

Tutorial

Fractional Calculus in Cybernetics

Blas M. Vinagre (bvinagre@unex.es)
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Abstract

In this course we will study the mathematical foundations, the historical development and the applications of Fractional Calculus in science and engineering, with a special emphasis on the applications in feedback control, robotics and bioengineering, related disciplines in the framework of cybernetics.

Introduction

Although the term cybernetics was first used in 1834 by the physicist and mathematician French André-Marie Ampère to describe the science of government, the modern definition of it, the control and communication in animals and machines, was established by Norbert Wiener. Since then, cybernetics is playing an increasingly important role in the study of systems man-machine and the analysis of cyber-physical systems. Often defined as integration and differentiation of non-integer order, the idea of Fractional Calculus first appeared in 1695 in a letter from Guillaume de L'Hôpital to Gottfried Wilhelm Leibniz, but more recent interest dates back to the seventies in the past century. Today, fractional calculus techniques are widely applied in many fields of science and engineering. This course proposes an approach to the partnership of the two disciplines by considering, mainly, the fields of feedback control and bioengineering.

Lectures

The course consists of six modules each containing four short presentations of approximately ten minutes. So, the total duration is about four hours (**half-day**). The modules are the following:

Module 1: Presentation – Presentation of the course, the teachers and the topics to be discussed.



Module 2: Fractional Calculus Fundamentals – Brief historical introduction. Definition of operators. Fractional dynamics.

Module 3: Fractional Order Control I – Basic control actions. Classic control. Control in state space.

Module 4: Fractional Order Control II – Nonlinear control. Applications.

Module 5: Applications in Bioengineering – Fractional calculus and biological systems models. MRI applications.

Module 6: Cybernetics and Fractional Calculus – Can Cybernetics and Fractional Calculus Be Partners? Search for new ways to solve complex problems.

Lecturers

- Blas Manuel Vinagre Jara, UEX, Spain
- Inés Tejado Balsera, UEX, Spain
- Vicente Feliu Batlle, UCLM, Spain
- Igor Podlubny, TUKE, Slovakia
- Ivo Petras, TUKE, Slovakia
- S.Hassan HosseinNia, TUDelft, Netherlands
- Richard L. Magin, UIC, USA
- YangQuan Chen, UMerced, USA

Short Bios

Blas M. Vinagre received the M. S. degree in Telecommunications Engineering from Technical University of Madrid, Madrid, Spain, in 1985. He worked in industry from 1985 to 1994, mainly in communications, automation and electronic war. In 1994 he joined the University of Extremadura as Assistant Professor. In 2001 he received the Ph.D. degree from the National University of Distant Learning, Madrid, Spain. From 2001 to 2016 he has been Associate Professor in the Department of Electric, Electronic and Automation Engineering, where he is now Full Professor of Automatic Control. His research interest focus on the applications of Fractional Calculus in Automatic Control and Robotics, including microrobotics for medical applications. He is a Senior Member of the IEEE.

Igor Podlubny (igor.podlubny@tuke.sk) earned his M.Sc. degree in applied mathematics in 1983 and his Ph.D. degree in differential equations and mathematical physics in 1989 from Odessa State University, Ukraine. In 2010, he



earned his Dr.Sc. (higher doctorate) degree in applied mathematics from the Slovak Technical University, Bratislava. In Odessa, he worked at Odessa State University, Odessa University of Economics, and the Odessa Naval Academy. In 1990, he moved to Slovakia and worked at the Technical University of Kosice as a senior research scientist, associate professor (starting in 1994), and professor (since 2001). He also served as head of the university's Department of Control and Informatization of Production Processes and as a vice dean for research and graduate studies. His research is focused mainly on the theory and applications of fractional calculus. Since 2017, he has been a member of the Learned Society of the Slovak Academy of Sciences. He is a full member of the American Mathematical Society and the Society for Industrial and Applied Mathematics and a Senior Member of the IEEE.

Richard Magin is an Emeritus Professor of Biomedical Engineering at the University of Illinois at Chicago. He served on the faculty of the University of Illinois for 40 years, 20 in Urbana in the Department of Electrical and Computer Engineering and 20 in Chicago in the Department of Bioengineering. He has published over 200 scientific reports, papers and patents and is the author of the book Fractional Calculus in Bioengineering. His current interests are modeling the anomalous diffusion observed in the brain using magnetic resonance imaging (MRI) and interpreting the stochastic basis for non-Gaussian molecular motion in biological tissues.

Ivo Petráš (Senior Member, IEEE) received the M.Sc. and Ph.D. degrees in process control from the Technical University of Košice, Slovakia, in 1997 and 2000, respectively, and the Dr.Sc. degree in process control from the Slovak University of Technology in Bratislava, Slovakia, in 2013. He works at the Faculty of BERG, Institute of Control and Informatization of Production Processes, Technical University of Košice, as a Professor, the Institute Director, and the Vice-Rector. He has published seven books, five book chapters, over 80 journal articles, and over 100 conference papers. His H-index is 28 (Web of Science), 32 (Scopus), and 43 (Google Scholar). His research interests include control systems, automation, and applied mathematics.

Inés Tejado received the B.E., M.E., and Ph.D. degrees, the last ones with honor, in Electronic Engineering from University of Extremadura, Spain, in 2003, 2006, and 2011, respectively. Currently, Dr. Tejado is an Associate Professor in the area of knowledge of systems engineering and automation in that university. She has been working on fractional order control for more than 15 years, and is authored/coauthored over 100 research publications in peer-reviewed journals, book chapters and conference proceedings in the research field of fractional order control. Likewise, she was involved in more than 10 research projects in such a field. Her current interests include applications in flexible robotics, mechatronics, and bioengineering.

Vicente Feliu (M'88-SM'08) received the M.Sc. (Hons.) degree in industrial



engineering and the Ph.D. degree in automatic control from the Polytechnic University of Madrid, Madrid, Spain, in 1979 and 1982, respectively. From 1980 to 1994, he was in the Electrical Engineering Department, Universidad Nacional de Educacion a Distancia, Madrid, Spain, where he was a Full Professor in 1990, and the Head of the Department from 1991 to 1994. From 1994 to 2008, he has been the Dean of the School of Industrial Engineering, Universidad de Castilla-La Mancha, Ciudad Real, Spain. His research interests include multi-variable and digital control systems, fractional dynamics and control, kinematic and dynamic control of rigid and flexible robots, and mechatronics. He is Senior Member of the IEEE.

Hassan HosseinNia received his PhD degree with honor «cum laude» in electrical engineering specializing in automatic control: application in mechatronics, form the University of Extremadura, Spain in 2013. His main research interests are in precision mechatronic system design, precision motion control and mechatronic system with distributed actuation and sensing. He has an industrial background working at ABB, Sweden. Since October 2014 he is appointed as an assistant professor at the department of precession and microsystem engineering at TU Delft, The Netherlands. He is an associate editor of the international journal of advanced robotic systems since 2017. He was part of technical committee/organizing committee/session organizer of several conferences like FDA, ICCMA, ECC, and ACC.

YangQuan Chen earned his Ph.D. from Nanyang Technological University, Singapore, in 1998. He had been a faculty of Electrical Engineering at Utah State University (USU) from 2000-12. He joined the School of Engineering, University of California, Merced (UCM) in summer 2012 teaching “Mechatronics”, “Engineering Service Learning” and “Unmanned Aerial Systems” for undergraduates; “Fractional Order Mechanics”, “Nonlinear Controls” and “Advanced Controls: Optimality and Robustness” for graduates. His research interests include mechatronics for sustainability, cognitive process control (digital twin enabled smart control engineering), small multi-UAV based cooperative multi-spectral “personal remote sensing”, applied fractional calculus in controls, modeling and complex signal processing; distributed measurement and control of distributed parameter systems with mobile actuator and sensor networks. He is listed in Highly Cited Researchers by Clarivate Analytics from 2018 to 2021. He received Research of the Year awards from USU (12) and UCM (20).

Some extra information

Although the lessons are video recorded, some of the teachers will be present to make the tutorial/workshop truly interactive.