Variable-Pitch Control of a Quadrotor using Feedback Linearization Controller and Direct Adaptive Feedback Linearization Controller

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1. Introduction

Due to their small dimensions, vertical takeoffs and landing and significant capabilities in various flight maneuvers, as well as extensive operational applications, quadrotors have been the focus of scientific research. Depending on the specific desired applications which users need, different modeling and appropriate selection of design control tools seem necessary. In turn, controlling quadrotor needs a proper control to: 1. achieve stability, robustness and desired dynamic properties, 2. have the ability to do nonlinear control, and 3. have the ability to adapt to changing parameters and environmental changes. The aim of this research is to propose a control method that allows different states of quadrotors to be converged to an arbitrary set of variable time reference states.

The fixed pitch quadrotor has been the focus of scientific studies because of having a simpler dynamic structure than other models. This kinds of quadrotors, despite their relative simplicity, create limitations such as shortening the flight time and various maneuvers.

Limited research has been conducted on the variable pitch quadrotor. The present research studies the development of a dynamic flight model for the variable pitch quadrotor. BET theory combined with Momentum theory is used to estimate the thrust and torque of each of the rotors as the blade's angular performance to develop a simple fly-out mechanical model and feedback linearization and direct adaptive feedback linearization controllers are used to control the variable pitch quadrotor. In general, this study addresses two issues: 1. creating a dynamic model for variable pitch quadrotor; 2. designing a feedback linearization and adaptive feedback linearization controller for stabilizing and tracking paths against changes in the system model.

2. Specifications of Variable Pitch Quadrotor

Firstly, the meaning of variable pitch in variable pitch quadrotor is discussed. The term pitch is taken from the distance between two teeth of a screw, so that with a rotation of the screw by one tooth along the axis perpendicular to it, the movement occurs by one pitch. In systems with rotating propellers like quadrotor, the pitch is obtained from the angle of the quadrotor propellers relative to each other. In fixed pitch quadrotor, it is not possible to change the angle of the rotor propellers, and the angle of the rotor propellers is fixed, and the movement of the quadrotor can be controlled only by increasing or decreasing their speed. However, the variable pitch means that it is possible to change the angle of the rotor propellers. In a variable pitch quadrotor, the speed of the rotors is constant and the movement of the quadrotor is controlled by changing the angle of the rotor propellers.

Features resulting from the addition of variable pitch propellers to the quadrotor include:

1. Wider control bandwidth;
2. Significant increase in flight duration;
3. Possibility of creating reverse force by rotors.

In Figure 1, the rotor structure with variable pitch propellers is shown.

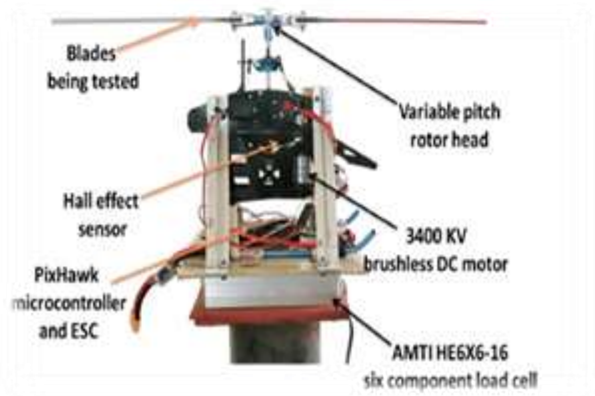

Figure 1. The rotor structure with variable pitch

3. Modeling the Variable Pitch Quadrotor

In this section, the variable pitch quadrotor control method, which is significantly different from conventional quadrotor based on fixed pitch propellers, is firstly investigated and the Newton-Euler equation of six degrees of freedom (Six-DOF) of variable pitch quadrotor is derived.

4. Controller Design

In this section, the design of the feedback linearization controller to control the variable pitch quadrotor is discussed. Since the precise elimination of nonlinear dynamics, as required in feedback linearization, is difficult in practice and in addition system parameters can be variable in time. To do this, a direct nonlinear adaptive control method is proposed. The asymptotic stability of this method has been proved by a variable based on Lyapunov theory. The adaptive method improves the performance of the feedback linearization

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directly by reducing the tracking error. This is done by modifying the parameters and the controller gains, based on the tracking error. The controller's goal is to reduce the tracking error, not necessarily the parameter estimation error. However, if the inputs are rich enough, the correct values of the parameters will also be obtained in the estimation.

5. Simulation Results

In this section, the simulation results of the feedback linearization controller and the adaptive variable pitch quadrotor feedback linearization controller are presented.

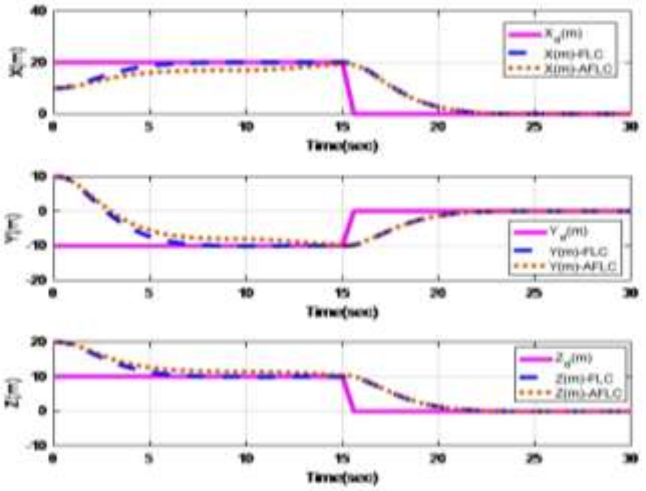

Figure 2. Position tracking with feedback linearization control and adaptive feedback linearization control

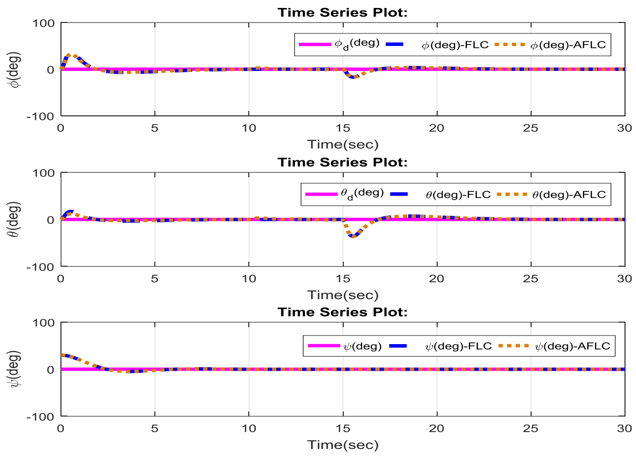

Figure 3. Attitude tracking with feedback linearization control and adaptive feedback linearization control

As can be seen in Figures 2 and 3, tracking is well done by both controllers.

6. Conclusion

In this paper, a variable pitch quadrotor's flight and control was analyzed. Compared to a fixed pitch quadrotor, these capabilities greatly increase the possibility of aggressive and acrobatic maneuvers, which indicates improved performance.

In the continuation of this article, feedback linearization and direct adaptive feedback linearization controllers were introduced. The designed feedback linearization controller has a good performance and the tracking of the position and attitude of the variable pitch quadrotor is done correctly using this controller. The introduced direct feedback linearization controller also automatically changes the parameters to achieve accurate tracking. Using Lyapunov's theory, it is proved that this controller is stable. The simulation results show that the adaptive strategy allows the quadrotor to follow variable time attitudes and altitude commands more accurately compared to non-adaptive linearization feedback controllers in the presence of disturbances or parameter errors. The adaptive approach has also had favorable results for tracking the position and attitude of the variable pitch quadrotor. Finally, the results of feedback linearization and adaptive feedback linearization controllers are compared with PID controller that it is shown adaptive linearization feedback and linearization feedback controllers have a better performance in reference tracking and reducing tracking errors.

Moreover, the results of feedback linearization and adaptive feedback linearization controllers with sliding mode and adaptive sliding mode controllers are also compared in quadrotor mass change conditions which show that adaptive feedback linearization controllers and adaptive sliding mode controllers have a high accuracy in reference tracking and little error in position and attitude tracking. This indicates that they performed better than the non-adaptive mode.