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Flight control reconfiguration of unmanned tiltrotor aircraft

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Abstract. The unmanned tiltrotor aircraft has many flying advantages, in the meantime it brings some new problems. In order to improve the flight stability of the UAV, the simulation of flight control law reconstruction was designed based on the multi-model adaptive control theory for actuator failure. Using the principle of small disturbance, the linear model of the UAV was established. Aiming at several typical actuator failures, the reconfigurable control strategy was designed. The classical PID control method was used to design the control law structure. Simulation results show that the proposed reconfiguration control strategy can be used in unmanned tiltrotor aircraft, which has good fault-tolerant effects and can significantly improve the safety of aircraft performance.

1. Introduction

The unmanned tiltrotor aircraft is a unique designed rotorcraft. It has normal helicopter vertical takeoff and landing, air hovering, good low speed and low altitude flight capability, and has the features of high-speed cruise flight by fixed-wing propeller aircraft [1-4]. The unmanned tiltrotor aircraft is one of the newly constructed rotorcrafts which has been successfully put into use.

The high reliability of the flight control system is an important guarantee for flight safety. When the aircraft fails, the flight control system can quickly change the control strategy according to the type of fault, and can also realize the minimum safety requirements of the aircraft through the reconstruction of the control system. The continued execution of the mission or the safe return of the flight is of great significance [5]. In the UAV flight control system, the actuator responds to the output command of the flight control computer, drives the pneumatic rudder surface, and realizes the attitude and trajectory control of the UAV. As the executive part of the flight control system, the steering gear and the motor play a vital role in the control of the aircraft. When fault occurs, it will have a serious impact on the flight performance of the aircraft. If the cause of fault can be diagnosed in time, the redundancy of the control surface function can be used to reconstruct the system after the fault as well, so the safety performance of the aircraft can be improved and the accident can be reduced.

With the development of UAV, the requirements for the reliability and stability of UAV flight control systems are getting higher and higher. The fault diagnosis and fault-tolerant control technologies of flight control systems have attracted the attention of relevant research [6-7]. The multi-model adaptive control technology can design the corresponding fault adjustment controller offline according to different fault condition, and select the reconstruction control strategy online. The reconstruction control strategy can eliminate the delay of online identification. And it can design and improve the control precision and stability after fault occurs.

This paper takes the unmanned tiltrotor aircraft as the research object. We carry out the theoretical research on the flight control reconstruction method of the unmanned tiltrotor aircraft and the online simulation verification. The overall idea of multiple model based on flight control reconfiguration is shown in the figure 1. Firstly, we design the multiple controllers based on different actuator faults. Secondly, the part of fault diagnosis detects actuator fault. Finally, the UAV uses the reconstructed control law to continue flight or safe landing.

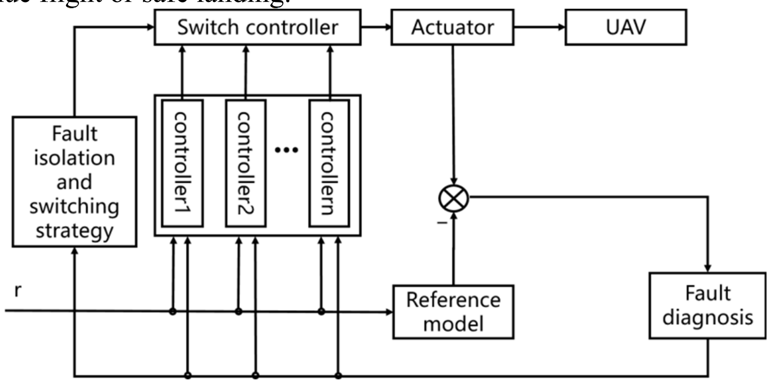

Figure1. The principle diagram of flight control reconfiguration.

2. Establishment of linear model for UAV

2.1. Control strategy

The UAV has a structure of a tilting rotor, so the control strategy of the tiltrotor aircraft is different from the ordinary fixed-wing aircraft. It has two flight states: the vertical takeoff state and the horizontal flight state. Control strategy of vertical takeoff is as follows:

Main rotor provides roll moment due to different power, then this forms the rolling channel. The pitch channel provides pitching moment by controlling the roration of the back motor. The yaw channel provides course moment by tilting servo motor. The height channel is a cooperation that the main rotor and the back motor provide vertical tension to increase the height together. The forward channel enables the UAV to generate a low pitch angle for forward control. The lateral channel is controlled by creating a roll angle.

Control strategy of horizontal flight is as follows:

The rolling channel produces a rolling moment by left and right aileron differential. The pitch channel produces a pitch moment by left and right aileron translation. The yaw channel produces a heading moment by the main rotor power differential. The height channel achieves height control through the left and right ailerons. The ailerons are translated to produce an angle of attack and the power compensation airspeed. The forward channel is an airspeed maintenance. The lateral channel achieves lateral control by creating roll angles.

2.2. Main parameters

The main parameters of the UAV are shown in the table 1.

Table 1. The main parameters of the UAV.

Name of parameters	value	Unit
Right motor coordinate	0.05，1.754362，0.025573	M
Left motor coordinate	0.05，-1.754362，0.025573	M
Back motor coordinate	-0.852，0.0，0.080646	M
Aircraft weight	38.5	Kg
Moment of inertia I_{xx}	24.148	kg.m^2

Moment of inertia I_{yy}	8.324	kg.m^2
Moment of inertia I_{zz}	31.468	kg.m^2
Moment of inertia I_{zx}	0.734	kg.m^2
Moment of inertia I_{xz}	0.734	kg.m^2

2.3. *Establishment of linear model*

We tuning PID control parameters, which is required for the conventional method. And then we can obtain a linear model of the system control law design. This paper establishes the rotor aerodynamic model, wing aerodynamic model, nacelle aerodynamic model, and aileron aerodynamic model. According to the conservation of momentum and the moment of momentum, the equation of state of the tilting rotor UAV can be calculated. The equation of state is as follow:

$$\begin{aligned} \dot{X} &= AX + BU \\ Y &= CX \end{aligned} \tag{1}$$

$$X = [u, v, w, p, q, r, \phi, \theta, \psi]^T, \quad Y = [u, v, w, p, q, r, \phi, \theta, \psi]^T, \quad U = [\delta_t, \delta_d, \delta_n, \delta_m]^T$$

Finally, the state equation is linearized based on the principle of small perturbation.

3. Reconfiguration control strategy design

3.1. *Actuator fault classification and impact*

This paper assumes that the fault has been obtained by the fault detection system. If the unmanned tiltrotor aircraft has a single-sided motor failure, pitch and roll channel can be adjusted by translation and differential of left and right ailerons. The aircraft has no rudder, so the heading during normal flight is controlled by the differential of main motor. The control of the situation cannot be achieved when a single motor fails. At this time, the thrust vector of the tail motor can be leveled by tilting the tail motor, so it can achieve the control of heading.

If the unmanned tiltrotor aircraft has a single-sided servo fault, the pulling direction of the single motor well be unstable, so the heading angle cannot be controlled during flight.

If the unmanned tiltrotor aircraft has a single-sided aileron fault, it can influence the rolling and pitch channels of the aircraft. Because the aileron translation can control the pitch channel, and the differential can control the rolling channel.

If the unmanned tiltrotor aircraft has a fault of tail rotor, the aircraft should stop taking off or returning. You need to ensure that the tail rotor of a redundant device has no failure.

3.2. *Reconfiguration control strategy*

For different actuator failures, it is necessary to design a corresponding control strategy. If the actuator has a failure, we need to change control strategy rapidly to reduce the impact of failures on the UAV.

When the right-sided motor fails, the control strategy needs to be changed. The rolling channel produces a rolling moment by left and right aileron differential. The pitch channel produces a pitch moment by left and right aileron translation. The tail rotor is tilted to the right by 90 degrees, which forms the yaw channel. The heading torque is generated by controlling the pulling force. The height channel achieves height control through the left and right ailerons translated to produce an angle of attack and a power compensation airspeed. The forward channel is an airspeed maintenance. The lateral channel achieves lateral control by creating roll angles.

When the right-sided rotor fails, we can stop the right motor. Then the control strategy is same as the single-sided motor fails. When the right-sided aileron fails, the rolling channel produces a rolling moment by left and right rotor differential. The pitch channel produces a pitch moment by left and right rotor translation. The yaw channel produces yaw moment by heading tail rotor.

4. Simulation experiment and analysis

The PID parameters of each channel of the UAV are shown in Table 2.

Table 2. PID parameters.

	Height channel	Airspeed channel	Rolling channel	Pitch channel	Yaw channel	Lateral channel
Kp	0.3	0.03	0.8	0.51	0.8	0.04
Ki	0.0	0.0	1	0.5	5.0	0.02
Kd	0.0	0.01	0.1	1.0	0.0	0.01
Damping coefficient			0.462	5.25	0.408	

In the initial state, the UAV files at a uniform speed of 2° at 50 meters high, so the pitch angle is 2°, and both the roll and the yaw angles are 0°. Then UVA files adds a height of 200m command at 50s. The simulation performs attitude stabilization control, airspeed maintenance, and altitude control. The simulation results are shown in the figure 2:

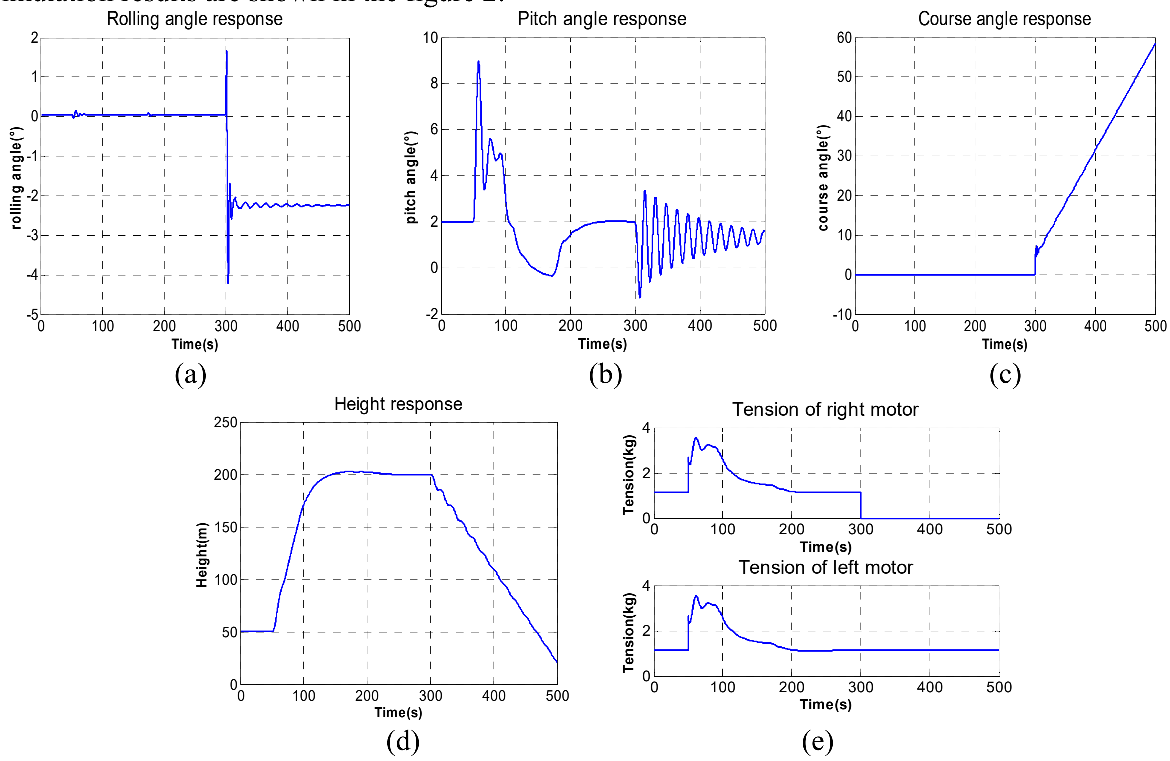

Figure 2. Simulation results.

These figures show that the UAV is stable before 300 s. At 300 s, the right motor fails and the power is 0. The three attitude angles of the UAV begin to diverge, and the height of the UAV begins to drop. We need to change the control strategy, so the UAV can drop smoothly.

Taking the right motor fault as an example, we should change the control strategy. In the initial state, the main motor of UAV is faulty, the tail motor is tilted to the right at 90°, and the angle of attack is 2°

at a height of 100 m, the command of a height of 0 m is also added at 200 s to make the UAV fall horizontally. The simulation results are shown in the figure 3:

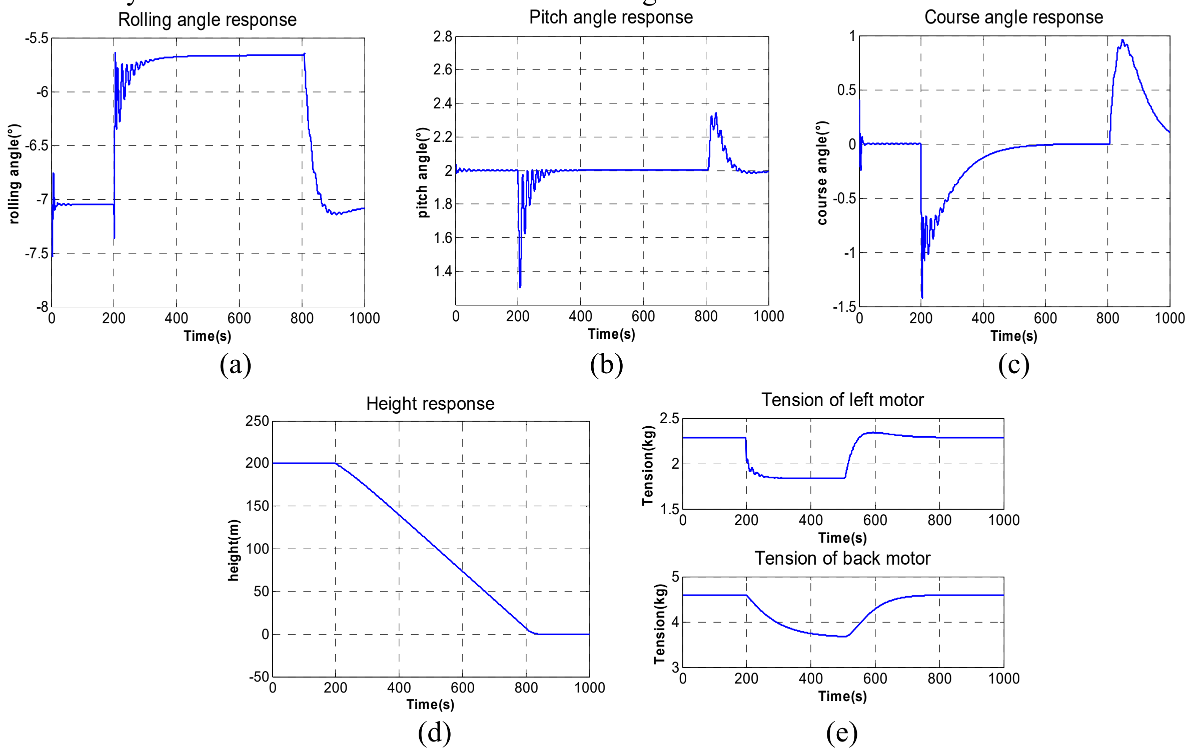

Figure 3. Simulation results.

Due to the addition of a lateral force, the UAV should have a certain roll angle to counteract the lateral forces generated by the tail motor. These figures show that the UAV can fall horizontally by changing control strategy.

5. Conclusions

When there is no fault, the system has good dynamic performance. When the fault occurs, the dynamic performance of the system becomes worse. After the reconstruction, the control effect is obviously improved. The reconstruction control law method is applicable to the unmanned tiltrotor aircraft to improve the safety performance of the UAV and reduce the probability of an accident.

References

[1] Anderson S B. An overview of V/STOL aircraft development. 1983 *Aircraft Design, Systems and Technology Meeting(Houston)* **2491** 1-13.
[2] Foster M. The Future Evolution of the Tiltrotor. 2003 *AIAA/ICAS International Air and Space Symposium and Exposition: The Next 100 Years, AIAA Paper.* **2652** 1-9.
[3] Bolkcom C. V-22 Osprey Tilt-Rotor Aircraft. 2007 *CRS Report for Congress*.
[4] Amarillo T. V-22 osprey pocket guide. 2007 *Bell Boeing V-22 Program Office*.
[5] Rafael I R. Optimal guidance laws with uncertain time of flight. 2000 *IEEE Transactions on Aerospace and Electronic Systems*. **36** 721-5.
[6] Lim S Y, Shin J Y. Fault tolerant controller design using hybrid linear parameter-varing control. 2003 *AIAA Guidance, Navigation, and Control Conference and Exhibit, AIAA Paper.* **5492** 11-4
[7] Bajpai G, Chang B C, Lau A. Reconfiguration of flight control systems for actuator failures. 2001 *IEEE AESS Systems Magazine*. **30** 29-33.