第25届中国控制会议论文集

Proceedings of the 25th Chinese Control Conference

上　册

主　编　程代展　段广仁

副主编　郑大钟　王　龙　张纪峰　贾英民　刘智敏

　　　　黄　一　黄显林　严质斌　张焕水　关新平

北京航空航天大学出版社

第 25 届中国控制会议论文集

Proceedings of the 25th Chinese Control Conference

上 册

主　编　程代展　段广仁
副主编　郑大钟　王　龙　张纪峰　贾英民　刘智敏
　　　　黄　一　黄显林　严质斌　张焕水　关新平

北京航空航天大学出版社

内容简介

本书共收入455篇论文。这些论文是经中国自动化学会控制理论专业委员会组织评审，作为第25届中国控制会议论文发表的。论文内容包括系统理论与控制理论、非线性系统、复杂性与复杂系统理论、建模、辨识与估计、优化控制与优化方法、鲁棒控制与H-inf控制、学习控制、稳定性与镇定、自适应控制、变结构控制、分布参数系统、混合系统与DEDS、大系统理论与方法、神经网络与控制、模糊系统与控制、故障诊断、CIMS与制造系统、仿真与控制系统CAD、智能信息处理系统、遗传算法与智能计算、分布式控制系统、运动控制、智能机器人、电力系统、环境与生物工程、人机系统、智能仪表、智能交通系统、社会经济系统、通信网络系统、模式识别等理论研究成果，以及控制理论在机器人、航空航天、工业生产、过程控制、能源环境、生物医学和社会经济系统等领域的应用研究成果。

本书可供从事自动控制理论及其应用研究的高等院校教师和研究生、科研单位的研究人员以及工业部门的工程技术人员参考。

图书在版编目(CIP)数据

第25届中国控制会议论文集/程代展，段广仁主编.
北京：北京航空航天大学出版社，2006.12
ISBN 7-81077-802-1

Ⅰ.第…　Ⅱ.①程…②段…　Ⅲ.自动控制理论—文集　Ⅳ.TP13-53

中国版本图书馆CIP数据核字(2006)第135025号

第25届中国控制会议论文集

Proceedings of the 25th Chinese Control Conference

主　编　程代展　段广仁

副主编　郑大钟　王　龙　张纪峰　贾英民　刘智敏
黄　一　黄显林　严质斌　张焕水　关新平

责任编辑　刘晓明　王媛媛　蔡　喆　韩文礼

*

北京航空航天大学出版社出版发行

北京市海淀区学院路37号(100083)　发行部电话:010-82317024　传真:010-82328026

http://www.buaapress.com.cn　E-mail:bhpress@263.net

各地书店经销

*

开本:890×1240　1/16　印张:146.25　字数:6 038千字

2006年12月第1版　2006年12月第1次印刷　印数:500册

ISBN 7-81077-802-1　定价:600.00元(上、中、下册)

第25届中国控制会议

主办单位： 中国自动化学会控制理论专业委员会
承办单位： 哈尔滨工业大学
协办单位： 中国科学院数学与系统科学研究院系统科学研究所
IEEE 控制系统协会
日本仪器与控制工程师协会
韩国控制、自动化与系统工程学会
黑龙江大学
哈尔滨工程大学

会 议 机 构

顾问委员会

曹希仁	香港科技大学	C. Martin	Texas Tech University
戴汝为	中国科学院	R. Ortega	CNRS, France
冯纯伯	东南大学	C. Park	Kyung Hee University, Korea
郭　雷	中国科学院	秦化淑	中国科学院
Y. C. Ho	Harvard University	宋　健	中国工程院
黄　琳	北京大学	M. W. Spong	University of Illinois
H. K. Khalil	Michigan State University	T. J. Tarn	Washington University
H. Kimura	Tokyo University	王子才	哈尔滨工业大学
王树国	哈尔滨工业大学	吴宏鑫	中国航天科技集团 502 所
卢　强	清华大学	张嗣瀛	东北大学

会议总主席

陈翰馥　　中国科学院

程序委员会

协 主 席：程代展　（中国科学院）　　段广仁　（哈尔滨工业大学）
秘 书 长：黄　一　（中国科学院）　　吴爱国　（哈尔滨工业大学）
区域主席：

B. Chen	(NUS, Singapore)	J. Huang	(CUHK, Hongkong)
T. W. Chen	(Univ. of Alberta Canada)	G. P. Liu	(Univ. of Glamorgan, UK)
J. W. Choi	(Pusan National Univ., Korea)	Z. L. Lin	(Univ. of Virginia, USA)
M. Y. Fu	(Univ. of Newcastle, Australia)	T. L. Shen	(Sophia University, Japan)

委员：

毕大川	曹希仁	陈翰馥	陈　杰	陈叔平
陈增强	陈志炜	陈宗基	程代展	楚天广
褚　健	丛　爽	戴冠中	段广仁	费树岷
冯　刚	耿志勇	关新平	关治洪	管晓宏
郭　雷	韩京清	韩志刚	侯忠生	胡德文
胡跃明	黄　捷	黄　一	霍　伟	贾英民
姜钟平	蒋昌俊	康　伟	李春文	李少远
李泽湘	潘　泉	秦化淑	阮晓钢	申铁龙
孙常胜	谭　民	谭永红	田玉平	涂菶生
王成红	王　华	王　龙	王　伟	王庆林
王诗宓	王先来	王行愚	吴　敏	吴　臻
吴宏鑫	武玉强	胥布工	薛安克	杨晓松
俞　立	郁文生	张　旭	张纪峰	赵　军
郑大钟	郑德玲	钟宜生	周鸿兴	周　彤

会前报告会

主　席：Z. P. Jiang　(Polytechnic Univ.，USA)　　陈兴林　(哈尔滨工业大学)

组织委员会

协主席：姚　郁　(哈尔滨工业大学)　　张纪峰　(中国科学院)

副主席：韩志刚　(黑龙江大学)　　刘智敏　(中国科学院)

沈　毅　(哈尔滨工业大学)　　王科俊　(哈尔滨工程大学)

王常虹　(哈尔滨工业大学)　　杨　明　(哈尔滨工业大学)

编辑委员会

主　编：程代展　(中国科学院)　　段广仁　(哈尔滨工业大学)

副主编：郑大钟　王　龙　张纪峰　贾英民　刘智敏

黄　一　黄显林　严质斌　张焕水　关新平

The 25th Chinese Control Conference

Organizing Institutions

Technical Committee on Control Theory, Chinese Association of Automation
Harbin Institute of Technology

Co-Sponsored by

Institute of Systems Science, Academy of Mathematics and Systems Sciences, CAS
IEEE Control Systems Society(CSS)
The Society of Instrument and Control Engineers(SICE)of Japan
The Institute of Control, Automation, and Systems Engineers (ICASE) of Korea
Heilongjiang University
Harbin Engineering University

Advisory Committee

X. R. Cao	(Hong Kong Uni. Sci. & Tech.)	C. Martin	(Texas Tech University, USA)
R. W. Dai	(Chinese Academy of Sciences)	R. Ortega	(CNRS, France)
C. B. Feng	(Southeast University)	C. Park	(Kyung Hee University, Korea)
L. Guo	(Chinese Academy of Sciences)	H. S. Qin	(Chinese Academy of Sciences)
Y. C. Ho	(Harvard University, USA)	J. Song	(CAE)
L. Huang	(Peking University)	M. S. Spong	(Univ. of Illinois, USA)
H. K. Khalil	(Michigan State Univ., USA)	T. J. Tarn	(Washington University)
H. Kimura	(Tokyo University, Japan)	Z. C. Wang	(Harbin Inst. of Tech.)
S. G. Wang	(Harbin Inst. of Tech.)	H. X. Wu	(CASC)
Q. Lu	(Tsinghua University)	S. Y. Zhang	(Northeast University)

General Chairman

H. F. Chen (Chinese Academy of Sciences)

Program Committee

Co-Chairmen

D. Z. Cheng	(Chinese Academy of Sciences)	G. R. Duan	(Harbin Inst. of Tech.)

General Secretares

Y. Huang	(Chinese Academy of Sciences)	A. G. Wu	(Harbin Inst. of Tech.)

Regional Chairmen

B. Chen	(NUS, Singapore)	J. Huang	(CUHK, Hongkong)
T. W. Chen	(Univ. of Alberta Canada)	G. P. Liu	(Univ. of Glamorgan, UK)
J. W. Choi	(Pusan National Univ., Korea)	Z. L. Lin	(Univ. of Virginia, USA)
M. Y. Fu	(Univ. of Newcastle, Australia)	T. L. Shen	(Sophia University, Japan)

Members

D. C. Bi	X. R. Cao	H. F. Chen	J. Chen	S. P. Chen
Z. Q. Chen	Z. W. Chen	Z. J. Chen	D. Z. Cheng	T. G. Chu
J. Chu	S. Cong	G. Z. Dai	G. R. Duan	S. M. Fei
G. Feng	Z. Y. Geng	X. P. Guan	Z. H. Guan	S. H. Guan
L. Guo	J. G. Han	Z. G. Han	Z. S. Hou	D. W. Hu
Y. M. Hu	J. Huang	Y. Huang	W. Huo	Y. M. Jia
Z. P. Jiang	C. J. Jiang	W. Kang	C. W. Li	S. Y. Li
Z. X. Li	Q. Pan	H. S. Qin	X. G. Ruan	T. L. Shen
C. S. Sun	M. Tan	Y. H. Tan	Y. P. Tian	F. S. Tu
C. H. Wang	H. Wang	L. Wang	W. Wang	Q. L. Wang
S. F. Wang	X. L. Wang	X. Y. Wang	M. Wu	Z. Wu
H. X. Wu	Y. Q. Wu	B. G. Xu	A. K. Xue	X. S. Yang
L. Yu	W. S. Yu	X. Zhang	J. F. Zhang	J. Zhao
D. Z. Zheng	D. L. Zheng	Y. S. Zhong	H. X. Zhou	T. Zhou

Pre-conference Workshop

Chairman

Z. P. Jiang (Polytechnic Univ., USA) X. L. Chen (Harbin Inst. of Tech.)

Organizing Committee

Co-Chairmen

Y. Yao (Harbin Institute of Technology) J. F. Zhang (Chinese Academy of Sciences)

Vice-Chairmen

Z. G. Han (Heilongjiang University) Z. M. Liu (Chinese Academy of Sciences)

Y. Shen (Harbin Inst. of Tech.) K. J. Wang (Harbin Engineering Uni.)

C. H. Wang (Harbin Inst. of Tech.) M. Yang (Harbin Inst. of Tech.)

Editing Committee

Chief-Editors

D. Z. Cheng (Chinese Academy of Sciences) G. R. Duan (Harbin Inst. of Tech.)

Deputy-Chief-Editors

D. Z. Zheng	L. Wang	J. F. Zhang	Y. M. Jia	Z. M. Liu
Y. Huang	X. L. Huang	Z. B. Yan	H. S. Zhang	X. P. Guan

前　言

“中国控制会议”是由中国自动化学会控制理论专业委员会负责组织的学术会议，自 1979 年至今已举办了 24 届。该系列年会的目的是为海内外系统控制领域的专家、学者、研究生及控制系统的设计人员提供一个学术交流的机会，以推动控制科学的学科发展和控制技术的应用。

第 25 届中国控制会议于 2006 年 8 月 7 日～11 日在北国名城哈尔滨举行。会议由哈尔滨工业大学承办，协办单位包括：中国科学院数学与系统科学研究院系统科学研究所，IEEE Control System Society，The Society of Instrument and Control Engineers (SICE) of Japan，The Institute of Control，Automation and System Engineers of Korea(KICASE)，并得到自然科学基金委员会等单位的支持和资助。

本着开拓创新、与时俱进的精神，本届大会加强了组织协调，为扩大国际交流，设立了美国、日本、英国、澳大利亚、加拿大、韩国、新加坡、香港等 8 个地区主席，得到海内外学者的热烈回应。中国控制会议正朝着国际化的目标稳步前进。

本届会议邀请 6 位知名学者做大会报告，他们分别是 Stephen P. Boyd (Stanford University，USA)，Graham C. Goodwin (The University of Newcastle，USA)，Lei Guo (Chinese Academy of Sciences，China)，Miroslav Krstic (University of California，San Diego，USA)，Anders Lindquist (Royal Institute of Technology，Sweden)，Tzyh-Jong Tarn (Washington University，USA)。

本次会议共收到投稿论文 674 篇，创造了新的记录。经程序委员会评审，论文集共收录 455 篇论文。论文作者来自中国大陆和香港、澳大利亚、加拿大、伊朗、日本、新加坡、瑞典、瑞士、英国、美国等十多个国家和地区。论文内容包括线性系统、非线性系统、变结构控制、最优控制、优化方法、鲁棒控制、H^∞ 控制、预测控制、过程控制、随机控制、自适应控制、稳定性分析、分布参数系统、DEDS 与 CIMS、复杂系统、模糊系统与控制、神经网络、机器人控制、交通系统、故障检测与诊断、电力系统等领域的研究成果。本论文集可供从事自动控制理论及其应用研究的高等院校教师和研究生、科研单位的研究人员以及工业部门的工程技术人员参考。

本届大会论文集将进入 IEEE Conference Publications Program (CPP) (IEEE 分类号：06EX1301)。

论文集的出版必将进一步促进系统科学的发展，推动先进控制理论与方法更好地为生产实践服务，促进控制技术产业化。

本届“关肇直奖”竞争激烈，申请论文达 57 篇。它的评选促使一批优秀的中青年控制科学工作者脱颖而出，为控制科学的发展注入了新的血液。

我们诚挚感谢为中国控制会议的发展献策出力的海内外朋友们，为论文集的出版付出辛勤劳动和出色工作的各位论文作者，论文集主编、副主编，程序委员会专家和北京航空航天大学出版社的同志们。

第 25 届中国控制会议程序委员会主席

程代展　　中国科学院

段广仁　　哈尔滨工业大学

Preface

The Chinese Control Conference (CCC) is an annual technical conference sponsored and organized by the Technical Committee on Control Theory, Chinese Association of Automation. The first conference was held in 1979, and this is the 25th session. The purpose of CCC is to provide a forum for both practitioners and theorists in the area of systems and control to report their latest research results, to exchange their ideas and experience, and to promote collaborative research activities. The participants from China and from abroad, will gather together to discuss the development of systems and control theory and its applications to engineering problems.

The 25th CCC had been held in the northeast historical city—Harbin, August 7-11, 2006. The Harbin Institute of Technology is the local sponsor. The conference is also co-sponsored by the Institute of Systems Science, Academy of Mathematics and Systems Science, Chinese Academy of Sciences, IEEE Control System Society, the Society of Instrument and Control Engineer (SICE) of Japan, the Institute of Control, Automation and System Engineers (KICASE) of Korea, the Heilongjiang University, and the Harbin Engineering University. Some supports and financial aids are from the Natural Science Foundation of China.

In the spirit of reform, openness, and internationalization, the 25th CCC is devoted to strengthening its cooperation with control communities from all over the world by establishing 8 Regional Chairs for USA, Japan, United Kingdom, Australia, Canada, Korea, Singapore, and Hong Kong, respectively. CCC is now earning its reputation as a true international conference.

For the 25th CCC six prominent scholars over the world are invited to deliver the plenary speeches. They are Professor S. P. Boyd (Stanford University, USA), Professor G. C. Goodwin (University of Newcastle, Australia), Professor Lei Guo (Chinese Academy of Sciences, China), Professor M. Krstic (University of California, San Diego, USA), Professor A. Lindquist (Royal Institute of Technology, Sweden), and Professor T. J. Tarn (Washington University, USA).

This year, we have received a record high submission of 674 papers. After a rigorous review process by the Conference Program Committee, 455 papers are accepted and included in the Conference Proceedings. The authors of the accepted papers are from various countries and regions including, in addition to the Chinese Mainland and Hong Kong, Australia, Canada, Iran, Japan, Singapore, Sweden, Switzerland, United Kingdom, USA, etc. The topics of the Conference include System Identification, Linear Systems, Nonlinear Systems, Sliding-Mode Control, Optimal Control, Optimization, Robust Control, H-infinity Control, Predictive Control, Process Control, Stochastic Control, Adaptive Control, Stability Analysis, Distributed Parameter System, DEDS, CIMS, Complex Systems and Complexity, Fuzzy Systems and Control, Neural Networks, Robot Control, Transportation Systems, Error Detection and Diagnosis, Power Systems, etc. The Conference Proceedings being a comprehensive collection of the latest research papers serve as an excellent reference for university professors and graduate students in the field of automation and control as well as for experts working in research institutions and engineers in industry.

The Conference Proceedings will be included in the IEEE Conference Publications Program (CPP) with IEEE Catalog Number 06EX1301. The CPP will handle the worldwide post-conference sales.

This year, we have also received a record-breaking number (57) of papers for competing Guan Zhao-Zhi Best Paper Award. This is an indication that outstanding young researchers in the area of systems and control are mushrooming. They are rapidly moving up to the forefront of the systems and control community in China.

We would like to express our sincere thanks to our domestic and overseas friends for their constant support to CCC. We greatly appreciate all contributors of the papers and members of the organizing committee, the program committee, and the editorial board of the conference proceedings. Taking this opportunity, we would also like to thank the publisher, BUAA Press.

Chairs of the Program Committee

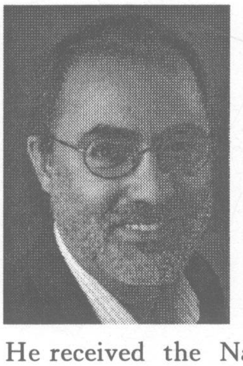
Daizhan Cheng Chinese Academy of Sciences

Guangren Duan Harbin Institute of Technology

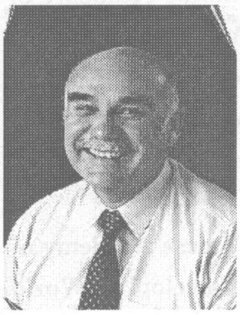
大会报告(Plenary)

Plenary Speakers at the 25th Chinese Control Conference

Tzyh-Jong Tarn received the D. Sc. degree in control system engineering from Washington University, St. Louis, MO. Currently, he is a Professor in the Department of Electrical and Systems Engineering and the Director of the Center for Robotics and Automation at Washington University, St. Louis, MO. He served as the President of the IEEE Robotics and Automation Society from 1992 to 1993, the Director of the IEEE Division X (Systems and Control), from 1995 to 1996, and was a member of the IEEE Board of Directors, from 1995 to 1996. At present, he serves as the Vice President for Conferences of the IEEE Robotics and Automation Society.
He received the NASA Certificate of Recognition for the creative development of a technical innovation on "Robot Arm Dynamic Control by Computer" in 1987. The Japan Foundation for the Promotion of Advanced Automation Technology presented him with the Best Research Article Award in March 1994. He also received the Best Paper Award at the 1995 IEEE/RSJ International Conference on Intelligent Robots and Systems, and the Distinguished Member Award from the IEEE Control Systems Society in 1996. He is the first recipient of both the Nakamura Prize at the 10th Anniversary of IROS in Grenoble, France, 1997 and the Ford Motor Company best paper award at the Japan/USA Symposium on Flexible Automation, Otsu, Japan, 1998. In addition, he is the recipient of the prestigious Joseph F. Engelberger Award of the Robotic Industries Association in 1999, the Auto Soft Lifetime Achievement Award in 2000 and the Pioneer in Robotics and Automation Award in 2003 from the IEEE Robotics and Automation Society. He is an IEEE Follow.



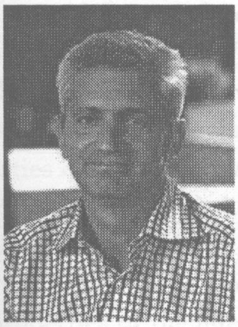
Miroslav Krstic is the Harold Sorenson Professor in the Department of Mechanical and Aerospace Egineering at University of California, San Diego (UCSD). He started his career in 1995 at University of Maryland and moved to UCSD in 1997. He obtained his PhD at University of California, Santa Barbara in 1994 and received the UCSB Best Dissertation Award.
Krstic is a coauthor of the books Nonlinear and Adaptive Control Design (1995), Stabilization of Nonlinear Uncertain Systems (1998), Flow Control by Feedback (2002), and Real Time Optimization by Extremum Seeking Control (2003).
He received the National Science Foundation Career Award, the Office of Naval Research Young Investigator Award, the Presidential Early Career Award for Scientists and Engineers, the Axelby Outstanding Paper Award, and the O. Hugo Schuck Best Paper Award. In 2005 he was the first engineering professor to receive the UCSD Award for Excellence in Research.
Krstic is a Fellow of IEEE and a Distinguished Lecturer of the Control Systems Society. He has served as Associate Editor for the IEEE Transactions on Automatic Control, the International Journal of Adaptive Control and Signal Processing, and Systems and Control Letters. He is currently Editor for Adaptive and Distributed Parameter Systems in Automatica. He has served as Vice President for Technical Activities and a member of the Board of Governors of the Control Systems Society, and Vice-Chair in his department at UCSD.



Graham Goodwin was born in Broken Hill, Australia in 1945. He obtained a BSc (Physics) BE (Electrical Engineering) and PhD from the University of New South Wales. He was a lecturer at Imperial College London from 1970 to 1974 and has been with the University of Newcastle since then. He is the author of 8 books and several hundred papers. He has twice won the IFAC Text Book Prize. He is a Fellow of the Royal Society London, The Australian Academy of Science, The Australian Academy of Technological Sciences and Engineering and is a Foreign Member of the Swedish Royal Academy of Science (The Nobel Prize Academy). His research interests include control, signal processing and communications.

Anders Lindquist received the Ph. D. degree in 1972 from the Royal Institute of Technology, Stockholm, Sweden. From 1972 to 1974 he held visiting positions at the University of Florida, Brown University, and State University of New York at Albany. In 1974 he became an Associate Professor, and in 1980 a Professor at the University of Kentucky, where he remained until 1983. He is now a Professor at the Royal Institute of Technology, where in 1982 he was appointed to the Chair of Optimization and Systems Theory. Presently, he is the head of the Mathematics Department there. Since 1989 he is also an Affiliate Professor of Optimization and Systems Theory at Washington University, St Louis.

Dr. Lindquist is a Member of the Royal Swedish Academy of Engineering Sciences, a Foreign Member of the Russian Academy of Natural Sciences, a Fellow of the IEEE and an Honorary Member the Hungarian Operations Research Society. He has served on many editorial boards of journals and book series. He is the recipient (together with C. I. Byrnes and T. T. Georgiou) of the George S. Axelby Outstanding Paper Award of the IEEE Control Systems Society (CSS) for the year 2003.



Stephen Boyd is the Samsung Professor of Engineering, and Professor of Electrical Engineering in the Information Systems Laboratory at Stanford University. He received the A. B. degree in Mathematics from Harvard University in 1980, and the Ph. D. in Electrical Engineering and Computer Science from the University of California, Berkeley, in 1985, and then joined the faculty at Stanford. His current research focus is on convex optimization applications in control, signal processing, and circuit design. He has held visiting Professor positions at Katholieke University (Leuven), McGill University (Montreal), Ecole Polytechnique Federale (Lausanne), Qinghua University (Beijing), Universite Paul Sabatier (Toulouse), Royal Institute of Technology (Stockholm), and Kyoto University.

Professor Boyd is the author of many research articles and three books: Linear Controller Design: Limits of Performance (with Craig Barratt, 1991), Linear Matrix Inequalities in System and Control Theory (with L. El Ghaoui, E. Feron, and V. Balakrishnan, 1994), and Convex Optimization (with Lieven Vandenberghe, 2004). He has received many awards and honors for his research in control systems engineering and optimization, including an ONR Young Investigator Award, a Presidential Young Investigator Award, and an IBM faculty development award. In 1992 he received the AACC Donald P. Eckman Award. In 1993 he was elected Distinguished Lecturer of the IEEE Control Systems Society, and in1999, he was elected Fellow of the IEEE. He has been invited to deliver more than 20 plenary and keynote lectures at major conferences in both control and optimization.

Lei GUO received his Ph. D. degree in control theory from the Chinese Academy of Sciences (CAS) in 1987, and was a postdoctoral fellow at the Australian National University (1987-1989). Since 1992, he has been a Professor of the Institute of Systems Science at CAS, where he had been the Director of the Institute (1999-2002). He is currently the President of the Academy of Mathematics and Systems Science, CAS.

Dr. Guo was elected Fellow of the IEEE in 1998, Member of the Chinese Academy of Sciences in 2001, and Fellow of the Academy of Sciences for the Developing World (TWAS) in 2002. He has twice received, in 1987 and 1997, the National Natural Science Prize of China. He was also the recipient of the 1993 IFAC World Congress Young Author Prize "for solving a long standing problem in control theory concerning covergence and convergence rate for the least-squares-based self-tuning regulators". He was invited to give lectures at various international conferences, including. Plenary Lecture at the 1999 IFAC World Congress, and Invited Lecture at the 2002 International Congress of Mathematicians (ICM).

He is currently a Council Member of IFAC, a member of the IFAC Award Committee, the Editor-in-Chief of the Journal of Systems Science and Complexity, and is on the editorial boards of numerous technical journals in the areas of Systems, Control and mathematics. He is a member of the Chinese National Award Committee on Science and Technology, a Vice-President of the Chinese Association of Automation, and a Vice-President of the Chinese Mathematical Society. He had been an Associate Editor of the SIAM J. on Control and Optimization (1991-1993), and the Chair of the IFAC Technical Committee on Modeling, Identification and Signal Processing (1999- 2002). He will serve as the general co-chair of the 48th IEEE-CDC to be held in China in 2009.

He has worked on problems in adaptive control, system identification, stochastic systems, nonstationary time-series analysis and adaptive signal processing. His current research interests include the maximum capability and limitations of feedback mechanism, global controllability of nonlinear systems, multi-agent systems, complex adaptive systems and quantum control systems.

Proceedings of the 25th Chinese Control Conference
7-11 August, 2006, Harbin, Heilongjiang

Feedback Control of Decoherence: Systems Theoretical Approach

Narayan Ganesan[1], Tzyh Jong Tarn[2]
1. Electrical and Systems Engineering, Washington University in St. Louis, MO-63130, USA
E-mail: ng@wuauto.wustl.edu
2. Electrical and Systems Engineering, Washington University in St. Louis, MO-63130, USA
E-mail: tarn@wuauto.wustl.edu

Abstract: This paper outlines the recent work on control of Decoherence in Open Quantum systems using systems and control techniques and the corresponding theoretical results obtained.

KeyWords: Quantum Control, Decoherence, Geometric Control

Many authors have studied the application of feedback methods in control of decoherence[16],[17]. Technological advances enabling manipulation, control of quantum systems and recent advances in quantum measurements using weak coupling, non-demolition principles etc, have opened up avenues for employing feedback based control strategies for quantum systems [18],[21],[17].

Since the state of a decohering quantum system rapidly reduces to a mixed state from a pure state, the density matrix approach or other stochastic dynamic approaches to analyze such systems seems to be the best tool at hand. Unfortunately such tools are not the most convenient when analyzing the controllability and reachability and other basic geometric properties of such systems, since the governing equations for the evolution is hard to rewrite in a bilinear form that is most amenable to such analysis. As was previously shown by the authors[6] the Lie Algebraic properties of the interaction hamiltonians can be exploited to learn about and control the decoherence in an open quantum system.

Properties and control of decoherence was studied by a number of authors including but not limited to Viola et al. [14][15], Lidar [13] et al. and the controllability properties of the master equation was studied in depth by Altifini[20]. In [16] Doherty et al, studied hamiltonian feedback strategies for quantum systems under a POVM measurement scheme. The authors proposed choosing a form for hamiltonian based on the output obtained from generalized POVM measurements. Since it is not always practically feasible to realize any form for the hamiltonian of the system at will or choose the type of measurement observable in POVM such strategies are far from readily implementable. Viola et. al[15] studied the group theoretic properties of the operators generated by interacting hamiltonians and proposed an open loop strategy to nullify the effects of decoherence through clever choice of controls. Recent developments by the same authors relaxed a few conditions regarding arbitrarily strong and fast "bangbang" pulses and the repertoire of available operators. Another approach to invert the effects of decoherence employing quantum information theoretic methods was proposed by Buscemi[19] et al., wherein change in entropy and other classical properties of the environment is monitored to devise a suitable feedback. The approach is shown to work for dimensions 2 and 3(qubit and qutrit systems). However feedback in the most easily implementable form (i. e by monitoring the outputs or states of a system) as a practical tool for quantum control still remains largely unexplored. Quantum non-demolition filters [22] and continuous measurement by quantum probe[3] which stems from the theory of quantum Zeno effect can be used to monitor a quantum system that might be coupled to extraneous unknown reservoirs. In this work we consider a continuous time measurement scheme with the help of a probe, which is a quantum system interacting with the system under analysis. The output from the probe which is read via a projective(weak) measurement performed on the probe observable is used to control the strength of the various controlling interactions. In this work we also analyze the applicability of the control model as discussed in [8] to a system which might collapse to a mixture due to measurement specifically in the context of decoherence. The approach of decoupling a chosen output or signal, from the effects of decohering interaction is adopted here. It is also shown that only the type of interaction hamiltonian H_{SE} is sufficient to analyze the decoherence properties of the system without delving too much into statistical properties of the environment/bath. It is to be noted that instead of regulating the coherence between basis states - when the exact amount of coherence changes dynamically during the course of quantum control or computation - we merely choose to render it independent of certain undesirable interactions. The former has the shortcoming that the exact coherence information to be regulated is not always known apriori as processing an unknown coherence (viz. processing unknown quantum information) is whole purpose of quantum computation in the first place. Consider an open quantum system interacting with the environment described by,

$$\frac{\partial \xi(t,x)}{\partial t} = [H_0 \otimes I_e(t,x) + I_s \otimes H_e(t,x) + H_{SE}(t,x) + \sum_{i=1}^{r} u_i(t) H_i \otimes I_e(t,x)]\xi(t,x)$$

where H_i, u_i are the control hamiltonian and strength of interaction to the control apparatus respectively. H_0, H_E, H_{SE} are the system, environment and interaction hamiltonian acting on H_s, H_e and $H_s \otimes H_e$ (system, environment and the joint) Hilbert spaces respectively. $\xi(t,x)$ is the wave function of the system and environment. Consider an output equation which could either be a nondemolition measurement or a general bilinear form monitoring the coherence of the system given by,

$$y(t) = \langle \xi(t) \mid C(t) \mid \xi(t) \rangle \quad (1)$$

Then the condition for such an output signal to be decoupled from the interaction hamiltonian in the open loop case is given by the following theorem which is in terms of distribution of quantum operators.

Theorem 0.1 *Let*

$$C_0 = C(t)$$

$$\tilde{C}_n = \text{span}\{ad^j_{H_i} C_{n-1}(t) \mid j = 0,1,\cdots;\ i = 1,\cdots,r\}$$

$$C_n = \left\{\left(ad_H + \frac{\partial}{\partial t}\right)^j \tilde{C}_n;j = 0,1,\cdots\right\}$$

Define a distribution of quantum operators, $\tilde{C}(t) = \Delta\{C_1(t), C_2(t), \cdots, C_n(t), \cdots\}$. *The output equation* (1) *of the quantum system is decoupled from the environmental interactions if and only if*,

$$[\tilde{C}(t), H_{SE}(t)] = 0$$

See [6] for a proof. The condition is greatly relaxed to $[\tilde{C}(t), H_{SE}(t)] \subset \tilde{C}(t)$ with the application of feedback control, suggesting the usefulness of such feedback techniques in controlling decoherence. In order to provide the feedback another quantum system labelled as the ***quantum probe*** or simply ***probe*** which interacts continuously with the system will be used to gather information. The governing Schrödinger equation modifies as,

$$\frac{\partial \xi(t,x)}{\partial t} = [H_0 \otimes I_e(t,x) + H_{SP}(t) \otimes I_e + I_s \otimes H_e(t,x) + H_{SE} + H_{PE} + \sum_{i=1}^{r} u_i(t) H_i \otimes I_e(t,x)]\xi(t,x)$$

where $H_0 = H_S + H_P$, is the free hamiltonian of the system and probe. The interaction hamiltonian between different subsystems are denoted by their respective subscripts. Decoherence, as discussed by Zurek[5] develops strong correlation between preferred pointer basis of a system and the states of environment. Under the framework of continuous measurement the question arises as to what can be said about the relationship between the pointer states of the system and the coupled (measurement) device. As is expected, if the corresponding pointer states of system and probe are not naturally correlated under the system probe interaction hamiltonian H_{SP}, the later would not be a good measuring device [4]. The pointer basis play an all too important role in the analysis of such systems. It will be shown that the Schrödinger equation for a system undergoing collapse can be thought of as probabilistic as long as one agrees to use the pointer basis as universal and the outputs and observations are interpreted to be "expected". We analyze the expected measurement results of the probe observable which is weakly coupled to the decohering system so as to gain knowledge about the state of the system. The expected measurement result reveals information about the degree of decoherence of the system which could be used to design the feedback control. Let $|s_i\rangle$ and $|A_i\rangle$ be the pointer basis of the system and probe respectively. The above mentioned bases inherit all the qualities of a pointer basis[?], viz. orthogonal and be able to distinguish, develop correlation between the bases under interaction etc. The probe observable that is measured by the environment is $\hat{A} = \sum_{i=0}^{N-1} a_i \mid A_i \rangle \langle A_i \mid$ where a_i's are eigenvalues of the probe observable. The probe system interaction hamiltonian will follow the structure $H_{SP} = g(t).\hat{s}.\hat{P}$ *where* $\hat{P} = \sum_{l=0}^{N-1} l \mid B_l\rangle\langle B_l \mid$ acts on probe Hilbert space and $\hat{s} = \sum_{l=0}^{N-1} s_j \mid s_j\rangle\langle s_j \mid$ acts on system's Hilbert space respectively. The signal $g(t)$ is the coupling strength which is assumed to be modulated externally.

We may assume that the initial wave function of the probe before the interaction was $\phi(a)$ in the $|A_k\rangle$ basis. The wave function of the probe after interaction with the quantum system becomes $\phi(a+G\hat{s})$ where $G = \int g(t)\,dt = \hbar c$. This is due to the shift generated by the interaction hamiltonian in the conjugate basis. The probability distribution of the probe measurement after the system probe interaction is $f(a) = \sum_j (\phi + Gs_j) |^2 \mid \langle s_j \mid \psi(t)\rangle \mid^2$, where $|\psi(t)\rangle$ is the combined state of system-probe[1]. Hence from the measurement result of the probe observable $\hat{A}$, information about the system observable $\hat{s}$ is given by the probability distribution, $f(s) = \sum_j W(s-s_j) \mid \langle s_j \mid \psi(t)\rangle \mid^2$, where $W(s-s_j) = \mid G \mid \cdot \mid \varphi(\langle a\rangle - G(s-s_j)) \mid^2$. Results from standard quantum tomography can now be applied to the probability distribution of $\hat{s}$ to obtain the estimate of the state in least square sense[7]. Hence it is possible to get an estimate of the type of state as well as a reasonably good estimate of the state itself from the expected value of the probe measurement which in turn is used to design the state feedback to the system of the form $u = \alpha(\xi) + \beta(\xi).\ v$, where α, β are vector and matrix valued functions of the state of the system, in order to decouple an apriori output function $y(t) = \langle \xi(t) \mid C(t) \mid \xi(t)\rangle$[6]. Such a problem at hand would invoke techniques of non-linear output regulation[2]. Alternatively, it could also be approached as output control problem where control inputs could be designed to steer the probe measurement output away from or towards a desired output value. The authors are currently investigating an algorithm for the invariant subspaces and design and construction of the feedback control.

REFERENCES

[1] H P Breuer and F Petruccione. The Theory of open quantum systems, *Oxford University Press*, 2002.

[2] Jie Huang. Nonlinear Output Regulation, Theory and Application, SIAM, 2004.

[3] W M Itano, D J Heinzen, J J Bolinger. Phys. Rev. A, 41, pp 2295-2300, 1990.

[4] W H Zurek. Phys. Rev. D, 24, 1516-1525, 1981.

[5] W H Zurek. Rev. of Modern Phyics, 75(3), 715-775, 2003.

[6] N Ganesan, T J Tarn. arXiv:quant-ph/0602217.

[7] V Bužek, G Drobný, R Derka. et al. arXiv:quant-ph/9805020.

[8] G M Huang, T J Tarn, J W Clark. Phys, 24(11), pp 2608, Nov 1983.

[9] M Brune, E Hagley, J Dreyer, et al. Phys. Rev. Lett., 77(24), 4887, 1996.

[10] S Haroche, M Brune, J M Raimond. Phil. Trans. R. Soc. Lond. A, 355, 2367-2380, 1997.

[11] J M Geremia, J Stockton, H Mabuchi. arXiv:quantph/0401107v4

[12] C Uchiyama, M Aihara. Phys. Rev. A, 66, 032313, 2002.

[13] D A Lidar, I L Chuang and K B Whaley. Phys. Rev. Letters,81(12), pp 2594, 1998.

[14] L Viola, E Knill, S Lloyd. Phys. Rev. Lett.,82(12), 2417, 1999.

[15] L Viola, S Lloyd, E Knill. Phys. Rev. Lett., 83(23), 4888, 1999.

[16] A C Doherty, K Jacobs and G Jungman. Phys. Rev. A, 63, 062306, 2001.

[17] D B Horoshko, S Ya. Kilin, Journal of Modern Optics, 44(11/12), pp 2043, 1997.

[18] S Wallentowitz. Phys. Rev. A,66, 032114, 2002.

[19] F Buscemi, G. Chiribella, and G. M. D'Ariano, Phys. Rev. Lett., 95, 090501, 2005.

[20] C Altifini, J Math. Phys, 44(6), pp 2357-2372, 2003.

[21] K Jacobs. Phys. Rev. A,67, 030301(R), 2003.

[22] J W Clark, C K Ong, T J Tarn, et al. Systems Theory, 18, pp 33, 1985.