FRICTION COMPENSATION AND NOISE FILTERING FOR IMPROVING THE PERFORMANCE OF FRICTIONAL MECHATRONIC SYSTEMS

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論 文 名 ：FRICTION COMPENSATION AND NOISE FILTERING FOR IMPROVING THE PERFORMANCE OF FRICTIONAL MECHATRONIC SYSTEMS （摩擦のあるメカトロニクスシステムの性能向上のための摩擦補償とノイズフィルタリング）

区　　分 ：甲

論 文 内 容 の 要 旨

This dissertation focuses on friction compensation and noise filtering for improving the performance of frictional mechatronic systems, i.e., a class of mechatronic systems in which friction has significant influence on the performance of the control system. This thesis proposes new techniques for compensation of friction force and filtering of noise in order to improve the performance of frictional mechatronic systems in terms of the following: (1) fast, non-overshooting and accurate positioning in position control systems (2) improving the sensitivity and backdrivability in force control systems and (3) reduction of vibrations in both position and force control systems by expanding the bandwidth of the system. A new dither-based friction compensator is proposed and it can be used for the actuators in which conventional compensation methods are difficult to apply. It is shown that the proposed compensator significantly improves the sensitivity to external force and backdrivability of the actuator. A new sliding-mode-based noise filter is proposed and it is shown that the new filter produces smaller phase lag than other linear and sliding mode filters. A new position controller that employs second order derivative and the friction compensator is proposed. By utilizing the noise filter developed in this dissertation, the noise due to the second derivative and the dither signal from the friction compensator is filtered, and thus enhancement of the stability of an admittance-type force control is realized. The discontinuous signum function, of which the output is a set when the input is zero, is involved in both of the friction compensator and sliding mode filter, and thus the concept of differential inclusions (DIs) is utilized and backward (implicit) Euler method is used for numerical integration of DIs. The new techniques developed in this dissertation are validated through experiments by employing a harmonic drive transmission in a robotic link.

Chapter 1 provides the background on friction compensation and noise filtering. The problems and solutions of friction and noise reported in previous studies are reviewed and the contributions of this dissertation are overviewed. The interconnection among chapters of the dissertation is also provided.

Chapter 2 proposes a new friction compensator that can be applied to geared actuators that do not exhibit sufficiently large displacement in response to actuator command at the level of maximum friction, i.e., actuators with high presliding stiffness. Most of existing friction

compensation techniques are based on friction models that use the velocity as their inputs. These methods are difficult to apply to inexpensive encoder-based actuator systems while the proposed compensator only requires the encoder signal as its input. The proposed compensator cancels: (a) static friction, (b) rate-dependent kinetic friction, and (c) presliding viscoelasticity. The dither-like torque command is employed in the first component, and the other two are based on friction models involving precalibrated parameters. The proposed compensator is validated through experiments in improving the sensitivity to external force and backdrivability of the actuator.

Chapter 3 proposes a sliding-mode-based noise reduction filter. Linear filters have been commonly used for noise reduction due to their simplicity. However, in the case of strong noise attenuation, linear filters produce large phase lag, which usually results in instability of the system. A previously reported filter that uses sliding mode technique with parabolic sliding mode surface, i.e., parabolic sliding mode filter, produces smaller phase lag than linear filter while it suffers from bias in the output. The new filter proposed in this dissertation is a combination of a new parabolic sliding mode filter, which is a variant of the previously reported parabolic sliding mode filter, and a linear second order low-pass filter. The new filter overcomes the problems of both of linear and previous sliding mode filters. In particular, it produces smaller phase lag and bias. The experimental results indicate that the proposed filter achieves better balance between the noise attenuation and signal preservation than other filters. The application of the proposed filter in a positioning system under PDD^2 (proportional, derivative, and second derivative) control is shown by removing the noise in the actuator and realizing the overdamped behavior simultaneously.

By utilizing the friction compensator in Chapter 2 and the noise reduction filter in Chapter 3, Chapter 4 presents an experimental investigation of a new position control scheme that enhances the stability of admittance control. The controller is characterized by four points: (a) PDD^2 (proportional, derivative, and second derivative) feedback, (b) dither-based friction compensation, (c) sliding-mode-based noise filtering, and (d) variable derivative (D and D^2) gains. The PDD^2 structure and the friction compensation are for enhancing the stability of the admittance control by expanding the bandwidth of the internal position-controlled subsystem. The sliding-mode-based filter is for smoothing the acceleration signals without producing a large phase lag. The variable derivative gains are for suppressing the effect of acceleration-measurement noise at low velocity. The experimental results indicate that the new position controller significantly enhances the stability of admittance.

Chapter 5 concludes the dissertation with concluding remarks and future works.