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学位論文題目	A Study on Adaptive Robust Control Theory of Uncertain Nonlinear Systems and Its Applications to Environmental Systems 不確かさをもつ非線形システムにおける適応ロバスト制御理論とその環境システムへの応用に関する研究関する研究
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学位論文の要旨

In a number of practical control systems, there always exist some uncertainties due to modeling errors, measurement errors, and changing of external environmental conditions. Moreover, such system uncertainties are often described by some unknown nonlinear functions which should degrade the system performance, and even make the systems unstable and difficult to control. Therefore, the problems of stability analysis and controller design of uncertain nonlinear dynamical systems are important, and have received considerable attention during the past decades.

Due to the approximation property of neural networks (NNs), the NNs-based control has been regarded as an effective approach to coping with the control problem for uncertain nonlinear systems. The main idea of such a control methodology is to utilize NNs to model the unknown nonlinear uncertainties in dynamical systems and then to synthesize the controllers by adaptive techniques. The drawbacks of NNs are that if the NNs have a complicated structure, such a complicated structure may lead to a heavy computational burden and longer learning time. On the other hand, if the NNs have a simple structure, it may result in inaccurate approximation results. Thus, it is necessary to find an appropriate structure for NNs. In fact, this is a very complicated process. Hence, to overcome the unknown nonlinear uncertainties with simple structure NNs or without NNs, the problem of controller design for nonlinear dynamical systems has been being one of main research topics. In this dissertation, the problems of robust stabilization and controller synthesis for dynamical systems with nonlinear uncertainties are considered, and the proposed control schemes are also applied to some environmental systems. The main works of this dissertation are summarized as follows:

(1) A NNs-based adaptive robust controller is presented for a class of dynamical systems with matched nonlinear uncertainties and external disturbances. It is supposed that the upper bounds of external disturbances are unknown. The NNs with a simple structure are used to model the unknown nonlinear uncertainties. In order to overcome the drawback of NNs, an adaptation law is employed to learn online the unknown parameters which contain the norm forms of weights and approximate errors of the NNs. The proposed controller is composed of two parts, one is the linear state feedback controller and the other is the nonlinear adaptive controller which contains NNs basis functions and online learning values. Furthermore, the proposed NNs control scheme is applied to the problem of water pollution control for uncertain river systems due to waste treatment facilities.

(2) A novel adaptive robust controller is also developed for the same uncertain nonlinear systems which have been researched in (1). It is assumed that the nonlinear uncertainties can be approximated by virtual NNs which mean that the NNs are not used in the actual control process. Since there is no practical use of NNs to construct the novel controller, which makes the control scheme simpler than the NNs-based adaptive robust control scheme reported in (1). Under this novel controller, it is proved that the states of the closed-loop systems converge asymptotically to zero. Such a control scheme is also applied to the problem of water pollution control to demonstrate its effectiveness.

(3) For a class of delayed uncertain nonlinear systems with generalized matched conditions, the adaptive robust controller reported in (2) is redesigned and a new adaptive robust controller is synthesized. Similar to (2), it is assumed that the delayed nonlinear uncertainties can be approximated by virtual delay-dependent NNs. It is clear that if the delay-dependent NNs are used in the actual control process, the time delays must be known. Here, the NNs will not be used to construct the control scheme, i.e. the time delays are not required to be known and the proposed control scheme is delay-independent. By employing a Lyapunov function, it is shown that the redesigned adaptive robust controller can guarantee the uniform asymptotic stability of the delayed uncertain nonlinear systems. The feasibility of applying the obtained results has been demonstrated by considering the problem of optimal long-time management of uncertain exploited ecological systems with two competing species.

(4) Finally, A NNs and backstepping approach-based adaptive robust controller is also proposed for a class of nonlinear systems with mismatched uncertainties which consist of structure uncertainties, external disturbances, and unknown time-varying virtual control coefficients. It is supposed that the upper bounds of the external disturbances and the

virtual control coefficients of the considered systems are unknown. Similar to (1), the unknown structural uncertainties are modeled by using simple structure NNs. The adaptation laws are employed to estimate the unknown parameters, which contain the upper bounds of the external disturbances and the virtual control coefficients, and the norm forms of weights and approximate errors of the NNs. By making use of these updated values, the adaptive robust state feedback controller is given recursively. It is shown that the proposed NNs-based adaptive robust backstepping controller is able to guarantee all the closed-loop signals uniformly ultimately bounded and the states to converge uniformly asymptotically to zero. The effectiveness of the proposed method is demonstrated through two numerical examples.

Concluding remarks: In this dissertation, the problems of robust stabilization and controller design have been considered for dynamical systems with nonlinear uncertainties which satisfy matched conditions, generalized matched conditions and mismatched conditions, respectively. A set of adaptive robust controllers has been developed for these dynamical systems, and the corresponding stability analysis has been made. As the application of the results, the problem of environmental systems control has been considered, and the corresponding simulations have been given. Simulation results show that the proposed control schemes are feasible and effective. According to the contents and results of this dissertation, the research directions to which we should pay more attention are presented as follows. One direction is to expand our control schemes to switched systems, neutral systems, and their combinations. Another is to achieve the optimal selection of modification parameters for our adaptation laws by introducing the optimal control algorithm. The third is to simplify the controller structure for the case of mismatched uncertain nonlinear systems. In particular, the results obtained in control theory may be expected to have more applications to environmental systems.

審査の結果の要旨

河川水質管理システム、生態システムなどのような実環境システムの制御問題においては、制御対象のモデリング誤差、測定誤差及び外部環境の変動などにより、ほとんどの場合には不確かさや未知の要素が存在し、動的システムの安定性を破壊する恐れがある。また、その不確かさは非線形性を有することが多く、そのすべてを把握することが極めて困難である。そのため、不確かさは制御問題を複雑化させる要因の一つとなっている。本研究は、不確かさをもつ非線形動的システムに関する適応ロバスト制御理論を研究し、得られた理論結果を環境システムなどへ応用した。

本論文は７章から構成される。第１章は緒言で、本研究の背景と目的を要約した。第２章では、本研究に必要な基本概念と手法をまとめた。第３章では、不確かさがマッチング条件を満足する動的システムに対して、簡単な構造をもつニューラルネットワーク(NN: Neural Network)に基づいてシステムの漸近安定性を保証できる適応ロバスト制御則を構築した。また、得られた制御則の有効性を検討するため、河川水質管理システムへの応用を行った。第４章では、NN を導入せずに新たな適応ロバスト制御則を提案し、その制御則はシステムの漸近安定性を保証できることを理論的に証明した。さらに、河川水質管理システムを用いて、その有効性を検証した。第５章では、一般的なマッチング条件を満足するむだ時間と不確かさを同時に有する非線形動的システムに対して、前章で提案した制御則を再設計し、動的システムの安定性を保証できる適応ロバスト制御則を構築するとともに、生態システムへの適用を行った。第６章では、マッチング条件を満足しない動的システムについて、Backstepping 法と簡単な構造をもつ NN を用いて、システムの漸近安定性を保証できる適応ロバスト制御則を新たに提案し、得られた結果を実システムにも応用した。第７章の結論では、本研究で得られた研究成果を総括し、今後の関連する研究課題について述べている。

以上、本論文は不確かさをもつ非線形動的システム理論に関する基礎的研究を行い、得られた結果を環境システムなどへ応用したものである。システムの構成、制御則の提案、安定性の解析など、適応ロバスト制御問題への新しいアプローチと環境システムへの応用を示すと同時に多くの有益な知見を得ている。これらの成果は不確かさをもつ非線形動的システムのロバスト制御理論に対する大きな貢献のみならず、環境システムおよび境界領域の学問であるシステム理論にも貢献するものと認められる。よって、本論文は博士（生命システム科学）の学位に十分に値するものと認められる。