EL Program: Smart Manufacturing Operations Planning and Control

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Strategic Goal: Smart Manufacturing, Construction, and Cyber-Physical Systems

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Summary: The Smart Manufacturing Operations Planning and Control Program will enhance U.S. innovation and industrial competitiveness by facilitating the adoption of smart manufacturing systems (fully-integrated, collaborative manufacturing systems that respond in real time to meet changing demands and conditions in the factory, in the supply network, and in customer needs). This program will enable smart manufacturing based on efficient networked sensing and control, prognostics and health management (including diagnostics and maintenance), integrated wireless platforms, industrial control security, efficient information exchange and interoperability of system components. Testbeds will be used to evaluate architectures, standards, and scale effects for reference implementations. The resulting manufacturing tools and resources will enable: increased efficiency of operations; manufacturing process development cycles at reduced risk, time and cost; and orders of magnitude expansion of manufacturers across increasingly diverse market segments. These efforts will directly address critical manufacturing needs as reported in 2011[1].

[1] The President's Council of Advisors on Science and Technology (PCAST) in its 2011 report stated that the Federal Government can promote advanced manufacturing in the U.S. by focusing on three broad areas of opportunity: advancing new technologies, supporting shared infrastructure, and dramatically rethinking the manufacturing process.

DESCRIPTION

Program and Strategic Goal: The Smart Manufacturing Operations Planning and Control Program supports the objectives of the Smart Manufacturing, Construction, and Cyber-Physical Systems Goal.

Objective: To develop and promulgate advances in measurement science that will result in the adoption of efficient smart manufacturing systems that increase the efficiency of networked sensing and control, prognostics and health management (including diagnostics and maintenance), integrated wireless platforms, industrial control security, efficient information exchange and interoperability of system components by FY 2018.

What is the problem? The success of smart manufacturing systems depends upon the ability to easily and rapidly reconfigure factory production and supply networks to optimize system performance. Such systems must deal effectively with uncertainty and abnormal events and learn from past experience to enable continuous improvement. These systems must enable seamless interoperability between small, medium, and large manufacturers. The complexity of the overall challenge is due to:

- Complex system, sub-system, and component interactions within smart manufacturing systems make it challenging to determine specific influences of each on process output metrics and data integrity.

- Lack of uniform processes that guide manufacturing operations management, integrated wireless technologies, prognostics and diagnostics, and cybersecurity at all levels (from component to system). Many existing solutions are currently proprietary and are seldom disseminated.

- Simultaneous operations of systems increase the intricacy of root cause analysis to foreshadow and resolve failures due to ill- and/or undefined information flow relationships.

Other specific problems exist within many existing manufacturing environments. Detailed automated prognostics and diagnostics are conducted at the lowest levels whereas higher-level prognostics and diagnostics are reliant upon detailed undocumented, ad-hoc human intervention and/or broadly-defined automated means. Methods, protocols, and tools are lacking for easily integrating and assuring operational efficiency of networked machine tools and robots, resulting in high costs and long lead times in responding to dynamic production requirements. The machine tools, robots, tooling, and equipment needed for smart manufacturing systems are complex. Modeling the information needed to easily integrate this equipment and measure its performance requires experts in many manufacturing areas, each with their own approaches.

In addition, common security technologies, such as encryption and device authentication have not been widely applied in smart manufacturing systems. Manufacturers are hesitant to adopt these advanced security measures due to potential negative performance impacts. This is exacerbated by a threat environment that has changed dramatically with the appearance of advanced persistent attacks (e.g. Stuxnet) that specifically target industrial systems.

Non-proprietary technology is lacking that enables smart manufacturing systems to communicate, interact, exchange information, make decisions, detect and respond to faults, and perform in a collaborative and reliable manner. Specific needs include standard data models, communication protocols, interface standards, and security procedures. Overcoming these barriers would enable widespread adoption of smart manufacturing systems and increase America's opportunity to obtain a greater manufacturing market share in the global environment. To ensure that this non-proprietary technology is sound and to speed its development, participation by NIST in developing the technology is needed, and testing tools and performance metrics developed by NIST are needed.

Why is it hard to solve? Manufacturing environments are inherently complex systems of systems attempting to interact together as efficiently as possible. Factories feature a combination of robotics, automation technology, machine tools, and humans working together to create a product. The increased demands for agility, asset utilization, and sustainability challenge this environment's ability to operate efficiently. The constant evolution of consumer demands is forcing manufacturers to do more with less; reconfigure and/or repurpose existing equipment and personnel to produce the most desired products. Likewise, government organizations are applying greater pressure and incentives to manufacturers to decrease the environmental footprint of both their products and their manufacturing processes.

How is it solved today, and by whom? The measurement science problems critical to the development, evolution, and implementation of smart manufacturing systems have yet to be solved. Efforts to address these problems include company-specific, adhoc solutions and proprietary solutions. Often, these solutions cannot or may not be adopted by other companies and are cost prohibitive for small to medium organizations. In some domains (i.e. industrial control security), new technologies have been developed, yet companies hesitate to adopt them for fear of potential negative performance impacts.

Why NIST? NIST is uniquely positioned to be the linchpin for collaborative partnerships between academia, industry, or non-profit groups due to our commitment to manufacturing standards, research focus, excellent reputation, successful standards development and implementation. Collectively, NIST personnel have experience in manufacturing operations management, wireless sensor networks, integrated robot technologies, performance characterization, cybersecurity technologies, information exchange, modeling and simulation, verification, and validation. The multi-disciplinary project teams will leverage numerous NIST resources including machine shops, a robot test laboratory, and virtual manufacturing testbed to ensure the successful execution of this program. NIST has an extensive history of being an unbiased, independent arbiter enabling them to be the ideal organization to ensure technology transfer to U.S. industry partners.

What is the new technical idea? The new idea is to address the measurement science needs in smart manufacturing that will:

a) Develop open metrics and methods for real-time, hierarchical, sensor-based manufacturing control that address performance assessment, protocol compliance, and model validation;

b) Develop standard measurement methods and security guidelines that assure manufacturers' wireless platforms achieve desired performance requirements and efficiency;
c) Extend the digital thread of product and process information from design to realization to maintenance;
d) Model and characterize the complexity of manufacturing process elements and operations performance to enhance prognostics and health management of smart manufacturing systems;
e) Develop guidelines, methods, metrics and tools to enable manufacturing stakeholders to assess and assure cybersecurity while addressing the demanding performance, reliability, and safety requirements of smart manufacturing systems.
f) Develop methodology and protocols to enable smart manufacturing systems engineers to efficiently exchange information with domain-specific engineers.

Why can we succeed now? Success is likely because of a combination of factors. There is a renewed national effort to increase the U.S.'s manufacturing capability. Government lawmakers and many manufacturing organizations, from small to large, recognize that future economic prosperity is contingent upon the country's ability to increase its exports while reducing imports and bringing back manufacturing jobs to the U.S. This mindset presents an environment that is highly supportive of EL's mission to advance manufacturing. Success is also likely because EL staff have the needed expertise and established relationships with key industry stakeholders and relevant professional societies and standards development organizations that will use the results. Lastly, there is already a track record of success from earlier work that has had demonstrable worldwide impact.

What is the research plan? The research plan consists of a portfolio of interrelated projects that focus on key areas of measurement science needed to achieve successful development and implementation of smart manufacturing systems. Collectively they provide a comprehensive approach that will lead to new industry standards and practices, which will result in efficient dynamic production systems. These projects all will be initiated with an assessment effort where industrial requirements for the project are elicited and analyzed. These requirements will scope the projects and guide the development and standardization work in subsequent years.

The *Smart Manufacturing Operations Management* project will focus on enabling more efficient sensing and control processes at the Manufacturing Execution Systems (MES)[2] level of assembly-centric manufacturing. This focus will include 1) high level sensing information commonly called "performance metrics" or "key performance indicators" (KPI)[3] and 2) the real-time correlation of product sensing information to process parameters, both for in-process and off-line sensing. In project outyears, hierarchical and networked aspects of sensing and control will be addressed.

The *Wireless Platforms for Smart Manufacturing* project will establish requirements and performance metrics for secure wireless platforms in smart manufacturing systems. This will involve performing a gap analysis to identify shortcomings or misalignments between

[2] MES is the production portion of Level 3 (Manufacturing Operations Management) of IEC 62264 (ISA-95)
[3] The MESA and ISO TC184 SC5 organizations use this terminology (see ISO 22400).

available wireless technology and the smart manufacturing needs. Additionally user requirements for wireless networking as well as deployment scenarios will be determined. Appropriate performance metrics for use of wireless technology in such environments will also be developed. Security is an important requirement for use of wireless in manufacturing environments. Security solutions and performance metrics will be developed in the Cyber Security project in the Smart Manufacturing Operations Planning and Control program. Finally the project will develop best-practice guidelines for an integrated methodology and protocols that will enable, assess, and assure the real-time performance of secure wireless platforms in smart manufacturing systems.

The *Digital Thread for Smart Manufacturing* project involves the effective communication of product designs to manufacturing engineering activities, the communication of manufacturing and assembly process considerations back to design engineers, and the use of the final component specifications for form and fit in the inspection systems and in-process measurement systems associated with product manufacture and assembly. This project is primarily concerned with the information content for the purpose of sharing in these various stages of the process rather than the mechanism for data transfer. It seeks to identify the information requirements, to formalize and promulgate descriptions of those requirements, and to support development and promulgation of standards for the interchange of that information. Use cases and activity models will be developed that will be used to derive the high-level information requirements. Likewise the state of the practice will be analyzed to determine what solutions exist, and work with industry to prioritize efforts to address gaps. This project will also include identification of information elements to support filling high priority gaps. Information elements will be formally modeled and codified in a way that is useful to the development of supporting tools. The analysis and dissemination of its results will provide the technical underpinning for new standards and tooling that enable more rapid development of manufacturing systems that reliably produce high-performance products.

The *Prognostics and Health Management for Smart Manufacturing Systems* project will identify the requirements for diagnostics and prognostics through the analysis of existing industry capabilities and best practices. Then, a hierarchical methodology will be developed to determine data sources for diagnostics and prognostics at the component, sub-system, and system levels within smart manufacturing systems. Once the methodology has been developed, protocols will be designed to facilitate communication of metrics across the component, sub-system, and system levels for diagnostics and prognostics. Standardization begins with the development of validated reference datasets, use cases, and test scenarios for implementation of protocols needed for diagnostics and prognostics. This will allow manufacturers, solution providers, and suppliers to benchmark and assess the robustness of their diagnostic and prognostic implementations. Conformity assessment tools will then be developed for the new protocols. These tools will enable industry to assure their implementations meet industry standards supporting real-time prognostics and diagnostics to enhance the efficiency of dynamic production systems.

The *Cybersecurity for Smart Manufacturing Systems* project will first host a security performance impacts workshop to determine the real-time measurements required to quantitatively determine the impact of cybersecurity on real-time performance, resource use, reliability and safety of smart manufacturing systems. Two research challenges will be addressed in this phase. The first challenge is the development of comprehensive requirements and use cases that represent practical, interoperable cybersecurity approaches for real world needs of complex dynamic production systems. The second challenge is the development of a suite of specific tests that measure the impact of cybersecurity technology when fulfilling these requirements. The project will develop a smart manufacturing system cybersecurity testbed to implement the test suite, and analyze the performance impact (e.g. latency, jitter) and operational impacts (e.g. efficiency, productivity) of the cybersecurity safeguards and countermeasures. NIST will then work with standards development organizations to develop new guidelines and standards to facilitate the implementation of cybersecurity requirements in dynamic production systems that do not negatively impact the performance of the system.

The *Smart Manufacturing Systems Interoperability* project will enable systems engineers to interact with discipline-specific engineers more effectively by extending overall systems modeling languages to support discipline-specific information. The project will identify common discipline-specific engineering methods and tools, compare their information content to systems engineering modeling languages to identify redundancies and commonalities, develop extensions to systems modeling languages for common discipline-specific information, and produce transformations between systems and discipline-specific information. The result will enable systems engineers to efficiently exchange information with discipline-specific engineers, producing more reliable and effective system specifications.

How will teamwork be ensured? The projects that make up the Smart Manufacturing Operations Planning and Control Program involve EL staff from multiple divisions, staff from ITL and PML, numerous outside partners through CRADAs and grants, and established relationships with professional society technical committees and standards committees. Each project has specific plans in place for coordination and information exchange needed to accomplish its goals. These plans include details for internal EL collaborations and also interactions with outside parties. Periodic meetings with project leaders will enable high-level coordination and information exchange between project teams.