別紙４－１（課程博士（英文））

Date of Submission (07 month 9 day, 2020 year)

Department of 機械工学専攻	Student ID Number	D155114		Supervisors	Prof. Naoki Uchiyama Prof. Kaiji Sato
Applicant's name	MATHEW RENNY MSUKWA				

Abstract (Doctor)

Title of Thesis	Adaptive Nonlinear Control for Energy-Efficient and High-Precision Motion of Industrial Feed Drive Systems

Approx. 800 words

The remarkable technological advancement in mechatronics, the synergetic application of electrical, electronic, computer, and control engineering, which has evolved over the past three decades, has led to a novel stage of life. In response to the rapid growth of technology and demand for precise products, the industrial community still require higher-accuracy and higher-speed manufacturing systems.

Feed drive systems are among the dominating motion components in production and manufacturing industries owing to their wide range of use, for instance in multi-axis motions. In addition, because in most cases, feed drive systems operate around the clock, they are among the major consumers of the industrial energy supply. Thus, energy consumption is part of the reasons for using lighter components in feed drive systems. While high-speed motion is preferred, it causes vibration in light systems, high-energy consumption, and poor precision. The precision of these systems depends mostly on the ability to overcome nonlinear uncertainties, which are common and generally unavoidable. The uncertainties come from either disturbance signals or from system modelling errors. When a system is approximated by a mathematical model, non-fundamental factors are normally ignored; factors like, high-frequency dynamics and mechanical vibrations which are caused by the system itself.

Many researches have been focusing on tracking and contouring control of servomotors, which are widely used in motion control applications owing to their basic advantages, such as high power-density and torque to inertia ratio, high performance and efficiency and low noise. On doing so, classical and modern control techniques such as sliding mode control (SMC), adaptive control, dynamic friction compensation methods, back-stepping control have been widely applied. On the other hand, for applications such as in feed drive systems, repetitive and iterative learning controls are commonly used under the assumption that these systems are used for mass-productions. However, since there are many feed drive applications that are not repetitive, it is indispensable to consider control strategies for general applications.

Robust controllers such as SMC have proven to provide reasonable performance under the effect of external disturbance and system uncertainties. The SMC, apart from its simplicity in design, it is robust against perturbation and invariant to matched uncertainties. Other variants of the SMC include adaptive sliding mode control (ASMC) and nonlinear sliding mode control. They are more flexible and offer higher precision compared to the traditional SMC. On the other hand, model-based approaches such as feedforward friction compensator are applied to cancel out the effect of the estimated friction force. However, because friction sources are generally of complex nonlinear properties, it is difficult to find a perfect model and the performance depends exclusively on the veracity of the estimated model. In some research, continuously differentiable nonlinear friction model is derived by modifying LuGre model which is piecewise continuous, and then propose a controller to take care of parametric uncertainties along with nonlinear friction compensation. Despite the promising performance of the mentioned approaches, it is indispensable to enhance both the precision and energy consumption of feed drive systems.

The primary objective of this research is to improve energy saving and high precision motion of multi-axis feed drive systems by explicitly considering the uncertainty dynamics. A nonlinear SMC with a feedforward compensator for system uncertainties is applied. The feedforward compensator refers to the modeled system with assumed uncertainty dynamics and the controller is designed by taking the difference between a reference model and the real system. The proposed method enhances the precision of feed drive systems while maintaining the required energy. An addition of another compensator for a specific uncertainty is expected not to degrade the performance of the proposed controller but enhance it. In order to enhance both precision control and energy-saving control for feed drive systems, an adaptive nonlinear sliding mode controller with a feedforward compensator for plant uncertainties is described in this thesis. Introductory remark is represented in chapter 1. In chapter 2, an adaptive sliding mode control with a nonlinear sliding surface is described. Experiments are conducted and results are compared to that of SMC without adaptation. In chapter 3, an adaptive sliding mode control with a feedforward compensator is applied. For performance evaluation, simulations and experiments are conducted and results are compared with those of an adaptive nonlinear sliding model controller. Results revealed that, based on the proposed controller, the tracking errors of feed drive systems can be reduced by about 33% on average and the maximum tracking error by about 64% on average. In addition, the energy consumption can be reduced by about 2% under similar tracking performance. In chapter 4, an adaptive sliding mode contouring control design based on reference adjustment (ASMCC) and uncertainty compensation is described. For performance evaluation, simulations are conducted and results are compared with those of ASMCC without the uncertainty compensator. Results show that the average and maximum contouring error can be reduced by 85.71% and 78.64%, respectively. Lastly, chapter 5 describes concluding remarks of this thesis and prospective future works.