Independent Accuracy Checks for Motion-Compensated LiDAR

by Amanda Whaling

Isn't it satisfying to say with confidence, "This XYZ point is accurate to within ±X meters"?

For hydrographic surveyors, independently verifying the accuracy of a single XYZ derived from a sounding is not usually feasible. We typically rely on:

- GNSS quality indicators
- IMU performance specifications
- Patch test results
- Crosslines and statistical comparisons

But those are internal consistency checks. They do not compare your dataset to a completely independent measurement method at the same physical location.

When you can independently verify XYZ accuracy—at multiple spatial locations—you gain meaningful insight into the true performance of your system and overall survey workflow.

Luckily for land surveyors, target-based validation methods are available. In drone-based LiDAR workflows, highly visible ground control points (GCPs)—such as checkerboard or "X" panels—are placed on surveyed locations. After collecting data in HYPACK HYSWEEP Survey, the HSX files can be opened in the Multibeam Editor (MBMAX64), where the cursor tool can be used to extract each target's center. These targets are easy to identify in the point cloud because the white portions of the panels reflect significantly more laser energy than the black portions. When the point cloud is colored by intensity in MBMAX64 (more on that later), this difference in reflectivity creates strong contrast, allowing the targets to stand out clearly.

Comparing the extracted centers to the surveyed coordinates provides a direct, quantitative check of accuracy, and if the differences fall within tolerance, confidence in the dataset is substantially increased.

The Problem with Vertical Scanning from a Vessel

When I was performing motion-compensated streambank LiDAR surveys from a canoe using HYPACK® (**Fig 1**), I knew I was going to need an independent accuracy check on my final XYZ point cloud, because the operational environment introduced additional uncertainty:

- Multipath near banks and structures
- Poor cellular coverage (loss of RTK corrections)
- Variable vessel speed due to dynamic flow

Figure 1

However, the GCP workflow breaks down when scanning vertically oriented features from the water or a vehicle on the ground. A planar checkerboard placed on the bank—even if visible on the ground from the vessel—might not be intersected by any laser returns due to scan geometry, grazing incidence angles, and vegetation occlusion.

Borrowing a Technique from Terrestrial LiDAR: Target Spheres

The solution comes from established terrestrial laser scanning (TLS) workflows that use target spheres for registration and control verification. Bright white spheres of known diameter are mounted over surveyed control points, providing a clean and symmetric geometric surface whose center can be reliably computed from the point cloud.

Because the spheres are clearly visible in overlapping scans, you can use processing software to isolate their returns and compute their centers using a least-squares best fit. Those computed centers are then used for target-based registration, tying scans into a common coordinate frame and georeferencing the dataset. After adjusting for the known sphere radius and measured tripod height, the derived coordinate can be directly compared to the surveyed benchmark.

While motion-compensated LiDAR collected using HYPACK HYSWEEP Survey is already georeferenced (via integration of an inertial navigation system), the sphere method can still be used—not for registration—but for independent accuracy assessment.

Figure 2

Field Deployment Strategy

To implement this in a water or ground-based mobile mapping scenario:

1. **Establish benchmarks:** Place multiple surveyed benchmarks along the survey reach.

2. **Position spheres:** Mount target spheres over each benchmark, ensuring they remain within the scanner's field of view (**Fig 2**).

3. **Record sphere metadata:** Carefully measure and record tripod height and sphere diameter.

4. **Acquire LiDAR data:** Conduct the mobile mapping survey as normal.

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Post-Processing Strategy

In MBMAX64, the spheres stand out clearly when the point cloud is colored by intensity (**Fig 3**) because the stronger return signal from their surfaces results in higher recorded intensity values, making them more visually distinct from surrounding features compared to coloring by Elevation (**Fig 4**).

Figure 3

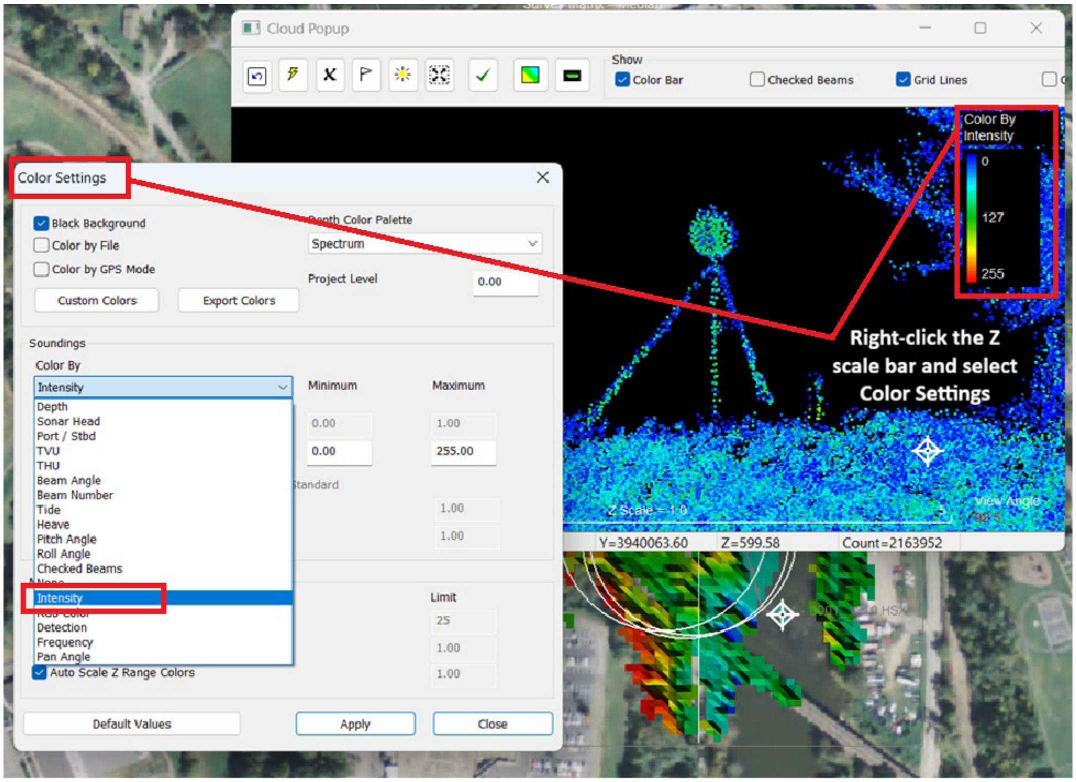
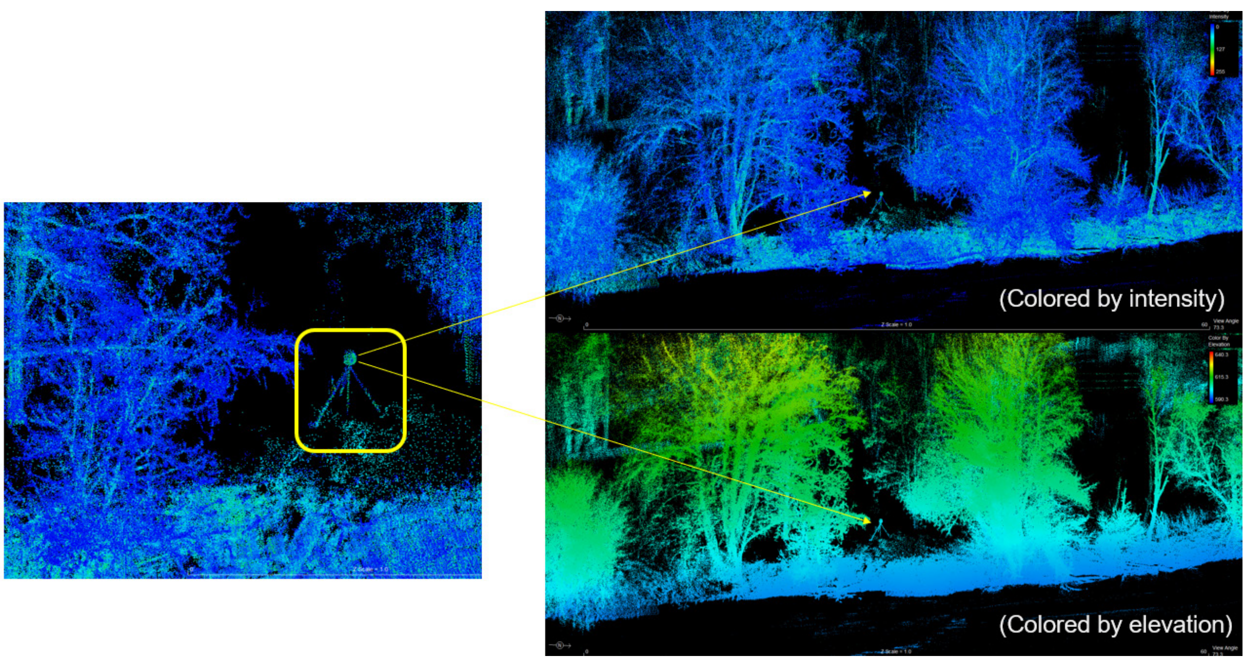


Figure 4



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Here is the step-by-step approach I used:

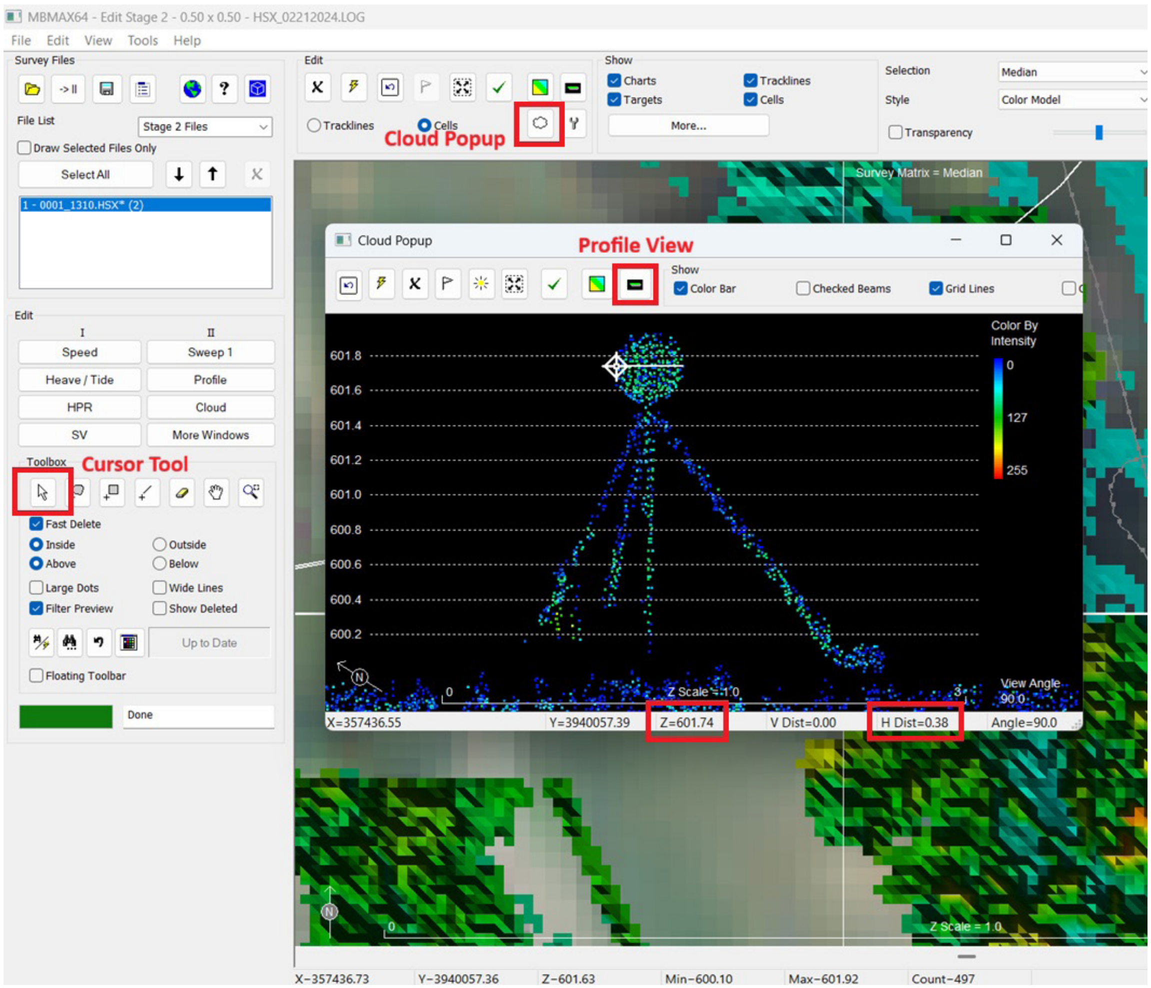
1. **Load the dataset:** First, open the LiDAR dataset in MBMAX64.

2. **Identify sphere locations:** To make this easier, you can first create a Target in the HYPACK Shell at the known benchmark location. In MBMAX64, enable Targets in the Show tray and open the Cloud Popup window with the point cloud colored by Intensity. You can also use Go to Position from the Tools menu and enter the known benchmark coordinates (hopefully your target sphere appears directly on top of it!).

3. **Compute Z from profile view:** Zoom in within the Cloud Popup window and switch to Profile View, orienting the point cloud so it matches the direction from which the scanner's laser beams intersected the sphere. Using the Cursor tool, click the outermost left and right edges of the sphere to capture the widest span; the distance between these two points should equal the known sphere diameter. Record the corresponding Z values and compute their average. Repeat this process for the topmost and bottommost points of the sphere in the same orientation, again averaging the recorded Z values. Subtract the known sphere radius and the measured tripod height from the averaged Z value to determine the benchmark elevation derived from the LiDAR dataset (**Fig 5**).

Note: For best results, perform this analysis on a separate edited file with surrounding points removed so that only the sphere and tripod remain.

Figure 5



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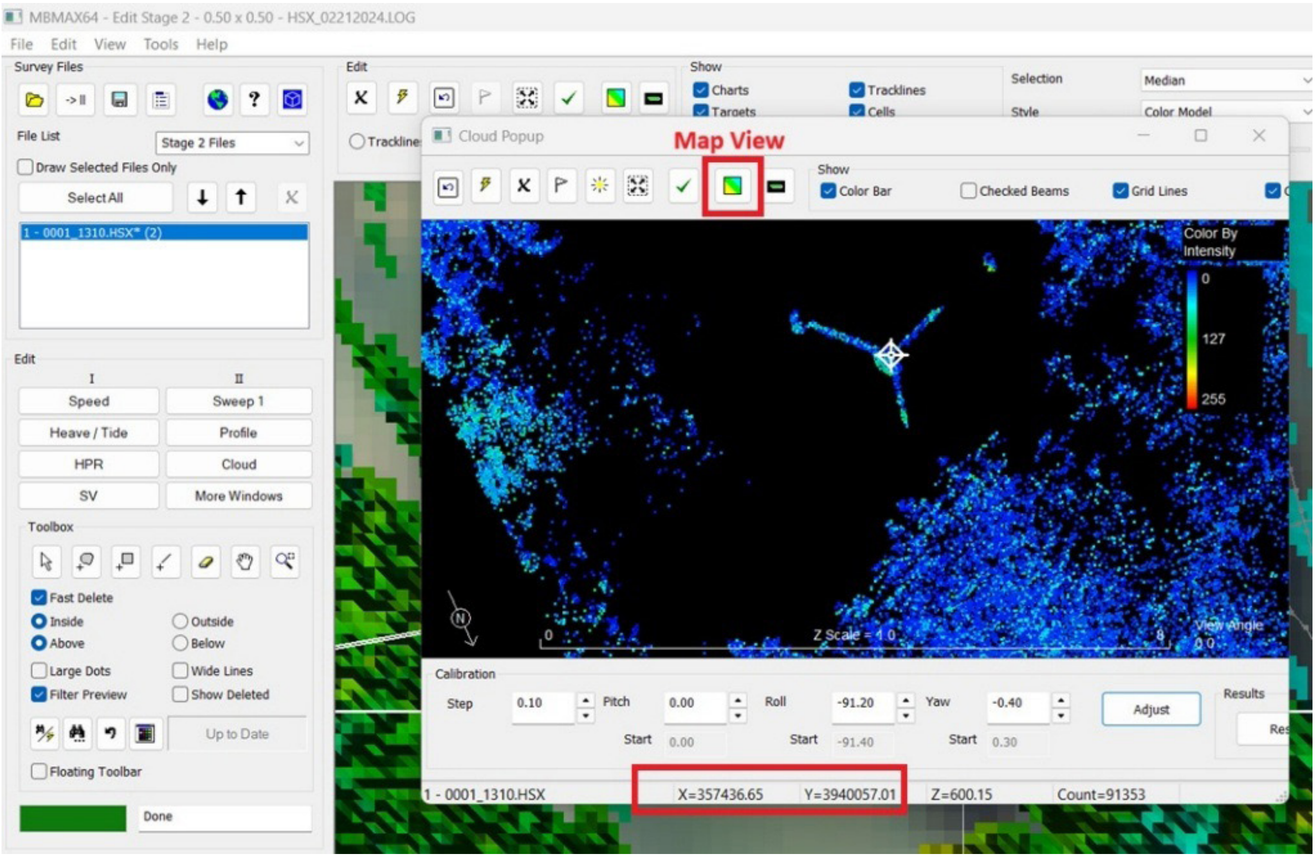
4. **Compute the sphere center:** Use the Map View in the Cloud Popup window to view the target sphere from above and use a similar approach. You may have to get creative since the vessel-mounted LiDAR only captured the river-facing hemisphere the sphere. For example, you can place a Target directly on the center tripod pole near its base to determine sphere's XY center instead of the sphere directly.

Figure 6



5. **Compute horizontal and vertical RMS:** Compare the LiDAR-derived benchmark coordinates to the independently surveyed coordinates and calculate the root mean square (RMS) error in both the horizontal (X/Y) and vertical (Z) directions to quantify the accuracy of the point cloud.

Lessons Learned in the Field

Initially, for my streambank surveys, I tried using 14cm SECO target spheres. These work well for static terrestrial scanners and low beam divergence systems that result in dense point clouds. However, the system I used was a Velodyne VLP-16 ("Puck"), which has a larger beam divergence and lower point density at distance. Combined with downstream vessel motion, the resulting returns on small spheres were insufficiently defined for reliable center fitting.

Upgrading to larger KOPPA spheres shown in Figure 6 significantly improved target detectability, return density, and geometric clarity.

Establishing Benchmark Truth

Where does the independent XYZ coordinate come from?

If no published control exists within your survey area, you will need to establish your own benchmark. Ideally, a permanent monument can be set if repeat surveys are planned; otherwise, a temporary monument—such as driven rebar—can be used. Next, perform a static GNSS occupation of four or more hours to support processing through the National Geodetic Survey Online Positioning User Service (OPUS), which provides the benchmark's coordinates and elevation. Longer occupations generally improve solution robustness and reduce coordinate uncertainty. Once the OPUS-derived coordinates are obtained, they can be compared directly against the sphere-derived LiDAR coordinates for independent accuracy validation.

The Results

In this case, independently derived LiDAR coordinates were within 3cm horizontally and 6cm vertically. Given the environmental challenges I was facing and the LiDAR sensor's specifications, this method provides a true independent accuracy check, quantified performance, documentation, evidence for QA/QC reporting, and confidence when performing repeat surveys or volume calculations. It is one thing to believe your motion-compensated LiDAR solution is accurate, it is another thing entirely to independently prove it!

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