別紙４（課程博士）

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Abstract

論文内容の要旨　（博士）

Title of Thesis 博士学位論文名	Robust and Energy-Efficient Controller Design for a Quad-Rotor Helicopter （４ロータヘリコプタのロバスト省エネルギー制御）

(Approx. 800 words)

（要旨　1,200 字程度）

Unmanned aerial vehicles (UAVs) have been applied for many applications such as surveillance, traffic monitoring, or monitoring areas surrounding a damaged nuclear plant where risks to a pilot are relatively high. Rotorcrafts have advantages over fixed-wing UAVs in numerous applications because of their vertical take-off and landing capability, and their augmented payload capacity. A quad-rotor helicopter (quadcopter) is a rotorcraft that has many advantages compared to a conventional helicopter because of its compactness, simple mechanical parts, and its high maneuverability. In addition, a quadcopter provides a large lift thrust force than a conventional helicopter, and payload capacity is increased. However, the quadcopter has highly nonlinear, time varying behavior, and always influenced by unpredictable disturbance, such as wind gust, especially in outdoor application. Therefore a robust control strategy is required to achieve good performance during autonomous flight. In its application, the quadcopter is provided with a limited power source. Therefore, an energy efficient controller is useful to extend the time operation of the quadcopter.

In this thesis, the robust and energy efficient control strategies are designed based on the sliding mode control algorithm. The underactuated problem which occurs in the dynamics of the quadcopter is solved by designing a cascade control structure which consists of two control loops, inner loop and outer loop. The inner loop handles the rotational motion of the quadcopter while the outer loop handles the translational motion. The least squares algorithm is utilized to solve the overdetermined problem in the translational dynamics and therefore all motions are considered for calculating the control inputs. This control structure is generic thus may be used for designing any control algorithm for the quadcopter.

In order to design a robust controller, firstly, we design a standard sliding mode control algorithm. The energy saving is attempted by reducing the chattering, which is a common problem in the sliding mode control design, by designing a thin boundary layer around the sliding surface. This technique is effective to reduce the energy consumption which is evaluated experimentally with the quadcopter experimental testbed. However, the robustness of the sliding mode control is reduced because inside the boundary layer, the discontinuous control law is replaced with a continuous one. Nevertheless, the discontinuous control law provides the robustness in the sliding mode control strategy. Secondly, we improve the performance of the sliding mode control strategy by

designing the nonlinear sliding surface. We propose two nonlinear sliding surfaces which have different characteristic. The first nonlinear sliding surface is designed for reducing the time constant if the error increases and therefore the control system responses faster to reduce the error. If the error is reduced converging to zero, the time constant increases and converges to a constant value. In contrarily, the second nonlinear sliding surface is designed to increase the time constant if error increases, and the time constant decreases converging to a constant value if error decreases convergence to zero. These techniques are also effective to reduce the energy consumption in the condition under disturbance which is evaluated in the experiment.

Reducing the chattering and designing the nonlinear sliding surface are effective to reduce the energy consumption in the sliding mode control strategy. However, it is also important to keep the discontinuous control input that causes the chattering, because it provides robustness in the sliding mode condition. The second order sliding mode control with super twisting algorithm (STA) provides a good solution for reducing the chattering phenomenon by keeping the discontinuous control part. The discontinuous control input occurs in the second order time derivative of the sliding surface function while in the standard sliding mode control strategy, it occurs in the first order time derivative. However, the original STA algorithm only provides strong behavior around the origin of the sliding surface. To provide strong behavior when the states are far or close to the origin of the sliding surface, the generalized-STA includes a linear stabilizing term. Furthermore, to reduce the energy consumption during the control operation, we utilize the nonlinear sliding surface. The robustness and energy efficiency of the generalized-STA with the nonlinear sliding surface are evaluated experimentally with the quadcopter experimental testbed.