WHAT IS STRIPALIGN?

Geometric error correction for airborne LiDAR

StripAlign is an automatic strip alignment tool: it registers overlapping LiDAR swaths and corrects both relative and absolute geometric errors. It allows to effectively reduce discrepancies between strips due to IMU attitude and position errors, and to combine corrections optimally in order to minimize both relative and absolute error. It uses a rigorous time-dependent approach to address effects such as IMU drifts and oscillations, which cannot be corrected with classical sensor calibration.

The registration algorithm takes advantage of all the last returns, filters out outliers on the fly (including vegetation, mismatched building walls, missing and bad data). LAS ground classification can be used if available but is not necessary. A roughness threshold can also be used to exclude vegetation and speed up the computation. Water bodies can be filtered based on height. No planes, or geometric objects of any type are required: natural surfaces work just as well as built-up areas.

It is possible to set some of the strips as references to keep them fixed, when they are part of an already aligned dataset, which saves time. No control data is required, but if available they can be used for QC and vertical bias compensation.

Required inputs and formats - point clouds and trajectories

Industry-standard LAS, LAZ and ASCII files are accepted, see input and output for more information. Even shuffled files can be used (where points are not in time order). Trajectory and attitude data are needed to achieve maximum accuracy correction or calibration, but not needed if the only goal is to scan, QC or register. Position/orientation files can be provided in Applanix SBET, Riegl POF, Leica SOL, Terrascan TRJ, or ASCII. GPS time can be in week seconds, day seconds, adjusted GPS, or a mixture. The software will convert to adjusted GPS whenever possible and also solve possible rollovers and ambiguities.

Calibration

Systematic effects, such as internal geometry mis-calibration and distortions, boresight misalignment, and lever arm errors are automatically computed, before treating the random effects. Therefore, sensor calibration is not a prerequisite; if done, the software will correct for imperfect calibration. Classical calibration is also possible, with a cross flight, or at least three lines. This allows the user to estimate external and internal parameters (rigorous or generic).

HF IMU drift correction

Trajectory and attitude are adjusted for each swath to compensate low and high frequency IMU drifts. This is made possible by using dense point cloud matching regardless of the content, which provides enough information to compute 1 Hz or faster corrections. Important parameters involved in this complex (but fast!) inversion are determined automatically, and the user only needs to enter information relevant to the dataset, which can be very simple for standard configurations.

Multi-channel data alignment

Forward/backward looking or rotated scanners can be used (e.g. Riegl Q-1560) and processed together with the specific mount of each channel to achieve optimal accuracy during corrections, avoiding inter-channel discrepancies. Registration is done for the main channel and between channels to minimize computation time.
QA/QC stats and maps

Quality control tools are also provided for convenience. Relative accuracy can be checked before and after registration, and after final corrections are applied, before generating the corrected files which saves time. It can also be checked on arbitrary sets of swaths or point clouds without running any alignment. Grayscale TIFF or color JPEG Z-difference maps can be easily exported. Point density, customizable shaded relief, height and roughness maps are also available as options. Various text files can also be generated if desired, eg. swath footprints, bounding boxes, simplified trajectories; these files have an explicit header and can be imported into GIS software. Fast file scanning with optional PO and geometry validation is also possible and very helpful to spot issues before attempting more intensive tasks such as registration or correction.

Absolute control is also possible using ground control point (GCP) files. A user-readable file is generated summarizing the GCP stats before and after correction. There is an option to cancel the global Z bias between LiDAR and control data through a uniform vertical shift. The main reason for this capability is to address a fundamental limitation in boresight calibration (which cannot provide the z-lever arm). GCPs are never used to derive corrections otherwise, due to the high number of parameters involved in HF drift estimation and lack of reliability of individual GCP.

This is a command-line tool

BayesStripAlign can run in a terminal (e.g. cmd or ConEmu on Windows), in an third-party external interface or in a batch file (.bat). Currently it has no graphical user interface, so double-clicking on the icon will not do anything, as the software requires to select at least the input dataset and some parameters.

Complex tasks can be achieved automatically with a simple command line, specifying the task, the input files, and various options. Good results can be achieved with default (missing) options in most cases so the command can be really very short. Commands can also be used in sequences in batch files, and invoked through high-level software interfaces.

Most parameters are optional, and have default values, so don’t panic when you see the full list of options! Minimal command line examples are provided with each task type, and are often sufficient. Expert options should be used with care, or unpredictable results may occur despite all safeguards. Long options are defined for clarity, and one-character versions are sometimes available for simplicity. Persistent options can be stored in a configuration file and used systematically. Option files and file lists are also accepted to alleviate the command line.

Current limitations

- Multi-channel data has to be provided as one file per channel as there is no standard for channel encoding (especially for more than 4).
- For PO data in geodetic coordinates, built-in projections include Transverse Mercator, Lambert Conformal Conic and Albers Equal Area Conic; for all others the user needs to supply projected PO data in ASCII or TRJ formats. Geoid support for multiple countries is provided through NGS binary files (can be downloaded from the same location as the software). Attitude angles are not transformed during projection.
- Manual corrections always come with scan and tiling, which is usually a benefit but the data is read twice, which is slower than a simple correction. The purpose of StripAlign is automatic correction; manual adjustment is mostly provided for convenience.
- A UAV setting is available but the registration algorithm is not always suitable for small-scale UAV LiDAR data due to the content (complex topology, mostly vertical features) especially in built-up areas. A specific add-on will be available separately for UAV users end of 2019.
- For internal sensor geometry, only linear scanners are fully supported for correction and calibration; elliptical scanners can be used but require splitting into forward/backward look angles and distortion compensation might not be optimal for those scanners.
- IBRC (intensity based range calibration) is not supported. Intensity information is not used. This type of calibration has to be addressed before attempting any geometric corrections with StripAlign or unpredictable results may occur.
Registration of a billion point, 50 km-long dataset in 15 min (4 cores, 4 GHz) (usually difficult due to both low and high vegetation), 4 parallel, 3 cross lines, unclassified swaths.

**Top:** Roughness map reflecting terrain properties (different types of vegetation, building edges). **Middle:** original data DZ map showing up to 50 cm vertical discrepancies. **Bottom:** DZ map after registration, 1 cm residual RMS vertical error, same color map. A roughness filter is used to remove high vegetation and bad data automatically (black areas) and speed up registration.

Part of a small dataset with cross-lines. **Top:** Roughness map reflecting terrain properties (different types of vegetation, natural terrain roughness and curvature). **Bottom:** original data DZ map showing up to 25 cm vertical discrepancies.

**Top:** Calibration (internal, lever arm, boresight) + Constant drift per swath corrections. **Bottom:** Calibration + HF IMU drift corrections at 1 Hz. The residual relative error goes from 2 cm to 1 cm RMS.
WHAT IS NEW IN VERSION 2.0?

Unlimited geometry

The major restrictions of version 1.3 have been removed, as the software no longer requires straight and parallel flight lines to correct large projects. Cross-lines should now be included as they help stabilize corrections and identify potential issues. Blocks or collects can be used all together, parallel or not. Now all tasks, from small calibration flights to very large multi-collect projects, are handled effectively thanks to a new spatial indexing scheme that stores no more than the LAZ size equivalent in a reusable cache. All steps involved in processing, from registration to inversion, have been rewritten accordingly.

Unlimited overlap topology

All possible overlaps are considered to maximize accuracy (in the previous version only the nearest neighbor intersections were used, which caused issues with lines collected as multiple swaths, so the user had to merge them manually). Multiple overlaps also help detect geometric discrepancies that might go unnoticed in a simple nearest neighbor topology without cross-lines. Due to the potential increase in computational complexity, options are available to restrict overlaps. Some of these options are activated by default to speed up multi-channel data registration.

Correction drift reduction, improved internal geometry

Correction drifts are unwanted large scale corrections that degrade absolute accuracy, usually occurring for large numbers of swaths. They are a side-effect of good relative error correction and will not show up on DZ maps or without GCP (but they can be detected on new image outputs). They are due to various biases, unexpected or improperly modeled, such as internal geometric distortions, and other complex effects. IMU error priors used in Bayesian inference are crucial in limiting the amount of correction, while allowing to compensate for relative errors, and their implementation matters.
A number of improvements helps make 2.0 more robust than 1.3 to such issues:

- Priors spatially distributed for optimum effectiveness
- New 6-parameter internal distortion models, both rigorous and generic
- Ability to let internal geometry parameters vary for each swath, useful with some scanners (initially one set per group)
- Large-scale, slow varying warp option acting as a subtle deformation field, effectively cancels the large-scale component of the mean correction field without compromising the relative accuracy improvement
- Mean correction vector cancellation, uniform component of warp, global shift only

Vector images from registration and correction

Signs (mean) or unsigned (max) versions can be saved depending on options. Warp vectors are also saved if computed (not shown here, same dimension as correction images).

These images are useful for QC, to evaluate the full 3D relative geometric accuracy from LiDAR data, and also to check that everything went smoothly (no large corrections or significant residuals).
More QC images and maps

Point density, swath overlap and height images: small images automatically written by StripAlign 2.0 during tiling, prior to any processing. Group overlap images (not shown here) are also produced.

Larger maps: surface roughness and shaded relief, written by StripAlign 2.0 upon request during gridding, with any QC, correction or registration operation (options -rmap and -smap). Large point density map also available with -dmap. Now a subsampling factor with respect to the grid GSD can be set (default 4) to avoid very large files.

Enhanced statistics reporting and spatial data export (text format)

All exported text files have a simple explicit header row, and can be used in various GIS or plotting software. Log files are easy to read outputs (calibration parameters, various QC, LiDAR and PO statistics).

Left: color-coded swath footprints (intersection footprints also available). Right: subsampled trajectory footprint, color-coded swath number, useful to check LiDAR/PO synchronization and spot possible coordinate system issues. (All footprints are optional, exported with option -fp)
Performance improvements

The tiling and correction processes are now limited only by file I/O, multithreaded with a limited number of threads. The registration (usually the most time consuming process) is fully multithreaded, with a brand new algorithm that is more effective in parallel and uses more memory to achieve maximum speed. Other improvements have been made to gridding and QC speed. The inversion algorithm (which computes corrections from registration data) is brand new, and optimized to handle the large numbers of parameters necessary for HF drift correction applied to hundreds of swaths simultaneously.

For a 10-billion points project in LAS with 15% sidelap (Optech Galaxy with SwathTrak), mostly parallel lines with a few cross-lines, the processing time is 70, 20, 60 and 75 minutes for tiling, gridding, registration and file correction, respectively (4 GHz core i7, quad-core, 8 threads, 16 GB memory, standard HD for data and SSD for temp. files).

Various improvements and additional features

- HF IMU drift corrections are now controlled by time period. The frequency can be as high as 1 Hz with current airborne LiDAR sensors. They are applied rigorously to trajectory and attitude (which can be exported after correction).

- The PO file reader is more robust with new features such as automatic rollover correction (week seconds and day seconds) and warnings for known format issues (ex. for Riegl POF and time formats). It also determines the time format and coordinate type automatically according to the format to avoid useless user inputs. The input is also simplified with a single option for all format (detected by extension). Radians have been added to ASCII format options.

- UAV scale projects can now be handled. Extra options were added to allow using UAV data (small scale, high density), so as long as the data looks like scaled airborne point clouds, the alignment should work just the same! QC will always work, but a UAV registration module will be required to deal with the specificities of small-scale objects (walls, pipes, trees etc.).

- The registration does not require PO data anymore. The advantage is that StripAlign can also be used for displacement estimation, to help analyze the geometric inter-swath accuracy in 3D (not only in the Z direction as most QC software). Vector images and stats can be conveniently used for this type of analysis.

- Additional scanning commands are now available to scan files with and without PO data, as a pre-check before more complex processing. Geometry validation has also been added, with automatic checking as well as stat file export. This helps find geometric issues (eg. multi-channel boresight angles, gross georeferencing errors) quickly. The software has a nested structure as shown on this diagram, an allows fail-safe multi-step processing.

- Point filtering based on LAS records has been updated to handle synthetic points. Grid cell filtering has been improved by adding a height filtering option so some water bodies and high points can be easily removed.

- Various new options are available to give more flexibility to the way groups are used for registration and calibration.

- Most Transverse Mercator projections (MTM, NZTM, LTM...) are now supported; the user just supplies an ASCII file with projection parameters in WKT format.

- It is now possible to repair or update LAS fields such as scan angle and GPS time rollovers, no registration needed.

- LAX (LAS index) files can be created on the fly upon request.

- PO files are no longer needed for fixed groups (groups containing only reference swaths that are not corrected).

- GCP reports are more detailed and include a processing string and group stats. Options are available for point weighting.
WHAT IS NEW IN VERSION 2.1?

**Time interval images, robust height**

Microtile time interval rasters (left) and improved height images (right) with increased robustness to outliers have been added in 2.1. The time intervals are used to determine the HF IMU drift correction interval automatically. Inspecting them helps spot self-overlap issues and multi-channel mixing, which affect the ability to map locations to timestamps accurately, reducing the frequency of the computed drift corrections.

**Various improvements and additional features**

- The period of HF IMU drift corrections is now computed automatically from the data (manual override possible).

- Simultaneous collects (eg, multi-channel) sharing the same flight line are now treated more rigorously and the PO data corresponding to each flight line are corrected accordingly. Only the input PO file names are duplicated but internally the flight line PO is shared between channels, yielding more consistent results and smaller corrections.

- Computed PO corrections can be saved as SBET if the input format is SBET. Otherwise flight line segmented ASCII files will be saved, in the same format as the PO data (geodetic or projected, deg or rad). This allows the use of corrected SBET files for more accurate georeferencing of photos or other non-LiDAR data. Option -opo needs to be added to export corrected PO data, and -po_tol controls the time buffer before/after LiDAR flight segments (when corrections are extrapolated).

- Point filtering has been extended to allow selecting first returns only: use -last 0 to disable (default) last return selection. All returns, including intermediate ones, can also be used instead of last or first, by adding option -keep_all.

- Registration data is now saved as binary DUT (more compact, faster to read) and can be exported to ASCII if needed.

- TIFF z-differences can be saved in 16 bits with option -dz16 and the range for jpeg and tiff can be controlled separately. Small images such as point density and height are saved in 16 bits to avoid saturation. This only applies when option -tiff is used and does not affect jpeg output.

- Due to built-in size limitations of tiff and jpeg formats, file size cannot exceed 4GB, with max 64K rows or columns. To address that, StripAlign now tiles large maps, and the tile size can be set with -map_size (default 32K).

- The LiDAR swaths can now be projected in Lambert Conformal Conic, so StripAlign now supports all major projections (most US state planes) through WKT files, allowing to use geodetic PO formats in most cases. WKT parsing is improved and can now read the unit (m, feet) so specifying feet manually with -feet is no longer needed when using the -wkt option.
• Support for geoids has been added, also extending the use of geodetic PO data to orthometric LiDAR heights in a simple and automated manner (no need to input an approx. geoid height). Geoid support for multiple countries is provided through NGS binary files (can be downloaded from the same location as the software) with option -geoid.

• A mathematical model update for the internal distortions allows to better model some of the biases and make them independent of laser boresight and therefore increases compatibility with elliptical and circular scanners (eg. Leica Chiroptera, Riegl miniVUX-1DL).

• A few adjustments and fixes helped increase the compatibility with UAV data (even if the official UAV registration module is yet to be released). Success has been reported in many cases including corridor mapping.

• Other minor improvements include -daysec to allow the use of day seconds, -plot_po to export binary PO data to ASCII, command -las_read_check to debug I/O errors, etc. LASlib was also updated to the latest version to support the latest v4 compression and fix a few minor issues.

Since version 2.12

• Support for PulseWaves pulse geometric correction has been added. Any PLS/PLZ file corresponding to a swath (same name and time format) will be corrected accordingly, if options -opls or -oplz are used.

Since version 2.14

• The LiDAR swaths can now be projected in Albers Equal Area Conic (AEAC) through WKT files. WKT parsing is improved for better robustness to spaces and spelling errors.

• The software can now handle large IMU errors for certain bad swaths (a few m) while preserving absolute accuracy, single step, fully automatic. To take advantage of this capability, use -C0 to disable calibration.

• A manual time delay correction capability has been added with option -t_corr to handle PO/LiDAR delays due to sync issues.

• Exported ASCII files (including world files) now compatible with LiDAR data in feet when using new option -out_metre 0.

• Added option -ics_rms to increase compatibility with circular/elliptical scanners (use -ics_rms 0)

• The manual correction mode can perform GCP-based vertical corrections only (only swaths, PO and GCP file needed)

• All swaths can be corrected with option -a or -corr_all, including those without overlap; calibration parameters and other time independent parameters applied (simple copy if no correction available)

• ASCII polylines (footprints and bounding boxes) can be exported in OBJ format with option -obj

• Registration of data with very large misalignments (20+ m) improved with new option -init 0

• Added support for module-based licensing: airborne, uav, noreg, nocorr (resp. large scale, UAV, registration disabled, corrections disabled) and limits for the UAV-only license module (400 Mp, 4 km²)

• Other improvements include a more robust IMU error estimate, more accurate DZ map and GCP computations for large displacements, AGL limit updated to allow the use of mobile scanning data, performance improvements (tile and grid caches, ASCII file output), reduced memory requirements for calibration
Since version 2.15

- Split option for multi-beam scanners (used in UAV) or elliptical/circular scanners (both UAV and airborne). Swaths can be split into multiple channels (up to 4) according to scan direction, LAS channel, scan angle, user data, point source ID or LAS classification) with command -split.

- Added support for various time formats in ASCII PO files (useful for UAV) through the use of existing option -A (long version renamed -po_time). Now accepting also standard GPS, UNIX and UTC. Separate microseconds column can now be parsed with code "u" (option -po-parse).

Please see the release notes for the full list of updates, bug fixes and performance improvements:

groups.google.com/forum/#!forum/bayesmapsoft

UAV test with StripAlign 2.1 (see "No Sugarcoating: Sweet LiDAR from RICOPTER carrying VUX-1UAV over Sugarcane" blog entry at rapidlasso.com). Top row, left to right: overlap, height, density and time interval small images. Middle left: hill shading. Bottom left: roughness (significant). Bottom large images: max abs z-differences before and after alignment.