

CALIBRATION AND DATA VALIDATION OF A LIDAR FIBER SCANNER

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presented at
ASPRS Annual Conference
May 24 to 27, 2004 Denver CO

ABSTRACT

Most customers require for each survey flight by airborne laser scanning separate calibration strips to ensure that the sensor system works properly or to compensate for detected and measured errors. This requirement is derived from the behavior of specific sensor systems and is not necessary in general.

This paper outlines some of the basic measurement principles, the components which form an ALS and the interrelations between these components. It shows why a fiber scanner is not sensitive to some of the errors by which other scanner systems are plagued and explains the measures taken by TopoSys to exclude a number of the error sources.

INTRODUCTION

A number of documents governing the acquisition of digital elevation models (DEM) by airborne laser scanning (ALS) ask for more or less complicated calibration procedures in course of survey flights. Reason behind these requirements is past experience with tilted strips, pillow distortions, shifts between adjacent strips and the like. Purpose of the requested procedures is to detect the errors, to measure them and to provide for corrective means at the stage of processing but not at data acquisition.

It seems to be far better, to avoid the errors and faulty measurements by designing and producing an ALS correspondingly. This avoids extra calibration flights, makes processing easier and faster, results in more reliable DEM and will save money.

TECHNICAL BASICS

To calculate a DEM from data acquired by an airborne laser scanner (ALS or LiDAR) one needs to know three parameters:

- distance
- direction into which the distance has been measured
- position from which the distance has been taken.

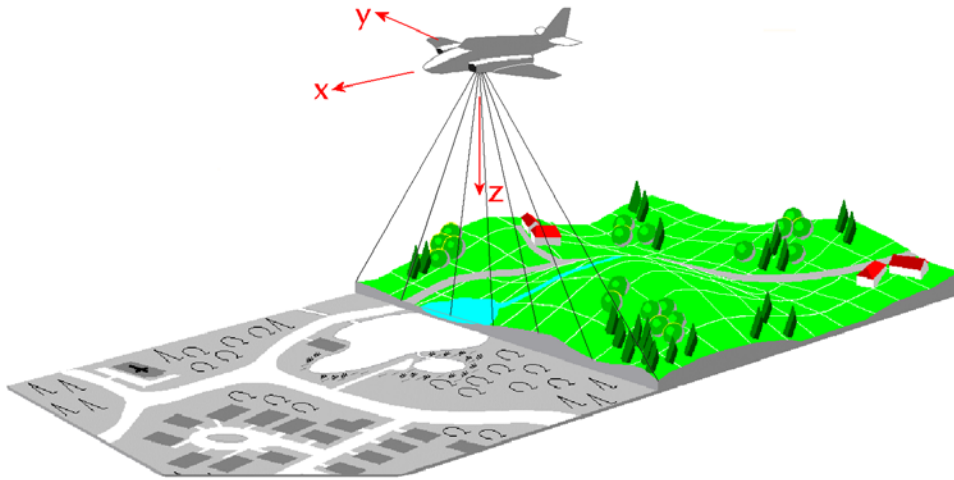


Figure 1. General Principle of Airborne Laser Scanning ALS

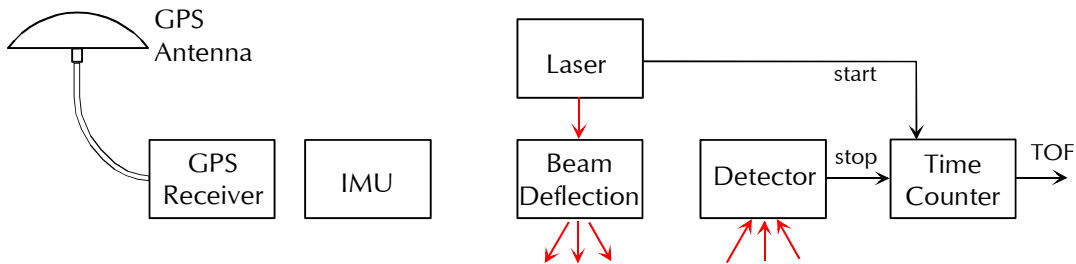


Figure 2. Basic Components

The basic components of an ALS are depicted in figure 2. Essentially they are completely independent elements which need to become a system by integrating them mechanically, optically and electronically. Only if this is done very precisely, one can expect an ALS working properly.

The following sections will give an outline about these components and their dependencies.

POSITION AND ORIENTATION

GPS – IMU

Position. The position is acquired by a GPS antenna and receiver at the aircraft and a GPS reference station located within the survey area. By combining the two data streams one can calculate a more precise DGPS position. The accuracy usually will be in the range of 0.05 m to 0.1 m if some restrictions have been maintained, which are primarily that reference and rover are not farther apart than 25 km, that PDOP is less than 2.5 and that there is no disturbance of the GPS frequencies by radars or micro-wave links. One need to keep in mind that this provides the position of the GPS antenna at the aircraft.

Attitude. The IMU measures accelerations and angular rates from which velocity, position and attitude are calculated. Due to the integration error the results show remarkable drifts. By combining the DGPS position and the derived velocities one can correct the IMU results and achieve very precise attitude and position data of the IMU. This procedure is usually called “strap-down” and can be done in real-time on-board and off-line on ground. Only the latter will achieve a high precision. At this stage the “lever-arm” between the IMU and the GPS-antenna is required. It can be measured at the time of installing the system in the aircraft but also by the “strap-down” process itself. It is advisable to fix this “lever-arm” for a given aircraft – ALS configuration, best from a survey with ideal conditions.

IMU Alignment. One very essential matter is that the IMU has to be aligned precisely to the earth's center of gravity. If there is even a minor miss-alignment this will result in tilts of the survey strip. The alignment can be done on ground prior to take-off or by in-flight alignment if the appropriate software is in use and if specific flight maneuvers are applied. If pilots are properly instructed, these maneuvers form part of the survey flight and do not require additional flight time.

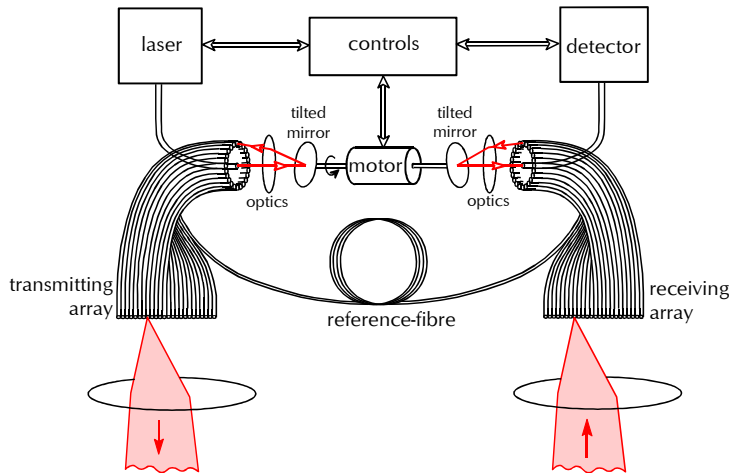


Figure 3. Principle operation of a fiber scanner

transmitted to ground. The reflected light is focused to the corresponding fiber at the receiving side from where it is guided to the circular array and coupled into the center fiber leading to the detector.

The direction of a transmitted laser beam is given by each individual fiber and remains stable. Any miss-alignment within this arrangement will lead to a loss of energy but not to a false direction.

Bore-sight alignment

The fiber scanner guarantees a precise knowledge about the beam direction with respect to the fiber-scanner itself but not necessarily with respect to the orientation of the sensor or the IMU. For this fiber-scanner and IMU are mounted close together on a CFRP plate as shown in figure 4. This ensures that the orientation between both becomes invariable against any mechanical forces induced by the aircraft or forced by thermal variations.

The bore-sight alignment for both is established by at least one specific calibration flight taking a large set of buildings of which the coordinates of the roof have been measured conventionally to a cm accuracy. To reduce the influence of errors from the DGPS positioning, such a calibration flight is done only at favorite conditions.

Laser-Beam Direction

IMU and GPS provide position and attitude of the IMU, but not the orientation of the laser beam. This is influenced by the device deflecting the laser beam perpendicular to the flight direction. Here is one essential difference between a fiber scanner used by TopoSys and the oscillating mirrors used by Optech and Leica or the rotating mirrors used by Riegl and Terrapoint.

Figure 3 gives a general overview on the principles of a fiber scanner. The light guiding fibers are arranged at one end in a circle and at the other end in a fixed linear array. The laser pulse is coupled from the laser into one of the fibers arranged in a circle at the left side of the diagram. From there it formed to a narrow beam and

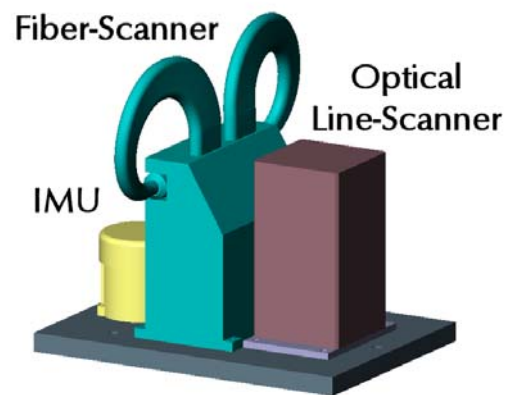


Figure 4. Mounting of IMU and Fiber-Scanner

DISTANCE MEASUREMENT

Counting device

The distance is measured by counting the time duration between the emission of the laser pulse and the reception of the echo (or reflection from ground) and by converting this “time of flight” (TOF) into distance. TopoSys applies for this time measurement specific devices which guarantee a stable counting over a wide temperature range from -20°C to 45°C . The software allows for a correction of the light speed, should the survey area be on high elevations and thus at a low average pressure.

Reference fiber

Counting the time of flight is influenced by all the various electronic devices from the electro-optic receiver to the time counter. Its accuracy might therefore degrade with temperature and/or aging processes. One of the fibers is directly fed from the transmitting side to the receiving side (see figure 3). This “reference fiber” has a precisely calibrated optical length of 2,200 m, simulating a distance of 1,100 m. The signal is attenuated such that it corresponds to an echo from a low reflecting surface. This distance is measured once per scan (i.e. each 1.6 msec) and is used to monitor all ranging electronics and eventually to correct for degradations.

Echo Detection

Echo detection means first to recognize the reflected laser light and then to register the echo. The most common approach is to take the raising edge of the echo as reference, because this edge of a laser pulse is usually much steeper than the trailing edge.

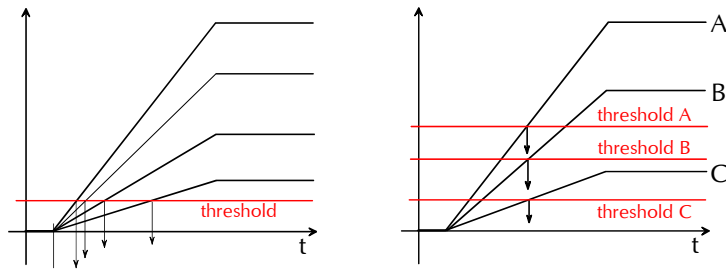


Figure 5. Echo and edge detection

Frequently echo edge detection is done by applying a threshold; if this threshold is exceeded by the echo signal, the time counter is caused to stop. As shown by the left diagram in figure 5 this method depends on the amplitude of the echo signal. As lower the amplitude becomes as later the threshold will be exceeded, causing a too long distance.

TopoSys applies an adaptive threshold and thus measures always the same distance independent from the amplitude of the echo.

A similar effect results from a slant viewing to the ground which causes a longer rise time of the echo and thus a delayed stop of the counter.

TopoSys applies a laser operating at a wavelength of $1.56\ \mu\text{m}$. Light at this wavelength gets reflected completely from water-surfaces and thus the TopoSys system provides reliable distance measurements over water. Light at shorter wavelengths penetrates partially into the water leading to a reflection from within the water and to a longer rise time of the echo.

DEM PRODUCTION

Scan Pattern

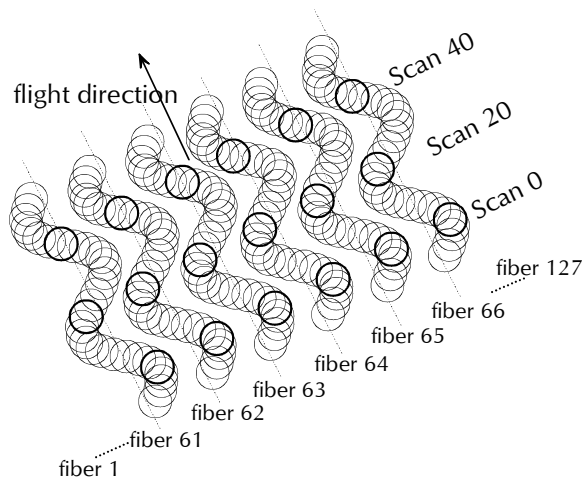


Figure 6. Scan-Pattern

The scan pattern of a fiber scanner looks like a push-broom scanner ranging from the right to the left side of a swath with a constant separation between adjacent fibers. Overlaying a slight swiveling with amplitude of about 1 mrad (0.06 deg) fills the gaps between the fibers completely.

Due to the high scan rate of 650 Hz adjacent scans overlap. The nominal scan lines are only about ½ foot apart. Unless there is a steep edge at the landscape adjacent measurements can not differ largely. If there are single measurements deviating from their neighbors they can be considered as erroneous.

Unlike widely separated measurements this method provides a high reliability of the resulting DEM coming close to the reliability of an electronic distance measurement device.

Gridding

Data from an ALS are often delivered as x, y, z co-ordinate triples, assorted into first, last and intermediate echoes. To derive from this an application oriented DEM requires an enormous additional effort, specifically as this would require knowledge about the sensor system by which these data have been acquired.

TopoSys went a different way and applies through all processing stages a regular grid. All co-ordinates are calculated directly in the target co-ordinate system which usually is a metric system, applying locally valid transformation parameters. At this early stage already a geoid undulation can be applied correcting for the orthometric height.

The grid used at all processing stages has a higher resolution (or smaller spacing) than the final grid requested by the customer. The width of the intermediate grid is ¼ or ½ of the final grid width. The elevation assigned to the final grid cell shall be the one which best represents the elevation of this cell in respect to the application of the DEM. Due to the high measurement density there are more than one measurement falling into the final grid cell. Usually the most reasonable of these measurements is assumed to best represent the correct elevation. For some specific applications the assigned elevation can be calculated by weighted averaging or by interpolating the measurements falling into this grid cell.

The method of measuring more data than required for an elevation model, makes this model much more reliable than taking wide spaced measurements requiring interpolation to fill gaps or to make the model more homogenous.

Edge detection

The DEM measured by TopoSys provide such details that easily buildings can be detected and extracted automatically. Figure 7 shows the measured elevations in color-code. The building and roof are easily identifiable.

The high density also provides the capability to detect break-lines. Figure 8 shows a hill-shaded elevation model of a meadow (left upper part), a small creek, a dike and the river surface. The green lines at the side show the automatically extracted soft break-lines at the creek and at the dike before transferring these data into vector form.

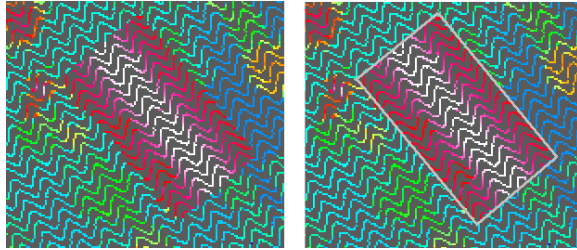


Figure 7. Edges of a building

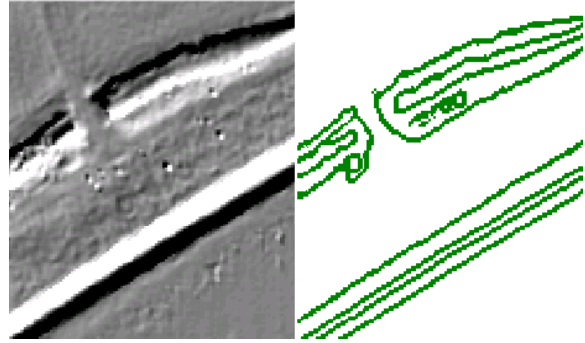


Figure 8 soft break lines

Thinned DEM

For a large number of available software packages the amount of data given by a dense DEM is too high either caused by the maximum size of files or by the processing time required. To solve this bottleneck TopoSys has developed algorithms for thinning out the regular grid DEM transforming it into a mesh with a variable width. By maintaining the original DEM data at the location of hard or soft break-lines one can preserve the DEM accuracy and reduce the amount of data to less than 1/10 or even to 1/100.

TRUE-ORTHO

Falcon incorporates an optical line scanner oriented in the same direction as the fiber scanner. The image data can be rectified onto the DSM giving true ortho images. One consequence of using a line scanner instead of a framing camera is that there are no shadowing effects in flight direction. Shadowing effects across the flight direction are marginal and are compensated by the neighboring flight strip.

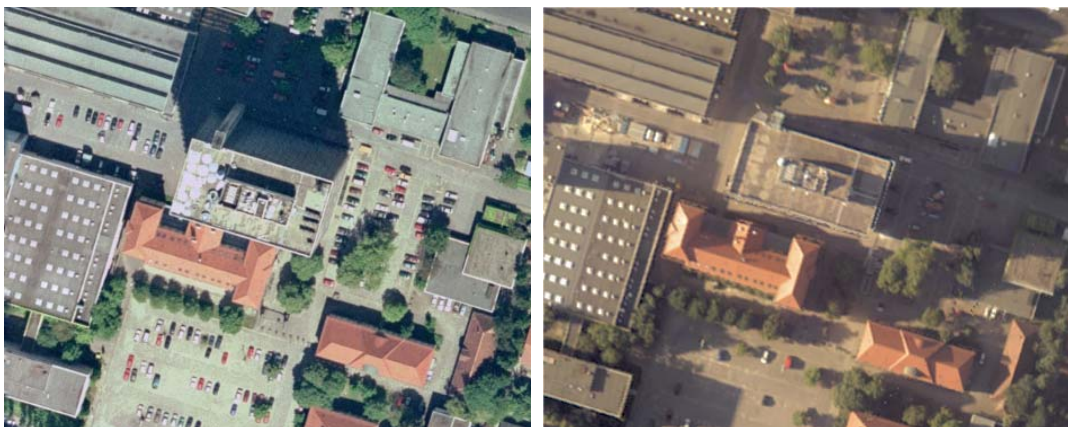


Figure 9. Ortho Image

and

True Ortho Image

The optical line scanner operates at four bands providing image data in blue, green, red and near infrared. From those one can derive standard RGB images or CIR images.

CONCLUSIONS

Applying the technology developed by TopoSys and incorporated in the FALCON sensor system provides a number of advantages:

- One calibration at factory acceptance and after exchange of major components.
- No calibration flights during normal survey missions.
- Control and proof of bore-sight alignment forms integral part of survey flights and does not require special efforts.
- Highly reliable DEM.
- Special DEM for various applications.
- Detectability and measurability of hard and soft break-lines.
- Simultaneous acquisition of image data in four spectral bands.

REFERENCES

- FEMA (2003). Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix A: Guidance for Aerial Mapping and Surveying. www.fema.gov/fhm/dl_cgs.shtm. April 2003
- Katzenbeisser, R. (2003). About the calibration of Lidar Sensors. – *Proceedings of the ISPRS WG III/3 workshop “3-D reconstruction from airborne laserscanner and InSAR data”*, Dresden 8-10 Oct. 2003, Vol. XXXIV, Part 3/W13.
- Schenk, T., Seo, S., Csatho, B. (2001). Accuracy study of airborne laser scanning data with photogrammetry. – *International Archives of Photogrammetry and Remote Sensing, XXXIV-3/W4*: 113-118, 2001.
- Schenk, T., (2001). Modeling and Recovering Systematic Errors in Airborne LaserScanners. – *In: Torlegard, K. (Editor): Proceedings of OEEPE workshop on Airborne Laserscanning and Interferometric SAR for Detailed Digital Elevation Models, Stockholm March 1 – 3, 2001.*