2012 EL Project Title and Number: Model-Based Engineering

Program Title: Systems Integration for Manufacturing and Construction Applications

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Summary: Technological advances and competitive pressures are causing companies to favor digital product models to integrate engineering processes across production networks. These models provide input to and requirements for the execution of those processes. Current standards and test methods to ensure efficient and reliable exchange of these models are inadequate. New materials and manufacturing processes have introduced requirements for new standards and measurement science. This project will develop the measurement science needed to improve U.S. manufacturing productivity by enabling efficient integration engineering and manufacturing applications. The project will enable new standards that improve the quality of manufacturing information and the flow of information among manufacturing systems. The project will develop measurement science needed to address requirements created by new materials such as composites and new manufacturing processes such as additive manufacturing and optical scanning.

Description:

Objective: Improve the productivity of manufacturing processes by applying the measurement science needed to enable efficient integration of model-based engineering systems and effective validation of model data for manufacturing by 2014.

What is the new technical idea? The technical barrier motivating this project is the inability to sufficiently integrate multiple engineering applications involved in the design, production, and inspection of products across the production network. Model-Based Engineering applies modeling and simulation technologies to integrate and manage all processes related to product development and production. The core MBE tenet is that data is created once and directly reused by all data consumers.

A model is a representation, or idealization of the structure, behavior, operation, or other characteristics of a real-world system. It serves as an abstraction for its real world counterpart. A model is used to convey design information, simulate real world behavior, or specify a process. In the context of manufacturing, a model is a set of data used to drive manufacturing processes. A product model is a container not only of the nominal computer-aided design (CAD) geometry, but also of any additional needed for production and support. This additional data may include geometric dimensions and tolerances (GD&T), material specifications (such as composite structures), bill of materials, process specifications, and inspection data. This additional data is critical to the model-based approach. Without it, the geometry definition alone lacks the details necessary for downstream analysis, manufacturing, and inspection processes.

Companies are beginning to realize some productivity gains from integrating engineering and manufacturing applications. A study by the Aberdeen Group documented significant time and cost savings when model-based techniques are compared to conventional engineering practices.[1] Further, savings and time compression of a factor of 5 were found in the engineering change management process.[2]

This project will apply formal modeling techniques to fill gaps in existing standards for the representation and exchange of these models. It will develop new test methods to ensure that information extracted from a model is faithful to the original source and meets the requirements of all downstream processes. Data model requirements for new materials, manufacturing processes, and inspection processes will be of particular interest to this project. Materials such as composites, additive manufacturing processes, and optical scanning inspection processes have created new requirements for standards and measurement science. For example, the latest optical inspection equipment can sample millions of points very quickly; but those points include significant noise that corrupts conventional inspection analysis. This can result in the acceptance of bad parts and the rejection of good parts. New measurement science in the form of well characterized inspection data fitting algorithms is needed to address this problem.

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[1] *The Transition from 2D Drafting to 3D Modeling Benchmark Report – Improving Engineering Efficiency*, Aberdeen Group, September 2006.
[2] *U.S. Combat Systems Benchmarking Notes*, BAE Systems, October 20, 2009, IMTI2010001.

What is the research plan? The *Model-Based Engineering Project* will conduct the underlying measurement science research necessary to develop standards and test methods for the following:

- Product Manufacturing Information (PMI) – Data appended to the CAD geometry defining additional information needed for manufacturing and inspection. PMI includes geometric dimensions and tolerances (GD&T), as well as detailed material specifications and other annotations, specified in a standardized formal language. PMI is essential to developing complete product data. Therefore, the model-based approach requires not only the ability to edit and display PMI, but also the ability to feed GD&T semantics to computer-aided manufacturing systems and other downstream applications.
- Product structure – Data representing relationships between objects that comprise a product; e.g., a bill-of-material, functional systems hierarchy, or a zonal breakdown. Product structure management and information exchange is a challenge because the various engineering applications involved in product development require differing views of a product hierarchy.[3]
- Composite structure – Data representing heterogeneous, non-isotropic constituents laminated in layers to create a part.[4] Manufacturers are increasingly relying on composite materials to build stronger, lighter-weight, and more versatile products. A 2011 report from the President's Council of Advisors on Science and Technology recommends government investment in the standards and technology needed to reduce the time it takes from the initial research stage to integrate a composite material into an engineering process.[5]
- Inspection information – Point sampling data generated by optical scanning equipment. Not only are new fitting algorithms needed to interpret this data, but quantitative results are also needed to understand how applying the algorithms impacts measurement uncertainty.

Conformance and interoperability testing of data exchange standards is essential to ensure the successful execution of post-design engineering processes. The generation of test cases for a specific data exchange standard is particularly difficult considering the extent of information that can be modeled and tested in any data exchange standard. Test methods for coverage analysis – the evaluation of a test suite against test purposes – are required to ensure more robust and complete tests.[6] These test methods must derive, represent, and implement test criteria to be used in the analysis of data exchange files. The use of coverage analysis will result in smaller sets of test files providing more coverage of the relevant data exchange concepts used in conformance and interoperability testing of software implementations. The measurement science for doing coverage analysis of data exchange standards used for manufacturing does not exist. Some preliminary research has been performed for developing coverage analysis for data exchange standards used in the building industry.[7]

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[3] Svensson, D. Malmqvist, J., "Strategies for Product Structure Management at Manufacturing Firms," Journal of Computing and Information Science in Engineering, 2002, Vol 2; No. 1.
[4] Recommended Practices for Composite Materials. CAx Implementor Forum. Version 1.1. July 15, 2010. http://www.cax-if.org/documents/Rec_Pracs_Composites_v11.pdf
[5] Report to the President on Ensuring American Leadership in Advanced Manufacturing. President's Council of Advisors on Science and Technology. June 2011. http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-advanced-manufacturing-june2011.pdf
[6] Kindrick J., Sauter J., Matthews R. (1996) "Improving Conformance and Interoperability Testing", StandardView, 4(1).
[7] Lipman, R. R. "Developing Coverage Analysis for IFC Files", Proceedings of the CIB W78 2010: 27th International Conference, Cairo, Egypt, November 2010.

Recent Results:

Outputs:

- Technical contributions to ISO STEP AP203 E2 standard for product model data. Led committee developing this standard.
- Frechette, S.P. "Model Based Enterprise for Manufacturing." 44th CIRP International Conference on Manufacturing Systems. Madison, WI, US. June 2011.
- Frechette, S.P.; Huang, P.J. "Model Based Enterprise Technical Data Package Requirements." NISTIR 7749. February 2011.
- Hunten, K.A.; Barnard Feeney, A. "Business Object Models For Industrial Data Standards." Proceedings of the ASME 2011 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference. IDETC/CIE 2011. Washington, DC, USA. August 2011.
- Lipman, R. R.; Palmer, M. E. "Assessment of Conformance and Interoperability Testing Methods Used for Construction Industry Product Models." Automation in Construction. Vol. 20. No. 4. April 2011.
- Lipman, R. R. "Developing Coverage Analysis for IFC Files." Proceedings of the CIB W78 2010: 27th International Conference. Cairo, Egypt. November 2010
- Lubell, J.; Hartman, N.; Cheney, D. **"**MBE Standardization and Validation." NISTIR 7796. July 2011.
- Srinivasan, V., Shakarji, C., Morse, E. "On the Enduring Appeal of Least-squares Fitting to Computational Coordinate Metrology." Submitted to Journal of Computing and Information Science in Engineering. Notice of final acceptance expected December 2011.
- Development of the IFC File Analyzer, a software tool for performing coverage analysis of IFC (Industry Foundation Classes) data exchange files used in the building industry. The IFC File Analyzer has been downloaded over 400 times since March 2010.

Outcomes:

- ISO STEP AP203 E2 published.
- Initial STEP standards for PMI delivered to ISO for publication.
- Quality of ISO standards improved by infrastructure put in place for faster development of STEP standards with automated quality checking.
- NIST-developed least-squares fitting algorithms used in emerging ISO Geometric Product Specifications standards

Standards and Codes:

Standard	NIST Staff	Expected Outputs/Outcomes
ISO TC213 Dimensional and Geometrical Product Specification and Verification	Srinivasan (leading) Shakarji	• Conformance tests for next generation of ISO/ASME PMI standards • TC213 report on characterization and application of fitting algorithms • Executable PMI conformance tests • Outcome: New standards superseding the current ISO and ASME PMI standards, representing an order of magnitude change, needed to keep pace with emerging CAD technology.
ASME Y14.5.3 Guidelines for the use of geometrical product specification and verification standards	Srinivasan (leading)	• PMI Standards and Technology roadmap report • Outcome: Standard providing guidance for US suppliers in interpreting PMI expressed using emerging ISO/ASME standards.
ISO STEP AP242 Managed model-based 3D engineering	Barnard Feeney Frechette	• Revisions to Application Protocol development guidelines • Upgrades to STEP standards publication process • Outcome: AP242 International Standard, enabling exchange of PMI graphics, PMI semantics, composites data, and application-level XML implementation models.
ISO STEP Part 59 Product Data Quality	Frechette/Lubell with industry partner	• Geometric validation properties for AP242 data exchanges.
Aerospace Industries Association LOTAR (Long term archiving of product data)	Lubell	• Validation properties and test methods for composites data. • Test methods for exchange using lightweight industry CAD formats • Outcome: Implementation of PMI, composites, and product structure exchange/validation in archival information systems.