Distributed Intelligent Systems

WS 2024-2025

Instructor: Alcherio Martinoli

Guest lecturer: I. Kağan Erünsal

Teaching assistants: I. Kağan Erünsal (Head TA), Wanting Jin (TA), Nicolaj Schmid (TA), Lucas Wälti (Head TA)

Support staff: Oussama Gabouj (Help TA), Donia Gasmi (Help TA), Alejandro Salamanca (IT support)

Course Website: https://disal.epfl.ch/teaching/distributed_intelligent_systems/

1 Credits and Workload

Distributed Intelligent Systems (DIS) distributes 5 ECTS. According to the European Commission guidelines, 1 ECTS is equivalent to up to 30 h of workload. Therefore, the total workload for DIS will be about 150 h over the whole semester. The approximate breakdown of the workload is 60 h for lecture attendance and exam preparation, 40 h for exercises (including preparation), and 50 h for carrying out and presenting the results of the course project.

2 Grade

The final grade for DIS will take into account the performance in the final oral exam as well as that obtained in the course project. Exercises are ungraded but solving them in a thorough and individual way will help the students to be well-prepared for the final exam. The final oral exam will involve questions focusing on the different topics covered during the course, the exercises, and the related reading handouts. 50% of the grade will be acquired during the semester, based on the performance in the course project. The remaining 50% of the grade will be based on the performance during the final oral exam.

3 Reading

DIS does not follow a specific course book. Weekly reading material will be exclusively made available in electronic format, downloadable from the Moodle server, typically the week before a given lecture and exercise session. Access to this material will be limited to students officially enrolled in the class. Most of this material is copyrighted and therefore it should exclusively be used for course purposes.

The reading material is classified in primary and secondary reading. Primary reading material is covered to large extent during the lecture: it represents therefore a good complement to slides. On average, the primary reading material consists of about 50 single-column pages per week (selected book sections and chapters, conference and journal papers, technical reports). Secondary reading material is only briefly mentioned during the lecture, typically because of one specific aspect complementing the information of the core messages. Availability of this material on Moodle can facilitate curious students to look more into such information. Finally, for students interested in a deeper understanding of specific topics, further tertiary reading pointers are suggested at the end of each lecture notes.

Note that, in any case, the handouts represent a loosely coordinated literature body: some redundancy is possible and their content might not exhaustively be discussed in the lecture, although students attending the lecture will get good guidance on the relevance of specific reading material.

4 Lecture Notes

For this edition of the course, lectures will be offered exclusively on-site. Recorded lectures of the past edition will be made available to students after each lecture. However, lectures of the current edition might significantly deviate from those of the previous one, even if the lecture's topic might appear to be the same. Therefore, we strongly recommend a regular lecture attendance in order to both be well-informed on the content of this edition and understand the emphasis given to the various topics covered by the large reading material. *Preliminary* lecture notes will be available on the course web site *shortly before* a given lecture (typically Monday evening), in PDF format. *Definitive* lecture notes will be available *after a given lecture* in timely fashion, with an e-mail notification through the Moodle forum.

5 Laboratories

The course will involve a total of ten lab exercises, all lasting three hours. All the lab exercises will be ungraded and no points are therefore mentioned on their assignments. The exercises have been designed and tested such as they are doable in the two computer rooms available for the course on campus, leveraging a Linux operating system and further software tools (Webots robotic simulator, Matlab, and further custom software packages). Most of the exercises can be also carried out on personal machines or on VDI terminals, provided that the corresponding software packages are available or have been correctly installed on the specific operating systems (not necessarily Linux). While we will make available some instructions on the Moodle server for this purpose, we will not offer any assistance for the deployment of such tools on private machines and VDI operation is still to be thoroughly tested for our tools.

Given the maximal enrolment cap of 40 students enforced for this edition, assistance for solving the laboratories will be exclusively offered in the large computer room (GR B0 01).

The assignment of labs will be made available at latest the day before a given lab session via the Moodle server. At the beginning of each lab session, a mini-tutorial of typically 5-10 minutes will be given by the main designer of the exercise. The corresponding slides will be made available on the Moodle server after the lab session. Official solutions will be distributed for each exercise after a given laboratory session. For the exercises, we encourage the students to take their own personal notes (they will be useful for the final exam).

Further discussion on specific points of the exercises can happen during office hours. Office hours will have to be scheduled upon appointment via the TA mailing list (dis-ta@groupes.epfl.ch); the Moodle discussion forum should be exclusively used for points of general interest (e.g., bug detection in the distributed code, etc.).

6 Course Project

DIS involves a 50h course project for each student (this includes reading, implementing, and presenting as a team). All teaching assistants (including Help TAs) will serve as project advisors. Projects will be carried out in groups of *three* (default) or two (if needed) students, belonging as much as possible to *different* teaching programs.

This edition should help the revamping of the course content and will therefore favor topic exploration in its course project. Students will receive multiple project options, each of them anchored to a specific topic covered in the lecture and in the corresponding lab session of the first part of the course (i.e. up to the kick-off session of the project). Each student team will be asked to express project preferences; we will eventually assign one of the options to each team taking into account maximally the expressed preferences. All the project options will involve an implementation in Webots (which can be carried out in C, Python, or Matlab). Each project option will be assigned to maximally three different student teams. The results of the course project will have to be presented during the last week of the semester by the team of students. Students having the same project option will be encouraged to serve as reviewers for another team with the same option during the presentation session. The student teams will have to be consolidated by Week 6, based on preferences expressed by the students. The lab session of Week 7 will be dedicated to the kick-off of the course projects. The lab session of Week 13 will be also dedicated to the assistance for course projects, and both lecture and lab periods in Week 14 will host the final presentations.

Further technical questions related to the course project will be accepted exclusively during the *last hour* of each lab session from Week 8 to 12 (as mentioned in class, questions about technical understanding and implementation choices will be possible but no debugging requests will be accepted). No further assistance for the course project will be provided outside the slots mentioned above.

Further details on the team organization, paper selection, and presentation schedule in the context of the course project will be communicated in timely fashion.

7 Course Syllabus

WEEK 1 – September 10 and 12

Lecture – 2h on Tue in GR C0 01 and 2h on Thu in CM 1 106
Course organization (credits, workload, logistics) and content overview. Introduction to Swarm Intelligence (SI) and key principles, natural and artificial examples. Foraging, trail laying/following mechanisms. Open-space, multi-source foraging experiments: biological data and microscopic models. Collective movements, flocking in natural societies.

Reading

Primary

- Bonabeau E., Dorigo M., and Theraulaz G., “Swarm Intelligence: From Natural to Artificial Systems", SantaFe Studies in the Sciences of Complexity, Oxford University Press, 1999, Ch. 1 (pp.1-23) and Ch. 2 (pp. 25-36).
- Martinoli A., “Collective Complexity out of Individual Simplicity”. Invited book review on "Swarm Intelligence: From Natural to Artificial Systems", by Bonabeau E., Dorigo M., and Theraulaz G. *Artificial Life*, Vol. 7, No. 3, pp. 315-319, 2001.

Secondary

- Beni G., “From Swarm Intelligence to Swarm Robotics”. In Şahin E. and Spears W., editors, *Proc. of the SAB 2004 Workshop on Swarm Robotics*, Santa Monica, CA, USA, July, 2004. Lecture Notes in Computer Science (2005), Vol. 3342, pp. 1-9.

Lab
No exercises.

WEEK 2 – September 17 and 19

Lecture
Ant-based algorithms applied to classical operational research problems (e.g., TSP) and routing in telecommunication networks: the AS, ACS, ACS-3-Opt, and Ant-Net algorithms; the Ant Colony Optimization (ACO) metaheuristic as an example of

successful translation of Swarm Intelligence principles to powerful metaheuristic algorithms.

Reading
Primary
- Bonabeau E., Dorigo M., and Theraulaz G., "Swarm Intelligence: From Natural to Artificial Systems", Santa Fe Studies in the Sciences of Complexity, Oxford University Press, 1999, Ch. 2 (pp. 39-56 and pp. 93-107).

Secondary
- Dorigo M. and Stützle T., "Ant Colony Optimization", MIT Press, 2004, Ch. 1 (pp. 1-24) and Ch. 2 (pp. 25-46).
- Dorigo M. and Stützle T., "Ant Colony Optimization: Overview and Recent Advances". M. Gendreau and Y. Potvin, editors, *Handbook of Metaheuristics*, 3rd edition, Springer Verlag, 2019, Vol. 272, pp. 311-351.

Lab 1
Trail laying and following mechanisms, emphasizing SI concepts; Ant Colony Optimization.

WEEK 3 – September 24 and 26

Lecture
Introduction to mobile robotics: basic concepts centered around the differential drive vehicle considered in the course (e-puck) and the high-fidelity, open-source robotic simulator (Webots). Introduction to control architecture for mobile robots with special focus on reactive control architectures.

Reading
Primary
- Michel O., "Webots: Professional Mobile Robot Simulation". *Int. J. of Advanced Robotic Systems*, **1**: 39-42, 2004.
- Siegwart R. and Nourbakhsh I. R., "Introduction to Autonomous Mobile Robots", MIT Press, 2004, Ch. 4 (pp. 89-98).
- Mondada F., Bonani M., Raemy X., Pugh J., Cianci C., Klaptocz A., Magnenat S., Zufferey J.-C., Floreano D., Martinoli A., "The e-puck, a Robot Designed for Education in Engineering". *Proc. of the 9th Conference on Autonomous Robot Systems and Competitions,* May 2009, Castelo Branco, Portugal, Vol.1, pp. 59-65.

Secondary
- Brooks R., "A Robust Layered Control System for a Mobile Robot". *IEEE Trans. on Robotics and Automation*, **2**(1): 14-23, 1986.
- Arkin R. C., "Motor Schema Based Mobile Robot Navigation". *Int. J. of Robotics Research*, **8**(4): 92-112, 1989.

Lab 2
Introduction to Webots, an open-source, high-fidelity robotic simulator.

WEEK 4 – October 1 and 3

Lecture
Localization methods in mobile robotics: positioning systems, odometry-based and feature-based localization. Sources of localization uncertainties and corresponding handling methods in 1D (Kalman Filter).

Reading
Primary

- Maybeck P. S. "Stochastic Models, Estimation, and Control", Academic press, 1979, Ch. 1 (pp.1-16).
- Siegwart R. and Nourbakhsh I. R., "Introduction to Autonomous Mobile Robots", MIT Press, 2004, Ch. 3 (pp. 47-53), Ch. 4 (pp. 102-103, 145-154), Ch. 5 (pp. 227-233).

Secondary

- None

Lab 3

Localization methods (odometry and feature-based localization) for single robots.

WEEK 5 – October 8 and 10

Lecture

Multi-dimensional Kalman Filter, localization uncertainties in wheel-based odometry, and corresponding handling methods (Extended Kalman Filter).
Collective movements in artificial systems: Reynolds' virtual agents (Boids), experiments with multi-robot systems on flocking and formation (behavior-based); graph-based formalism for consensus-based algorithms (rendez-vous, formation).

Reading

Primary

- Reynolds C. W. "Flocks, Herds, and Schools: A Distributed Behavioral Model, in Computer Graphics", *Proc. of SIGGRAPH '87*, 21(4), pp. 25-34, 1987.
- Siegwart R. and Nourbakhsh I. R., "Introduction to Autonomous Mobile Robots", MIT Press, 2004, Ch. 5 (pp. 181-191, 212-214).
- Gowal S., "A Framework for Graph-Based Distributed Rendezvous of Nonholonomic Multi-Robot Systems", EPFL Thesis no. 5845, Ch. 6 and 7 (pp. 49-60), 2013.

Secondary

- Fredslund J. and Matarić M. J., "A General, Local Algorithm for Robot Formations", *IEEE Transactions on Robotics and Automation*, special issue on Advances in Multi-Robot Systems, Vol. 18, p.5, pp. 837-846, 2002.
- Siegwart R. and Nourbakhsh I. R., "Introduction to Autonomous Mobile Robots", MIT Press, 2004, Ch. 5 (pp. 233-244).
- Pugh J., Raemy X., Favre C., Falconi R., and Martinoli A., "A Fast On-Board Relative Positioning Module for Multi-Robot Systems". Special issue on Mechatronics in Multi-Robot Systems, Chow M.-Y., Chiaverini S., Kitts C., editors, *IEEE Trans. on Mechatronics*, 14(2): 151-162, 2009.
- Falconi R., Gowal S., and Martinoli A., "Graph-Based Distributed Control of Non-Holonomic Vehicles Endowed with Local Positioning Information Engaged in Escorting Missions". *Proc. of the 2010 IEEE Int. Conf. on Robotics and Automation*, May 2010, Anchorage, AK, U.S.A., pp. 3207-3214.
- Gowal S., "A Framework for Graph-Based Distributed Rendezvous of Nonholonomic Multi-Robot Systems", EPFL Thesis no. 5845, Ch. 9-10 (pp. 69-78), 2013.

Lab 4

Collective movements (flocking, formations) in simulation.

WEEK 6 – October 15 and 17

Lecture

Division of labor and task-allocation mechanisms: threshold-based and market-based algorithms.

Reading

Primary

- Stentz A., Dias M. B., "A free market architecture for coordinating multiple robots". Technical report CMU-RI-TR-99-42, Robotics Institute, Carnegie Mellon University, December 1999.
- Bonabeau E., Dorigo M., and Theraulaz G., "Swarm Intelligence: From Natural to Artificial Systems", SantaFe Studies in the Sciences of Complexity, Oxford University Press, 1999, pp. 109-139 (Chapter 3).
- Kalra N. and Martinoli A., "A Comparative Study between Threshold-Based and Market-Based Task Allocation". *Proc. of the Eight Int. Symp. on Distributed Autonomous Robotic Systems*, July 2006, Minneapolis/St. Paul, MN, U.S.A. Distributed Autonomous Robotic Systems 7 (2006), pp. 91–102.

Secondary

- Agassounon W. and Martinoli A., "Efficiency and Robustness of Threshold-Based Distributed Allocation Algorithms in Multi-Agent Systems". *Proc. of the First ACM Int. Joint Conf. on Autonomous Agents and Multi-Agent Systems*, July 2002, Bologna, Italy, pp. 1090–1097.
- Dias M. B., Zlot R., Kalra N., and Stentz A., "Market-Based Multirobot Coordination: A Survey and Analysis". *IEEE Proceedings,* 94(7): 1257-1270, 2006.

Lab 5

Multi-robot systems coordination using market-based and threshold-based algorithms.

Project

Consolidation of student teams.

WEEK 7 – October 29 and 31

Lecture – Guest lecturer: I. Kağan Erunsal

Distributed sensing: static and mobile sensor networks.

Reading

Primary

- Barrenetxea G., Ingelrest F., Schaefer G. and Vetterli M., "The Hitchhiker's Guide to Successful Wireless Sensor Network Deployments". *Proc. of the 6th ACM Conference on Embedded Networked Sensor Systems* (SenSys 2008). Raleigh, NC, USA, 5-7 November 2008.
- Evans W. C., Bahr A., and Martinoli A., "Evaluating Efficient Data Collection Algorithms for Environmental Sensor Networks". *Proc. of the Tenth Int. Symp. on Distributed Autonomous Robotic Systems*, November 2010, Lausanne, Switzerland; Springer Tracts in Advanced Robotics (2013), Vol. 83, pp. 77-90.
- Arfire A., Marjovi A., and Martinoli A., "Mitigating slow dynamics of low-cost chemical sensors for mobile air quality monitoring sensor networks," *Proc. of the Int. Conf. on Embedded Wireless Systems and Networks*, February 2016, Graz, Austria, pp. 159-167.
- Marjovi A., Arfire A., and Martinoli A., "Extending Urban Air Pollution Maps beyond the Coverage of a Mobile Sensor Network: Data Sources, Methods, and Performance Evaluation," *Proc. of the Int. Conf. on Embedded Wireless Systems and Networks*, February 2017, Uppsala, Sweden, pp. 12-23.

Secondary

- Culler D., Estrin D., and Srivastava M., "Guest Editors' Introduction: Overview of Sensor Networks". *IEEE Computer*, Vol. 37, No. 8, pp.41-49, 2004.
- Evans W. C., Bahr A., and Martinoli A., "Distributed Spatiotemporal Suppression for Environmental Data Collection in Real-World Sensor Networks". *Proc. of the 2013 IEEE Int. Conf. on Distributed Computing in Sensor Systems*, May 2013, Boston, U.S.A., pp. 70-79.
- Marjovi A., Arfire A., and Martinoli A., "High Resolution Air Pollution Maps in Urban Environments using Mobile Sensor Networks". *Proc. of the 11th International Conference on Distributed Computing in Sensor Systems*, June 2015, Fortaleza, Brazil, pp. 11-20.

Lab
Kick-off of course project: guidelines, material, etc.

WEEK 8 – November 5 and 7

Lecture
Distributed sensing: robotic sensor networks (focus on gas sensing, 2D vs. 3D).

Reading
Primary
- Lochmatter T. and Martinoli A., "Tracking an Odor Plume in a Laminar Wind Field with Bio-Inspired Algorithms". *Proc. of the Eleventh Int. Symp. Experimental Robotics,* July 2008*,* Athens, Greece, Springer Tracts in Advanced Robotics (2008), Vol. 54, pp. 473-482, 2008.
- Soares J. M., Aguiar A. P., Pascoal A. M., and Martinoli A., "A Distributed Formation-based Odor Source Localization Algorithm - Design, Implementation, and Wind Tunnel Evaluation," *Proc. IEEE Int. Conf. on Robotics and Automation*, 2015, pp. 1830–1836.
- Rahbar F. and Martinoli A., "A Distributed Source Term Estimation Algorithm for Multi-Robot Systems", *Proc. of the IEEE Int. Conf. on Robotics and Automation,* May-August 2020, Paris, France, online organization, pp. 5604-5610.

Secondary
- Rahbar F., Marjovi A., Kibleur P., and Martinoli A., "A 3-D Bio-inspired Odor Source Localization and its Validation in Realistic Environmental Conditions," *Proc. of the IEEE/RSJ Int. Conf. on Intelligent Robots and Systems*, September 2017, Vancouver, Canada, pp. 3983-3989.
- Ercolani C. and Martinoli A., "3D Odor Source Localization using a Micro Aerial Vehicle: System Design and Performance Evaluation", *Proc. of the IEEE/RSJ Int. Conf. on Intelligent Robots and Systems*, October 2020, Las Vegas, NV, USA, online organization, pp. 6194-6200.
- Ercolani C., Jin W., and Martinoli A., "3D Gas Sensing with Multiple Nano Aerial Vehicles: Interference Analysis, Algorithms and Experimental Validation", Special Issue on Robotics for Environment Sensing, Neumann P. P., editor, *Sensors*, 23(20): 8512 (22 pages), 2023.

Lab 6
Distributed sensing with static, mobile, robotic sensor networks.

Project
Preference expression and definitive assignment of course project options for student teams.

WEEK 9 – November 12 and 14

Lecture
Introduction to multi-level modeling techniques (underlying theoretical framework, levels, assumptions, principles). Linear and nonlinear modeling case studies.

Reading
Primary
- Lerman K., Martinoli A., and Galstyan A., "A Review of Probabilistic Macroscopic Models for Swarm Robotic Systems". In Sahin E. and Spears W., editors*, Proc. of the SAB 2004 Workshop on Swarm Robotics*, July 2004, Santa Monica, CA, USA. Lecture Notes in Computer Science (2005), Vol. 3342, pp. 143-152.
- Martinoli A., Easton K., and Agassounon W., "Modeling of Swarm Robotic Systems: A Case Study in Collaborative Distributed Manipulation". Special Issue on Experimental Robotics, Siciliano B., editor, *Int. Journal of Robotics Research*, Vol. 23, No. 4, pp. 415-436, 2004.

Secondary

- Correll N. and Martinoli A., “Collective Inspection of Regular Structures using a Swarm of Miniature Robots”. In Ang Jr., M.H. and Khatib, O., editors, *Proc. of the Ninth Int. Symp. Experimental Robotics,* June 2004*,* Singapore*.* Springer Tracts in Advanced Robotics (2006), Vol. 21, pp. 375–385.

Lab 7
Multi-level modeling of swarm robotic systems – Introduction.

WEEK 10 – November 19 and 21

Lecture
Calibration of model parameters. Additional selected multi-level modeling case studies. Combined modeling and learning methods for control optimization; diversity and specialization metrics.

Reading
Primary
- Agassounon W., Martinoli A., and Easton K., “Macroscopic Modeling of Aggregation Experiments using Embodied Agents in Teams of Constant and Time-Varying Sizes”. *Autonomous Robots*, special issue on Swarm Robotics, Dorigo M. and Sahin E., editors, 17(2-3): 163-192, 2004.
- Li L., Martinoli A., and Abu-Mostafa Y., “Learning and Measuring Specialization in Collaborative Swarm Systems”. Special issue on Mathematics and Algorithms of Social Insects*,* Balch T. and Anderson C., editors, *Adaptive Behavior,* Vol.12, No. 3-4, pp. 199-212, 2004.

Secondary
- Martinoli A., Ijspeert A. J., and Gambardella L. M., “A Probabilistic Model for Understanding and Comparing Collective Aggregation Mechanisms”. In Floreano D., Mondada F., and Nicoud J.-D., editors, *Proc. of the Fifth Europ. Conf. on Artificial Life*, September 1999, Lausanne, Switzerland. Lectures Notes in Artificial Intelligence (1999), Vol. 1674, pp. 575–584.
- Baumann C. and Martinoli A., “Spatial Microscopic Modeling of Collective Movements in Multi-Robot Systems: Design Choices and Calibration”, *Frontiers in Robotics and AI*, 9: 961053 (19 pages), 2022.

Lab 8
Multi-level modeling of swarm robotic systems – Advanced.

WEEK 11 – November 26 and 28

Lecture
Introduction to evaluative machine-learning techniques for automatic design and optimization: terminology and classification. Particle Swarm Optimization (PSO): algorithm and performance evaluation. Application of metaheuristic learning techniques to automatic control design and optimization of single-robot systems.

Reading
Primary
- Eberhart R. C. and Kennedy J., “A New Optimizer using Particle Swarm Theory”. *Proc. of the Sixth IEEE Int. Symp. Micro Machine and Human Science*, Nagoya, Japan, 1995, pp. 39–43.
- Shi, Y. H., Eberhart, R. C. “A Modified Particle Swarm Optimizer” *Proc. of the IEEE International Conference on Evolutionary Computation,* Anchorage, Alaska, May 1998, pp. 69-73.

- Pugh J., Zhang Y., and Martinoli A., "Particle Swarm Optimization for Unsupervised Robotic Learning". *Proc. of the Second IEEE Symp. on Swarm Intelligence,* Pasadena, CA, USA, June 2005, pp. 92-99.
- Engelbrecht A. P., "Particle Swarm Optimization: Where Does it Belong?" *Proc. of the Third IEEE Symp. on Swarm Intelligence,* Indianapolis, IN, USA, May 2006, pp. 48-54.

Secondary

- Poli R., Kennedy J., and Blackwell T., "Particle Swarm Optimization: An Overview". *Swarm Intelligence Journal,* **1**(1): 33-57, 2007.
- Floreano D. and Mondada F., "Evolution of Homing Navigation in a Real Mobile Robot", *IEEE Trans. on System, Man, and Cybernetics: Part B*, **26**(3): 396-407, 1996.
- Lipson, H., Pollack J. B., "Automatic Design and Manufacture of Artificial Lifeforms", *Nature*, **406**: 974-978, 2000.
- Bongard J., Zykov V., Lipson H. (2006), "Resilient Machines Through Continuous Self-Modeling", *Science* Vol. 314. no. 5802, pp. 1118 – 1121.
- Baumann C., Birch H., and Martinoli A., "Leveraging Multi-Level Modelling to Automatically Design Behavioral Arbitrators in Robotic Controllers", *Proc. of the IEEE/RSJ Int. Conf. on Intelligent Robots and Systems*, October 2022, Kyoto, Japan, pp. 9318-9325.

Lab 9

Particle Swarm Optimization: application to benchmark functions and control shaping for single robot.

WEEK 12 - December 3 and 5

Lecture

Noisy and expensive optimization problems. Application of metaheuristic learning techniques to automatic control design and optimization of multi-robot systems. Specific issues for automatic control design and optimization in distributed systems (e.g., credit assignment problem).

Reading

Primary

- Pugh J. and Martinoli A., "Distributed Scalable Multi-Robot Learning using Particle Swarm Optimization". *Swarm Intelligence Journal*, **3**(3): 203-222, 2009.
- Di Mario E. and Martinoli A., "Distributed Particle Swarm Optimization for Limited Time Adaptation with Real Robots". Chirikjian G. and Hsieh A., editors, Special issue on Distributed Robotics, *Robotica*, 32(2): 193-208**,** 2014.
- Di Mario E., Navarro I., and Martinoli A., "A Distributed Noise-Resistant Particle Swarm Optimization Algorithm for High-Dimensional Multi-Robot Learning", *Proc. of the 2015 IEEE International Conference on Robotics and Automation*, May 2015, pp. 5970–5976.

Secondary

- C. Chen, J. Lin, E. Yücesan, and S. E. Chick, "Simulation Budget Allocation for Further Enhancing the Efficiency of Ordinal Optimization," *Discrete Event Dynamic Systems: Theory and Applications*, pp. 251–270, 2000.
- Di Mario E., Navarro I., and Martinoli A., "The Effect of Fitness Distributions on PSO: Multi-Robot Learning and Benchmark Functions". *Proc. of the 2014 IEEE Congress on Evolutionary Computation*, July 2014, Beijing, China, pp. 2785-2792.
- Endo W., Baumann C., Asama H., and Martinoli A., "Automatic Multi-Robot Control Design and Optimization Leveraging Multi-Level Modeling: An Exploration Case Study", *Proc. of the 22nd World Congress of the International Federation of Automatic Control*, July 2023, Yokohama, Japan; IFAC PapersOnLine, Vol. 56, Issue 2, pp. 11462-11469.

Lab 10

Particle Swarm Optimization application to noisy problems: benchmark functions and multi-robot problems.

WEEK 13 – December 10 and 12

Lecture
Selected topics in distributed intelligent systems. General take home messages of the course.

Reading
TBA

Lab
Assistance for course project.

WEEK 14 – December 17 and 19

Lecture
Course project presentations.

Reading
None.

Lab
Course project presentations.