

Control Theory and Engineering of Cyber-Physical Systems

Yingying Liu

Control and Artificial Intelligence Group
Department of Core Informatics
Osaka Metropolitan University, Japan

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Research Background

Cyber-Physical Systems (CPS): A complex system

- Integrates **computing, networking, and physical environments.**
- Collaboration of **Computation, Communication, and Control technology.**
- Achieves **real-time perception, dynamic control, and information services.**



(a) Industrial production



(b) Transportation system



(c) Medical system

Research Fields:

- Prediction and control of CPS with application in agriculture
- Motion and path planning of multi-agent systems with application in emergency rescue
- Distributed control of multi-agent Discrete-Event Systems (DES)
- LLM-based path planning

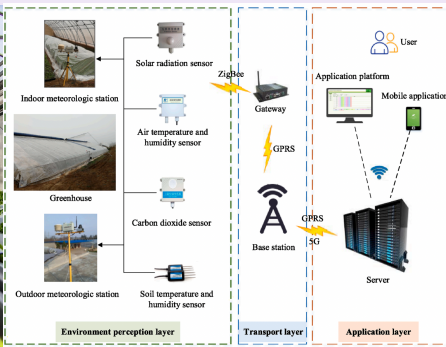
which involve a mixture of analysis, algorithm design, and implementations.

Prediction and control of CPS with application in agriculture

Multistep ahead prediction of temperature and humidity in Solar greenhouse.



(d) Solar greenhouse



(e) Greenhouse control system

Prediction and control of CPS with application in agriculture

Solutions: Proposed a feed-forward attention mechanism- long-short term memory (FAM-LSTM) model, where

- **FAM** generates different attention weights for the input features at different time steps
- **LSTM** networks capture the nonlinear relationships between historical environmental factors to offer a 5 min forecast of temperature and humidity.

[1] Y. Yang, **Y. Liu***, J. Hu, et al., "Multistep ahead prediction of temperature and humidity in solar greenhouse based on fam-lstm model," *Computers and Electronics in Agriculture*, vol. 213, p. 108 261, 2023.

Distributed control of multi-agent DES

Multi-agent DES typically can be divided into several groups in each of which the agents have **similar/identical state transition structures**, where DES is a dynamic system with discrete state set and discrete and event-driven state transitions.



(f) Logistics robots



(g) Mechanical arms



(h) UAVs

Distributed control of multi-agent DES

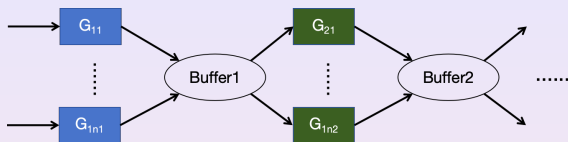
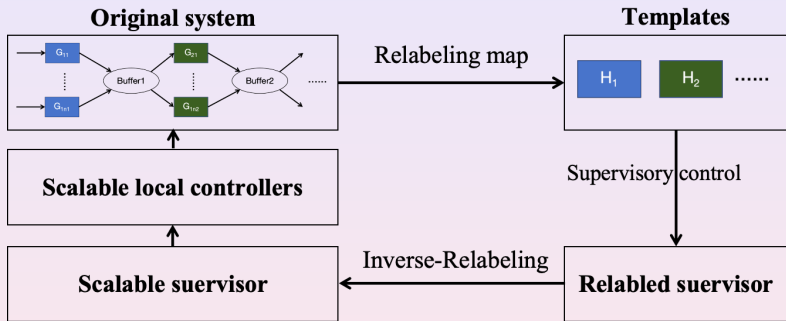


Figure 1: Abstraction of mechanical arms

Problem: How to design a supervisor with **low computational load** when the number of agents is changed?

- The state size of the supervisor **increases exponentially as the number of agents increases**;
- The supervisor must be **recomputed or reconfigured** whenever the number of agents changes.

Solutions: Modular supervisory control of DES to combat system variability.



[1] Y. Liu, K. Jan*, M. Tomas, and Z. Li, "Modular control of discrete-event systems using similarity," *Automatica*, vol. 142, p. 110 431, 2022.

[2] Y. Liu, K. Cai*, and Z. Li, "On scalable supervisory control of multi-agent discrete-event systems," *Automatica*, vol. 108, p. 108 460, 2019.

[3] Y. Liu, K. Cai*, and Z. Li, "On scalable supervisory control of multi-agent discrete-event systems," in *14th Workshop on Discrete-Event System*, 2018. (Awarded "Best Student Paper Award")

Problem/Drawback:

- Large-Scale DES (e.g. AGV fleets, multi-robot cells) face a **state explosion** challenge in supervisory control.
- Traditional Supervisory Control Theory ensures **safety/nonblocking** by synthesizing supervisors, but monolithic methods become *infeasible as system size grows*.

where **nonblocking** requires that the controlled system should always be able to reach a marked (goal) state from any reachable state (no livelock).

How to solve this problem?

Hierarchical Control: Design local supervisors for each specification and additional coordinators such that collectively they achieve the same behavior as an optimal monolithic supervisor.

Challenges in Hierarchical Control:

- Explosion of supervisors
- Infeasible coordination in one shot
- Hierarchical solution

Key issue: How to group supervisors effectively at each level. The grouping impacts coordinator size and synthesis complexity.

Poor grouping = large clusters \implies complex coordinators.

Markov Clustering Approach: Propose a **Markov Clustering (MCL)** based grouping algorithm to *automatically* cluster supervisors during the hierarchical synthesis process.

- **Fully automated & flexible:** No prior structural knowledge needed; grouping adapts to any DES.

Used Markov Clustering to group supervisors efficiently, with just one tunable parameter (β);

- **Maintains correctness:** The resulting multi-level supervisors + coordinators achieve global nonblocking.

Markov Clustering (MCL): A graph clustering algorithm that simulates random walks within a graph to find natural clusters. It uses iterative expansion and inflation operations on an adjacency matrix. The inflation parameter (β) controls the granularity: higher β favors smaller, tighter clusters; lower β yields larger clusters.

Supervisory control of discrete-event systems

Partially-observed DES: some events are unobservable due to the limited observation cost or observation capacity.

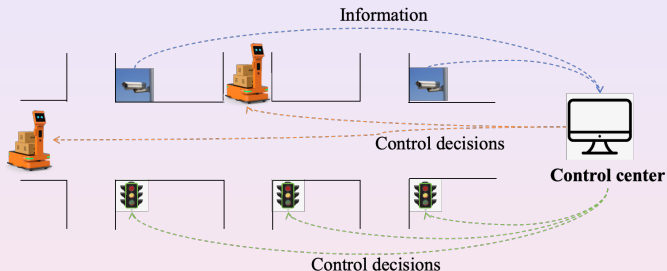


Figure 2: Logistic warehouse system

Remote control case: the sensor and the user of the information are physically **different** and located at a **remote distance**.

Supervisory control of discrete-event systems

Remote control case: the sensor and the user of the information are physically **different** and located at a **remote distance**.

Problem: How to synthesize an *information transmission policy* Ω to reduce the communication/transmission loads.

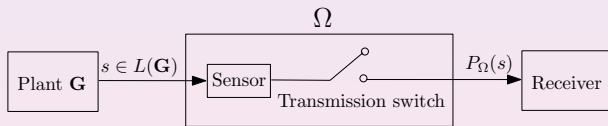


Figure 3: Architecture of transmission mechanism

New scheduling analysis techniques for **remote state estimation of discrete-event systems**, arising in optimal sensor scheduling problems, to reduce the communication/transmission loads.

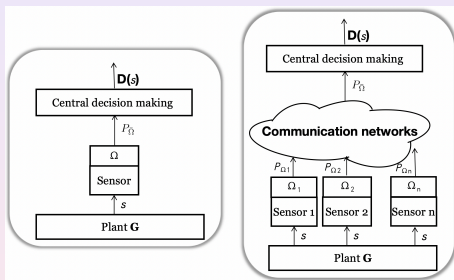


Figure 5: Centralized (left) and distributed (right) structures

[1] Y. Liu, Li, S., Hu, J., & Yin, X. (2025). Distributed Sensing and Information Transmission of Discrete-Event Systems With Edge Sensors. IEEE Transactions on Automatic Control.

Proposed a feedback- long-short term memory (FB-LSTM) model.

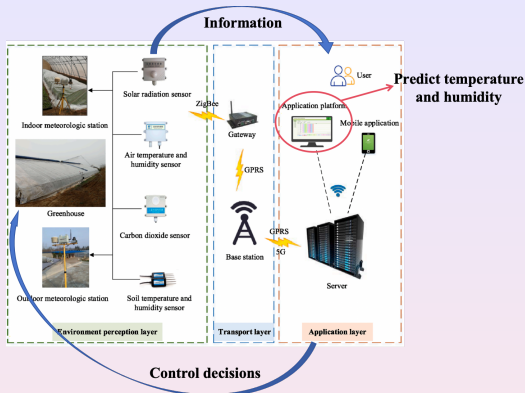


Figure 6: Greenhouse control system

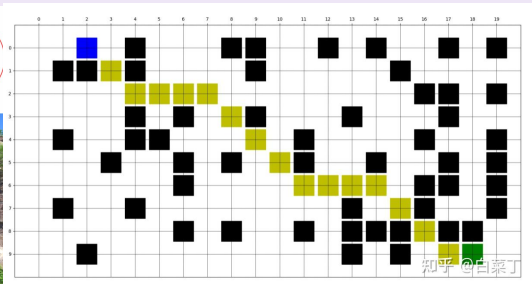
The experiments show that the FB-LSTM architecture achieves superior prediction performance by transmitting only **2.78%** of data in the best case, significantly reducing transmission burden.

[1] Y. Liu, Zhang, S., Li, X., & Hu, J. (2025). Multi-Variable Environmental Prediction for Chinese Solar Greenhouse

Motion and path planning of multi-agent systems with application in emergency rescue



(a) Emergency rescue



(b) Motion and path planning

Solutions: A leader-follower communication protocol for motion planning is proposed in partially known environments.

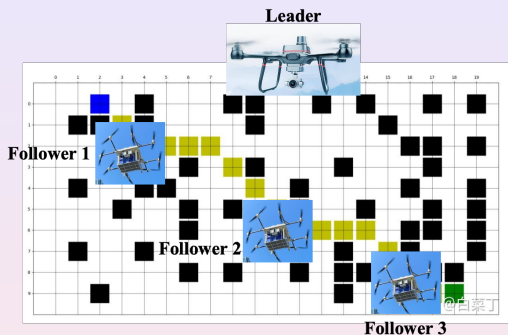
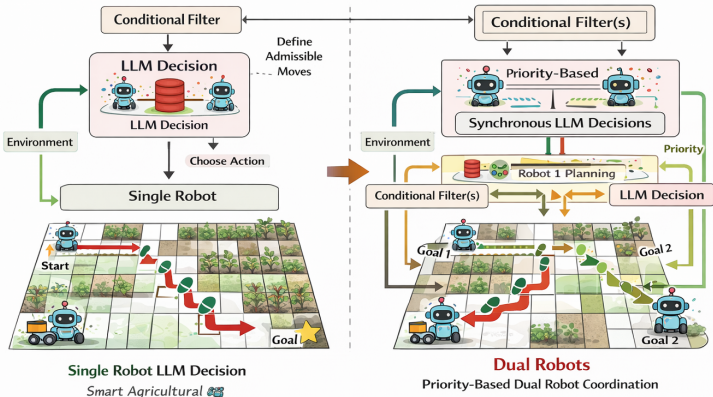


Figure 7: A leader-follower structure

[1] X. Yan, **Y. Liu***, R. Chen, and W. Duan, "A leader-follower communication protocol for motion planning in partially known environments under temporal logic specifications," *IET Control Theory & Applications*, vol. 18, no. 8, pp. 998-1006, 2024.

LLM-based path planning

Single vs. Dual Robot Supervisory Path Planning



Thank you for your attention!

Yingying Liu

Email: *i25263y@omu.ac.jp*