Multiple Model Adaptive Control for Passive Rotating Spherical Shell UAV

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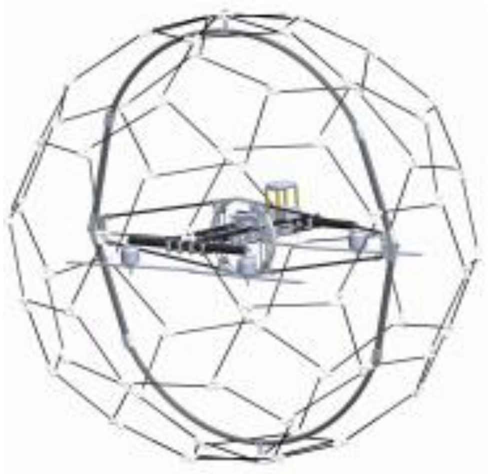
1. RESEARCH BACKGROUND



Passive Rotating Spherical Shell UAV (PRSSUAV)

① Specification

- Internal structure is similar to conventional UAV
- Use Quadrotor H as a main airframe
- 3 Rotatable Axis provide 3 degrees of freedom

② Advantages

- Fully protected by outer spherical shell
- Rollable by 3-DOF
- Rough landing support
- Able to install camera for inspection purpose

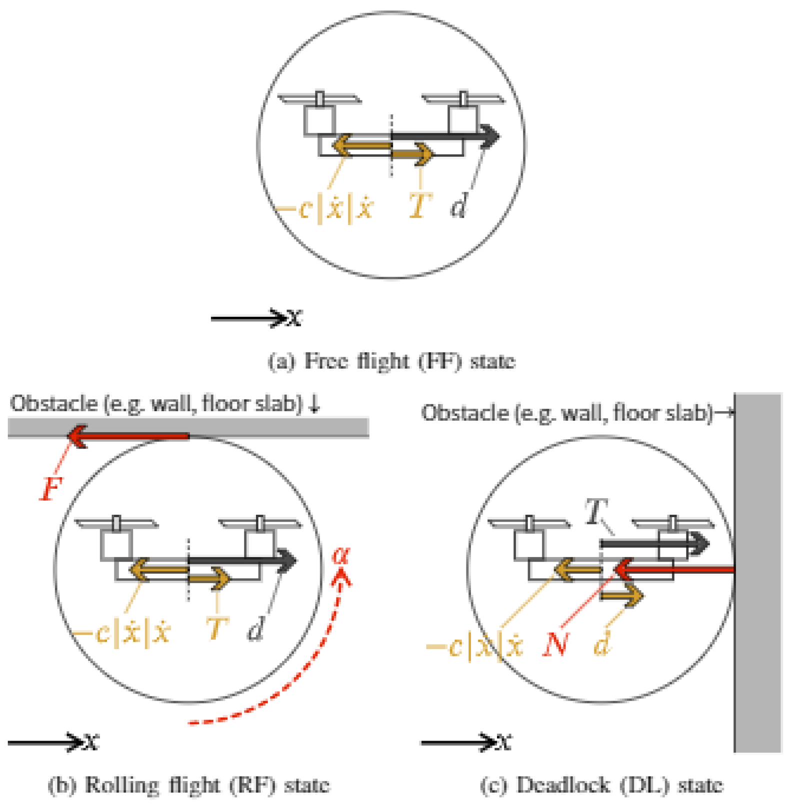
③ Limitation

- Complex structure
- Need specific control methods due to various movement stages

2. METHODOLOGY

2.1 Math's Modelling

3 flight states can be separated according to different flying tasks.



- **Free Flight (FF)**

The state when PRSSUAV flies similarly to an ordinary UAV.

$$\ddot{x} = \frac{b}{m}u - \frac{c}{m}|\dot{x}|\dot{x} + \frac{d}{m}$$

- **Rolling Flight (RF)**

The state when PRSSUAV contacts and rotates along surface.

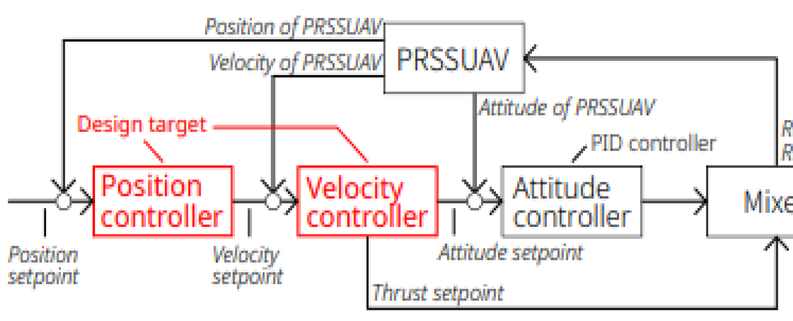
$$\ddot{x} = \frac{mr^2}{I+mr^2}\left(\frac{b}{m}u - \frac{c}{m}|\dot{x}|\dot{x} + \frac{d}{m}\right)$$

- **Deadlock (DF)**

The state when PRSSUAV gets stuck or it holds at given position.

$$\ddot{x} = \frac{b}{m} - \frac{c}{m}|\dot{x}|\dot{x} + \frac{d}{m} - \frac{N}{m}$$

2.2 Controller Design



Control Diagram of Multicopter

Position controller and velocity controller are only two modules involved in PRSSUAV controlling methods.

Reference velocity and desired thrusts in different states can be acquired as follows.

- **Free Flight (FF)**

$$v_{ref} = \lambda_{pos} e_{pos} + \dot{x}_{ref}$$

$$u = \hat{P}(e_{pos} + \lambda_{vel} e_{vel} + \dot{v}_{ref} + \hat{C}|v_{uav}|v_{uav} - \hat{D})$$

- **Rolling Flight (RF)**

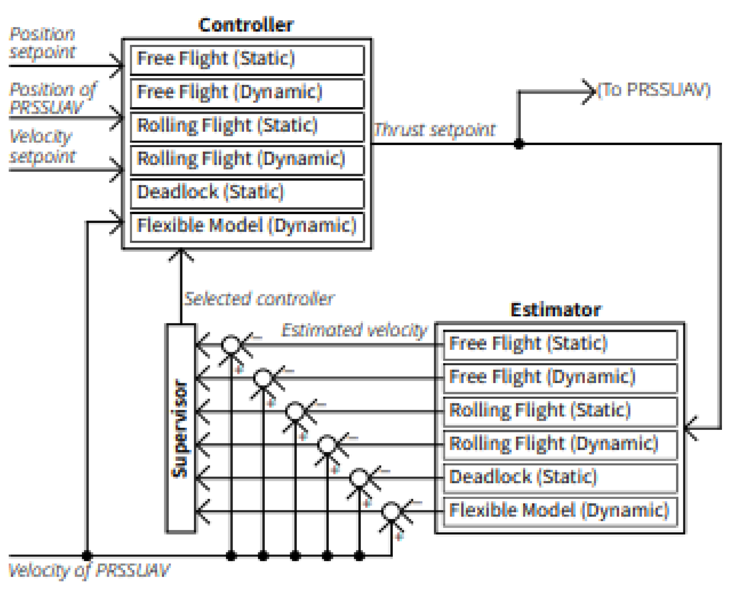
$$v_{ref} = \lambda_{pos} e_{pos} + \dot{x}_{ref}$$

$$u = \hat{P}_{ff}\{\hat{\rho}(e_{pos} + \lambda_{vel} e_{vel} + \dot{v}_{ref}) + \hat{C}|v_{uav}|v_{uav} - \hat{D}\}$$

- **Deadlock (DF)**

$$v_{ref} = \lambda_{pos} e_{pos} + \dot{x}_{ref}$$

$$u = \hat{P}_{ff}(e_{pos} + \lambda_{vel} e_{vel} + \dot{v}_{ref} + \hat{C}_{ff}|v_{uav}|v_{uav} - \hat{D}_{ff})$$



Multiple model adaptive controller selects the state model which has the lowest performance index (u_k) for every iteration.

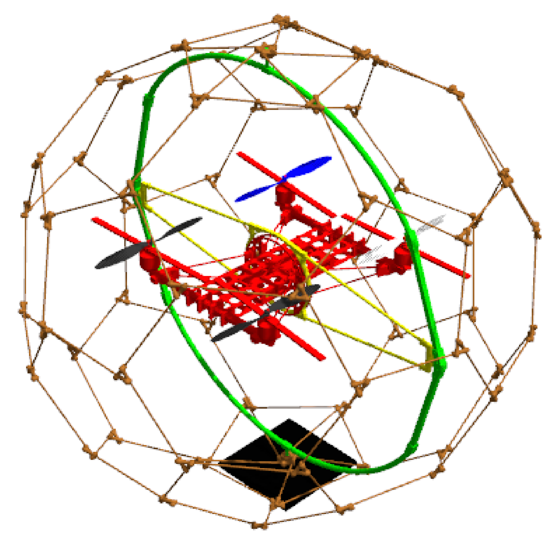
$$u_k = \int_{-t_{k-1}}^{t'} \exp(2\lambda_{per}\tau)\, e_{est}^2\,(t_{k-1} + \tau)\, d\tau$$

3. SIMULATION

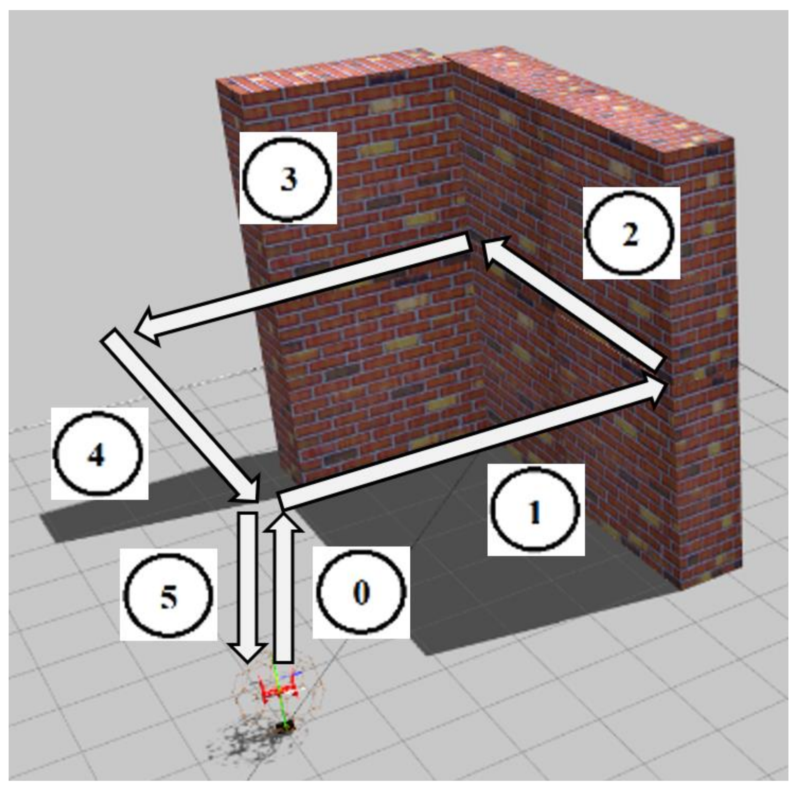
The model and world environment were built on Gazebo simulation with PX4 software in the loop as the firmware for PRSSUAV. The specification of simulated model is displayed below.

Table 1. Specifications of PRSSUAV

Properties	Value
Radius of shell	1 m.
Weight	3.15 kg.
Propeller radius	0.125 m.



PRSSUAV Model in simulation

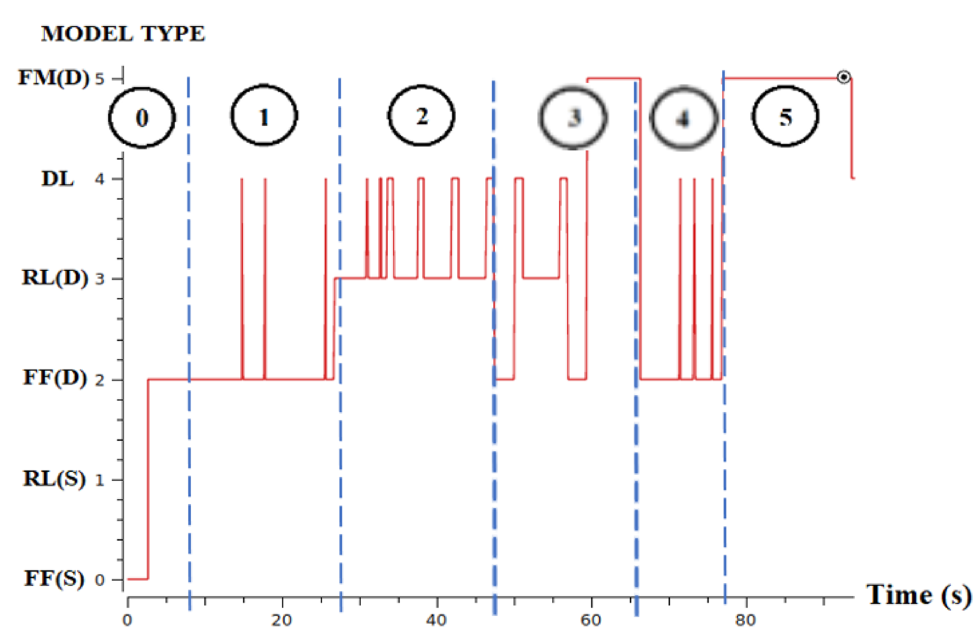


Tested Environment with Wall Obstacle

In simulated environment, applying square waypoint to PRSSUAV to let it move from origin to different positions and finally return to origin.

- 0^{th} waypoint – Takeoff
- 1^{st} waypoint – No obstacles
- 2^{nd} waypoint – Obstacles
- 3^{rd} waypoint – Obstacles
- 4^{th} waypoint – No obstacles
- 5^{th} waypoint – Landing

4. RESULT



Model Selection

- 0^{th} wp – Free flight (D)
- 1^{st} wp – Free flight (D)
- 2^{nd} wp – Rolling flight (D) & Deadlock
- 3^{rd} (1) wp – Rolling flight (D) & Deadlock
- 3^{rd} (2) wp – Flexible model
- 4^{th} wp – Free flight (D)
- 5^{th} wp – Flexible Model

5. CONCLUSION

- Overall, the model can switch to different dynamic models based on movement states.
- At 1^{st} waypoint and 4^{th} waypoint, MMAC spontaneously switched to Deadlock model although PRSSUAV was in Free flight state due to some noises in state estimation.
- 2^{nd} waypoint periodically switched between Rolling flight and Deadlock models due to obstacles.
- Other switching algorithm can be applied to remove noise and improve switching smoothness.