ASTM E57 3D Imaging Systems Committee:
An Update

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ABSTRACT

In 2006, ASTM committee E57 was established to develop standards for the performance evaluation of 3D imaging systems. The committee's initial focus is on standards for 3D imaging systems typically used for applications including, but not limited to, construction and maintenance, surveying, mapping and terrain characterization, manufacturing (e.g., aerospace, shipbuilding), transportation, mining, mobility, historic preservation, and forensics. ASTM E57 consists of four subcommittees: Terminology, Test Methods, Best Practices, and Data Interoperability. This paper reports the accomplishments of the ASTM E57 3D Imaging Systems committee in 2007.

Keywords: 3D imaging system, ASTM, LADAR, laser scanners, performance evaluation, sensor characterization, standards

1. INTRODUCTION

As the applications for 3D imaging systems continue to grow, the need for standards to evaluate these systems become more critical. There are a few on-going efforts to accomplish this goal. The ASTM E57 3D Imaging committee – established in 2006 – was formed specifically to develop standard terminology, test methods, best practices and data interoperability specifications for these instruments. The Association of German Engineers (VDI) is also developing standards relating to 3D imaging systems - VDI/VDE 2634 Part 2 [1]. Other standards committees that may become involved in developing standards for 3D imaging systems include ISO TC 172/SC6 - Geodetic and surveying instruments and ASME B89.4 - Coordinate Measurement Technology.

This paper will present an update of the activities of the ASTM efforts. The full ASTM E57 committee met in January 2008, and the activities at this meeting are included in this paper. The scope statement for E57 is as follows:

ASTM E57 3D Imaging System Committee Scope Statement

The development of standards for 3D imaging systems, which include, but are not limited to, laser scanners (also known as LADAR or laser radars) and optical range cameras (also known as flash LADAR or 3D range camera).

The initial focus will be on specification and performance evaluation standards for 3D imaging systems for applications including, but not limited to:

- *Construction and Maintenance*
- *Surveying*
- *Mapping and Terrain Characterization*
- *Manufacturing (e.g., aerospace, shipbuilding, etc.)*
- *Transportation*
- *Mining*
- *Mobility*
- *Historic preservation*
- *Forensics*

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The work of this Committee will be coordinated with other ASTM Committees and outside organizations of mutual interest.

As of January 2008, there were 84 registered members of this committee. Current subcommittees of ASTM E57 are working on standards for terminology, test methods, data interoperability, and best practices. Full committee meetings are regularly held in January and again in June of each year. Subcommittees meet more frequently, most often via teleconference.

Because the standards and documents produced by ASTM E57 can have wide-ranging impacts - for example how manufacturer specifications are written, how customers decide on which instrument to purchase, and how contractual language for 3D imaging services are specified, input and participation from the larger 3D imaging community is actively sought. The remainder of this paper provides the current status and future plans of the four subcommittees in E57.

2. SUBCOMMITTEES

2.1. Terminology Subcommittee (E57.01)

The scope statement of the terminology subcommittee is: "The development of terminology commonly used for 3D imaging systems. The work of this Subcommittee will be coordinated with other ASTM E57 Subcommittees."

The subcommittee developed a terminology standard, ASTM E 2544-07 [2], in 2007. This standard contains terms that are specific to 3D imaging systems and these terms are shown in Table 1. Additionally, this standard contains other metrology terms as defined by other standards that are relevant to the 3D imaging community. A set of seven terms, shown in column 2 of Table 1, were submitted for ballot in Dec. 2007. Of the seven terms, five terms require resolution and two terms were approved. The terms shown in column 3 of Table 1 are terms that the subcommittee will be working on.

Table 1. Terminology

Terms in ASTM E2544	**Terms submitted in Dec. 2007 for Ballot**	**Terms To Be Defined**
3D imaging system	**Requires Resolution**	3D image
angular increment	beam diameter	ambiguity interval
beam propagation ratios	control points	angular resolution, lateral resolution, range resolution, spatial resolution
beam width	stigmatic beam	coherent system
first return	spot size	field of view (FOV)
flash LADAR	3D imaging systems	frame
instrument origin		frame rate
last return		imaging device
multiple returns	**Approved in Jan. 2008**	LADAR (laser detection and ranging) / LIDAR (light detection and ranging)
pixel	beam divergence angles	modulation transfer function
point	registration	noise/clutter
point cloud		outlier
second order moments		phase-based system
simple astigmatic beam		pixel cross talk
voxel		point density
		range
		registration error
		scanning -spiral, raster, lissajous
		time-of-flight systems
		triangulation systems

At the committee meeting in January 2008, the subcommittee was able to resolve the terms receiving negative votes (Table 1, 2nd column, "Requires Resolution") with the exception of the term *stigmatic beam*. The subcommittee is currently working on the terms *stigmatic beam, 3D image*, *resolution* - (*lateral, angular, and range*), and *FOV*.

The major challenges that the subcommittee faces when developing definitions include:

- ensuring that the definition applies to or encompasses all instances / conditions / instruments to the extent possible.
- harmonizing the terms across disciplines (the same terms often have different generally accepted definitions within different disciplines – the challenge is to select or develop an appropriate definition that does not conflict with existing use or create ambiguity).
- balancing simplicity and accuracy (technical correctness) of definition.
- having members who have expertise in the varied disciplines (e.g., optics, surveying, physics) that is required when defining terms.

The subcommittee invites suggestions for additional terms but requests that when suggesting a term, the following information be given:

- Justification - why the term is needed
- Context - where/how is the term being used
- Examples of current usage with references if possible
- A proposed definition

The suggestions may be sent to Ms. Gerry Cheok (cheok@nist.gov), chair, or Dr. Kamel Saidi (kamel.saidi@nist.gov), vice-chair.

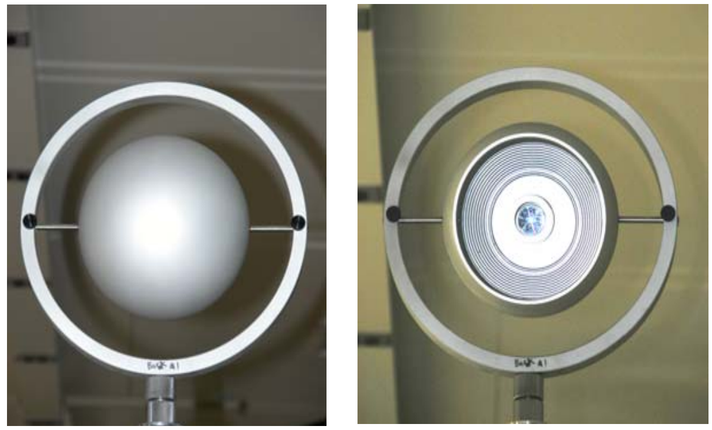
Test Methods Subcommittee (E57.02)

The scope of this subcommittee is: "To develop a standardized set of data collection procedures, data analysis and reporting methods for characterizing the measurement performance of 3-D imaging systems." The subcommittee has been working on a draft protocol, as described in [3], to evaluate the ranging performance of a 3D imaging system. The current draft protocol evaluates the range error as a function of the following four factors: distance, target reflectivity, angle of incidence (AOI), and azimuth angle. The initial version of the protocol called for the use of planar targets and 60 test combinations of the four factors. Among the initial tasks undertaken by the subcommittee was the determination of the practicality of the tests - how long do the tests take, how easy is it to conduct the tests? Two rounds of tests were conducted; the first is described in [3] and was performed in Dec. 2006.

In the second round of tests [4] performed in May 2007, a more objective method was used to pare down the number of tests from the initial 60 tests. Sixteen tests were judged to be a reasonable number that could be completed within a reasonable time frame (i.e., one day). The question was - would 16 tests yield sufficient information? The reduction in the number of tests was achieved through a 4^{4-2} fractional factorial experimental design (4 factors, 4 levels)[1] [5]. In the second round of tests, two types of targets were used - planar and spherical (see Figure 1). It was felt that the use of spherical targets would be easier in terms of test set-up and data analysis. The effects of reflectance and angle-of incidence on measurement error could not be determined using the spherical targets. Thus, only the effect of distance on the range measurement could be determined for the spherical target tests.

[1] This design is geometrically equivalent to the 4 x 4 Graeco-Latin Square.

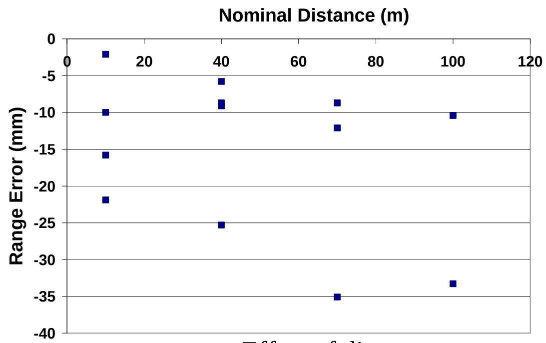
a. Planar target - 99 % reflectivity.



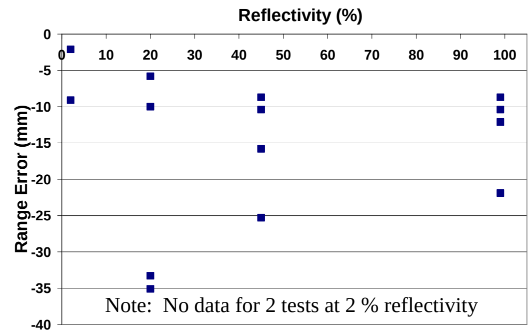
b. Spherical target - the spherical target is a 152 mm (6 in.) diameter spherically mounted retro-reflector (SMR). Front (left image) and back (right image) sides are shown.

Figure 1. Planar and spherical targets used in second round of tests to evaluate the ranging protocol.

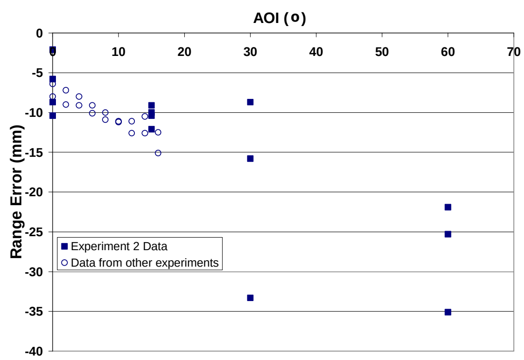
The results of the tests for the planar and spherical targets are shown in Figs. 2 and 3, respectively. From Fig. 2, it can be seen that the effects of the main factors can be determined, i.e., 16 tests are sufficient. There were no results from two of the 16 tests, i.e., no measurements were possible. These two tests involved the target with the lowest reflectivity (2 %) combined with longer distances and higher angle of incidence. Therefore, it may be more useful to specify that the lowest target reflectivity be (10 to 15) % in the range protocol.



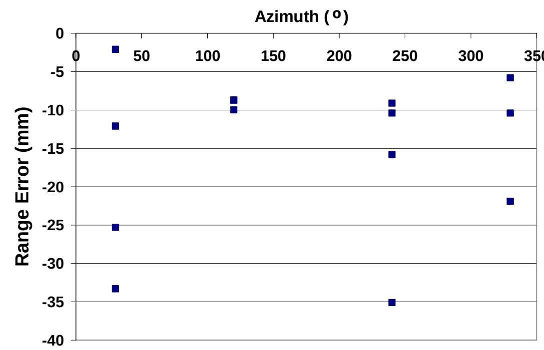
a. Effect of distance



b. Effect of target reflectivity



c. Effect of angle of incidence



d. Effect of azimuth angle

Figure 2. Main factor effects using planar targets.

The purpose of using spherical targets was to determine if spherical targets, as compared to planar targets, were easier to set-up and to determine the target center. As expected, the testing showed that spherical targets were easier to set up and the target center was easier to determine. However, a comparison of Figs. 2a and 3 also show that the range error is significantly influenced by the combination of the four factors and/or that the use of spherical targets yields less error in the range measurement. The use of spherical targets will not easily allow for the determination of the influence of the combined main factors.

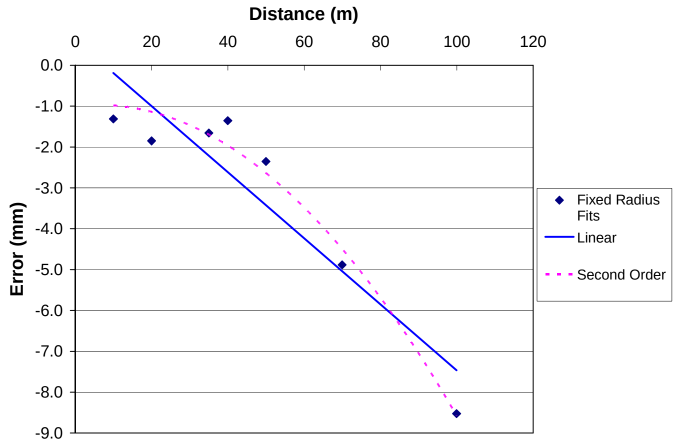


Figure 3. Range error vs. distance using sphere targets.

The discussions of the planar vs. spherical targets and set-up procedures led a manufacturer to suggest an alternate test procedure to evaluate the range. This manufacturer has offered to conduct some initial tests using this procedure, which specifies the use of the target shown in Fig. 4. The target will be made of vapor blasted aluminum (see discussion on targets in this section).   Another member of E57.02 has also offered to perform these tests. The viability and results from these tests will be reported at the June 2008 committee meeting.

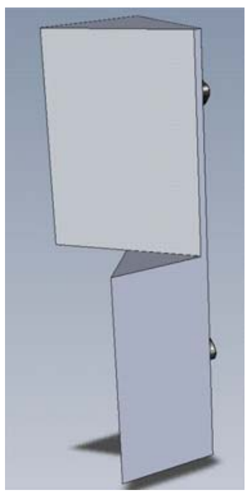


Figure 4. A suggested target for use in the ranging protocol. This target allows for the evaluation of two different incident angles.

The subcommittee faces several issues. A fundamental issue is the purpose of the test - to allow for comparison of instruments (using standard targets) or to evaluate the instrument(s) using real world materials. The former purpose was one of the main reasons for the establishment of ASTM E57 - then as now, there is no objective method to evaluate and compare instruments. The latter is an important issue for service providers who are often asked by clients about the accuracy of the data when measuring materials found in their particular project. The problem with using real world materials is that there are numerous materials and conditions (e.g., wet or dry, surface preparation, types of wood or brick, etc.). Also, the reflectivity of real world material varies with the different instruments (different wavelengths); thus no fair comparison between instruments is possible.

The decision at the January 2008 meeting was to first use a standard target (i.e., similar optical properties for the wavelengths of interest), develop test procedures and evaluate these procedures. The target would be flat (planar) with the size and shape to be decided later. Once the procedures for data acquisition and analysis are agreed upon, these same procedures can then be applied to targets made of other materials. The results from the range tests that the majority of the subcommittee felt should be reported were: 1.) distance error, 2.) a value that gives an indication of the noise of the measurements (e.g., standard deviation of the plane fit), 3.) the time associated to acquire the scan (when the time begins or ends has yet to be decided), and 4.) the number of points or points/area or point spacing.

Target material is another major issue that the subcommittee faces and has spent a majority of their time on in 2007. A diffuse target material, commonly used for general optics tests, is Spectralon[2]. This material has relatively uniform reflectivity for wavelengths from 250 nm to 2500 nm However, penetration of the Spectralon is about 3 mm for the wavelengths (500 nm to 1600 nm) used in most of the commercially available 3D imaging systems. Additionally, target costs are an issue. The ideal target would be diffuse with little or no penetration, have relatively uniform reflectivity for wavelengths between 500 nm and 1600 nm, uniform reflectivity over the entire target surface, robust/stable over time, and inexpensive. Some alternate target materials discussed were vapor or sand blasted aluminum and color cards used for photography. Reasons for using vapor or sand blasted aluminum was that it was relatively diffuse [6] and color cards were inexpensive and readily available. It was also felt that instead of manufacturing a target with stringent optical specifications, it may be easier (and less costly) to measure the optical properties of each target to verify that they are within specified limits. Some measurements of the reflectivity characteristics were made of vapor blasted aluminum and color cards. Further optical measurements of vapor blasted aluminum will be conducted in 2008.

At the January 2008 meeting, a new task group was formed for short-range instruments - instruments with maximum range of 2 m or less. Dr. Steve Phillips (Steven.Phillips@nist.gov) will lead this task group. In general, short-range instruments are more accurate than longer-range instruments. Therefore, tests of short-range systems are expected to be more sensitive to errors introduced by aspects such as target set-up, target material, reference measurements, and other experimental procedures.

Further information on this subcommittee's activities, please contact Mr. David Ober (david.ober@metris.com), chair or Mr. Darin Ingimarson (dingimarson@quatapoint.com), vice-chair.

2.2. Best Practices Subcommittee (E57.03)

The scope of this subcommittee is to develop, validate, document and communicate best practices in the successful and consistent application of 3D imaging technology. Using these practices and guidance, end users can specify application requirements and associated deliverables traceable to accepted standards. Practitioners can determine instrumentation, procedures, and quality control processes yielding work product suited to their application requirements. The subcommittee has defined a best practice as a process or method that, when executed effectively, leads to enhanced project performance.

The initial focus of the Best Practices subcommittee is to provide standard guidelines for the communication of 3D imaging project requirements and deliverables between service providers and customers. The subcommittee has drafted a structure for developing best practices documents (Figure 5). In Fig. 5, the documents at the bottom level (safety, data management, etc.) are common to all projects, and the subcommittee is putting its initial efforts into developing these documents.

[2] Certain trade names and company products are mentioned in the text or identified in an illustration in order to adequately describe the experimental procedure and equipment used. In no case does such an identification imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the products are necessarily the best available for the purpose.

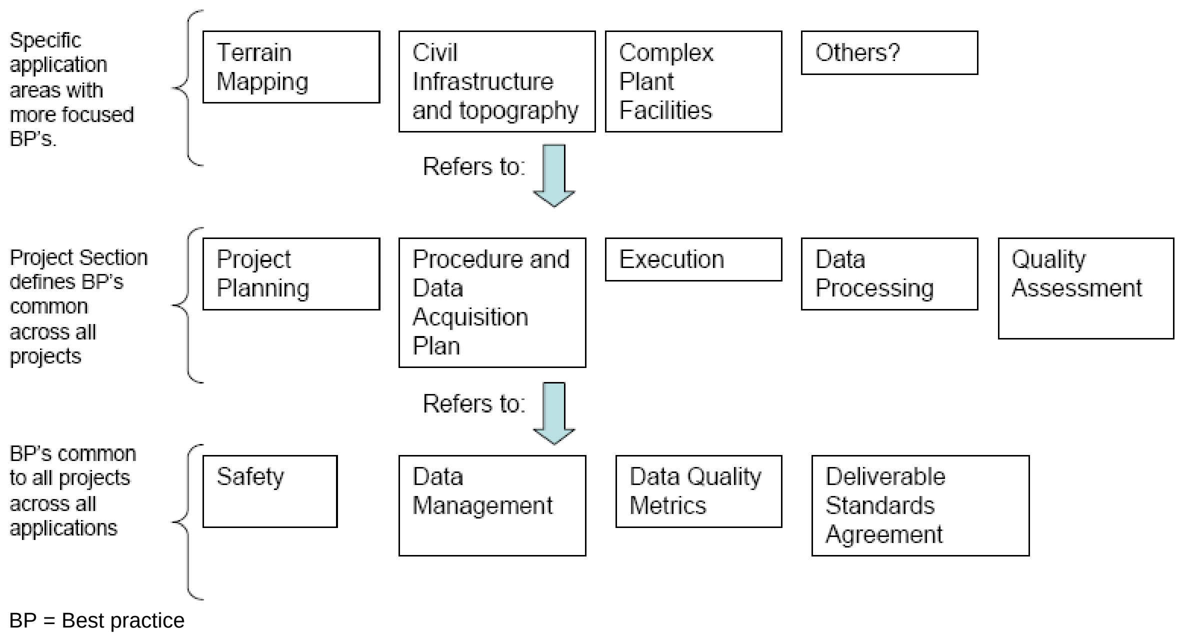


Figure 5. Best Practices Structure (Draft)

Since the June 2007 meeting, the subcommittee has been working on a safety standard and expects to have this done by June 2008. This document does not set prescribed safety standards but rather refers the user to established standards such as OSHA (Occupational Safety and Health Administration) and ANSI (American National Standards Institute). The subcommittee also started developing a document on data quality metrics. This document is expected to communicate best practices in determining and reporting data accuracy.

As reported in [3], E57.03 held a one-day forum in January 2007 to discuss guidelines for communicating 3D imaging projects for the U.S. General Services Administration (GSA) as part of GSA's National 3D-4D Building Information Modeling Program. The input from this forum was incorporated into GSA's draft Guide on 3D Imaging Systems. This draft may be viewed by going to www.gsa.gov/bim and clicking on the 3D Laser Scanning link. Comments on this document may be sent to cheok@nist.gov.

For further information of this subcommittee's activities, please contact Mr. Ted Knaak (tknaak@rieglusa.com), chair or Mr. Eric Hoffman (ehoffman@quantapoint.com), vice-chair.

2.3. Data Interoperability Subcommittee (E57.04)

The scope of the Data Interoperability subcommittee is "To develop and promulgate open standard data exchange mechanisms for 3D imaging system derived data in order to promote its widest possible use." The subcommittee has developed a requirements document - a document that describes the required properties of an acceptable design for a 3D image data format. This document was sent to the full ASTM E57 committee for comment in December 2007. If you would like to review and/or comment on this document please contact, Mr. Gene Roe (gene.roe@autodesk.com), chair or Mr. Mark Klusa (mark.klusza@trimble.com), vice chair of E57.04.

In the requirements document, two categories of intended file usage were identified - data exchange and archiving. These categories have different (but partially overlapping) data and performance requirements. For Exchange Usage, unidirectional data transfer is desired between two software applications: the writer and the reader. In general, the two software applications are written by different vendors and run by different users at different times on different computers with different operating systems. Typically, due to the large amount of data, both writer and reader will store the data internally in a proprietary (disk-based) database format. Typically, the data will be transferred only a single time between writer and reader, and will be stored in the transfer file format for a short duration (< 1 week), after which the transfer file will be deleted.

Archival requirements will not be addressed in the first phase of the interoperability standard, but the requirements will be considered during the initial design to increase the likelihood that they can be accommodated by extension of the standard rather than by replacement.

There are different levels of archival storage goals, with the simplest relating to ensuring the data remains useful over time to more advanced goals such as archiving all information related to the scanning project and maintaining audit logs of changes. Archival Usage may have several requirements that make it different from Exchange Usage, in particular:

- The archival store needs to be more robust over time (possibly decades), which will mean that error detection will need to be more robust, and error correction may need to be accounted for.
- Ideally, the archival store would be completely self documenting. In Exchange Usage, supplementary documents describing the format are acceptable, but an archival store may be found without supplementary documents and the data should be accessible.
- The archival store may need features such as tamper detection and digital signing that are not necessary in an exchange format
- The archival store may need to include more extensive meta-data as well as other types of data related to the work product (such as field notes, digital images, etc.)

The file format shall contain scan data that has been collected from a 3D imaging device which has been corrected to be as accurate as possible in representing the physical world. This raw data should not be processed into other forms such as polygonal models, masked scenes, project models, or process data forms.

The topics covered in the requirements document is given in Fig. 6.

ASTM 3D Image Data Format Requirements
E57.04.01 Data Format Requirements Taskgroup
Version: 0.08 (Draft)

Table of Contents

Figure 6. Table of Contents of the Data Format Requirements Document

Next steps for the Data Interoperability subcommittee in 2008 include:

- complete draft requirements for fixed or static position(s).
- compare requirements with LAS (LASer file format exchange) document (specification for airborne data format)
- research mobile scanning requirements
- develop design proposals
- develop format specification

Because the output of this effort has wide implications for both hardware and software vendors and users, the subcommittee is very actively seeking input/comments on the draft requirements. The design proposals (how the requirements can be achieved) will be discussed at the June 2008 ASTM E57.04 meeting and participation of interested parties at this meeting is strongly encouraged by the subcommittee.

3. SUMMARY / HOW TO PARTICIPATE

This paper presents the current efforts and progress of the ASTM E57 3D Imaging Systems committee and its various subcommittees: terminology, test methods, best practices, and data interoperability.

The terminology subcommittee, E57.01, has produced a standard, ASTM E 2544-07a, in January 2007. They have submitted additional terms for balloting - May and Dec. 2007. Their current efforts involve the addition of new terms to E 2544.

The test methods subcommittee, E57.02, is working on a test method to evaluate the ranging error of 3D imaging systems. The subcommittee has spent a majority of their time in 2007 on the issue of target material. At the January 2008 meeting, the subcommittee 1.) decided to first use a standard target for the range tests and 2.) formed a task group to work on short range instruments.

The best practices subcommittee, E57.03, has developed a scope statement and intends to have a safety standard document ready by June 2008. They are also working on a data quality metrics document.

The data interoperability subcommittee, E57.04, has developed a draft of the requirements document and is seeking comments on this document. The subcommittee intends to develop several design proposals by June 2008. The design proposals are documents describing how the requirements can be met.

As with any consensus based standard, input from the community that it serves is vital. Interested parties may get involved in ASTM E57 by going to the ASTM website (www.astm.org), search for technical committees, and select E57. On the E57 page, there is a committee membership application.

4. ACKNOWLEDGEMENTS

The success of the ASTM E57 3D Imaging Systems Committee is due to the hard work of many volunteer members, and there are too many to list individually. However, the authors wish to formally thank the members of E57 for their time and commitment. Of equal importance, the authors wish to thank the many employers of these members for providing time and travel necessary to move this standards effort forward.

5. REFERENCES

1. *VDI Guideline: VDI/VDE 2634 Part 2, Optical 3D-measuring systems - Optical systems based on area scanning,* VDI (Association of German Engineers), Dusseldorf, Germany, August, 2002.
2. ASTM Standard E2544, 2007a, “Standard Terminology for Three-Dimensional (3-D) Imaging Systems,” ASTM International, West Conshohoken, PA, www.astm.org.
3. Lytle, A. M., Cheok, G. S., and Saidi, K. S., “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, 2007.
4. 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.
5. Box, G. E. P., Hunter, W. G., and Hunter, J. S (1978), *Statistics for Experimenters*, John Wiley and Sons, New York.
6. Bevan, M. G., Darrin, M. A. G., Walts, S. C., Schneider, W., Mills, C. S., and Conde, R. F., “Free-space optical data bus for spacecraft,” in Earth Science Technology Conference, NASA, 2003.