Resilience and Sustainability of Collaborative Enterprise Networks:

Recent Advances & Future Opportunities

Plenary Presentation

Shimon Y. Nof

PRISM Center, PGRN, & School of Industrial Engineering
Purdue University, W. Lafayette, Indiana, USA
nof@purdue.edu

PURDUE
UNIVERSITY

PRISM Lab/Purdue
Since 1991

PRISM
Global
Research
Network

Our purpose:

This conference theme is:

"Sustainable Operations and Digitalization in SMEs in a Post-Pandemic Era:

Challenges and Opportunities."

Under this theme we explore here:

- Recent advances and emerging opportunities for production researchers worldwide -- **Resilience & Sustainability of production**;

- How can cyber-collaborative production overcome disruptions and sustain our life?

Outline

1. Be Resilient and sustainable → overcome disruptions

2. Cyber-Collaborative Production (**CCP**) models to overcome disruptions

3. **C-AR**, Cyber-Collaborative augmented production in factories & supplies of the future

4. Summary and opportunities

...... Is it a dream for SMEs?

No! Look at your cellphone 😉

What is Cyber? What is Cyber-Collaborative?

➢ **Cyber:** → digital software & hardware

   1. Computing
   2. Communication (incl. Internet, IoT)
   3. Real Time Control
   4. Digital brain models (cybernetics, AI, learning, IoS)

➢ **Cyber-Collaborative** Production & Logistics:

   1. Cyber
   2. Physical items & systems
   3. Networked
   4. cc-Work & cc-Management

Brief overview from ICPR 26_Taiwan_2021

Challenges and Contributions to Intelligent and Transformative Production

Before, During, and Beyond Pandemic Times

URL: 26th ICPR Taiwan Aug. 2021_Plenary

PURDUE
UNIVERSITY

PRISM Lab/Purdue
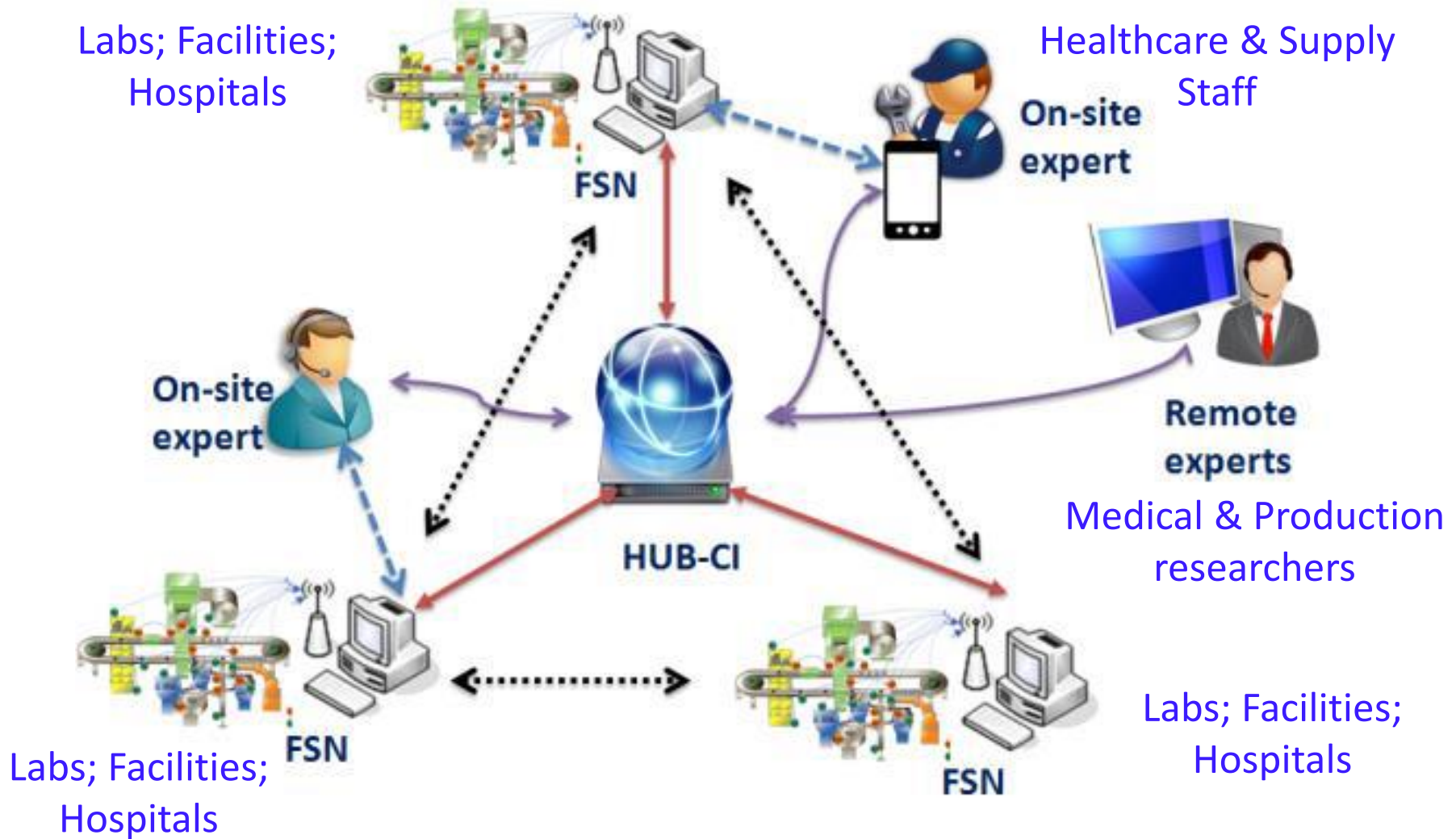Since 1991

PRISM
Global
Research
Network

Disruptions in
Production, Supply Chains/Supply Networks, e-Work, and Cyber Physical Systems

- **Disturbances** and **obstacles** that interrupt normal operations, activities, and processes.

- Example: A pandemic is a series of disruptions that **propagate**, and cause damages.

  ➢ *They continue now, post-pandemic*

1. Disruptive failures ➔ *Damaging*
2. Disruptive innovations ➔ *Opportunities*
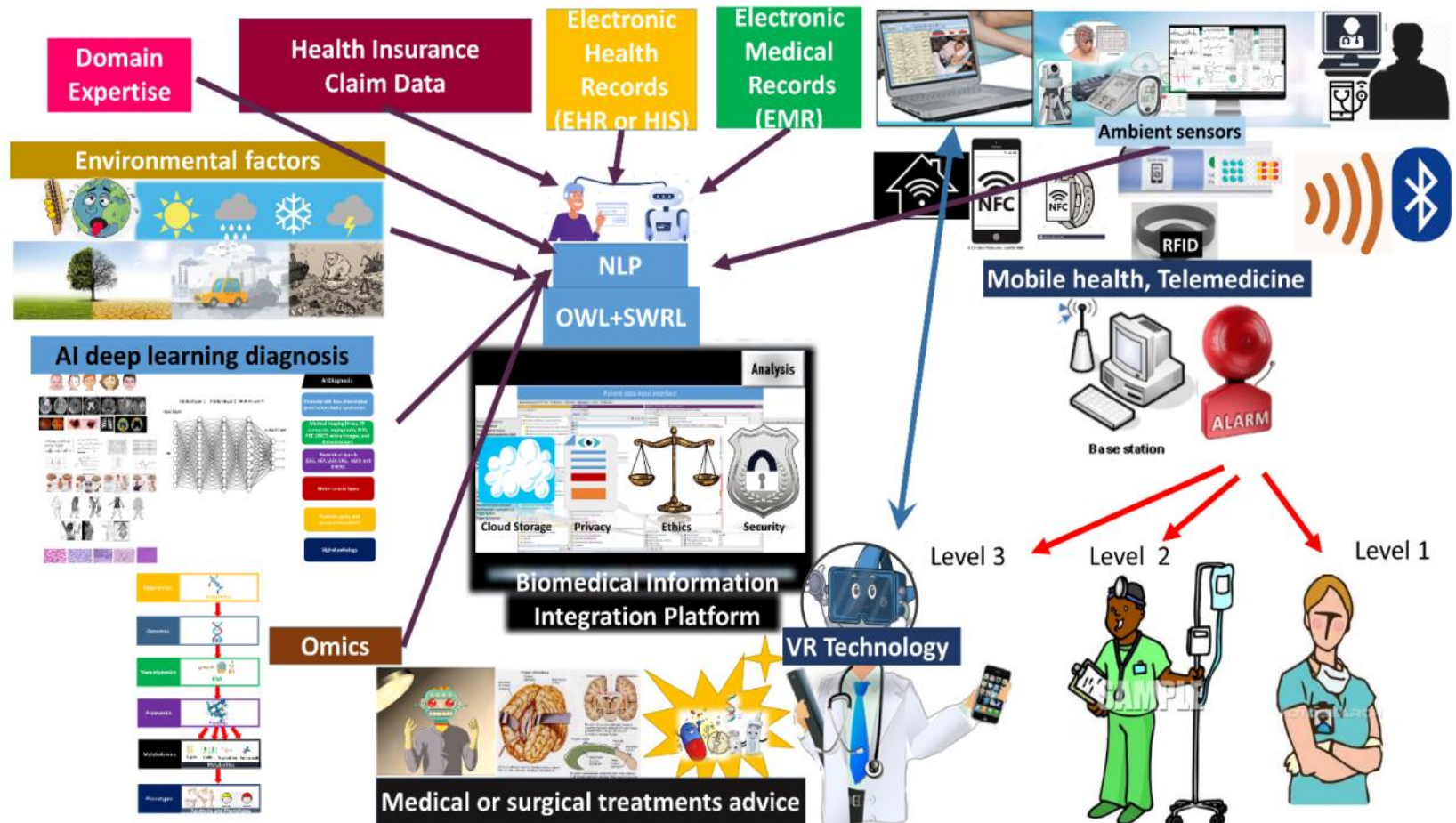
Lessons learned: Production researchers' roles

1. Understand disruptions' characteristics
2. Predict, diagnose, prevent, recover from disruptions
3. Prepare the workforce of the future

➢ Massive data to collect, analyze, learn from

➢ Share intelligence, knowledge, skills, tasks

➢ Use data science & O.R. to develop cyber collaborative logic + augmentation to do that

Resilience by Disruptions' Prediction, Prevention & Response

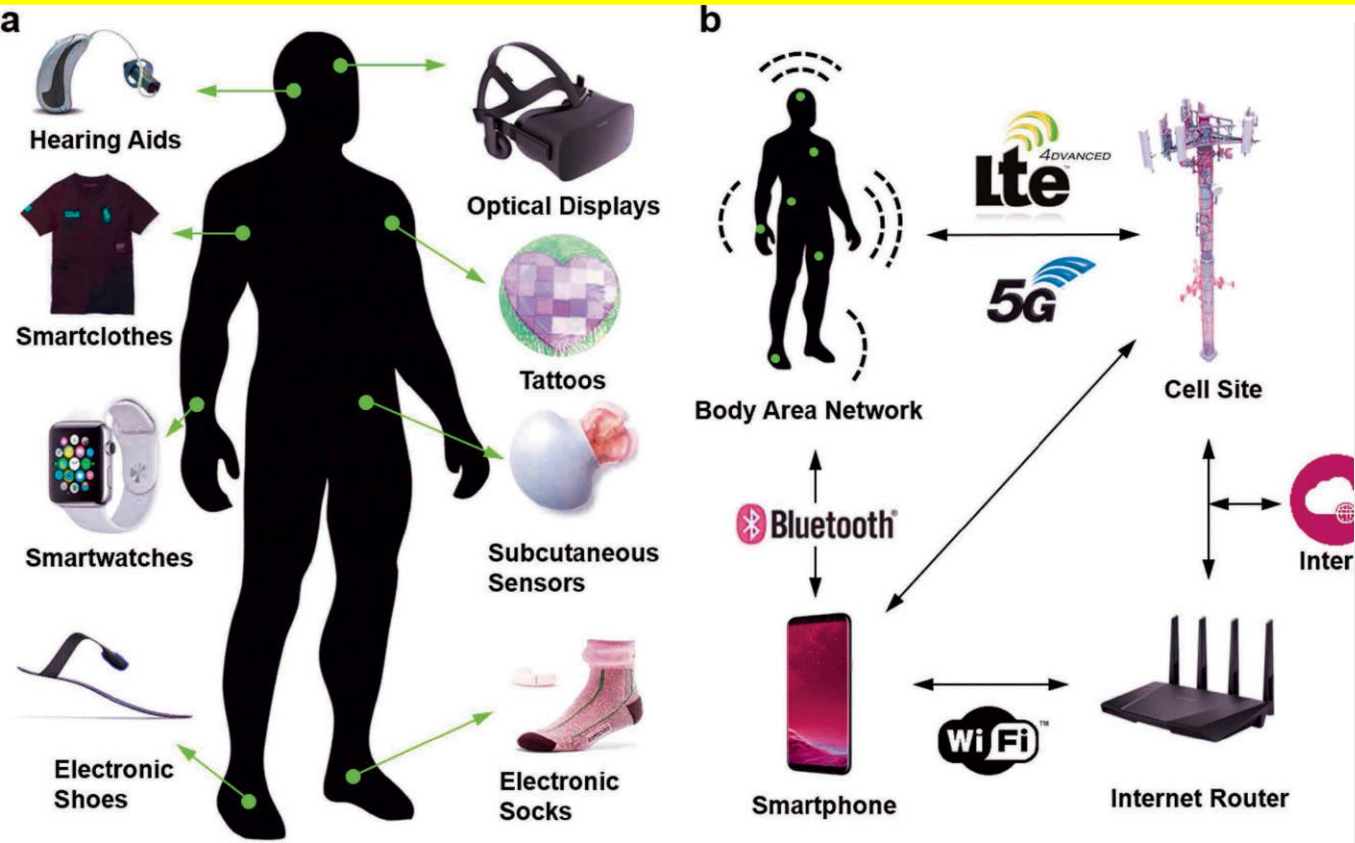Labs; Facilities; Hospitals

Healthcare & Supply Staff

On-site expert

FSN

On-site expert

Remote experts

HUB-CI

Medical & Production researchers

Labs; Facilities; Hospitals

FSN

Labs; Facilities; Hospitals

FSN

[1, 2]

Illustrated telemedicine and tele-critical care model for the future

[3]

a

- **Hearing Aids**
- **Optical Displays**
- **Smartclothes**
- **Tattoos**
- **Smartwatches**
- **Subcutaneous Sensors**
- **Electronic Shoes**
- **Electronic Socks**

b

- **Body Area Network**
- **Lte** 4DVANCED
- **5G**
- **Cell Site**
- **Bluetooth**
- **Inter**
- **Smartphone**
- **WiFi**
- **Internet Router**

c) **Monitor, diagnose, predict, deliver/Prevent**

- Smart bandages
- Smart stickers
- Wearable bio-electronics
- Implantable soft robotics to monitor and to deliver drug, therapy, nutrition

a) **Wearables collect data;**
b) **Data analyzed locally/sent to analysis**

[4, 5]
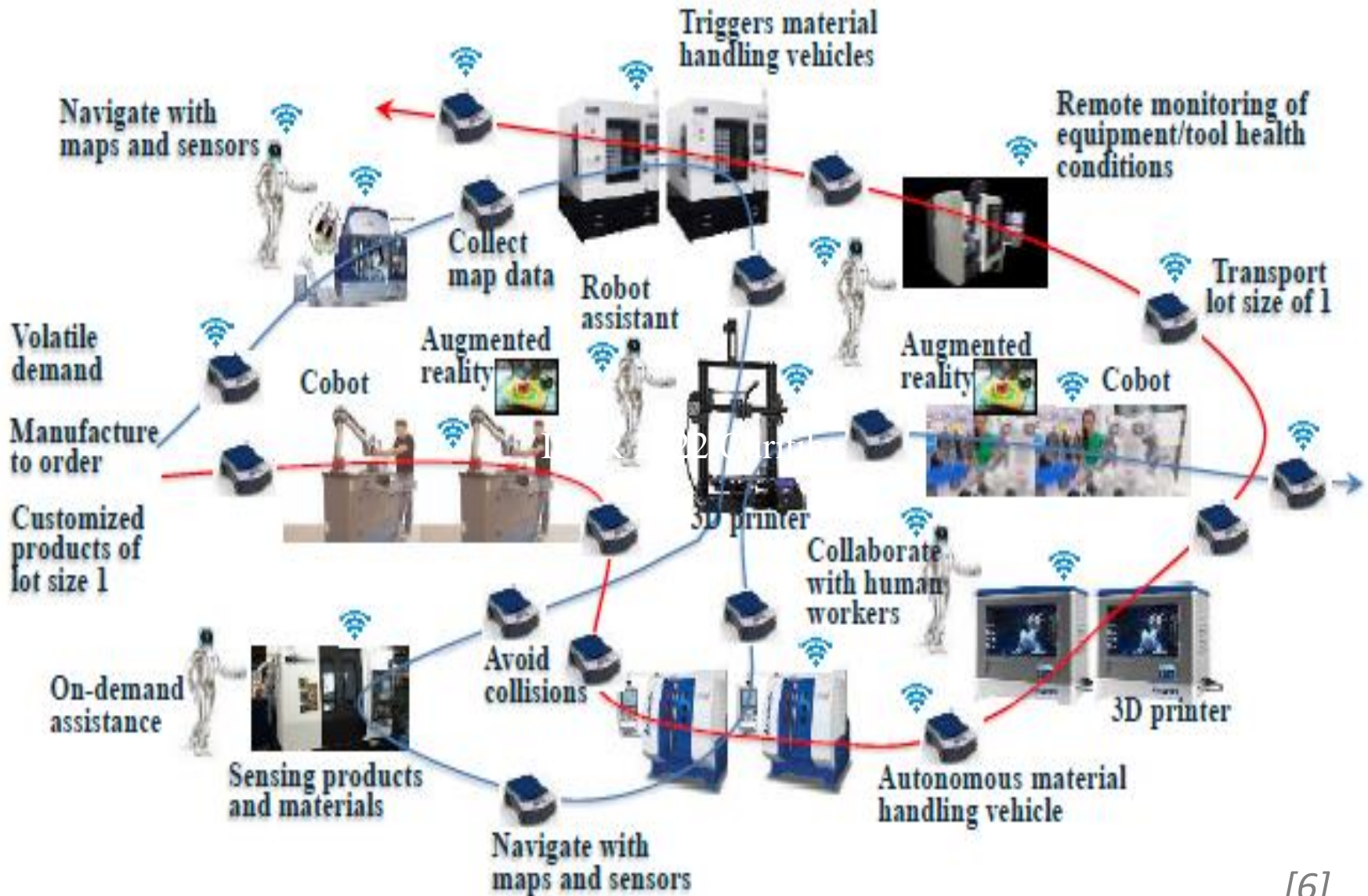
[6]

1. framework to understand;

2. network modeling;

3. model and develop cyber logic;

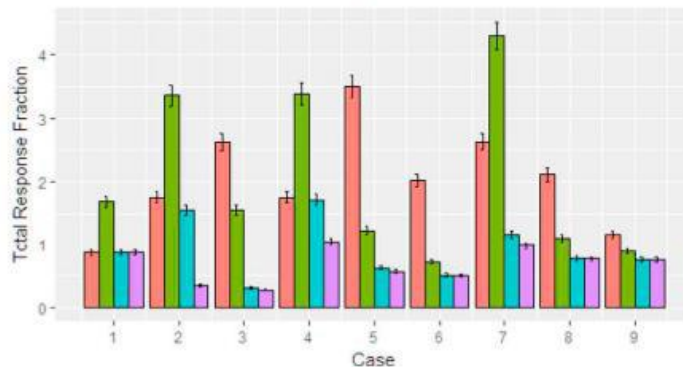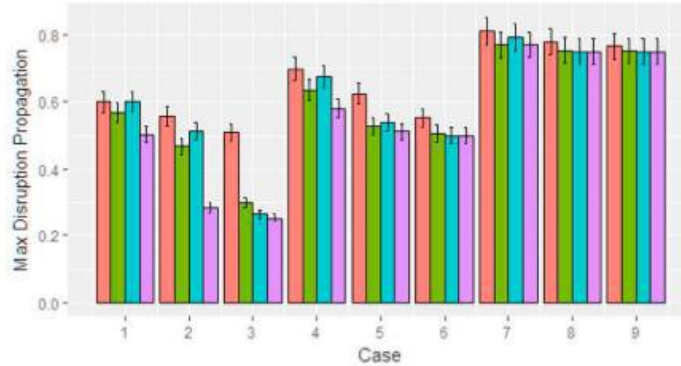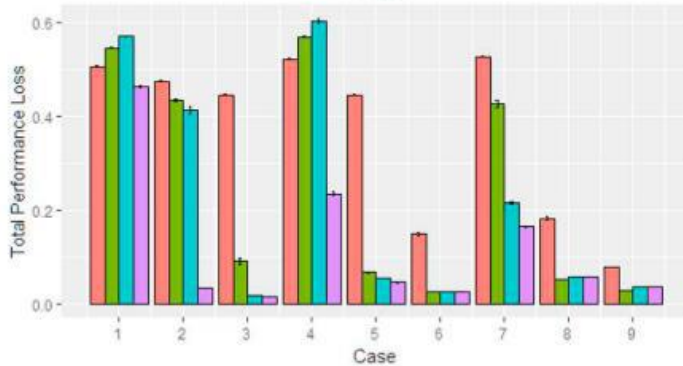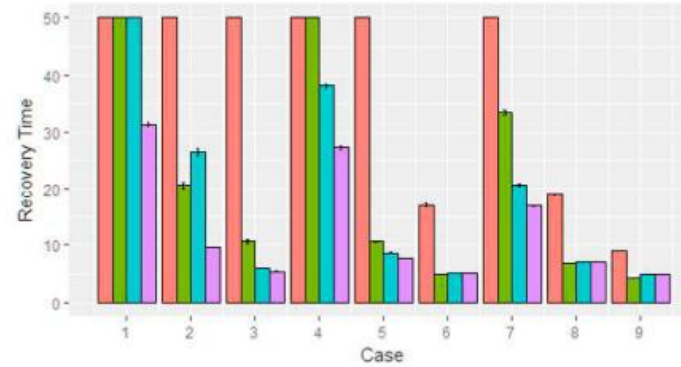4. applied for supply networks of power, goods, foods, water, information.
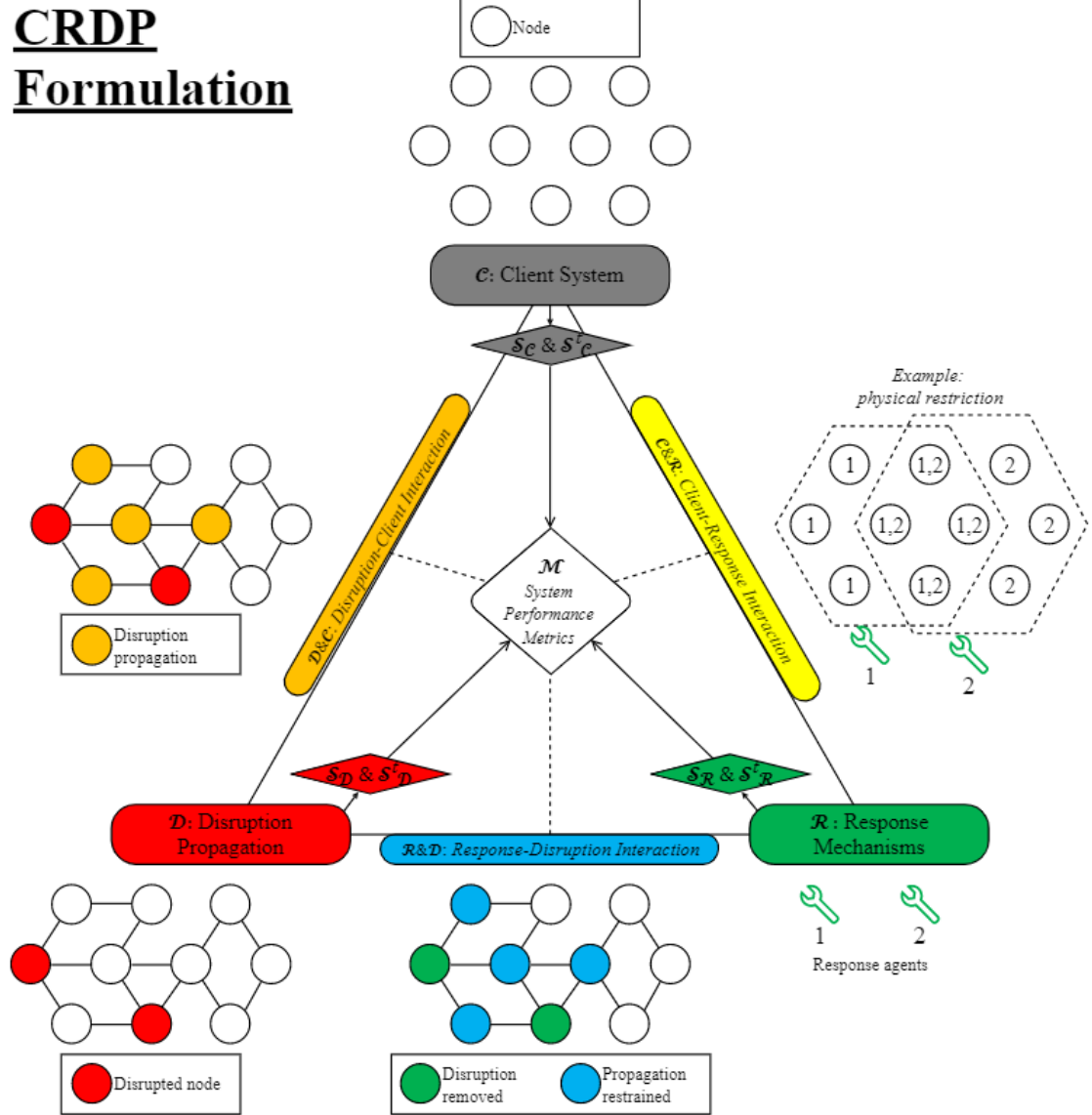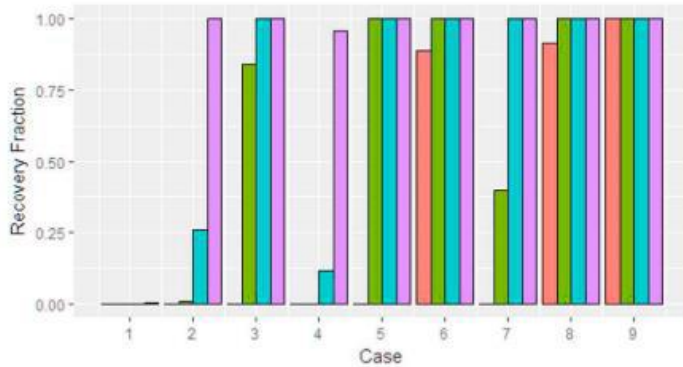
[7]

Example: Cyber vs. non-cyber protocols in the disruption propagation repair case of complex production systems

1. Disruptions are not known to operators ahead of time.

2. Strategic resources can be deployed to prevent / handle disruptions, with dynamic response capabilities.

3. Strategic resources can also cover multiple nearby nodes.

4. For better disruption prevention results, the best allocation combinations for prevention coverage were determined.

5. Network analyses tested the extent of damages in affected systems, after a certain amount of time.

6. Experiments indicate: Cyber protocols provide significantly better resilience.

*[7, 8, 9]*

Compare protocols in the examples analyzed

FCFS: First call first served
SPT: Shortest process time
MNDP: Minimizing neighbor disruption propagation
MATW: Minimizing additional task workload

Non cyber

Cyber

Protocol
0_FCFS
1_SPT
2_MNDP
3_MATW

Food supply chain security by agricultural robotic + cyber systems for early detection, diagnosis, and treatment

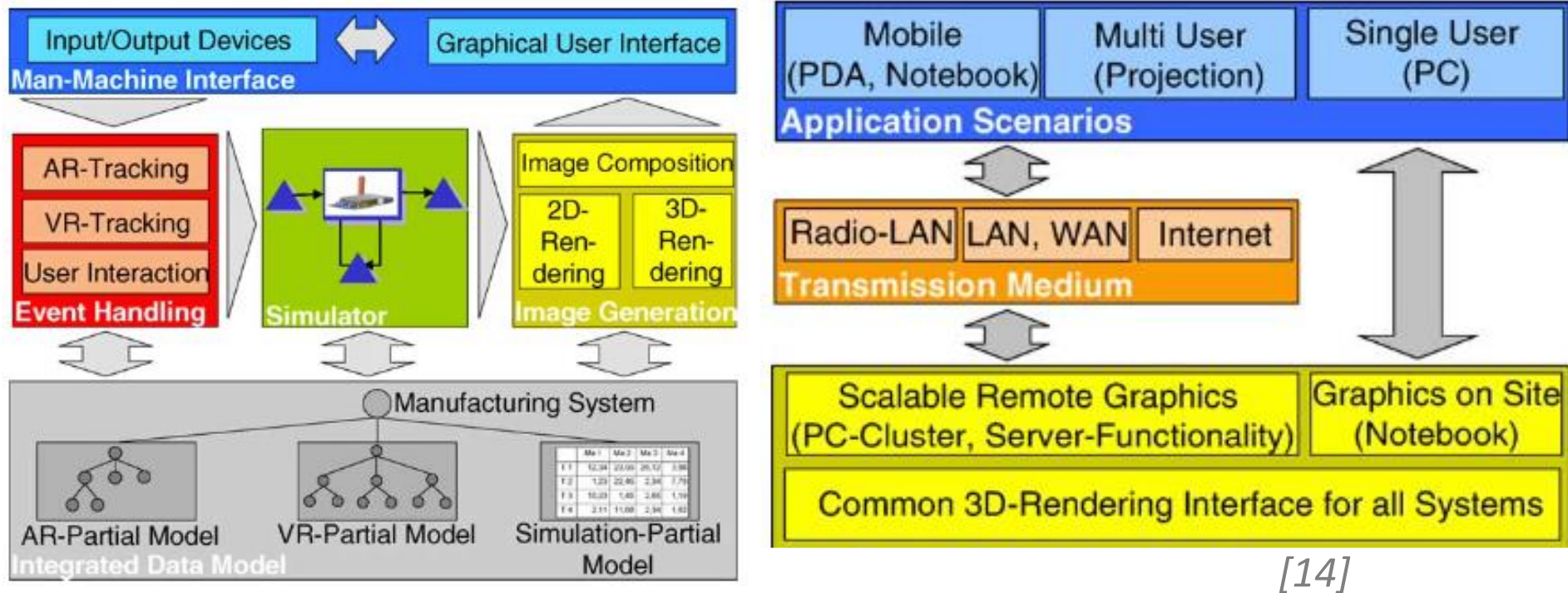Agriculture CPS network

[10, 11, 12]
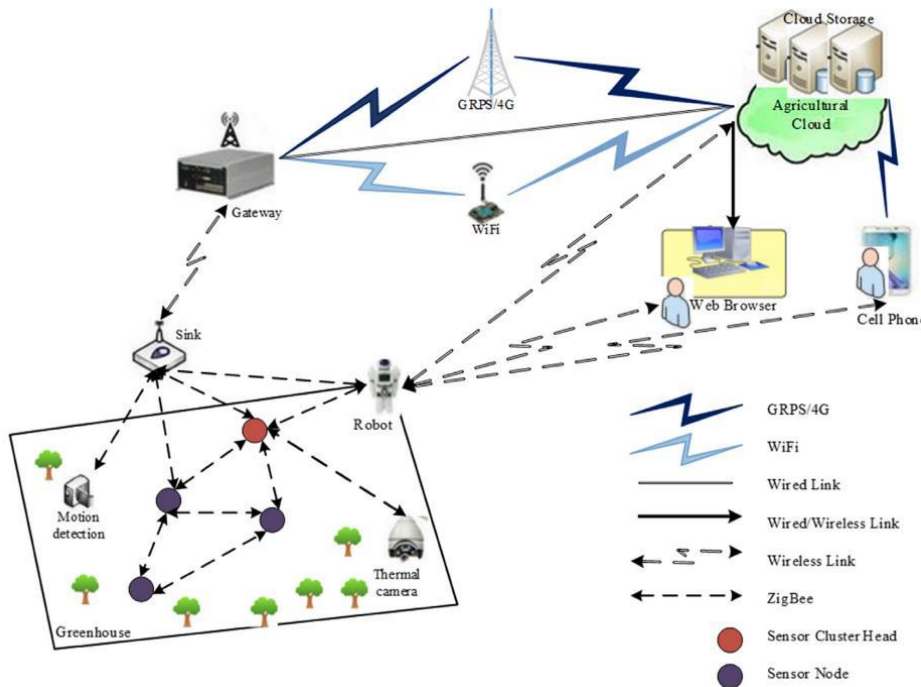
Agricultural Robotic System with HUB-CIs   *[13]*

Cyber collaborative Augmented Reality (C-AR) for CCP

1. Augment human-machine-team interfacing/sharing: knowledge, skills, and data *(L)*

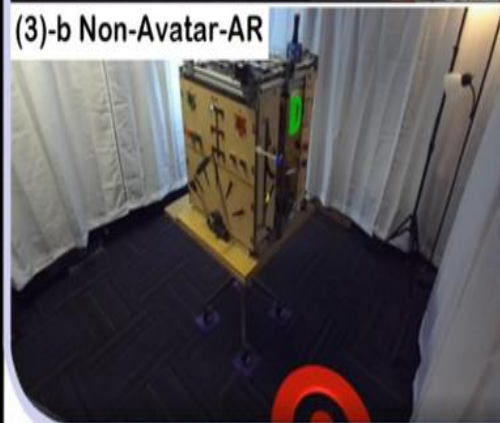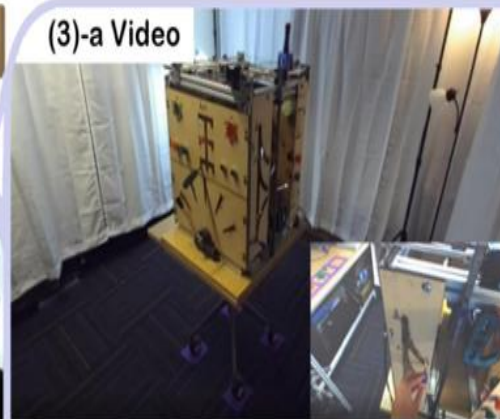2. Augment by simulating and distributing 2D / 3D / video results and instructions *(R)*

[14]

A. Real-time, dynamic simulations and predictive decision support
B. Optimal allocation and distribution of C-AR to individual (H/M/T)
C. Authoring/creating adaptive C-AR

Authoring and creating effective AR presentations

1. An expert demonstrate task performance *[15, 16, 17]*
2. AR system captures/adapts a digital embodiment of expert (= Avatar) to create AR Tutor
3. Learner-worker uses smart glasses to observe, understand, execute the task

(1) Expert demonstration
(2) Learner observation
(3)-a Video
(3)-b Non-Avatar-AR
(3)-c Half-body+AR
(3)-d Full-body+AR

Dimensions and features of the design space with existing AR authoring systems [18]
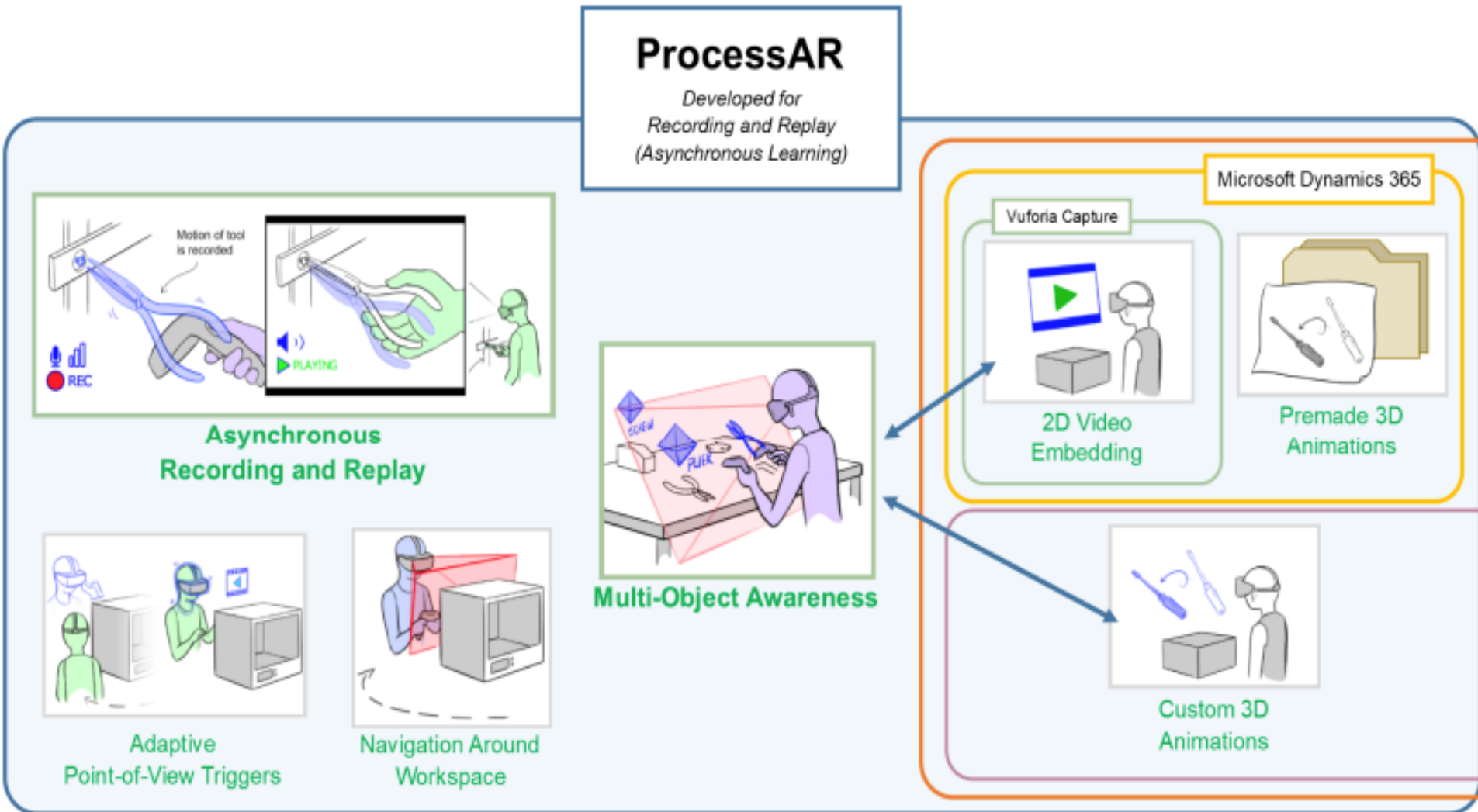
AR Capture System

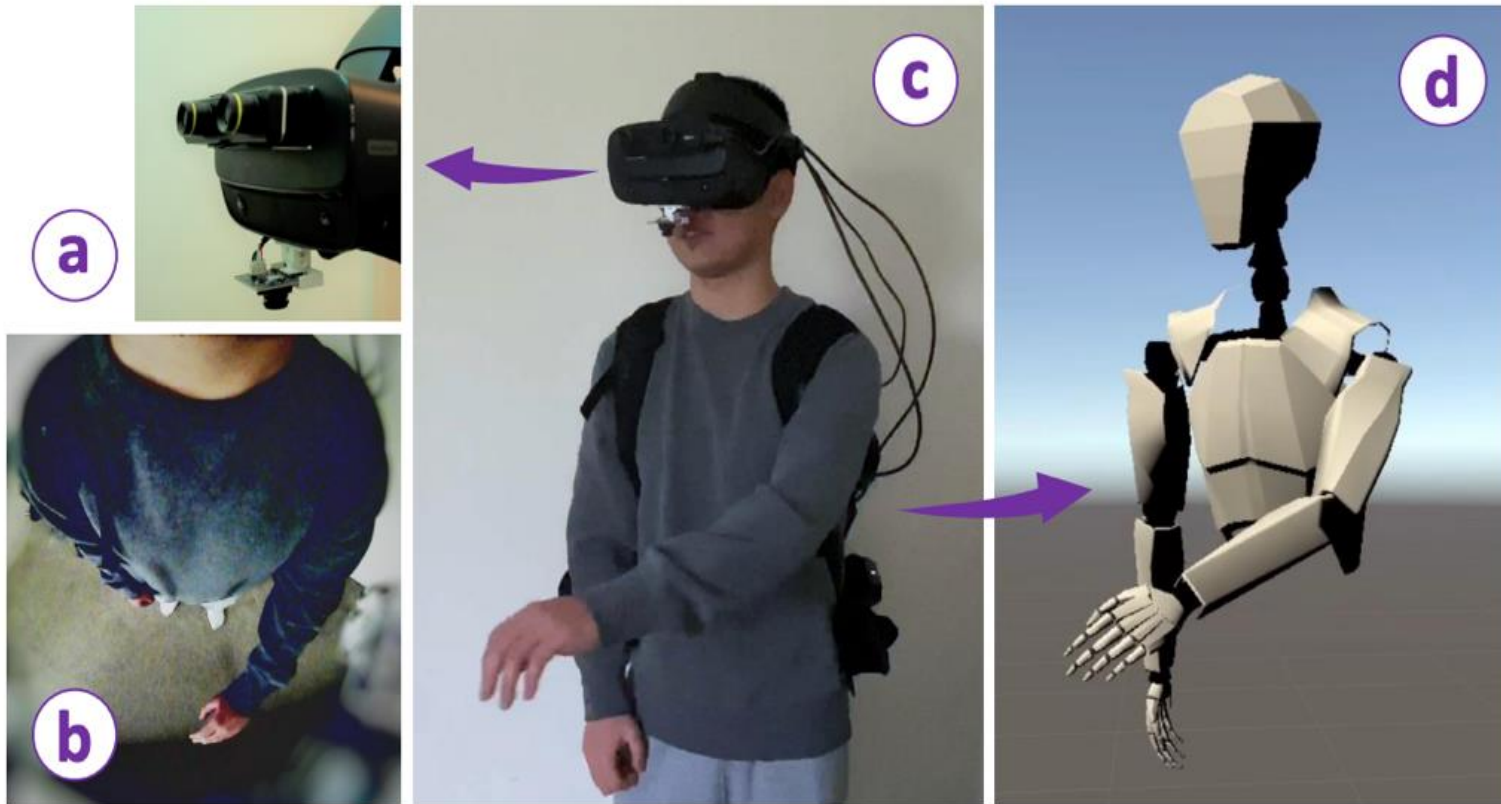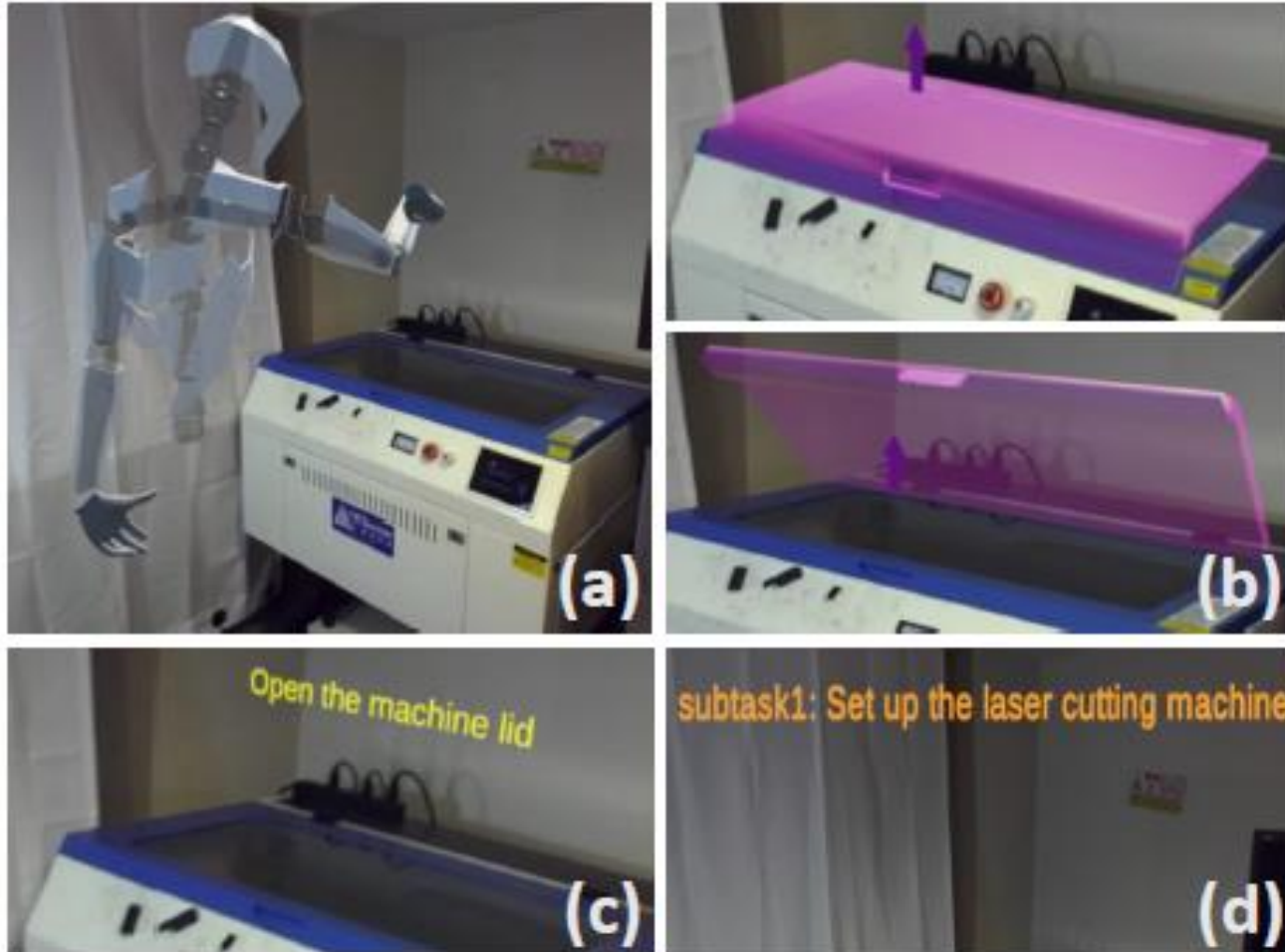a. Captures with stereo and fisheye cameras
b. Fisheye camera view
c. Backpack computer
d. → Creates upper body embodiment

Tutoring elements of AR e.g., AdapTutAR

AR tutoring elements to convey knowledge to worker: (a) Avatar; (b) animation and arrow; (c) step instruction; (d) sub-task description.

[17]

HUB-CIs architecture: Protocols & algorithms collect, learn, predict, prevent

Interaction ⟷
Data ⬸ - - -
Information ⟵

Worker

Augmented Reality

Virtual Assistant

Wearable Sensors

Collaborative Robot

HUB-CI

IoT Data

Software Systems

Direct Expert Instructions

Robot Management System

-> other workers   **-> other HUBs**   **-> other sources**
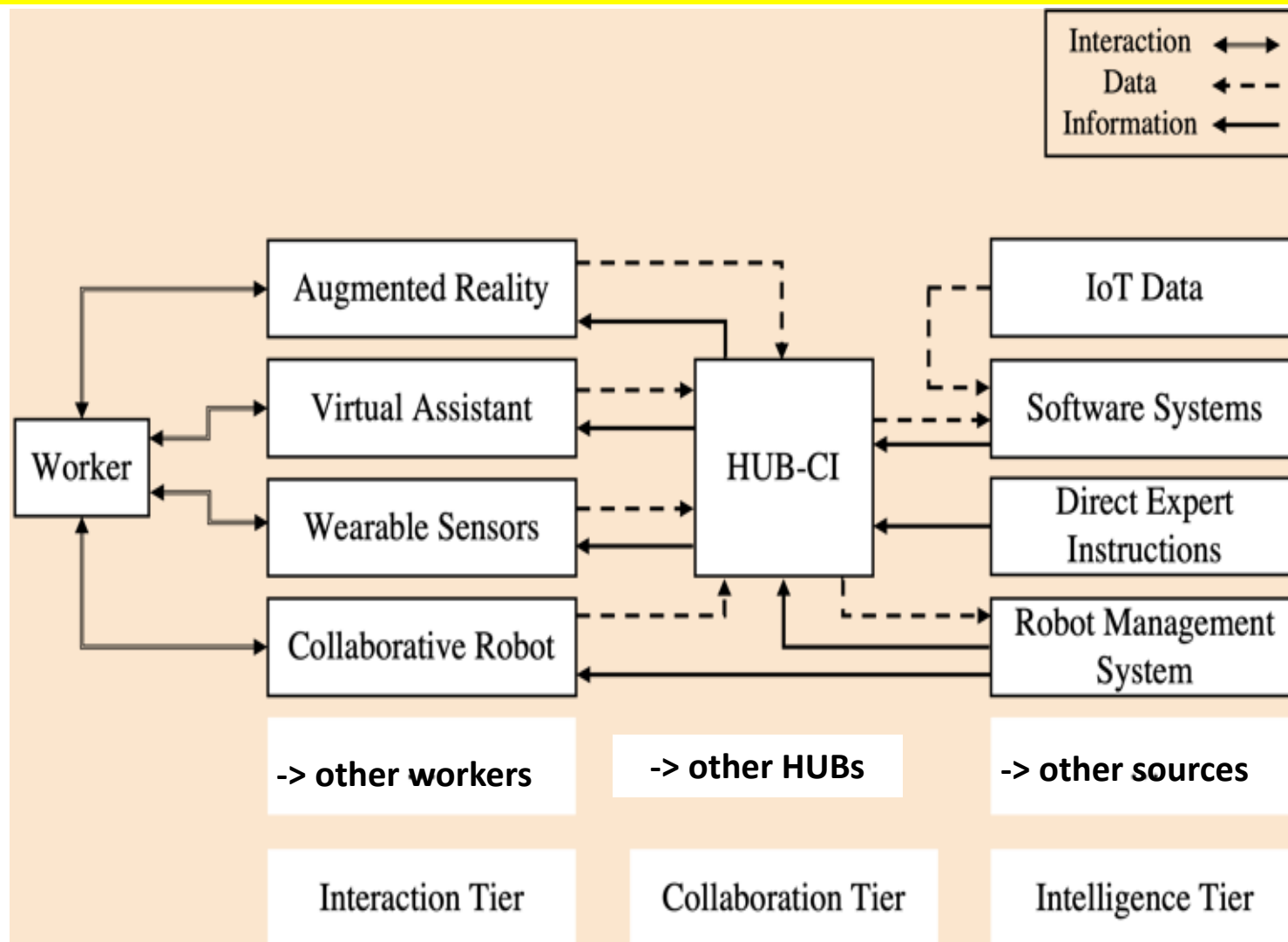
Interaction Tier   Collaboration Tier   Intelligence Tier   *[19]*

Summary

Five realizations on disruptions and opportunities:

1. We can never assume there is no disruption coming just around the corner. Or that it will take another 100 years to occur.

2. Our civilization knows how to survive when terrible events happen. (We hope.)

3. Disruptions can have negative impacts, and can have positive effects.

4. Being *prepared ahead of time* for uncertain yet eventual disasters is preferred.

5. Production researchers have been contributing.
   Let's   continue being prepared.

Acknowledgements

ICPR 2022 Curitiba
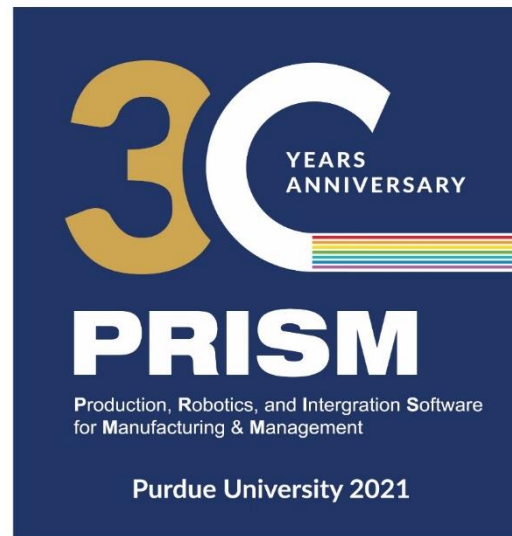
Digital & Cyber in Production Automation:
Augments abilities of workers, robots, and organizations

CYBER (Cybernetics) = Computing + Communication + Real-time control + Brain models for collaboration protocols

Increasing levels of computers, communication, mobility, and **computational intelligence** lead to higher levels of automation intelligence, and of resilience to internal and external disruptions.

Digital & Cyber Augmentation	
1.0	Computerized
2.0	Computer Integrated
3.0	Internetworked + Mobile
4.0	Cloud-Based + Machine Learning
5.0	Cyber-Physical + Cybernetics

[1] CCT, 2007: Nof, S.Y. Collaborative control theory for e-work, e-production, and e-service *Annual Reviews in Control*, 31(2), pp. 281-92.

[2] Zhong, H., Nof, S.Y., and Filip, F.G. 2014: Dynamic Lines of Collaboration in CPS Disruption Response. *Proc. 19th IFAC World Congress,* Cape Town, South Africa.

[3] Chiang, K.L., and Huang, C.Y. 2022: Precision medicine and telemedicine. In *Springer Handbook of Automation 2nd ed.*

[4] Munoz, et al. (2023) *Engineering Applications of Social Welfare Functions*, Springer ACES Series

[5] Martinez, R. (2022) Chapter in *Springer Handbook of Automation* 2nd Ed.

[6] Yetisen et al., (2018) Adv. Materials.

[7] Nguyen, W.P. V. (2020) Collaborative Response to Disruption Propagation (CRDP), PhD Dissertation, Purdue University School of Industrial Engineering, USA

[8] Nguyen, W.P. V., Nof, S.Y .(2019) Collaborative response to disruption propagation (CRDP) in cyber-physical systems and complex networks. Dec. Support Syst. 117, 1–13 (2019). https://doi.org/https://doi.org/10.1016/j.dss.2018.11.005

[9] Nguyen, W.P.V., Dusadeerungsikul, O.P., and Nof, S.Y. Collaborative Control, Task Administration, and Fault Tolerance for Supply Network, in Supply Network Dynamics and Control (A. Dolgui, D. Ivanov, and B. Sokolov, Eds.), Springer Series in Supply Chain Management, 2022.

[10] Guo, P., Dusadeerungsikul, P.O., Nof, S.Y. (2018) Agricultural cyber physical system collaboration for greenhouse stress management. Comp. Electron. Agric. 150, 439–454.

[11] Dusadeerungsikul, P.O., Nof, S.Y. (2019) A collaborative control protocol for agricultural robot routing with online adaptation. *Comp. Ind. Eng.* 135, 456–466.

[12] Dusadeerungsikul, P.O., Nof, S.Y. (2021) A cyber Collaborative Protocol for Real-Time Communication and Control in Human-Robot-Sensor Work. *Int. J. Comp. Commun. & Control,* 16,

[13] Bechar, A., Nof, S.Y. (2023) Chapter in *Systems Collaboration and Integration*, (Huang, C.Y., Yoon, S.W, eds.) Springer ACES Series

[14] Dangelmaier, W., Fischer, M., Gausemeier, J., Grafe, M., Matysczok, C., & Mueck, B. (2005). Virtual and augmented reality support for discrete manufacturing system simulation. *Computers in Industry*, 56(4), 371–383. https://doi.org/10.1016/j.compind.2005.01.007

[15] T. Wang et al.,(2020) CAPturAR: An augmented reality tool for authoring human-involved context-aware applications, *Proc. of 33rd Ann. ACM Symp. on User Interface Software and Technology*, 328–341. doi: 10.1145/3379337.3415815.

[16] Y. Cao, et al. (2020) An exploratory study of augmented reality presence for tutoring machine tasks, *Proc. of the 2020 CHI Conf. on Human Factors in Computing Systems*, 1–13.

[17] G. Huang et al., (2021) AdapTutAR: An adaptive tutoring system for machine tasks in augmented reality, *Proc. 2021 CHI Conf. on Human Factors in Computing Systems*, 1–15.

[18] Chidambaram, S., et al., (2021) ProcessAR: An augmented reality-based tool to create in-situ procedural 2D/3D AR instructions: 10.1145/3461778.3462126.

[19] Moghaddam, M., Nof, S.Y. (2022) Information flow optimization in augmented reality for production & manufacturing, *Proc. of ICPR_AR*, Curitiba 2022.

ICPR 2022 Curitiba