2009 BFRL Project Description

Project Title: Construction Control Using 3D Imaging and Building Information Models

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BFRL Program: Construction Integration and Automation Technology (CONSIAT)

Objective: To improve construction productivity by enabling construction site process control, progress monitoring, and archiving as-built status by developing the metrics and methods for combining 3D Imaging (3DI) data and Building Information Models (BIM).

Problem:

What is the problem? Automated, real-time construction site monitoring and control has the potential for enabling increases in construction productivity[1], thus alleviating many of the cost and schedule overruns that currently afflict the industry.[2, 3] Achieving such a level of situation awareness and being able to automatically update project status is complicated by the variable nature of the construction environment and by the complex information modeling tasks required. The rapid proliferation of 3D imaging systems in construction and the continued reduction in system costs offer a future where 3D site information is available anytime and anywhere. The challenge is to automatically extract, isolate, verify, and make use of the important information in the avalanche of data that these systems produce.

Much effort is being expended by the construction industry in order to generate a standardized Building Information Model to facilitate interoperability between software and project information management systems. Given a future scenario where the cost of 3DI systems is sufficiently low that they become ubiquitous in and around a construction job site, and where the entire project has an associated BIM, how can 3DI data be combined with BIM to automatically update job status, verify construction quality, and provide infrastructure for intelligent systems to operate in a construction environment? The measurement science needed for combining 3DI data with BIM to achieve this vision is currently lacking.

Why is it hard to solve? Automatically recognizing objects in cluttered 3DI data represents a challenge with no well-established solutions. Traditional 2D image analysis techniques break down due to object occlusions and to the computing power needed to process the unprecedented

[1] "Locating and Tracking Resources with Smart Sensors," White Paper - Idea #70, April, 2006, http://www.construction-institute.org/scriptcontent/btsc-pubs/CII-BTSC-70.doc
[2] Construction Industry Institute, *Strategic Plan*, Austin, TX, 2005.
[3] FIATECH, Capital Projects Technology Roadmapping Initiative, Austin, TX, October 2004.

amounts of data that 3DI systems produce[4]. In addition, creating linkages between 3DI data and BIM is a new information modeling task that has recently surfaced due to the rapid proliferation of 3DI technology within the construction industry.

How is it solved today, and by whom? The problem is not solved and represents a clear technical challenge in an area where NIST can make a significant contribution in the generation of new knowledge. There are several related research efforts such as work on: construction defect detection using 3DI systems at Carnegie Mellon University; steel erection tracking at the University of Waterloo; and testing of construction product data standards at NIST (among others). Industry has also begun to look at how to manually generate 3D models from 3DI data. However, none of these efforts have focused on automating and integrating 3DI and BIM information for both construction control and as-built archiving.

Why NIST? The creation of new measurement science for automatically integrating 3DI data and BIM is directly aligned with BFRL's strategic priority area in Measurement Science for Breakthrough Improvements in Construction Productivity, as well as BFRL's core competency in information, communication and automation technologies for intelligent integration of building design, construction and operation. In addition, this work is in keeping with BFRL's vision of creating critical solution-enabling tools (metrics, models, and knowledge) and promoting performance-based standards used by the U.S. building industry. BFRL is also uniquely qualified to pursue this research due to its expertise in 3DI, information modeling, and data standards. BFRL's in-house expertise and collaborative relationships with industry and academia are already in place.

Approach:

What is the new technical idea? The new technical idea is to combine the use of 3DI systems with BIM to enable control of construction processes. Specifically, an association scheme is required between 3DI data of the as-built conditions of a structure and the building information model of the as-designed structure. By exploiting this association, augmented building information models and other project information management systems can be updated automatically with as-built information and ultimately can provide feedback to control the construction process. This will require methods for analysis of 3DI data, extraction of relevant information, and implementation of robust world models and control architectures given the unstructured nature of construction environments.

Why can we succeed now? NIST has several key discriminators that enable success in this project. These include: (1) expertise in 3DI systems and object recognition, (2) expertise in information modeling, and (3) the necessary facilities and equipment to conduct experimental work. Those discriminators, coupled with BFRL's strong ties with researchers conducting related work (e.g., CMU, UW, etc.) and industry organizations such as CII and AISC that are interested in this research, are the key elements which will enable success. The U.S. General Services Administration (GSA) has also expressed a desire for combining 3DI and BIM.

What is the research plan? Building on past BFRL work in object recognition from 3DI systems and in building information models for structural steel, the key task is to associate 3DI

[4] 3DI systems can currently capture data at a rate of millions of points per second.

data with the geometric representation of the individual parts of structures in the BIM and be able to update the BIM about the status of a part. Initially, this is only a one-way update of information from the as-built scans to an augmented BIM that can associate as-built and as-designed information in a meaningful way. Eventually the information can be used to make decisions about controlling the construction process. Future scenarios also envision comparing the as-built location of parts to their as-designed locations to see if they are properly placed.

The erection of structural steel is the exemplar construction process that will be used for developing the proposed linkage of 3DI and BIM. Its characteristics include: relatively isolated activity that can be dealt with on its own; discrete parts that lend themselves to scanning and recognition using today's 3DI systems; well-defined open-standards based information representations (CIS/2, IFC) that are already in use with project management systems; and other material tracking technologies such as bar-coding and RFID are already being applied. These characteristics constrain this project to a well-defined scope to improve the chance of success in its early stages. The project can be expanded later to accommodate other common processes. Two examples are the erection of precast concrete, where the information models are not yet well-defined, and the erection of piping systems and equipment, where the methods of scanning and recognition using today's 3DI systems are not as well developed.

Previous research at other institutions showed how 3DI data could be used to monitor progress on a construction site, however, there was no linkage between the scans and an information model. Other research showed how construction defects could be detected by comparing 3DI data with virtual models. Again, there was no attempt to update the building information model based on knowledge gained from the 3DI data. The work in BFRL will create the connection between the as-built 3DI data and as-designed BIM to be able to update the BIM and project information management systems, and to be able to control the construction process. This work will form the basis for the evaluation of various control architectures (such as the NIST-developed realtime control system) for their ability to control the construction process.

Beyond demonstration of the technical capability developed, the expected outcomes of this research include: (1) methods for analysis of 3DI data and for extraction of information that can be integrated into project control systems, (2) reference implementations of these methods that can be used in testbeds in partnership with industry, (3) evaluated 3DI datasets that can be used for assessment purposes by technology developers and users, (4) simulation programs that can be used to conduct experiments synthetically that would be too time consuming, or too costly, or even impossible to conduct using real 3DI systems in real construction projects, and (5) an augmented building information model schema for representing 3DI and related information in BIM that can be adopted in a future release of the Industry Foundation Classes (IFC).

Recent Results:

Output: "Automatic Reconstruction of As-Built 3D Building Information Model from Point Clouds: A Review of Related Techniques" Collaborative journal article in preparation with Carnegie Mellon University. Expected completion Q1FY09.

Outcome: Provide research basis for linking 3DI sensor data with BIM.

Standards and Codes:

Proposed representations, in construction industry data standards such as IFC and CIS/2, of point cloud information and associated metadata and derived quantities will be developed. Project staff participates in many IFC and CIS/2 committees.