**A Half Day Tutorial Proposal On**

**Smart Predictive Maintenance (SPM) of Mechatronic Systems based on Smart Big Data (SBD) and Digital Twins (DT)**

#### at

#### **The 9th IFAC Symposium on Mechatronic Systems**

#### **(Mechatronics 2022)**

#### **The 16th International Conference on**

#### **Motion and Vibration Control (MoViC 2022)**

#### **Jointly held at University of California, Los Angeles on September 7-9, 2022**

<https://ifacms-movic2022.seas.ucla.edu/home/>

1. **Title of tutorial:**

*Smart Predictive Maintenance (SPM) based on Smart Big Data (SBD) and Digital Twins (DT)*

1. **Outline of the tutorial/workshop (topic and description)**

## **Workshop Abstract (why important and why timely and why good for audience):**

## The field of health monitoring, fault diagnosis and predictive maintenance is expanding dramatically to maintain successful operation in many engineering applications. Experienced engineers and researchers agree that before designing a predictive maintenance program, we need to ask two questions 1) “What do we have/know?” and 2) “What do we want?” and after we have designed a systematic approach, we also need to ask two questions 1) “How optimal?” and 2) “How robust?”. With the emerging wave of “Digital Transformation” such as Industry 4.0, we promote asking the third question: “How smart?”. This workshop introduces a new frontier for engineers: Smart Predictive Maintenance (SPM), using Smart Big Data (SBD) and Digital Twins (DT) as the enabler technology combined with IAI (industrial artificial intelligence) and groundbreaking technologies like Deep Learning, AI, Data Analytics, Big Data, and edge computing.

## For SPM, the concept of “smartness” follows the notion of the US NSF program on S&AS (smart and autonomous systems) based on the following attributes 1) Taskable; 2) Cognitive; 3) Reflective; 4) Ethical; 5) Knowledge-rich. It means that a smart predictive maintenance system can learn from past actions and induced errors (resilience), discover hidden patterns and anomalous behaviors at multiple time scales and reach the desired operation specifications. This workshop will present a case study to illustrate the SPM fundamentals enabled by SBD and DTs.

## This tutorial workshop prepares our audience with

## *What is SPM: Smart Predictive Maintenance?*

## *Digital Twins (DT) concept, example DT platforms, and DT behavior matching algorithms, and usage for fault detection and RUL estimation*

## *SPM design based on SBD and DT*

## *Edge computing, embedded and industrial AI applications towards SPM.*

## *Mechatronics testbed for smart predictive maintenance and case studies.*

## *Rich future research opportunities in SPM and DT.*

**Topics: Half day – 13:30-17:30**

1. 13:30-13:40. Introduction to the Tutorial Workshop program (YangQuan Chen)
2. 13:40-14:30. What is SPM: Smart Predictive Maintenance? (Furkan Guc/ YangQuan Chen)
3. 14:30-15:20. Digital Twins: overview, construction and usage for fault detection and RUL estimation (Jairo Viola)
4. 15:20-15:40. Coffee break and free chats.
5. 15:40-16:10. Smart big data and complexity-aware advanced analytics (YangQuan Chen)
6. 16:10-16:40 Heavytailedness-aware control system performance assessment and fault detection (Paweł D. Domański/Furkan Guc)
7. 16:40-17:10. Mechatronics testbed for smart predictive maintenance and case studies/ Implications in mechatronics education (Furkan Guc/Jing Wang)
8. 17:10-17:30 Discussions continue to group dinner time if needed.

**More background information:**

**Recent books from the presenters:**

* **Paweł D. Domański** and **YangQuan Chen** and Maciej Ławryńczuk (2022). “[**Outliers in Control Engineering – Fractional Calculus Perspectiv**e](https://www.degruyter.com/document/isbn/9783110729122/html).” March 2022. De Gruyter. Book Series on “[Fractional calculus and its applications in science and engineering](https://www.degruyter.com/serial/fcase-b/html)” <https://doi.org/10.1515/9783110729122>

# Paweł D. Domański (2020). Control Performance Assessment: Theoretical Analyses and Industrial Practice, Springer, <https://link.springer.com/book/10.1007/978-3-030-23593-2>

* **Jing Wang**, Jinglin Zhou, Xiaolu Chen (2022). **Data-Driven Fault Detection and Reasoning for Industrial Monitoring**, Springer, <https://link.springer.com/book/10.1007/978-981-16-8044-1>
* **Jairo Viola, YangQuan Chen**. (April 2022). "**Digital Twin Enabled Smart Control Engineering - A Framework and Case Studies**" New Springer Monograph

**Recent papers from the presenters:**

* Furkan Guc, and YangQuan Chen. **"Fault Cause Assignment with Physics Informed Transfer Learning."** IFAC-PapersOnLine 54.20 (2021): 53-58.
* Jairo Viola, Sina Dehghan, YangQuan Chen. **“Embedded RIOTS - Model Predictive Control Towards Edge.”** In Proceedings of the 2019 ASME IDETC, ASME/IEEE MESA, August 2019, Anaheim, CA, USA. IDETC2019-97046 (Best paper [award certificate](http://mechatronics.ucmerced.edu/sites/mechatronics.ucmerced.edu/files/news/documents/award_certificate_20190825105021.pdf))
* J Viola, YQ Chen, J Wang. **FaultFace: Deep Convolutional Generative Adversarial Network (DCGAN) based Ball-Bearing Failure Detection Method** Information Sciences (2020) <https://doi.org/10.1016/j.ins.2020.06.060>
* Jairo Viola and YangQuan Chen "**Digital Twin Enabled Smart Control Engineering as an Industrial AI: A New Framework and A Case Study**". Proc. of the Second International Conference on Industrial Artificial Intelligence (IAI20), Oct., 2020, Shenyang, China. Presented and published   <https://arxiv.org/abs/2007.03677>
* Jairo Viola, Carlos Rodriguez, YangQuan Chen. "**PHELP: Pixel Heating Experiment Learning Platform for Education and Research on IAI-based Smart Control Engineering**". Proc. of the Second International Conference on Industrial Artificial Intelligence (IAI20), Oct., 2020, Shenyang, China. Presented and published.  <https://arxiv.org/abs/2007.03048>
1. **Duration and sessions**

Half day, 13:30-17:30 (could be in the morning – flexible, perhaps preferred)

1. **Description of the intended audience and the expected learning outcomes**

Graduate students, postdocs, engineers, and faculty members dealing with complex process control, health monitoring, fault diagnosis and predictive maintenance tasks.

**Expected learning outcomes:**

1. Basic knowledge on “being smart” of predictive maintenance and ways to achieve smart predictive maintenance (SPM)
2. Digital Twin basics, usage of DTs in fault detection and RUL estimation, example demo DTs.
3. Outliers, Heavytailedness, smart big data (SBD) and complexity-aware advanced analytics
4. Edge AI idea and its use in process monitoring using real time data analytics and fractional order signal processing.
5. **Desired prerequisite knowledge of the audience**
6. Basic knowledge of signals and systems, classical control system (Control-I).
7. PID control tuning, control system performance monitoring
8. (optional) edge computing, deep learning
9. **The tutorial speaker(s)**

**Prof. YangQuan Chen,**

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1. **Brief biographies for each tutorial/workshop speaker (no more than 300 words per person)**

**YangQuan Chen**earned his Ph.D. from [Nanyang Technological University](http://www.ntu.edu.sg/eee/), Singapore, in 1998. He had been a faculty of Electrical Engineering at Utah State University from 2000-12. He joined the School of Engineering, University of California, Merced 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, 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. His most recent book is “*Outliers in Control Engineering -- Fractional Calculus Perspective*”(280 pages with P. Domanski and M. Lawrynczuk, 2021 De Gruyter series in Fractional Calculus in Applied Sciences and Engineering). He is listed in Highly Cited Researchers by Clarivate Analytics in 2018, 2019, 2020 and 2021. He received Research of the Year awards from USU (12) and UCM (20).

**Paweł D. Domański** was born in Warsaw, Poland in 1967. He received his M.Sc. in 1991, Ph.D. in 1996 and D.Sc. in 2018 all in automatic control from Warsaw University of Technology, Faculty of Electronics and Information Technology. He works in the Institute of Control and Computational Engineering, Warsaw University of Technology from 1991. Apart from scientific research he participated in dozens of industrial implementations of APC and optimization in power and chemical industry. He is the author of more than 100 publications in books, journals and conferences. His most recent book is “*Outliers in Control Engineering -- Fractional Calculus Perspective*”(280 pages with Y. Chen and M. Lawrynczuk, 2021 De Gruyter series in Fractional Calculus in Applied Sciences and Engineering). His main research interest is with industrial APC applications, control performance quality assessment and optimization.

**Furkan Guc** is a PhD student in Mechanical Engineering at the University of California, Merced, and working at the Mechatronics, Embedded Systems, and Automation Lab (MESA Lab). He received his master’s degree in Mechanical Engineering from Bilkent University, Turkey in 2020. His research interest includes Applied Fractional Calculus, Smart Control Engineering, Industrial AI, Control Performance Assessment, Smart Predictive Maintenance, Fault Diagnosis and Health Monitoring in Process Control.

**Jairo Viola** is Electronic Engineer with a master’s degree in Electronics from Universidad Pontificia Bolivariana, Colombia. Currently, he is pursuing his PhD on Mechanical Engineering, and works at the Mechatronics, Embedded Systems, and Automation Lab (MESALab) at University of California, Merced. For five years, he worked as a professor in the faculties of Electronic Engineering and Computer Sciences at the Universidad Pontificia Bolivariana, Colombia, teaching Programming, Computer Architecture, and Operating Systems courses. His research topics are Process Control, Robotics, Artificial Intelligence, Machine Learning and Big Data, Edge Computing and Failure Detection for Industrial Processes, and Applied Fractional Order Calculus.

**Jing Wang** received the B.S. degree in industry automation and the Ph.D. degree in control theory and control engineering from Northeastern University, Shenyang, China, in 1994 and 1998, respectively. She has been a Professor in the Department of Automation, School of Electrical and Control Engineering, North China University of Technology (NCUT), Beijing, China since 2020. She was a Professor with the College of Information Science and Technology, Beijing University of Chemical Technology, Beijing, China. She was a Visiting Professor with the University of Delaware, Newark, DE, USA, in 2014. Her current research interests include application of advanced control schemes to nonlinear, multivariable, constrained industrial processes; modeling, optimization, and control for complex industrial process; nonlinear model-based control of polymer microscopic quality in chemical reactor; and process monitoring and fault diagnosis for complex industrial process.