A Thesis for the Degree of Ph.D. in Engineering

Advanced Robust Control via Disturbance Observer: Implementations in the Motion Control Framework

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Graduate School of Science and Technology
Keio University

EMRE SARIYILDIZ

Thesis Abstract

No.________

Registration Number	■ “KOU” □ “OTSU” *Office use only	Name	Sariyildiz, Emre

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Thesis Summary

Disturbance Observer (DOb) has been widely used in motion control fields to achieve high performance robust motion control systems since it was introduced at the first IPEC conference in 1983. However, its applications still suffer from insufficient analysis and design control methods; therefore, the applications highly depend on designers own experiences. Since DOb is a very efficient and practical robust control tool, deriving novel analysis and design control methods for DOb based control systems simplifies several complex robust control problems and high impact in different fields such as motion and process control areas.

The main objective of this research is to extend the application areas of DOb by proposing novel analysis and design control methods and clarify its design constraints in the motion control field.

Chapter 1 presents the background and objective of this dissertation. A detail literature survey on the robust control problem is provided.

Chapter 2 describes the fundamentals of DOb based robust control systems.

Chapter 3 introduces two novel robust analysis methods for DOb based control systems. Firstly, conventional analysis methods, which depend on Small Gain theorem and μ-analysis, are explained, brielfy. It is shown that conventional analysis methods suffer from conservatism and do not provide a clear insight into the robustness characteristics of DOb. To eliminate conservatism, a new robustness analysis method is proposed by using Kharitonov, Edge and Tsypkin-Polyak theorems. Although conservatism is eliminated and the robustness of DOb is clarified, the proposed method suffers from the strict assumption on the dynamics of uncertain plant model and DOb. To remove the strict assumption, a new robustness analysis method is proposed for DOb based control systems by using Bode and Poisson integral formulas. The proposed method can be implemented to wide range of application areas such as plants with time-delay and right half plane poles. However, it is influenced by conservatism which may degrade the performance of control systems. Although the conservatism can be lessened by using more complex analysis methods as shown in Chapter 3, it is not a severe problem since the proposed method clarifies the robustness of DOb qualitatively.

Chapter 4 introduces novel analysis and design control methods for DOb based motion control systems by using linear control methods. Firstly, the inner-loop of DOb based motion control systems is re-considered by applying the practical constraint which occurs due to the low-pass-filter (LPF) of velocity measurement. It is shown that the bandwidth of DOb and the nominal inertia in the design of DOb are limited by the practical design constraint of imperfect velocity measurement. Then the stability and robustness of the DOb based position and explicit force control systems are analyzed in detail. It is shown that the stability and performance of the robust position and force control systems are improved by increasing the bandwidth of DOb and the nominal inertia. However, they are limited due to the practical constraints; therefore, there is a trade-off between the stability of the robust motion control systems and the robustness of DOb. Implicit and explicit environmental impedance estimation methods are considered by using a force sensor and a reaction force observer (RFOb) and a detail comparison is provided. Finally, a novel adaptive design method is proposed for RFOb based robust force control systems.

Chapter 5 presents a novel non-linear stability analysis method for the DOb based robust position control problem of robot manipulators by using the equivalence of the passivity and DOb based controllers. Similar to Chapter 4, it is shown that the stability of the robot control systems can be simply improved by increasing the bandwidth of DOb and the nominal inertia matrix in the design of DOb. Although asymptotic stability can be achieved if regulator problem is considered, the error of the robot control system is uniformly-ultimately bounded if trajectory tracking control problem is considered when conventional acceleration based robust control system is used. The bound of error can be shrunk by increasing the bandwidth of DOb and nominal inertia.

Chapter 6 summarizes and concludes this dissertation.