論 文 の 内 容 の 要 旨

論文題目　　Frequency response data-driven disturbance observer design by convex optimization -Experimental verification with a non-minimum phase motion stage
（外乱オブザーバの凸最適化を用いた周波数応答データ駆動設計法の研究
- 非最小位相系の位置決めステージによる実験検証）

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Unavoidable disturbances downgrade the performance of industrial control systems and disturbance rejection has been an essential objective for motion control field.

To reject the effects of disturbance, disturbance observer (DOB) has been proposed in whose idea is to utilize the estimated disturbance, which is the difference between reproduced plant input and input signal, to reject the influence of real disturbance. Despite its simple structure, the efficiency of DOB has been verified in many engineering applications, such as robotics, mechatronics, and automation.

The low pass filter (Q filter) in the disturbance observer configuration is crucial in guaranteeing the causality and robustness of the whole system and the design of the said filter influences the disturbance rejection performance significantly. Various researches have been carried out to investigate the design of Q filter for minimum phase systems via, say, trial-and-error methods or H-infinity based approaches. For a non-minimum phase plant, unlike its counterpart whose inversion is stable, unstable inversion leads to internal instability and sensitivity function limitation which make DOB design challenging. Some researchers have designed the disturbance observer by analyzing Poisson integral formula limitation. Some researchers have made the controlled plant is in parallel with a filter to make it become a minimum phase one. The Q filter design has been transformed into standard H-infinity controller design problem in by analyzing the internal robust stability.

In previous studies, to eliminate the influence of RHP zeros appeared in non-minimum phase plant, pole-zero analysis, such as coprime factorization, is always employed which necessitate the usage of parametric model. Therefore, plant is carefully identified from the frequency response data (FRD) and used in the design of DOB throughout conventional methods. However, since the bandwidth of DOB is limited by unmodeled plant dynamics and noises, the uncertainties brought in the identification process is prone to making the design result conservative.

Frequency response data-based controller design has appeared as an alternative way of designing controller. Researchers have used loop shaping method in the Nyquist plot to optimize the parameters of linearly parameterized fixed order controllers for single-input-single-output (SISO) system was proposed. By defining margin constraint which is linear with respect to controllers' parameters, parameters of controller can be obtained through linear programming. Fixed structure controller has been designed based on frequency response data and solved by non-convex optimization. Convex optimization has been used to compute robust controllers for SISO systems depicted by frequency response data as well as in MIMO systems.

Inspired by the frequency response data-based controller design research, in which controller is obtained by an FRD-based optimization process while desired controller specifications have been formulated into optimization constraints, frequency response data-based Q filter design has been conducted and further extended to in which nominal plant and Q filter have been designed simultaneously in continuous domain and discrete domain.

In the thesis, first I introduced the research background and previous research survey result including some technical words' explanation, e.g. non-minimum phase system, then the experimental test bench has been introduced thoroughly. Necessary mathematical preliminaries have been given in chapter 2. In chapter 3, I introduced the design of Q filter, including normal second order case and high order case both in continuous domain and discrete domain. The detailed problem formulation process and constraints have been illustrated. Furthermore, mathematical transformation process from non-linear constraints to convex constraints has been shown. The simulation results for different case studies have been analyzed. The comparison with conventional studies have also been given followed by the proposal of simultaneous design of plant and filter. In this part, I have also given a detailed introduction of the proposal, including the problem formulation, constraints and separation of Pn and Q from optimized open loop gain as well as the simulation results and comparison with conventional studies in both continuous domain and discrete domain. The proposed design methodology can not only be used in single frequency data set as well as in multiple data sets, e.g. the frequency response of hard disk drive changes as the operating condition changes. Furthermore, all the above proposal has been verified by the experimental results.