**SCIENCE CHINA**
Information Sciences

• **MOO PAPER** •

March 2016, Vol. 59 033201:1–033201:4
doi: 10.1007/s11432-015-5505-5

# Variable thrust directional control technique for plateau unmanned aerial vehicles

Yin WANG[1] & Daobo WANG[2]*

[1]*College of Astronautics, Nanjing University of Aeronautics and Astronautics, Nanjing* 210016*, China;*
[2]*College of Automation Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing* 210016*, China*

Received October 9, 2015; accepted November 19, 2015; published online January 21, 2016

**Abstract** In order to increase the lift force of the unmanned aerial vehicles (UAV) in plateau areas, the UAV is commonly equipped with high span chord ratio wings. However, it may decrease the maneuverability of the aircraft, and thus increasing the risk of flight in complex terrain regions. Thrust vector control is a direct force flight control technique, which enhances the maneuverability and introduces the residual of the flight control system. In this paper, we develop a novel variable thrust direction mechanism, which provides the normal propeller UAV with the capability of directional force control. We propose a combinational flight control strategy for the newly developed UAV. Simulations and real flight test demonstrate the performance of the proposed technique in increasing the maneuverability of the conventional propeller UAV.

**Keywords** unmanned aerial vehicle, thrust vectoring control,combination control, plateau application, propeller engine

**Citation** Wang Y, Wang D B. Variable thrust directional control technique for plateau unmanned aerial vehicles. Sci China Inf Sci, 2016, 59(3): 033201, doi: 10.1007/s11432-015-5505-5

## 1 Introduction

The unmanned aerial vehicles (UAV) designed for plateau missions are usually installed with high span chord ratio wings, which provides more lifting force at a relatively low airspeed. The UAVs employ high span chord ratio wings, however, tend to lose their maneuverability. Hence, they usually need larger turning radius and unable to maintain the altitude during sharp slope turning as the lifting force produced by the wings decrease dramatically when the bank angle is large. The discarding of the flight performances may risk the safety of the flight in plateau mountain regions. Variable thrust direction (VTD) technology is a type of thrust vectoring control (TVC) approach that allows to manipulate the directions of thrust to the fuselage of the aircraft. In addition to the conventional aerodynamic control surface of aircraft, the VTD technique produces direct and instantaneous control forces to the aircraft, and thus increasing the maneuverability of the plane [1–3]. TVC technique is employed to control an aircraft's motions in roll, pitch and yaw, at low airspeeds and very high angles of attack, both of which are otherwise inoperable flight regimes [4–6]. In the application of TVC to the aircraft, the actuators are commonly employed to alter the direction of the engines [7–9], which requires coordinating the motions

* Corresponding author (email: dbwangpe@nuaa.edu.cn)

 

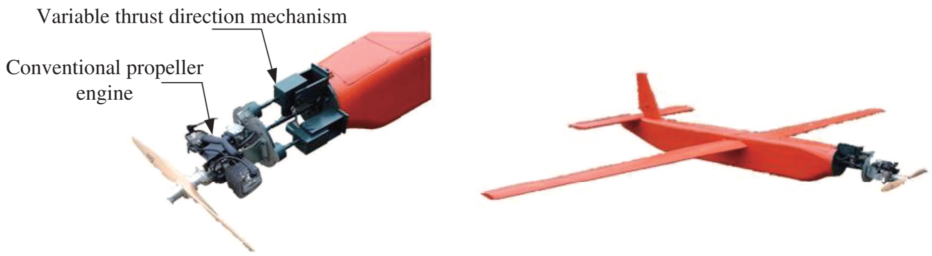


**Figure 1** (Color online) The proposed variable thrust direction mechanism.

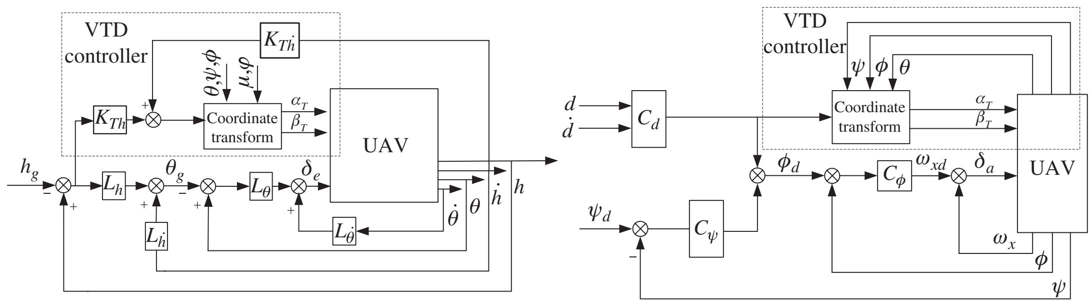


**Figure 2** The schematic diagram of the VTD UAV flight controller.

of the actuators in order to moving the engine in the pitching and yawing directions. Coordinated control techniques [10–12] are used to address the coupled control problems. To the best of our knowledge, most of the existing works are designed for jet engines, which cannot be applied to the conventional propeller engine aircraft. In this paper, we develop a novel VTD mechanism to the conventional propeller engine UAV, which allows redirecting parts portion of the thrust from the propeller engine to other directions rather than normal axial direction. A combination flight controller for the VTD enhanced UAV is then proposed to coordinate the VTD controlled forces and aerodynamic surfaces forces. Finally, we verify the performance of the proposed VTD technique, in terms of the maneuverability, via both simulations and real flight test.

## 2 The proposed VTD mechanism

The proposed variable thrust direction mechanism is shown in Figure 1, a conventional propeller engine is mounted on a two dimensional rotate disk, which is driven by two servo actuators. By combining the linear motions of the actuator, both the azimuth and the altitude angle of the disk with respect to the fuselage can be controlled, and thus changing the thrust direction of the propeller.

## 3 The flight control of the VTD UAV

As shown in Figure 2, the control schedule was employed that both the conventional control loop for aerodynamic surfaces and a VTD controller were used. Within conventional longitude control loop the error between desired height and actual height was used to drive the elevators and keep height constant. The error also was used to drive direction of thrust of propeller to land and provide a direct lift.

For the latitude loop, both the conventional control loop and VTD control outputs are working coordinately to ensure the UAV flight on the desired path. Both the position feedbacks and the navigation information are used, providing directly control force and torque to the aircraft. Therefore, the performances of the UAV, in terms of the tracking capability and maneuverability, can be improved when compared with conventional propeller engine UAV.

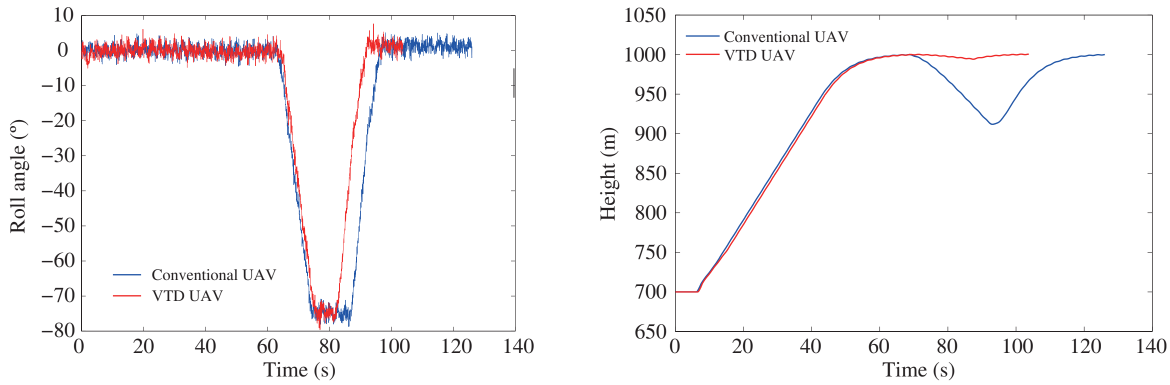


**Figure 3** The roll angle (left) and altitude (right) responses the UAV with (blue) and without (red) of the proposed VTD control technique in the simulation scenario.

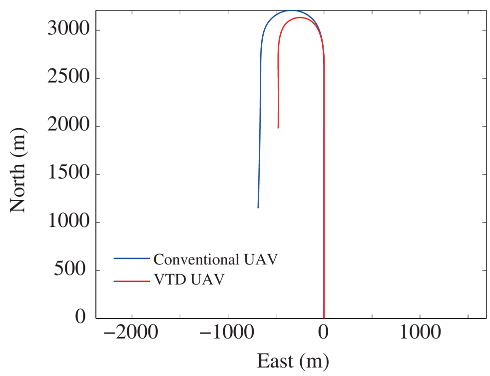


**Figure 4** The trace of the UAV with (blue) and without (red) the VTD control technique in the simulation scenario.

## 4 Implementation

To demonstrate the efficiency and flexibility of the proposed propeller variable thrust technique in improving the maneuverability of the UAV, we verify our method through ground simulations and flight test. The simulations were carried out under VC environment in an industrial PC. In the simulation, the UAV firstly climb to 1000 m from its initial flight level, and then the UAV is required to turn around with a bank angle up to 75 degrees.

Figures 3 and 4 depict the simulation results of the propeller plateau UAV with and without the proposed VTD control technique. It can be observed from Figure 3 that the conventional UAV starts losing altitude when the bank angle increasing, this is because the amount of the aerodynamic lifting force produced by the wings becoming smaller when the UAV keeps increasing the turning angle. On the other hand, the UAV with VTD control technique is capable of maintain its flight level during the sharp turning, since the VTD engine can compensate for the lift force. Moreover, the turning radius of the VTD enhanced UAV is smaller than the conventional propeller UAV as shown in Figure 4.

## 5 Conclusion

In this paper we present a novel variable thrust direction control technique for conventional low cost propeller UAVs. The thrust direction deflection device is designed with a simple yet reliable mechanism and a combinational flight control strategy is developed. By the introduction of the VTD capability to the conventional propeller UAV, the maneuverability of the UAV has been greatly enhanced, since the VTD engine enables direct force control of the aircraft. The newly developed VTD UAV was applied to implement plateau missions, which demonstrates the usefulness of the proposed technique.

**Supporting information** The supporting information is available online at info.scichina.com and link.springer.com. The supporting materials are published as submitted, without typesetting or editing. The responsibility for scientific accuracy and content remains entirely with the authors.

**Acknowledgements** This work was supported by National Natural Science Foundation of China (Grant No. 61503185).

**Conflict of interest** The authors declare that they have no conflict of interest.

## References

1 Victoriagatlin R, Kempel D, Matheny R. The F-18 high alpha research vehicle—a high-angle-of-attack testbed aircraft. In: Proceedings of 6th AIAA Biennial Flight Test Conference, Hilton Head Island, 1992. AIAA-92-4121
2 Sparks A, Buffington M, Banda S. Fighter aircraft lateral axis full envelope control law design. In: Proceedings of 2nd IEEE Conference on Control Applications, 1993. 21–26
3 Atesoglu Ö, ÖzgÖren K. High-alpha flight maneuverability enhancement of a twin engine fighter-bomber aircraft for air combat superiority using thrust-vectoring control. In: Proceedings of AIAA Guidance, Navigation, and Control Conference and Exhibit, Keystone, 2006. AIAA 2006-6056
4 Sutton G P, Biblarz O. Rocket Propulsion Elements. 7th ed. New York: John Wiley and Sons, 2001. 608–623
5 Berrier B L, Taylor J G. Internal performance of two nozzles utilizing gimbal concepts for thrust vectoring. NASA TP-2991, 1990
6 Kuang M, Zhu J. Hover control of a thrust-vectoring aircraft. Sci China Inf Sci, 2015, 58: 073201
7 Hall C E, Shtessel Y B. Sliding mode disturbance observer-based control for a reusable launch vehicle. J Guid Control Dyn, 2006, 29: 1315–1328
8 Brown D, Georgoulas G, Bae H, et al. Particle filter based anomaly detection for aircraft actuator systems. In: Proceedings of IEEE Aerospace Conference, Big Sky, 2009. 1–13
9 Hu C, Yao B, Wang Q. Coordinated adaptive robust contouring control of an industrial biaxial precision gantry with cogging force compensations. IEEE Trans Ind Electron, 2010, 57: 1746–1754
10 Cho J U, Le Q N, Jeon J W. An FPGA-based multiple-axis motion control. IEEE Trans Ind Electron, 2009, 56: 856–870
11 Lin F J, Chou P H. Adaptive control of two-axis motion control system using interval type-2 fuzzy neural network. IEEE Trans Ind Electron, 2009, 56: 178–193
12 Gao J, Hu Y W. Direct self-control for BLDC motor drives based on three-dimensional coordinate system. IEEE Trans Ind Electron, 2010, 57: 2836–2844