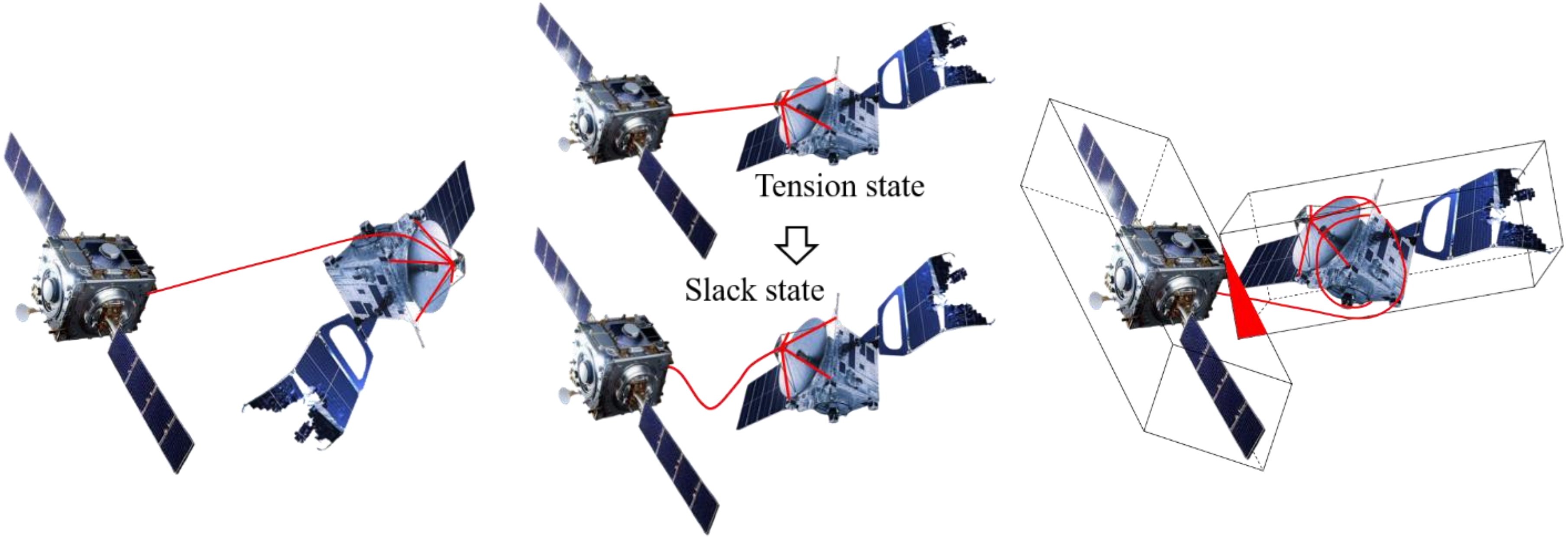
- Net Capture Method

ESA e-deorbit mission



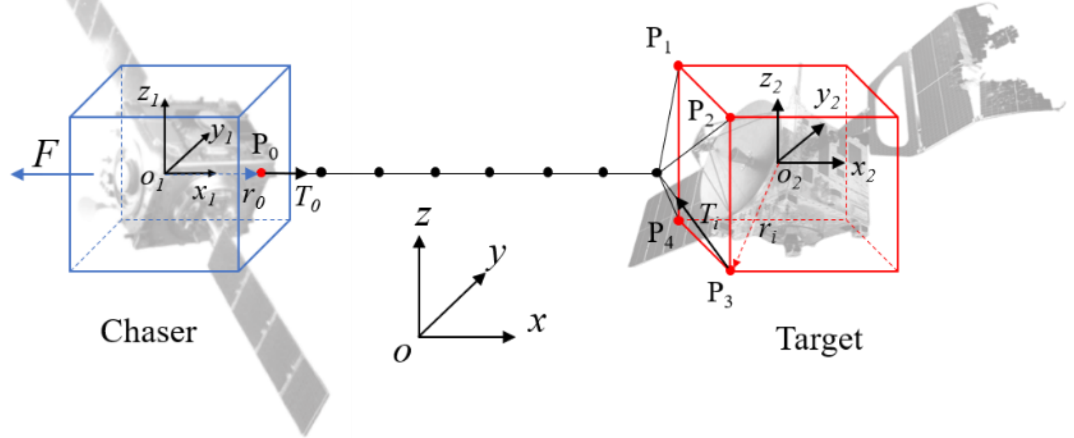
- Potential Risks

- Tether entanglement
- Tether libration(switch between slack and tension)
- Satellite collision



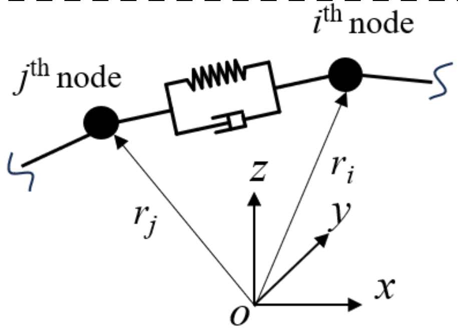
Dynamic modeling

- Rigid-flexible coupling dynamic model



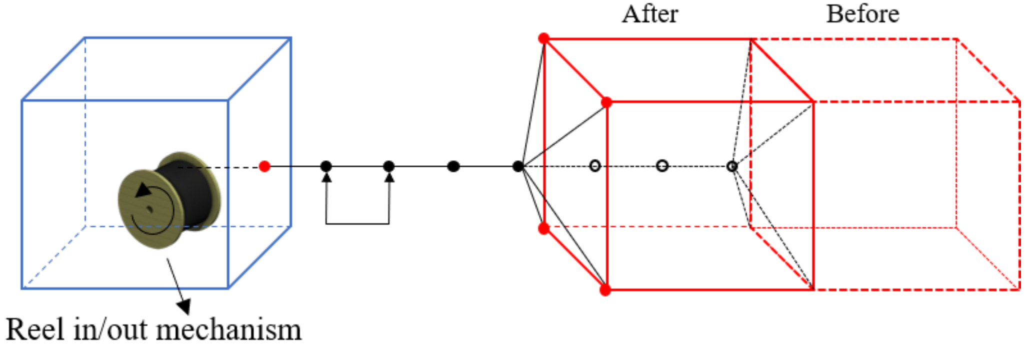
$$F + T_0 = m_S a_S \qquad \sum_{i=1}^{4} T_i = m_T a_T$$

$$J_S \dot{\omega}_S + \omega_S \times J_S \omega_S = r_0 \times T_0 + M_C \qquad J_T \dot{\omega}_T + \omega_T \times J_T \omega_T = \sum_{i=1}^{4} (r_i \times T_i)$$

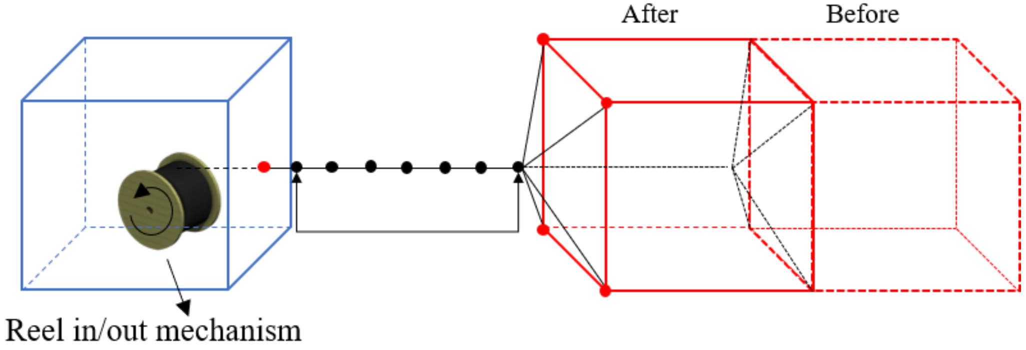


$$T_{ij} = \begin{cases} (-k(l_{ij} - l_0) - c\dot{l}_{ij}) e_{ij} & l_{ij} > l_0 \\ 0 & l_{ij} \le l_0 \end{cases}$$

- Variable length tether dynamic model



- Fixed node distance- for long dimensions and multiple nodes



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- Fixed node number- for small dimensions and less nodes

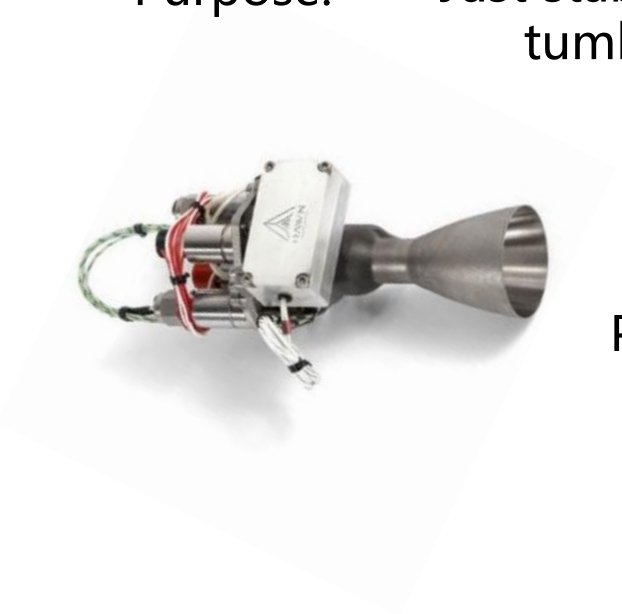
Detumbling Strategy

- Detumbling strategies review

Propulsion Control Strategy

Method
- Based on tether tension
- Based on relative velocity

Purpose: Just stabilization of the tumbling target



- Variable Force

Provided by thrusters

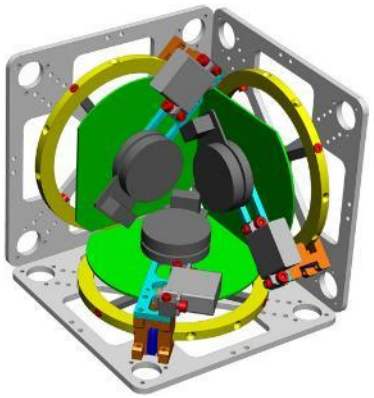
Attitude Control Strategy

Method
- Based on PID control
- Based on hierarchical sliding mode control

Purpose: Stabilization of both the tumbling target and the chaser

- Attitude Torque

Provided by reaction wheels

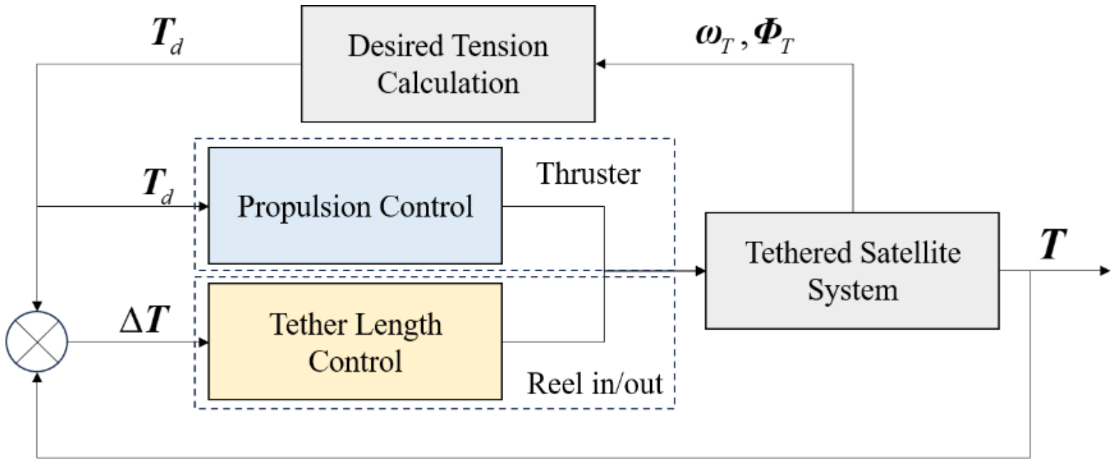


Indirectly regulated tether tension

Detumbling Strategy

- Tension regulation control

[Control Frame]

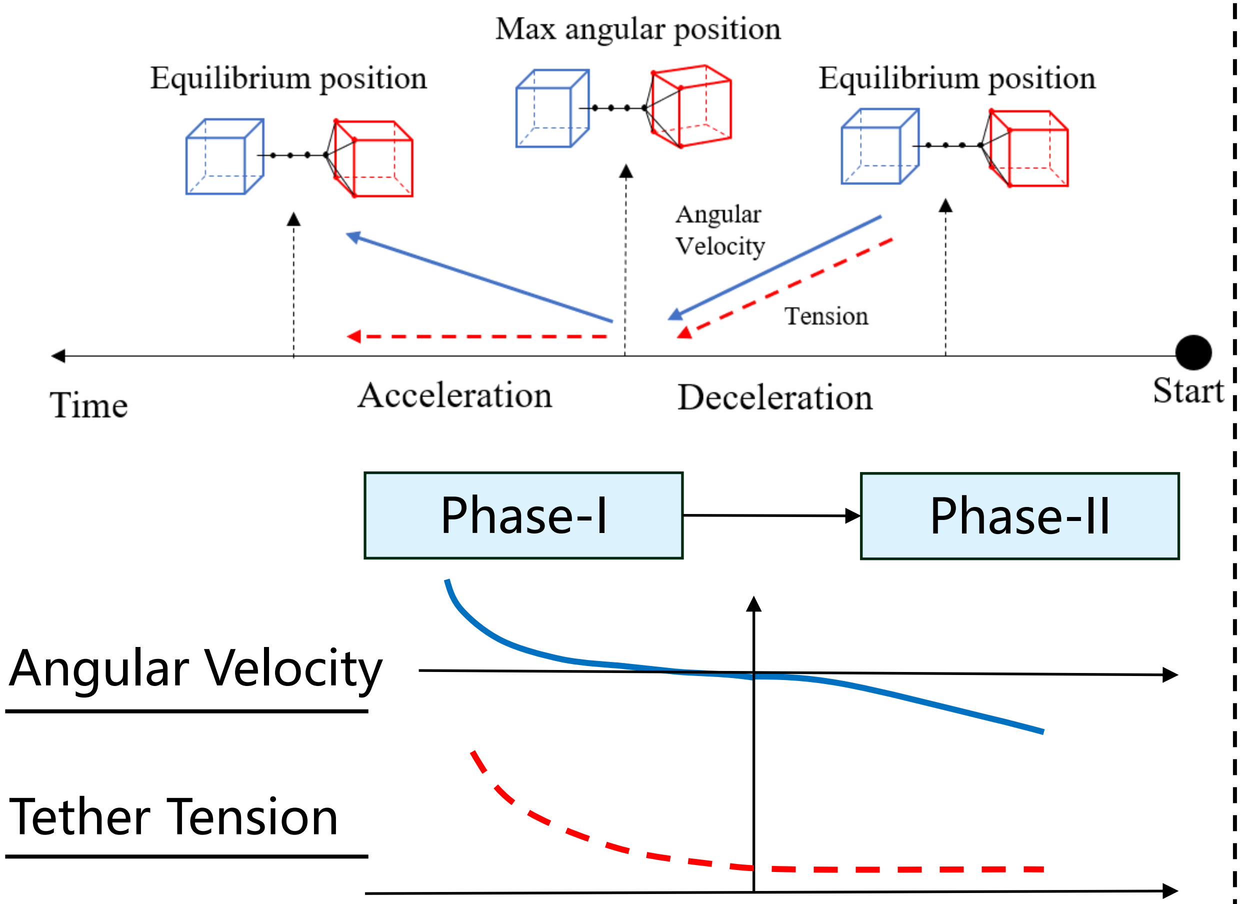


[Coordinated control]

Propulsion: $F_d = (1 + m_S / m_T) T_d$

Length: $u_l = -k_l (m_s + m_T) / m_s m_T (|T_d| - T_t)$

[Regulation Principle]



Detumbling Strategy

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➢ Comparative analysis

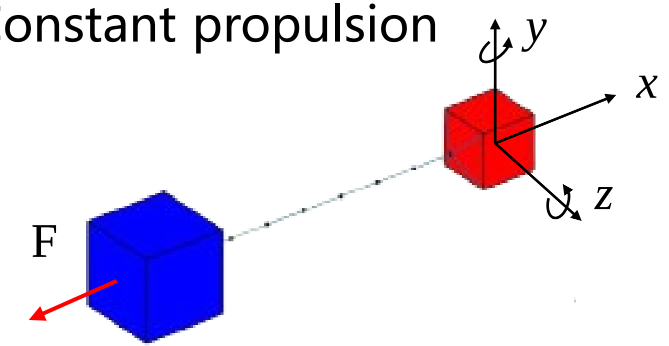
strategy		Propulsion control		Attitude control		Tension regulation control
method		Tether tension based	Relative velocity based	PID control	HSMC	Coordinated control
Evaluation perspectives	Method complexity	★	★	★★	★★★	★★
	Hardware requirement	★★	★★	★	★	★★★
	Implementation safety	★★	★	★★	★★	★★★
	Fuel consumption	★★	★	★★★	★★★	★

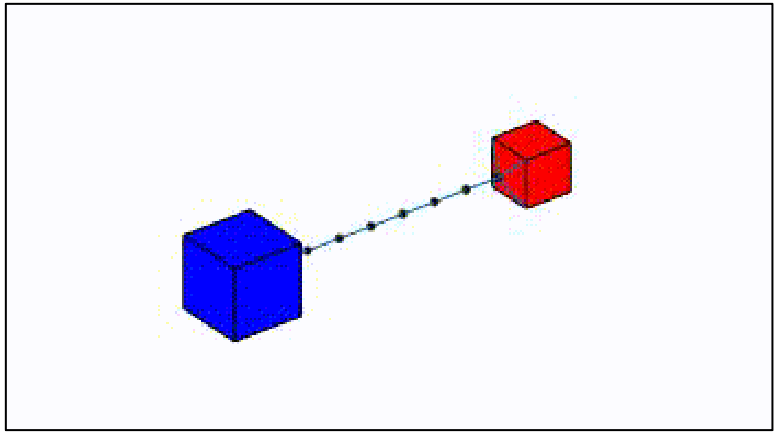
Scenario	for limited sensor payload situation	for limited execution payload situation	Stable operation with sufficient payload resource situation

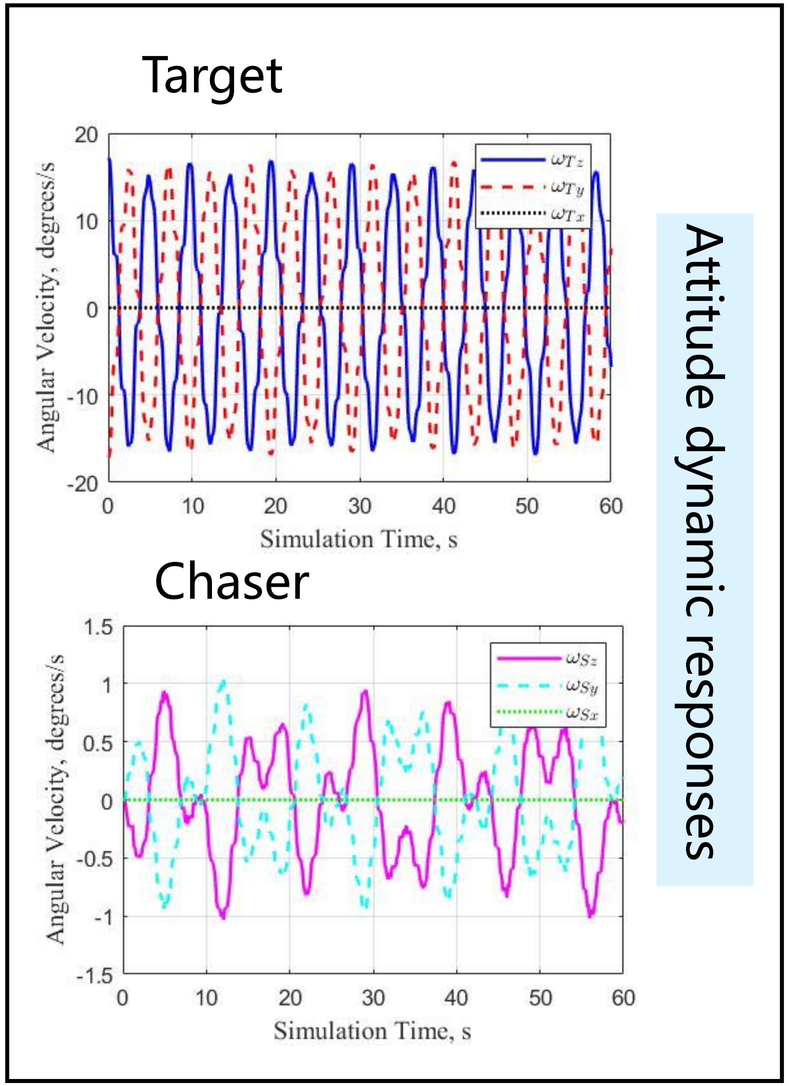
Simulation

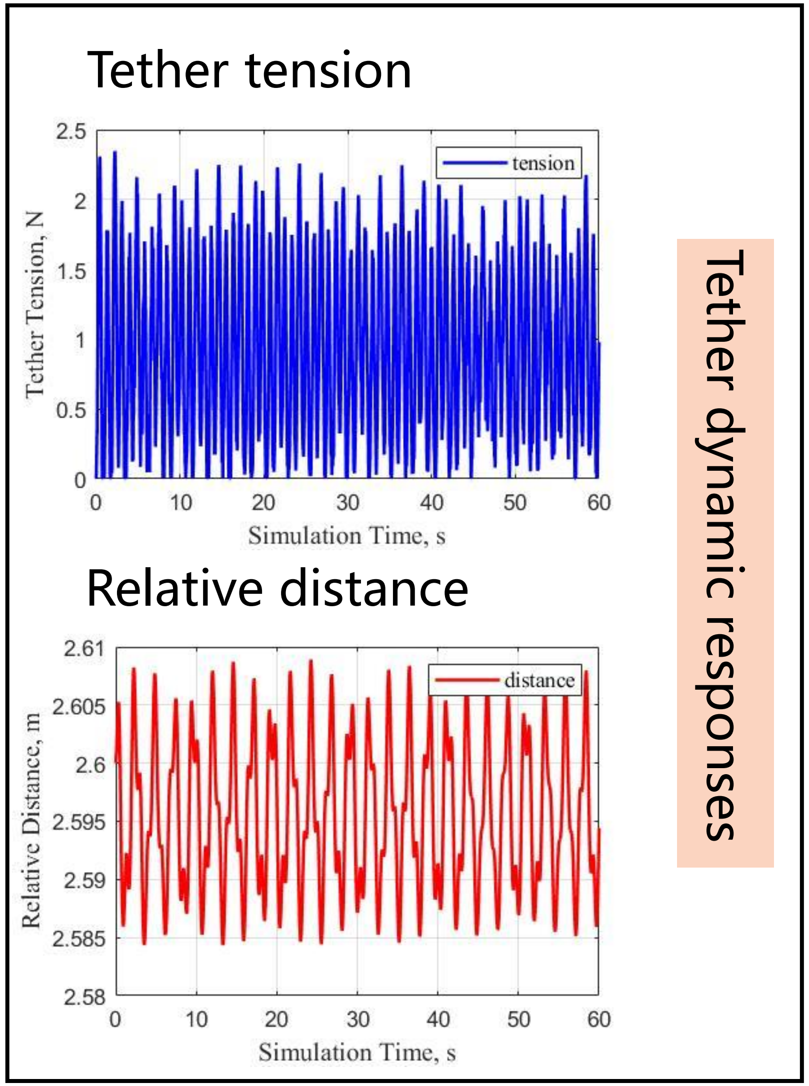
➢ Scenario without active control

- Tumbling target with 0.3rad/s around y and z
- Constant propulsion





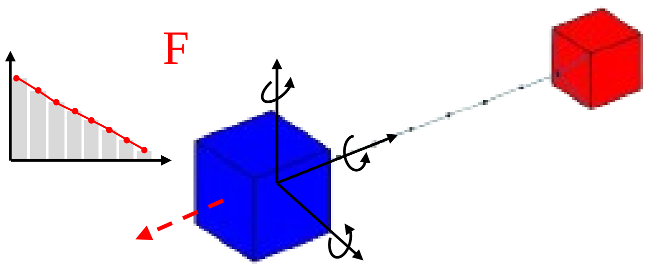


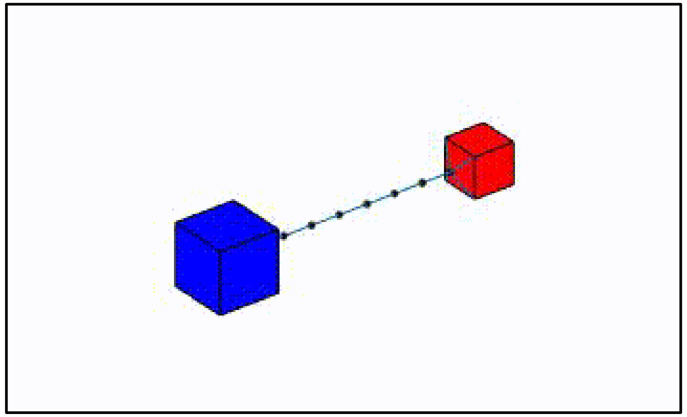


Simulation

- Scenario with different detumbling strategies

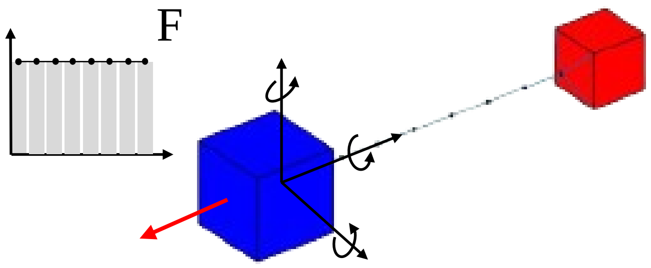
Propulsion Control

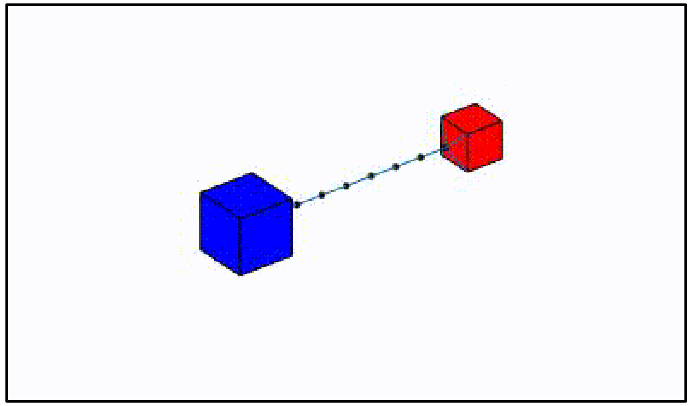




- Based on the tether tension

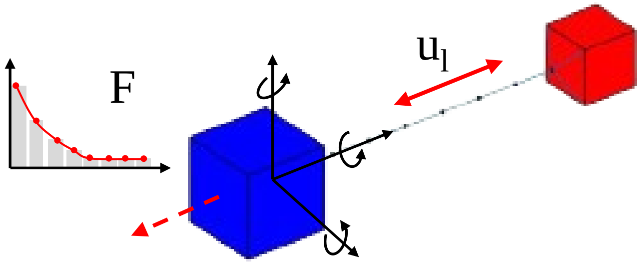
Attitude Control

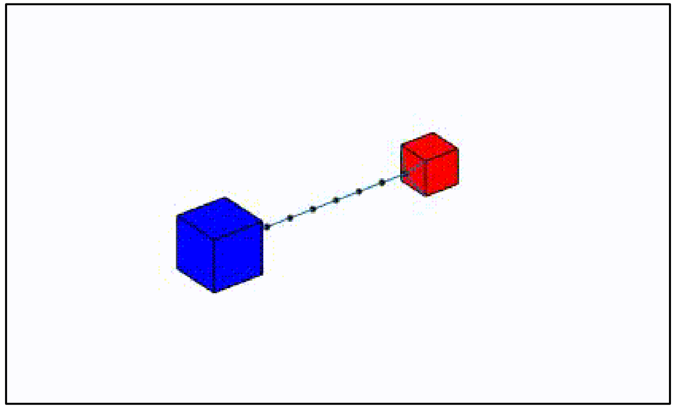




- Based on the HSMC

Tension Regulation Control

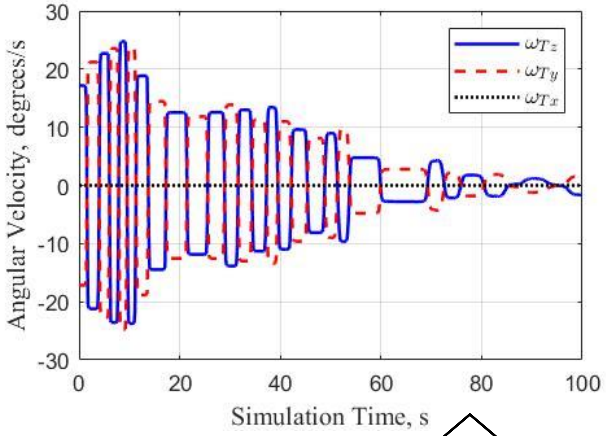


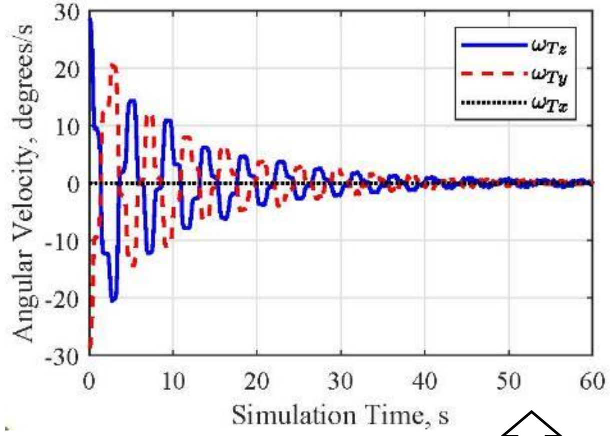


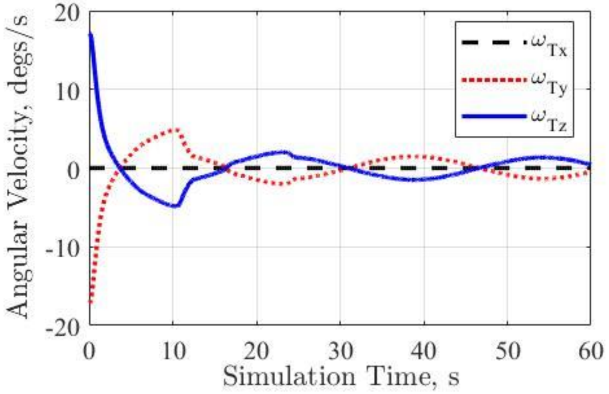
- Based on coordinated control

Simulation

- Attitude dynamic responses under different detumbling strategies







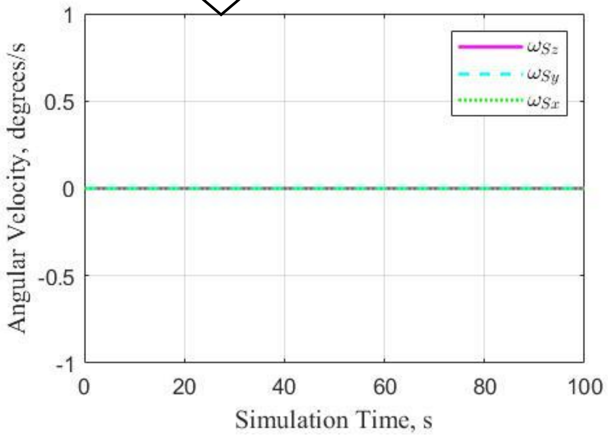
Tumbling target

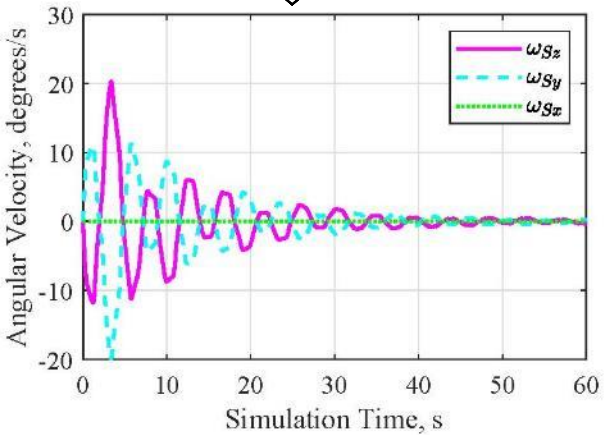
Propulsion Control

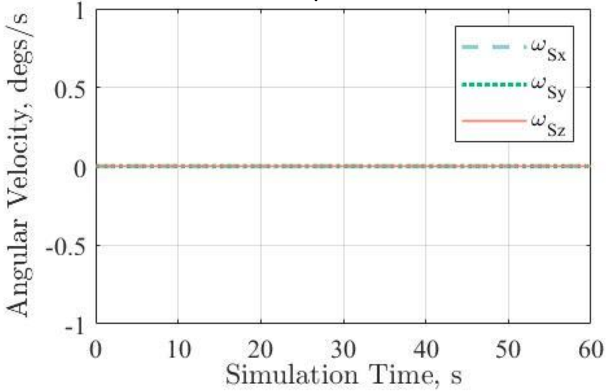
Attitude Control

Tension regulation Control

Maneuverable chaser



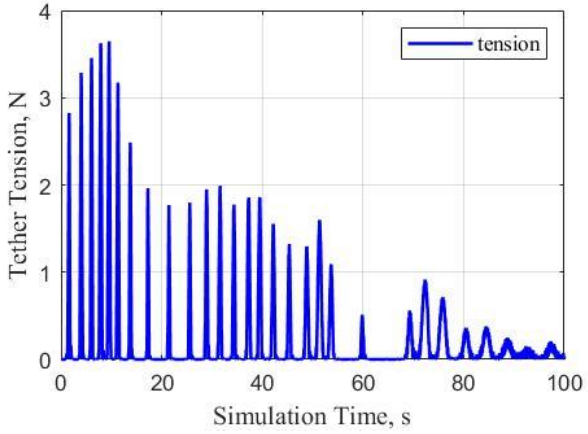


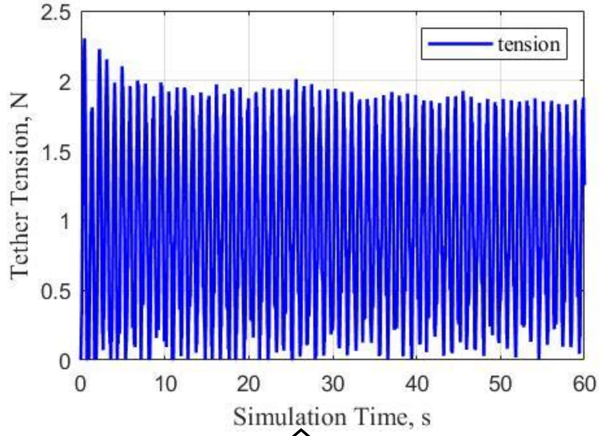


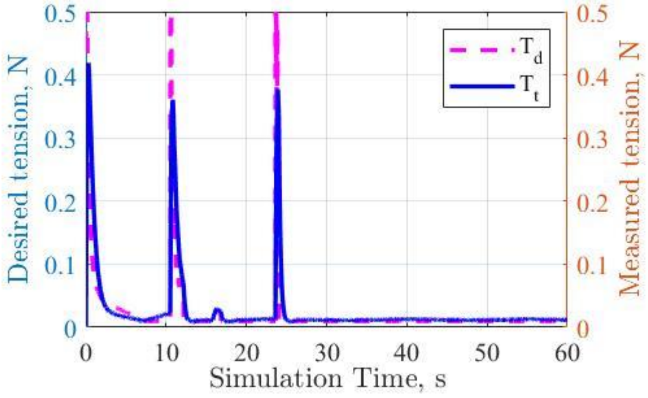
Simulation

- Tether dynamic responses under different detumbling strategies

Tether tension



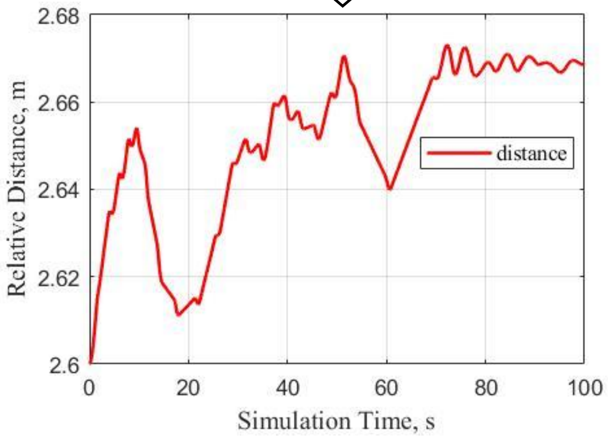


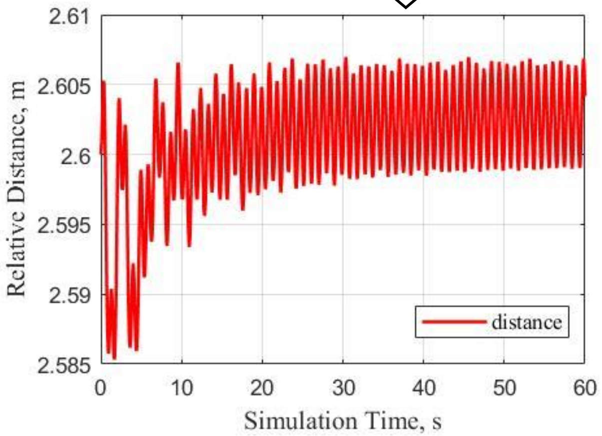


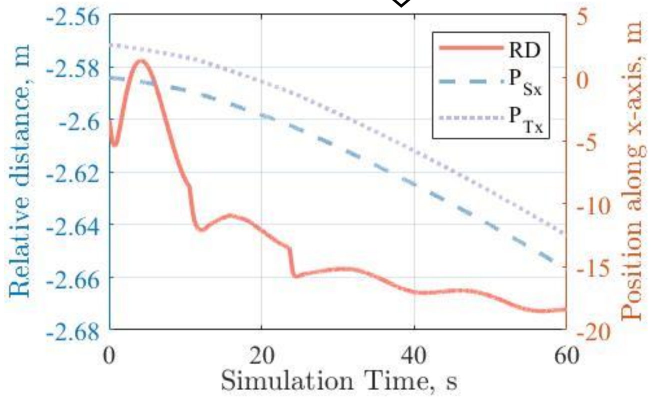
Propulsion Control

Attitude Control

Tension regulation Control







Relative Distance

Conclusion

- Variable tether length dynamic model based on the discrete mass spring damping method has been illustrated to support the implementation of the reel in/out mechanism.
- A tension regulation control strategy coordinated with propulsion and tether length has been proposed for multiple tasks of tether libration suppression and detumbling of the target.
- Compared with the propulsion control and attitude control, tension regulation control presents better performance in terms of detumbling efficiency and tether slack suppression.

Thank you for your Listening!

If you have problems, place contact us:

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