# 2009 BFRL Project Description

## Project Title: Performance and Use of 3D Imaging Systems

11/03/2008

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**BFRL Program:** Construction Integration and Automation Technologies (CONSIAT)

**Objective:** To enable the performance evaluation of 3D imaging systems[1] through the development of the necessary measurement science to support standards development (ranging performance, point cloud uncertainty, and error propagation from instrument to end product) for these systems..

**Problem:**

***What is the problem?*** The lack of standard test methods for 3D imaging systems is a recognized and authenticated US Measurement System need (2006). The need for standards has also been recognized by the 3D imaging community based on a survey conducted in 2008 by an industry organization[2] which represents 3D imaging interests and a series of workshops (2003-2006) held at NIST.

Despite the growing prevalence of these systems, measurement science is lacking to determine the sources of errors (hardware and software), to quantify these errors, to evaluate the overall performance of these instruments, and to determine the uncertainties associated with the derived output from the 3D data (e.g., 3D models, volumes, dimensions) - propagation of instrument error to the end product. The construction industry, historically, invests little in the research to generate the necessary measurement science. One reason for this underinvestment is the inability of any one company to profit from the research[3].

***Why is it hard to solve?*** Fundamental research is required to determine and characterize both the performance and the errors associated with 3D imaging systems. Understanding the error sources requires the development of robust 3D image system sensor models from experimental data. As 3D imaging system data are most often used to generate other outputs

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[1] A 3D imaging system is a non-contact measurement instrument used to produce a 3D representation (e.g., a point cloud) of an object or a site. Some examples of a 3D imaging system are laser scanners (also known as LADARs or LIDARs or laser radars), optical range cameras (also known as flash LIDARs or 3D range cameras), triangulation-based systems such as those using pattern projectors or lasers, and other systems based on interferometry.

[2] Spar Point Research, www.sparllc.com.

[3] Chapman, R., "Stimulating Innovation and Competitiveness in Construction and Building: Addressing Market Failures through Government-Funded Research," NIST White Paper, February, 2007, pp. 15-16.

(e.g., 3D models, volumes), methods of propagating the measurement errors through to the end product are necessary and will have to be developed. Since this work supports consensus-based standards development, attention must be placed on methods that are applicable to a broad range of systems and where cost and complexity are minimized where practical.

***How is it solved today, and by whom?*** Standard methods to evaluate the performance of 3D imaging systems do not currently exist. Some efforts to solve the problem have been undertaken in the last few years. NIST hosted a series of four industry workshops on 3D imaging systems which led to the establishment in 2006 of ASTM E 57 committee, 3D Imaging Systems. NIST has on-going research into the performance characterization of 3D imaging systems and is closely involved in ASTM E57. Other standards development efforts include ISO TC 172 - Geodetic Instruments, VDI/VDE 2634 (German standard), and ASPRS (American Society of Photogrammetry and Remote Sensing). NIST will assist ASTM E57 in creating linkages with other research and standards efforts.

***Why NIST?*** The performance metrics, measurement and evaluation methods, and algorithms developed in this project directly supports BFRL's mission to promote U.S. competitiveness by the meeting measurement science and standards needs of the U.S. Building industry. 3D imaging systems enable reduced errors and rework, schedule reduction, improved responsiveness to project changes, increased worker safety, and better quality control. These benefits improve construction productivity. This effort is aligned with BFRL's strategic priority in Measurement Science for Breakthrough Improvements in Construction Productivity and is within BFRL's core competency of Information, communication and automation technologies for intelligent integration of building design, construction and operation.

## Approach:

***What is the new technical idea?***

The new technical idea is to develop the measurement science needed to:

- characterize the basic measurement (range) of a 3D imaging system
- develop a method to predict the uncertainty of a point cloud
- quantify the effect of registration error on the point uncertainty
- develop a method to determine the effect of the data quality (e.g., point uncertainty, point density) on a derived end product (e.g., geometric primitive, 3D model)
- propagate the instrument uncertainty to the uncertainty of an end product derived from 3D imaging data

As with the development of any standard test methods, the test method must be verified (building the model right) and validated (building the right model). Verification assures that the method accurately assesses the measured characteristic in a repeatable manner. Validation determines how well the implementation of the method represents the real world for its intended purpose. Experimentation is a critical part of the verification and validation processes. It is also required to assess the feasibility and practicality of the procedures outlined in the proposed test methods, and to determine potential factors that could affect the performance. Similarly, algorithm

development is an integral part of this project. It is necessary to perform simulations to determine the sensitivity of the various parameters.

The proposed methods and experimental results will be submitted to ASTM E57 for consideration.

***Why can we succeed now?*** The applications and use of 3D imaging systems have grown tremendously in the past decade. The need for standards to evaluate the performance of 3D imaging systems is critical. BFRL has gained expertise and experience with these systems through their research in this area since 1998 and is recognized by industry as a leader in this area. Therefore, the collaboration between BFRL and industry is in-place.

***What is the research plan?*** The research plan will focus on five areas to provide the required measurement science for the performance evaluation of 3D imaging systems. The five areas are: 1) characterization of the basic measurement (range) of a 3D imaging system, 2) prediction of the uncertainty of a point cloud, 3) quantification of the effect of registration error on the point uncertainty, 4) characterization of the effect of data quality (e.g., point uncertainty, point density) on a derived end product (e.g., geometric primitive, 3D model), and 5) propagation of the instrument uncertainty to the uncertainty of a end product derived from 3D imaging data.

<u>1) Characterization of the range performance of a 3D imaging system</u> - conduct experiments to determine the effect of range, reflectivity, angle-of-incidence, and azimuth on the range error. Develop a prototype model to predict the range error as a function of the four experimental factors.

<u>2) Prediction of the uncertainty of a point cloud (FY09)</u> - refine prototype model developed in 1 as required, develop algorithm to estimate uncertainty of the point cloud based on the model.

<u>3) Quantification of the effect of registration error on the point uncertainty (FY10)</u> - develop analytical expressions for error of registration transformation parameters, propagate the effect of the transformation errors to the registered point location, implement procedures to experimental data.

<u>4) Characterization of the effect of data quality (e.g., point uncertainty, point density) on a derived end product (e.g., geometric primitive, 3D model) (FY11)</u> - develop analytical expressions for errors in the model parameters, implement procedures to experimental data.

<u>5) Propagation of the instrument uncertainty to the uncertainty of a end product derived from 3D imaging data (FY12)</u> - develop expressions and algorithms combining previously obtained results to the final uncertainty.

**Recent Results:**

**Outcomes (a)**:

1. Establishment, in 2006, of a standards committee for 3D Imaging Systems - ASTM E57.

**Impact (a)**: Standards

1) Approval of 1st ASTM standard for 3D imaging systems - ASTM E2544 - Terminology in 2007.

2) Consumer[4] ability to fairly evaluate and compare3D imaging systems allowing them to make more informed purchase decision.

3) Instrument manufacturers will reduce costs by eliminating special tests requested by individual users.

**Output (b)**:

1. 2008 - Establishment of the National Center for 3D Imaging System Performance Evaluation and Calibration. This center consists of five specialized facilities developed and operated by BFRL and MEL. The two BFRL facilities are: Indoor artifact facility. (established 2006) and the outdoor benchmark facility. (established 2008)

2. Cheok, G. S., Lytle, A. M., and Saidi, K. S. [2008], "ASTM E-57 3D Imaging Systems Committee: An Update," in Laser Radar Technology and Applications XIII, edited by M. D. Turner and G. W. Kamerman, Proceedings of SPIE, Vol. 6950, March 19-20, 2008.

3. Cheok, G. S., Saidi, K. S., and Lytle, A. M. [2007], "Evaluating a Ranging Protocol for 3D Imaging Systems," Proceedings of ISARC 2007, September 19-21, Kochi, India.

4. Lytle, A. M., Szabo, S., Cheok, G. S., Saidi, K. S. [2007], and Norcross, R.J., "Performance Evaluation of a 3D Imaging System for Vehicle Safety," in Unmanned Systems Technology IX, edited by G. R. Gerhart, D. W. Gage, and C. M. Shoemaker, Proceedings of SPIE , May 2007.

5. Lytle, A. M., Cheok, G. S., and Saidi, K. S. [2007], "ASTM E-57 3D Imaging Systems Committee - An Update of the Standards Development Effort," in Laser Radar Technology and Applications XII, edited by G. W. Kamerman and M. D. Turner, Proceedings of SPIE, April.

**Outcomes (b)**:

1. The facilities provide consumers* measurement services for ground truth measurements with uncertainties of ±100 μm (indoor facility) and ± 2 mm (outdoor facility).

2. Prototype artifacts allow for algorithm development and instrument evaluation.

**Outputs (c)**:

1. Franaszek, M. Cheok, G., and Witzgall, C. [2008], "Fast automatic registration of range images from 3D imaging systems using sphere targets Automation in Construction Journal, in review.

[4] Consumer include surveyors, service providers, building/facility owners (e.g., GSA, U.S. Corps of Engineers, Anheuser-Busch), state DOTs (e.g, CALTRANS), manufacturing companies (e.g., Boeing, Airbus), law enforcement agencies (e.g., FBI, police departments), archeologists (e.g., Smithsonian).

2. Franaszek, M. Cheok, G., Saidi, K., and Witzgall, C. [2008], “Fitting Spheres to Range Data from 3D Imaging Systems,” IEEE Transactions on Instrumentation and Measurement, in review.

3. Franaszek, M. Cheok, G., Saidi, K., and Witzgall, C. [2008], “Effect of scanning density on the accuracy of locating sphere centers for registration,” Proceedings ISARC 2008, Vilnius, Lithuania.

**Outcomes (c)**:

New method to fit spheres to reduce the error in locating the sphere center.

**Standards and Codes:**

Standard: ASTM E2544-07a - Terminology - approved 2007.

Committee Participation:

ASTM E57 - Chair
ASTM E57.01 - Terminology Subcommittee - Chair and Vice-chair
ASTM E57.02 - Test Methods Subcommittee – Four members.
ASTM E57.04 – Data Interoperability Subcommittee – One member.

Impact: Standards will facilitate industry adoption and will serve as a technology pull to inform manufacturers on necessary improvements to better serve the construction sector.