2009 BFRL Project Description

Project Title: Development of an Autonomous Precision Positioning Measurement Testbed

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BFRL Program: Service Life Prediction of Nanostructured Polymeric Materials

Objective: **C**reate a fully automated material handling laboratory using robotic technology which will 1) demonstrate automated sample analysis to enable new measurement science for service life prediction of polymeric materials, and 2) enable new measurement methods for analyzing construction component movement, placement, and tracking construction productivity improvement.

Problem:

What is the problem? The polymeric materials industry requires high-throughput analytical measurements for improved service life prediction of materials through the use of laboratory robots and automated analytical equipment. The measurement science is lacking for determining proper procedures and measures for utilizing high-throughput measurements in service life prediction. In a related problem, the construction industry needs to automate the movement and installation of construction materials to help realize breakthrough improvements in construction productivity. The measurement science is lacking for evaluating the performance of intelligent construction component placement technologies such as those needed for automated structural steel placement during construction operations, or the automated tracking of pipe spools from fabrication, to laydown, to installation.

Why is it hard to solve? Analytical measurements of polymeric materials are routinely made in a sequential sample measurement mode and are rarely automated. All of the major instrument manufacturers use proprietary software that make interfacing motion control devices with instrument control software difficult. Also, analytical instrument calibration is required so that measurements made on different instruments can be rigorously compared.

Successful movement and installation of construction materials requires precise positioning and tracking in dynamic and unstructured environments.

How is it solved today, and by whom? These problems are not solved today. High-throughput analytical measurements are routinely made in the pharmaceutical industry (liquid samples), but not in the polymeric materials field (solid samples). Typically, measurements are

made more for quality control purposes rather than high-throughput measurements for service life prediction.

Automated placement technologies adopted in other industries, such as the manufacturing sector, rely heavily on highly structured and static environments for success. Defense-related and space exploration research efforts lead the development of automation technologies designed to operate in unstructured and dynamic environments. There are few, if any, qualitative assessments of automation performance to facilitate technology adoption by the construction industry.

Why NIST? This project is aligned with the BFRL mission and vision by providing tools that can be used for the high-throughput characterization of building materials and by the building and construction industry for construction site automation. The industry needs addressed herein are aligned with two of BFRL's strategic priorities: *Measurement Science for Sustainable Infrastructural Materials and Measurement Science for Breakthrough Improvements in Construction Productivity*. BFRL has core competencies in performance, durability and service life prediction of building materials as well as in information, communication and automation technologies for intelligent integration of building design, construction and operation that will be used to carry out this project.

Approach:

What is the new technical idea? The two needs described in "What is the Problem?" may appear divergent but the capabilities required by both industries represented are fundamentally similar, and include the ability to recognize, track, place, and verify the movement of objects based on a hierarchical planning system, whether this is a materials characterization test protocol or a 4D CAD-based capital project build sequence.

BFRL has a reconfigurable tabletop automation testbed that can be used to demonstrate the feasibility of state-of-the-art automated materials handling concepts. This testbed, known as the Automated Analytical Laboratory (AAL), consists of multiple analytical instruments and a 6-axis robotic arm mounted on a linear stage (7-axis). The AAL is being developed to carry out automated analytical tasks on polymeric specimens exposed in the NIST SPHERE, and requires further research to enable specimen transfer between analytical instruments, specimen ID techniques, and workflow optimization. BFRL possesses the necessary expertise and experience to develop these capabilities so that the full functionality of AAL can be realized.

In the process of developing the full functionality of the AAL, BFRL will gain expertise in the development and use of table-top automation testbeds. In the AAL, the specimens being analyzed represent manufactured subassemblies or prefabricated components. The 7-axis laboratory robot represents an industrial robot used on a construction site for pick-and-place operations, and the analytical instruments represent sub-sites or stations on a construction site that the pre-fabricated components would be moved to and from.

Why can we succeed now? BFRL possesses expertise in robotics and in a wide variety of analytical and high-throughput tools for characterizing polymeric materials. The first year of this

project provided experience in robotic control and advancement in hardware needed to outfit the laboratory testbed.

- ***What is the research plan?*** Requirements document was produced detailing specific automation tasks for automated specimen identification, movement, and analysis for the AAL. The NIST real-time control system (RCS) methodology was used to consider many scenarios of potential system behavior and choose both nominal and off-nominal scenarios necessary for proper operation of the AAL. BFRL initiated collaboration with MEL to incorporate the NIST 4D/RCS architecture methods and design process. Cartesian control of the 7-axis robot was developed for placement of samples as well as detailed knowledge of the robot's software libraries. Prototype designs for the grippers, specimen holder, and instrument positioners were produced. In cooperation with MEL, a preliminary experiment was performed to evaluate the dynamic performance of a 3D imaging system using the 7-axis AAL robot. This work informed future design for an AAL-based testbed for construction component tracking and placement.

The final design, fabrication, and installation of the grippers, specimen holder, and instrument positioner will be completed. Additionally, a single cell specimen handler will be designed, fabricated, and installed. Knowledge of the 7-axis robot Application Programming Interface (API) will be combined with the task requirements from FY08 to design and develop the planning and control software to provide fully autonomous measurement of a single specimen with a single instrument.

The planning and control software for the AAL will be extended to provide fully autonomous measurement of multiple specimens with multiple instruments. To accomplish this, a multi-cell specimen handler will need to be designed, fabricated, and installed based on the experiences with the single-cell handler from. With this infrastructure in place, the AAL will enable a quantitative performance assessment of a construction component tracking system using a 3D imaging device to be performed with the AAL.

If successful, this project will contribute to the development of new automation capabilities that will lead to better measures of service life prediction as well as cost and time reductions in the delivery of construction products and projects.

Recent Results:

***Outputs*:**

1. A NIST RCS-based requirements document for the automated analytical laboratory (AAL).
2. T. Chang, R. Eastman, T. Hong, G. Holguin, and M. Shneier, "6DOF Metrology for Evaluating a Visual Servoing Algorithm", Proceedings of the 2008 Performance Metrics for Intelligent Systems (PerMIS) Workshop, Gaithersburg, MD, August 19-21, 2008.

***Outcomes*:**

1. New technical expertise and capabilities for evaluating the dynamic performance of 3D imaging-based tracking systems using a 7-axis manipulator and a laser tracker.
2. Design and production of prototypes for custom grippers, specimen holders, and instrument positioners for use by 7-axis manipulator.

Standards and Codes: None