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学 位 論 文 内 容 の 要 旨

博士の専攻分野の名称　　博士（情報科学）　　氏名　Sheng Hao

学 位 論 文 題 名

Vibration Control for Nonlinear Mechanical Systems with Relative Information
（非線形メカニカルシステムに対する相対情報を用いた制振制御）

In this dissertation, vibration controllers based on relative information for nonlinear mechanical systems are proposed. Vibration suppression is a core concern in mechanical system design. With the advancement of society's informatization, the demand for vibration control for information technology has grown in recent years. For decades, active vibration reduction technologies have been employed in mechanical systems.

Unfortunately, most active vibration control approaches are based on the premise that all states are precisely understood. It will be simple for sensors to observe the state if it is relative information with a reference plane. If the reference plane, on the other hand, vibrates, it is impossible to determine the absolute location and velocity using affordable sensors.

The key idea of the proposed controllers is to use the passivity properties of the mechanical systems and skyhook strategies. Interconnection and damping assignment passivity-based control (IDA-PBC) method is applied in most of our results due to its theoretical advantages on energy shaping and stabilization of nonlinear systems. The content of this dissertation is as follows.

In Chapter 1, we illustrate this study's background and problem statements.

In Chapter 2, we firstly consider the vibration control problem for the system with an external control force. The considered system can be expressed as any floating nonlinear mechanical structure with spring and damper. We derive the matching condition between the controlled system and the desired system. We derive a control law including some free parameters with some constraints. The controller uses only relative information, which can be easily measured. We propose a new parameter design method for more generalized nonlinear controlled objects than the previous work. We show differential equations that determine the inertia matrix of the desired closed-loop system. The stability of the nonlinear closed-loop system is guaranteed theoretically by the IDA-PBC method. We have proposed an efficient parameter selection scheme achieving a good vibration suppression effect. Under the proposed parameter selection, the proposed control law realized a virtual skyhook damper using only relative information. Simulation results for an example verify the good vibration effect of the proposed controller.

Chapter 3 considers the vibration control problem for the system with an internal control force. We present a new nonlinear active DVA control system in which the information of the controller is not based on the world-coordinate information. The proposed method can simultaneously control the vibrations that are excited by a force disturbance and velocity disturbance. The control law uses only the relative displacement and velocity of the vibration system, which can be easily measured by sensors. We revealed the equality and inequality constraints for matching the plant system with the desired system. The numerical solutions of the partial differential equations are not required with our proposed method. The main idea of the controller design is to convert a nonlinear DVA system into a desired system with multiple virtual springs and dampers. We also derived selection guidelines for the parameters of the desired system. The global asymptotical stability is guaranteed automatically through passivity-based control theory, although the parameter design is based on linearization.

In Chapter 4, the ISS analysis for nonlinear systems with multiple disturbances is proposed. We construct an ISS Lyapunov function for a class of nonlinear mechanical Hamilton systems with a force disturbance and a velocity disturbance. We divide the discussed system into a system with a force disturbance and a system with a feedback input and a velocity disturbance. Then we constructed the ISS Lyapunov function for those two systems, respectively. The construction is based on several assumptions for the system parameters, while those assumptions are easy to be satisfied in practical application.

Chapter 5 proposes a novel IDA-PBC design for a quarter car nonlinear active suspension system. We develop a feedback rule based solely on the relative displacement and velocity of the suspension system, whereas most previous research has relied on absolute data. It is calculated by obtaining the suspension system's pH form from the dynamics of the suspension system and rewriting it using relative coordinates. A low-cost sensor may be employed in practice with our unique controller. There is a proposal for an IDA-PBC-based controller design for an active suspension system with a nonlinear spring, a nonlinear damper, and mass uncertainty. Unlike other IDA-PBC implementations, our approaches focus on changing the nonlinear suspension system into a desired linear system with perfect aseismatic features, which tend to regulate the position or velocity. We design a virtual vehicle body, an unsprung mass, and damper coefficients in addition to a standard controller utilizing the SH control approach. We establish the requirements that guarantee the suspension system's GAS in the absence of model errors or disturbances, as well as parameter selection suggestions that can assure robust stability in the face of parameter uncertainties in the mass, springs, and dampers. Variations in passenger numbers and vehicle body loads, as well as aging suspension parts and measurement mistakes, can all contribute to these inaccuracies.

Chapter 6 describes the conclusion of this dissertation.