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PRISM Center
Production, Robotics, and Integration Software for Mfg. & Management

"Knowledge through information; Wisdom through collaboration"

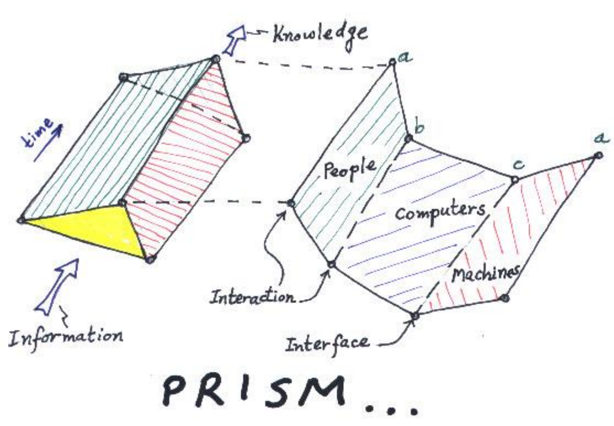
PRISM Global Research Network

PURDUE UNIVERSITY

PRISM Center of Purdue University has led research in automatic control of intelligent systems for more than 20 years. Our mission is the investigation, development, and experimentation of computer intelligence and information technologies for better quality and effectiveness of distributed and collaborative production and service systems.

We have served and contributed to more than 70 state, national and global organizations. The NSF-industry supported PRISM Center has investigated theories of computer intelligence and computer-supported collaboration; invented, innovated and delivered algorithms, protocols, software and system tools for interactive and collaborative e-Work networks.

Since 2001, PRISM Global Research Network (PGRN) was established to support the worldwide collaboration among more than 25 affiliated research centers and institutes in 20 countries.



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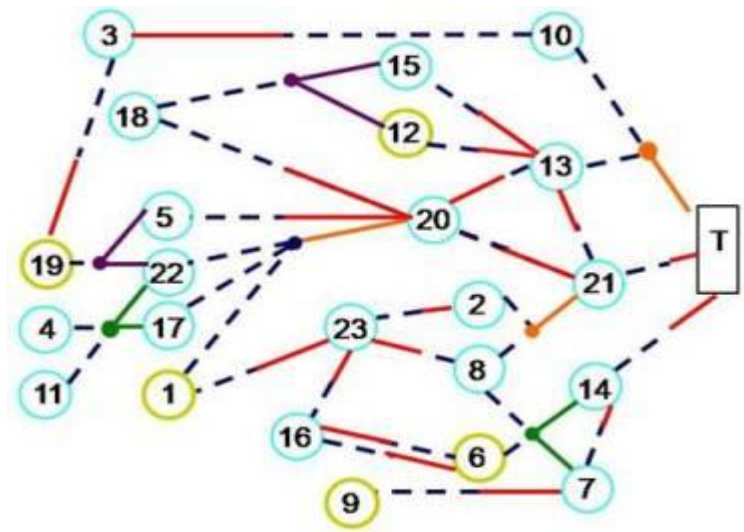
Conflict/Error Prevention and Detection over e-Work Networks



Conflicts and errors are unavoidable in complex e-Work networks such as smart grids and supply networks. Conflict/error prevention and detection (CEPD) become difficult due to the complexity phenomena in the networks. Algorithms for effective and automated CEPD are necessary to reduce the diagnosis time and the system damage; and to improve the detection coverage ability and the preventability of CEPD agents.

Methodology Highlights

- Complex constraint network is developed to define conflicts/errors and their relations.
- Topology-aware and agent-based algorithms for effective CEPD
- Integration of automatic CEPD and decision support systems for fault diagnostics.

Impact

- Ensuring greater availability and reliability of cyber-physical systems
- Efficient failure prevention, detection and recovery in power grids
- Dynamic conflict prevention in complex air transportation systems
- Effective decision support from automated agents to distributed human controllers.

Sample References

Chen, X.W. & Nof, S.Y. (2012). Conflict and error prevention and detection in complex networks, *Automatica*, 48(5), 770-778.

Landry, S.J., Chen, X.W., Nof. S.Y. (2013). A decision support methodology for dynamic taxiway and runway conflict prevention, *Decision Support Systems*, 55(1), 165-174.

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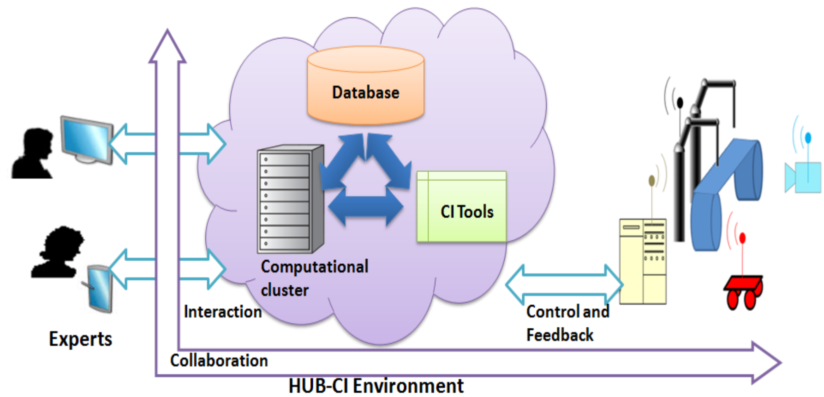
Collaborative Telerobotics

Distributed teams of experts require a system to support their collaborative work, in which cyber and physical interactions are both necessary. Telerobots, with supporting systems and tools, are developed to improve the collaboration effectiveness and efficiency.



Methodology Highlights

- Multi-dimensional collaboration supported by the *HUB-CI* cyber-infrastructure
- Collaborative insights management to improve consensus decision-making
- Conflict prevention and tolerance by smart command aggregation mechanisms
- Intuitive interaction (e.g., hand gesture) for human- robot collaboration.

Impact

- Real-time remote laboratory for education and research (e.g., massive online course)
- Middleware system for *Mass Customization* with intelligent manufacturing/3D printing
- Applicable to the *Co-Robot* paradigm (efficient & safe humans and robots tasks sharing)
- Remote coordination/maintenance of intelligent vehicles (e.g., drones, autonomous cars)
- Human-in-the-loop selective harvesting in agriculture and aquaculture applications.

Sample References

Zhong, H., Wachs, J.P., Nof S.Y. (2014). Telerobot-enabled HUB-CI model for collaborative lifecycle management of design and prototyping*, Computers in Industry*, 65(4), 550-562.

Zhong, H., Wachs, J.P., Nof, S.Y. (2013). A collaborative telerobotics network framework with hand gesture interface and conflict prevention, *Int. J. Production Res.*, 51(15), 4443-4463.

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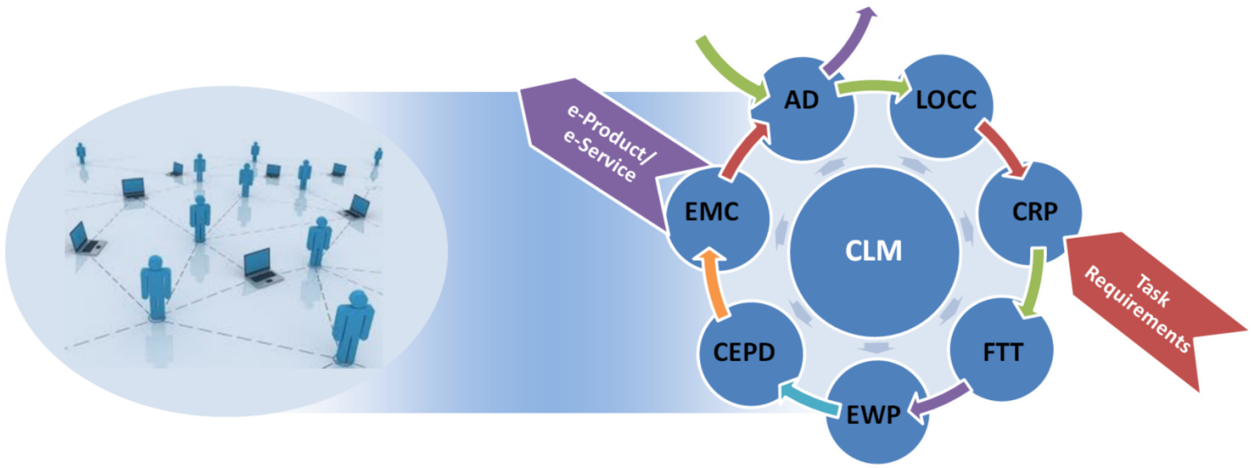
Collaboration Lifecycle Management (CLM)



CLM is a collection of tools and mechanisms to support the lifecycle of collaborative e-Work among human experts, systems, and/or organizations based on the collaborative control theory.

Methodology Highlights

- Association-Disassociation (AD): Optimization of team formation and reformation
- Lines of Collaboration and Command (LOCC): Efficient workflow management
- Collaboration Requirement Planning (CRP): Precise allocation of resources
- Fault Tolerance by Teaming (FTT): Fusion of the intelligence from individuals
- e-Work Parallelism (EWP): Supporting distributed task execution
- Conflict/Error Prevention and Detection (CEPD): Systematic resolution and prevention
- e-Measurement and e-Criteria (EMC): Automated evaluation protocols and systems.

Impact

- Timely deliver critical discoveries and accurate information through matched interfaces
- Collaborative design for assembly through improved knowledge sharing
- Simplify collaboration workflows in complex education and healthcare networks.

Sample References

1. Zhong, H. & Nof, S.Y. (2013) Collaborative design for assembly: the HUB-CI model. *22 Int. Conf. Production Research*, Iguassu Falls, Brazil.

2. Seok, H. & Nof, S.Y. (2011) The HUB-CI initiative for cultural, education and training, and healthcare networks, *21 Int. Conf. Production Research*, Stuttgart, Germany.

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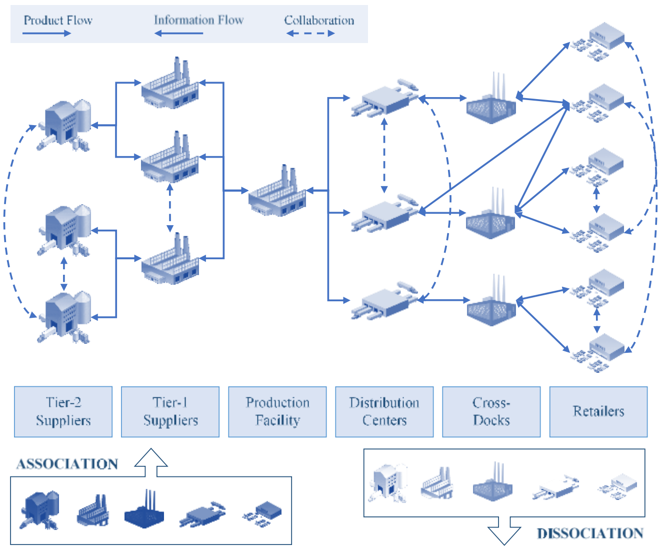
Collaborative Decision Support for Supply Networks

Globalized, competitive, dynamic, and complex business environments and behaviors are the main drivers for transformation of traditional, self-reliant and centralized enterprises to Collaborative Networks (CN) of Small-to-Medium Enterprises. It has brought about opportunities and challenges. The emerging requirements for reactive and proactive responses to the growing complexity and emergence of CNs necessitate higher levels of intelligence and autonomy of agents for smarter, more effective interactions, integration, and collaboration.



Methodology Highlights and Impact

PRISM Center at Purdue University is one of the pioneering research centers in the area of supply network collaboration. The Collaborative Decision Support for Supply Networks (CDSN) initiative, based on the Systems of Systems concept, aims at the harmonization, integration, and augmentation of collaborative e-Activities in distributed supply networks. The specific objectives include:

- Better and timelier decisions by dynamic visibility and Just-In-Time philosophy of information
- Effective interaction and collaboration among individual/clustered enterprises enabling co-existing and co-operation of entities without central supervision
- Agile response to unanticipated internal/external disturbances, lowering long-term instability
- Fault tolerance at both macro (entire CN) and micro (individuals/clusters) levels, and timely diagnosis and prognosis of errors and conflicts
- Enhanced product traceability throughout the entire lifecycle
- Integrated, reconfigurable, scalable, and evolvable architectures capable of accommodating/ dismantling new/old subsystems (*e.g.*, plug-and-play systems); *i.e.*, emergent networks.

The design principles of Collaborative Control Theory (CCT) are applied to address the aforementioned challenges. Major supporting tools and principles include Coordination/Task Administration Protocols, Agent-Based Technology, and Service-Oriented Architectures to enhance the orchestration of services and enable high-level collaboration for better results.

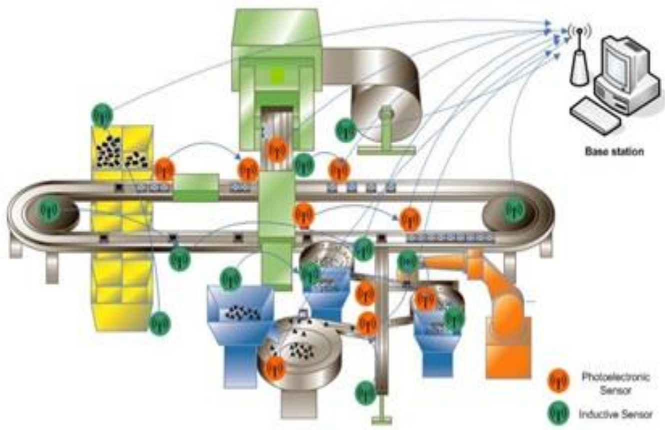
Sample Publications

[1] Ko, H.S., Nof, S.Y., 2012. Design and application of task administration protocols for collaborative production and service systems. *International Journal of Production Economics 135*, 177-189.

[2] Nof S.Y., Ceroni J., Jeong W., Moghaddam M., 2015. *Revolutionizing Collaboration through e-Work, e-Business, and e-Service*. Springer Series in ACES, Automation, Collaboration, & E-Service, Springer Publishers.

Facility Sensor Networks

Facility Sensor Networks (FSN) are reliable tools in unpredictable and noisy environments, with a variety of real-time control and automation applications. With the growing advances in micro-miniaturization and the emerging needs for decentralized, intelligent, automated, and collaborative control of cyber-physical facilities, emerging e-Criteria such as latency, fault tolerance, scalability, and connectivity have become the foremost issues in the design of wireless micro-/nano-sensors networks.



Methodology Highlights and Impact

The FSN initiative at the PRISM Center deals with the design and development of application-specific sensor network models and protocols for monitoring various Cyber-Physical Systems (CPS). The challenges being addressed by the FSN initiative include:

- Development of collaborative control, monitoring, and feedback mechanisms for CPS processes; Intelligent (re-)configuration of FSNs, identification and resolution of interference and noise
- Optimal and dynamic configuration of sensor clusters and deployment strategies
- Effective utilization of resources under heterogeneous sensor environment
- Collaboratively delivering/processing/integrating sensory data to meet quality/accuracy/service goals
- Accuracy and reliability of information flow with minimum influence of environmental noise and interferences, and energy consumption
- Automation of e-Manufacturing/e-Service process monitoring and control.

In line with the emergence of decentralized CPSs and the needs for effective interaction and collaboration, an emerging challenge is to enable communication and gather information on the real-time *states* of distributed agents. The Collaborative Control Theory (CCT) and its design principles provide the foundation for more reliable, fault tolerant, adaptive, and scalable FSNs.

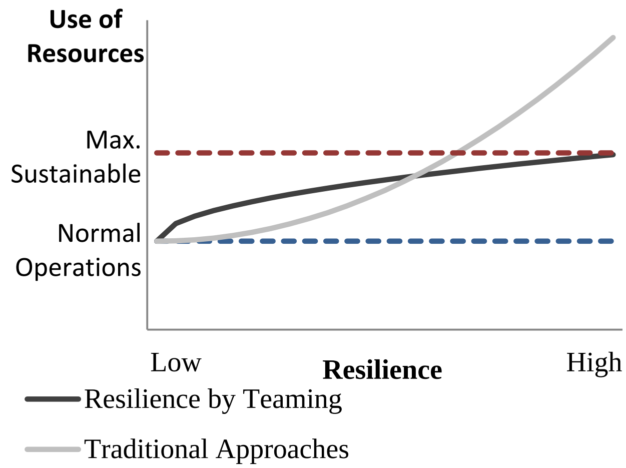
Sample Publications

[1] Ko, H.S., Lim, H., Jeong, W., Nof, S.Y., 2010. A statistical analysis of interference and effective deployment strategies for facility-specific wireless sensor networks. *Computers in Industry 61* (5), 472-479.

[2] Jeong, W.T., Ko, H.S., Lim, H.J., and Nof, S.Y., A protocol for processing interfered data in facility sensor networks, *International Journal of Advanced Manufacturing Technology*, 2013, 67(9-12), 2377-85.

Resilient Supply Networks

Supply networks (SNs) are collections of autonomous agents with self-interests that interact to enable physical, digital and service flow. Interactions constitute a form of e-Work, defined as *any collaborative, computer-supported and communication-enabled productive activities in highly distributed organizations of humans and/or robots or autonomous systems*. Over time, e-Work systems have become complex, and ineffective interactions among agents become harder to detect, anticipate, and avoid, causing disruptions affecting individual agents and sub-systems.



Current practices of SN resilience design threaten long-term sustainability since they rely on increased use of resources (flexibility by excess capacity). To address this problem, we develop new resilience mechanisms to form network-teams of "weaker"– thus, less costly – agents, able to fulfil required performance under normal conditions, while anticipating and responding smartly to any disruptions.

Methodological Highlights and Impact

Resilience by Teaming (RBT), based on Collaborative Control Theory, focuses on design of supply networks based on dynamic team re-formation protocols with intra- and inter-team collaboration protocols enabling to (1) achieve target performance during normal operations; (2) anticipate, prepare for, and overcome disruptions; (3) address unexpected, unforeseen events to avoid losses.

- RBT designs SNs of weaker agents able of achieving equal, and even higher, performance than those pursuing resilience through increased use of resources and more reliable, hence costlier agents.
- RBT applies to physical, digital, and service SNs, e.g., sensor networks; physical distribution and retail; utility and communication; services (financial and commercial applications).
- Centralized protocols with RBT have been successfully applied to industrial problems. Team-based resilience-enabling control outperforms traditional production line management protocols, increasing throughput while simultaneously reducing work-in-progress and throughput variability.
- Decentralized team formation/re-configuration flow protocols under RBT were applied to physical distribution networks, equaling performance of shortest time routing with significant cost reductions.
- RBT influences emergent SN topology by creating more interconnections among core agents, providing increased resilience to local disruptions and preventing these from spreading across the SN.

Sample References

[1] Reyes Levalle, R., & Nof, S. (2014). Resilience by Teaming in Supply Network Formation and Re-configuration. *International Journal of Production Economics,* In printing.

[2] Reyes Levalle, R., Scavarda, M., & Nof, S. Y. (2013). Collaborative production line control: Minimisation of throughput variability and WIP. *International Journal of Production Research*, 51(23-24), 7289–7307.