Zhejiang University 2023 SDG Global Summer School

Networked Autonomous Systems

I. Overview

Networked Autonomous Systems (NASs) have been rapidly developing in recent years due to advancements in robotics, AI, and sensing technologies. It gradually becomes one of the key enabling technology empowering sustainable transportation, manufacturing, healthcare, energy, etc.

Together with our international partners, we are planning to offer a comprehensive summer course which will enable students to have a solid understanding on the theory and practice of networked autonomous systems.

This course consists of three modules:

- **The first module** will cover the fundamental theory of unmanned systems and swarm intelligence, as well as the essential concepts of perception, planning and control. It will also incorporate several interdisciplinary cutting-edge topics such as optimization, learning, game theory, security.
- **The second and third modules** highlight the potential applications of NASs in sustainable manufacturing, energy, transportation, etc. The second module will focus on green production and intelligent manufacturing, covering topics such as Industrial Internet of Things, metaverse and telerobotics, while the third module will be dedicated to renewable energy, as well as initiatives on smart grid, green transportation, and edge computing.

II. Faculty Team

The faculty team of the course consists of more than 10 outstanding instructors from Zhejiang University and its international partners.

1. **Dr. Francesco Bullo** is Distinguished Professor of Mechanical Engineering at the University of California, Santa Barbara. His research focuses on modeling, dynamics and control of multi-agent network systems, with applications to robotic coordination, power systems, distributed computing and social networks.He has published more than 300+ papers in international journals, books, and refereed conferences. For more details, please refer to his homepage at https://fbullo.github.io/index.html

2. **Dr. Peng Cheng** is a professor at the College of Control Science and Engineering, Zhejiang University (ZJU). He is interested in networked sensing and control, cyber-physical systems, control system security, and robust control. He has published more than 200 papers in various journals and conferences. For more details, please refer to Google Scholar at

https://scholar.google.com/citations?user=0Z1uk7YAAAAJ&hl=zh-CN.

3. **Dr. Yuanchao Shu** is a professor at the College of Control Science and Engineering, Zhejiang University (ZJU). Before joining ZJU, he worked at Microsoft Research and Cloud Computing Department. His research interests include mobile and wireless systems, network control and optimization, and edge computing. He has published more than 50 papers in top journals and conferences. For further details, please refer to his homepage, accessible at https://yshu.org.
4. **Dr. Ying Sun** is a tenure-tracked professor with the Department of Electrical Engineering, The Pennsylvania State University. She received her Ph.D. degree in Electronic and Computer Engineering from the Hong Kong University of Science and Technology in 2016. Her research focuses on nonlinear optimization algorithms and statistical learning, with an emphasis in decentralized methods over networks. For more details, please refer to his homepage via https://ysunac.github.io/education.html.
5. **Dr. Jinming Xu** is a tenure-tracked professor at the College of Control Science and Engineering, Zhejiang University (ZJU). He received his Ph.D. degree from Nanyang Technological University (NTU). He was a Postdoctoral Researcher at Purdue University and Arizona State University, respectively. His research interests include distributed optimization, large-scale machine learning, data privacy, and security of algorithms. For more details, please refer to his homepage via https://jinmingxu.github.io/index.html.
6. **Dr. Qi Ye** is a tenure-tracked professor at the College of Control Science and Engineering, Zhejiang University. She received her Ph.D. degree from Imperial College London. Her research interests include computer vision and machine learning. To learn more, please check out google scholar at https://scholar.google.com/citations?hl=en&user=4D-HZ98AAAAJ.
7. **Dr. Wenchao Meng** is a tenure-tracked professor at the College of Control Science and Engineering, Zhejiang University. He conducted postdoctoral research at Carleton University, Canada. His research interests include adaptive control, cyber-physical systems, renewable energy, and smart grid. He has published more than 30 papers in top-tier conferences and journals. You can find additional information on google scholar by visiting https://scholar.google.com.hk/citations?hl=zh-CN&user=OiQ2UisAAAAJ.
8. **Dr. Mingyang Sun** is a tenure-tracked professor at the College of Control Science and Engineering, Zhejiang University. He received his Ph.D. degree from Imperial College London. His research interests include energy system security assessment, smart meter data analysis, energy forecasting, and large-scale energy system investment planning. Please visit his homepage https://www.imperial.ac.uk/people/mingyang.sun11 for further information.
9. **Dr. Chen Wang** is an assistant professor of computer science and engineering at the State University of New York (SUNY) in Buffalo. His research interests include robotic perception, vision, and learning. He has published more than 20 papers in various journals and conferences. He is also an associate editor of the International Journal of Robotics Research

(IJRR). If you want to know more, check out his homepage via https://sairlab.org/team/chen/.

10. **Dr. Liang Li** is a tenure-tracked professor at the College of Control Science and Engineering, Zhejiang University. He is an outstanding young scholar of Zhejiang University's Qizhen Program. His research interests include mobile robots, autonomous driving, SLAM, etc. He has published nearly 20 papers in robotics journals and conferences. For more details, please refer to google scholar at https://scholar.google.com/citations?hl=zh-CN&user=6JscxDkAAAAJ.
11. **Dr. Shuo Li** is a tenure-tracked professor at the College of Control Science and Engineering, Zhejiang University. He has been devoted to researching the autonomous racing of MAVs under limited computational resources for many years. He won the second prize in the IROS autonomous racing drone competition in 2016. Please visit google scholar via https://scholar.google.com/citations?hl=zh-CN&user=-MINoSEAAAAJ for further information.
12. **Dr. Fei Gao** is a tenure-tracked professor at the College of Control Science and Engineering, Zhejiang University. His research interests are mobile robots, motion planning, environmental perception, sensor fusion, SLAM, etc. In the past five years, he has published more than 50 papers in well-known journals/conferences including Science Robotics, TRO, JFR, etc. To learn more, please check google scholar via https://scholar.google.com/citations?hl=zh-CN&user=4RObDv0AAAAJ.
13. **Dr. Chengcheng Zhao** is a tenure-tracked professor at the College of Control Science and Engineering, Zhejiang University. She was a postdoctoral researcher at the University of Victoria. Her research interests include distributed control and optimization, industrial control security, and unmanned system security. Please visit google scholar for further information https://scholar.google.ca/citations?user=MxytyjoAAAAJ&hl=en.
14. **Dr. Gaofeng Li** is a tenure-tracked professor at the College of Control Science and Engineering, Zhejiang University. He was a Postdoctoral Researcher at the Italian Institute of Technology (IIT), Genova, Italy from Dec. 2018 to Feb. 2022. His research interests include Lie Group in Robotics, Telerobotics, Robotic Manipulation, Imitation Learning, etc.. He was the Recipient of the Outstanding Doctoral Dissertation of Nankai University and the Recipient of the Outstanding Doctoral Dissertation of Tianjin Municipality. You can find additional details on google scholar by visiting https://scholar.google.com/citations?hl=zh-CN&user=EFpCF6oAAAAJ.
15. **Dr. Cong Wang** is a tenure-track professor at the College of Control Science and Engineering, Zhejiang University. He was a tenure-track assistant professor at the George Mason University, Fairfax, VA, USA. His research interests include edge computing and adversarial machine learning. You can find additional details on google scholar by visiting https://scholar.google.com/citations?hl=zh-CN&user=kzqkUUkAAAAJ
16. **Dr. Yue Wang** is a tenure-track professor at the College of Control Science and Engineering, Zhejiang University.He was an exchange research student

in University of Technology, Sydney and Stanford University from 2013 to 2015. His research focus is to build persistent autonomy for robot using artificial intelligence, machine learning and computer vision. You can find additional details on google scholar by visiting https://ywang-zju.github.io/

III. Course

Teaching Plan (48 class hours)

Time Slot	Module	Course	Class Hour	Instructor(s)
1	Unmanned System and Swarm Intelligence	Introduction to Networked Systems	2	Fracisco Bullo
2		Distributed Optimization and Its Application in Multi-robot Collaboration	2	Jinming Xu
3		Basics for ROS system and Gazebo	3	Jing Zhou Yuyang Shen
4		A Tutorial on SLAM	3	Liang Li
5		Geometry and Robotic Visual Learning	2	Chen Wang
6		Planning and Navigation of Aerial Robots	3	Fei Gao
7		Control Theory and Techniques of Quadrotors	2	Shuo Li
8		Introduction to Distributed Learning	2.5	Ying Sun
9		Adversarial Machine Learning	2	Cong Wang
10		Discussion	2	/
12	Green Production and Intelligent	Introduction to the Industrial Internet of Things	3	Peng Cheng

13	**Manufacturing**	Metaverse and Smart Manufacturing	**2**	Qi Ye
14		Teleoperation and Human-Machine Interaction	**2**	Gaofeng Li
18		Introduction to Place Recognition	**1**	Yue Wang
19	**Clean Energy and Smart Transportation**	Introduction to Renewable Energy Control	**3**	Wenchao Meng
20		Artificial Intelligence for Future Low Carbon Energy Systems	**2**	Mingyang Sun
21		Fundamentals of Cloud and Edge Computing	**2**	Yuanchao Shu
22		Vehicle Platooning with Non-Ideal Communication Networks	**2**	Chengcheng Zhao
23		Discussion	**2**	/
24	**Evaluation**	Student Presentation	**4**	Faculty team

Module 1 Unmanned System and Swarm Intelligence

Introduction

In recent years, advancements in technology have led to the development of intelligent autonomous systems, which are capable of carrying out complex tasks without human intervention. These systems include autonomous vehicles, drones, robots, and other devices that can perceive their environment and make decisions based on data analysis and machine learning algorithms. On the other hand, swarm intelligence is the phenomenon of groups of individuals working together to solve problems or achieve goals that would be difficult or impossible for any individual to achieve alone. This concept has been applied in fields such as crowdsourcing, collaborative decision-making, and social networking. In summary, the introduction of unmanned systems and swarm intelligence can bring significant benefits to society and humanity. By improving efficiency and productivity, and enhancing safety, they can contribute to the fundamental transformation of social and economic development, promoting sustainable development and the harmonious development of humans and nature.

Course Goal

This course on unmanned systems and swarm intelligence is designed to provide students with a comprehensive understanding of these cutting-edge technologies. This module will encourage students to develop their critical thinking skills, interdisciplinary thinking abilities, and their ability to apply theoretical knowledge to practical situations. By exploring the principles and applications of unmanned systems and swarm intelligence, students will gain an appreciation for the capabilities and limitations of these technologies. They will also examine the ethical and social implications of their use, and learn to evaluate the trade-offs between efficiency and effectiveness. Working in teams with peers from diverse backgrounds and disciplines, students will engage in hands-on projects to design and develop unmanned systems and swarm-based solutions to complex problems. Through this collaborative process, they will learn to think creatively and innovatively, and to apply learned knowledge and skills to real-world problems.

Expected Learning Outcomes:

(1) Understand the basic concepts and characteristics of networked autonomous systems as well as their basic structure and working principles;
(2) Identify the potential applications of networked autonomous systems in various fields, including autonomous driving, mobile robot, drones, etc;
(3) Describe the fundamental concepts, principles, theories in swarm intelligence;
(4) Apply the principles and practices of swarm intelligence to distributed systems, large-scale machine learning, game, and system security;
(5) Develop the ability to apply simulation tools to hands-on projects.

Content

Course 1: Introduction to Networked Systems

1.1 Introduction to discrete/continuous-time averaging and flow systems
1.2 Basic notions in matrix and graph theory
1.3 Basic properties of averaging and flow systems

Course 2: Distributed Optimization and Its Application in Multi-robot Collaboration

2.1 Basics for convex optimization
2.2 Distributed convex optimization
2.3 Applications to Robotic Networks

Course 3: Basics for ROS system and Gazebo
3.1 Introduction and Installation of ROS system
3.2 Introduction and Installation of Gazebo
3.3 Examples and Demos

Course 4: A Tutorial on SLAM
4.1 Introduction to SLAM
4.2 Filtering-based SLAM
4.3 Graph-based SLAM
4.4 State-of-the-art SLAM algorithms
4.5 Future prospects and challenges of SLAM

Course 5: Geometry and Robotic Visual Learning
5.1 Progress of learning-based visual robotic localization
5.2 Key issues of geometry and rotation representation in machine learning.
5.3 2nd-order optimization and its integration with learning.
5.4 Practice in geometry inference and reasoning

Course 6: Control Theory and Techniques of Quadrotors
6.1 Modeling of the dynamics of a quadrotor
6.2 Classic multi-loop controller for quadrotors

Course 7: Planning and Navigation of Aerial Robots
7.1 Basic Concepts and System Overview of Autonomous Drones
7.2 Polynomial, MPC, and Other Framework for Online Kinodynamic Planning
7.3 Single or Swarm Autonomous Drones Flying in the Wild

Course 8: Introduction to Distributed Learning
8.1 Introduction to ERM problems
8.2 Primal learning algorithms: FL, DSGD and DGT
8.3 Extensions to block-wise updates, time-varying graph, asynchronization

Course 9: Adversarial Machine Learning
9.1 Basic Concepts of Deep Neural Networks
9.2 Adversarial Attacks on DNNs (White-box/Black-box/Transferability Attacks)
9.3 In-class Demo
9.4 Defense against adversarial attacks

Course 10: Discussion
Group assignment

Reading Materials
[1]. Bullo F. Lectures on network systems[M]. Kindle Direct Publishing, 2020.
[2]. Introduction to Graph Theory. By Gary Chartrand[J]. The American Mathematical Monthly, 1987, 94(5): 483-485.
[3]. Dynamic Programming: Deterministic and Stochastic Models, Prentice-Hall, 1987.
[4]. Bertsekas, D. Reinforcement learning and optimal control. Athena Scientific, 2019.
[5]. Convex Optimization, by Stephen Boyd and Lieven Vandenberghe, Cambridge University Press
[6]. Paden B, CČáp M, Yong S Z, et al. A Survey of Motion Planning and Control Techniques

for Self-driving Urban Vehicles[J]. IEEE Transactions on Intelligent Vehicles, 2016, 1(1): 33-55
[7]. Snider J M. Automatic steering methods for autonomous automobile path tracking[J]. Robotics Institute, Pittsburgh, PA, Tech. Rep. CMU-RITR-09-08, 2009
[8]. Mellinger D, & Kumar V. Minimum snap trajectory generation and control for quadrotors. In 2011 IEEE international conference on robotics and automation (pp. 2520-2525).
[9]. Richter C, Bry A & Roy N. Polynomial trajectory planning for aggressive quadrotor flight in dense indoor environments. In Robotics Research: The 16th International Symposium ISRR (pp. 649-666).
[10] Cadena C, Carlone L, Carrillo H, et al. Past, present, and future of simultaneous localization and mapping: Toward the robust-perception age[J]. IEEE Transactions on robotics, 2016, 32(6): 1309-1332.
[11] Mur-Artal R, Montiel J M M, Tardos J D. ORB-SLAM: a versatile and accurate monocular SLAM system[J]. IEEE transactions on robotics, 2015, 31(5): 1147-1163.
[12] Zhang J, Singh S. LOAM: Lidar odometry and mapping in real-time[C]//Robotics: Science and systems. 2014, 2(9): 1-9.

Module 2&3 Green Manufacturing and Clean Energy

Introduction

Green manufacturing is a concept that emphasizes the use of sustainable materials, processes, and practices to minimize the environmental impact of industrial activities. With the growing concerns over climate change and resource depletion, green manufacturing has become an urgent priority for many companies and governments around the world. By adopting eco-friendly technologies and practices, manufacturers can reduce waste, save energy, and improve the quality of their products. Meanwhile, AI has been rapidly evolving in recent years and has the potential to transform various industries, including the energy sector. With its ability to analyze large amounts of data and optimize complex systems, AI can help to increase the efficiency of renewable energy sources such as wind and solar power. AI-powered energy management systems can also help to balance the supply and demand of electricity, reduce energy waste, and improve the reliability of the grid.

Course Goal and Learning Outcomes

The goal of this module is to provide students with a comprehensive understanding of the concepts and applications of green manufacturing and clean energy. After taking this course, students will be able to:

(1) Understand the basic principles of green production and intelligent manufacturing, especially in terms of Industrial Internet of Things, metaverse and telerobotics;
(2) Identify the latest trends and technologies in green manufacturing and their potential applications in various industries;
(3) Understand the basic concepts and applications of AI-enabling technologies and how it can be used to optimize renewable energy systems;
(4) Identify the challenges and opportunities in the energy sector and their potential impact on the environment and society;
(5) Work on hands-on projects that apply what you have learned to real-world problems;

Content

Course 1: Introduction to the Industrial Internet of Things

1.1 Basic concepts of Industrial Internet of Things
1.2 Introduction to replay attack model
1.3 Non-intrusive attack detection
1.4 Examples on industrial robots

Course 2: Metaverse and Smart Manufacturing

2.1 Basic concepts of Metaverse and other related concepts
2.2 Why do we need Metaverse and how does Metraverse develop
2.3 The shared components and technologies making an immersive Metaverse experience
2.4 Case study of the applications of Metaverse in Industires

Course 3: Shared Control Strategies in Telerobotics

3.1 The basic concepts and key issues of telerobotics
3.2 The classification of existing shared control strategies
3.3 The new trends of telerobotics.

Course 4: Introduction to Place Recognition

4.1 Basic concept and key issue in place recognition
4.2 Bag of words for visual place recognition
4.3 Learning based place recognition.

Course 5: Introduction to Renewable Energy Control

5.1 Introduction to renewable energy
5.2 Control of Wind energy
5.3 Control of Solar energy

Course 6: Artificial Intelligence for Future Low Carbon Energy Systems

6.1 Basic concepts and key challenges of low carbon energy systems
6.2 Key artificial intelligence techniques for energy systems
6.3 AI-enabled autonomous operation and control for low carbon energy systems
6.4 Conclusion and future work

Course 7: Fundamentals of Cloud and Edge Computing

7.1 Cloud Principles
7.2 Cloud Solutions - IaaS, Paas, and SaaS
7.3 Edge Computing and 5G

Course 8: Vehicle Platooning with Non-Ideal Communication Networks

8.1 basic concepts and key issues of vehicle platooning
8.2 Vehicle platoon under non-ideal communication networks
8.3 Internal and string stability analysis
8.4 Conclusion and future prospects

Course 9: Discussion

Group Assignment

Reading Materials

[1] I.J. Goodfellow, J. Shlens,and C. Szegedy, “Explaining and harnessing adversarial examples,” https://arxiv.org/abs/1412.6572, 2014
[2] Madry et. al., Towards Deep Learning Models Resistant to Adversarial Attacks，ICLR 2018.
[3] N. Carlini and D. Wager, Towards Evaluating the Robustness of Neural Networks, IEEE SP Oakland, 2017.
[4] G. Niemeyer, C. Preusche, S. Stramigioli, and D. Lee. Chapter 43: Telerobotics. In B. Siciliano and O. Khatib, editors, Springer Handbook of Robotics, 2nd Edition.
[5] Richard M. Murray, Zexiang Li, S. Shankar Sastry. Chapter 2-3, A Mathematical Introduction to Robotic Manipulation, CRC Press, 1994.
[6] John J. Craig, Chapter 2-4, Introduction to Robotics -- Mechanics and Control, Pearson Education International, 2005, 3rd edition.
[7] Lowry S, Sünderhauf N, Newman P, et al. Visual place recognition: A survey[J]. ieee transactions on robotics, 2015, 32(1): 1-19.
[8] Garg S, Fischer T, Milford M. Where is your place, visual place recognition?[J]. arXiv preprint arXiv:2103.06443, 2021.
[9] Olivares, D. E., Mehrizi-Sani, A., Etemadi, A. H., Cañizares, C. A., Iravani, R., Kazerani, M., ... & Hatziargyriou, N. D. (2014). Trends in microgrid control. IEEE Transactions on smart grid, 5(4), 1905-1919.
[10] Zhao, Chengcheng, Lin Cai, and Peng Cheng. "Stability analysis of vehicle platooning with limited communication range and random packet losses." IEEE Internet of Things Journal 8.1 (2020): 262-277.
[11] Zhao, Chengcheng, et al. "Vehicle platooning with non-ideal communication networks." IEEE transactions on vehicular technology 70.1 (2020): 18-32.
[12] Naus, Gerrit JL, et al. "String-stable CACC design and experimental validation: A frequency-domain approach." IEEE Transactions on vehicular technology 59.9 (2010): 4268-4279.
[13] Naus, Gerrit JL, et al. "String-stable CACC design and experimental validation: A frequency-domain approach." IEEE Transactions on vehicular technology 59.9 (2010): 4268-4279.

Individual Project
Each student is required to independently complete their individual assignment based on the topic provided by us. The specific content and grading criteria for the assignment will be announced on "Learning in ZJU" online platform after the course begins.

IV. Evaluation

This module includes an evaluation process. In addition to the attendance rate and class discussion, and a individual project were designed.

Each Student must complete the individual project independently, and participate in the three class discussions according to the previously assigned teams. All the optional topics in class discussion will be presented in advance in learning in ZJU, and each team will select a topic and send representatives to express their views, again, every discussion needs to be attended.

The score of the individual project will be evaluated through instructor's evaluation according to the completeness, accuracy, and innovation of the report.

The final score is calculated as follows:

20% Participation
30% Discussion
50% Individual Projects