別紙４－１（課程博士（英文））

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Department of Mechanical Engineering	Student ID Number	D219101		Supervisors	Naoki Uchiyama Junji Takahashi
Applicant's name	Haryson Johanes Nyobuya				

Abstract（Doctor）

Title of Thesis	Enhancement of Simple Adaptive Control for Industrial Feed Drive Systems

Approx. 800 words

In precision manufacturing, the ability to track a trajectory with high-precision while simultaneously reducing energy consumption is highly desirable. A wide range of industrial machines such as computer numerical control, industrial robots, and assembly equipment uses a ball-screw driven mechanism for micron-scale positioning applications. Ball-screw mechanisms are widely used because of their simple dynamic nature and low cost. The tasks performed by the ball-screw mechanisms are repetitive in nature, leading to high energy consumption. In addition, tracking error is induced by ball-screw assembly. Given the current worldwide situation of high energy costs, environmental effects, and the depletion of energy sources, energy-saving is needed. In addition, precise motion is vital for machines to manufacture high-quality products. Therefore, the industrial sector is driven by a high need for machines with accurate motion and energy-saving capabilities.

Adaptive control is one of the most effective methods, which can consider the parametric uncertainties and disturbances with online adaptive rules. Simple adaptive control (SAC) is a simplified approach to direct model referencing adaptive control. The SAC control technique has attracted much attention from researchers in recent decades because of its simplicity and the ease of implementing its algorithm. In addition, this control technique has the advantage of not requiring full state access or estimators in the control loop. Moreover, the SAC technique does not require full knowledge of the system's dynamics to implement. To successfully apply the SAC to a real system the "almost strictly positive real (ASPR)" property is required to be satisfied. ASPR ensures the stability of the system even when the gains are high. Most systems fail to meet the ASPR requirement and therefore, other methods are needed to meet the ASPR requirement. In the literature, many studies have focused

on the typically used parallel feedforward compensation (PFC) method. However, the PFC approach deviates the output signal from the desired which increases the tracking error. There have been numerous proposals for improving the situation by researchers to counteract this problem though parallel type structure design still holds.

To enhance machine performance in terms of tracking and contouring accuracy with less energy consumption in industrial machines, the proposed control approaches are described as follows in this thesis: Introductory remarks are presented in Chapter 1 followed by a literature review in Chapter 2 describing the related studies in adaptive control, simple adaptive control, integral terminal sliding mode control and industrial feed drive systems dynamics. Chapter 3 presents the use of jerk-based augmented output signal for the ASPR property. The proposed approach allows SAC to track the desired signal more precisely at high frequencies. This is achieved by placing the zeros of the system at effective locations. To verify the feasibility of the proposed approach, simulation and experiment are conducted. The results are compared with those of the commonly used PFC approach. Experimental results revealed that the proposed approach reduced the tracking error by about 80% compared to PFC without any additional control input. Moreover, the proposed approach has been proved to be energy-efficient by about 21% than PFC under similar tracking conditions. Simple adaptive contouring control (SACC) using jerk-based augmented output signal for the ASPR property is presented in Chapter 4. SACC is designed by following the tangent contour control scheme while using the SAC technique to enhance the contouring accuracy. Jerk-based augmented output signal ensures that the ASPR property is met and allows the SACC to track accurately the desired contour at high frequency. The proposed contouring approach achieves lower contour error and energy consumption by about 45% and 3% respectively, as compared to the most common parallel feedforward compensation approach.

Chapter 5 describes the approach focusing on application of integral terminal sliding mode control (ITSMC) to the feed drive system because of its robustness against disturbances and finite-time convergence of the tracking error. However, its design requires a good understanding of plant dynamics and estimated parameters. To alleviate this concern, a solution of modifying the original ITSMC law to an adaptive ITSMC law based on SAC technique. To implement SAC-like adaptive law to a real plant, ASPR property is required to be satisfied. ASPR property is satisfied using velocity-based augmented output signal that ensures the stability even when gains are high. Based on the experimental results, this formulation allows the adaptive controller to follow the reference trajectory more precisely than conventional methods. Lastly, Chapter 6 presents the concluding remarks of this thesis and prospective future works.