状态空间方法

状态空间方法是以状态空间模型为种子
长出来的一颗大树，已近苍老

全驱系统方法

全驱系统方法是以全驱系统模型为种子
长出来的一颗新树，正在茁壮成长

看今日，全驱系统赋新意
望明朝，控制科技领风骚

全驱系统控制理论简介

全驱系统理论与应用专委会

全驱系统控制理论

诞生背景、发展现状与应用进展

二零二四年五月

国家自然科学基金委基础科学中心项目组编制

项目名称：高阶全驱系统理论与航天器控制技术
依托单位：哈尔滨工业大学
合作单位：中国航天科工集团有限公司 南方科技大学
项目经费：6000万元
执行年限：2022.01~2026.12

原创驱动
引领发展

一、原创篇

状态空间方法的兴衰

1750

Leonhard Euler（1707-1783）
瑞士数学家、物理学家、天文学家

提出了将 n 阶非齐次常系数线性微分方程化为一阶方程组的求解方法，最早的控制系统响应问题的解。

1892

Aleksandr Mikhailovich Lyapunov （1857-1918）
俄国著名数学家和力学家

完成了他的博士论文《运动稳定性的一般问题》；
建立了近乎完备的稳定性理论体系；
采用了一阶系统的描述形式。

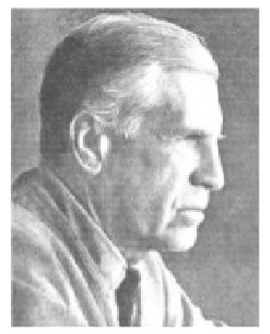
1960

Bellman 动态规划（1952-1957）

将离散最优控制问题转化为 HJB (Halmilton-Jacobi-Bellman) 方程的求解问题。

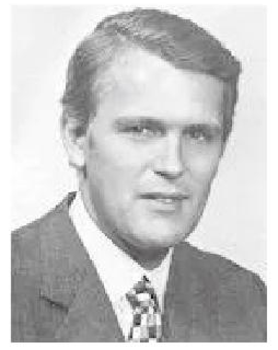
Pontryagin 极大值原理（1956-1958）

把一般连续非线性控制问题转化为 HJB 方程两点边值问题进行求解。



Kalman 滤波器（1959 -1961）

解决了线性离散和连续随机系统的滤波和预测问题，打破了早期滤波器设计的维纳理论关于平稳随机过程假设的限制。

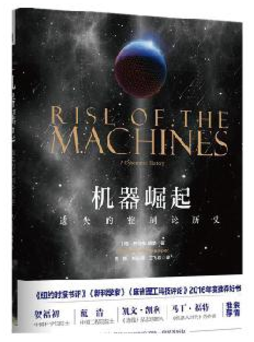


1970

线性系统理论得到基本完善。

1980

人们开始把重点转向非线性系统，但出乎预料的是：统治控制理论百余年发展的状态空间方法不再奏效了！



“从 20 世纪 80 年代，控制论开始失去其学术地位，……，它‘就此枯萎消亡。’”

1982

高为炳院士
中国控制界早期的学部委员之一

译文：“目前所有的迹象都指向这样一个结果：寻找一个完全通用的非线性系统理论有点类似于寻找圣杯，是相对无害的活动，充满了许多愉快的意外和轻微的失望，而最终则是白费力气。”

John Casti
美国数学家，动态规划创始人
Richard Bellman 的学生

原文：“All current indications point toward the conclusion that seeking a completely general theory of nonlinear systems is somewhat a kin to the Search for the Holy Grail: a relatively harmless activity full of many pleasant surprises and mild disappointments, but ultimately unrewarding.”

1995

Edward Davison
加拿大工程院院士
国际著名控制学者

“Nonlinear systems theory, almost everything [is open]”
“非线性系统理论，几乎所有的问题都没有解决！”

Alberto Isidori
欧洲控制联合会前主席
国际自动控制联合会前主席
非线性控制领域著名科学家

“Inexplicably, ..., from the mid 1990’s, the study of problems of feedback design for MIMO nonlinear systems came to a (almost complete) stall.”
“令人费解的是，……，从1990 年中期开始，关于多变量非线性系统反馈设计问题的研究就几乎出现了完全的停滞。”

2010

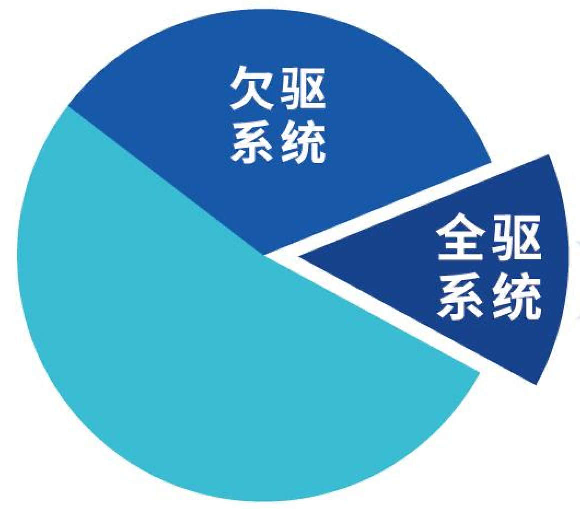
何毓琦
哈佛大学终身教授
美国工程院院士
中国科学院和工程院外籍院士
控制理论著名专家

“‘Control is dead’ until it is reborn like Lazarus by a Jesus Miracle.”
“控制已死，要重生就要等待类似于耶稣使拉萨路复活的那种奇迹发生，或许是在等待另一个黄金时代的再次出现。”

原有的状态空间方法体系好比一座开垦已久的矿山，已近贫瘠。尽管人们还在努力地开采，但收获甚微。

我们不期待在这个矿山中再发现两个矿，而是要找到另一个更大、更丰富的矿山。

全驱系统(FAS)方法的诞生



动态系统

- 机械系统中的一类系统
- 每个自由度都配有执行器
- 很容易实现控制系统设计
- 闭环系统可为线性定常系统
- 贵族般的存在，得天独厚、与众不同
- 只可惜太少

既然全驱系统如此之好，我们
- 能不能从数学的角度出发多造出一些全驱系统?
- 能不能把欠驱系统化成数学意义下的全驱系统?

推广的全驱系统模型

$$x^{(m)} = f(x, \dot{x}, \cdots, x^{(m-1)}, t) + B(x, \dot{x}, \cdots, x^{(m-1)}, t)u$$

$$x^{(m)} = f(x, \dot{x}, \cdots, x^{(m-1)}, t) + g(x, \dot{x}, \cdots, x^{(m-1)}, u, t).$$

$$\begin{bmatrix} x^{(n_1)} \\ x^{(n_2)} \\ \vdots \\ x^{(n_m)} \end{bmatrix} = \begin{bmatrix} f_1\left(x_p^{(0\sim n_p-1)}\Big|_{p=1\sim m}, \zeta, t\right) \\ f_2\left(x_p^{(0\sim n_p-1)}\Big|_{p=1\sim m}, \zeta, t\right) \\ \vdots \\ f_m\left(x_p^{(0\sim n_p-1)}\Big|_{p=1\sim m}, \zeta, t\right) \end{bmatrix} + B\left(x_p^{(0\sim n_p-1)}\Big|_{p=1\sim m}, \zeta, t\right)u$$

动态系统模型的两个极端

状态空间模型		全驱系统模型
微分阶次最低	⟷	微分阶次最高
标量方程个数最多	⟷	标量方程个数最少
由原始物理方程增广得到	⟷	由原始物理方程消元得到
以状态向量为主角	⟷	以控制向量为主角
更适合解决状态相关问题	⟷	更适合解决控制问题

Mr. State space

Mr. FAS

全驱系统理论体系突破了状态空间方法难以处理的非线性、时变性、时滞特性、非完整约束特性等复杂特性的束缚，为控制理论发展开辟了崭新的途径。

自动化学报“高阶系统方法”系列论文

——提出了全驱系统理论的部分基本概念和基本思想。

段广仁 . 高阶系统方法，自动化学报

I. 全驱特性与参数化设计 . 2020, 41(7): 1333-1345.

II. 能控性与全驱性 . 2020, 46(8): 1571-1581.

III. 能观性与观测器设计 . 2020, 46(8): 1885-1895.

世界上第一篇
全驱系统方法
的论文

国际上第一篇
全驱系统方法
的论文

国际系统科学（*Int. J. Systems Science*）杂志系列论文

——解决了复杂非线性系统的反馈镇定、鲁棒控制、自适应控制等一系列问题，建立了全驱系统理论的体系框架。

Guang-Ren Duan, High-order fully actuated system approaches, *Int. J. Systems Science*

Part I. Models and basic procedure, 2021, 52(2): 422-435.

Part II. Generalized strict-feedback systems, 2021, 52(3): 437-454.

Part III. Robust control and high-order backstepping, 2021, 52(5), 952-971.

Part IV. Adaptive control and high-order backstepping, 2021, 52(5), 972-989.

Part V. Robust adaptive control, 2021, 52(10), 2129-2143.

Part VI. Disturbance attenuation and decoupling, 2021, 52(10), 2161-2181.

Part VII. Controllability, stabilizability and parametric design, 2021, 52(14), 3091-3114.

Part VIII. Optimal control with application in spacecraft attitude stabilization, 2022, 53(1): 54-73.

Part IX. Generalized PID control and model reference tracking, 2022, 53(3): 652-674.

Part X. Basics of discrete-time systems, 2022, 53(4): 810-832.

平均长度：
20 页 / 篇

原创性

- originally proposed;
- constructively proposed;
- originally established;
- first introduced;
- creatively proposed.

重要性

- the most notable work;
- prominent works;
- substantial works;
- his holistic approach;
- lightening a new direction for control theory.

公开学术评价

- is a model oriented for control design, it is convenient to perfect the complete expression of the control law;
- provides a systematic method and structure to solve nonlinear system control problems;
- gained wide attention rapidly;
- has been proven to be very effective and simple;
- has more universality, simplicity and flexibility.

先进性

Int. J. Systems Science **网站专设网页对10篇系列论文给予了高度评价**

https://www.tandfonline.com/journals/tsys20/collections/HOFA_

Taylor & Francis Online

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Home ▶ All Journals ▶ International Journal of Systems Science ▶ Collections ▶ High-order fully actuated (HOFA) system approaches

International Journal of Systems Science

Enter keywords, authc

High-order fully actuated (HOFA) system approaches

High-order fully actuated (HOFA) systems represent a nuanced frontier in control theory, bridging intricate dynamics with profound control capabilities. Rooted in the realm of systems with advanced differential degrees, these systems, which are often derived from complex physical laws such as Lagrangian mechanics, boast a balanced ratio of control inputs to system outputs. This characteristic, synonymous with being "fully actuated", ensures a more direct control strategy, rendering them particularly favorable in fields like mechanical engineering, aerospace, and electrical systems. While their high-order nature encapsulates multifaceted behaviors, the full actuation empowers engineers and scientists with a robust platform to achieve precise and desired system responses. Included in this collection is a set of ten seminal papers published in the International Journal of Systems Science, which forms the foundation of the HOFA systems theory. In fact, due to their theoretical significance and practical importance, HOFA systems have already attracted widespread attention with applications to various control problems such as robust control, adaptive control, disturbance rejection, optimal control, and tracking control. It is envisaged that this collection of the pioneering results would help disseminate the HOFA systems theory, which would have a lasting impact on control theory and control engineering.

控制理论方向主要SCI刊物的影响因子

Journals on Control Theory	IF	Journals on Control Theory	IF
1. IEEE Trans. Automatic Control	6.8	17. Int. J. Control	2.1
2. Automatica	6.4	18. Measurement & Control	2.0
3. Int. J. Systems Science	**4.3**	19. Nonlinear Analysis-Modelling and Control	2.0
4. IEEE Trans. Control of Network Systems	4.2	20. Optimal Control Applications & Methods	1.8
5. Journal of Process Control	4.2	21. Transactions of the Institute of Measurement and Control	1.8
6. J. Franklin Institute-Eng. Appl. Math.	4.1	22. J. Dynamic Systems, Measurement & Control	1.7
7. Int. J. Robust & Nonlinear Control	3.9	23. Studies in Informatics and Control	1.6
8. European J. Control	3.4	24. IMA J. Mathematical Control and Information	1.5
9. Int. J. Control, Automation & Systems	3.2	25. ESAIM-Control Optimisation and Calculus of Variations	1.4
10. Int. J. Adaptive Control & Signal Processing	3.1	26. Int. J. Automation and Control	1.2
11. IEEE Control Systems Letters	3.0	27. Mathematics of Control, Signals, and Systems	1.2
12. IET Control Theory & Applications	2.6	28. Archives of Control Sciences	1.2
13. Systems & Control Letters	2.6	29. Information Technology and Control	1.1
14. J. Guidance, Control, & Dynamics	2.6	30. J. Dynamical and Control Systems	0.9
15. Asian J. Control	2.4	31. Int. J. Modelling Identification and Control	0.7
16. SIAM J. Control and Optimization	2.2	32. Automation and Remote Control	0.7

团队基于发现的描述一般动态系统的全驱系统模型，提出了全驱系统理论的基本思想，建立了控制理论的一个全新的全驱系统理论体系框架，打破了当前控制理论的发展困境，将“对控制理论与工程产生深远的影响”。

二、开拓篇

国家自然科学基金基础科学中心

全驱系统理论与航天器控制技术

核心成员

段广仁
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中国科学院院士
CAA/IEEE/IET Fellow

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哈尔滨工业大学（深圳）
国家杰青
教育部高层次人才

揭牌仪式

2022年8月 哈尔滨 会议现场

全驱系统理论与航天器控制技术基础科学中心第一届学术委员会名单

职　务	姓　名	工作单位及介绍
主　任	桂卫华	中南大学，中国工程院院士
	陈　杰	北京理工大学，中国工程院院士
副主任	乔　红	中国科学院自动化研究所，中国科学院院士
	郭　雷	北京航空航天大学，中国科学院院士
	周东华	清华大学，国家杰青、教育部高层次人才
委　员	柴　利	浙江大学，国家杰青
	陈　虹	同济大学，国家杰青、教育部高层次人才
	陈　谋	南京航空航天大学，国家杰青
	董海荣	山东科技大学/北京交通大学，国家杰青、教育部高层次人才
	段广仁	哈尔滨工业大学/南方科技大学，中国科学院院士
	段海滨	北京航空航天大学，国家杰青、教育部高层次人才
	侯增广	中国科学院自动化研究所，国家杰青
	华长春	燕山大学，国家杰青、教育部高层次人才
	贾英民	北京航空航天大学，国家杰青、教育部高层次人才
	姜　斌	南京航空航天大学，教育部高层次人才
	李少远	青岛科技大学，国家杰青
	李贻斌	山东大学，国家百千万人才工程
	孙希明	大连理工大学，国家杰青、教育部高层次人才
	谭　民	中国科学院自动化研究所，国家杰青
	田玉平	南方科技大学，国家杰青、教育部高层次人才
	王　龙	北京大学，国家杰青、教育部高层次人才
	徐胜元	南京理工大学，国家杰青、教育部高层次人才
	张焕水	山东科技大学，国家杰青、教育部高层次人才
	张纪峰	中国科学院数学与系统科学研究院，国家杰青
	赵千川	清华大学，国家杰青
	赵玉新	哈尔滨工程大学，国防卓青

注：委员按姓氏拼音排序

平台与团队建设

在国家自然科学基金委基础科学中心项目的有力支持下，围绕全驱系统理论与应用研究方向，我们又获得了下述几方面资助：

- “全驱系统控制理论与技术”广东省重点实验室，400万元
- “控制理论与智能系统”深圳市重点实验室，500万元
- “全驱系统理论与应用”深圳市“孔雀团队”，1500万元

基金委基础科学中心项目组发表论文概况

截止到2023年底，基础科学中心项目组发表SCI期刊论文158篇，其中Automatica 4篇、SCIENCE CHINA Information Sciences 10篇、自动化学报英文版2篇，另有IEEE汇刊44篇：

- *IEEE Transactions on Automatic Control* 1篇
- *IEEE Transactions on Cybernetics* 8篇
- *IEEE Transactions on Systems, Man, Cybernetics-Systems* 6篇
- *IEEE Transactions on Industrial Electronics* 7篇
- *IEEE Transactions on Industrial Informatics* 4篇
- *IEEE Transactions on Circuits and Systems I-Regular Papers* 4篇
- *IEEE Transactions on Circuits and Systems II-Express Briefs* 1篇
- *IEEE Transactions on Power Electronics* 1篇
- *IEEE/ASME Transactions on Mechatronics* 2篇
- *IEEE Transactions on Smart Grid* 3篇
- *IEEE Transactions on Network Science and Engineering* 2篇
- *IEEE Transactions on Geoscience and Remote Sensing* 1篇
- *IEEE Transactions on Neural Networks and Learning Systems* 2篇
- *IEEE Transactions on Instrumentation and Measurement* 1篇
- *IEEE Transactions on Aerospace and Electronic Systems* 1篇

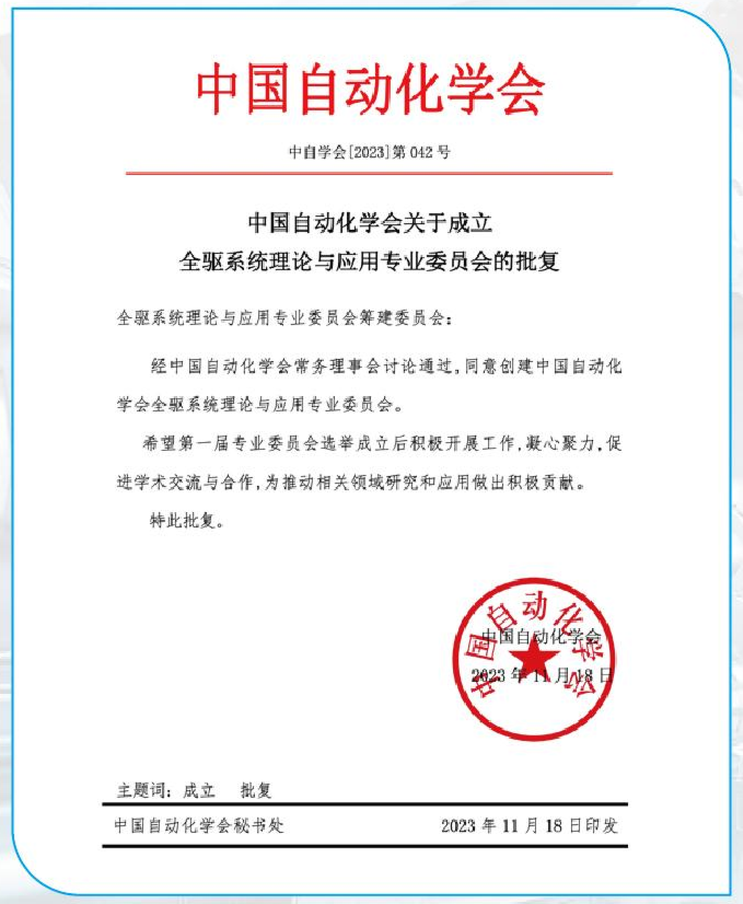
中国自动化学会全驱系统理论与应用专业委员会

Technical Committee on Fully Actuated System Theory and Applications, Chinese Association of Automation

第一届全驱系统理论与应用专业委员会领导机构

主　任：	段广仁
副主任：	周东华、邹 云、冯俊娥、华长春、吴爱国、徐 翔
秘书长：	张 颖

该专委会于2022年5月得到中国自动化学会的筹备创建批复，2023年11月得到中国自动化学会的成立批复。
网址：http://www.fasta.org.cn.


中国自动化学会

中自学会[2023]第042号

中国自动化学会关于成立
全驱系统理论与应用专业委员会的批复

全驱系统理论与应用专业委员会筹建委员会：

经中国自动化学会常务理事会讨论通过，同意创建中国自动化学会全驱系统理论与应用专业委员会。

希望第一届专业委员会选举成立后积极开展工作，凝心聚力，促进学术交流与合作，为推动相关领域研究和应用做出积极贡献。

特此批复。

中国自动化学会
2023年11月18日

主题词：成立　批复

中国自动化学会秘书处　　2023年11月18日印发

中国自动化学会公开报道: http://www.caa.org.cn/article/201/3013.html

全驱系统理论与应用国际学术年会(FASTA)

International Conference on Fully Actuated System Theory and Applications

FASTA2022（哈尔滨，2022.08.05至2022.08.07）

大会报告

- 魏毅寅 (中国航天科工集团有限公司), 精确打击武器集群协同技术发展探讨
- 乔　红 (中国科学院自动化所), 受人启发的机器人系统
- 周东华 (清华大学), Stochastic High-order Fully-actuated Systems: Model, Equivalence and Stabilization
- 刘国平 (南方科技大学), 高阶全驱预测协调控制
- 华长春 (燕山大学), 基于全驱动系统方法的一类非线性时滞系统的自适应控制
- 刘腾飞 (东北大学), 一类全驱系统的主动安全控制问题
- 邹　云 (南京理工大学), 完全能达性:系统状态的行为主义目的论视角观察

FASTA2023（青岛，2023.07.14至2023.07.16）

会议网址：http://cfasta2023.sdust.edu.cn/index.htm

来自全球相关高校及研究院所的430余位专家学者参加了会议，参会代表和论文来自中国（包括台湾和香港）、美、加、英、澳、土耳其、比利时和新加坡等9个国家和地区。自本届起，该会由IEEE协办，会议论文集已经进入IEEE Xplore数据库并被EI检索。

大会报告

段广仁 (南方科技大学/哈尔滨工业大学), Fully Actuated System Approach for Control — Results Overview and Further Problems

Guoxiang Gu (美国路易斯安那州立大学), Asymptotic Full Actuation Control with Applications to Control of Autonomous Vehicle Platoons

Xiaoping Liu (加拿大Lakehead大学), Weak Disturbance Decoupling of High-order Fully Actuated Nonlinear Systems

FASTA2024（深圳，2024.05.10至2024.05.12）

会议网址：http://fasta2024.fasta.org.cn

FASTA2024由南方科技大学和全驱系统理论与应用专委会主办。会议共收到来自中、美、加、法、日、澳、新加坡和荷兰等12 个国家和地区的投稿论文353 篇，经过严格、认真的评审程序，最终录用308篇。

大会报告

- Zhong-Ping Jiang (New York University), Small-Gain Theory for Stability and Control of Interconnected Systems
- 刘国平 (南方科技大学), High-order Fully Actuated Predictive Control for Networked Systems
- Michael V. Basin (Autonomous University of Nuevo Leon), Predefined-Time Convergent Continuous Controllers: Design and Applications

FASTA2025（南京，2025.07.18至2025.07.20）

系列论文与专刊/专栏

Guang-Ren Duan

SCI. CHINA INFORM. SCI.

1. Discrete-time delay systems 系列
   - Part I. Global fully actuated case, 2022, 65(8): 182201
   - Part II. Sub-fully actuated case, 2022, 65(9): 192201
2. Fully actuated system approaches for continuous-time delay systems 系列
   - Part I. Systems with state delays only, 2023, 66(1): 112201
   - Part II. Systems with input delays, 2023, 66(2): 122201
3. A FAS approach for stabilization of generalized chained forms 系列
   - Part I. Discontinuous controllers, 2024, 67(2): 122201
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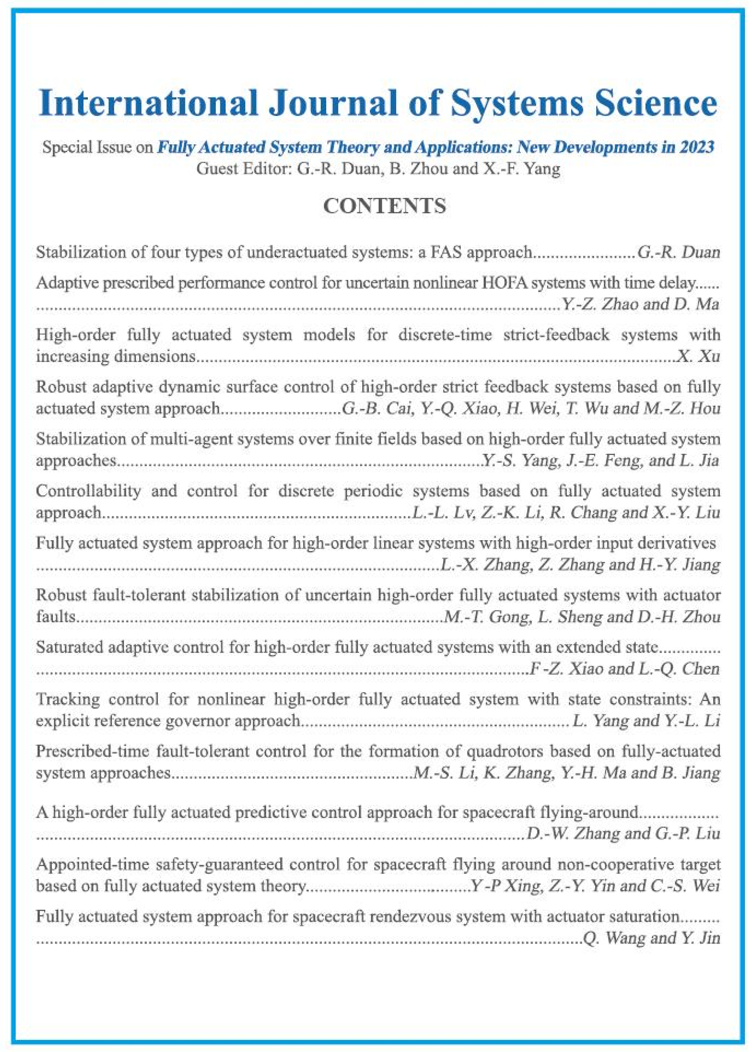

International Journal of Systems Science

Special Issue on *Fully Actuated System Theory and Applications: New Developments in 2023*
Guest Editor: G.-R. Duan, B. Zhou and X.-F. Yang

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Int. J. Systems Science 专刊

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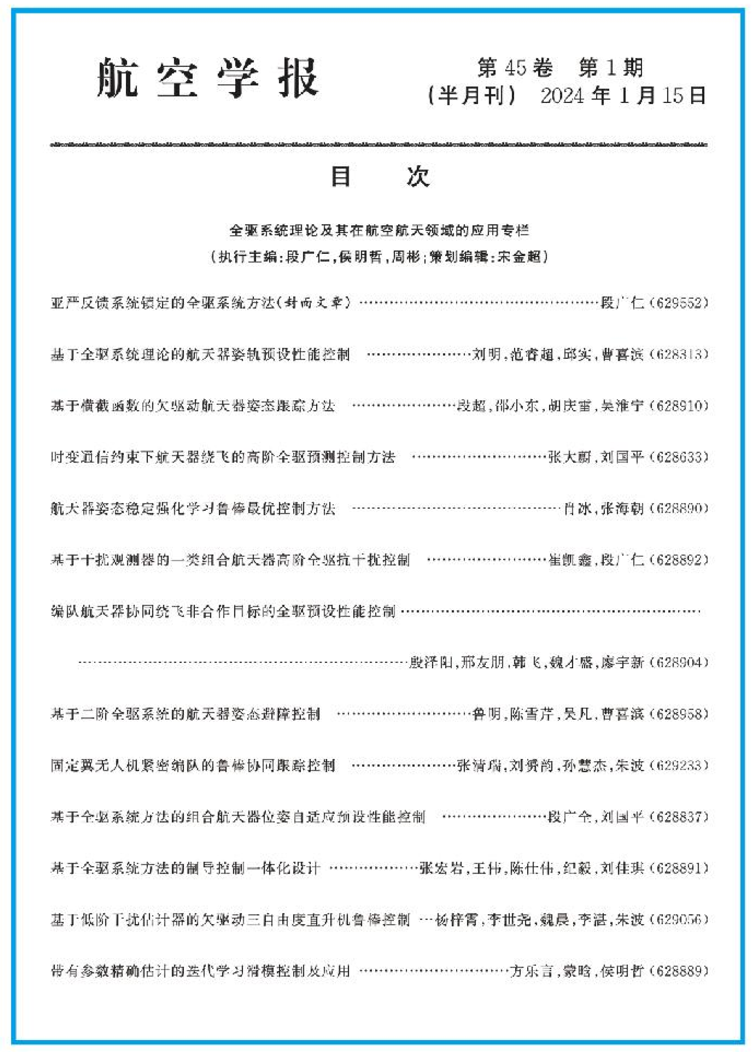

航 空 学 报　　第 45 卷　第 1 期
（半月刊）　2024 年 1 月 15 日

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全驱系统理论及其在航空航天领域的应用专栏
（执行主编：段广仁，侯明哲，周彬；策划编辑：宋金超）

《航空学报》专栏

三、引领篇

在短短两年的时间里，团队工作已经引领了包括中、美、加、韩、丹麦和土耳其在内的全球47所高校的73个团队在该全新方向上公开发表论文300余篇。

国内研究团队

- 哈尔滨工业大学段广仁、曹喜滨、刘明、高会军、邱剑彬、周彬、刘健行、郑雪梅、侯明哲教授团队
- 南方科技大学刘国平、刘德荣、徐翔教授团队
- 清华大学周东华、李东海教授团队
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- 同济大学孙继涛教授团队
- 东北大学张化光、王大志、刘腾飞、马丹教授团队
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- 中国石油大学(华东)盛立教授团队
- 聊城大学庄光明、孙伟教授团队
- 中国航天科工三院郝明瑞研究员团队
- 华南理工大学丘东元教授团队
- 东北电力大学顾大可教授团队
- 北京科技大学蔺凤琴教授团队
- 北京理工大学王伟教授团队
- 上海航天控制技术研究所韩飞、叶赛仙研究员团队
- 内蒙古大学赵国亮教授团队
- 合肥大学闫晓辉教授团队

IEEE汇刊论文(30篇)

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国外学者参与情况

一些国外大学的团队也深入地介入到全驱系统控制理论的研究领域：

- 澳大利亚University of Adelaide的P. Shi团队
- 新加坡Nanyang Technological University的Feroskhan团队
- 美国Arizona State University的Tsakalis 团队
- 美国Louisiana State University的Yan & Gu团队
- 加拿大Lakehead University的X. P. Liu团队
- 韩国Yeungnam University的Ju H. Park团队
- 英国Alabama University伯明翰分校的C. Zhang团队
- 英国University of the West of England的Q. M. Zhu团队
- 丹麦Aalborg University的Josep M. Guerrero团队
- 土耳其Istanbul University的Adiguzel & Yalcin团队

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涉及的研究方向

Control methods

Stabilization and tracking control
Adaptive control
Predictive control
Fault-tolerant control
Observers/observer-based designs
Prescribed performance control
Disturbance decoupling
Saturation and constrained control
Safety control
Sliding mode control
Output feedback control
Actuator saturation control

Dynamical Systems

Linear systems
Sub-fully actuated systems
Nonholonomic systems
Strict feedback systems
Time-varying systems
Time-delay systems
Impulsive systems
Fractional order systems
Periodic systems
Multi-agent systems
Stochastic systems
Discrete-time systems

Applications

Spacecraft control
Aircraft and quadrotors
Robotic control
Servo system control
DC microgrid control
Underactuated systems
Inverted pendulum systems
Intelligent vehicle systems
Heterogeneous MASs systems
Thermoacoustic systems
Fuel cell air feed systems
Engine control

全驱系统理论与应用方向的大会报告

近3年，中国学者在国际学术会议上作全驱系统理论与应用方向的主旨报告20余次，其中包括国内外许多顶级会议，如：

- IEEE工业电子学会的顶级会议IEEE IECON 2023
- 我国导航制导与控制领域顶级国际会议ICGNC 2022
- 国际自动控制联合会时滞系统领域顶级会议IFAC TDS 2021
- 机器人与自动化领域重要会议IEEE CYBER 2023
- 国际先进机器人与机电一体化领域重要会议IEEE ARM 2020
- 我国控制理论界顶级国际会议CCC 2021
- 我国控制与决策领域顶级国际会议CCDC 2021
- 国际机器人领域顶级会议IEEE ICRA 2021
- 国际优化领域重要会议POC 2023

重要大会主旨报告

1. Guangren Duan. Tracking Control in Satellite Optical Communication: A Parametric Comprehensive Design, *The 5th IEEE International Conference on Advanced Robotics & Mechatronics (IEEE ARM 2020)*, China,Shenzhen, 2020-12-19~2020-12-20.
2. Guangren Duan. Controllability and Stabilizability: Frameworks in State-Space Approaches and Fully Actuated System Approaches, *Chinese Conference on Decision and Control (CCDC 2021)*, China, Kunming, 2021-05-22~2021-05-24.
3. Guangren Duan. Full Actuation—From Physical to Mathematical, *2021 IEEE International Conference on Robotics and Automation (IEEE ICRA 2021)*, China, Xi'an, 2021-06-02~2021-06-03.
4. Guangren Duan. State-Space Approaches vs Fully Actuated System Approaches, *Chinese Control Conference (CCC 2021)*, China, Shanghai, 2021-07-27~2021-07-30.
5. Guangren Duan. Time-delay Systems: A Fully Actuated System Approach, *The 17th IFAC Workshop onTime-delay Systems (IFAC TDS 2021)*, China, Guangzhou, 2021-09-29~2021-10-01.
6. Guangren Duan. Fully Actuated System Approach and Nonholonomic Systems, *2022 International Conference on Guidance, Navigation and Control (ICGNC 2022)*, China, Harbin, 2022-08-05~2022-08-07.
7. Guangren Duan. Fully Actuated System Approach and Data Driven Control, *2023 IEEE 12th Data Driven Control and Learning Systems Conference (DDCLS 2023)*, China, Xiangtan, 2023-5-12~2023-5-14.
8. Guangren Duan. Fully Actuated System Approach for Control, *International Conference on CYBER Technology in Automation, Control, and Intelligent Systems (IEEE CYBER 2023)*, China, Qinhuangdao, 2023-7-11~2023-7-14.
9. Guangren Duan. Fully Actuated System Approach for Control—An introduction, *Annual Conference of the IEEE Industrial Electronics Society (IECON 2023)*, Singapore, 2023-10-16~2023-10-19.
10. Guangren Duan. Fully Actuated System Approach for Control—Backgrounds and Developments, *The 3rd Pacific Optimization Conference (POC 2023)*, Kula Lumpur, Malaysia, 2023-12-08~2023-12-11.

全驱系统理论与应用青年研究基金

为了支持国内控制理论界青年学者在全驱系统控制理论方向做出优秀成果，段广仁院士依托其负责的国家自然基金基础科学中心项目和黑龙江省头雁计划项目，设立了全驱系统理论与应用青年基金。该基金针对教师项目的资助额度为20万元/人，针对博士生项目的资助额度为2万元/人。

受资助单位	年份	教师	博士生	金额（万元）
哈尔滨工业大学	2022	7	6	152
	2023	13	18	296
	2024	5	2	104
燕山大学	2021	4	1	82
	2022	7	6	152
	2023	4	6	92
哈尔滨工业大学（深圳）	2022	/	4	8
	2023	8	3	166
	2024	2	4	48
南京航空航天大学	2022	6	/	120
	2023	3	/	60
山东大学	2022	4	4	88
	2023	4	/	80
上海交通大学	2022	5	/	100
聊城大学	2023	1	/	20
曲阜师范大学	2023	1	/	20
辽宁科技大学	2023	1	/	20
合 计		75	54	1608

全驱系统理论与应用青年基金获得者工作汇报会　2023年7月 青岛

四、应用篇

主要应用论文列表

[1] F. Zhang and G. Duan, "Coupled dynamics and integrated control for position and attitude motions of spacecraft: A survey," *IEEE/CAA J. Automatica Sin.*, vol. 10, no. 12, pp. 2187–2208, 2023.

[2] F. Xiao and L. Chen, "Attitude control of spherical liquid-filled spacecraft based on high-order **fully actuated** system approaches," *J. Syst. Sci. Complex.*, vol. 35, no. 2, pp. 471–480, 2022.

[3] M. Liu, R. Fan, S. Qiu, and X. Cao, "Spacecraft attitude-orbit prescribed performance control based on **fully actuated** system approach," *Acta Aeronaut. Astronaut. Sin.*, vol. 45, no. 1, Art. no. 628313, 2024, (in Chinese).

[4] K. Cui, G. Duan, D. Zhang, and D. Gu, "Discrete-time high-order **fully actuated** adaptive stabilization control for a type of combined spacecraft with unknown parameters," *IEEE Trans. Aerosp. Electron. Syst.*, 2024, doi: 10.1109/TAES.2024.3360948.

[5] S. Chen, W. Wang, J. Fan, and Y. Ji, "Impact angle constraint guidance law using **fully-actuated** system approach," *Aerosp. Sci. Technol.*, vol. 136, Art. no. 108220, 2023.

[6] C. Yan, J. Xia, J. H. Park, J. Feng, and X. Xie, "**Fully-actuated** system approach-based dynamic event-triggered control with guaranteed transient performance of flexible-joint robot: Experiment," *IEEE Trans.Circuits Syst. II, Exp. Briefs*, 2024, doi: 10.1109/TCSII.2024.3367180.

[7] E. Kang, Y. Liu, and H. Qiao, "Sliding mode-based adaptive tube model predictive control for robotic manipulators with model uncertainty and state constraints," *Control Theory Technol.*, vol. 21, pp. 334–351, 2023.

[8] G. Liu, B. Li, and G. Duan, "An optimal **FASA approach** for UAV trajectory tracking control," *Guid. Navigat. Control*, vol. 3, no. 3, Art. no. 2350015, 2023.

[9] S. Lu, K. Tsakalis, and Y. Chen, "Development and application of a novel high-order **fully actuated** system approach-Part I: 3-DOF quadrotor control," *IEEE Control Syst. Lett.*, vol. 7, pp. 1177–1182, 2023.

[10] Q. Zhang, Y. Liu, H. Sun, and B. Zhu, "Robust cooperative tracking control for close formation of fixed-wing unmanned aerial vehicles," *Acta Aeronaut. Astronaut. Sin.*, vol. 45, no. 1, Art. no. 629233, 2024, (in Chinese).

[11] L. Chen, J. Xiao, Y. Zheng, N. A. Alagappan, and M. Feroskhan, "Design, modeling, and control of a coaxial drone," *IEEE Trans. Rob.*, 2024, doi: 10.1109/TRO.2024.3354161.

[12] P. Li and G. Duan, "High-order **fully actuated** control approach for servo systems based on dynamical compensator and extended state observer," *IEEE/ASME Trans. Mechatron.*, 2024, doi: 10.1109/TMECH.2024.3356594.

[13] P. Li and G. Duan, "High-order **fully actuated** control approaches of flexible servo systems based on singular perturbation theory," *IEEE/ASME Trans. Mechatron.*, vol. 28, no. 6, pp. 3386–3397, 2023.

[14] Y. Yu, G. Liu, Y. Huang, and J. M. Guerrero, "Coordinated predictive secondary control for DC microgrids based on high-order **fully actuated** system approaches," *IEEE Trans. Smart Grid*, vol. 15, no. 1, pp. 19–33, 2024.

[15] Y. Yu, G. Liu, Y. Huang, and J. M. Guerrero, "Distributed learning-based secondary control for islanded DC microgrids: A high-order **fully actuated** system approach," *IEEE Trans. Ind. Electron.*, vol. 71, no. 3, pp. 2990–3000, 2024.

[16] Z. Gao, D. Zhang, and S. Zhu, "Network-induced asynchronous fuzzy control for vehicle steering using switching event-triggered communication mechanism," *IEEE Trans. Intell. Veh.*, vol. 8, no. 11, pp. 4559–4571, 2023.

[17] Y. Zhao and D. Ma, "Adaptive prescribed performance control for uncertain nonlinear **HOFA** systems with time delay," *Int. J. Syst.* Sci., 2024, doi: 10.1080/00207721.2024.2304652.

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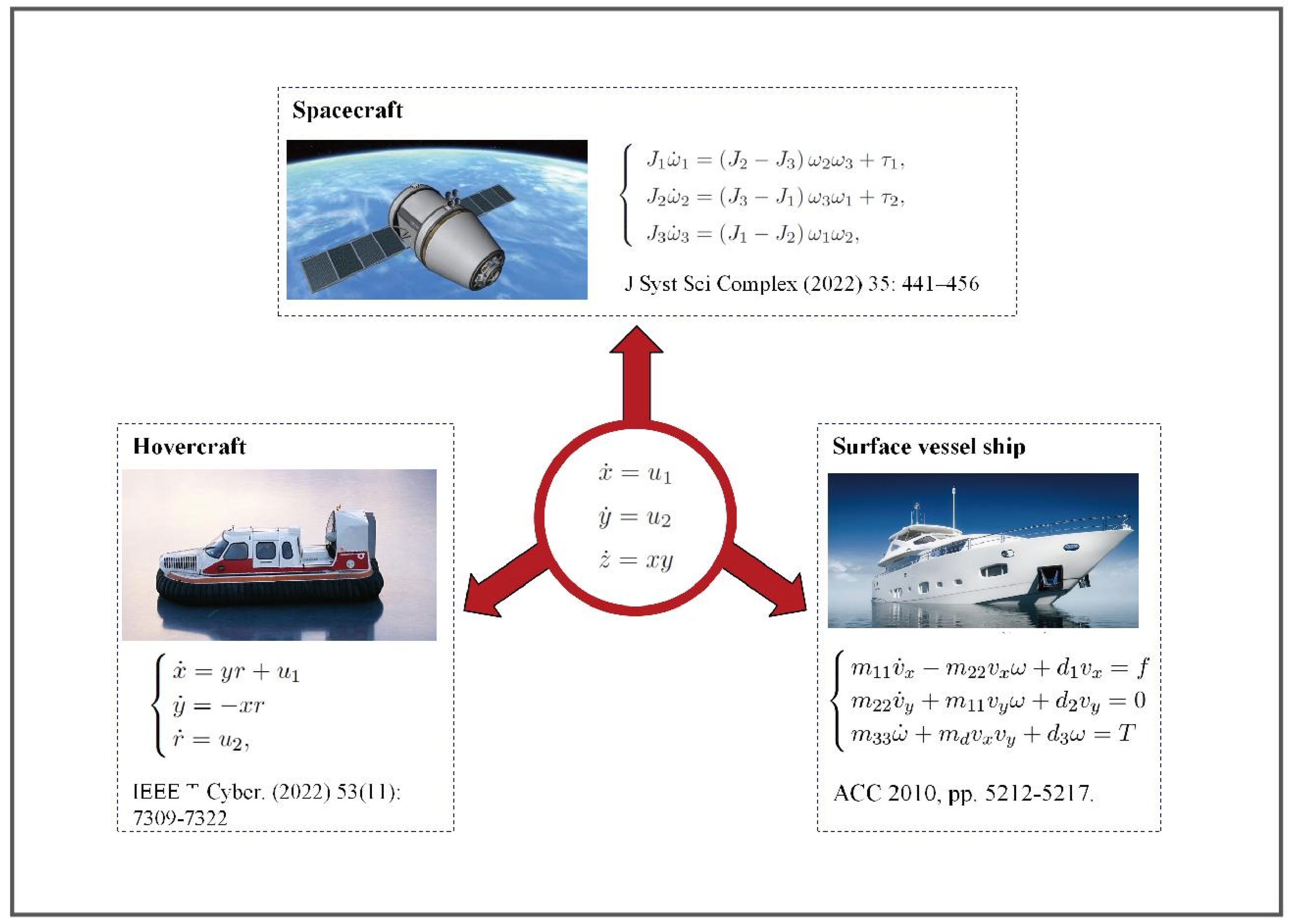
[19] F. Lin, W. Liu, and P. Yu, "Adaptive synchronization control of pressing down system of cold strip rolling mill based on **fully actuated** system method," *J. Syst. Sci. Math. Scis.*, vol. 41, no. 11, pp. 2758–2772, 2023, (in Chinese).

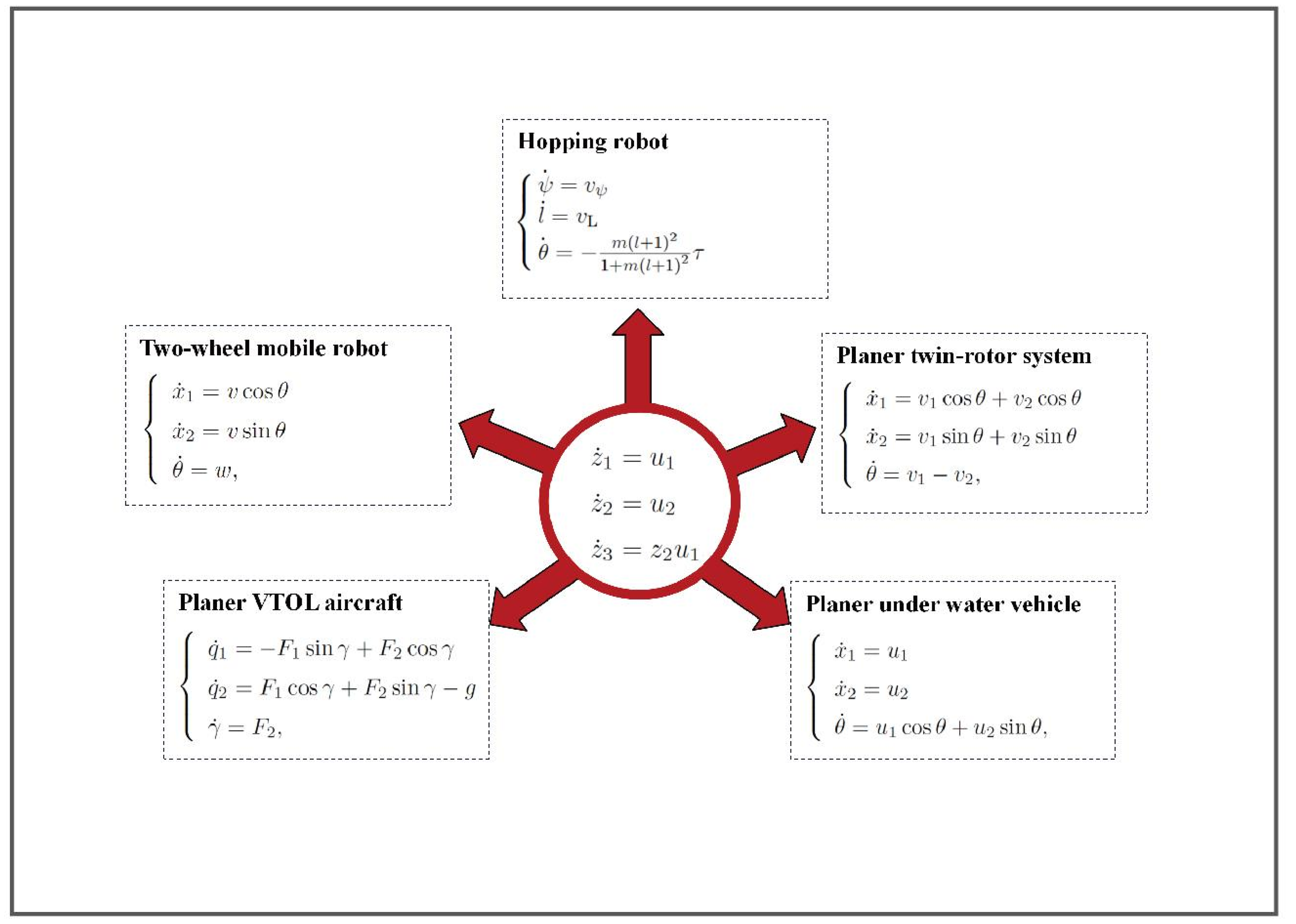
[20] Y. Yu, G. Liu, Y. Huang, and P. Shi, "Optimal cooperative secondary control for islanded DC microgrids via a **fully actuated** approach," *IEEE/CAA J. Automatica Sin.*, vol. 11, no. 2, pp. 405–417, 2024.

非完整系统

- 著名非线性理论科学家Roger W. Brockett于1983年在其题为"Asymptotic stability and feedback stabilization"的论文讨论了两个典型的非线性系统，引发了人们后续关于非完整系统的热烈探讨。
- 虽然两个系统描述都极其简单，但却都有多方面应用背景。
- 由于其非完整特性，他们被称之为"deceivingly simple looking"、"tough and thorny"，不存在光滑甚至连续的时不变反馈控制律。
- 基于全驱系统方法，这两个典型系统的镇定问题得到圆满解决，其结果亦被推广到带有时滞的更加一般的时变非完整系统上。



系统 1 及相关应用背景



系统 2 及相关应用背景

非完整系统方面的代表性论文

- G. R. Duan (2022). Brockett's first example: An FAS approach treatment. *Journal of Systems Science & Complexity*, 35(2):441-456.
- G. R. Duan (2023). Brockett's second example: A FAS approach treatment. *Journal of Systems Science & Complexity*, 36(5):1789-1808.
- G. R. Duan (2023). Substability and substabilization: Control of subfully actuated systems. *IEEE Transactions on Cybernetics*, 53(11):7309-7322.
- G. R. Duan (2024). A FAS approach for stabilization of generalized chained forms: part 1. Discontinuous control laws. *SCIENCE CHINA Information Sciences*, 67(2):118-143.
- G. R. Duan (2024). A FAS approach for stabilization of generalized chained forms: part 2. Continuous control laws. *SCIENCE CHINA Information Sciences,* 67(3):114-135.

航天器控制应用

单体/编队卫星的姿轨控制

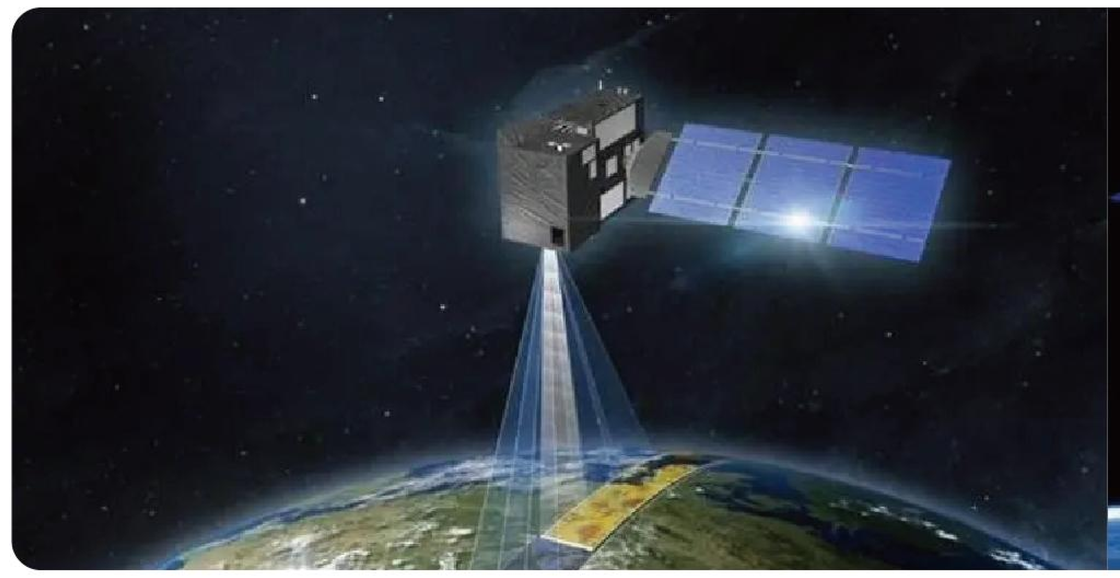
针对时变转动惯量、执行机构饱和、姿态指向约束等复杂情形，基于欧拉角、四元数、姿态旋转矩阵、修正罗德里格斯参数等航天器运动学模型，研究了基于全驱系统理论的刚体、充液、挠性、编队卫星的姿态机动控制、姿态跟踪控制、最优控制、预设性能控制等问题[1],[2]。

航天器交会对接姿轨一体化控制

针对空间航天器在轨操控中的交会、绕飞、对接等关键任务，考虑空间干扰力矩、执行机构饱和、非合作目标、无线网络通讯等复杂约束，研究了基于全驱系统理论的航天器交会对接过程中姿轨耦合情形下的扰动观测器、预设时间控制、预测控制、自适应预设性能控制、自适应迭代学习控制等问题[3]。

组合体航天器轨姿一体化控制

针对存在未知模型参数、空间干扰力矩等影响的组合航天器的位置和姿态控制问题，考虑其由于航天器组合导致的复杂运动学约束以及未知模型参数，分别在连续和离散时间域内研究了基于全驱系统理论的位姿耦合一体化控制、最优控制、预设性能控制、抗干扰控制以及制导律设计等问题[4],[5]。

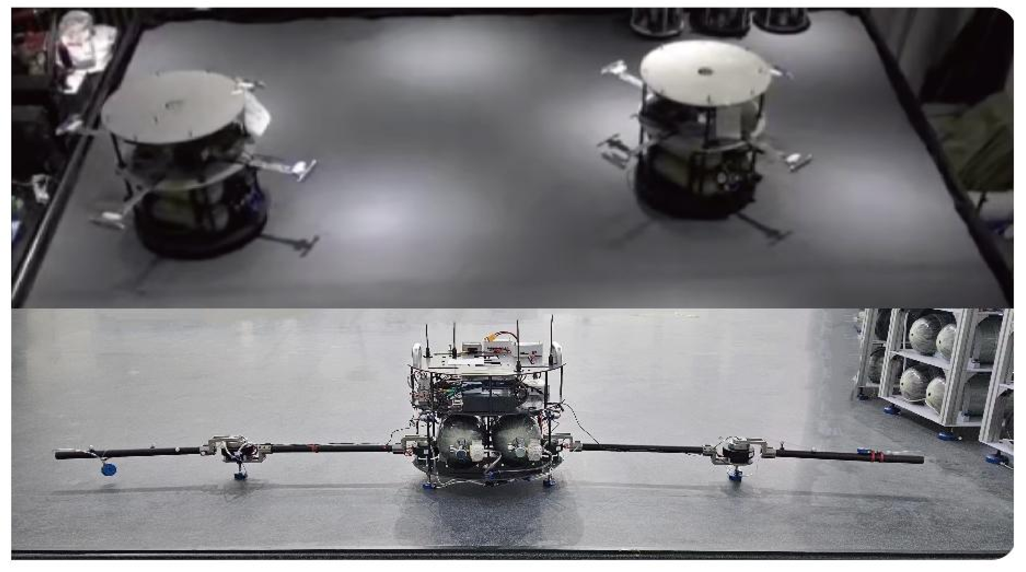


高速飞行器全驱系统控制方法及综合仿真验证

航天三院魏毅寅院士团队：针对高速飞行器在宽域飞行状态下的强非线性、强耦合性，进而超出传统控制系统边界的问题，开展了基于全驱系统理论的高速飞行器姿态二阶全驱系统模型建立、全驱姿态控制方法设计等研究工作，并为下一步的工程应用奠定了良好的理论基础。

基于气浮台的编队卫星、空间机械臂半物理仿真验证

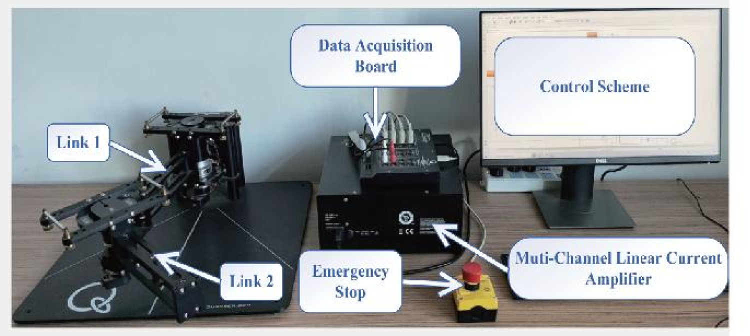
哈工大曹喜滨院士团队：搭建了多气浮台卫星模拟器编队、双臂空间机械臂的半物理仿真演示验证系统，开展了基于全驱系统理论的卫星轨道协同控制算法、空间双臂机械臂位姿控制算法的仿真验证工作，充分展示了全驱系统控制理论在航天器中的应用性和有效性[3]。



其他方面应用

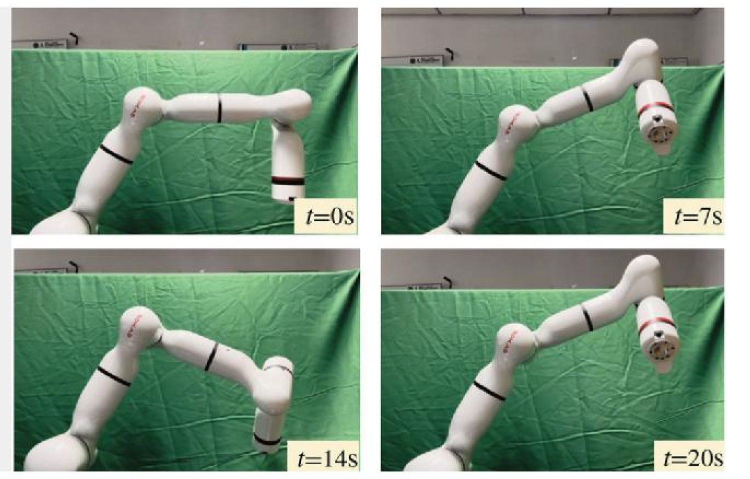
挠性关节机器人

韩国科学院院士Ju H. Park团队：考虑动态事件触发通信、暂态性能约束等影响，提出了基于全驱系统理论的挠性关节机器人事件触发控制方法[6]，降低了挠性关节机器人控制系统设计的计算复杂度。



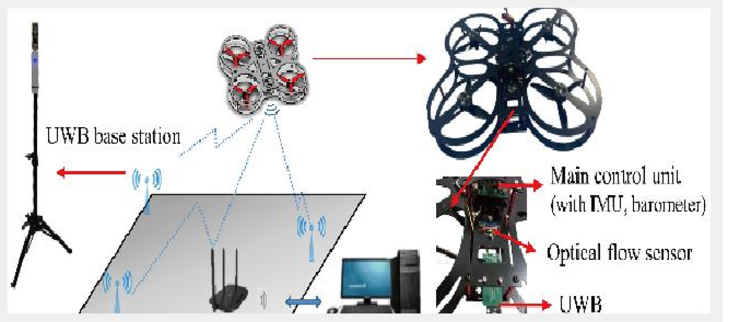
工业机械臂

中科院自动化所乔红院士团队：考虑状态约束、不确定模型动态等复杂情形，提出了基于全驱系统理论的工业机械臂管式滑模预测控制方法，采用神经元网络对系统未知动态部分进行补偿，保证了系统状态估计误差在一个管状不变集内变化[7]。



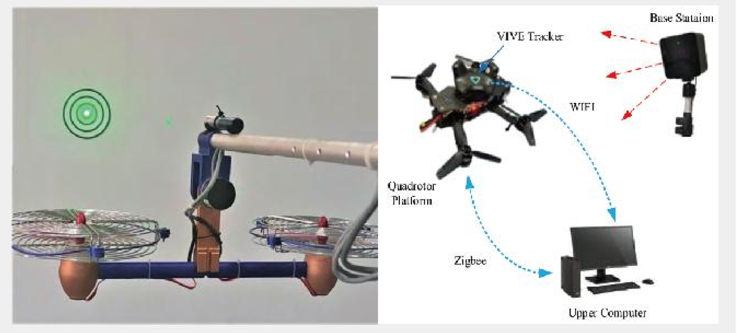
四旋翼无人机

针对系统不确定性、外部扰动和执行器约束的四旋翼无人机的姿态跟踪问题，采用全驱系统设计方法，提出了基于主动扰动抑制控制、跟踪微分器、拓展状态观测器的四旋翼无人机的预测控制器参数化设计方法，可通过调节系统矩阵的特征值和特征向量来保证控制系统性能[8]。



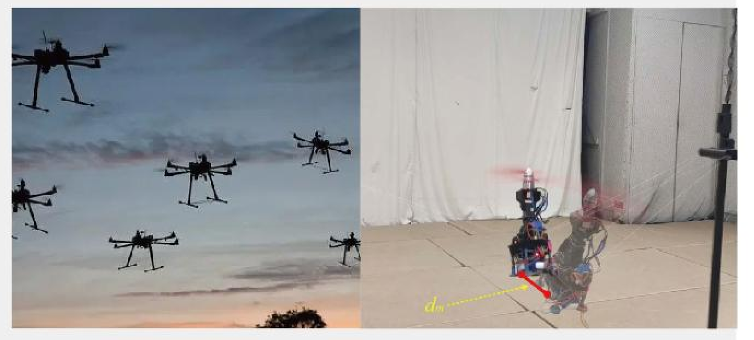
3-DOF 直升机、6-DOF 无人机

针对状态空间法可能无法完全解决无人机分层控制的难题，提出了无需伪严格反馈形式的拓展全驱系统方法，应用到了3-DOF 直升机和6-DOF 无人机的控制器设计问题中[9]。



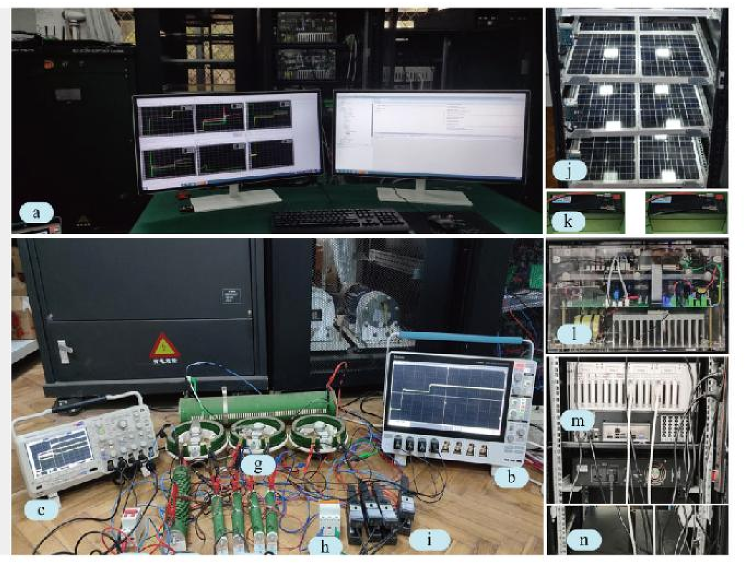
固定翼无人机、共轴双桨无人机

针对固定翼无人机紧密编队飞行的自主跟踪问题，综合考虑轨迹平滑性、运动协同性和跟踪鲁棒性等需求，采用全驱系统理论提出了一种多层次鲁棒协同跟踪控制方法[10]。针对带有两个对转螺旋桨的共轴双桨无人机，提出一种基于全驱系统的位置和姿态控制向量分配和控制器设计方法，可产生期望的力矩来实现无人机位置变量和偏航角的期望控制目标[11]。



直流微电网等系统

基于全驱系统理论方法，开展了伺服电机系统、挠性伺服系统、能源电力系统、欠驱动机械系统、倒立摆系统、智能汽车系统、多智能体系统、里克管中的热声不稳定系统、民用涡轮风扇发动机、质子交换膜燃料电池空气供给系统、冷条式轧机系统等各类实际系统的控制系统综合设计[12-20]。



附录：全驱系统控制理论的诞生与成长

孕育期

2014 提出了高阶伪线性系统理论

2020

- 07,24 世界上第一篇全驱系统方法论文问世（自动化学报）

婴儿期

2021

- 01,25 国际上第一篇全驱系统方法论文问世（IJSS）
- 05,26 基金委基础科学中心项目答辩
- 06,02 在IEEE ICRA2021上做全驱系统方法的大会报告
- 07,27 在CCC2021上做全驱系统方法的大会报告
- 09,29 在IFAC TDS2021上做全驱系统方法的大会报告
- 10,13 基金委基础科学中心项目现场考察会议
- 11,23 基金委基础科学中心项目正式获批

少儿期

2022

- 04,18 *Journal of Systems Science and Complexity*专刊出版
- 05,10 中国自动化学会全驱系统理论与应用专业委员会正式筹建
- 08,04 基金委基础科学中心项目启动会
- 08,05 在ICGNC2022上做全驱系统方法的大会报告
- 08,05 第一届全驱系统理论与应用国际学术年会（FASTA2022）
- 09,01 “全驱系统理论与应用”青年研究基金项目启动
- 10,28 FAS方法的第一篇IEEE汇刊论文问世（TCAS II, 华长春团队）
- 12,14 FAS方法的第一篇实际应用论文问世（IEEE/AMSE汇刊, 刘国平团队）

少年期

2023

- 06,01 FAS方法第一篇Automatica论文问世（长文，周东华团队）
- 07,14 第二届全驱系统理论与应用国际学术年会（FASTA2023）
- 07,15 “全驱系统理论与应用”青年研究基金汇报会
- 07,15 基础科学中心项目年度学术委员会会议
- 10,16 在IEEE IECON2023上做全驱系统方法的大会报告（新加坡）
- 10,27 “全驱系统理论与应用”深圳市“孔雀团队”获批
- 11,18 全驱系统理论与应用专业委员会正式获批
- 12,08 在POC2023上做全驱系统方法的大会报告（吉隆坡）

青年期

2024

- 01,15《航空学报》全驱系统理论专刊出版
- 02,07 “全驱系统控制理论与技术”广东省重点实验室获批
- 05,10 “全驱系统理论与应用”专业委员会成立大会
- 05,10 基金委基础科学中心项目年度学术委员会
- 05,11 第三届全驱系统理论与应用国际学术年会（FASTA2024）
- 06,30 *Int. J. Systems Science*专刊出版

在短短四年的时间里，全驱系统理论体系走过了“从无到有、从小到大、由弱到 强”的发展历程，当前在众多国内外控制界同仁的呵护下，正在飞速发展！