Autonomous reconfigurable hybrid tail-sitter platform U-Lion

Kangli Wang, Yijie Ke, Ben M. Chen

National University of Singapore, Unmanned System Research Group

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Outline

- Introduction
- Platform design
- Inner loop control design
- Outer loop control design
- Results
- Conclusion

I. Introduction -- Motivation

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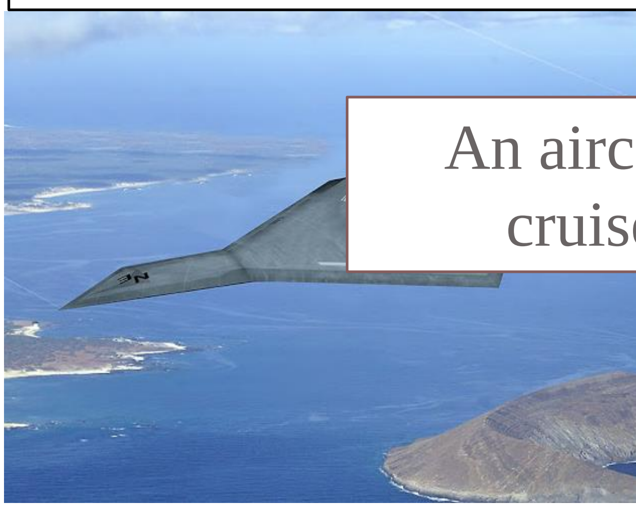
Long Range
Flight Efficiency

VTOL
Maneuverability

An aircraft with VTOL and
cruise flight capability



I. Introduction -- Sea surveillance

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- Long range
- Fast speed
- VTOL Capability

I. Introduction -- Existing platforms

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I. Introduction -- U-Lion

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II. Platform design

II. Platform design -- Evolution

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First prototype

Second prototype

Current prototype

II. Platform design – Overall Structure

- Tail sitter configuration
- Reconfigurable wing
- Vectoring thrust
- Multiple control surfaces tail

II. Platform design -- Vectoring thrust

- Multi-direction lift
- 6-D motion control
- Fast response
- Direct torque for transition

II. Platform design -- Tail fins structure

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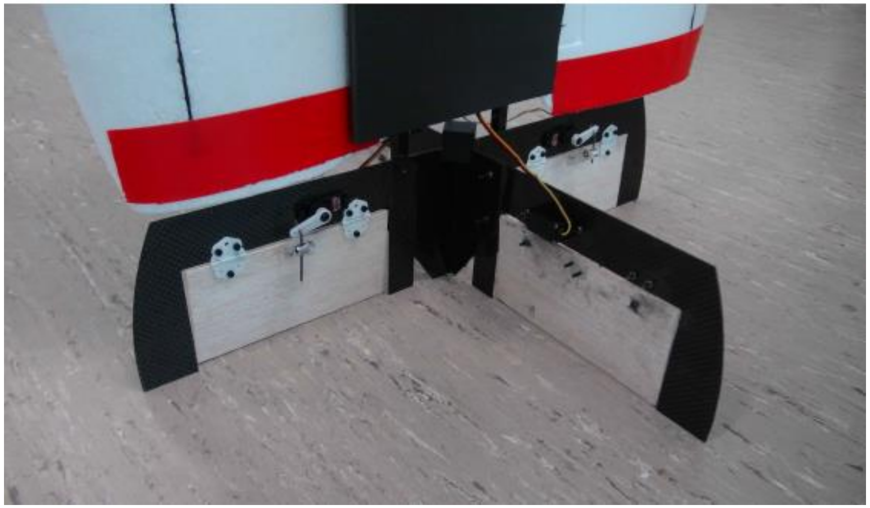
- VTOL yaw control
- Transition control
- Extra controllability



II. Platform design -- Fuselage design

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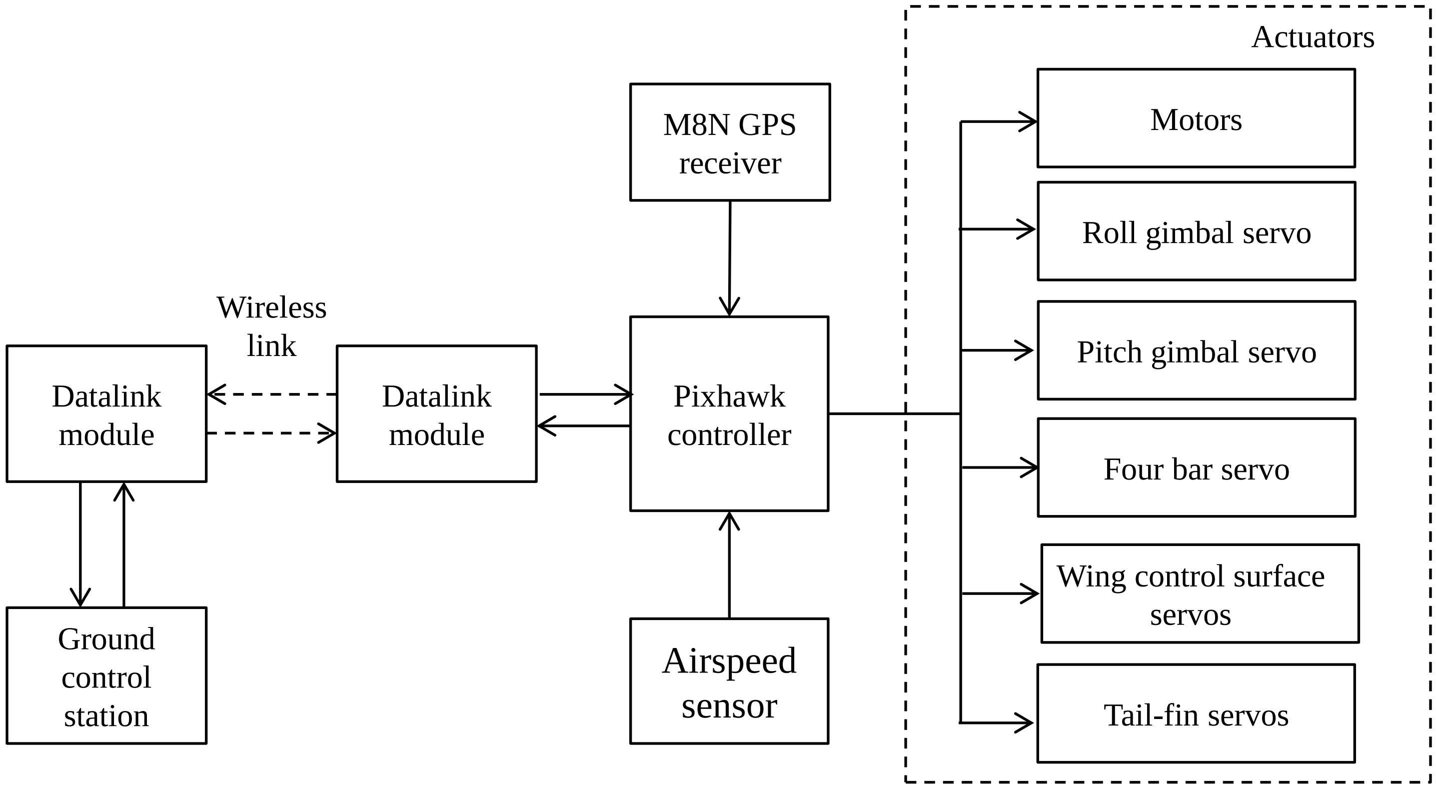
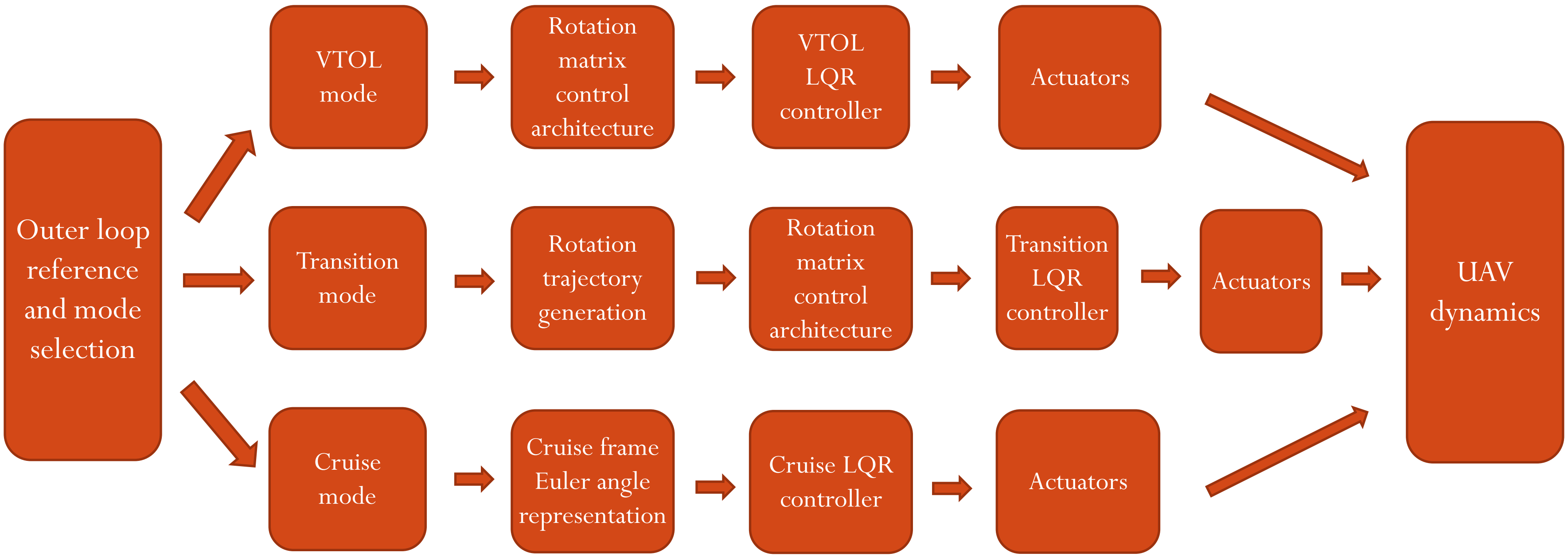
- Light weight
- Provide up to 30% of lift
- Installment of avionics

II. Platform design -- Avionics system



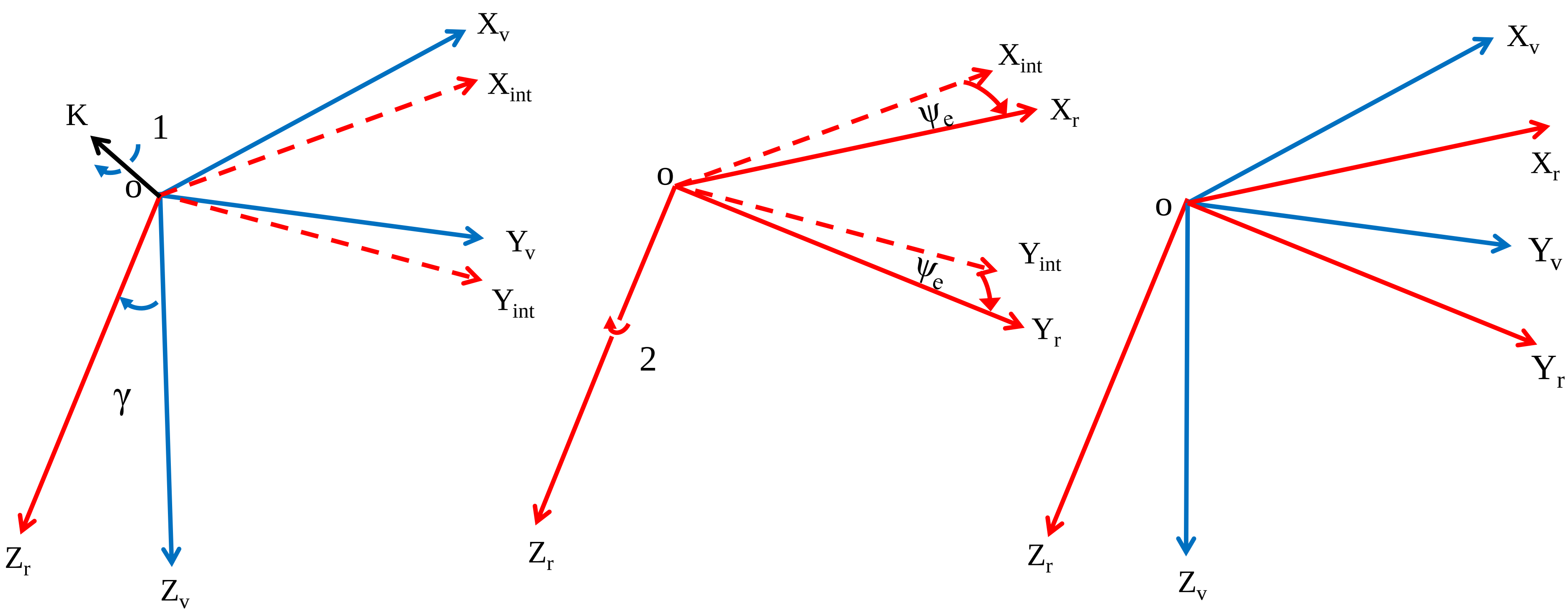
III. Inner loop control design

III. Overall inner loop control structure



III. VTOL inner loop control

-- *Rotation angle generator*



(a) Alien Z_v-axis with the Z_r-axis by rotating about the K-axis which is perpendicular to the two axes by an angle of γ and results in an intermediate frame F_{int}

(b) Rotate the frame F_{int} about Z_r-axis by an angle of ψ_e to match the reference axis

(c) The original frame F_v and the reference frame F_r

III. VTOL inner loop control
-- *Advantages*

- Find the angle error in the true body frame
- Works well in wider pitch angle range
- Applicable for transition control
- Stabilize the U-Lion in any initial condition
- Allow for faulty recovery from fail transitions

III. VTOL inner loop control

-- *LQR control on pitch channel*

- Let the state be the angle error, angular rate and angle error integration

$$\mathbf{x} = [\theta_e \quad p \quad \int_{(\theta_e)}]^T$$

- The state space equation is then

$$\frac{d}{dt}\begin{bmatrix} \theta_e \\ p \\ \int_{(\theta_e)} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 0 \\ 1 & 0 & 0 \end{bmatrix}\begin{bmatrix} \theta_e \\ p \\ \int_{(\theta_e)} \end{bmatrix} + \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} u$$

where *u* is the virtual acceleration input

- Design the LQR controller with u = Fx, so that the cost function

$$J = \int \mathbf{x}^T Q \mathbf{x} + uRu$$

is minimized

III. VTOL inner loop control

-- *Map the angular acceleration to actuators*

- Pitch angular acceleration provided by vectoring thrust

$$u = Tsin(\theta_{\text{tilt}})L_m/I_y$$

- The tilting angle θ_{tilt} could be obtained

- Map the θ_{tilt} to the servo input

T ------ Thrust by the propulsion

θ_{tilt} ------ Tilting angle of vectoring thrust in pitch direction

L_m ------ Distance between CG to motor

I_y ------ Moment of inertia in y direction

III. Cruise inner loop control

- Transform the rotation matrix into cruise frame Euler angle representation
- Apply the LQR controller to obtain the angular acceleration input
- Map the angular acceleration input to the control surface tilting angle by the relationship

$$M(\delta_{\text{fin}}) = \pi\delta_{\text{fin}}\rho V_{\text{air}}^2 S_{\text{fin}} l_{\text{fin}}$$

δ_{fin} ------ The control surface deflection angle
ρ ------ The air density
V_{air} ------ The air flow velocity
S_{fin} ------ Control surface area
l_{fin} ------ The distance from the control surface center to the CG

III. Transition inner loop control

-- *VTOL to cruise transition*

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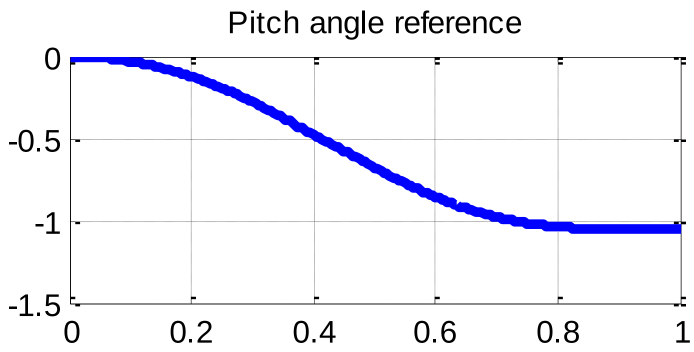
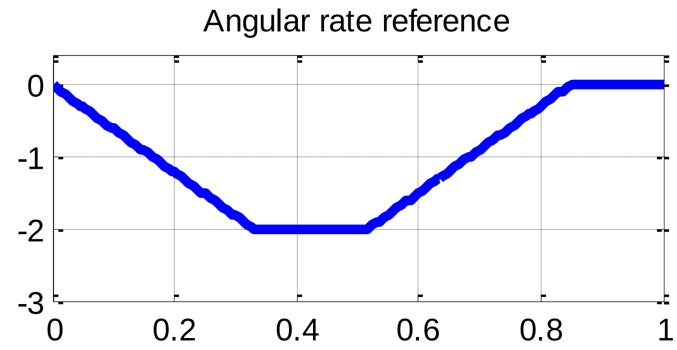
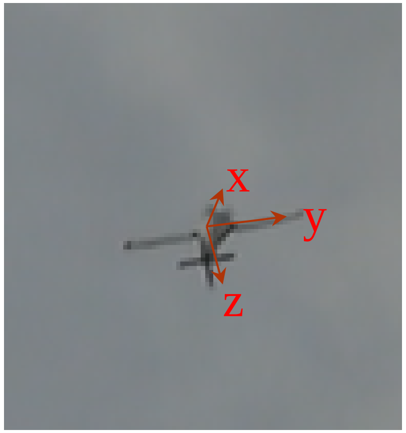
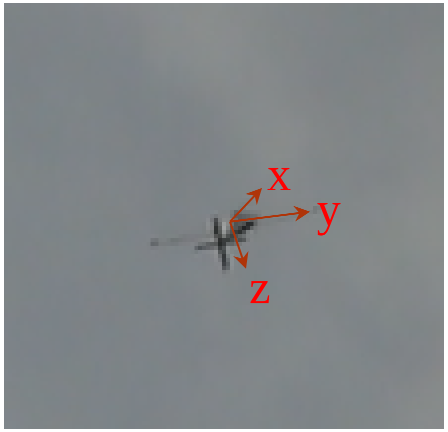
- Generate smooth trajectory for the pitch angle reference

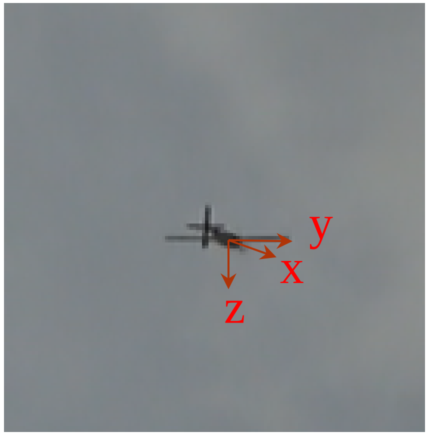




- Generate smooth rotation matrix trajectory to push the head down





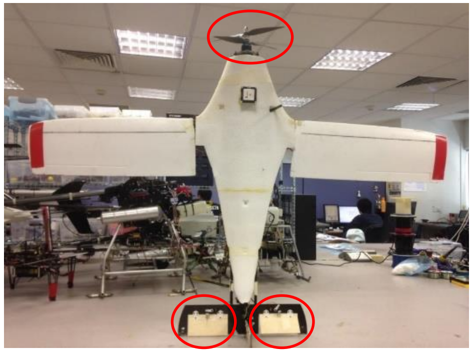


III. Transition inner loop control

-- *VTOL to cruise transition*

- LQR controller
  - Larger Q matrix for higher bandwidth of control
  - All possible actuators utilized for assisting the transition process
- Actuator mapping

Pitch mapping



Roll mapping

Yaw mapping

- Proportional controller applied for the speed control

- Once falls in the stabilizable region of cruise flight, switch to cruise flight

IV. Outer loop control design

IV. Overall outer loop control structure

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User mission command

↓

Trajectory generation algorithm layer

↓

Outer loop control logic layer

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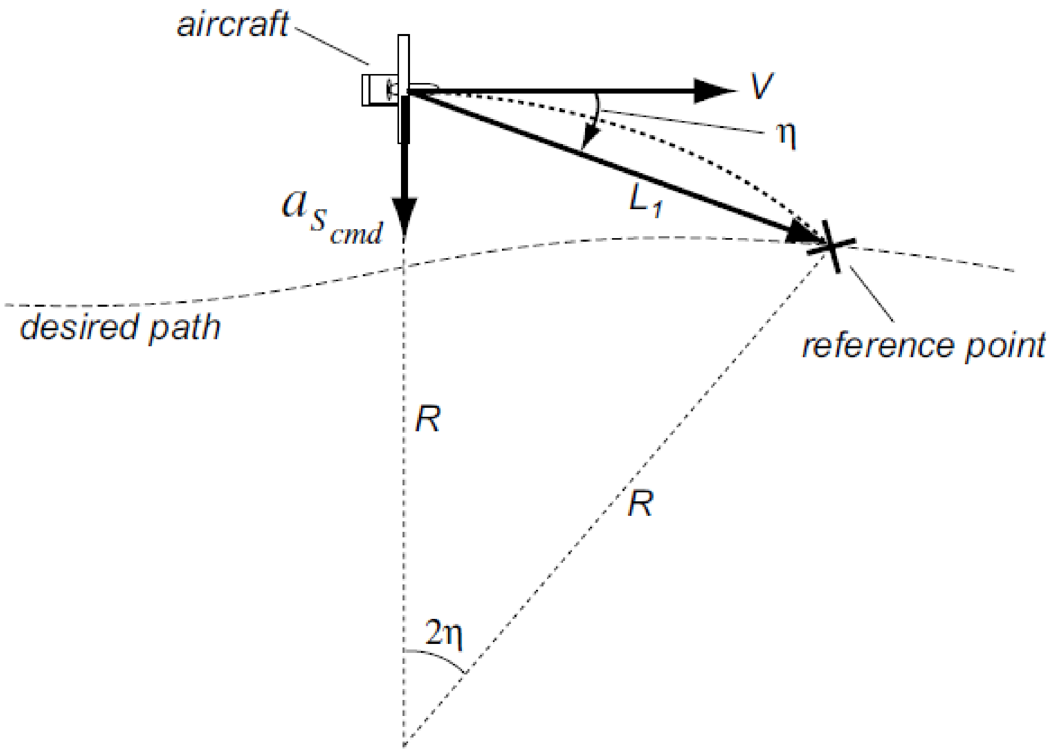
Outer loop control algorithm layer

IV. Trajectory generation algorithm layer
-- *L1 guidance generation*

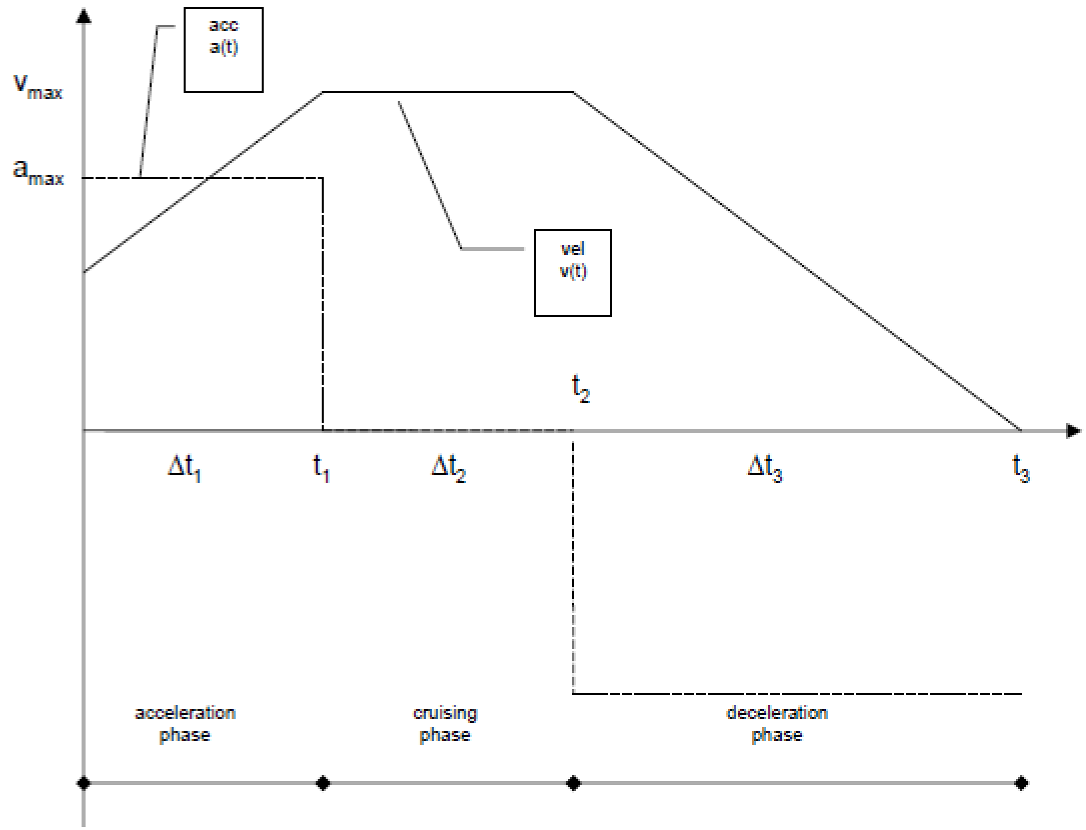
$$a_{s_{cmd}} = 2\frac{V^2}{L_1}\sin\eta$$



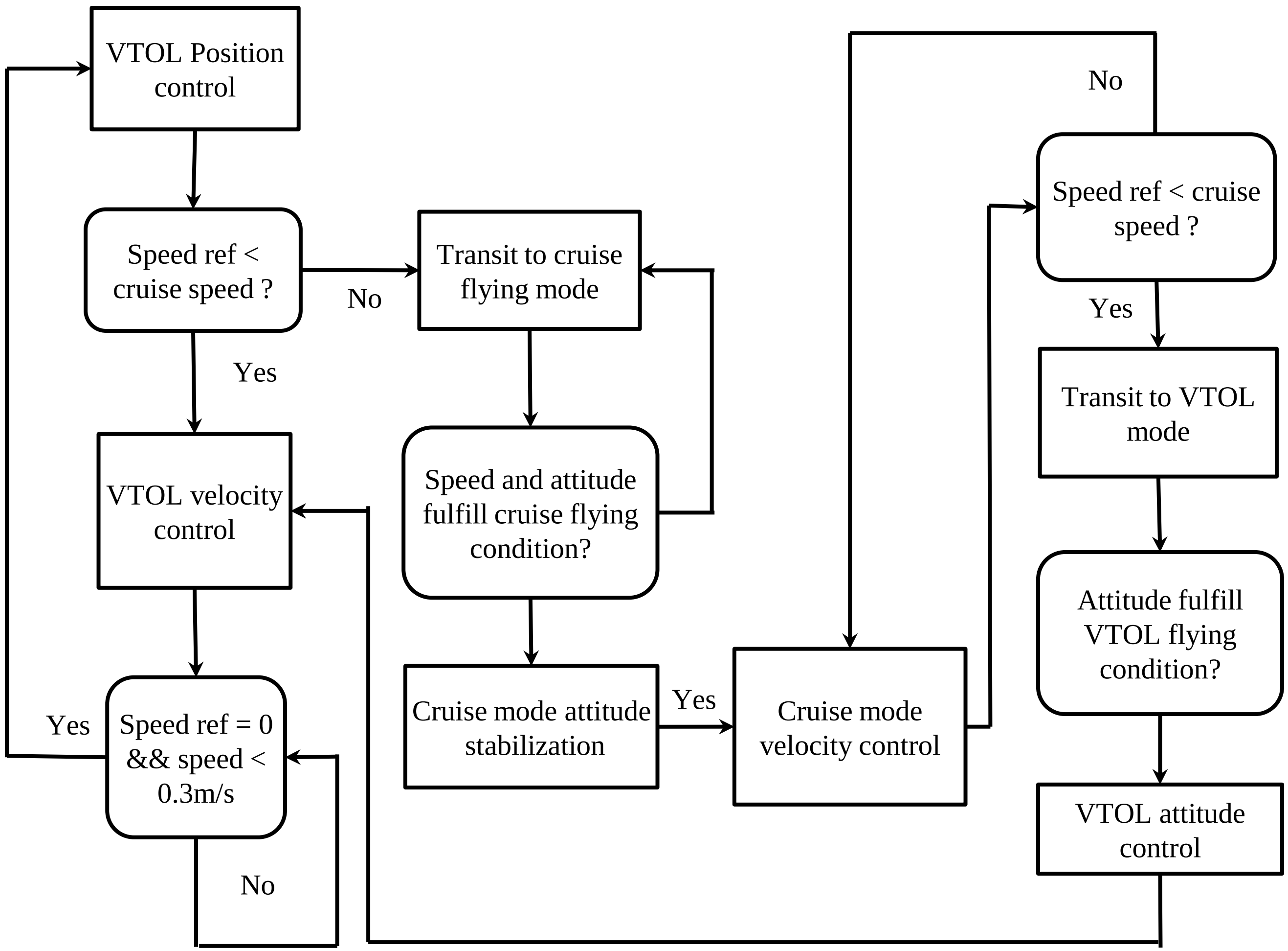
IV. Trajectory generation algorithm layer

-- *Speed reference generation*

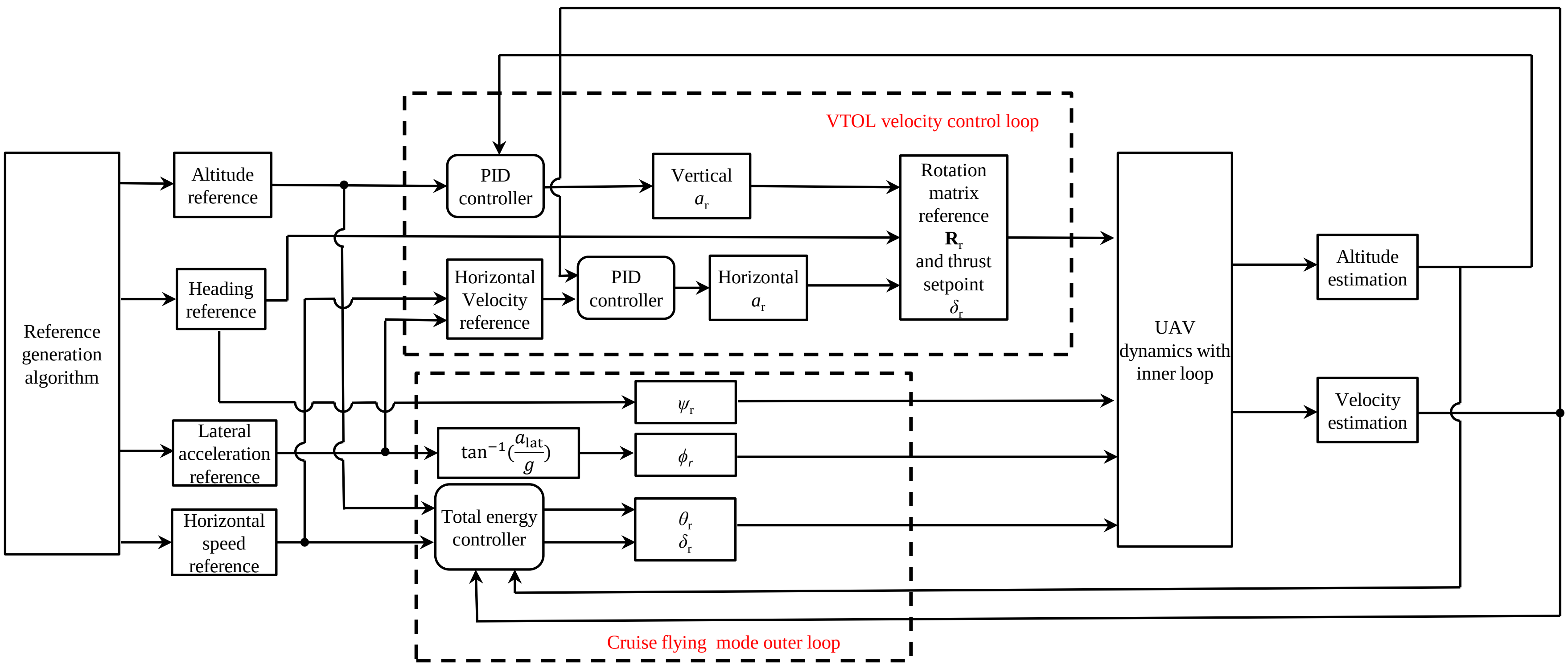
- Based on the target position distance the speed reference is generated as a trapezoidal shape
- Velocity profile includes acceleration phase, cruising phase and deceleration phase



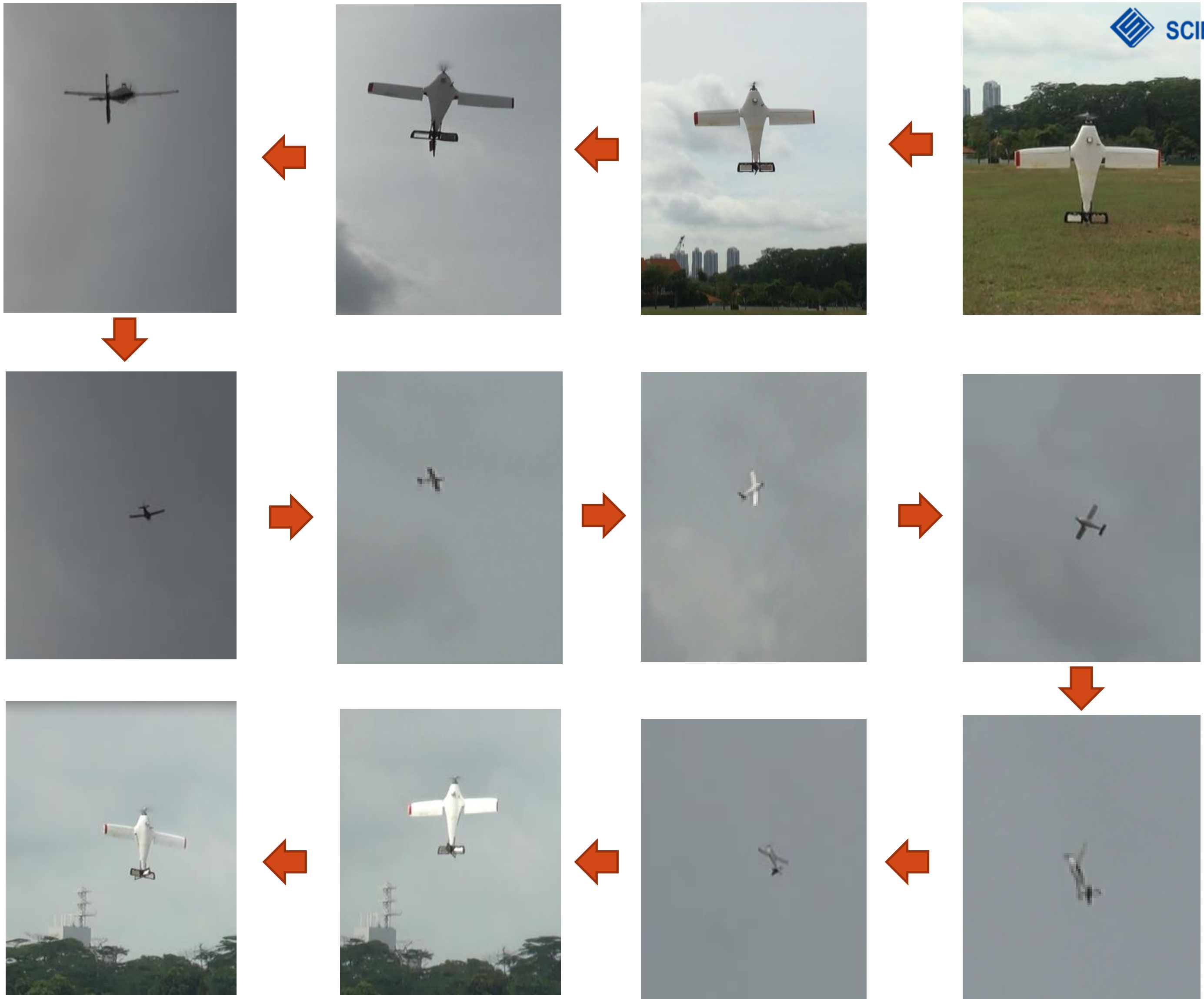
IV. Outer loop control logic layer



IV. Outer loop control algorithm layer



V. Results -- An autonomous fly test



V. Results -- An autonomous fly test data

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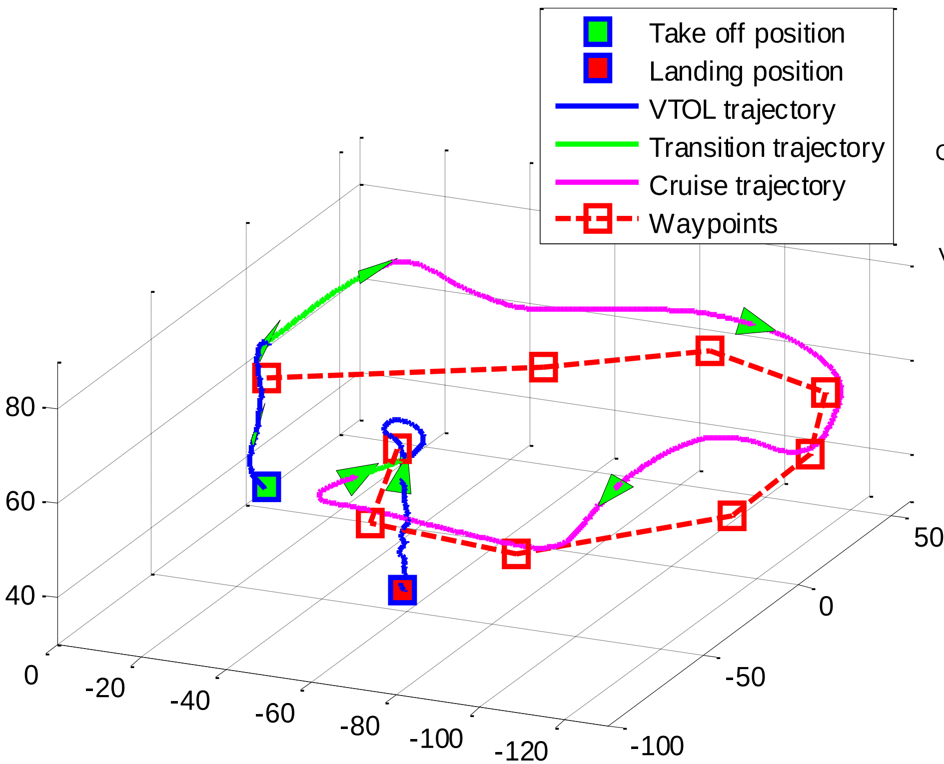
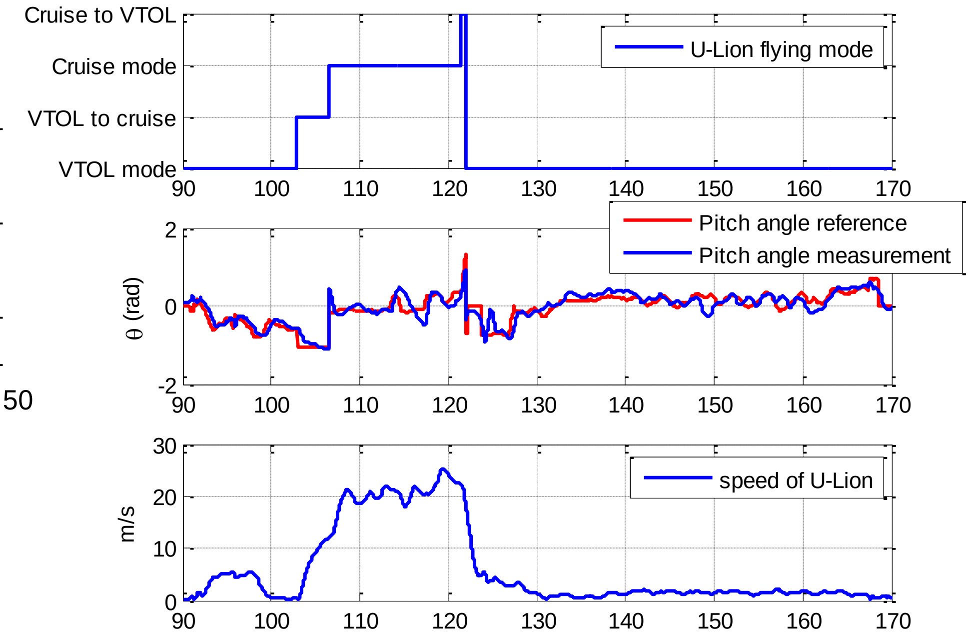


(a) Position response



(b) Angle response

VI. Conclusion

- Autonomous hybrid UAV platform U-Lion
- Designed featured with vectoring thrust and reconfigurable wings
- Inner loop control algorithm proposed for three flying mode
- Entire control framework proposed for autonomous waypoint flight
- Auto flight test demonstrates the effectiveness of platform design and control frame work

VI. Future work

- Continue to optimize platform structure

- Improve control performance

- Integrate vision-based target detection and tracking system to carry out some real applications

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