Foundations for Innovation in Cyber-Physical Systems

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CPS R&D Needs Assessment Workshop

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Cyber-Physical Systems: NIST Context

- Growing demands on NIST for standards associated with smart systems applications
  - Smart Buildings, Smart Grid and Infrastructure, Smart Manufacturing, Smart Health Care, Smart Transportation, …
- NIST has responded with programs in individual domain areas
- Significant crosscutting technology gaps and fundamental research challenges exist
- Potential impact on manufacturing: Innovative new classes of manufactured products, systems of products, and production systems

Many Federal Agencies Have a Common Stake in CPS R&D

- CPS are becoming increasingly important to mission success
- Increasing significance for innovation and economic growth
- Agencies with interests in CPS R&D include NSF, DOD, DOT, FDA, DOE, NASA, NSA, DHS, NIST…
- Federal NITRD (Networking and IT R&D) program plays a key role in interagency coordination of CPS R&D

NITRD National Coordination Office for Networking and Information Technology Research and Development

CPS Application Sectors and Benefits

Application Sectors:

- **Manufacturing** (includes smart production equipment, processes, automation, control, and networks; new product design)
- **Transportation** (includes intelligent vehicles and traffic control)
- **Infrastructure** (includes smart utility grids and smart buildings/structures)
- **Health Care** (includes body area networks and assistive systems)
- **Emergency Response** (includes detection and surveillance systems, communication networks, and emergency response equipment)
- **Warfighting** (includes soldier equipment systems, weapons systems and systems of systems, logistics systems)

Benefits:

- Improved **quality of life** and **economic security** through **innovative functions, production, products,** and/or **systems of products**

Cyber-Physical Systems

Sector	Innovative New Products	Cyber-Physical Systems	Primary Mission Area(s)	Primary Benefits of Innovative Solutions
Smart Production	Manufacturing equipment Robots and sensors Process/assembly plant	Equipment systems Automation systems Process/assembly systems	Commerce and Trade	Efficiency and agility, reliability, resilience
Transportation	Vehicles (surface/air/space) Traffic control equipment	Vehicle systems Traffic control systems	Transportation Aeronautics & Astronautics	Safety, efficiency, congestion reduction, capacity building
Infrastructure	Electric power equipment Water and wastewater equipment Oil and gas equipment	Electric power grid Water and wastewater grid Oil and gas distribution grid	Energy Infrastructure	Reliability, security, efficiency
Healthcare	Medical devices Personal care equipment	Body area networks Assistive healthcare systems	Healthcare	Improved outcomes and quality of life, cost reduction
Buildings and Structures	Building materials and equipment Building automation and controls Appliances	Building and structural systems Building automation systems Networked appliance systems	Energy Infrastructure	Efficiency, comfort and convenience, occupant health
Warfighting	Soldier equipment Weapons and weapons platforms Supply equipment	Soldier equipment systems Weapon systems and systems-of-systems Logistics systems	National Security	Warfighter effectiveness, security, efficiency and agility
Emergency Response	Emergency response equipment Communications equipment Fire fighting equipment	Detection and surveillance systems Communications networks Emergency response equipment systems	Homeland Security	Emergency responder effectiveness, safety, efficiency and agility

- **R&D Goal: Strengthen U.S. economic and national security, enhance U.S. competitiveness, and improve quality of life for Americans by positioning the U.S. as a global leader in cyber-physical systems**
- **R&D Objective: Enable new capabilities and address cross-cutting R&D challenges (e.g., safety and security, reliability and resilience, agility and stability, autonomy, efficiency and sustainability) for cyber-physical systems by conducting fundamental research, developing self-consistent solutions, and facilitating open standards platforms through strong interagency and public-private partnerships**
- **U.S. Economic Impact: Increased U.S. exports, reshoring/onshoring of manufacturing within the U.S., development of innovative new categories of products and associated services, creation/retention of U.S. jobs**

CPS Platform Technology Gaps and R&D Grand Challenges

- **Platform Technology Gaps** (Systems-Engineering Based Architectures and Standards)
  - Modularity and composability
  - Deep-physics and digital world model integration
  - Control, communications, and interoperability (adaptive and predictive; time synchronization)
  - Cyber-security
  - Scalability, complexity management, and resilience (integration with legacy systems)
  - Wireless sensing and actuation
  - Validation and verification; assurance and certification (software, controls, system)
- **R&D Grand Challenges**
  - Co-designing hybrid networked systems with integrated cyber, engineered, and human elements
  - Synthesizing and evolving complex, dynamic systems with predictable behavior (diagnostics, prognostics); anticipating emergent behaviors arising from interactions
  - Multi-scale, multi-physics modeling across discrete and continuous domains
  - Incorporating uncertainty and risk into reasoning and decision-making
  - Modeling and defining levels of autonomy and optimizing role of the human
  - Enabling education and workforce development; technology transfer

Definition of Cyber-Physical Systems

Function:

Cyber physical systems are hybrid networked cyber and engineered physical elements co-designed to create adaptive and predictive systems for enhanced performance*

Essential Characteristics:

- Co-design treats cyber, engineered, and human elements as integral components of a functional whole system to create synergy and enable desired, emergent properties
- Integration of deep physics-based and digital world models provides learning and predictive capabilities for decision support (e.g., diagnostics, prognostics) and autonomous function
- Systems engineering-based architectures and standards provide for modularity and composability for customization, systems of products, and complex or dynamic applications
- Reciprocal feedback loops between computational elements and distributed sensing/ actuation and monitoring/control elements enables adaptive multi-objective performance
- Networked cyber components provide a basis for scalability, complexity management, and resilience

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*Performance metrics include safety and security, reliability, agility and stability, efficiency and sustainability, privacy

Foundations for Innovation in Cyber-Physical Systems Workshop

Charge: Identify **crosscutting R&D needs** that are limiting innovation and U.S. competitiveness in cyber-physical systems

Breakout Topic Areas:

- Reliable, safe, secure systems you can trust your life with
- Networked, cooperating, human-interactive systems
- Engineering across the digital-physical divide
- Architecture and platforms for cyber-physical systems
- Education, workforce training, and technology transition

Foundations for Innovation in Cyber-Physical Systems Workshop

Steering Committee:

Susan Ying (Co-chair), Boeing
Janos Sztipanovits (Co-chair), Vanderbilt University
Isaac Cohen, United Technologies Research Center
David Corman, Boeing
Lonny Stormo, Medtronic, Inc.
Jim Davis, UCLA and Smart Manufacturing Leadership Coalition
Himanshu Khurana, Honeywell Automation and Control Solutions
Pieter Mosterman, Mathworks
Venkatesh Prasad, Ford

Target Outcome: Workshop findings documented in a 20-40 page opportunities document, to be used to inform strategic planning efforts at NIST and other government agencies, and provide planning information customers and stakeholders

Workshop Agenda

	Tuesday, March 12, 2012
7:30 am	**Registration and Continental Breakfast**
8:30 am	**Welcome and Opening Remarks:** Shyam Sunder, Director, NIST Engineering Laboratory
8:45 am	**Plenary Presentations:** *Stage-setting presentations on the state-of-the-art, technology challenges, and advances in CPS*
12:00 pm	**Networking Lunch**
1:00 pm	**Concurrent Facilitated Breakout Sessions:** *Participants will explore visions for the future, measures of success, next generation ideas, technology/measurement and non-technical challenges impeding CPS, priorities for action*
4:30 pm	**Breakout Group Reports**
5:00 pm	**Adjourn Day One**
5:00 pm	**Networking Reception**

Workshop Agenda

	Wednesday, March 13, 2012
7:30 am	**Registration and Continental Breakfast**
8:30 am	**Plenary Session**
10:15 am	**Concurrent Facilitated Breakout Sessions:** *Review priority challenges and develop action plans/approaches. Identify areas where collaboration can catalyze and accelerate progress*
12:30 pm	**Networking Lunch**
1:15 pm	**Breakout Group Reports**
2:15 pm	**General Comment Period:** *Synergies and Cross-cuts, Next Steps*
3:00 pm	**Adjourn Workshop**