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TRAJECTORY GENERATION AND CONTROL FOR PERCHING MANEUVERING WITH QUADROTOR

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Abstract

Micro quadrotors have great applications in the area of military events, civil use and scientific research due to its tiny size, agility and portability. However, miniaturization reduces the space of energy storge, leading to the loss of endurance and deterioration of deployment performance. Perching maneuvering, originating from birds perching, is a hot topic for exploring the solution for extending the endurance of micro quadrotor. This method aims to take the advantage of maneuverability to achieve perching the quadrotor on the inclined or vertical surface with the help of perching mechanism. When perching, interaction force from vertical surface could afford the gravity of quadrotor and there is no need to maintain the aerodynamics. Therefore, motors could be turned off and energy consumption would be much less than flight. Perching maneuvering involves complex problems such as motion control. In this paper, perching control is solved by trajectory generation and track control. First, dynamics model is built to describe the motion of perching quadrotor and the model is further simplified into longitudinal model. Then, planning trajectory is generated and initial state is set with reference to the perching restrictions. Finally, geometry control method is applied to achieve the tracking control and modified method is also brought up to make the track more precisely, which is verified in the Simulink experiments.

Keywords: Micro Quadrotor, Perching Maneuvering, Trajectory Generation, Tracking Control.

1. Introduction

1.1 Background

Micro quadrotor, a current hot topic, has great applications in military events, civil use and scientific research. In military events, quadrotors could be equipped with squad or soldiers, executing the tasks of inspection and destruction. For civil use, quadrotors play the role as mapping, monitoring, data gathering or air camera. In scientific research, quadrotors turn into an ideal platform for multidisciplinary integration, including concept design, flight control, sensor, navigation, MEMS technology, et al. Although bringing advantages in maneuverability and portability, miniaturization also causes shrinking energy storge space, leading to discount in endurance and deterioration of performance. There-fore, there is great need to explore the solution to extend the endurance of micro quadrotor with tiny size.

Originated from bird perching behavior, perching maneuvering is an effective method to extend the endurance for micro quadrotor. This bionic strategy, imitating the bird landing on the ground or branches, give quadrotor the ability to perch on the surface of room and buildings with the aid of perching mechanism. When perching, resting quadrotor no longer requires thrust from rotor because the gravity will be afforded by the interaction force from the surface. Therefore, rotors could be turned off in perching, which means much less energy consumption and longer endurance.

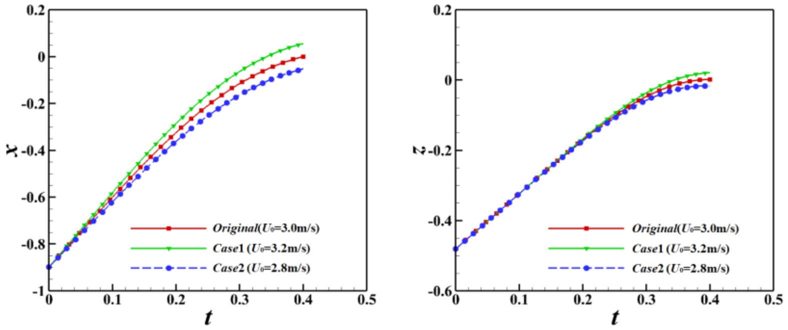
1.2 Research status of perching quadrotor

Domestic and foreign study about perching maneuvering concentrates on perching mechanism, motion planning and control design. To generate the attachment force, researchers develop the mechanism that could make use of macroscopic interaction, van der Waals force and atmosphere pressure. Morgan from Stanford combined the quadrotor with micro spines and developed the multi-modal robot that could fly, perch and climb on outdoor surface. Hawkes developed the dry adhesive pad, utilizing the van der Waals force. Directional adhesive comes when shear force is applied in the

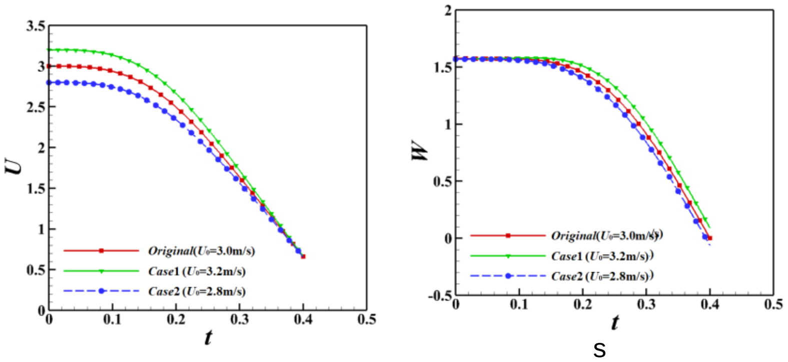
Table 2 Parameters of Simulation Experiments

Case Name	z	U_0	W_0
Nominal Trajectory	0	3	0
Case1	0	3.2	0
Case2	0	2.8	0
Case3	0	0	0.2
Case4	0	0	-0.2
Case5	0.02	0	0
Case6	-0.02	0	0

Case1 and Case2 set error on the initial horizontal velocity. The results in tracking control are shown in Fig2



(a) *t-x* (b) *t-z*



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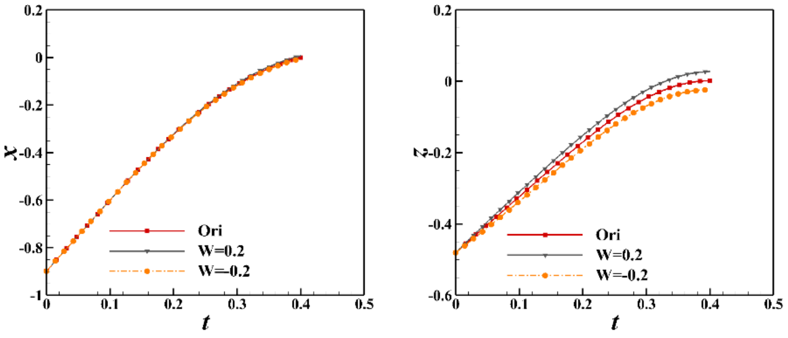
(c) *t-U* (d) *t-W*

Fig. 2 Control Results with horizontal velocity error



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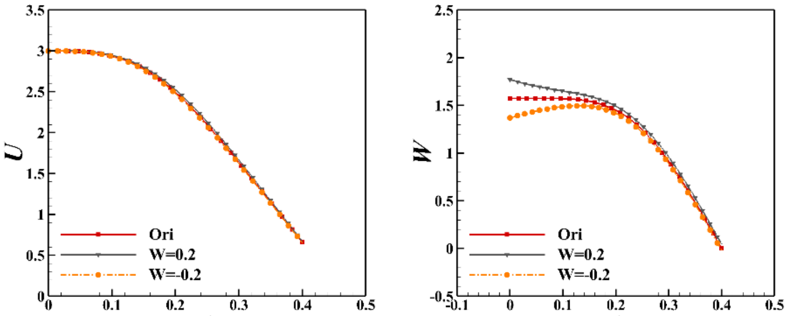
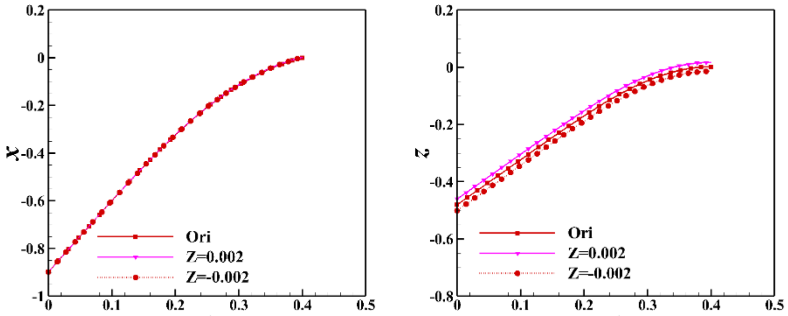
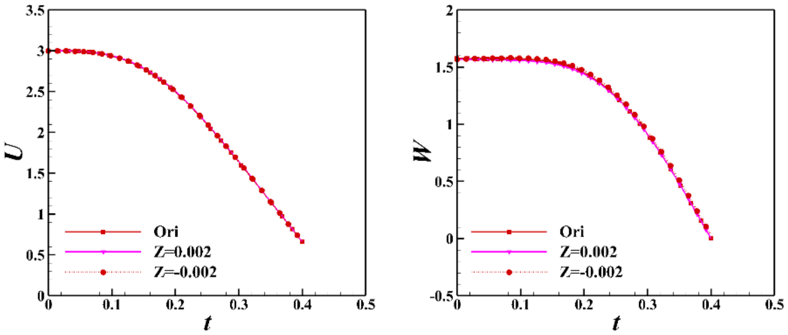


(c) *t-U* (d) *t-W*

Fig. 3 Control Results with vertical velocity error



(a) *t-x* (b) *t-z*



(c) *t-U* (d) *t-W*

Fig. 4 Control Results with vertical velocity error

4.3 Modified Tracking Control Method for Perching

The test of geometry tracking control in subsection 3.2 shows that geometry tracking control could achieve tracking control of nominal trajectory, but this method is not completely suitable for this problem. For instance, in case1, a slight increase of initial horizontal velocity leads to higher average velocity and early cut-off in trajectory. In case1, the time of contact is 0.343s, which is less than the estimated time. However, the normal contact velocity arises from 0.659m/s to 1.263m/s and tangential contact velocity grows to 0.244m/s, which is unexpected for successful perching. Therefore, original geometry tracking control is not entirely appropriate for the task of perching.

In order to improve the control effects, we review the theory of geometry tracking control and the characteristics of quadrotor perching again. It is found that quadrotors with different initial states fly across the same distance in perching while trajectory tracking algorithm executes with error signal at current moment and doesn't response to current position feedback. Thus, current tracking algorithm can only deal with the convergence of velocity in finite time but can't achieve convergence of displacement. That's why the tracking algorithm will finish ahead of schedule or exceed the estimated time.

In this paper, we modify the control method by setting the position and velocity feedback based on position interpolation instead of time interpolation. The flow chart of modified method is shown as blow. The results of modified control method are shown in Fig 13.

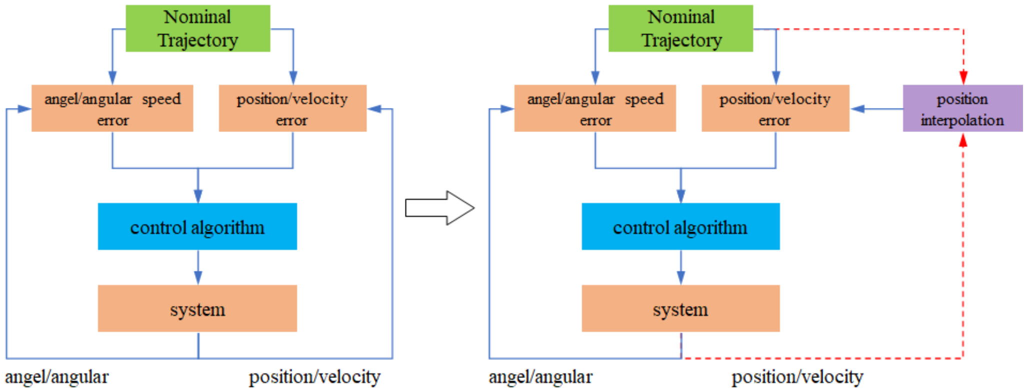
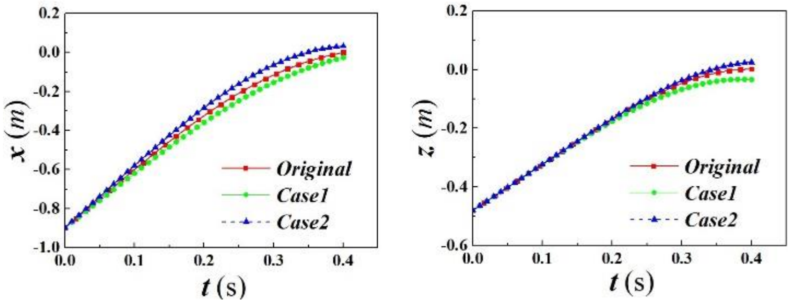
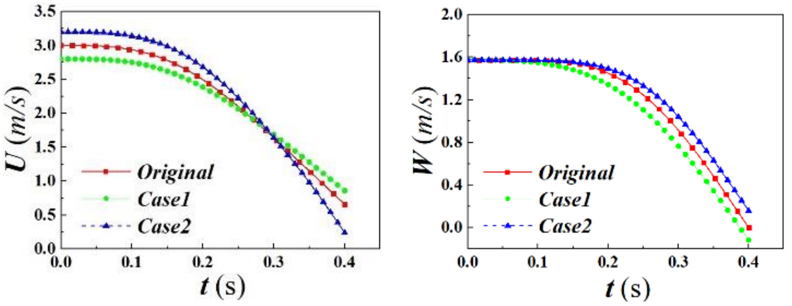


Fig. 5 Flow chart of modified control method



(a) *t-x*　　　(b) *t-z*



(c) *t-U*　　　(d) *t-W*

Fig. 6 Control Results with horizontal velocity error for modified control method

In Table 3, simulation results of different cases are shown with geometry tracking control and modified control method. The name, original, shows the result of planning trajectory. The name, case, shows the parameter setting in Table 2. The suffix, GTC, means geometry tracking control used in simulation while Mod means modified method.

In the simulation of Case0, both methods achieve precise tracking control with no initial error. While in case1 and case2, modified control method has better performance in converging the disturbance of initial velocity. In case1, initial horizontal velocity has increment of 0.2m/s and geometry tracking control lands the quadrotor with 1.263m/s, while modified could reduce the contact speed to 1.010m/s.

Table 3 Simulation Results for Modified Control Method

Case Name	T_{att}	z	U	W	θ
Original	0.4	0.002	0.659	0.000	-1.571
Case0-GTC	0.4	0.002	0.661	0.012	-1.573
Case0-Mod	0.4	-0.005	0.618	0.009	-1.557
Case1-GTC	0.343	0.000	1.263	0.344	-1.515
Case1-Mod	0.348	0.004	1.010	0.109	-1.509
Case2-GTC	0.4	-0.017	0.655	-0.063	-1.555
Case2-Mod	0.4	-0.034	0.858	-0.115	-1.514

Case3-GTC	0.39	0.026	0.769	0.143	-1.573
Case3-Mod	0.385	0.013	0.765	0.182	-1.551
Case4-GTC	0.4	-0.024	0.653	-0.019	-1.568
Case4-Mod	0.393	-0.025	0.711	0.051	-1.555
Case5-GTC	0.397	0.017	0.691	0.027	-1.572
Case5-Mod	0.389	0.012	0.737	0.110	-1.554
Case6-GTC	0.399	-0.013	0.671	0.037	-1.572
Case 6-Mod	0.389	-0.024	0.738	0.121	-1.554

5. Conclusion

Perching maneuvering is an effective way for quadrotors to extend its mission endurance. In this paper, trajectory planning and tracking control are applied in perching the quadrotor on vertical surface. In trajectory planning, we set the open-loop trajectory and solve the initial states referring to the constraints and trajectory displacement. Then, tracking control method is applied to guide the quadrotor to achieve precise landing.

In the simulation of geometry tracking control, it is found that initial velocity disturbance will lead to termination in tracking ahead of time, resulting in excursion in desired landing states. Reviewing the basic principles of geometry tracking control and the features of perching maneuvering, we find that tracking control respond to trajectory error in time while the termination is decided by position. Hence, geometry tracking control is not completely suitable for the problem of perching. Therefore, based on analysis above, modified method is brought out by replacing the time-domain error feedback by position interpolation for position and velocity. Simulation experiments show that modified method could achieve better tracking results.

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