

A Half Day Tutorial On

Smart Control Engineering (SCE), Digital Twins, and Industrial AI (IAI) – A New Research Frontier

The 2021 IEEE Conference on Control Technology and Applications (CCTA)

<https://ccta2021.ieeecss.org/>

Wednesday, August 9 – 11, 2021, Westin San Diego Gaslamp Quarter in downtown San Diego, CA

1. Title of tutorial:

Smart Control Engineering (SCE), Digital Twins, and Industrial AI (IAI) – A New Research Frontier

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

Workshop Abstract (why important and why timely and why good for CCTA2021 audience):

Experienced control engineers and researchers agree that before designing a controller, we need to ask two questions 1) “What do we have/know?” and 2) “What do we want?” and after we have designed a controller, 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, I promote asking the third question: “How smart?”. This talk introduces a new frontier for control engineering: Smart Control Engineering (SCE), using Digital Twins (DT) as the enabler technology combined with IAI (industrial artificial intelligence) and breaking technologies like Deep Learning, AI, Data Analytics, Big Data, and edge computing.

For SCE, 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 control system can learn from past actions and induced errors (resilience), discover hidden patterns and anomalous behaviors at multiple time scales and reach the desired closed-loop and operation specifications. This workshop will present a case study to illustrate the SCE fundamentals enabled by DT using IAI for process control engineering.

This tutorial workshop prepares CCTA2021 our audience with

- *What is SCE – smart control engineering and how to make control systems smarter?*
- *Digital Twins (DT) concept, example DT platforms, and DT behavior matching algorithms, and practical implementation*
- *SCE control design based on DT (SOC, ITL, R2R)*
- *Edge computing, embedded and industrial AI applications towards SCE*
- *Rich future research opportunities in SCE and DT.*

Topics: Half day - 14:00-17:30

- 1) 14:00-14:10. Introduction to the Tutorial Workshop program (YangQuan Chen)
- 2) 14:10-15:00. What is SCE: Smart Control Engineering? (YangQuan Chen)
- 3) 15:00-15:50. Digital Twins: overview, construction, behavior matching and live demos (Jairo Viola/Paweł D. Domański)
- 4) 15:50-16:10. Coffee break and free chats.
- 5) 16:10-16:40. Edge Computing, Industrial AI and A Case Study: DCGAN based FaultFace recognition for a benchmark ball-bearing fault diagnosis (Jing Wang/Jairo Viola)
- 6) 16:40-17:10 DIY spatial temperature uniformity control test bench using edge computing RIOTS based MPC and towards fractional order MPC at the Edge (Jairo)

1. Taskable; 2. Cognizant, 3. Reflective, 4. Ethical, 5. Knowledge Rich

Viola/ YangQuan Chen)

7) 17:10-17:30 Discussions continue to group dinner time if needed.

More background information:

- 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](#))
- Paweł D. Domański and YangQuan Chen and Maciej Ławryńczuk. “**Outliers in Control Engineering – Fractional Calculus Perspective.**” Book to appear in 2021. De Gruyter. Book Series on “Fractional calculus and its applications in science and engineering”
- Jairo Viola, YangQuan Chen. “**Smart Control Engineering via Digital Twins**” Book to appear in 2021. Springer Brief. (to appear)
- 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, YangQuan Chen and Jing Wang. "**Information-Based Model Discrimination for Digital Twin Behavioral Matching**". Proc. of the Second International Conference on Industrial Artificial Intelligence (IAI20), Oct., 2020, Shenyang, China. Presented and published. <https://arxiv.org/abs/2007.03676>
- 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>

3. Duration and sessions

Half day, 14:00-17:30 (could be in the afternoon – flexible, perhaps preferred)

4. Description of the intended audience and the expected learning outcomes

Graduate students, postdocs, engineers and faculty members dealing with complex process control and monitoring tasks.

Expected learning outcomes:

- 1) Basic knowledge on “being smart” of control systems and ways to achieve smart control engineering (SCE)
- 2) Digital Twin basics, construction and behavior matching, example demo DTs.
- 3) MPC towards edge - MPC using general purpose optimal problem solver running on edge device in a (plant)-plug-n-play manner.
- 4) Edge AI idea and its use in process monitoring using real time data analytics and fractional order signal processing, FaultFace idea to leverage the deep learning results.

5. Desired prerequisite knowledge of the audience

- 1) Basic knowledge of signals and systems, classical control system (Control-I).
- 2) PID control tuning, control system performance monitoring
- 3) (optional) edge computing, deep learning

6. The tutorial speaker(s)

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



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 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. He is listed in Highly

Cited Researchers by Clarivate Analytics in 2018, 2019. He received Research of the Year awards from USU (12) and UCM (20).



Pawel 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 main research interest is with industrial APC applications, control performance quality assessment and optimization.



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 is 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.



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.