NIST Smart Manufacturing Programs:

Driving Innovation and Reducing Risks of Adoption of New Technologies

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U.S. Department of Commerce

NIST and Manufacturing

"It is therefore the unanimous opinion of your committee that no more essential aid could be given to manufacturing […] than by the establishment of the [National Bureau of Standards]."

House Committee report, May 1900

NIST Mission: To promote U.S. innovation and industrial competitiveness by advancing **measurement science**, **standards**, and **technology** in ways that enhance economic security and improve our quality of life.

A partner to US manufacturers for more than a century, NIST helps the nation's manufacturers to invent, innovate, and create through:

- **Measurement science** – manufacturers and technology providers use NIST test methods, measurement tools, performance measures, and scientific data every day
- **Advanced materials** – NIST is building a materials infrastructure to accelerate the timeline from design to deployment of new materials
- **Standards development** – NIST provides the scientific and technical basis for voluntary consensus codes and standards
- **Partnerships** – collaborations with the private sector and academic organizations help advance and disseminate research and support US manufacturers

NIST Helps Drive Innovation and Reduce Risks of Adoption of Emerging/Disruptive Manufacturing Technologies

…by contributing to **standards** that provide a **common language** and **test methods** that technology suppliers and users can use to assess and communicate **technical capabilities and performance**.

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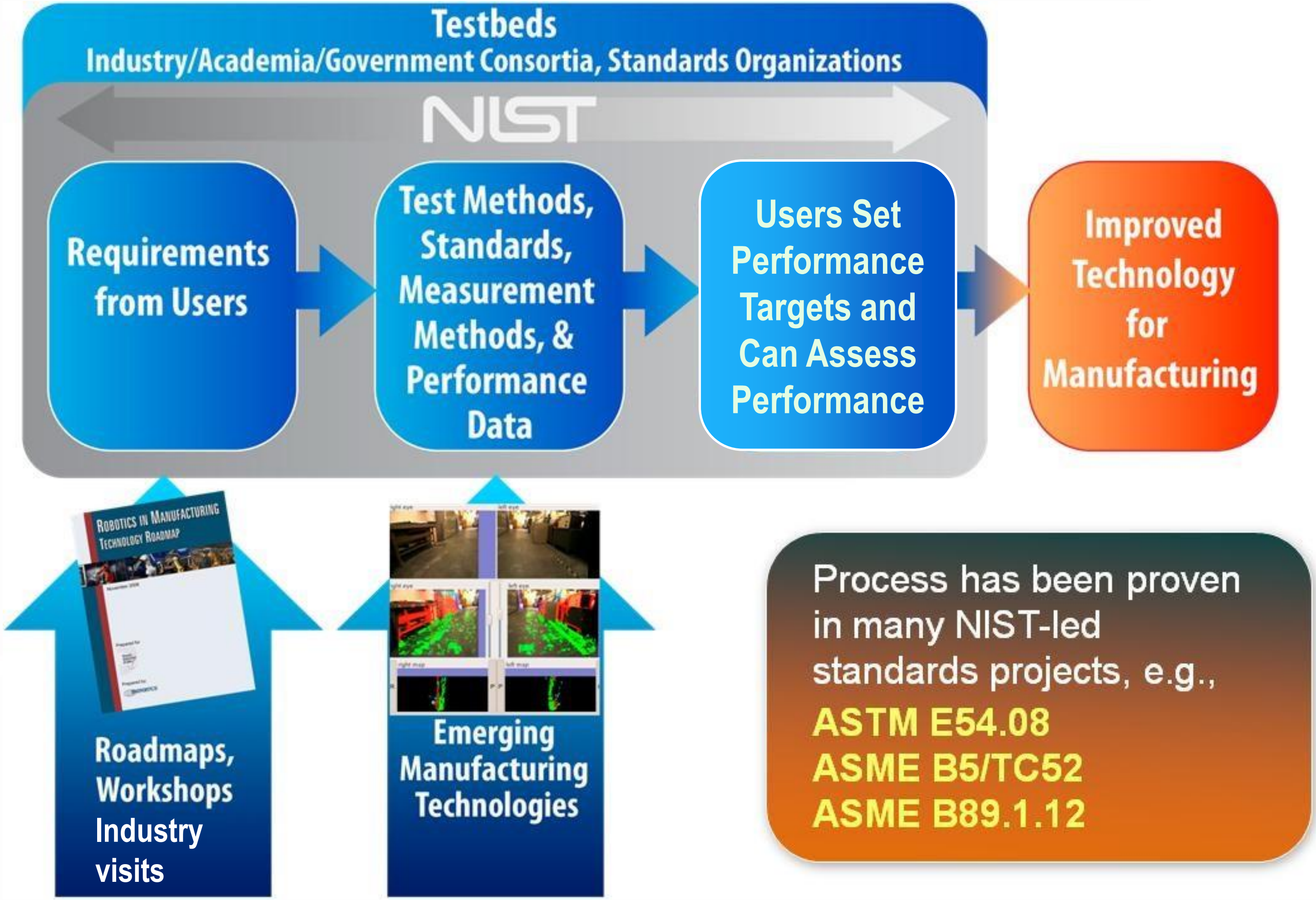
Driving Innovation and Reducing Risks of Technology Adoption Through Measurements and Standards



Example: 3D Sensor Systems

NISTIR 7664

DYNAMIC PERCEPTION WORKSHOP REPORT: Requirements and Standards for Advanced Manufacturing

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Industry Input

solutions in perception

identifying the current state of maturity of robotic perception

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SOLUTIONS IN PERCEPTION CHALLENGE

Sponsors: Willow Garage, NIST, IEEE, Robotics and Automation Society

Competitions to Verify & Validate Performance Test Methods

Topic: Experimental Design for the NIST data sets

Personnel: Dr. Charles Hagwood from Statistical Engineering Division, Jeremy Marvel, Tommy Chang and Tsai Hong from ISD

The objective of this data collection experiment :

1. Designed to capture a statistically significant portion of the complexity of the tes... sparse manner. In particular, design for data collection in 1-2 days.
2. The data sets can be used to capture the robustness and accuracy of the 6DOF s... submitted by the ICRA-2011 perception teams.

The NIST artifacts :

The NIST artifacts and settings include 15 texture objects (see Figure 1) , 3 fixture... different rotations (see Figure 2), and the supporting apparatus (see Figure 3).

Figure 1. NIST 15 objects

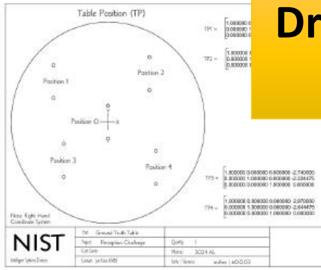

Figure 2 a Five Positions

A.2 Final Score

Let:

- $S_{h,i}$ be the n...
- $S_{m,i}$ be the number of misses (i.e., false-neg...
- $S_{n,i}$ be the number of noise (i.e., false-po...
- $S_{r,i}$ be the rotation score in frame i.
- $S_{t,i}$ be the translation score in fram...
- $S_{-,i}$ be the negative scores in fr...
- N be the total number of frames from ... Runs combined.
- O be the total number of detectable objects in all frames and Runs combined.

Then,

$$\text{Final Score} = \frac{1}{2}\sum_{i=1}^{N} \max\left(\left(S_{h,i} - 0.5S_{m,i} - S_{n,i} + \frac{S_{r,i}+S_{t,i}}{2}\right), 0\right)$$
$$= \frac{1}{2}\sum_{i=1}^{N}\left(S_{h,i} - 0.5S_{m,i} - S_{n,i} + |S_{-,i}| + \frac{S_{r,i}+S_{t,i}}{2}\right)$$
$$\leq O$$

Draft Metrics & Test Methods

Input to Standards

Designation: E2919 – 14

Standard Test Method for Evaluating the Performance of Systems that Measure Static, Six Degrees of Freedom (6DOF), Pose[1]

1. Scope

2. Referenced Documents

3. Terminology

ASTM E57 3D Sensor Systems

Emerging Technologies

Innovation through

- **Standardized methods of measuring performance to reduce risk of adopting wrong solution.**
- **Metrics to guide design improvement, with inclusion of manufacturing-relevant objects by NIST.**

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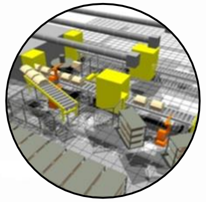
Smart Manufacturing:

The synthesis of **advanced manufacturing capabilities** and **digital technologies** to produce highly customizable products faster, cheaper, better, and greener

NIST Smart Manufacturing Program Areas:

Additive Manufacturing



Manufacturing System Design and Analysis

Robotic Systems

Manufacturing Operations Planning and Control

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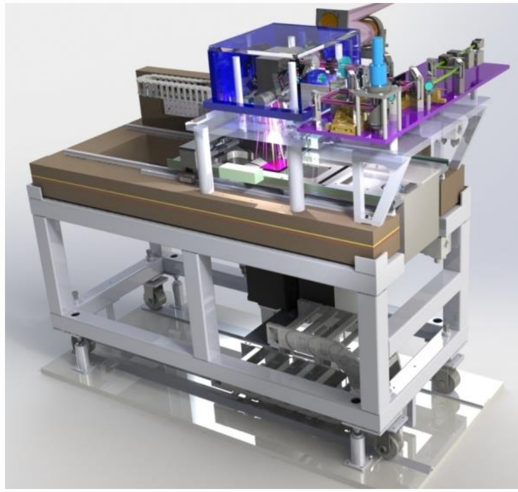
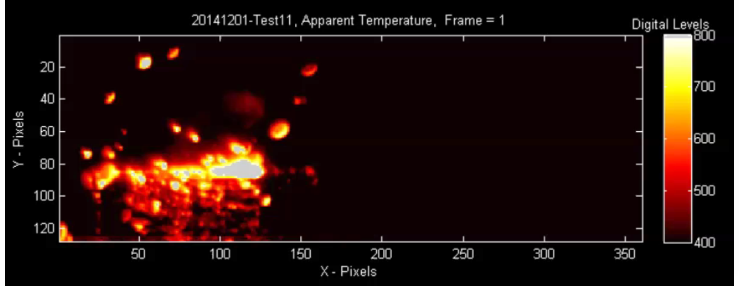
Measurement Science for Additive Manufacturing

Metal Additive Manufacturing: Building **metal** parts by adding layer upon layer; like 3D printers, but with metals

- What are important measurements for metal Additive Manufacturing **materials**, and how do you make them?
- How can you get the best **performance** out of metal Additive Manufacturing processes?
- What measurements are needed to support **qualification** of metal Additive Manufacturing materials, processes, and parts for critical applications?
- What information is needed to **integrate** metal Additive Manufacturing into end-to-end manufacturing production?



NIST AM Metrology Testbed



Thermal imaging of AM process

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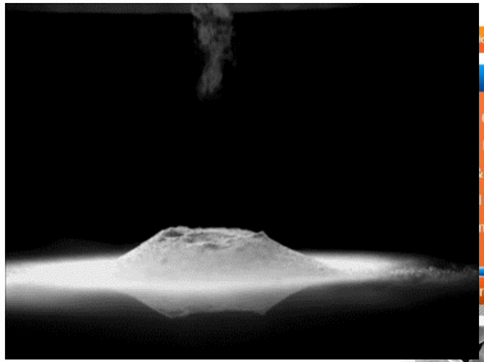
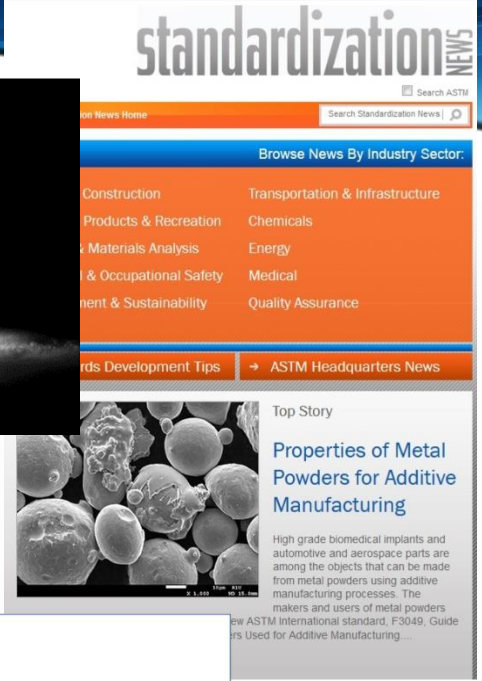
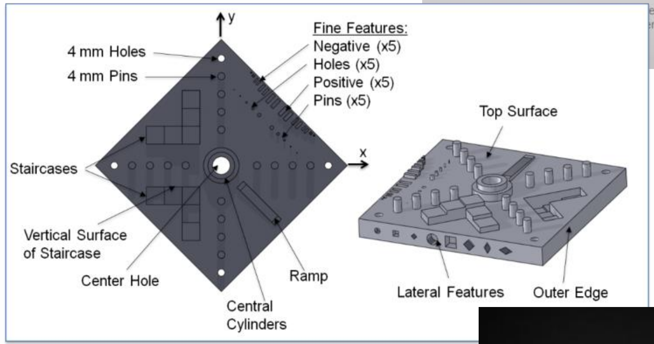
Standards Contributions

- ASTM Standard Guide for Characterizing **Properties of Metal Powders** used for AM Processes
  - Dimensional – mechanical – thermal – powder bed density – recyclability
- ASTM Standard Guide for Evaluating **Mechanical Properties of Metal Materials** made via AM Processes
  - Mechanical – microstructure – porosity – density – post processing
- Leading ASTM/ISO Joint Working Group for the development of standards for **AM test artifacts**
- Conducting **round robin studies** for AM
- Leading new ASME efforts on **Product Definition for AM**
- Leading new work item in ASTM on **Principles of Design Rules**
- Prototype **Materials Database** for AM accessible by public
- Lead development of **AM standards strategy** within ASTM F42 Executive Committee

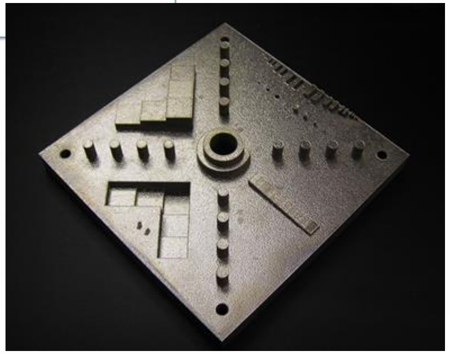


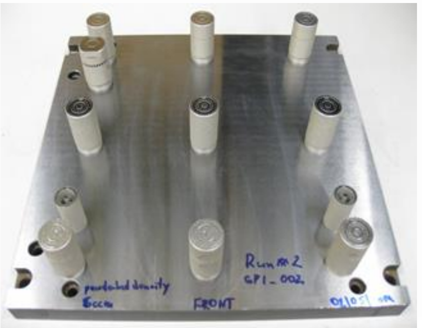
Powder property characterization





NIST AM Test Artifact





Traceable powder bed density (PBD) measurements

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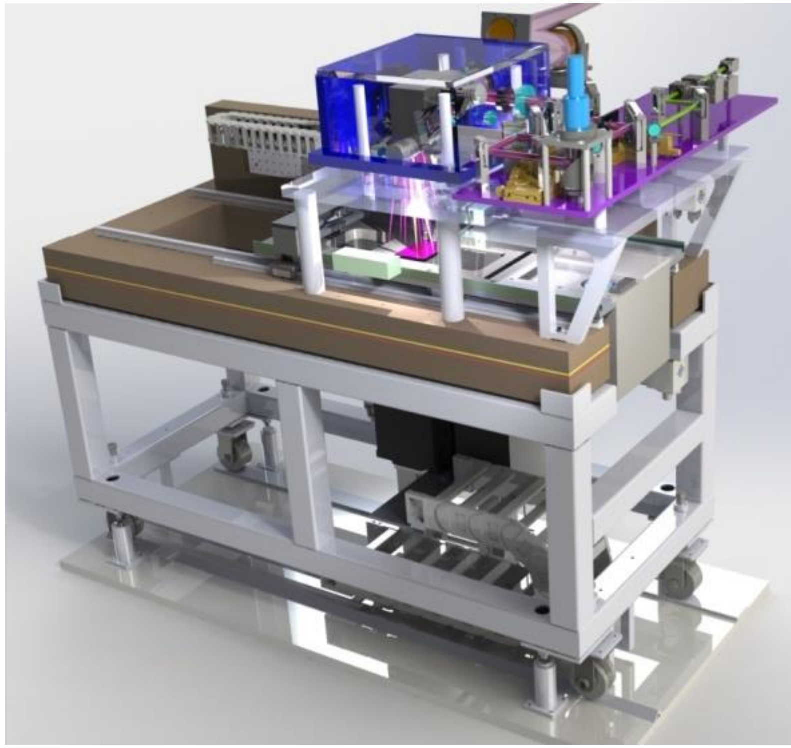
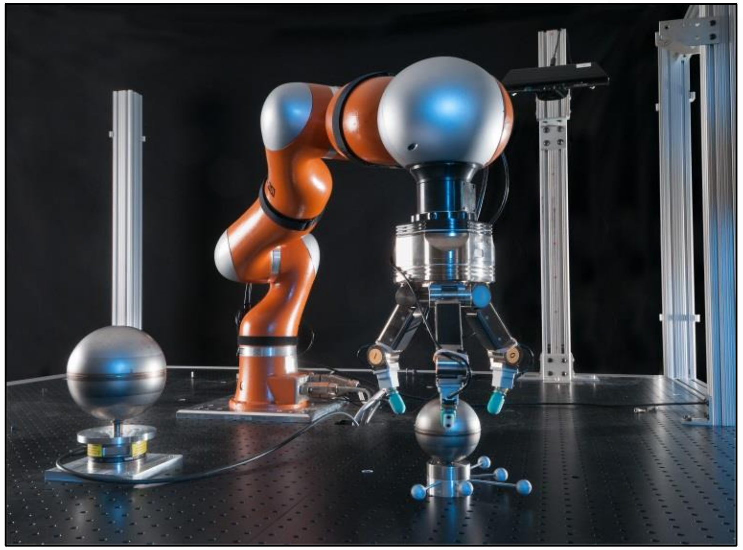
PHM for AM?

- Initial NIST AM focus is on process understanding, improvement, repeatability, and predictability, rather than PHM aspects
- Early yet to have a good handle on common failure modes for AM
- AM machines are complex, with a number of critical subsystems that each have potential failure modes
  - Powder handling/management and spreading/delivery
  - Gas flows/build environment control
  - Laser/energy control and scanning
- Equipment manufacturers build in sensors, maintenance features, protocols



Robotic Systems for Smart Manufacturing

- How can you measure the performance of robotic capabilities such as **perception, grasping, manipulation, and mobility**?
- How can you measure the effectiveness and safety of new **collaborative** robotic technologies?
- How can you measure and advance the **agility** of robotic systems (ease of teaching new tasks, recovering from errors)?
- What standards are needed to more easily **integrate robot systems** with other factory and control equipment?
- How can we help make robotic technologies **more easily adoptable by small and medium-sized manufacturers**?



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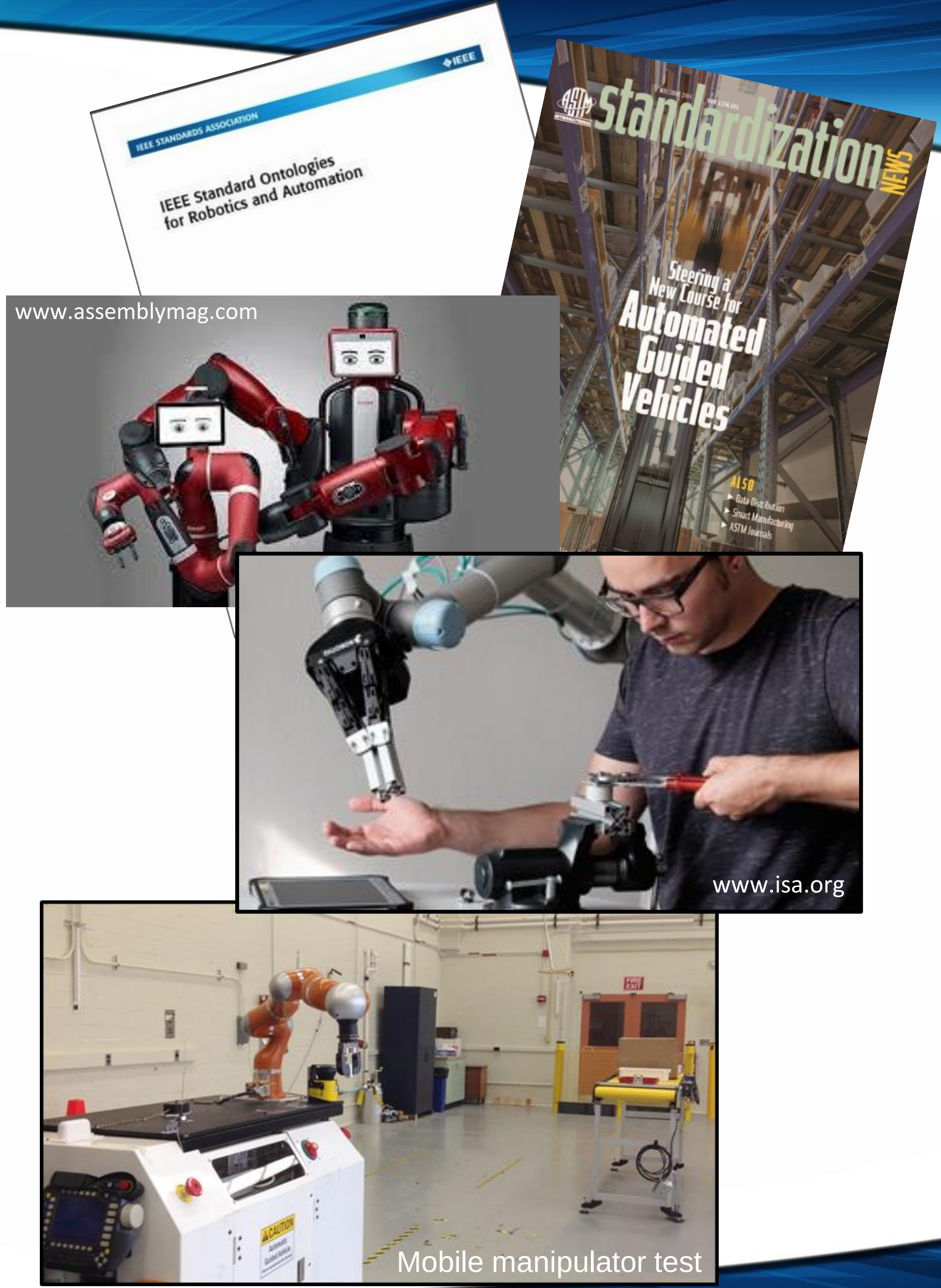
Standards Contributions

- Performance evaluation of 3D Imaging Systems, including two **test methods for 6D pose measurement systems**
- Revision of Automatic Guided Vehicle safety standard to **enable non-contact obstacle sensing**
- New ASTM Committee on **performance standards for industrial vehicles**
- New international technical specification for **collaborative robots safety** in industrial settings
- New Robotic Industries Association effort on **mobile manipulator safety standards**
- New IEEE standard for **knowledge representation for robot systems**



Smart Manufacturing Systems Design and Analysis

- What standards are needed to support new models of **distributed or service-oriented manufacturing**?
- What standards are needed to **streamline information flow** for food manufacturing?
- How can different kinds of **modeling software** be integrated effectively to support Smart Manufacturing systems?
- What are the best ways to measure the overall **performance of manufacturing operations**?
- What standards are needed to support **data analytics** for Smart Manufacturing systems?

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Standards Contributions

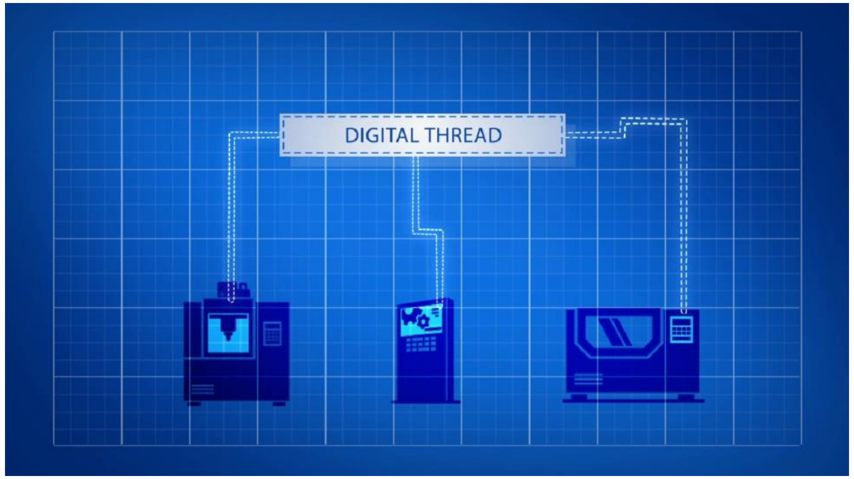
- ASTM E60.13 *Guide for Sustainability Characterization of Manufacturing Processes*
  - Will provide a common basis for **sustainability assessment of manufacturing processes**.
- Semantic Refinement methodology published as OAGI Working Group specification
  - Enables platform-specific **manufacturing applications to interoperate** based on a common standard (e.g., Mobile vs Enterprise applications)
- Smart manufacturing in the cloud workshops
  - *OAGi-NIST workshop on Open Cloud Architectures for Smart Manufacturing:* identified and prioritized technology and standards' gaps for **cloud-enabled manufacturing services**
  - *NIST Workshop on Cloud-Based Applications for Sustainable Manufacturing:* defined a standards' strategy to use data from process measurements to **quantify manufacturing process sustainability**.

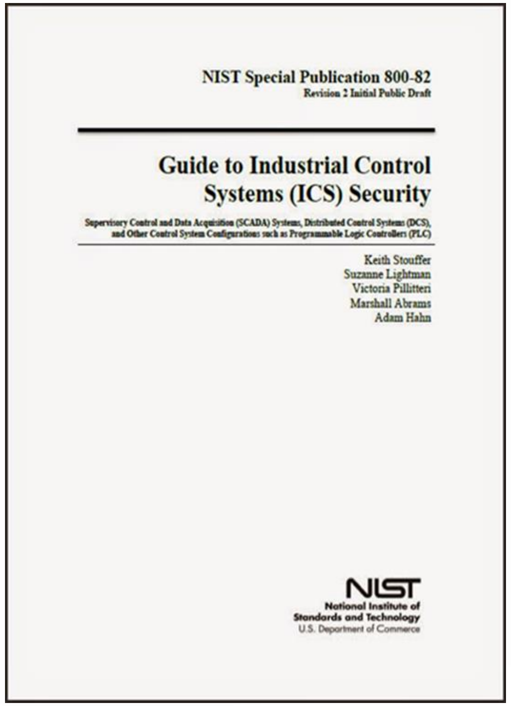
Smart Manufacturing Operations Planning and Control

- How can you use **sensors, data, and computation** to **assess machine health**, optimize maintenance, and **avoid downtime**?
- How can you use **wireless communications** in **industrial environments** for more flexible manufacturing?
- How do you **secure** the computers and networks that **control manufacturing operations**?
- How can you use the same **digital model** to **support the entire product lifecycle**, from design to production to service and sustainment?
- How can you integrate different **analysis tools** to **improve manufacturing operations**?

Standards Contributions

- STEP AP 242 (ISO 10303-242) standard on Managed Model Based 3D Engineering
  - Provides for **interoperability of Product Lifecycle Management (PLM) information** to enable the “digital thread” of model-based information for manufacturing, to reduce costs and improve responsiveness.
- NIST Special Publication 800-82 Guide to Industrial Control Systems Security
  - Provides guidance on **how to secure industrial control systems** while addressing their unique performance, reliability, and safety requirements
- Quality Information Framework (QIF) standard
  - Streamlines the **flow of quality information** across the complete product-quality lifecycle.




NIST Special Publication 800-82
Revision 2 Initial Public Draft

Guide to Industrial Control Systems (ICS) Security

Supervisory Control and Data Acquisition (SCADA) Systems, Distributed Control Systems (DCS), and Other Control System Configurations such as Programmable Logic Controllers (PLC)

Keith Stouffer
Suzanne Lightman
Victoria Pillitteri
Marshall Abrams
Adam Hahn

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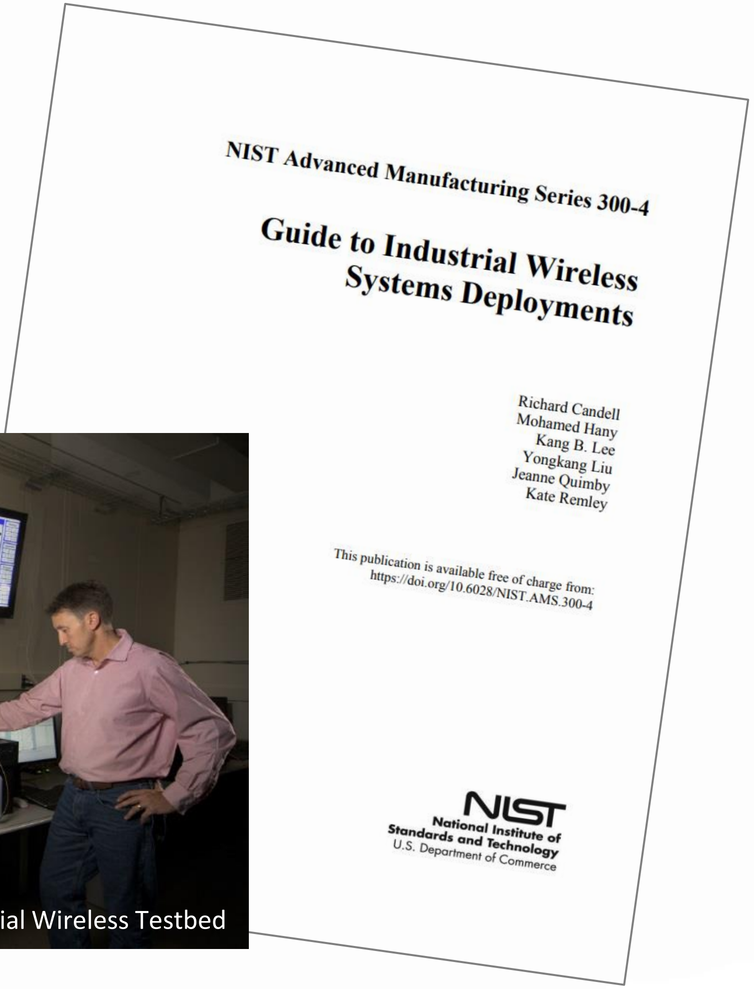
U.S. Department of Commerce

Hot Off the Press: NIST Guide to Industrial Wireless Systems Deployments

- Industrial Wireless Fundamentals
- Business Case for Wireless
- Wireless Lifecycle
- Wireless for Safety
- Industrial Wireless Security
- Best Practice Considerations
- Checklists
- Wireless Applicability Matrix

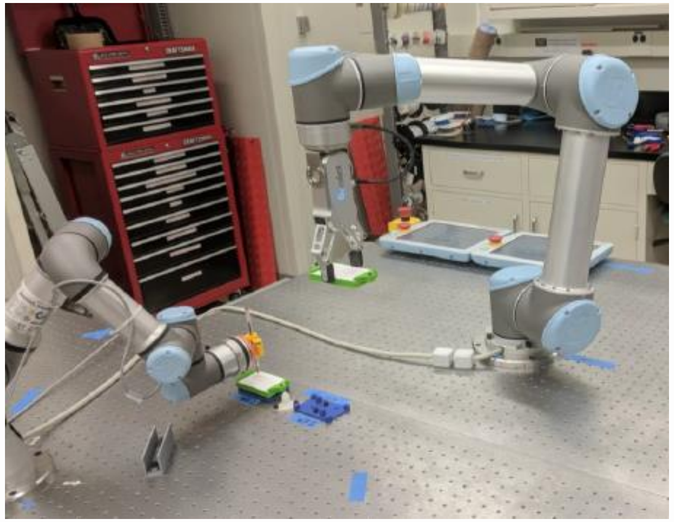


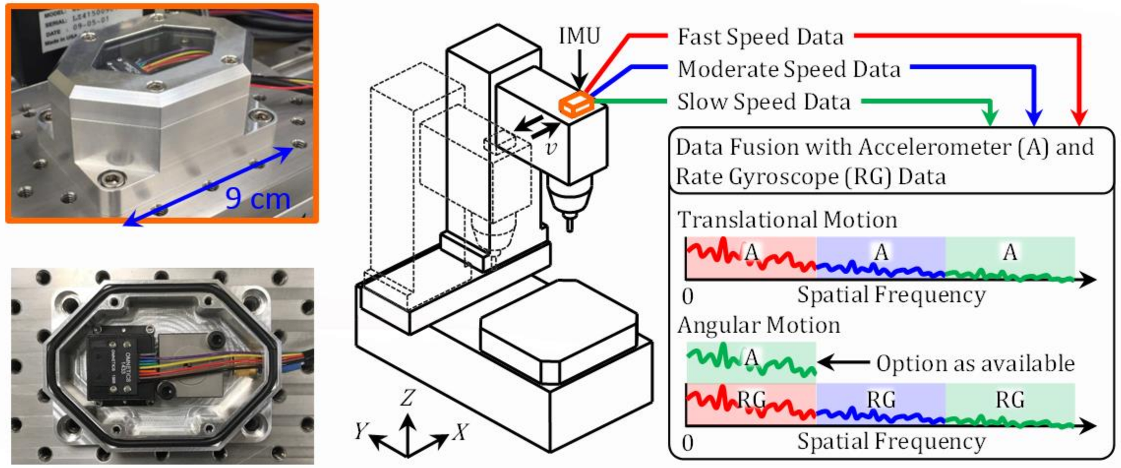

NIST Industrial Wireless Testbed

Acknowledgement: NIST industrial wireless technical working group (IWSTWG) members

Prognostics, Health Management, and Control Project

- Manufacturing Process and Equipment Monitoring
- Health and Control Management for Robot Systems
  - Robot Positioning Performance Degradation
  - Workcell-level PHM V&V
- Machine Tool Linear Axes Diagnostics and Prognostics





IMU for Linear Axis Monitoring

ASME Standards Meeting – Monitoring, Diagnostics, and Prognostics for Manufacturing Operations

Here, Friday! Discussion of:

- Standardized Terminology for PHM Guideline on Data and Collection Strategies
- Guideline to Determine What Health Data to Capture and Collection Strategies to Employ
- Guideline to Determine What Sensors and Where They Should Be Employed to Inform on Process/Equipment Health
- Guideline for Implementing Sensor Data Fusion/Multi-modal Data Fusion
- Guideline to Determine When and Where PHM Should Be Added/Integrated
- Expand MTConnect/Data Communications

Working With Others

Major stakeholder groups

- Manufacturing enterprises
- Software vendors & equipment providers
- Small and medium sized enterprises (SMEs)
- Industry consortia and standards developing organizations
- Government agencies
- Universities and research organizations

Modes of engagement

- Consortia, standards developing organizations
- Workshops, conferences, summits
- Site visits
- Cooperative Agreements

Question for this forum:

What measurement science and standards are needed to **drive innovation** and **reduce risks of adoption** of emerging/disruptive **PHM technologies**?

Thank you!

Questions?

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