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Advantages of High Tolerance Measurements in Fusion Environments Applying Photogrammetry

T. Dodson, R. Ellis, C. Priniski, S. Raftopoulos, D. Stevens, M. Viola

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Advantages of High Tolerance Measurements in Fusion Environments Applying Photogrammetry

T. Dodson, R. Ellis, C. Priniski, S. Raftopoulos, D. Stevens, M. Viola
Engineering Infrastructure Department
Princeton Plasma Physics Laboratory (PPPL)
Princeton, NJ USA
tdodson@pppl.gov

***Abstract*— Photogrammetry, a state-of-the-art technique of metrology employing digital photographs as the vehicle for measurement, has been investigated in the fusion environment. Benefits of this high tolerance methodology include relatively easy deployment for multiple point measurements and deformation/distortion studies. Depending on the equipment used, photogrammetric systems can reach tolerances of 25 microns (0.001 in) to 100 microns (0.004 in) on a 3-meter object. During the fabrication and assembly of the National Compact Stellarator Experiment (NCSX) the primary measurement systems deployed were CAD coordinate-based computer metrology equipment and supporting algorithms such as both interferometer-aided (IFM) and absolute distance measurement-based (ADM) laser trackers, as well as portable Coordinate Measurement Machine (CMM) arms. Photogrammetry was employed at NCSX as a quick and easy tool to monitor coil distortions incurred during welding operations of the machine assembly process and as a way to reduce assembly downtime for metrology processes.**

This paper will explore the use of photogrammetry on NCSX during field period assembly (FPA) and the results it achieved. It will also explore other applications of this method and discuss future plans for use.

Keywords- photogrammetry, metrology, National Compact Stellarator Experiment, NCSX, measurement

I. Introduction to Photogrammetry

Photogrammetry is a three-dimensional coordinate measuring technique that uses photographs as the fundamental medium for metrology (or measurement). The essential principle utilized for facilitation of the measurement is triangulation. Thus, the survey photographs must be taken from at least two separate locations to develop “lines of sight” from the camera to the object being measured. The “lines of sight” (rays) are then mathematically intersected in order to determine the 3-D location of the points of interest on the object. Points of interest on the object are indicated using retro-reflective targets. These targets come in many different shapes and sizes, and the type of targets used depends solely on the desired measurement. Several types of targets can be seen in Fig. 1.

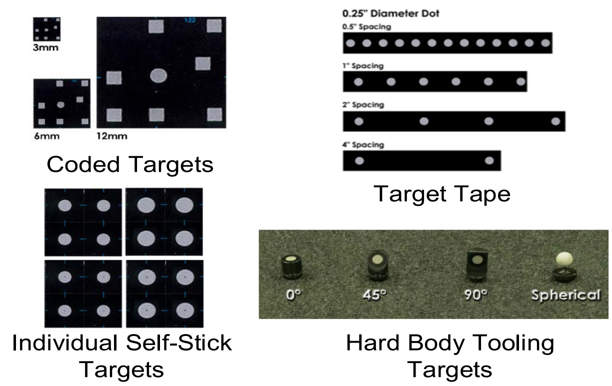

Figure 1. Examples of retro-reflective targets used for photogrammetry

The 3-D coordinates of each target are observed indirectly by finding the center of the circular dot. Each observation of the target is used to create a point cloud of centers where the mathematical center of the cloud is calculated to be the actual 3-D location of the point of interest on the object. The x, y, and z values are delivered by the software complete with their subsequent accuracy. Thus, the quality of the data can be viewed both instantly and easily.

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II. The Use of Photogrammetry on NCSX

Photogrammetry was introduced to the National Compact Stellarator Experiment (NCSX) project in January of 2008. The aim of the system was to minimize downtime attributed to metrology processes during Station 2 of Field Period Assembly (FPA) where the coils were assembled into the 3-packs that would be wound onto the vacuum vessel. The system was initially thought to either replace or supplement many of the Laser Tracker measurements. Since each coil had approximately eighty (80) fiducials, which could be measured with the Laser Tracker throughout the course of about one day, the speed and ease of photogrammetry served as a positive risk for the activities of the time-critical Station 2.

After review of several brands of photogrammetry systems, PPPL opted for a Geodetic Systems Incorporated (GSI) based system using a modified commercial-off-the-shelf (COTS) Nikon D2Xs digital camera and V-Stars software. During the training and integration of the photogrammetry system it was used in tandem with Laser Tracker, mimicking the measurements that it took in order to validate the system and establish a process in which it would be used.

A photograph of two NCSX Coils that are targeted and ready for survey can be seen in Fig. 2. During the survey, attention must be paid to ensure each target is captured per established photograph criteria:

- At least 12 well-distributed targets per photo
- At least 4 well-distributed coded targets per photo
- 2-D objects require at least 6 photos
- 3-D objects require at least 4 photos
    - Both must have at least 3 different camera stations (locations where the photos are taken)
- Each target must be seen at least 4 times
- Overlap photos to accomplish these goals

The camera must also be rotated 90 degrees, at least once, to facilitate self-calibration of the system during the survey as well.

Fig. 3 is an example of a post survey image processed by the software. V-Stars reduces the digital images to ten (10) shades of grey in order to easily distinguish the targeted points from any “false” targets. The identified targets are then labeled and measured.

Fig. 4 is an example of the V-Stars software 3-D representation of the measured points. Once the measurement is completed, the points are assigned coordinates based on the system established by the user (driver file) or a default system that is established by the software using the location of the first measured camera station.

Figure 2. A photograph of two NCSX Coils targeted and ready for survey.

Figure 3. An example of post-survey image processing by the software.

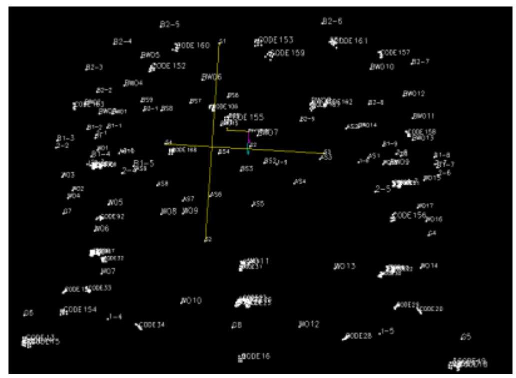

Figure 4. The V-Stars software 3-D representation of the measured points.

III. RESULTS

It was found that photogrammetry was best used to monitor the distortions of the septum during the welding processes and to survey the modular coil fiducials during assembly. Since there was no way to monitor the welding real time, photogrammetry proved to be a viable replacement for the Laser Tracker here because of the ability of the system to capture a large amount of data in a short period of time and was able to deliver results comparable to those of the Laser Tracker whose accuracy was about 0.04 mm (~0.0015 in) as seen in Fig. 5.

An additional benefit of photogrammetry is self-calibration through roll diversity. This simple process is completed by taking at least one of the photos with the camera at a 90 degree difference from the other photos, doing away with the time spent on reevaluating the Laser Tracker alignment and sight checks. After overcoming the learning curve of the V-Stars software, the same 80 fiducials were able to be surveyed using photogrammetry in twelve (12) minutes. Once the survey was complete, it took roughly twenty (20) minutes to complete the measurement and compute the 3-D coordinates of the fiducials in the software, once the driver file was completed.[1] Though

[1] A driver file is a file that can be created in V-Stars to ease the processing of repetitive measurements. It can be used to define

the significant time savings that photogrammetry could provide were not fully realized due to the untimely stopping of the NCSX project, it was useful for it to serve as a verification of the data presented by the Laser Tracker during the tandem use of the two systems.

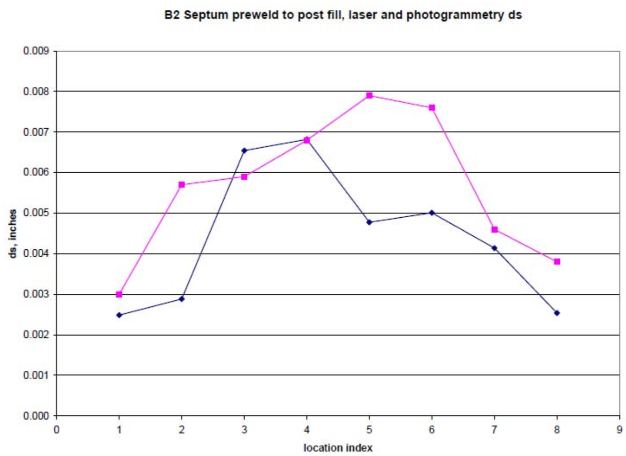

Figure 5. Photogrammetry data (pink) was shown to agree with the data taken by the Laser Tracker (blue). Deviations were well within the acceptable range for error.

IV. Other Applications

Photogrammetry is a widely used metrology method with current applications in the aerospace, antenna building, automotive, nuclear, and shipbuilding industries. Aside from its use on NCSX, in December 2008 the PPPL system was used to characterize Port 270 of the DIII-D Tokamak at General Atomics (GA) to facilitate the design and installation of the new ECEI diagnostic. The proposed area for the new diagnostic serves as a machine access point and walkway. The preliminary design of the diagnostic required an accurate knowledge of objects in the area with which it could possibly collide. The photogrammetric data gathered was easily converted into an IGES file that can be uploaded and manipulated by almost any CAD software, facilitating simple model construction of the local area around the port as well as the measurement of distances between components in the surrounding area that previously were uncharacterized.

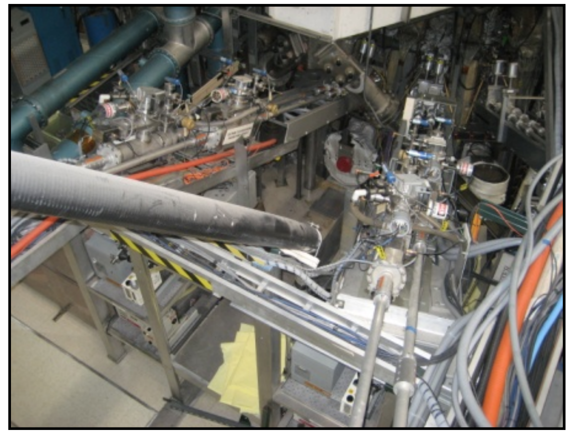

Figure 6. Photograph of DIII-D Port 270 in situ.

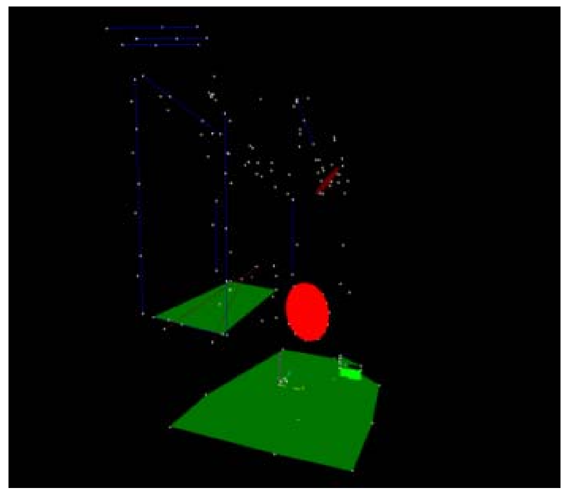

Figure 7. V-Stars representation of the measured data with a mock-up of the surfaces of interest. Port 270 is shown by the red circle.

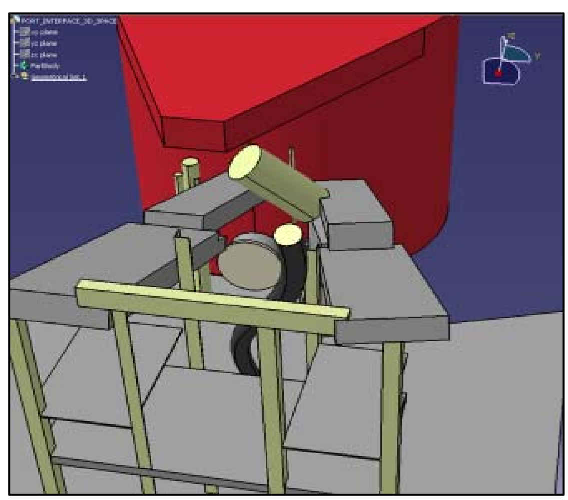

Figure 8. A CAD model generated from the data gathered by the photogrammetry.

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the desired coordinate system, reference data, and labeling convention, among others.

V. SUMMARY OF THE ADVANTAGES OF USING PHOTOGRAMMETRY

In comparison to the Laser Tracker, photogrammetry proved to be an easy way to gather a large amount of data in minimal time. The GSI V-Stars software provided a way to quickly determine the quality of the data that was collected. If the data was found to be lacking, or targeted points were missing, repeating or supplementing the measurement was fast and easy to complete. Most importantly, the speed of the process did not detract from the accuracy of the measurement, as it was shown to give results comparable to those of the Laser Tracker as well.

VI. FUTURE PLANS

Currently, the National Spherical Torus Experiment (NSTX) at PPPL is undergoing an upgrade to the center solenoid of the machine. Additionally, installation of a third neutral beam is planned and in the initial design phases. Photogrammetry will conceivably be used to position and/or document the final position of the coils, coil support structures, and beam box during the assembly and installation activities. Prior to this, completion of a survey of the current layout of the NSTX coils is also being discussed.

ACKNOWLEDGMENTS

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Information Services
Princeton Plasma Physics Laboratory
P.O. Box 451
Princeton, NJ 08543

Phone: 609-243-2750
Fax: 609-243-2751
e-mail: pppl_info@pppl.gov
Internet Address: http://www.pppl.gov