Standards for Ground Control for Geospatial Data & Dual-Sensor Configurations

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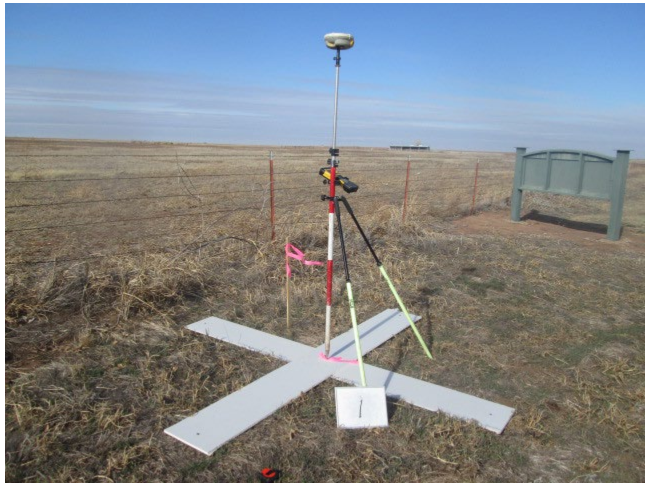
Definitions: GCPs vs. Checkpoints

- Ground Control Points (GCPs)
  - Points with known (surveyed) horizontal and/or vertical coordinates **used as fixed references in establishing attitude and position** of geospatial data wrt a defined datum and coordinate system
    - Example: GCPs used in photogrammetric aerial triangulation (AT)
- Checkpoints
  - **Used to assess spatial accuracy** of final geospatial products (e.g., orthoimagery and point clouds)
  - Must be “independent source of higher accuracy” than data being tested
    - The “independence” criterion necessitates that GCPs and checkpoints be separate from one another
      - In no case can a point that was used as a GCP also be used as a checkpoint
- *“GCPs are used to **improve** the accuracy; checkpoints are used to **test** the accuracy.”*

Note: historically, collecting GCPs has been 10-50% of total cost of a project (Wolf et al., 2014)



Horizontal vs. Vertical vs. 3D GCPs and check points

- Horizontal
  - Well-defined points with accurate planimetric (*X*, *Y*) coordinates
  - Distinct, identifiable in geospatial data
    - Examples:
      - Sidewalk intersections
      - Corners of tennis court
      - Paint stripes
      - Pre-positioned targets (photo panels)
- Vertical
  - Not necessarily required to be clearly-identifiable, well-defined points
  - Accurate height
  - At locations that minimize interpolation errors (low slopes; not near breaklines)
- 3D
  - Need to meet both sets of requirements: must be well-defined and have accurate 3D spatial coordinates (*X*, *Y*, *Z*)

ASPRS Positional Accuracy Standards for Digital Geospatial Data

(EDITION 1, VERSION 1.0. - NOVEMBER, 2014)

Photogrammetric Engineering & Remote Sensing
Vol. 81, No. 3, March 2015, pp. A1–A26.
0099-1112/15/813–A1

doi: 10.14358/PERS.81.3.A1-A26

- First Edition of *ASPRS Positional Accuracy Standards for Digital Geospatial Data*
  - Published in 2014
  - Serves as industry standard (e.g., used in contracting specs)
  - Superseded legacy standards
    - 1947 *National Map Accuracy Standards (NMAS)*
    - 1990 *ASPRS Accuracy Standards for Large-Scale Maps*
    - 2004 *ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data*
- Over past decade
  - Accuracies of geospatial data products continued to improve
  - Emerging technologies for generating geospatial products, such as UAS and structure from motion (SfM) photogrammetry
  - Some challenges noted by users of the standards

Second Edition of *ASPRS Positional Accuracy Standards for Digital Geospatial Data*

- **Team**
  - Dr. Qassim Abdullah, Woolpert
  - Josh Nimetz, USGS
  - Dr. Riadh Munjy, CSU – Fresno
  - Mike Zoltek, GPI
  - Colin Lee, MnDOT

- **Revision Working Sub-Groups**
  - Lidar Mapping Best Practices and Guidelines
  - – Lead: Sagar Deshpande, Dewberry
  - Photogrammetric Mapping Best Practices and Guidelines
  - – Lead: Dr. Riadh Munjy, CSU - Fresno
  - UAS-based Mapping Best Practices and Guidelines
  - – Lead: Jacob Lopez, Towill
  - Field Surveying Techniques Best Practices and Guidelines
  - – Lead: Jim Gillis, VeriDaaS Corporation

Important Change 1: Easing accuracy requirement for GCPs and Checkpoints

- 1st Edition (2014)
  - GCPs: 4X more accurate than produced geospatial products
  - Checkpoints: 3X more accurate than produced geospatial products
- 2nd Edition (2023)
  - GCPs photogrammetry and lidar: 2X more accurate than produced geospatial products
  - Checkpoints for photogrammetry and lidar: 2X more accurate than produced geospatial products
- Reasons for change
  - Accuracy of geospatial products has continued to improve
    - UAS-SfM projects can easily produce orthos and point clouds with accuracies on the order of 4-6 cm, horizontal and vertical, respectively
  - Edition 1 accuracies for GCPs and checkpoints can't be met with RTK GNSS
  - With today's high-accuracy geospatial products, no longer need "safety factor" in GCP and checkpoint accuracies

Important Change 2: Factoring in the accuracy of the surveyed check points when computing product accuracy

- 1st Edition (2014)
  - Ignored errors in surveyed checkpoints in quantifying product accuracy (considered negligible)
- 2nd Edition (2023)
  - Factor in the accuracy of surveyed checkpoints in quantifying product accuracy
- Example

$$RMSE_z = \sqrt{(8.00)^2 + (2.00)^2} = 8.25 \text{ cm}$$

Fit to checkpoints RMSE (8.00) — Checkpoint accuracy (2.00)

- Reasons for change
  - As accuracy of geospatial products continues to improve, the impact of errors in checkpoint coordinates on computed product accuracies becomes larger
  - With today's high-accuracy geospatial products, no longer need "safety factor" in GCP and checkpoint accuracies

Important Change 3: Required Number of Checkpoints

- 1st Edition (2014)
  - In no case shall an NVA, digital orthoimagery accuracy or planimetric data accuracy be based on less than **20 checkpoints**
- 2nd Edition (2023)
  - In no case shall the test for…data accuracy…be based on less than **30 check points**
- Reasons for change
  - The previous requirement of 20 checkpoints was not based on statistics or science
  - Avoid small sample sizes (low # of checkpoints), which can bias your accuracy assessment

Other Important Changes

- Definition of 3D positional accuracy
- Accuracy measure of 95% confidence level is removed due to the confusion it creates for users of the standard
  - Just report RMSEs
  - Standards do still provide methods for converting from RMSE to 95% C/L values for those who need to do so
- Removal of the fail/pass requirement of Vegetated Vertical Accuracy (VVA) for lidar data
- Addition of Best Practices and Guidelines Addendums

Another GCP and checkpoint requirement from Standards

- "Unless specified to the contrary, it is expected that all ground control and check points should normally follow the guidelines for network accuracy as detailed in the Geospatial Positioning Accuracy Standards, Part 2: Standards for Geodetic Networks, Federal Geodetic Control Subcommittee, Federal Geographic Data Committee (FGDC-STD-007.2-1998)."

Accuracy requirements for GCPs for AT

- GCPs used for AT should have higher accuracy than the expected accuracy of derived products :
  - Accuracy of ground control designed for **planimetric data** (orthoimagery and/or digital planimetric map) production only:
    - $RMSE_{H(GCP)} = 1/2 \times RMSE_{H(Map)}$
    - $RMSE_{z(GCP)} = RMSE_{H(Map)}$
  - Accuracy of ground control designed for **elevation data**, or planimetric data and elevation data production:
    - $RMSE_{H(GCP)} = 1/2 \times RMSE_{H(Map}$
    - $RMSE_{z(GCP)}= 1/2 \times RMSE_{z(DEM)}$

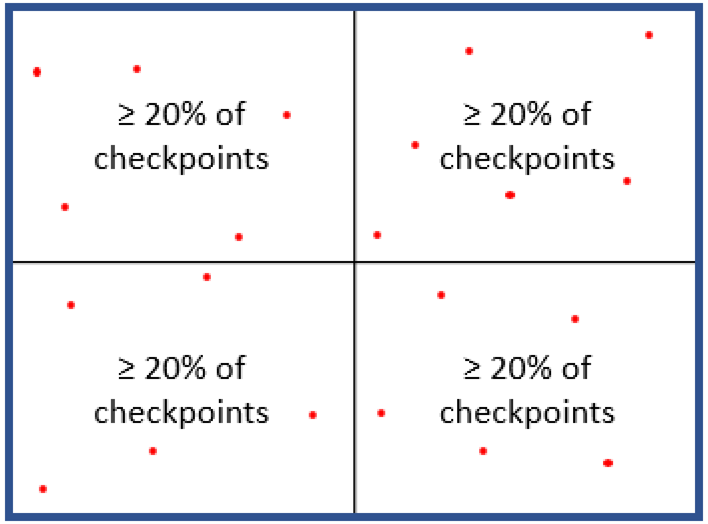
Interpretation: if your final products are planimetric-only, the vertical accuracy of the GCPs doesn't have to be as high

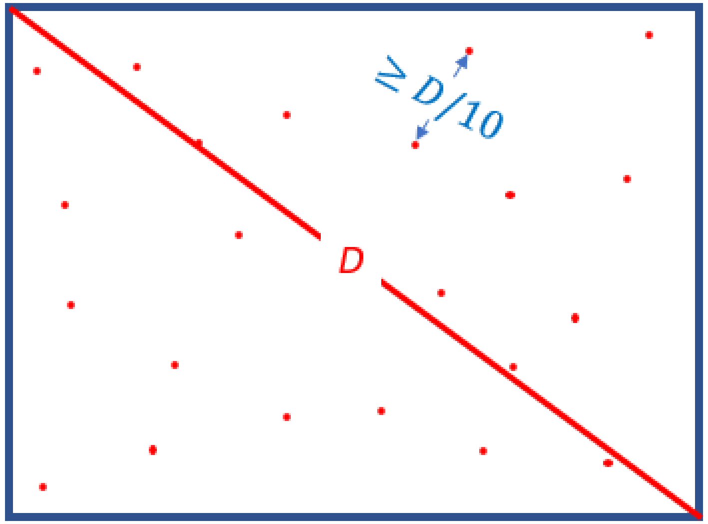
Accuracy requirements for Lidar GCPs

- GCPs used for lidar calibration and boresighting should be 2X more accurate than the derived product
- Similarly, independent check points required to assess lidar data accuracy should be 2X more accurate than the tested product
- Similar requirements can be followed for other digital data acquisition technologies such as IFSAR

Checkpoint placement requirements (density and distribution)

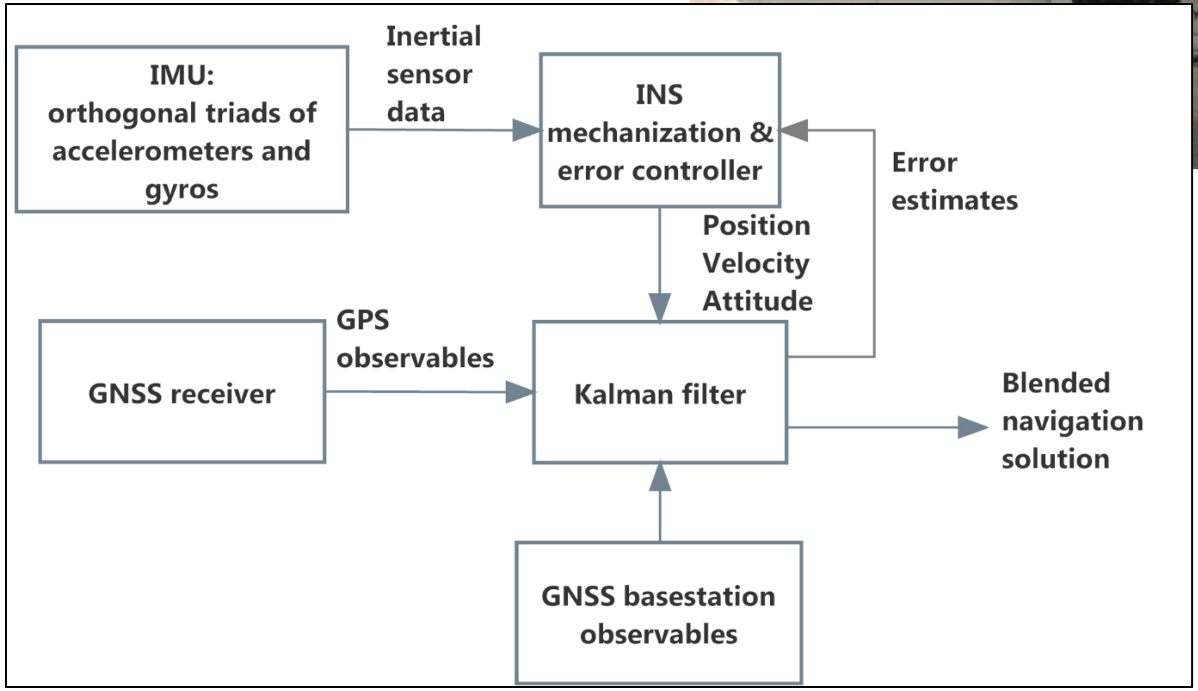
- “When accuracy testing is to be performed, check points should be well distributed around the project area as much as possible” (ASPRS, 2023)
- Following **FGDC NSSDA**
  - Checkpoints may be distributed more densely in the vicinity of important features
  - For a data set covering a rectangular area that is believed to have uniform positional accuracy, checkpoints may be distributed so that points are spaced at intervals of at least 10% of the diagonal distance across the data set and at least 20% of the points are located in each quadrant of the data set.
  - Where it is not geometrically or practically applicable to strictly apply the NSSDA method, data vendors should use their best professional judgment



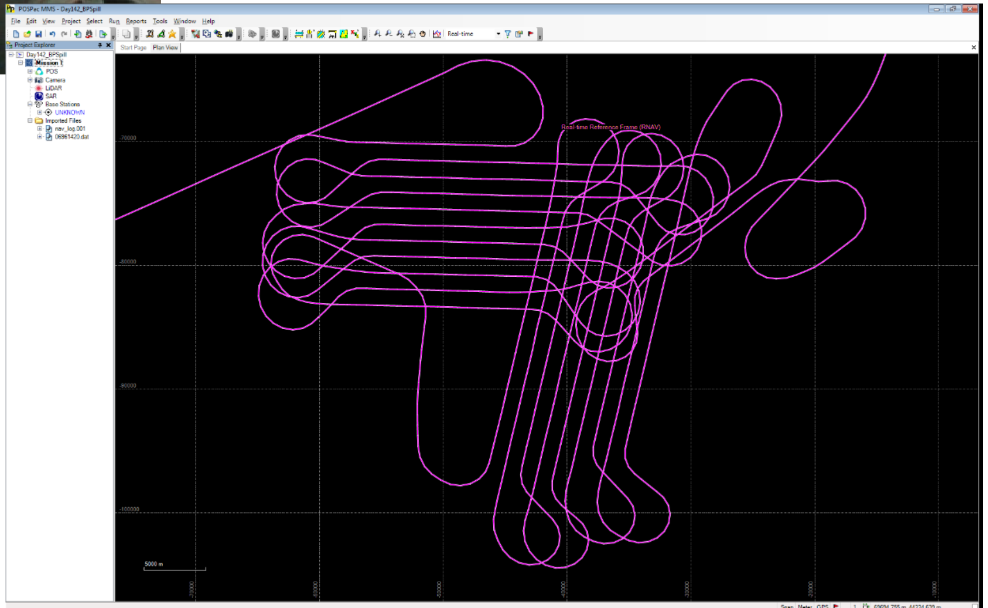


Adapted from Ruiz-Lendínez et al., 2019

Reducing GCP requirements through Direct Georeferencing: GNSS-aided Inertial Navigation Systems (INS)



“For IMU-based direct orientation, image orientation angle quality shall be evaluated by comparing check point coordinates read from the imagery (using stereo photogrammetric measurements or other appropriate method) to the coordinates of the check point as determined from higher accuracy source data” (ASPRS, 2023)



Next Steps and Timeline for 2nd Edition of *ASPRS Positional Accuracy Standards for Digital Geospatial Data*

- Public comment period
  - Today through March 15, 2023
  - Send to ASPRS Board of Directors for Approval: April 12, 2023
- Documents:
- ASPRS Positional Accuracy Standard, 2nd Edition - Main Body and Annexes
- ASPRS Positional Accuracy Standard, 2nd Edition - Addendum I: General Guidelines and Best Practices
- ASPRS Positional Accuracy Standard, 2nd Edition - Addendum II: Field Survey Guidelines and Best Practices
- Google Form for public feedback: Google Form: https://forms.gle/rtn3ofZSZue9Pzrd9

Lidar horizontal GCPs and checkpoints

- For lidar data, horizontal GCPs and checkpoints are often not used, due to the resolution challenge
- ASPRS Standards contain empirical TPU equation:

$$Lidar\ Horizontal\ Error(RMSE_H) = \sqrt{(GNSS\ positional\ error)^2 + \left(\frac{tan\ (IMU\ role\ or\ pitch\ error) + tan\ (IMU\ heading\ \ error)}{1.47800114}\ x\ flying\ altitude\right)^2}$$

- Historically
  - Sparse point clouds
  - Didn’t always have intensity
  - GCPs needed to be identifiable in point clouds

See photo and point cloud containing lidar round tabletop ground targets in this paper:

Csanyi, N. and Toth, C.K., 2007. Improvement of lidar data accuracy using lidar-specific ground targets. *Photogrammetric Engineering & Remote Sensing*, *73*(4), pp.385-396.

Route Scene:
https://www.routescene.com/ground-control/uav-ground-control-targets/

But: Is this changing?

- Most lidar systems collect intensity data, in addition to *X*, *Y*, *Z* coordinates
- Point densities are much higher than in the past

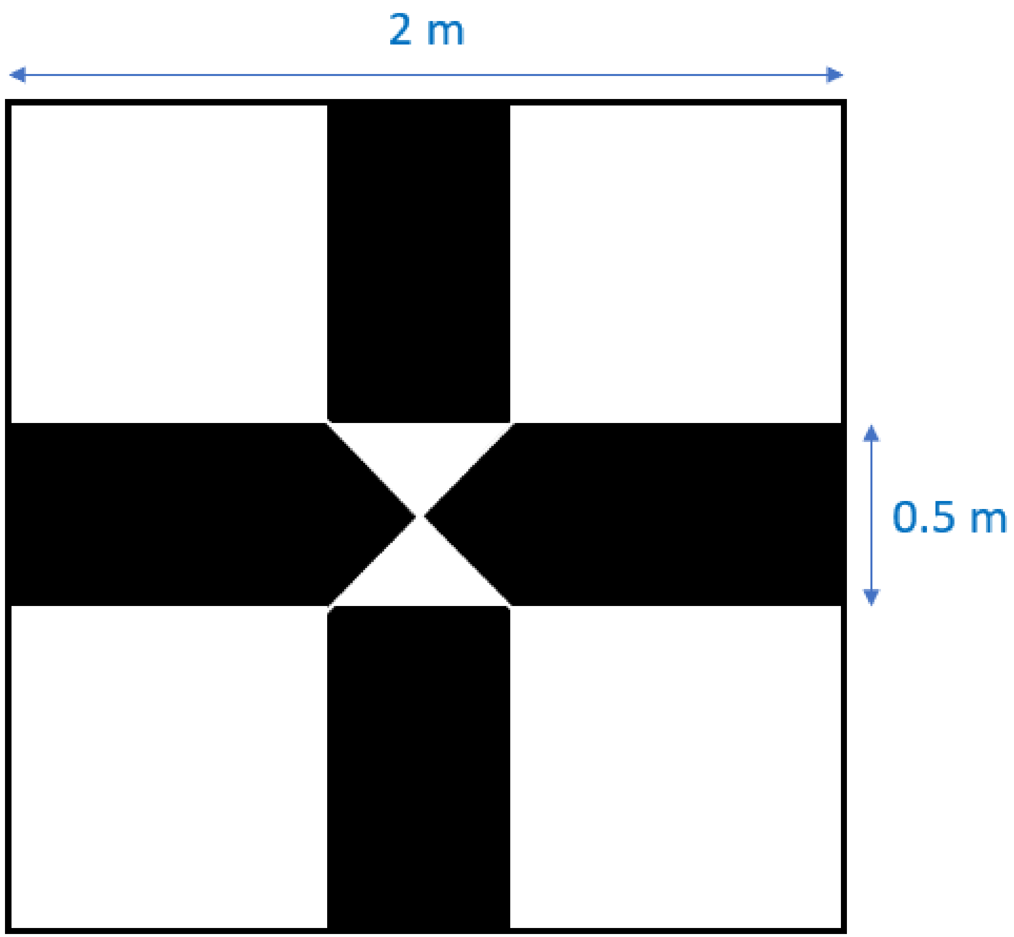
➢ **Can today's lidar systems support using same GCPs and checkpoints as imagery?**

➢ **Can dual-sensor collects use a single set of GCPs and single set of checkpoints**

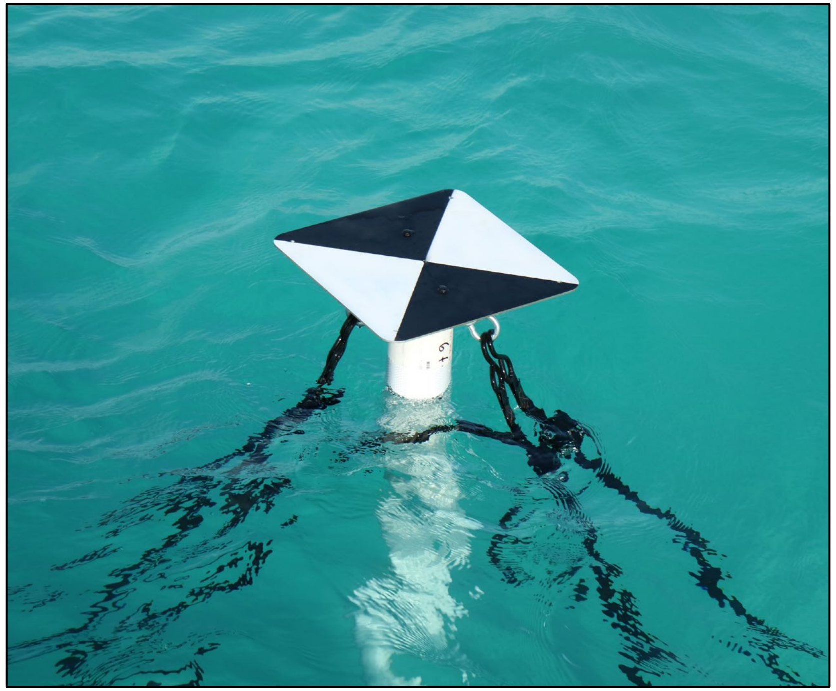
- Main challenge: vastly differing spatial resolutions
  - Lidar median point spacing is typically much less than GSD of imaging sensor
  - Ex: 10 cm imagery GSD vs. 8 pt/m^2 lidar density (corresponding to 35 cm point spacing)

Possible solution

- Panels designed specifically for multi-resolution sensor configurations
- “Nested” panel design
  - Panel within a panel



And, a topic for a future meeting…bathymetric GCPs and checkpoints…



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