Laser Scanning with AAD's LaDAR system

A quick guide

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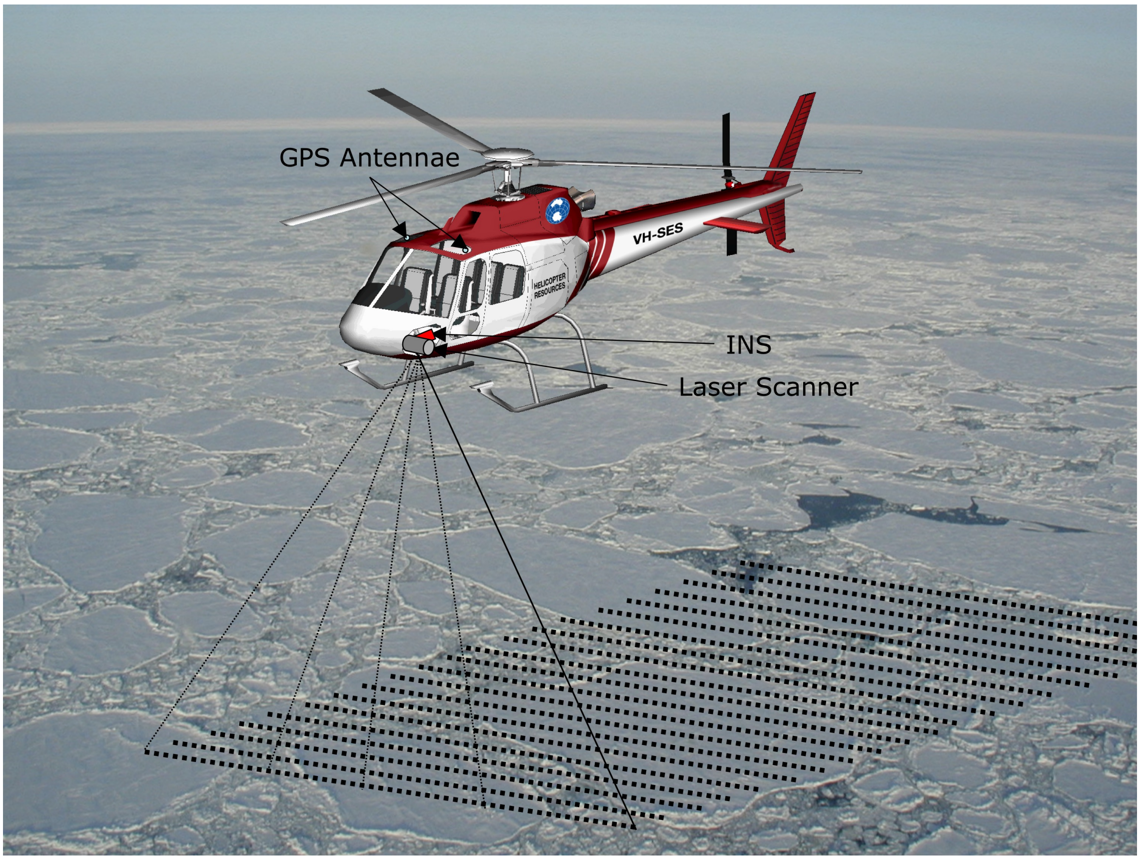

Image by Jan L Lieser (ACE CRC) & Adam Steer (AAD)

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1 Background

The term laser[1] scanner refers to a system using an opto-mechnical scanning mechanism to measure the range between the sensor and the illuminated spot on the object surface. In case of airborne laser scanners the laser beam is generally directed down so that this spot is on the ground. In contrast to multispectral scanners like the space borne LANDSAT Multispectral Scanner MSS or Thematic Mapper TM, laser scanners are active systems and use a laser beam as the sensing carrier. There are two common acronyms for such systems: LiDAR (Light Detection And Ranging) and LaDAR (Laser Detection And Ranging). While LiDAR systems might be built up with any kind of light source (for example xenon or flash lights), LaDAR specifically refers to laser sources.

The LaDAR system described in the following was purchased by the sea ice group within the glaciology program at the Australian Antarctic Division (AAD) to undertake large-scale sea ice (plus snow cover) surface elevation and roughness surveys for the validation of satellite-based measurements. The system is aircraft-independent, which means that it can be used from helicopter and fixed-wing aircraft. The infrastructure available through the Australian Antarctic program can therefore play a crucial role in validation studies of laser and radar altimetry programs, operated by both NASA and ESA, including the existing ICESat (a laser altimeter satellite, operated by NASA) and ENVISAT (which has a radar altimeter and is operated by ESA) missions, as well as planned ICESat II and CryoSat II (a dedicated cryosphere radar altimeter, operated by ESA) missions.

Making sufficient surface measurements for satellite validation is a challenging proposition, given the coarse nature of satellite data compared with ground truth point measurements on single ice floes. The spatial differences in the two measurement techniques make it essential to conduct some form of aircraft-based measurements, as an intermediate layer between highly-detailed surface observations and low-resolution satellite measurements. Space-based instrumentation offers the only means by which sea ice and snow cover thickness can be monitored globally, making field validation efforts over the next decade crucially important to the development and improvement of algorithms using data from these instruments.

Deriving ice freeboard height F (or any other kind of surface elevation) from laser scanner data is based on the following relationship:

$$F = h_{GPS} - H_{Laser} - N - \Delta h$$

where F is the ice freeboard height, h is the height of the aircraft, H is the measured range to the ice surface, N is the geoid, and Δh includes measurement errors, geoid errors, and ocean dynamic topography (tides and mean). These freeboard estimates can then be converted into ice thickness estimates assuming isostatic equilibrium between sea ice and water. In situ measurements of snow thickness and density from ice stations will provide the necessary in situ

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[1] The acronym laser stands for light amplification by stimulated emission of radiation.

data to help with the interpretation of the aircraft-based measurements.

The system consists of three components: the laser scanner, an inertial measurement unit, and a logging (and processing) PC. It will not only be used for marine cryosphere work but also provides capabilities of high precision range measurements for digital elevation mapping of glaciers, ice shelves, icebergs, and islands. In combination with coincident digital aerial photographs high resolution 3D digital elevation models can be produced.

2 The Laser Scanner

Figure 1: The RIEGL LMS-Q240i-60 2D Laser Scanner

The RIEGL LMS-Q240i-60 2D Laser Scanner makes use of the pulsed time-of-flight range measurement principle and beam scanning by means of an opto-mechanical scan mechanism, providing fully linear, unidirectional and parallel scan lines. The scanner has two major components: 1) range finder electronics, and 2) a rotating mirror.

The range finder electronics consists of a fast repetition rate laser, signal processing electronics and high speed data interface. The angular deflection of the laser beam is realized by a rotating polygon with four reflective surfaces. It rotates continuously at an adjustable speed to provide a unidirectional scan within an angle of $q = 60^\circ$. For every measurement RANGE, SCAN ANGLE, SIGNAL AMPLITUDE, and optionally a TIMESTAMP are provided via a TCP/IP Ethernet interface. The LMS-Q240i accepts a TTL-signal (i.e., 1 pulse per second) from a GPS receiver, to reset an internal timer, which is used to timestamp every measurement.

The laser has a nominal measurement range of up to 650m (2100ft) for natural targets with $r^3 = 80\%$. The minimum range is 2m. The accuracy and precision of the measurements are 20mm and 15mm, respectively. The pulse repetition rate is fixed at 30kHz giving an effective measurement rate of about 8kHz (taking the rotation of the polygon into account, when the laser beam is not directed through the scanner window - at the edges of the polygon). The laser wavelength is at near IR (905nm). The beam has a divergence of 2.7mrad, which results in a foot print at typical survey altitudes over snow covered surfaces of 36cm at 450ft (137m), and 119cm at 1500ft (457m). The scanning rate is adjustable between 6 and 80 scans per second.

Technical specifications are:

Input voltage range	18 -32 V DC
Current consumption	approx. 1.8 A @ 24 V DC
Main dimensions (diameter x length)	180 x 374 mm
Weight	approx 7 kg

3 The Inertial Measurement Unit (IMU)

An Inertial Measurement Unit (IMU) (or Position and Orientation System, POS) is mandatory for airborne LiDAR surveys. In conjunction with the AAD's laser scanner an Inertial and GPS Navigation System (INS/GPS) manufactured by Oxford Technical Solutions is used: RT4003. This IMU is a six-axis inertial navigation system that incorporates an L1/L2 Real Time Kinematic GPS receiver for position and a second GPS receiver for accurate heading measurements. It delivers better than 0.02m positioning under dynamic conditions using differential corrections and 0.1° heading using a 2m separation between the GPS antennas.

The RT4003 INS/GPS includes three angular rate sensors (gyros), three servo-grade accelerometers, the GPS receivers and all the required processing in one compact box. It has a fast update rate (250Hz) and a wide bandwidth. All outputs are computed in real-time with a very low latency and broadcast over CAN-bus, RS232 and Ethernet.

The internal processing includes the strapdown algorithms (using a WGS-84 earth model), Kalman filtering and in-flight alignment algorithms. The internal Pentium-class processor runs QNX real-time operating. The Kalman filter monitors the performance of the system and updates the measurements using GPS. The second GPS receiver measures the difference in position compared to the primary GPS receiver using the carrier-phase observations from both. The use of two GPS receivers delivers accurate measurements of heading even when the vehicles dynamics are low.

Technical specifications are:

Input voltage range	9 - 18 V DC
Power consumption	20 W
Main dimensions	234 x 120 x 80 mm
Weight	2.4 kg

4 The setup

As it stands at the moment the system can be used from helicopters to provide long uninterrupted transects across the pack ice. The laser instrument is currently fitted in a custom made shock mount that holds both the laser scanner and the IMU, as well as a pyrometer (which can be run simultaneously, but is not scope of this document). This mount fits in a Eurocopter AS 350 B ’Squirrel’ helicopter in the front left floor window with a cowling to be slipped on to the mount instead of the window. An Engineering Order (EO) is issued for all Squirrel helicopters available through Helicopter Resources Pty Ltd., the current aircraft charterer for RV Aurora Australis; however, the boreholes in the base plate of the mount and more importantly the cowling are made to fit only the aircraft with the call sign VH-SES.

The laser points down through the outside part of the mount platform in a way that it produces a scan pattern across flight direction. A mechanical shutter protects the laser window (and pyrometer lens) against dispersing dust during take off and landing. The IMU is mounted as recommended by the manufacturer so that the x-axis of the instrument points in forward vehicle (helicopter) axis, the y-axis of the instrument points to the right, and the z-axis points down[2].

(a) The laser mount installed in the front left floor window of the helicopter.

(b) The cowling over the laser mount in the front left floor window.

Figure 2: Installation of the laser system in VH-SES

Two GPS antennae (Antcom 42GO1215A4-XT-1) are mounted in the skylight (roof) windows of the helicopter and connect to the IMU directly. Power and data distribution is done through a central rack installed on the floor of the helicopter in front of the back bench. For more detailed information on this and

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[2] The RT4003 could be mounted in any direction. Variations in the actual mounting can be accounted for in the post-processing of the raw data using the supplied software package.

the wiring inside the aircraft refer to AAD Science Technical Support document Helicopter Equipment, compiled by Peter Jansen and Kym Newbery.

5 Data collection

The laser scanner data are collected using a set of purpose built PASCAL routines by Wolfgang Lieff of Airborne Research Australia (ARA) at Flinders University, Adelaide. The scanner control software 'ricontrol' provides all necessary commands for normal operation. All parameter needed to be set for a specific scan pattern (lines per second, start angle of polygon for measurements, number of measurements per line, trigger mode) are hard wired in the software at the moment and transferred to the laser via 'Send Setup' of 'ricontrol'. However, all parameters can be set individually trough ASCII control lines via 'ricontrol', once the laser scanner is put in programming mode (as opposed to scanning mode). They can be adjusted to suit different applications, especially speeds.

The main parameters and their interaction are illustrated in the following:

- SCN_ThetaD gives the rotation speed of the polygon. Given that the RIEGL LMS Q240i operates at a fixed pulse rate of 30kHz the effective scan speed in lines per second (LPS) is adjusted by ThetaD/30. For example: ThetaD set to 1800 results in 60 lines per second. The technically possible LPS range with this scanner is 6 - 80, which corresponds to a ThetaD range of 180 - 2400.
- SCN_ThetaS denotes the starting angle of the polygon for the first laser shot. At ThetaS = 600000 (i.e. 60°) the first laser pulse can leave the instrument during a scan. This angle can be increased (meaning the total opening angle of the scanner decreased) if for example shadowing effects could interfere with the measurement when the scanner is not mounted plain on the floor of the vehicle (aircraft), but inside any kind of housing or belly panel. For the maximum opening angle of the scanner the polygon angle should reach 1200000 (120°).
- SCN_ThetaN specifies the number of pulses per line. ThetaN=ThetaS/ThetaD.

This above setup produces 333 pixels per line at 60 LPS. At 6 LPS a line would consist of 3333 pixels, or at 80 LPS a line would consist of 250 pixels. Given full 60° opening angle of the scanner the length of a line is approximately the same as the altitude. At an altitude of 300m the above setting would result in 1 pixel per meter perpendicular to flight direction at a given speed above ground of 60m/s (or 116kn). This would also produce one pixel per meter along flight direction, meaning more or less square pixels on the ground. At 150m altitude it would be 1 pixel per 0.5 meter, requiring a speed above ground of only 30m/s if an isotrope coverage is desired.

The trigger mode can be set to either internally (following the built-in clock) or externally (forced by a TTL signal). All programming/setting up of the laser scanner has to be finalised by a 'SCN_APPLY' command. This way the scanner tries to apply all provided parameters (hardware test) and switches into operation mode if successful. The laser scanner produces approximately 250MB of raw data per scanning hour.

Another required check before the data logging might start is synchronisation to an external GPS. This is also done via 'ricontrol' and customised to accommodate the output from RT4003. To obtain measurements accurate to 0.02m, the RT4003 requires differential corrections from a suitable base station. During surveys commencing from RV AURORA AUSTRALIS L1/L2 GPS base stations are required on board the ship and the ship should preferably be as stationary as possible. Data collection should be also requested from other suitable base stations (for example, land bases in Tasmania and/or Antarctica).

The IMU stores raw data on an internal hard drive (500 MB, approx. 15 hrs. data). These data files can be transferred through the Local Area Network. Once the hard drive reaches its capacity, the oldest data are being overwritten. The IMU is configured using manufacturer supplied software RT Configuration Wizard (RTCfg). Here the orientation of the system and position of the primary and secondary antenna relative to a reference point in the INS have to be specified. Also a couple of options for improving the performance of the system can be set, for example vehicle start direction (level/not level), vibration of the environment, and initialisation speed. The IMU typically requires a minimum vehicle speed to initialise; however, static initialisation is possible when the appropriate box is ticked in the configuration.

A flight checklist should include:

- check external DGPS units are switched on and logging
- Laser shutter closed
- aircraft main power on
- fire up IMU: check IMU power lights on - 15 sec later: lights on Ethernet switch start flashing
- check logging laptop externally powered and start up
- connect logging PC: Ethernet/Serial/Power
- confirm PC runs on UTC; turn off auto adjust in Date/Time if required
- Laser power on: confirm beep ???
- logging PC: start ScannerControl
- logging PC ScannerControl: Request Info (should echo no errors)
- logging PC ScannerControl: GPS Sync
- logging PC ScannerControl: Send Setup - wait for Scan_Apply
- after lift-off: open shutter
- start logging
- before landing: close shutter
- logging PC ScannerControl: Exit
- Laser / IMU power off

6 Flight track pattern

After the operating system is airborne, it is recommended to perform a figure Eight pattern (or a race track pattern) over any kind of know structure, for example the airport's runway or a ship's deck. This will help to rectify the good accuracy during data processing. If the known pattern appears congruent regardless of flight direction this is an easy test of the performance of the system.

The typical survey usually consists of a series of cross sections over specific regions, transects hereafter. The following are three types of transects that are flown commonly over sea ice:

1. Ice station transects are repeated flights at low altitude across sea-ice floes adjacent to the ship during ice stations to validate the airborne data with the surface measurements.
2. Longer transects flown on a specific heading are to collect large-scale information on the sea ice. This data in turn is used to validate satellite information. High accuracy of these transects (matching temporal and geographic coverage of satellite overpass) is imperative to validate the satellite data for example from ICESat, which has a footprint of 70 metres at 150 metre intervals.
3. The buoy array is a third type of transect where repeated flights allow for quantifying dynamic processes in the sea ice (convergence and divergence) and lateral movement.

Also, it is helpful for the INS to re-orientate its gyros when the aircraft performs a gentle horizontal 360° turn every half hour, or so, when flying long transects.

7 Data processing

The IMU raw data (*.rd files) are post-processed using the manufacturer supplied software package 'RTPostProcess'. It is pretty self-explanatory software, however, a few crucial points are described here: The Config file should always be extracted from RD file; that way it is possible (and recommended anyway) to review the settings during data acquisition. After successful post-processing the raw data Position and Heading are the essential parameters to be exported in a comma separated value (csv) file at a minimum rate of 100Hz. Also, it should be checked to export the data in SI units. This csv-file is required as input to the laser processing. Processing of the GPS data, especially differential GPS, is not yet finally established.

The laser scanner data are post-processed using a set of purpose built PASCAL routines by Wolfgang Lieff of ARA at Flinders University, Adelaide (recent version 080529). These routines were originally designed for processing data from RIEGL's full waveform laser scanner. Processing involves typically three steps and is done through a WINDOWS command prompt:

1. Extract attitude data from IMU processed output file (*.csv). Use routine 'read_att' for this.

2. The second step transforms the data output of LMS Q240i to SDC format (output of RIEGL full waveform laser scanner).
3. The actual attitude correction of the range measurements, geolocation, and quality checking of the raw laser data is performed with 'scan_proc'. This routine is called with a range of options; the list of options appears with 'scan_proc -help'. Output data are written to a file either in UTM, LLZ, or LAS[3] format.

8 Data visualisation

Any commercial software able to display geographical data can be used to display the data. MATLAB® and SURFER® are currently used at ACE CRC and ARA for UTM or LLZ formatted files. There is a range of commercial software available to deal with LAS formatted files.

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[3] The size of the data and the data archiving and management issues were handled by the development of a LiDAR data archiving standard called the LAS file format. The LAS data format serves as the data storage, access, display and processing format. The LAS format is in essence a binary file format that stores the raw x,y,z, and return values of a particular LiDAR data set and ancillary descriptive and numeric attributes, within the framework of a single flight line. Advantages include a LiDAR data standard, binary data compression, reading and writing from a single file, and attribution of data so that the original data is always present, only class type of the point changes during processing.