A Sliding Mode-Based Amplitude- and Rate-Saturated Controller and Its Application to Wind Turbine Systems

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論 文 名　：　A Sliding Mode-Based Amplitude- and Rate-Saturated Controller and Its Application to Wind Turbine Systems
（出力の大きさと時間変化率に制限があるスライディングモード・ベースト制御器と，その風力タービンシステムへの応用）

区　　分　：　甲

論 文 内 容 の 要 旨

Systems' actuators like pumps, valves, and compressors have movement limitations and threshold capacity. These limitations protect the controlled plants from drastic commands and physical wear such as in aerodynamics systems, and if these limitations are not handled and respected through the control method, it may cause unexpected behavior or performance degradation ending with crashes. Some flight incidents have been recorded in which the extreme pitching-action caused circling and instability that ended with an accident. On another side, some studies of wind turbine systems show that a reduction in the oscillations' amplitude of the generated torque and power significantly improves the lifetime of the mechanical parts, and consequently, it improves the maintenance cost of such systems.

The behavior of closed-loop systems under limitations on both of the actuator signal's amplitude and the actuator signal's rate-of-change is the main interest of this dissertation. A constraint on the actuator signal's amplitude, unfortunately, converts a linear controlled plant into a nonlinear one, and imposing constraints on the actuator signal's rate-of-change further complicates the stability problem. A major problem raised in these systems is the trade-off between the stability region and the closed-loop performance, where a low-gain control action is a good solution to prevent the actuator from being saturated, but it does not allow the controlled plant to work at high performance, especially in the presence of uncertainties or external disturbances. This dissertation is going to adopt a new sliding-mode technique to deal with the aforementioned limitations.

Chapter 2 proposes a new nonlinear controller applicable to single-input linear systems under bounded disturbance. The controller provides control signals satisfying specified amplitude and rate-of-change limitations. The limited rate-of-change is realized by the sliding mode-like structure comprising a set-valued function, while the control signal's amplitude is limited by a saturation function, implemented inside the set-valued function. The limited control action here is considered as an additional state besides the original states of the system, and the sliding mode feature effectively transforms the relatively high order system to a lower order system to facilitate the controller design. The controller also employs a nonlinear parameter, which is designed to be inversely proportional to the control action. It holds at high values when the state is far from the origin, and consequently, it facilitates a

large region of attraction. Meanwhile, this nonlinear parameter holds at low values after the state comes near the origin to consequently produce a high-gain control action, which is a classical method used to reduce the effects of disturbances. This chapter also proposes a discrete-time implementation of the proposed controller based on a model-based implicit discretization scheme. The validity of the proposed controller is tested by simulations.

Chapter 3 presents a selection procedure to obtain parameter values of the proposed amplitude- and rate-saturated controller. The proposed selection procedure involves a set of linear matrix inequalities and also includes iterative computation. The effectiveness of the proposed selection procedure is shown through a comparison with the parameter-tuning guideline of Chapter 2.

Chapter 4 applies the proposed controller of Chapter 2 to a nonlinear system, which is a wind turbine system. The proposed controller in this chapter is a collective pitch controller to maintain the generator speed constant in the region above the rated wind speed. This controller satisfies the amplitude and rate limitations imposed by the pitch actuator system. Due to the features of the proposed controller of Chapter 2, a low-gain control action is produced when there is a significant variation in the wind speed to avoid the performance degradation that may happen due to the limitations of the pitch actuator. Moreover, the controller produces a high-gain action when the system's state is near the origin to reject the wind speed variations and to regulate the generator speed. The proposed controller is validated by applying it to a three-bladed horizontal-axis wind turbine emulated by a software simulator (FAST). The proposed controller is compared with a gain-scheduling proportional-integral controller and a linear feedback controller.

Finally, concluding remarks and future studies are stated in **Chapter 5**.