Photogrammetric Approach to Monitor Radiation Safety System at APS*

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Abstract

One of the many responsibilities of the Survey and Alignment Team at the Advanced Photon Source (APS) is the periodic monitoring of the positional stability of the Radiation Safety System (RSS). The RSS for all operational experiment x-ray beamlines consists of approximately one thousand (1,000) components. Access to these components is limited to a brief maintenance period, and the use of traditional survey techniques and optical tooling is very time consuming. The APS Survey and Alignment Team is currently testing the suitability of close range industrial photogrammetry for this application. Initial results discussed in this poster suggest that an inexpensive fully automated photogrammetric system is capable of quickly determining 3D position of targeted points with accuracy well below 0.5 mm.

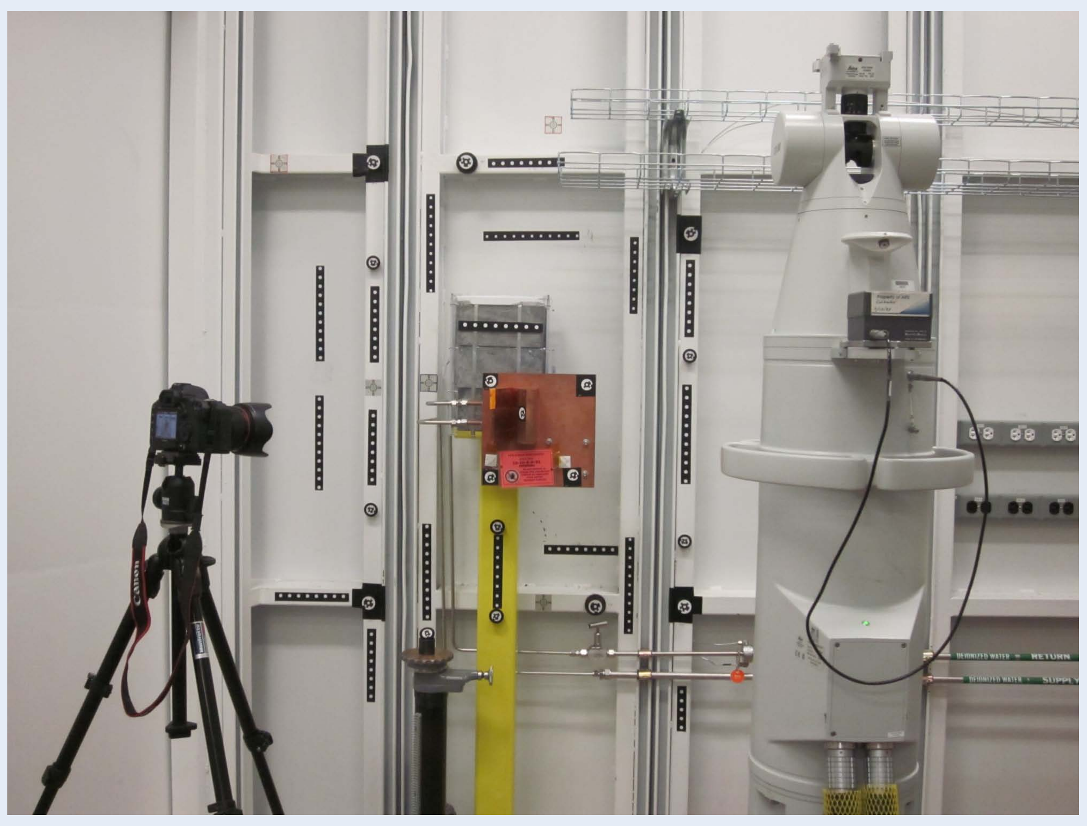

Figure 1. APS Sector 16-ID Beamline Sta. D.

Introduction

The constraints of short access time and time needed to measure RSS components using traditional methods motivated us to investigate the applicability of photogrammetric approach to remedy our situation. The two (2) key questions we tried to answer by going through these exercises were:

1. Is the accuracy of an inexpensive but fully automated photogrammetric system based on a consumer grade high resolution DSLR camera and commercially available state-of-the-art photogrammetric software better than 1 mm in the real environment of an APS beamline experiment station?
2. Is such a photogrammetric system capable of detecting component motions smaller than 1 mm within a fixed reference frame of the experiment station?

To find the answers we conducted two (2) sets of exercises to measure an actual Beam Stop in the experiment station D, 16-ID Beamline at APS (Figure 1). The photogrammetric system consisted of a Canon 5D Mark II digital SLR camera with full-frame CMOS sensor with 21.1 effective megapixels and PhotoModeler ver. 6.0 photogrammetric software from Eos Systems, Inc. The 1st set involved only coded targets, and the 2nd set a combination of coded and un-coded targets. The photogrammetric data were then compared directly to the measurements from Leica Laser Tracker LTD500 recently calibrated to NIST traceable standards.

Figure 2. Tooling microscope with special fixture used for in-house production of RAD coded spherical targets compatible with Laser Tracker and optical targets.

Figure 3. Interchangeable 1.5″ diameter spherical targets (Laser Tracker, optical, photogrammetry) used to measure 3D control points.

Methodology

- Camera was calibrated utilizing 12 images of the calibration grid with 144 targets provided by PhotoModeler.
- RAD (Ringed Automatically Detected) coded targets were printed in scale designed for the farthest anticipated distance. The 1.5″ diameter spherical targets compatible with Laser Tracker retro reflector were built in house (Figures 2-3).
- Control points defined by magnetic cups and ring magnets were strategically situated around the RSS component (Figures 5-6).
- Stick-on targets were permanently glued on the RSS component and around it as additional temporary tie points (Figures 5-6).
- Images were taken from multiple camera positions (8-11 images per data set). Effort was made to capture at least 8-10 coded targets on each photo and each target to appear on 2-3 photos minimally.
- Commercial software package PhotoModeler was used for all photogrammetric data processing – including camera calibration, RAD coded targets printing, automatic sub-pixel marking (Figure 7), automatic referencing, and bundle adjustment (Figure 4).
- All common control points were measured with a Laser Tracker.
- One point (target code #200) mounted on a linear translation stage was moved approximately 1 mm to simulate RSS component displacement.
- The displacement of this point (#200) was measured by the Laser Tracker.
- The second set of photogrammetric data was taken after the displacement.
- The 7-parameter least squares fit of photogrammetric coordinates was performed utilizing common control points and results were tabulated and analyzed (Figures 8-9).
- This process was repeated for the second test utilizing combination of RAD coded and un-coded targets (Figures 10-11).

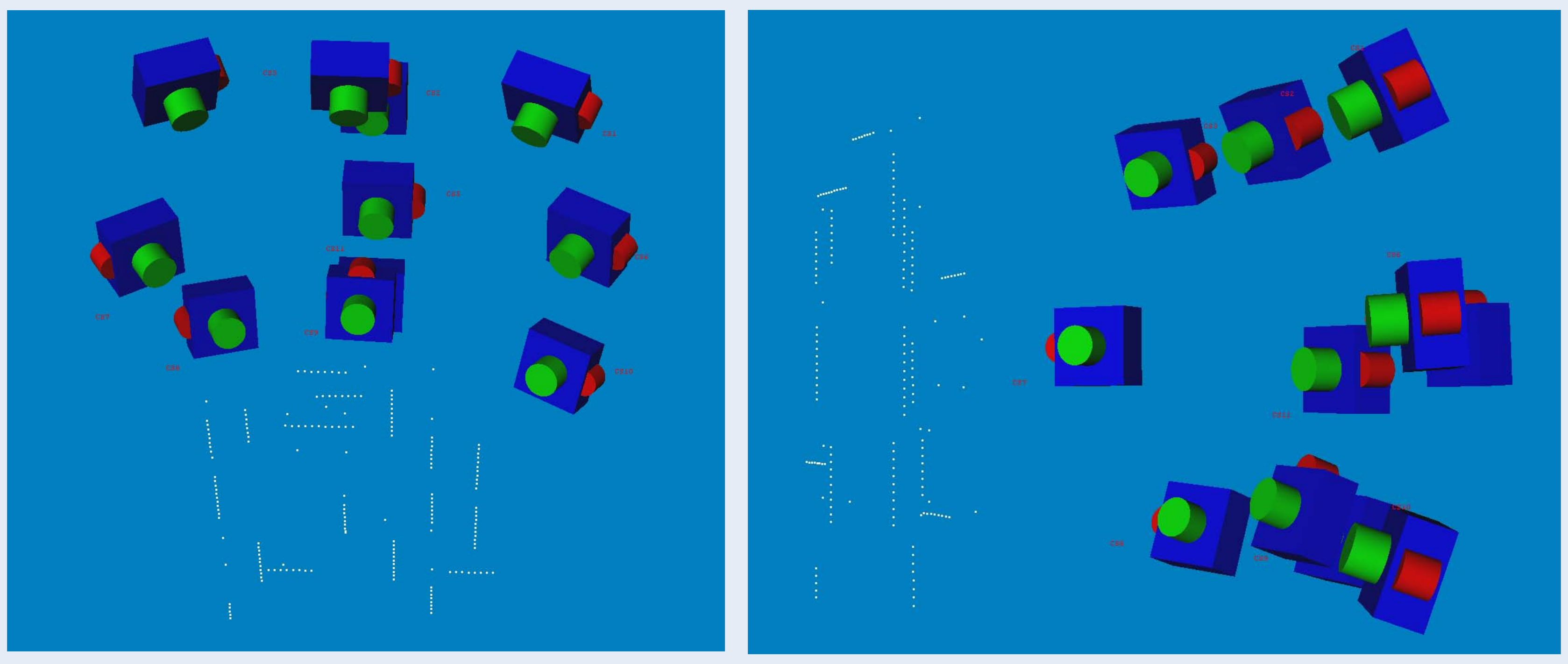

Figure 4. Photomodeler's 3D Viewer displays the final set of 3D points and camera locations and orientations as determined by bundle adjustment algorithm.

Figure 5. Combination of RAD coded and un-coded targets.

Figure 6. RAD coded targets only.

Figure 7. Automatic detection and marking of the sub-pixel centroid of the target.

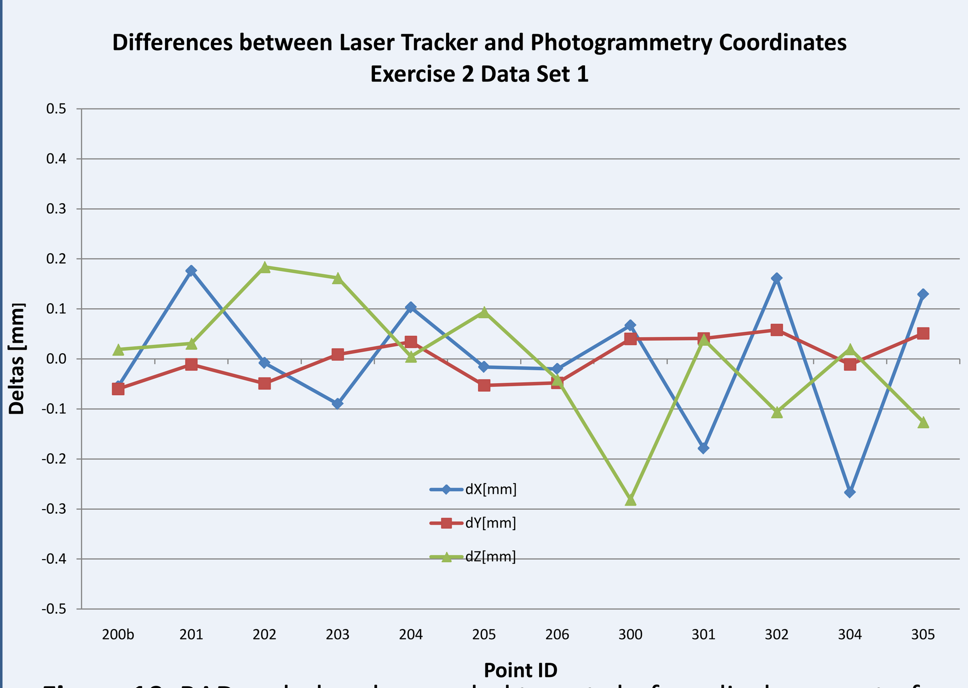

Figure 10. RAD coded and un-coded targets before displacement of target #200.

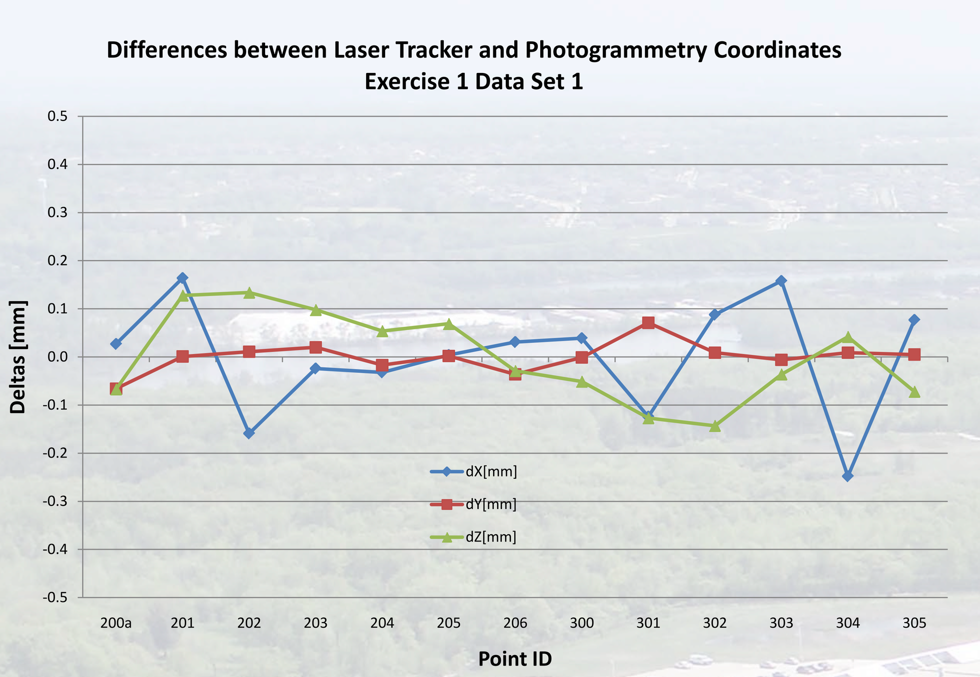

Figure 8. Only RAD coded targets before displacement of target #200.

Motion Detection Test #1								
Measurement	LASER TRACKER				PHOTOGRAMMETRY			
	X[m]	Y[m]	Z[m]	vector length [m]	X[m]	Y[m]	Z[m]	vector length [m]
Pt 200a	5.233137	2.730124	0.986671		5.233164	2.730058	0.986604	
Pt 200aM (moved point 200a	5.232137	2.730117	0.986676		5.232243	2.730135	0.986621	
Displacement (200aM-200a)	-0.001000	-0.000007	0.000005	**0.001000**	-0.000921	0.000077	0.000017	**0.000924**

Figure 12. Photogrammetric method detected movement of Point 200 to be at 0.924 mm as compared with Laser Tracker observation of 1.000 mm.

Motion Detection Test #2								
Measurement	LASER TRACKER				PHOTOGRAMMETRY			
	X[m]	Y[m]	Z[m]	vector length [m]	X[m]	Y[m]	Z[m]	vector length [m]
Pt 200b	5.200889	2.727887	0.986541		5.200834	2.727827	0.98656	
Pt 200bM (moved point 200b)	5.201890	2.727898	0.986556		5.201752	2.727707	0.986351	
Displacement (200bM-200b)	0.001001	0.000011	0.000015	**0.001001**	0.000918	-0.000120	-0.000209	**0.000949**

Figure 13. Photogrammetric method detected movement of Point 200 to be at 0.949 mm as compared with Laser Tracker observation of 1.001 mm.

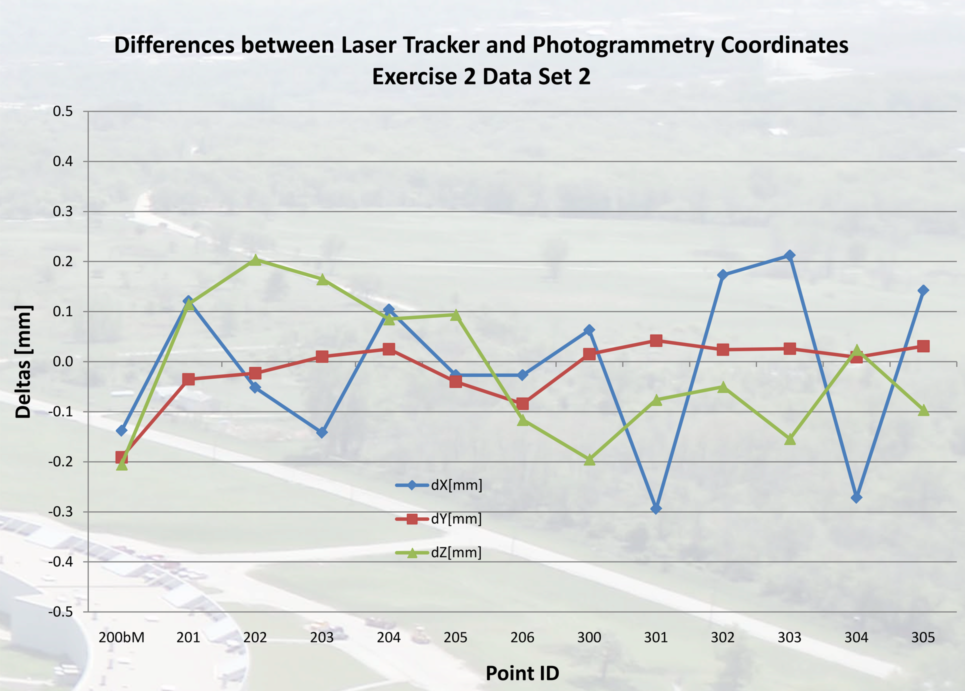

Figure 11. RAD coded and un-coded targets after displacement of target #200.

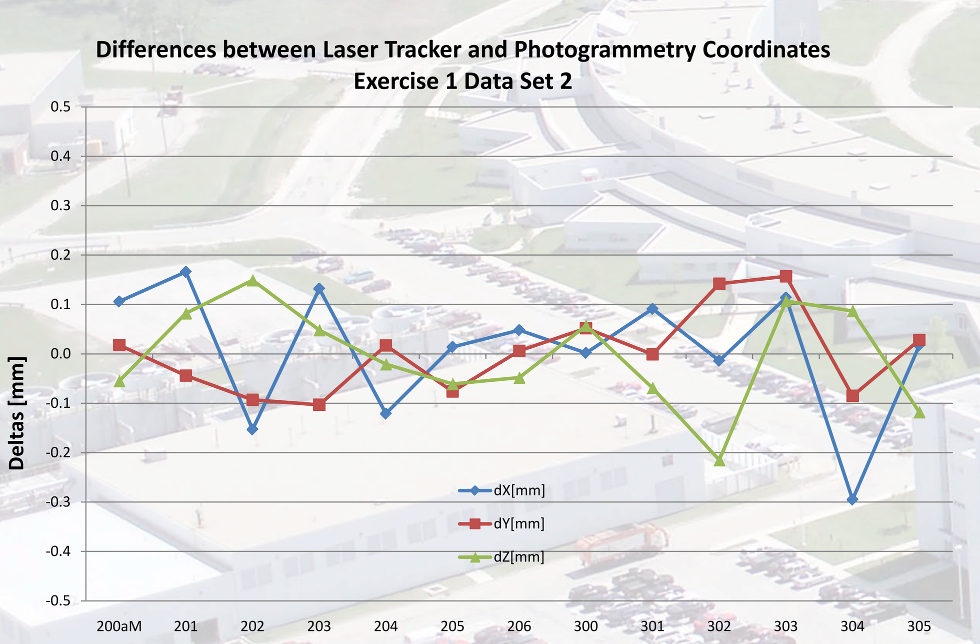

Figure 9. Only RAD coded targets after displacement of target #200.

Conclusion

Initial results were encouraging. The 3D coordinates of targeted points obtained by photogrammetric survey matched the Laser Tracker data better than expected for non-metric camera (Figures 8-11). The total RMS errors of four (4) data sets of measurements ranged from 0.086 mm to 0.120 mm. The simulated 1 mm displacement detected by photogrammetric means was of great confidence (Figures 12-13), making us believe this innovative approach offers a viable alternative for the monitoring of positional stability of the APS Radiation Safety System.

One of the lessons learned, however, was the avoidance in the use of un-coded targets. While processing of RAD coded targets was almost 100% automatic and error free, the un-coded targets were not always marked and referenced correctly. In the future we are also planning to do more detailed testing of retro-reflecting targets. We were very impressed that our inexpensive photogrammetric system (under $7K) was competitive in terms of accuracy and speed with technologies costing one order higher. With the fast advancement in consumer digital cameras we expect cameras with higher resolution to soon appear on the market at comparable prices. This will translate directly into much higher accuracy for pixel-based systems at the same cost.

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