第十一届系统控制前沿科学问题研讨会

The 11th Symposium on Frontier Problems in Systems and Control

2013 自抗扰控制研讨会-----纪念韩京清先生逝世五周年

2013 Active Disturbance Rejection Control Workshop
-- In Memory of Prof. Jingqing Han on the 5th Anniversary of His Passing

主办单位：中国科学院系统控制重点实验室、中国科学院国家数学交叉中心

Organizers: Key Lab of Systems and Control, Chinese Academy of Sciences
National Center for Mathematics and Interdisciplinary Sciences, Chinese Academy of Sciences

协 办 单 位：**Center for Advanced Control Technologies, Cleveland State University**

Co-organizer: Center for Advanced Control Technologies, Cleveland State University

时间：2013 年 7 月 24 至 25 日

Time: July 24-25, 2013

地 点：西安绿地笔克国际会展中心 101 会议室

Venue: Room101, Xi'an Greenland Pico International Convention & Exhibition Center Location

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注：本次研讨会不收注册费，参会人员食宿自理，欢迎感兴趣的科研人员、工程师、学生参加。

Registration: Free

日程：7 月 24 日

9:00-10:00　回顾与纪念

难忘的时光，黄 一（中国科学院数学与系统科学研究院）

不灭的理念 （自抗扰控制技术的产生与发展），高志强（Cleveland State University ）

10:00-10:15　茶歇

10:15-11:45　行业性的控制问题与自抗扰控制技术的应用-1，主席：谢辉(天津大学)

10:15-10:45 自抗扰控制在现代内燃机复杂控制中的应用，谢辉（天津大学内燃机燃烧学国家重点实验室）

10:45-11:15 自抗扰控制在快速刀具伺服系统中的应用研究，吴丹（清华大学机械工程系）

11:15-11:45 自抗扰飞行控制的实践, 孙明玮，陈增强 （南开大学）

14:00-16:00　行业性的控制问题与自抗扰控制技术的应用-2，主席：李东海（清华大学）

14:00-14:30 钢铁流程的控制问题及自抗扰控制技术的应用，尹怡欣，孙长银，王丽君（北京科技大学）

14:30-15:00 航海领域的控制问题与自抗扰控制技术的应用， 郭晨，李铁山 (大连海事大学）

15:00-15:30 放卷张力系统解耦控制器设计， 刘善慧（西安交通大学）

15:30-16:00 典型热工过程的自抗扰控制设计与整定， 李东海（(清华大学）

16:00-16:15　茶歇

16:15-18:15　为了继续前进——回忆韩老师，主席：韩雪花

日程：7 月 25 日

9:00-11:00　精彩纷呈的各种抗扰控制方法

主席：郭雷（北京航空航天大学）

9:00-9:20　复合分层抗干扰控制， 郭雷（北京航空航天大学）

9:20-9:40　基于干扰观测补偿的运动控制系统方法及其应用， 李世华（东南大学）

9:40-10:00　基于 ADRC 的机器人无标定手眼协调， 苏剑波（上海交通大学）

10:00-10:20 Disturbance rejection in the Embedded Model Control, Enrico Canuto （意大利都灵理工大学）

10:20-10:40 Linear ADRC of underactuated mechanical systems, Hebertt Sira-Ram´ırez (Cinvestav)

10:40-11:00 Time-varying repetitive control for disturbance rejections with applications to fuel injection systems and high density data storage systems, Zhen Zhang (Tsinghua University), and Peng Yan (Beihang University)

11:00-11:15　茶歇

11:15-12:45　学生学者互动论坛，主席：高志强(Cleveland State University)

本论坛以互动的形式，邀请天津大学宋康,北京理工大学蔡涛、宋雪梅，CSU 郑勤玲、张晗、Jason Tatsumi，大连海事大学李荣辉、雷正玲，南开大学徐琦，航天部王凯等老师和同学与大家交流自抗扰研究和应用中碰到的问题和体会，并欢迎所有参加论坛的老师同学发言、提问。暂定的讨论题目有 1）学习、研究、使用自抗扰控制的经验与教训。2） 硕、博研究生课题的选择；3）怎样入门？4） 如何灵活运用 ADRC 的理念？ 5）怎样重新分析、解决控制中的老大难问题？等等。另外，我们还会根据听众的具体问题，探讨能否将其整理为抗扰问题，从而应用自抗扰的理念。参与者：本科生、研究生、青年教师、工程师。

14:00-16:00　自抗扰控制理论分析的进展与挑战

主席：薛文超（中国科学院数学与系统科学研究院）

本论坛的目的是促进大家在自抗扰控制理论分析的研究进展和挑战性问题等方面的交流。论坛的开放性学术报告将围绕“不确定性系统自抗扰控制的设计方法及性能分析”展开，这些报告将从基于自抗扰控制器闭环系统的时域性能和频域性能、自抗扰控制器的参数调节以及自抗扰控制器的能力极限等多个角度分析自抗扰控制器的特性。论坛还专设报告人与听众自由交流的环节，这些交流将促进自抗扰控制理论研究与应用研究的结合，使得自抗扰控制的理论分析能够切实为其实用化和工程化提供理论指导。

1）线性自抗扰控制的参数整定方法研究，孙明玮（南开大学）

2）阶和相对阶不确定对象的自抗扰控制设计与整定，赵春哲（清华大学）

3）On Frequency Response Characteristics of ADRC, Jason Tatsumi(Cleveland State University)

4）稳定对象的低阶线性自抗扰控制，黄从智（华北电力大学）

5）一类最小相位非线性不确定系统的自抗扰控制，姜甜甜（中国科学院数学与系统科学研究院）

6）采样自抗扰控制器的参数调节和控制能力分析，薛文超（中国科学院数学与系统科学研究院）

16:00-16:15　茶歇

16:15-18:15　自抗扰控制技术的挑战

主席：高志强(Cleveland State University)

黄一（中国科学院数学与系统科学研究院）

自抗扰控制的线性和参数化形式给它的工业化发展提供了有效途径，在工程应用上显示了巨大的潜力。同时它也给我们提出的一系列的问题和挑战。在技术上，有时间、频率尺度以与结构和参数优化的问题，有大延迟系统以及非最小相位的控制问题，等等；在普及方面，有人才培养问题和与工程界的交流问题；在科研方面，有新理念的提出和研究层次的问题，即自抗扰的研究如何在理论、技术、应用三个层次上同时开展，对人才培养提出了新的要求。本论坛为所有科研人员提供一个平台，探讨自抗扰的发展方向，对科研问题的提出，研究生论文题目的产生，以及工控产品的研发提出设想和建议。

Agenda:
July 24th

9:00-10:00 Memory and Footsteps

Moments That Stay True Forever, Yi Huang (Academy of Mathematics and Systems Science, Chinese Academy of Sciences)

The Journey of an Idea , Zhiqiang Gao (Cleveland State University)

10:00-10:15 Tea Breack

10:15-11:45 Industry Cluster Problems and ADRC: Part 1

Chair: Hui Xie (Tianjin Unicersity)

10:15-10:45 Application of ADRC for Complicated Control of Internal Combustion Engines, Hui Xie (Tianjin University)

10:45-11:15 Active disturbance rejection control with application to fast tool servo, Dan Wu (Tsinghua University)

11:15-11:45 Active Disturbance Rejection Flight Control Practice, Mingwei Sun, Zengqiang Chen (Nankai University)

14:00-16:00 Industry Cluster Problems and ADRC: Part 2

Chair: Donghai Li (Tsinghua University)

14:00-14:30 Control Problems in Iron and Steel Process and the Applications of ADRC, Yixin Yin, Changyin Sun, Lijun Wang (University of Science and Technology Beijing)

14:30-15:00 The marine control problems and the ADRC, Chen Guo, Tieshan Li (Dalian Maritime University)

15:00-15:30 Decoupling Controller Design for Unwinding Tension System, Shanhui Liu (Xi'an Jiaotong Univ.)

15:30-16:00 Design and tuning of ADRC on the representative thermal processes, Donghai Li (Tsinghua University)

16:00-16:15 Tea Break

16:15-18:15 Family and Friends Session: Celebration of the life of Prof. Jingqing Han

Chair: Xuehua Han

Agenda:
July 25th

9:00-11:00 Showcasing Various Methods of Disturbance Rejection

Chair: Lei Guo (Beihang University)

9:00-9:20 Composite Hierarchical Anti-Disturbance Control, Lei Guo (Beihang University)

9:20-9:40 Theory and Application on Disturbance Observation and Compensation Based Motion Control Method, Shihua Li (Southeast University)

9:40-10:00 Robotic Uncalibrated Hand-Eye Coordination based on ADRC, Jianbo Su (Shanghai Jiaotong University)

10:00-10:20 Disturbance rejection in the Embedded Model Control, Enrico Canuto (Politecnico Di Torino)

10:20-10:40 Linear ADRC of underactuated mechanical systems, Hebertt Sira-Ram´ırez (Cinvestav)

10:40-11:00 Time-varying repetitive control for disturbance rejections with applications to fuel injection systems and high density data storage systems, Zhen Zhang (Tsinghua University), and Peng Yan (Beihang University)

11:00-11:15 Tea Break

11:15-12:45 Interactive Session of Students, Young Researchers and engineers

Chair: Zhiqiang Gao(Cleveland State University)

Students from various universities get together to discuss the problems and solutions in the applications of ADRC. Topics include lessons learnt in studying, researching and using the concept of ADRC; possible thesis topics; where to begin? How to use the concept of ADRC intelligently? Rethinking of those problems hard to crack, etc. Participants include students, both undergraduate and graduate, and young professors and engineers.

14:00-16:00 Theoretical Analysis and Challenges

Chair: Wenchao Xue (Chinese Academy of Sciences)

This session is designed to move forward the theoretical analysis on ADRC. It has several topics concerning with the design methods and performance analysis in dealing with typical uncertain systems in practice. The topics also cover present analysis results of ADRC from various perspectives, such as the frequency-domain analysis, the time-domain performance analysis, the controller's parameters tuning law and the controller's capability. Furthermore, the session provides a platform where the participants can discuss, debate and rethink what kinds of theory of ADRC can help the engineers to understand and design ADRC.

1) On Tuning of Linear Active Disturbance Rejection Control, Mingwei Sun (Nankai University)
2) Design and tuning of the ADRC for the plant with unknown order and unknown relative degree, Chunzhe Zhao (Tsinghua University)
3) On Frequency Response Characteristics of ADRC, Jason Tatsumi (Cleveland State University)
4) On Frequency-Domain Analysis of Linear Active Disturbance Rejection Control, Congzhi,Huang (North China Electric Power University)
5) The Active Disturbance Rejection Control of a Class of Minimum-phase Nonlinear Uncertain

Systems, Tiantian Jiang (Academy of Mathematics and Systems Science, CAS)

6) On Parameters Tuning and Capability of Sampled-data ADRC for Nonlinear Coupled Uncertain Systems, Wenchao Xue (Academy of Mathematics and Systems Science, CAS)

16:00-16:15 Tea Break

16:15-18:15 The Outlook and Challenges for ADRC

Chair: Zhiqiang Gao (Cleveland State University), Yi Huang (CAS)

Linear ADRC and its parameterization paved the way for its industrial adoption, with a great prospect. It also presents us with a range of problems and challenges. There are problems of time and frequency scaling and optimization of the structure and parameter selection; there are problems of time delay and non-minimum phase systems; and there are problems of producing qualified students and engineers. The research should be conducted simultaneously at three levels: new idea generation, technology, and application. This forum provides a platform where these issues will be discussed and debated.

交通线路及会场位置

1. 西安咸阳机场—西安绿地笔克国际会展中心

路线 1：乘机场大巴 1 号线至钟楼 换乘 6 路公交车至锦业路站 下车向南步行 150 米到达
路线 2：乘机场大巴 2 号线至西稍门 换成 322 路公交车至北沈家桥 下车向西步行 560 米到达
路线 3：乘出租车，路程约 40 公里（正常 60 分钟）

2. 西安火车站—西安绿地笔克国际会展中心
路线 1：乘 6 路公交车至锦业路站 下车向南步行 150 米到达
路线 2：乘出租车，路程约 24 公里（正常 40 分钟）

3. 西安北站（高铁站）—西安绿地笔克国际会展中心
路线 1： 地铁 2 号线至永宁门站 换乘 6 路公交车至锦业路站 下车向南步行 150 米到达
路线 2： 地铁 2 号线至省体育场站 换乘 709 路公交车至锦业路站 下车向南步行 300 米到达
路线 3：乘出租车，路程约 35 公里（正常 50 分钟）

4. 相关信息
西安咸阳机场大巴时刻： http://www.xxia.com/guide-149.aspx
西安公交车时刻： http://www.xxia.com/guide-149.aspx

7 月 24 日

10:15-11:45　行业性的控制问题与自抗扰控制技术的应用-1
(Industry Cluster Problems and ADRC: Part 1)

自抗扰控制在现代内燃机复杂控制中的应用

谢辉

天津大学内燃机燃烧学国家重点实验室

在节能减排的驱动下，现代内燃机已经成为机、电、液一体化的复杂多变量、非线性时变系统。多变量耦合、瞬态过程控制、以及复杂的控制参数标定等问题成为现有控制方法在内燃机中应用时遇到的难点。将复杂的内燃机控制问题转化为抗扰问题，并采用 ADRC 思想进行处理，是一种有效的解决方案。

本报告将首先概述现代内燃机控制面临的主要问题和挑战。然后，以内燃机的空气系统及燃烧过程控制等为例，介绍将复杂的内燃机控制转化为抗扰问题的思路，基于 ADRC 思想的复合抗扰控制方法，以及已有的实际应用效果。最后，分享天津大学对未来内燃机控制问题的展望和思路。

Application of ADRC for Complicated Control of Internal Combustion Engines

Hui Xie, Tianjin University

The modern internal combustion engine (ICE) has become a complicated electro-mechanical and hydraulic integrated system with nonlinear and time-variant characteristics. Consequently, the existing ICE control system has suffered from the cross-coupling, transient process control as well as the time-consuming control parameter calibrations. From a new aspect, ADRC could be an effective solution by treating this complicated control problem as a disturbance rejection one.

This presentation will firstly talk about the main problems and challenges in ICE. Then as practical examples, the air system control and combustion process control will be given, illustrating the though process, the resulting ADRC-based disturbance rejection solution, as well as the according experimental application results in ICE. Finally, some further thoughts and control ideas of Tianjin University for the ICE control problems in the further will be shared and discussed with the audience.

自抗扰控制在快速刀具伺服系统中的应用研究

吴丹

清华大学机械工程系

非对称车削是实现非圆截面零件和非轴对称零件精密和超精密加工的有效方法，其关键是高性能快速刀具伺服系统。加工过程中，快速刀具伺服系统应能克服时变的切削力负载，驱动刀具按照指定的轨迹完成频率高达数千赫兹的高精度跟踪运动。为了解决快速刀具伺服系统的快速精密跟踪控制问题，我们根据非对称车削表面参考轨迹已知的特点，应用自抗扰控制原理和前馈控制策略，设计了线性和非线性自抗扰控制器，并综合利用传递函数和描述函数方法，在频域对两种控制器的跟踪精度、动态刚度和稳定性进行了分析和比较，探讨了非线性自抗扰控制系统的极限环问题。基于自抗扰控制的快速刀具伺服系统已应用于异形发动机活塞表面的精密车削和正弦微结构表面的超精密车削。

Active disturbance rejection control with application to fast tool servo

Wu, Dan

Department of Mechanical Engineering, Tsinghua University

Non-symmetrical turning is highly effective for precision and ultra-precision machining noncircular or non-rotationally symmetric workpieces. A fast tool servo with high performances is crucial to the machining success. In such a machining process, the fast tool servo should actuate the cutting tool to complete desired high accuracy tracking motions with high frequency up to several kHz, while rejecting the time-varying cutting force disturbance. To solve the precision and fast tracking control problems in the fast tool servo application, the design of both linear and nonlinear controllers are presented. Based on the known reference trajectory, both the active disturbance rejection control concept and feed-forward strategy are used to improve the tracking and disturbance rejection performances. Then the transfer function and describing function techniques are applied to analyze and compare the tracking accuracy, dynamic stiffness and stability of the linear and nonlinear controllers in the frequency domain. The problem of the existence of limit cycles in the nonlinear active disturbance rejection control system is also explored. The developed fast tool servos have found applications in precision machining noncircular engine pistons and ultra-precision machining micro-structured surfaces.

自抗扰飞行控制的实践

孙明玮 陈增强
南开大学信息技术科学学院自动化系，天津，300071，中国

飞行控制作为一个相对成熟的领域，传统 PID 控制的统治地位很难被打破，其他控制方法基本没有任何用武之地并被工程界所直接排斥。但是 PID 控制由于自身局限性使得系统性能提升受到限制，设计过程难以适应低成本要求。自抗扰控制对于 PID 控制是一个有效的继承与提升，在飞行控制领域具有工程应用的巨大潜力。但是如何将这种潜力转变为现实，则需要深入扎实地进行前期基础性工作，包括对于实际对象力学真实问题的深刻体会、对于工程传统方法的熟练掌握、对于设计者工作习惯、心理状态和思维方式的准确把握，才能有的放矢地把自抗扰控制有效地应用于合适的场合，并为工程师接受和熟练掌握，成为一种可以依赖的设计规范和流程。本报告结合作者多年在飞行控制领域的实践与推广自抗扰控制的工作体会，对于上述问题进行简要介绍。

Active Disturbance Rejection Flight Control Practice

Sun Mingwei Chen Zengqiang
Department of Automation, Nankai University, Tianjin, 300071, China

Nowadays flight control is rather mature. The traditional PID control plays a dominant role in this area while other approaches are almost boycotted entirely by practitioners and have no chances of implementation. However the further improvements of system performance are checked by the specific structure of PID control, and the R&D cost for control system design is unable to meet the current requirements. As both the inheritor and the upgrade of PID control, Active Disturbance Rejection Control (ADRC) has a great potential in flight control applications. But how to transform this potential into reality needs a great deal of works in advance, including insightful understanding of practical problems, proficiency in traditional engineering methods, acquaintanceship to the design routines, psychology and thinking modes of engineers. Based on these foundations, we have the possibility of using ADRC in a proper scenario and make it be understood and accepted by engineers to become their favorite and a design criterion. We interpret these aspects in detail with practical experiences of popularizing ADRC in the realm of flight control.

7 月 24 日

14:00-16:00 行业性的控制问题与自抗扰控制技术的应用-2
(Industry Cluster Problems and ADRC: Part 2)

钢铁流程的控制问题及自抗扰控制技术的应用

尹怡欣 孙长银 王丽君
北京科技大学自动化学院，北京

摘要：对于炼钢、炼铁、连铸、轧钢等钢铁生产过程，具有时变、随机不确定性、多变量耦合、混沌、高阶次、非线性等复杂性。针对这些控制问题，探讨如何应用自抗扰控制技术对不确定扰动进行有效地估计和补偿。

Control Problems in Iron and Steel Process and the Applications of ADRC

Yixin Yin, Changyin Sun, Lijun Wang
School of Automation & Electrical Engineering, University of Science and Technology Beijing, Beijing

There are many complex characteristics in iron and steel process, such as: nonlinear, large time delay, time-varying, random uncertainty, multivariable coupling, chaotic, high order and so on. These features are commonly found in iron making, steel making, continuous casting, rolling and other processes. In this talk, solutions of active disturbance rejection control are presented in its practicality and the ability to handle the uncertain disturbances in the simple manner.

航海领域的控制问题与自抗扰控制技术的应用

郭晨 李铁山
大连海事大学

将对航海领域的一些控制问题进行解析，如航向控制，航迹控制，减摇控制，动力定位控制，编队控制，自动靠离泊控制，主机推进控制，船舶操纵与主机推进联合控制，等等。并探讨自抗扰控制技术在船舶运动控制中的应用。

The marine control problems and the ADRC

Guo Chen, Li Tieshan

Abstract: In this topic，some problems about marine ship motion control, such as ship course control, ship track control, anti-roll control, dynamic positioning control, ship formation control, auto-docking control, and propulsion control or marine engine control, integrated control of ship manoeuvring and main propulsion system, will be interpretated, as well as the ADRC applications in the interested area.

放卷张力系统解耦控制器设计

刘善慧
西安交通大学机械工程学院

针对凹版印刷机放卷系统对张力控制稳定性的要求，提出了一种利用自抗扰控制(ADRC)技术来设计张力解耦控制器的新方法。根据放卷系统的工作机理，建立了放卷张力系统的非线性耦合数学模型，用 ADRC 方法推导了张力系统的解耦模型，得到了系统阶数和静态解耦模型。在放卷张力系统模型的基础上，利用 ADRC 技术对放卷系统的张力解耦控制器进行了设计。控制器内部鲁棒性和抗干扰性能的对比仿真结果表明，所设计的 ADRC 解耦控制器可以较好地实现系统的解耦，并具有比传统比例积分微分控制器更好的内部鲁棒性和抗干扰性。

Decoupling Controller Design for Unwinding Tension System

Shanhui Liu
Xi’an Jiaotong University

A new decoupling controller based on a unique active disturbance rejection control (ADRC) strategy is presented to strengthen tension stability in unwinding system of gravure printing machine. A nonlinear model is established according to the unwinding system working principle, and a decoupling model is constructed to determine the system order and static decoupling part. Then following the decoupling model, an ADRC decoupling controller is designed to enhance the tension stability in the unwinding system. The simulation shows that the proposed tension controller is able to realize a decoupling control for unwinding system and endowed with better internal robustness and disturbance rejection than traditional proportional-integral-derivative controller in tension control.

典型热工过程的自抗扰控制设计与整定

李东海
清华大学

近年来，本课题组围绕典型热工过程等工业对象，开展了一定规模的自抗扰控制（ADRC）应用研究，针对不同系统给出了 ADRC 设计原则、参数整定方法和一些理论分析。典型成果主要包括 SISO 对象的低阶 ADRC 设计，MIMO 对象的低阶 ADRC 解耦，热传导系统（分布参数模型）的低阶 ADRC 设计，并对经典的机炉电协同控制问题和 ALSTOM 气化炉控制问题设计了 ADRC 解决方案，还进一步将 ADRC 推广应用到分数阶对象上，其控制效果得到了相关领域的认可。虽然上述研究中的被控对象具有不同的数学模型，但都要求在模型未知、或者已知信息很少的情况下完成 ADRC 设计。这无疑是 ADRC 的理论和应用研究中的一个重要问题，也是本课题组今后努力探索的方向。

Design and tuning of ADRC on the representative thermal processes

Donghai Li
Qsinghua University

In recent years, we concentrate on designing the active disturbance rejection control (ADRC) scheme for the representative thermal processes and some other industrial processes. Much effort is made to search the rules in designing ADRC, summarize the tuning methods and do the theoretical analysis for different kinds of systems under ADRC. For example, the low-order ADRC schemes are built for the SISO system, the MIMO system and the heat conduction system with the distributed parameter model. The ADRC technique is also applied to the typical problems of the coordinated boiler-turbine-generator control system and the ALSTOM gasifier benchmark. And the effectiveness of the ADRC on the fractional-order system is recognized by the researchers recently. Although the former work involves the different plant models, they all require building the ADRC with none or very little information about the models. Means to meet this requirement is a very important topic in the theory and application research of ADRC, which is the direction of our future studies.

7 月 25 日

9:00-11:00 精彩纷呈的各种抗扰控制方法
(Showcasing Various Methods of Disturbance Rejection)

复合分层抗干扰控制

郭雷
北京航空航天大学

介绍一种多源干扰系统的精细抗干扰控制方法。传统抗干扰控制方法多针对一个等价干扰，未充分利用干扰本身的特性。本方法采用干扰估计和前馈补偿的内环以及反馈抑制的外环结构，可同时实现两类干扰的同时补偿和抑制。

Composite Hierarchical Anti-Disturbance Control

Lei Guo
Beihang University

Abstract: This talk will introduce a type of refined anti-disturbance control method for systems with multiple disturbances. Classical anti-disturbance control approaches focused on only one disturbance in most cases, where the characteristics of various disturbances cannot be used sufficiently. CHADC has an inner-loop including a disturbance observer and compensator, as well as an outer-loop including a disturbance attenuation controller, with which the simultaneous rejection and attenuation can be achieved.

基于 ADRC 的机器人无标定手眼协调

苏剑波
上海交通大学

介绍机器人手眼协调，特别是无标定手眼协调问题，以及把 ADRC 引入研究该问题的过程，及与已有对策之间的关联。给出用 ADRC 来研究机器人无标定手眼协调的具体思路和实现手段，以及特定系统的收敛性分析。思考其与 DOB 的联系和区别。

Robotic Uncalibrated Hand-Eye Coordination based on ADRC

Jianbo Su
Shanghai Jiaotong University

Abstract: This talk is to present the introduction to robotic uncalibrated hand-eye coordination problem, and how ADRC is employed to deal with it effectively. Traditional ways are first retrieved, based on which the ADRC is explored to show its advantages over traditional strategies. Convergence of the ADRC in some specific cases is primarily analyzed. The relationship between ADRC and DOB is also proposed for further investigation.

基于干扰观测补偿的运动控制系统方法及其应用

李世华
东南大学

干扰无处不在，常常影响闭环系统性能。与高增益以及积分控制等方法相比，基于干扰估计观测的控制方法给出了另外一种不同的解决途径，它可以很好地提升闭环系统抗干扰性能，保证闭环系统的鲁棒性。本次报告将讨论如何从干扰建模估计和前馈补偿角度提高闭环系统的抗干扰性能，给出了这方面的一些最新理论研究进展和成果；结合运动控制系统应用特点，探讨了几种基于干扰观测补偿的运动控制系统复合控制方法设计实例及实验验证结果。

Theory and Application on Disturbance Observation and Compensation Based Motion Control Method

Shihua Li
Southeast University

Disturbances widely exist and always bring adverse effects on the closed-loop control systems. Compared with high gain control and integral control methods, disturbance estimation based control provides a different way to handle disturbance. Disturbance estimation based robust control method can effectively improve the disturbance rejection ability and ensure the robustness of closed-loop system. In this talk we will discuss how to improve the disturbance rejection ability based on disturbance estimation and feedforward compensation. Some new research developments and results on this topic will be introduced. Considering the characteristics of motion control system, several composite motion control design schemes based on disturbance estimation and compensation are presented with experimental verification results.

Disturbance rejection in the Embedded Model Control

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The core of the Embedded Model Control is the embedded model running in parallel to the plant. The model output compared to plant output (the model error) is a real-time measure of the ignorance, that may efficiently update a ‘disturbance’ state, which becomes a repository of the past ignorance and provides a prediction to be contrasted by the plant command. Since causality prevents complete disturbance rejection, the residuals (parameter variability, neglected dynamics, noise) combine in the model error, being the unique source of the residual ignorance. In the Kalman filter framework, residuals (model error) are command-independent colored noise (innovation); in the practice they mix up all the model-to-plant discrepancies (mainly command dependent, the unknown loop) due to the constrained past command action. The control design art is to spill from the model error suitable signals (noise estimator), which are capable of reducing ignorance (updating the disturbance state), without exciting the unknown/neglected loop as the latter may become source of instability and degraded performance. The unknown loop is part of the error loop, from which stability and performance inequalities are derived. The role of the state predictor (embedded model plus noise estimator) can be shown be essential, as the sensitivity bandwidth fixes the boundary between cancelled and unrejected ignorance. The latter can be shown to be the control jitter, responsible of control inaccuracies. A simple example in motion control will confirm assertions.

Linear ADRC of underactuated mechanical Systems

Hebertt Sira Ramírez
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ADRC is a mature field of research providing an interesting and new paradigm in challenging industrial and academic automatic control engineering problems. The combination of differential flatness and ADRC has proven to be quite effective in the robust control of nonlinear feedback linearizable systems i.e., flat systems. A certain class of underactuated systems turns out to be nonflat, i.e., they are not feedback linearizable via state coordinate change and either static or dynamic feedback. Nevertheless, some of these systems enjoy the property of exhibiting a controllable (i.e., flat) tangent linearization, around an equilibrium point, along with a unique cascading structural property. In this presentation, we take a step further in merging ADRC and the flatness property for the control of the described special class of underactuated nonflat systems. We show how to exploit local flatness in global trajectory tracking problems with a substantial decoupling and simplification of the extended disturbance observers in the cascaded linearization. Experimental results will be presented for a rotational inverted pendulum.

Time-varying repetitive control for disturbance rejections with applications to fuel injection systems and high density data storage systems

Zhen Zhang
(Tsinghua University)
Peng Yan
(Beihang University)

In this talk, we first present recently developed time-varying repetitive control methodology for disturbance rejection. The motivation of the proposed framework is to track and/or reject signals and/or disturbances dependent of rotational-angle or linear-position. Then we show how this approach can be applied to some emerging industrial applications.1) For common rail (CR) fuel injection system of internal combustion engines, the pressure pulsations inside the common rail caused by the incoming and outgoing flows negatively affect the accuracy of both injected fuel quantities and flow rates. To design a new regulation mechanism to suppress the pressure pulsation in the rail, we leverage on the periodic nature of the injection event with respect to the rotational angle as the stroke by stroke engine operation generates pressure pulsations in the rail. We design a time-varying repetitive controller to control an active fluid storage device like a piezoelectric actuator (PZT) to minimize the pressure fluctuations.2) In high density Hard Disk Drive (HDD) data storage systems, disturbance rejection algorithms are widely used to minimize TMR (Track Misregistration). Frequency-varying harmonic disturbance rejection is an important and challenging topic in RRO (repeatable runout) suppression. A time-varying repetitive servo control algorithm is discussed for the purpose of RRO disturbance rejections, which enables higher TPI (Track-per-Inch) for high density HDD.

7 月 25 日

14:00-16:00 自抗扰控制理论分析的进展与挑战 (Theoretical Analysis and Challenges)

线性自抗扰控制的参数整定方法研究

孙明玮 陈增强
南开大学信息技术科学学院自动化系，天津

自抗扰控制最近几年已经逐渐得到了工程师的认可，并已经在一些重要场合得到了有效应用。线性自抗扰控制作为一种参数化设计方法，算法简洁，便于实现，是实际应用中的一个主要形式，同时在使用中的一些需求和暴露出来的问题也促使我们对于该方法进行了有针对性的分析，通过参数整定规律的形式反馈给工程师作为实际应用中的指导。本报告介绍相关的几部分工作，通过对于典型过程环节特性结合线性自抗扰控制的闭环分析，得到形式上具有直观物理意义并且能够被工程师接受的实用原则：针对一些过程工业对象避免超调的需求，分析得到了参数选取的组合条件；针对飞行器姿态控制的背景，提出了基于稳定裕度吸引子的图形化参数整定方法，对于适用性进行了归纳，并与静态输出反馈鲁棒控制建立起了联系；针对控制中的核心部件—扩张观测器，通过输入时延摄动鲁棒性的方式，定量给出了控制带宽与控制增益的约束范围。

On Tuning of Linear Active Disturbance Rejection Control

Mingwei Sun, Zengqiang Chen
Department of Automation, Nankai University, Tianjin

Active Disturbance Rejection Control (ADRC) has gradually been accepted by practitioners in recent years and several successful applications have been reported. As a concise algorithm, Linear ADRC (LADRC) is a major paradigm for use in reality. The practical requirements and the problems demonstrated in LADRC applications urge us to perform related investigations and feedback the corresponding results to the practitioners in the form of tuning rules. The closed-loop analysis process is based on the typical processes combining with LADRC; and the results are several useful tuning guidelines, which have definite physical meanings and can provide engineers with insightful understandings. At first, the tuning rules are obtained to avoid overshoot for typical industrial processes. Secondly, the graphical tuning rules for flight control based on stability margin tester are presented and the applicability is summarized. Furthermore, the relationship between the LADRC tuning and the static output feedback robust control has been established. Finally for the key component, Extended State Observer (ESO), the effects of the observer bandwidth and the control gain on the closed-loop sensitivity to the input time-delay perturbation are quantitatively analyzed

阶和相对阶不确定对象的自抗扰控制设计与整定

赵春哲
清华大学， 北京

在工业过程的控制问题中，对象模型往往难以准确获得，甚至模型的阶和相对阶也无法确定。本工作主要讨论对模型未知的 SISO 系统的自抗扰控制（ADRC）设计与整定。所涉及的被控对象，不仅具有参数不确定性，其阶和相对阶也是未知的。针对最小相位对象、开环稳定对象给出了 ADRC 设计方法，并对稳定性、闭环性能进行了理论分析，基于数学证明给出了对这两类对象进行 ADRC 设计的充要条件。还证明了 ADRC 可以用于 PID/PI 可控的 SISO 对象，并给出了基于 PID/PI 控制器参数，进行 ADRC 设计的简便方法。为验证此方法的有效性，我们进行了大量仿真实验。选取的实验对象能够代表很多工业过程，不仅验证了上述理论结果，还发现此方法对时滞系统也有一定的实用价值。

Design and tuning of the ADRC for the plant with unknown order and unknown relative degree

Chunzhe Zhao
Tsinghua University, Beijing

In the industrial control problems, the exact plant model is often difficult to be obtained, even the order and the relative degree of the model can be unknown. This work is on how to design and tune the ADRC for the plant with the unknown model. The controlled plant has the parameter uncertainty, and its order and relative degree are unknown. The ADRC design and tuning methods are given for the minimum-phase system and the open-loop stable system, and the stability and the performance of the close loop is analyzed theoretically. The necessary and sufficient conditions are established for designing ADRC on the two kinds of systems via the mathematical proof. It is also proved that ADRC can be applied to the system which can be stabilized by the PID/PI controllers. And a quick method is given to design ADRC based on the PID / PI controller parameters. In order to verify the effectiveness of this method, we conducted a large number of simulation experiments. The selected models are representative for many kinds of industrial processes, can confirm the theoretical results and reveal the practical value of applying this method to some systems with time delay.

On Frequency Response Characteristics of ADRC

Jason Tatsumi, Zhiqing Gao
Cleveland State University, Ohio, U.S.A.

The extended state observer (ESO), a key piece in active disturbance rejection control (ADRC), is brought from time domain into the frequency domain to show how well it makes a plant approximate a cascaded integral form. In particular, a root locus technique is presented to show insight on how ADRC mitigates uncertainties in plant dynamics, within the bandwidth of the observer. Graphical examples are provided to visualize how the system dynamics loses its uncertainty as the observer bandwidth increases and to see how certain kinds of system dynamics put a limitation on the observer bandwidth.

稳定对象的低阶线性自抗扰控制

黄从智
华北电力大学控制与计算机工程学院，北京

在针对二阶被控对象设计的线性自抗扰控制反馈控制系统中，当对象参数摄动时开环传递函数高频段几乎保持一致，且扰动通道传递函数在所有频段几乎完全一致。线性自抗扰控制器为何具有如此优越的频率特性呢？本报告试图从传递函数 Bode 图本身的角度揭示其本质原因。在由低阶线性自抗扰控制器和开环稳定对象组成的反馈控制系统中，通过分析其开环传递函数和扰动通道传递函数 Bode 图发现：低阶线性自抗扰控制器对被控对象参数摄动都具有较强的鲁棒性，对控制回路中的扰动都有很强的抑制能力。实例分析结果验证了低阶线性自抗扰控制器的这些优良频域特性。

On Lower Order Linear Active Disturbance Rejection Control for Stable Process

Congzhi Huang
School of Control and Computer Engineering, North China Electric Power University, Beijing

It was reported that in the feedback control system consisting of the second order process and a linear active disturbance rejection controller (LADRC for short), the high frequency sections of the open loop transfer function are immune to the process parametric perturbations, and the disturbance rejection transfer functions are also nearly the same for all frequencies. Why does the LADRC has such great frequency characteristics? This talk tries to uncover the intrinsic reason from the Bode plots of the transfer functions themselves. In the feedback control system consisting of an open loop stable process and a lower order LADRC, the following conclusions are discovered by analyzing the Bode plots of the open loop as well as the disturbance rejection transfer functions: the lower order LADRC has very strong robustness against the process parametric perturbations, and it also has very strong disturbance rejection ability. These excellent frequency-domain characteristics of the lower order LADRC are validated by the given examples.

一类最小相位非线性不确定系统的自抗扰控制

姜甜甜
中国科学院数学与系统科学研究院，北京

本报告主要研究一类单输入单输出最小相位非线性不确定系统的反馈控制问题。该类系统的内部和外部动态都含有高度非线性不确定动态，并且外部动态控制通道中含有不确定动态。我们提出基于扩张状态观测器（ESO）和投影梯度估计算法的不确定动态估计方法，摆脱了控制器设计对系统控制增益中不确定动态先验估计的依赖。证明了基于该估计算法设计的控制器可以保证闭环系统的稳定性，并可以实现对参考轨迹的合理跟踪。该结果改进了已有研究中需要已知控制增益中不确定动态先验估计的不足，一定程度上优化了自抗扰控制（ADRC）方法。

The Active Disturbance Rejection Control of a Class of Minimum-phase Nonlinear Uncertain Systems

Tiantian Jiang
Academy of Mathematics and Systems Science, Chinese Academy of Sciences, Beijing

This talk will illustrate the stabilization and tracking problem for a class of SISO minimum-phase nonlinear uncertain systems, where unknown nonlinear functions exist both in the internal and the external dynamics. For the external dynamics, there also exists uncertainty in the input channel. We develop a method to estimate the unknown dynamics by combing the extended state observer (ESO) and the projected gradient estimator. This method overcomes the difficulty that it needs a “good” estimate for the uncertainties in the input gain. The stability of the closed-loop system is proven and the tracking performance is also analyzed. This work improves the existing active disturbance rejection control (ADRC) technique to some extent.

采样条件下一类非线性耦合系统的自抗扰控制器参数调节和能力分析

薛文超，黄一
中国科学院数学与系统科学研究院，北京

研究了采样自抗扰控制的参数调节和和控制能力极限。提出一类典型的（相对阶）1 阶不确定多输入多输出非线性耦合系统中不确定性的刻画，定量地研究固定采样步长下如何调节自抗扰控制器参数使得闭环系统稳定且动态过程接近其参考轨迹。最后，分析了在固定采样步长条件下，自抗扰控制可对付不确定性的能力极限。

On Parameters Tuning and Capability of Sampled-data ADRC for Nonlinear Coupled Uncertain Systems

Wenchao Xue, Yi Huang
Academy of Mathematics and Systems Science, Chinese Academy of Sciences, Beijing

We concern with the parameters tuning and the capability of Active Disturbance Rejection Control (ADRC) to deal with the nonlinear uncertain system under fixed sampling rate. Firstly, a three-dimension criterion is proposed to describe the uncertainties for a typical class of nonlinear systems. We give a rule of designing ADRC to reach the control objects including exponential stability and transient performance recovery of a reference trajectory. The rule quantitatively shows the relationship among the parameters of ADRC, the sampling rate and the uncertainty to be dealt. Finally, we investigate the capability of sampled-data ADRC under given sampling rate.