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Modeling and control of an agile tail-sitter aircraft

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Abstract

This paper presents a model of an agile tail-sitter aircraft, which can operate as a helicopter as well as capable of transition to fixed-wing flight. Aerodynamics of the co-axial counter-rotating propellers with quad rotors are analyzed under the condition that the co-axial is operated at equal rotor torque (power). A finite-time convergent observer based on Lyapunov function is presented to estimate the unknown nonlinear terms in co-axial counter-rotating propellers, the uncertainties and external disturbances during mode transition. Furthermore, a simple controller based on the finite-time convergent observer and quaternion method is designed to implement mode transition.

1. Introduction

This paper focuses on the design and control of an agile tail-sitter aircraft, where such an aircraft can not only taking off and landing vertically, but also flying forward with high speed in the same way as a conventional fixed wing aircraft.

Vertical take-off and landing (VTOL) aircrafts and fixed-wing airplanes have their advantages and shortcomings. Traditional aircrafts can take off and land vertically, but they cannot fly forward with high speed carrying large payloads [1–4]. On the other hand, conventional fixed-wing airplanes can fly forward with high speed and can carry large payloads. However, they cannot take off and land vertically, and appropriate runways are required.

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Nomenclature

F_c	sum of the thrusts of the co-axial propellers
$F_{ri}, i = 1, \cdots, 4$	thrust of each quad rotor
F_d	forces due to uncertainties and external disturbances
$\tau_{ri}, i = 1, \cdots, 4$	reactive torque generated in free air by the rotor due to rotor drag for quad rotors
τ_{gyro}	gyroscopic effects of the propellers
τ_d	moments due to the uncertainties and external disturbances
$f_{ai}, i = 1, \cdots, 4$	force generated by each blade of torque amplifier
$\omega_i, i = 1, \cdots, 4$	rotational velocity of each quad rotor
ω_u	rotational velocity of upper rotor
ω_l	rotational velocity of lower rotor
m	mass of aircraft
g	acceleration of gravity
l_1	distance between center of gravity of aircraft and force operating point of fixed wing
l_2	distance between center of gravity of aircraft and plane center of quad rotors
l_3	distance between two quad rotor
l_c	distance between center of gravity of aircraft and fixed wing
ϕ	roll angle
θ	pitch angle
ψ	yaw angle
α	angle of attack
γ	flightpath angle
L_1	lift force generated by left fixed wing
L_2	lift force generated by right fixed wingd
L_f	the lift force generated by the fuselage, respectively
D_1	drag force generated by left fixed wing
D_2	drag force generated by right fixed wing
D_f	the drag force generated by the fuselage, respectively
S	area of fixed wing
C_{L0}	lift coefficient when angle of attack α is equal to zero for fixed wing
$C_{L\alpha}$	lift coefficient due to angle of attack α
C_{lf}	lift coefficient of fuselage
C_{df}	the drag coefficient of fuselage
C_{df0}	the constant in the coefficients of drag force of fuselage
δ_i	normal flap bias angle of fixed wing
$C_{L\delta}$	lift coefficient due to flap bias angle δ_i
J	inertial matrix of aircraft
p_Γ	position of center of gravity relative to right handed inertial frame
v_Γ	velocity vector of center of gravity relative to right handed inertial frame
F_f	body force of aircraft
R	transformation matrix representing the orientation of the rotorcraft
τ	sum of the moments in the fixed-body frame
Ω_Λ	angular velocity of the airframe expressed in body frame