別紙４－１（課程博士（英文））

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Abstract (Doctor)

Title of Thesis	Adaptive Nonlinear Control for Robust Trajectory Tracking Control and Energy Saving of a Quadrotor Helicopter

Approx. 800 words

Quadrotor helicopter or quadcopter unmanned aerial vehicles (UAV) have attracted research interest due to its wide range of applications such as navigation task (surveillance, mapping, rescuing, etc.) and recently, physical interaction task (environment and manipulation of object). This is due to the relatively small body, low mechanical complexity, highly maneuver motion, and energy consumption. The control performance is always influenced by aerodynamic forces and gyroscopic effect, and also by variation of altitude and wind payload and its resources. The characteristic of quadcopter dynamics is nonlinear and coupled, and therefore it requires a robust controller to compensate for the uncertainties and external disturbances. In real application, the quadcopter operation is unable to have long time and also use a limited power source. Because of this reason, the quadcopter should consider the energy consumption in its operation, when the energy can be saved then it can lengthen the operational time.

The main objective of this thesis is to design adaptive nonlinear for robust tracking and energy saving control based on sliding mode control (SMC) of quadcopter dynamics. More specifically, this thesis is focused to design SMC strategy which are effective in controlling systems affected by uncertainty/disturbance. The conventional sliding mode controller is presence of high frequency oscillations in the control input which is known as chattering that may damage the actuators and increase the energy consumptions. Another disadvantage in most SMC design is the requirement of information about boundary of disturbance which is not easily obtained in practical cases.

An adaptive gain tuning mechanism based on super twisting algorithm (STA) can estimate the uncertainty adaptively is proposed in this thesis. Therefore, the information about boundary of uncertainty/disturbance is not needed in the proposed adaptive STA-SMC. The idea of adaptive sliding mode is dynamically increased the control gain until reaching the 2-sliding mode. Then the control gain will start reducing and can be reversed as soon as the sliding variable or its derivative start deviating from the equilibrium point of 2-sliding mode. Therefore, a boundary layer of sliding mode as "limiter" is used in this adaptive STA-SMC that prevents the control gains overestimated.

When the condition of sliding variable is under boundary layer, then the control gain is dynamically reduced until the condition is reversed. Then the control gain will dynamically increase to force the sliding variable reaching to the previous condition in finite time.

The proposed adaptive sliding mode strategy is used to design a modified super twisting algorithm controller which is a second sliding mode controller for quadcopter. To improve the transient performance of the quadcopter, a nonlinear sliding surface based adaptive chattering free sliding mode controller is proposed. The nonlinear sliding surface changes the closed-loop dynamics damping ratio from its initial low value to a final high value in accordance to the error magnitude. Therefore, fast initial response and gradually decreased overshoot will be occurred.

This dissertation mainly consists of three parts. First part of thesis describes the kinematic and dynamic model of a quadcopter. The model is obtained by applying the Newton-Euler formulation for 6-DOF rigid-body in free motion with two reference coordinate frames. In addition, the thrust force of real motor is obtained from empirical formula with respect to the voltage, the resistance of real motor is estimated to obtain the energy consumption, and the quadcopter experimental testbed used in this works is explained together with the sensors configuration including parameters of the experimental testbed.

Second part of thesis describes the construction of cascade control structure based on the dynamics, translational and rotational dynamics; and application of the velocity states estimator based on a reduced-order observer which estimates from a continuous-time dynamic model by considering the discrete-time control system. Virtual input is introduced to solve the underactuated problem in control structure and create fully-actuated system then become a decoupled system; therefore, the input on each motion can be controlled independently with any control algorithm. The effectiveness of the control structure and the observer experimentally is verified by using a sliding-mode controller and compared the results to those of a backward-difference method combined with a low-pass filter. The reduced-order observer gives relatively higher gain for the closed-loop controller, hence greatly reducing tracking error.

Third part of thesis presents robust tracking and energy saving control for quadcopter with the combination of the second order SMC based on modified-super twisting algorithm with gain adaptive (ASTA) and nonlinear sliding surface (NLSS). The Lyapunov stability theory is applied to prove stability of the proposed method in and out of sliding mode. A comparative study with STA and ASTA was conducted. In simulations are performed to verify the effectiveness of the proposed method, and there is no significant difference between ASTA with NLSS (ASTAN) and ASTA approaches. The effectiveness and reliability of the proposed method in the experimental testbed with two condition disturbances (without disturbance and under wind disturbance) are evaluated by performing several times experiments. In experimental results show that the ASTAN provides robust tracking performance with less energy.
The last part of dissertation is summary and future works are described.