

The AG2I Voxelite™ as a Control Surface: Certification of Disparate Datasets by Reference Alignment

Intersection Test Area One · OpenVoxelite / OpenLineWorks

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Abstract

An AG2I Voxelite™ is a geospatial primitive: an orthoimage fused with a coincident elevation surface and stored as a single four-band raster (R, G, B, Z). When the Voxelite is generated from an aerotriangulated aerial survey, it carries a known, control-derived accuracy. This report defines the use of such a Voxelite as a *control surface* — a certified spatial reference to which disparate datasets are registered, so that an aligned dataset inherits the reference accuracy to within the measured registration residual. The registration is performed by OpenLineWorks, which matches an input dataset to a reference raster using dense feature correspondence (LoFTR, or SIFT/ORB with normalised cross-correlation) and a thin-plate-spline warp. Planimetric control transfer is demonstrated on two real datasets: a 0.25 m public orthoimage registered to a 0.08 m reference (633 tie points, pre-registration mean offset 1.18 m), and a 0.30 m public orthoimage registered to a 0.05 m reference (630 tie points, pre-registration mean offset 14.8 m). Layered integration of an HD-map vector set, an uncontrolled mobile-LiDAR point cloud, and a Voxelite over a single urban intersection is shown. Principal limitations: the current registration uses the image bands only and does not consume the Voxelite Z band, so control transfer is presently planimetric; the accuracy-inheritance computation is defined here but not yet implemented in code; and the residual measured at the registration tie points is a fitting floor, not an accuracy — a certified figure requires independent check points.

1. Data

- **Voxelite reference surface** — four-band R,G,B,Z GeoTIFF generated from the Dragon aerial survey DSM and true-ortho (0.05 m GSD, EPSG:25833), gap-free over the surveyed area.
- **High-accuracy reference orthos** (control-transfer tests) — 0.08 m aerial ortho (Barcelona); 0.05 m aerial ortho (Gleisdorf, Austria).
- **Disparate datasets registered to reference** — 0.25 m public orthoimage (Barcelona); 0.30 m public orthoimage (Gleisdorf).
- **Layered-scene datasets** (Intersection Test Area One):
 - HD-map vector set — lane edges, lane centres, road markings, signs, signals.
 - **Mobile LiDAR** — collected without ground control; positioning by IMU/GNSS and a distance-measuring instrument (rear-wheel encoder). No certified accuracy.

- Voxelite surface over the intersection.
- All datasets in WGS84 / UTM ellipsoidal metres; no reprojection between layers.

2. The AG2I Voxelite primitive

An AG2I Voxelite stores, per pixel, the three colour bands of an orthoimage and a fourth band giving the surface elevation Z at that pixel. XY is given by the GeoTIFF geotransform; the CRS is embedded. Viewed from directly above it is an orthoimage; viewed obliquely it is a coloured surface model with photographic texture on every cell. It is a continuous, gap-free surface generated from the DSM and true-ortho of a photogrammetric survey, in contrast to a point cloud, which is sparse and gapped at low density.

The surface is 2.5D: each XY has exactly one Z . It does not represent overhangs, vertical faces, or multi-level structure. Three-dimensional scene content (LiDAR returns, poles, wires, building geometry) is rendered above the surface, which provides their spatial and photographic context.

Position of the primitive relative to standard products:

Product	Geometry	Carries	Accuracy role
DEM / DTM	2.5D raster	bare-earth elevation	terrain shape; no colour
DSM	2.5D raster	top-surface elevation	surface shape; no colour
Orthophoto	2D raster	rectified colour	map-accurate colour; elevation borrowed from the rectifying DTM
Voxel / voxelmap	3D volume	per-cell occupancy/attributes	volumetric; no inherent survey reference
Voxelite	2.5D surface, R,G,B,Z per cell	colour and elevation, gap-free	survey-referenced surface; serves as a control surface

3. Method: control transfer

Definitions. The *control surface* is the certified reference (the Voxelite). *Control transfer* is the registration of a disparate dataset to the control surface. A *conformed stack* is a set of datasets all registered to one control surface and therefore sharing one accuracy reference.

Registration pipeline (OpenLineWorks). (1) coarse alignment from GNSS/IMU or manual seeds; (2) dense feature matching of the input to the reference raster — LoFTR where a GPU is available, otherwise SIFT or ORB with normalised-cross-correlation autocorrelation; (3) RANSAC outlier rejection; (4) thin-plate-spline warp; (5) iterative re-match and re-warp (“refry”) to convergence; (6) georeferenced output. Vectors and LiDAR are carried through the solved warp by the `transform-vectors` and `transform-lidar` operations.

Accuracy model. Let the control surface have accuracy σ_{ref} (one sigma, from its survey control) and let the registration residual against independent check points be σ_{align} . The aligned dataset’s accuracy is

$$\sigma_{\text{dataset}} = \sqrt{(\sigma_{\text{ref}}^2 + \sigma_{\text{align}}^2)}.$$

When $\sigma_{\text{align}} \ll \sigma_{\text{ref}}$ the aligned dataset approaches the reference accuracy class. This model is the certification rule; its implementation is listed as outstanding in §5.

4. Results

4.1 Planimetric control transfer (real data)

Dataset	Source GSD	Reference GSD	Tie points	Pre-registration mean offset	Pre-registration max offset
Barcelona	0.25 m	0.08 m	633	1.18 m	3.57 m
Gleisdorf	0.30 m	0.05 m	630	14.8 m	38.7 m

In both cases the dense matcher produced 600+ correspondences and the thin-plate-spline warp registered the source to the reference. The residual evaluated at the tie points is at the numerical floor (the spline interpolates its own control points), and is therefore **not** an accuracy statement; an independent-check-point accuracy is pending (§5). The meaningful measured quantity is the offset removed: a 1.18 m mean (max 3.57 m) and a 14.8 m mean (max 38.7 m) gross misregistration brought onto the reference frame.

4.2 Layered integration (Intersection Test Area One)

The control surface integrates an abstract vector map and an uncontrolled point cloud into one coherent scene.

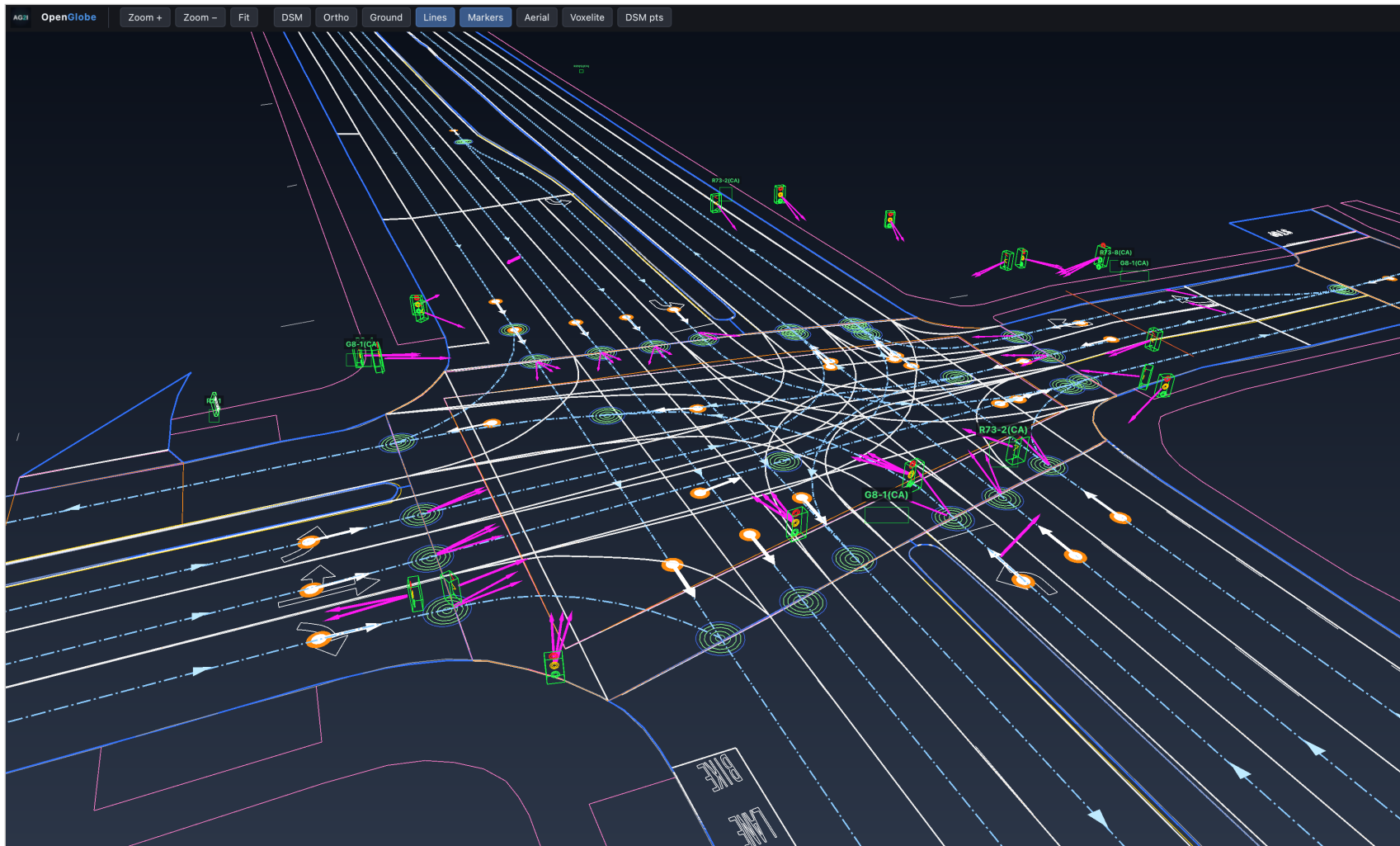


Figure 1. HD-map vector set — lane edges and centres, markings, signs, signals — rendered without a surface. The geometry is precise but has no ground reference.

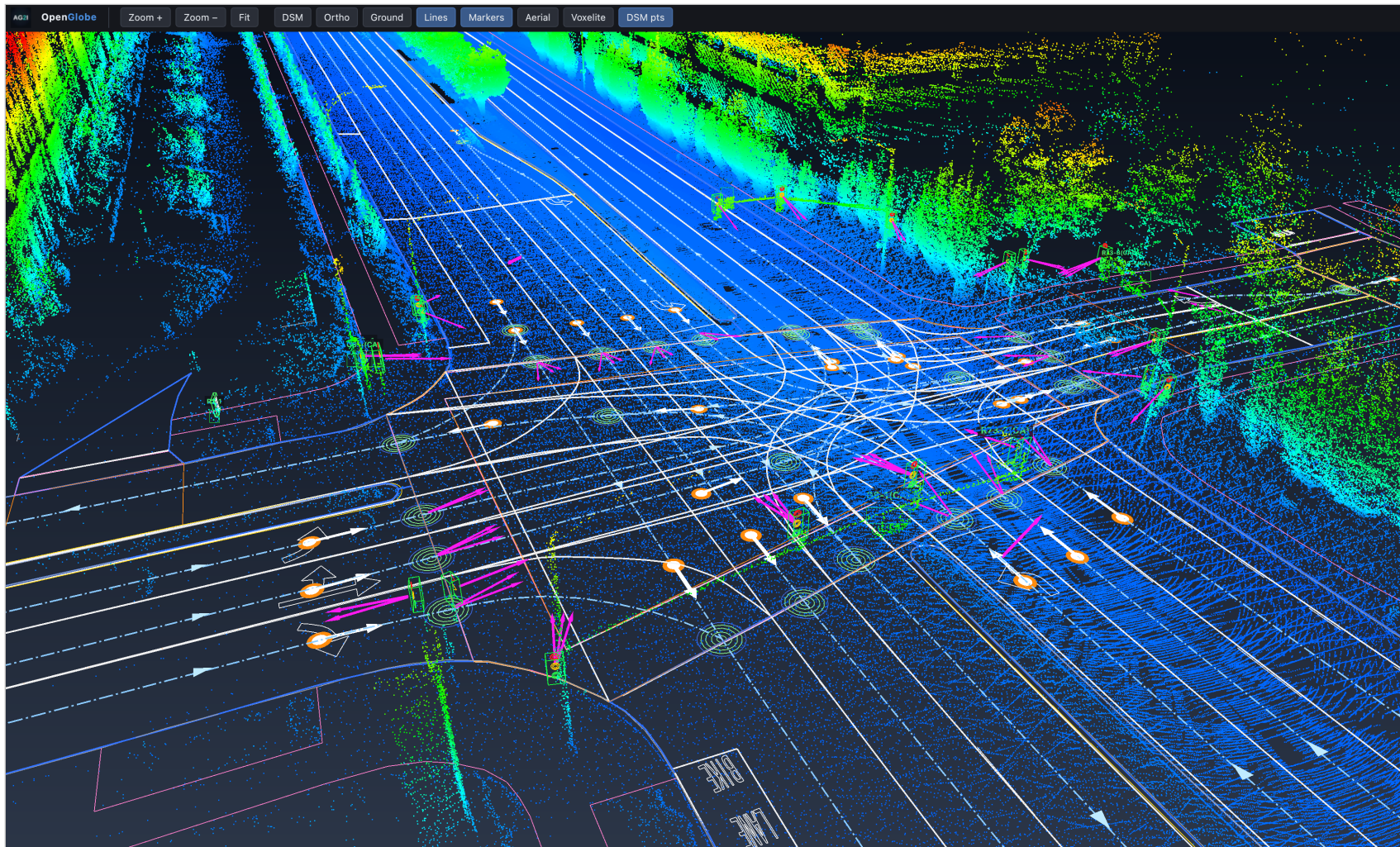


Figure 2. The same vectors with the mobile-LiDAR point cloud added. The cloud supplies dense 3D scene geometry but is uncontrolled (IMU/GNSS + distance-measuring instrument; no certified accuracy).

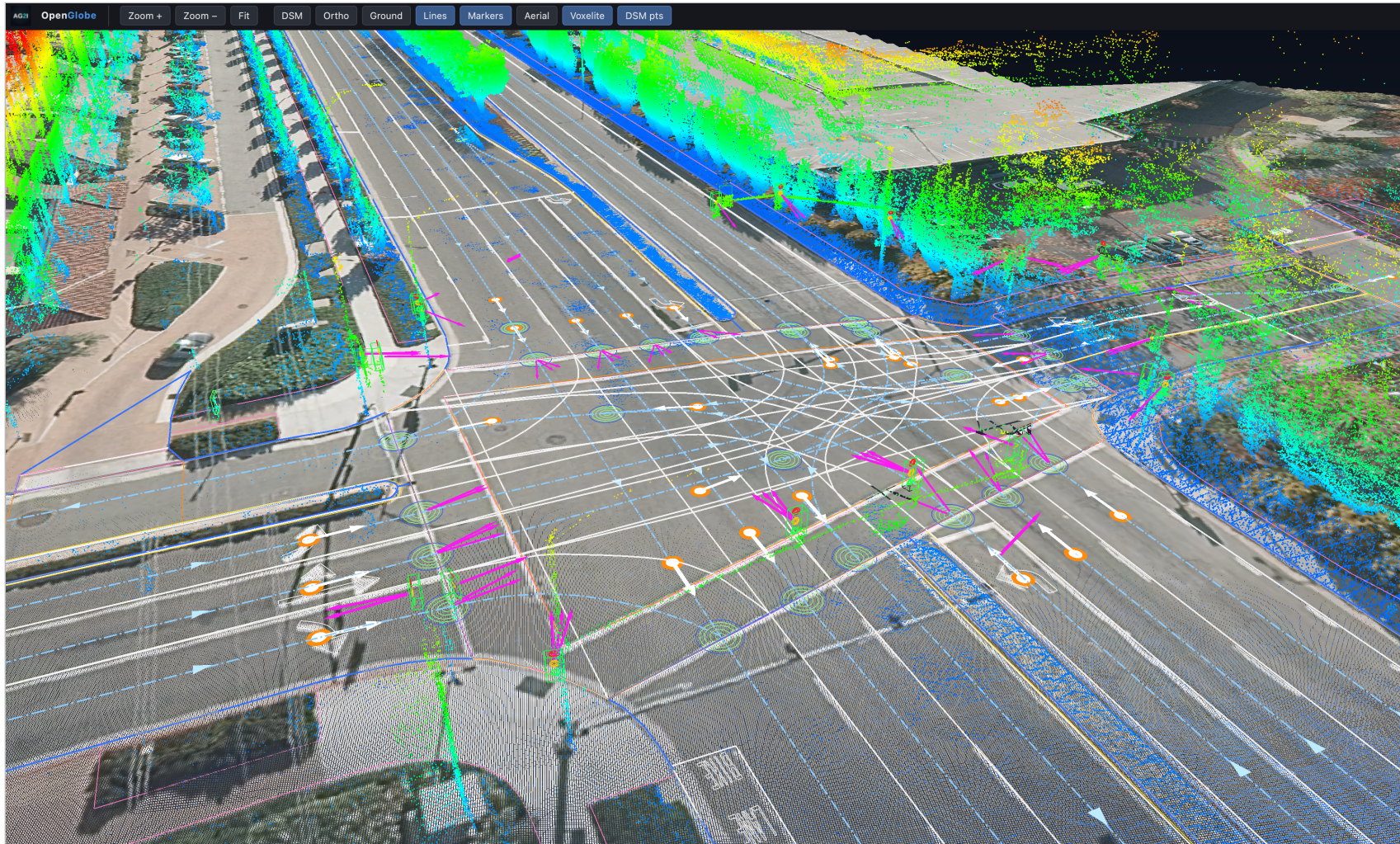


Figure 3. The Voxelite control surface added. The photographic road surface appears at its surveyed elevation; the HD-map vectors register to the road; the mobile LiDAR is seen in context against the surveyed surface. The three layers form one conformed scene.

For reference, surface comparison of the mobile LiDAR against the certified aerial surface over this area measures the mobile LiDAR a median 0.15–0.18 m low with approximately 0.3 m scatter — the offset that control transfer is intended to remove. This is a surface-comparison measurement, not an OpenLineWorks result.

5. Limitations and outstanding implementation

1. **Z band not consumed.** OpenLineWorks matches on the image bands only; the Voxelite Z band is preserved but does not drive the warp. Control transfer is therefore presently planimetric. Vertical control transfer requires sampling the reference Z at matched points and solving a vertical adjustment — not yet implemented.
2. **Accuracy inheritance not implemented.** The link file and report module record registration residuals only; there is no field for the reference accuracy and no computation of $\sigma_{\text{dataset}} = \sqrt{(\sigma_{\text{ref}}^2 + \sigma_{\text{align}}^2)}$. The model in §3 is defined but not yet in code.
3. **Residual at tie points is a fitting floor.** A thin-plate spline fits its control points exactly; the near-zero residual is not an accuracy. A certified accuracy requires check points held out of the solution. The validation module supports check-point evaluation; the real-data runs above did not include independent checks.
4. **2.5D surface.** Multi-level structures (overpasses, tunnels) cannot be represented by a single Z per XY; such cases require the textured mesh or a true volumetric model.

6. Conclusion

The Voxelite primitive and the planimetric registration engine are implemented and demonstrated on real data, removing gross misregistration (1.18 m and 14.8 m mean) between public orthoimagery and high-accuracy aerial references. The control-surface certification model — registration to a survey-referenced Voxelite, with accuracy inherited by quadrature — is defined. Three components remain to make a certified accuracy a measured claim rather than a model: consumption of the Z band for vertical control transfer; the accuracy-inheritance computation; and independent-check-point validation on real data.

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