Survey Strategies in Use of Lidar

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Definitions (while boring – important)

Airborne Laser Scanning (ALS) – aka Lidar is an active (photogrammetry is passive) remote sensing technology that measures topography and reflectance intensity; ALS contains a Direct Georeferencing System often call a Position Orientation System (POS) that determines position and orientation of the plaform

Along Track Resolution – spaces of pulses in direction of flight

Artifacts – Remnants of buildings, trees, other elevated features in a bare earth elevation model

Definitions

Attitude

(1) Pitch – vertical rotation of aircraft (nose up/down)

(2) Roll – rotation of aircraft along flight vector (wing up/down)

(3) Yaw – horizontal rotation of aircraft (nose left/right)

Beam divergence – increase in beam diameter with distance from its aperture (beginning); measured in milliradians; higher frequency beams have lower divergence

Definitions

Boresight – calibration of a sensor system primarily correction of roll, pitch, yaw of IMU

Collimated – light that does not disperse and thus low beam divergence – typical of Lidar

Cross track resolution – spacing of pulses in scanning direction (perpendicular to flight direction)

Direct georeferencing – direct measurement of X,Y,Z and roll, pitch, yaw of a sensor

Echo – multiple returns from one pulse (top of tree vs. ground)

Definitions

Inertial Measuring Unit (IMU) – sometimes called Inertial Navigation System (INS) – measures rotations with gyroscopes and acceleration with accelerometers; integrating the measurements enables precise orientation for each time increment often 50 to 200 Hz (times per second)

Lever Arm Offsets – perpendicular distance from rotation axis to force line of action; all offsets between system components must be calibrated

Definitions

Near Infrared (NIR) – 800 to 2500 nm by definition; Lidar is 1000, 1047, 1064, or 1550 nm based on lasing materials, natural surfaces reflect well at those wavelengths, and NIR has small signal to noise ratio and is eye safe

Nominal Point Spacing – NPS – flight planning estimates this and density of resulting data

Point cloud – the cluster of Lidar points

Point dropout – no solution (in ground Lidar measurements into the air above objects

Definitions

Point spacing – average distance between successive pulse returns – grows if further from sensor

Pulse footprint – area of ground intersected by a laser pulse – function of distance, angle of incidence, and beam divergence

Pulse footprint smearing – laser is reflected from sloped terrain especially when away from center of scan

Pulse repetition frequency – PFR – Points per second of the laser

Definitions

Pulse return – the reflectance received by the sensor since it reflected off a surface

Pulse return intensity – the reflective intensity that can allow discrimination and classification of scanned features

Range – distance

Repetition rate – pulses per second denoted in KHz – 200 KHz is 200,000 pulses per second (amount out is this which does not always equal the amount of return)

Definitions

Scan angle – half the angle of a full sweep of a scanning mirror scanner – large angles are (rarely exceed 30 degrees) not used in aerial work due to high dropout rates, increased error, and obstruction shadowing at scan edges

Scan rate – frequency of a cross track of a mirror scanner in Hz

Swath width – width of survey area from a complete sweep of the scanner is a function of flying height and scanner angle

Absorption vs. Reflectance

When laser hits a surface light is

(1) Transmitted

(2) Absorbed or

(3) Reflected

Example – Frequency doubled neodymium doped yttrium aluminum garnet has a wavelength of 523 nm and will penetrate water to measure a lake bottom

But that wavelength can hurt your eye!

You want lots of reflectance!

Strange Lidar reflectance properties

Wet snow reflects dark gray to black in usual Lidar spectrum

But 1064 nm Nd:YAG (not usually for topographic) can easily see snow

Dry grass has a high reflectance in normal Lidar

Comparing

(1) Photogrammetry – Day time only (passive technology)

Vs. Lidar – Day or night collection (active technology)

(2) Photogrammetry – sophisticated image matching required to generate 3-D

Vs. Lidar – Direct acquisition of 3-D coordinates

Comparing

(3) Photogrammetry – vertical quality weaker than horizontal (aerial)

Vs. Lidar – horizontal quality weaker than vertical (aerial)

(4) Photogrammetry – long established accuracy standards

Vs. Lidar – too new to have well defined accuracy standards

Comparing

(5) Photogrammetry – high image redundancy (simple to improve solution for exposure stations)

Vs. Lidar – no inherent redundancy – same exact point not measured 2+ times thus difficulty to update trajectory

(6) Photogrammetry – dense positional information along break lines

Vs. Lidar – concept of break line not present in point clouds

Comparing

(7) Photogrammetry – ground control requirements well defined

Vs. Lidar – amount of ground control checks in development

(8) Photogrammetry – cannot map near vertical terrain/objects

Vs. Lidar – multiple responses map steep terrain

Comparing

(9) Photogrammetry – human extracts features

Vs. Lidar – automated processes classify information

(10) Photogrammetry – one elevation per X,Y coordinate pair (2.5 dimensional)

Vs. Lidar – multiple response creates multiple Z's for some X,Y's (3 dimensional as vertical surfaces can exist)

Comparing

(11) Photogrammetry – must be able to see the ground

Vs. Lidar – penetrates vegetation to bare earth (usually)

(12) Photogrammetry – human dependent feature extraction

Vs. Lidar – automated extraction based on reflection and elevation

Comparing

(13) Photogrammetry – time consuming for final topographic deliverable

Vs. Lidar – point cloud delivered quickly

(14) Photogrammetry – natural stereo viewing

Vs. Lidar – need to create stereo perspective viewing

Comparing

(14) Photogrammetry – very precise operator measured hydrographic information

Vs. Lidar – details of hydrographic features difficult to extract and enforce hydrographic rules.

(15) Photogrammetry – all topographic features extracted by human

Vs. Lidar – edges of linear and polygonal features difficult to extract

Lidar basic hardware

Two basic types are used in surveying

(1) Time-of-flight scanners – a pulse of light is reflected off a scanned object

- Time measured to and from the reflected surface
- Distance = (Speed of light * time of flight) /2
- Many Time-of-flight scanners can measure several arrival times (like top of vegetation as first response and ground as last response)

Lidar basic hardware

(2) Phase-shift scanners (more expensive, more accurate, short distances, faster)

- A laser with a sine wave function
- Reflected light is detected and compared to emitted light to determine phase shift (like an EDM)
- Time of Flight = Phase shift / (2 * PI * Modulation frequency)
- Time of Flight then inserted into Time-of-flight scanner equation
- Multiple frequencies increase accuracy like an EDM

Laser Scanning Techniques

(1) Oscillating mirror (zig-zag) – mirror moves back and forth in a limited extent creating a zig-zag sinusoidal pattern

- Advantage is mirror is always pointed to the ground/object so all pulses are used
- The mirror has to slow down to turn at limits of scan, then speeds up again – this creates more points at ends of scan

Laser Scanning Techniques

(2) Rotating mirror (line scanning)

- Mirror rotates continuously at a constant velocity in one direction via a motor
- Points are thus on parallel lines and no acceleration type errors
- Disadvantage is a major portion of the time mirror is pointing away from the target

Laser Scanning Techniques

(3) Push Broom (Fiber Scanning)

Also called fiber optical or nutating scan

- Fibers are arranged in one end in a circle and other end in a fixed linear array
- Circular patterns of data appear in flight direction that will overlap

Laser Scanning Techniques

(4) Palmer (elliptical) scanning

An elliptical pattern that overlaps so redundant data can be used for calibration

(5) Strip-wise scanning

-laser line generating unit and a video camera

Triangulation as in photogrammetry calculates the distance to every point on the laser line

Point cloud

- A rotating mirror (vertical and horizontal) moves the scan pulse
- The measurements can be made thousands of times per second
- Intensity of the return is also collected which can be turned into 0 (black) -255 (white) gray tone image
- Closer object gives higher intensity
- Light colored object gives higher intensity

The “future” – full waveform scanners

- As opposed to “discrete-return” as previously discussed
- Full waveform digitizes the entire return at a high scan rate increasing data amounts dramatically
- Has been used for improved vegetation ground segmentation, airport obstruction mapping, military target detection, habitat analysis among others
- http://www.isprs.org/proceedings/XXXVII/congress/1_pdf/69.pdf for full waveform discussion

The future – 3D Flash Imaging Lidar

- More real time
- 1 m to 10 m – vision and autonomous navigation tasks
- 10 m to 10 km – mapping, tracking, targeting and autonomous rendevous
- 10 km + - Geiger mode lidar – photon counting arrays for targeting and tracking
- Flash imaging is similar to digital camera with flash, but the flash is a pulsed laser
- Usually associated with real-time non absolute positioning applications (no post processed GPS-IMU)

The future – 3D Flash Imaging Lidar

“Map as you fly”

Sequential imagery is associated spatially and stitched together to create a 3D model

Stitching uses INS and scene characteristics

Point cloud coordinates

If (1) scanner location coordinates known

(2) 3-D direction of laser known

3-D coordinates can be calculated of object point

Point cloud coordinate generation

- Static scan – a scanner can be thought of like a total station where a known backsight orientation exists and the instrument height of scanner is known
- Each measurement is associated with a horizontal and zenith circle reading like a total station
- Coordinates are thus calculated like an occupied station with a total station taking topographic measurements with a zero value for target height

Point cloud coordinate generation #2 scenario

- Again a static scan
- Points in the cloud have survey measured coordinates and are identified in the office
- This is equivalent to the resection process with a total station where more than one point with known coordinates is measured to resolve the occupied station coordinates

Point cloud coordinate generation #3 scenario

- Usually for a mobile scanner (airborne or ground)
- Kinematic GPS solves for position at very fast epochs (0.5 – 1 second)
- Inertial Measuring Unit (IMU) which really are gyroscopes measures three angles of scanner orientation and coordinate shifts in between GPS epochs via an accelerometer

Scanner hardware found at (in no order)

InteliSum www.intelisum.com

Isite www.maptek.com

Faro www.faro.com

Leica Geosystems www.leica-geosystems.com

Optech www.optech.ca

Riegl www.riegl.com

Topcon www.topconpositioning.com

Trimble www.trimble.com

Zoller+Frohlich www.zf-laser.com

This list is not intended to be inclusive.

Information version Jan. 2016

Trimble as an example

Trimble SX 10 (total station/Lidar) 26,600 points per second

http://www.trimble.com/Survey/Total-Station-SX10.aspx

- Capture and combine scanning, imaging and surveying deliverables with the singular solution designed for surveyors. Integrating the technologies of advanced optical surveying, metric imaging and 3D scanning, the Trimble® SX 10 is the only surveying instrument that does it all and does it with ease.
- To improve the efficiency of capturing advanced Spatial Imaging deliverables, Trimble provides an integrated solution for bringing these technologies together within the traditional workflows surveyors already use. So you have the flexibility to perform feature-rich scans every day, without the complexity of setting up a separate scanning system or switching to specialized field software.
- **Video-Assisted Control**
- Trimble VISION™ gives you the power to see everything the instrument sees. Direct your work with live video images on the controller Now you are free to capture measurements to prism or reflectorless surface with a point and click.
- **Empower Your Surveys with Trimble RealWorks**
- With the ability to capture metric images with the Trimble VX in the field, you are also able to make additional measurements and attribute the data back in the office. Advanced 3D models and image-rendered 3D surfaces are within your reach with the rich data delivered by Trimble Spatial Imaging sensors and the powerful workflows of Trimble RealWorks™ software.

Trimble Static Lidar TX8

- The Trimble TX8 delivers the power and flexibility to tackle even the most demanding projects. Designed for performance the Trimble TX8 enables you to complete 3D laser scanning projects faster than ever.
- 1 million points per second
- Typical high quality scan time of only 3 minutes
- IEC EN60825-1 class 1 eye safe laser
- High accuracy maintained over entire range
- 340 meter range
-

  With the Trimble TX8 you can capture more detailed datasets at high speed while maintaining high accuracy over the entire range of the scan.

http://www.trimble.com/3d-laser-scanning/tx8.aspx?tab=Technical_Specs (specs)

Trimble Mobile Lidar MX2 (MX1 photo only)

- The Trimble MX2 is a vehicle-mounted spatial imaging system which combines high resolution laser scanning and precise positioning to collect geo-referenced point clouds for a wide range of requirements. The system can be rapidly deployed onto on- and off-road vehicles of all sizes, and significantly reduces project field time and operator skill levels compared to traditional techniques. The MX2 is supplied with Trimble's proven Trident software to rapidly extract and analyze the raw data to turn it into useful geospatial intelligence.
- **Features**
- High performance laser scanner captures fully synchronized point clouds
- Precision positioning using tightly coupled GNSS and inertial referencing system
- Rugged, reliable and lightweight design with low power consumption
- Deploys on all sizes of on- and off-road vehicles, quad bikes, and boats
- **Benefits**
- Versatile system offers significant operational flexibility
- Outstanding performance and value with low cost of ownership
- Optimizes staff utilization and lowers skill requirements
- Reduces project timescales through fast deployment, data capture, and analysis
- Highly efficient, proven analysis workflows
- Enhances operational capabilities and expands market opportunities
- http://trl.trimble.com/docushare/dsweb/Get/Document-666707/022515-152E_TrimbleMX2_DS_US_0216_LR.pdf (data sheet)

Trimble Mobile Lidar MX7

- The Trimble MX7 is a premium mobile spatial imaging system capturing fully synchronized, high-quality georeferenced point clouds and high-resolution imagery. The vehicle-mounted system is designed for surveyors, engineers, and geospatial professionals conducting as-built modeling, inventory, inspection, encroachment analysis, and asset management for roadways, bridges, railway, utilities and other infrastructure management.
- **Features**
- Performance 360-degree mobile dual laser scanners collecting over one million points per second
- High-frequency digital cameras at set orientations capturing high resolution panorama and surface imagery
- Market-leading POS LV positioning and orientation system delivering extremely fast position updates (up to 200Hz) and high accuracy results even when GNSS signals are interrupted
- Rigidly mounted and fully calibrated pod with wide navigation and sensor base for easy installation on a variety of vehicle types
- Trimble Trident software to extract survey, GIS and construction deliverables
- **Benefits**
- Combined with ground control, the MX7 achieves industry leading data accuracy
- Incredibly detailed 3D infrastructure geometry without gaps in a single pass from a vehicle moving at regular traffic speeds
- Conduct projects that would be too slow, cost-prohibitive, disruptive, dangerous or simply impossible using traditional survey methods
- Automated and manual feature extraction capabilities including change analysis impossible using other technologies

http://trl.trimble.com/docushare/dsweb/Get/Document-736670/022516-126G_Trimble_MX7_DS_US_0816_LR.pdf (data sheet)

Trimble Airborne AX 60i

- Trimble AX 60i set a new standard for digital image acquisition and laser scanning. Designed for both aircraft and helicopter operation, the Trimble AX 60i is ideal for area mapping.
- Incorporating a wide-angle, airborne laser scanner, the Trimble Harrier 68i enables you to extract the most comprehensive information. The laser scanner's 266 kHz effective measurement rate (at 60 deg scan angle) delivers high point density on the ground to provide the detailed modeling data needed for precise planning, engineering, and monitoring applications. The Trimble AX 60i allows flight at a typical maximum altitude of 1,600 meters.
- The Trimble AX 60i is an integrated solution, providing unmatched capabilities to tackle your most complicated projects:
- Advanced laser scanner and camera sensors
- Applanix POSTrack GNSS-aided inertial direct georeferencing and advanced flight management system
- Computer system
- Data storage and backup system

http://trl.trimble.com/docushare/dsweb/Get/Document-702113/022516-044_TrimbleAX60i_DS_0214_LR.pdf

(data sheet)

Trimble Airborne AX80

- The Trimble AX80 can be used for the majority of survey projects from wide area mapping at 15,500 feet to low level corridor mapping, and remote sensing.
- The Trimble AX60 is a high performance, versatile, and fully integrated airborne LIDAR solution designed to meet most aerial survey requirements. It captures very dense point clouds at high resolution using a powerful laser system with a pulse repetition rate (PRR) of 400 kHz. The solution also exploits advanced techniques such as simultaneous multi-pulse processing, echo digitization, and waveform analysis.
- **Key features:**
- Versatile solution for aerial survey, remote sensing, wide area and corridor mapping
- Fully integrated, end-to-end solution covers pre-flight planning to post-flight processing
- Single laser with 400kHz pulse repetition rate gives class-leading ground resolution
- Wide effective swath width allows efficient data capture and optimized flight profiles
- Low cost-of-ownership through proven reliability and high workflow productivity
- With its Trimble flight planning and sensor management software, and Trimble Inpho processing software, the AX80 has been designed as an end-to-end solution to deliver unparalleled performance, operational flexibility and efficiency, and in-service reliability. At the same time it offers a low cost-of-ownership for aerial survey companies while long-term lifecycle support is provided by Trimble's global organization.
- **Applications typically include:**
- Agriculture and forestry management;
- Mining, oil and gas exploration;
- Complex city and urban mapping;
- Power line and pipeline surveys and monitoring; and
- Snowfield and glacier mapping.
- The airborne sensor suite can be installed on both fixed- and rotary-wing aircraft.

http://trl.trimble.com/docushare/dsweb/Get/Document-702107/022516-045A_TrimbleAX80_DS_1114_LR.pdf(data sheet)

Principles of Kinematic GPS/GNSS

-Differential – a static permanent or field base station is used
- Best precision is when base is local to the job
- Moving system (airplane, helicopter, truck, van, car, etc.) sets still before and after the mission as this enhances resolve of ambiguities
- If no loss of significant satellite lock, individual epochs when moving will be fixed ambiguity solutions

Principles of Kinematic GPS/GNSS

- Forward and back post-processing
- Loss of lock in normal time order may be resolved for individual epochs by processing backward from the post-mission static observations
- If both forward and back solutions are fixed ambiguity, the final coordinates are a weighted average based on error estimates
- If one solution is fixed and one is float ambiguity only the fixed solution is used

Principles of Kinematic GPS/GNSS

Multiple base stations

- The individual epochs can be solved from each base station and the final coordinates compared for data quality assessment
- This also solves the potential problem of one of the base stations having a problem (batteries, satellite blockages, etc.)
- On a long job multiple base stations can keep at least one base station “close” to the moving scanner system

Principles of Kinematic GPS/GNSS

- Using CORS stations - Applanix will be used as an example www.applanix.com
- More specifically Pos Pac software at

http://www.applanix.com/products/pospac-mms.htm

Pos Pac principles

- Obtain reliable accuracy (<0.1 m) from existing reference station network
- Generate a set of GNSS observables corrected for atmosphere and geometric errors at the location of the remote receiver
- Use this local information (actually Virtual Reference Station – VRS) to process the remote receiver coupled with the IMU data
- Atmosphere delays eliminated as VRS is on job site
- IMU used to resolve ambiguities during poor GNSS solutions

White papers on GPS-IMU processing

http://www.applanix.com/products/pospac-mms.htm

http://www.applanix.com/products/centerpoint-rtx.htm

Leica equivalent GPS-IMU processing is discussed at

http://leica-geosystems.com/products/airborne-systems/software

With more Lidar processing information at

http://www.leica-geosystems.com/en/HDS-Software_3490.htm

http://leica-geosystems.com/products/airborne-systems/software/leica-lidar-survey-studio

IMU enhancing the GPS solution

Especially in mobile ground based Lidar, loss of GPS lock due to urban canyons and vegetation will invariably happen.

IMU (Inertial Measuring Unit) and INS (Inertial Navigation System) are the same thing!

An inertial unit is made up of 3 gyroscopes and 3 accelerometers

IMU measures at 100-1000 Hz (measurements per second) way more information that GPS which is 0.5-1 second epochs

IMU basics

Gyroscopes sense angular velocity.

Accelerometers sense force (motion).

Angular velocities are integrated with respect to time to provide orientation changes with respect to its initial orientation.

Force measurements derive body acceleration after double integration with respect to time providing positional differences relative to an initial position.

GPS allows determination of trajectory.

- IMU basics
- Velocity change is performed by one integration on acceleration
- Position change is calculated from a second integration on velocity change
- IMU is very accurate short term with high data rate
- IMU “drifts” over long term due to sensor errors
- IMU is self contained (does not depend on outside source such as available satellites)

GPS-IMU basics

- IMU's downfall – the double integration makes the time dependent position errors exceed most trajectory determination applications thus frequent updating is required.
- GPS can deliver excellent position accuracy but cycle slips lead to trajectory discontinuity. One GPS receiver does not measure angles like IMU can.
- In absence of cycle slips GPS offers IMU the required frequent updates.
- Inertial precise short term position & velocity can be used for cycle slip identification/correction.

Combined solution

9 measurements

GPS – 3 measurement – DX, DY, DZ (coordinate shifts) base to rover to determine a position

IMU – 6 measurements – 3 gyroscopes (3 angles) and 3 accelerometers (position change)

But only 6 unknowns (X,Y,Z and 3 rotations) relative to X,Y,Z

A redundant checkable solution!!!

Optimizing the GPS-IMU redundancy

Also Fiber Optic Gyro accuracy has increase tenfold in recent years.

Since the IMU can predict the location of the next GPS epoch, inaccuracy of the GPS produced location indicates a cycle slip.

The cycle slip can be corrected by filtering or by direct use of the IMU measurements.

Kalman filtering

GPS raw measurements, or computed positions and velocities calibrate the IMU sensor error.

IMU short term solution can bridge GPS cycle slips

2 steps

(1) Kalman predicting – predicts system state and covariance for next epoch based on information from the current epoch

(2) Kalman update – corrects the errors in the next epoch (predicted state vector and its covariance) based on an observation model using the measurements

State vector

Consists of

(1) Position error

(2) Velocity error

(3) Attitude error

(4) Accelerometer and gyro biases

(5) Scale factor error

(6) Non-orthogonality

(1) Loosely coupled GPS-IMU

- GPS measurements are processed in a separate Kalman filter (estimate what next epoch should like)
- GPS position & velocity are fed into the GPS-IMU Kalman filter
- Simple and reliable when enough GPS satellites are present (no urban canyons)

(2) Tightly coupled GPS-IMU

- GPS measurements are fed directly into the integrated Kalman filter
- This allows GPS measurements to be used even when less than 4 satellites are available.
- This process (< 4 satellites) would not be possible in loosely coupled

(3) Deeply coupled GPS-IMU

- IMU derived velocity is fed into the tracking loop of a GPS receiver hopefully allowing it to better track a weak signal
- This allows reacquiring signal faster
- This is critical in an urban canyon when a satellite is in and out of lock frequently.

IMU “strap-down”

In a perfect world the IMU would not rotate with the vehicle so it could stay in its initial axis system.

Strap-down, a more realistic application, the IMU rotates with the vehicle, so it basically undergoes similar forces and rotations as the vehicle.

Kalman Filter Basics

- Large amounts of moving GPS-IMU data is more suited to Kalman Filtering instead of Least Squares Analysis
- Kalman filter is iterative, using previous results as input to the next iteration

Kalman Filter Basics

$Z = f(x) + v = Hx + v$

Z consists of “m” measurements that can be expressed as a linear combination of n elements of estimate x and measurement error v.

H is called a design matrix. It consists of partial derivatives of measurements identical to what goes in an observation equation matrix in least squares.

Kalman Filter Basics

This tool estimates current state of a dynamic system out of incomplete noisy indirect measurements.

Phase 1 – prediction – estimates the state of the system and its covariance in epoch k based on its estimate for the preceding epoch k-1.

Phase 2 – update – Kalman gain is the weight of the actual measurement with respect to the estimated value

Comparing predicted to actual allows residual computation and fine tuning of covariance (small residual leads to smaller covariance)

Kalman filter in point positioning (car navigation)

- Based on previous GPS epochs an estimation of speed and acceleration exists which allows the estimate of the position of the next GPS epoch
- If no loss of lock the prediction and actual will be close if speed/acceleration was maintained
- Due to loss of lock and change of speed the Kalman filter iterates to the next epoch solution

Lidar systems and calibration

"Lever arm" stuff

(1) From origin of the Lidar to center of the IMU

(2) Origin of the Lidar to the GPS antenna phase center (or the GPS ARP – antenna reference position)

One can try to measure these offsets, or one can use a calibration process to determine them.

(3) The Lidar and the positioning system may also have a misalignment (a mechanical setup is not perfect). Calibration is required as it cannot be directly measured.

Lidar system calibration

- Up to 14 parameters
- X,Y,Z location of GPS antenna (3)

Roll, pitch and yaw of the mobile platform (3)

3 boresight angles from each individual scanner (3)

X,Y,Z lever arm offsets IMU origin to each scanner (3)

Scanner scan angle and range measurement (2)

Lidar system calibration

A system calibration corrects for manufacturing errors and is usually done by the manufacturer.

Produces parameters that remain constant as long as the hardware is not modified

As opposed to “geometric correction / adjustment corrects for GPS/IMU processing errors by adjusting scan data to control or between adjacent passes

Lidar system calibration from field data

- A plane (flat, though a constant slope can be used) area is flown multiple times (forward, back, perpendicular, etc.).
- The plane area flown in multiple directions allows a very direct systematic correction to be applied to all IMU angle information.
- Note the systematic error due to apparent non-flatness will offset in different directions based on different flight directions

Applying Photogrammetric Bore Sight calibration principles to Lidar

- A precisely surveyed dense set of targets calibrates GPS-IMU in photogrammetry as that technology simply allows direct measurement of the targets
- With Lidar it is doubtful the center of the target will be exactly at a Lidar point
- Lidar targetting (two concentric circles of black vs. white) allows reflectance values to be used to “best fit” the center of the target and mimic photogrammetric bore sight calibration

Applying Photogrammetric Bore Sight calibration principles to Lidar

All of the 14 parameters in the previously described calibration slide can be resolved especially if multiple passes in different directions over the bore site are used.

Nature of Lidar data

- The X,Y,Z point cloud is random not gridded
- Thus the raster storage of Z only due to a known gridded pattern cannot be used directly
- Non gridded creates more storage and computational necessities
- Tools for converting point cloud to raster is including in all commercial software

Data organization for processing

Streaming raw range data is often converted to geocoded “flight line” data (drive “take” in mobile Lidar).

These flight lines are divided into a tiling scheme for subsequent processing.

Tiling makes size of data more manageable and allows multiple people to work simultaneously on the data set.

Tiling also merges overlapping field flight line/ drive takes

LAS data format (LAZ is compressed version)

http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html

A standard binary format for Lidar accepted by all vendors similar to RTCM in RTK GPS.

Additions to ver. 1.4

(1) 256 Point classes vs. 32 in 1.3
(2) Field sizes support full 64 bit addressing
(3) Definition of new classes
(4) Extension of scan angle to 2 bytes supports finer angular resolution
(5) Sensor channel bit field supports mobile mapping

LAS data format 1.4 improvements

(6) Well known text (WKT) for coordinate reference systems (see http://en.wikipedia.org/wiki/Well-known_text)

(7) Added an overlap bit indicates pulses in an overlap region while maintaining class

(8) Added optional extra bytes for additional information to be stored with a point

LAS data format 1.4 point data record format (PDRF) additions

(6) Base type

(7) Red, green, blue (3 channel) colorization support

(8) Red, green, blue, near infrared (NIR) (4 channel) colorization support

(9) Waveform packet support

(10) Combined support of (8) and (9)

LAS format in general

ASPRS classifications

0 created never classified

1 Unclassified (classification failed)

2 ground

3 low vegetation

4 medium vegetation

5 high vegetation

6 building

7 low point (noise)

8 reserved

9 water

10 rail

LAS format in general

ASPRS classifications continued

11 Road service

12 reserved

13 wire – guard (shield)

14 wire – conductor (phase)

15 transmission tower

16 wire structure connector (insulator)

17 Bridge deck

18 High noise

19-64 reserved

Lidar data and complimentary technologies

Lidargrammetry

- Stereo models generated directly from lidar point cloud data
- This allows lidar to be inserted into traditional photogrammetric workflows
- Lidar is poor at extracting linear features and sharp edges that has dimensions smaller than point cloud resolution
- It is easy to see where the road is (in Lidar), but difficult to define the edge of the curb

Lidargrammetry

-Historically return intensity values are used to create

(1) ancillary data such as grayscale pseudo-images in raster form or

(2) Secondary data that improves classification

- Repetition rates of more than 500 kHz exploits intensity capture abilities

Lidargrammetry

- While rasterization of the Lidar point cloud moves it to more image looking, eventually the actual point cloud viewed in stereo could be used
- Success of Lidargrammetry potentially eliminates use of concurrent imagery in a project
- Note the process sounds like it is creating redundant products but ….

Lidargrammetry potential advantages

(1) Direct insertion to existing photogrammetric software solutions

(2) Potential improvement of the manual component of Lidar processing

(3) Photogrammetric workflows take advantage of more precise Lidar elevations and operator does not measure Z

(4) Eliminates use of developing Lidar extraction technologies

Lidargrammetry

Lidar post-processing compares to Photogrammetry’s aerotriangulation

Lidar automated classification compares to Photogrammetry’s stereomodel creation

Lidar manual editing compares to Photogrammetry’s point and break line extraction via feature coding

Potentially both processes can occur with same data concurrently optimizing positives of each system.

Lidargrammetry

-established techniques exist for converting orthophotography into "stereo mates" using an elevation model.

- With Lidar images are generated as if captured from exposure positions using a pseudo base-height parameter
- Thus parallax is generated by creating perspective instead of orthographic information
- Value of the pixel is usually the Lidar intensity

Lidargrammetry

- Must have high repetition rate
- Proper sensor parameters critical for intensity image quality
- Could also be used for mobile Lidar (viewing buildings in stereo example)
- Not having to measure the Z (as in traditional photogrammetry) speeds up the work flow
- Clean-up time of Lidar incorrect classification can be slower that Lidargrammetry manual extraction

Lidargrammetry

- Information collected in stereo can be fed back into the Lidar point cloud for better success in classification
- The lidar stereo models can cover larger areas than traditional photography so less setup time
- Lidar stereo models are successful in shadowy areas
- Water edge easier to see in Lidar stereo vs. traditional image

Lidargrammetry

- different base to height ratios can be used in problem areas to better identify vertical information
- Use of existing software, hardware, and operator infrastructure must enhance productivity