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Leica ALS70 – Point Density Multiplication for High Density Surface Acquisition

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ABSTRACT

While numerous methods of point cloud generation continue to develop, using both direct and indirect methods for measurement, airborne LIDAR continues its development at an extremely rapid pace. Output data accuracy has reached somewhat of a plateau, and therefore system productivity continues to be a key focus of development. An overview of airborne LIDAR development is given, with a focus on the Point Density Multiplier technology employed in the most recent generation of Leica Airborne LIDAR systems.

1. HISTORICAL DEVELOPMENT IN AIRBORNE LIDAR SYSTEMS

Since the onset of commercialized use of airborne LIDAR in the mid 1990s, there has been rapid growth in both the worldwide installed base as well as the capabilities of these systems. In some respects, airborne LIDAR affected somewhat of a dark period for the use of photogrammetric data in the generation of both digital surface models (DSMs) and digital elevation models (DEMs). Recent developments in photogrammetric extraction of DSMs (e.g., semiglobal matching on a pixel-by-pixel basis) have brought renewed attention to the technique, and essentially turned imaging devices into DSM acquisition machines with point acquisition rates nearly equal to the pixel rate of the imaging device.

Even so, as a direct-measurement technique, airborne LIDAR has a certain measure of attraction, and the technique does hold advantages in certain applications. In particular, extraction of DEMs in vegetated areas has proven to provide many times more forest floor “hits” per measurement attempt than can be achieved through photogrammetric means. This, of course, is intuitive because airborne LIDAR only needs a clear line of sight to a given point on the forest floor one time, and stereo images of the same point on the ground are not needed.

Other applications take advantage of the fact that airborne LIDAR is an active sensor system. For instance, the ability to acquire data after dark expands the number of flying hours and can provide for covert operation.

1.1. Market development

As can be seen in Figure 1, the cumulative number of airborne LIDAR systems sold accelerated rapidly during the middle of the last decade. Some leveling in market demand has occurred, at least in part due to recent events in the world economy. Some recovery in the market is currently seen, with the current rate of system sales in the market coming close to pre-2010 levels when viewing the total installations of all manufacturers combined.

1.2. Technology development

Over time, technology development in airborne LIDAR has focused on a number of areas, including:

- accuracy
- pulse rate
- minimum vertical separation distance
- full-waveform digitization and exploitation
- scan pattern control (pattern shape and maximum scan rates)

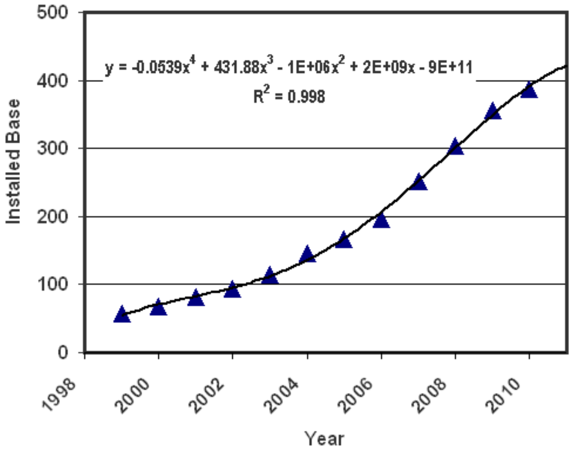

Figure 1: Growth in world-wide LIDAR installed base. The degree of leveling in recent years may be a result of market saturation, recent world economic events, or a combination of both.

Market forces have pushed to the greatest degree in the areas of accuracy and pulse rate, with the other attributes mentioned above developing at a reasonable, though slower, rate. Figure 2 shows that accuracy improvement has leveled off in recent years, being limited ultimately by the accuracy of both airborne GNSS trajectory information and, to a lesser extent, by the accuracy of the ground control to which the processed point cloud may be tied.

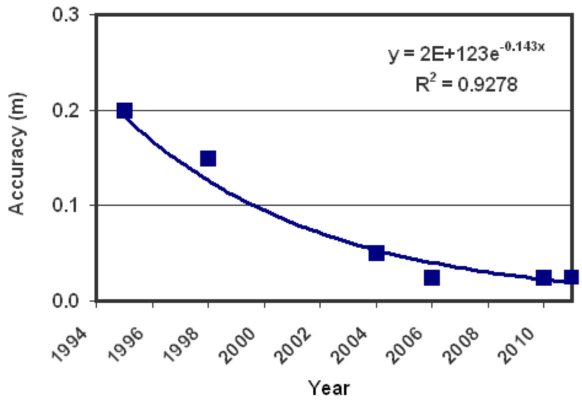

Figure 2: Airborne LIDAR typical achievable accuracy, showing leveling in recent years.

By contrast, growth in the maximum measurement rate has been both substantial and continual. Measurement rate can be interpreted as a prime indicator of data acquisition productivity. This is due to both the fact that a higher-measurement-rate system simply adds more points to the point cloud for each second of flight, but that is a simplified view. In addition to faster acquisition of individual points, one also can also achieve a given point density over a wider swath. Since planimetric navigation error is essentially fixed (a function of pilot skill and meteorological conditions), the wider swath allows the mission plan to be executed with a lower percentage side overlap[1].

Maximum measurement rate has been advancing at a rate approximating a two-fold increase every two years[2], and the capabilities of the industry's most advanced offerings have grown from a maximum pulse rate of 5 kHz in the mid 1990s to 500 kHz currently. In the process, a change in nomenclature has resulted. The industry now refers to "effective pulse rate" as opposed to simply laser pulse rate. This recognizes the inherent differences between scanning approaches (e.g., raster scanning systems have less than a 100% duty cycle) and also the fact that some systems utilize multiple scan heads in a single system. This will be discussed further in the next section.

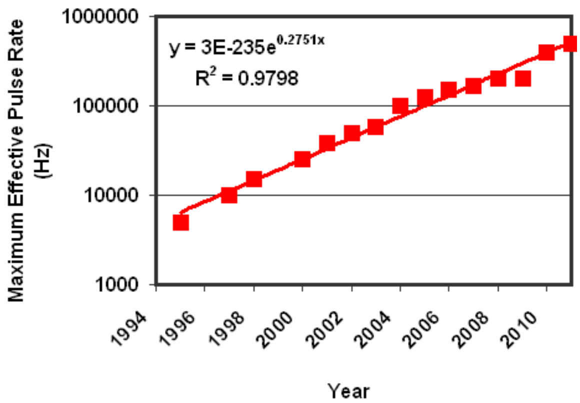

Figure 3: Growth in airborne LIDAR effective measurement rate. Note the high coefficient of determination (R^2), indicating the high degree of predictability in the growth of measurement rate.

2. RECENT DEVELOPMENTS

As mentioned in 1.2 above, there has been sustained growth in effective measurement rate over the past decade. In the early period, until about 2004 measurement rates were constrained by laser pulse rate and end-of-measurement-cycle timing overhead. The only way to enable higher pulse rates was to reduce this overhead or to fly closer to the terrain. By reducing end-of-measurement-cycle overhead, higher pulse rates for any given flying height could be obtained. Maximum pulse rate was ultimately limited by the round-trip propagation time of the laser pulse as it travelled from the aircraft to the ground and back, leaving lower flying heights as the remaining method for achieving higher measurement rates.

In 2006, the introduction of Multiple Pulse in Air (MPiA) technology allowed users to overcome the limitations imposed by the speed of light by effectively "juggling" outbound and return pulses such that an additional outbound pulse could be fired prior to receiving the return reflection from the previous pulse. With the advent of MPiA, systems could be operated at twice or even 3 times the measurement rate of single-pulse-in-air systems for any given flying height. The major limitation became laser performance, obtaining (1) laser pulses with high pulse-to-pulse consistency over a wide range of pulse rates to preserve range measurement accuracy and (2) adequate pulse energy at high pulse rates and at the greater flying heights allowed by using the MPiA functionality. By 2009, the state of the art in effective measurement rate leveled off at 200-266 kHz.

Recent LIDAR developments have focused on obtaining a significant jump in effective measurement rate. Leica Geosystems' Point Density Multiplier is an example of an application of new technology resulting in a more than doubling of maximum effective measurement rate for any given flying height over that offered by the immediately-preceding generation of systems. Point Density Multiplier consists of two main technical elements: (1) a multiple-output scanning system and (2) new and innovative range measurement electronics.

2.1. Multiple-output scanners

Multiple-output scanners are a recent innovation that provide a LIDAR implementation where the system provides more than one output and return signal reception path. In effect, multiple-output scanners can be viewed as parallel scanning devices. The resulting effect is similar to that of having two fully synchronized LIDAR systems flying in the same aircraft at the same time. The resulting scan pattern is schematically illustrated in Figure 4.

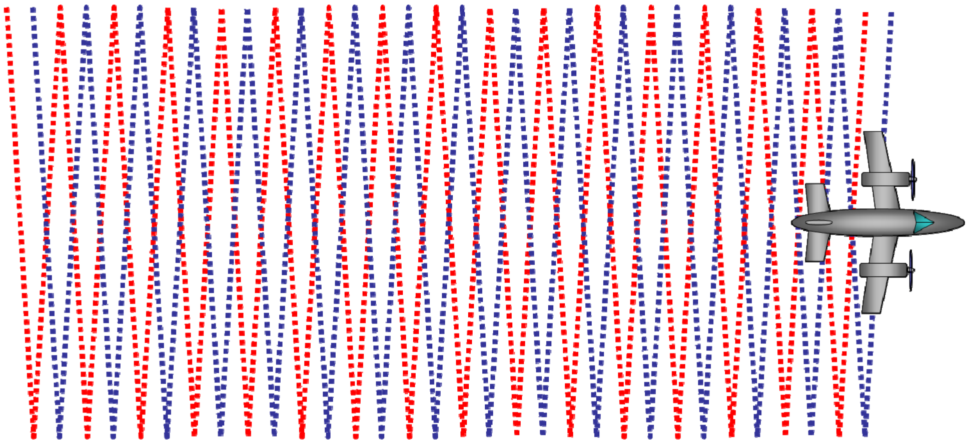

Figure 4. Representation of point pattern on ground of dual-output airborne LIDAR scanner. The blue point pattern is the forward-looking channel and the red point pattern is the rearward-looking channel. Note that, in a properly-controlled scanning system, the target of having the scan patterns from the forward-looking and rearward-looking channels remain out-of-phase is achieved.

Three distinct embodiments are seen in commercially-available systems:

- Use of multiple complete, or nearly complete, systems
- Use of multiple scan heads in a single scanner
- Use of a single laser, single scanner and single receiving optics

It is the third embodiment above that is used as an integral part of the Point Density Multiplier technology employed in the Leica ALS70-CM and ALS70-HP systems. All three of the above embodiments have the advantage of effectively doubling both measurement rate and scan rate over that of a single-output system of similar design. However, the third embodiment also results in a simplified design. It requires only a single laser, single scan mirror/scan actuation electronics and a single set of receiving optics. Of course, at least some of the system components must be duplicated in order to maintain a multi-channel system. In the case of Point Density Multiplier, the laser output and detection circuitry is duplicated.

Although only a single laser is used, the laser output is split upstream of the scan mirror. This provides two outputs, one aimed slightly forward and one aimed slightly rearward, prior to impacting the scan mirror. These two outputs are steered toward various points along the scan by the scan mirror. Return reflections from terrain below the aircraft are then reflected back toward the system, impinging on the scan mirror and are then reflected into the receiving optics.

Unlike the optics used in imaging systems, the optics used in airborne LIDAR typically feature a relatively small maximum focal plane size. In a dual-output optical system, the two detectors must be mounted off-axis by a distance large enough to match the off-axis angle of the laser outputs. In the case of the Leica ALS70-CM and ALS70-HP, the focal plane size is adequate to allow the needed off-axis detector mounting without the need to redesign the receiving optics.

An issue with multi-output scanning systems is caused by variations in speed-to-height ratio during the course of a flight line. As the speed of the aircraft, height above terrain or both vary, the ideal scan rate that would maintain the forward- and rearward-looking channels out of phase (refer back to Figure 4) changes. If the two scan patterns approach an "in-phase" orientation, the along-track point spacing benefits associated with the dual-output scanner are not realized[3]. For this reason, an integral feature of Point Density Multiplier is a continuous in-flight monitoring of both speed and height above terrain, with subtle adjustments being made automatically to maintain an out-of-phase orientation of the two scan patterns.

Similar to the phase variations caused by changes in speed over ground and flying height, attitude changes can also cause undesirable changes in the relationship between the two scan patterns. In particular, changes in aircraft pitch can cause the two scan patterns to depart from the ideal out-of-phase positioning. At present, the best available solution is mounting of the scanner on a stabilized platform such as the Leica PAV80. Such mounting has the additional benefit of fully compensating for drift variation ("crabbing") so that additional side overlap is not needed between flight lines in order to compensate for the presence of cross winds.

2.2. Low range-measurement-cycle overhead range counting electronics

As mentioned earlier, reduction in range-measurement-cycle overhead allows the ranging system to operate at pulse rates closer to the limitations imposed by the speed of light (even with MPiA operation). This measurement-cycle overhead has been further improved through the use of new range measurement electronics as part of the Point Density Multiplier. The net result is the ability to operate at higher pulse rates than previously achieved at any given flying height. It also offers the benefit of a wider MPiA operating envelope (range accommodation) for any given pulse rate. This fact makes MPiA operation easier, particularly over areas of rugged terrain.

An added benefit of the new range measurement electronic architecture is a reduction in circuit card count. In the previous generation of system control and measurement hardware, scaling of the design to accommodate a dual-output scanner would have resulted in a nearly 50% increase in circuit board count. Instead, a simpler approach is used whereby all return pulses are counted by the same range measurement circuit. This includes both the returns from forward- and rearward-looking channels as well as from the multiple returns that might result from each laser pulse. The result is a consistent range counting process for all returns and simplified calibration.

The new range measurement architecture also yields an improvement in minimum range separation, as well as removing any limit on the number return reflections which can be measured for each outbound laser pulse. The combination of these two can be particularly beneficial in acquiring higher levels of detail in tree canopy, without requiring the high data overhead of full waveform data collection. In many respects this can be a reasonable compromise, while providing a wealth of data.

3. AREAS FOR CONTINUED DEVELOPMENT

The implementation of Point Density Multiplier in the latest generation of Leica Geosystems' airborne LIDAR systems has provided a substantial (>2x) improvement in system productivity. It also is an inherently scalable technology. As a parallel scanning architecture, systems could conceivably be produced with more and more output channels, subject only to the available laser output and the ability for receiving optics to provide a focal plane large enough to accommodate a larger array of detectors.

While improved "wide field" optics are almost trivial (at least in comparison to those used on large-format imaging systems), the same cannot be said of laser sources. As additional optical channels are allocated, the need for higher pulse energy is clear. Pulse energy must increase in proportion to the number of optical outputs. The expansion of MPiA technology to more than two pulses in the air simultaneously (in addition to having multiple optical channels) means that these same higher pulse energies will be required at higher pulse rates, in proportion to the increase in number of pulses in the air. The combination of the two above factors will put serious demands on the type of laser selected, and will also likely affect power consumption and system size.

Therefore, continued expansion of this technology is warranted, with due attention to laser sources and, to a lesser extent, receiving optics. Still, the current technology can act as a secure baseline for future introductions that keep airborne LIDAR performance climbing on the current trajectory of doubling productivity approximately every two years.

4. ADDITIONAL THOUGHTS

Although the current state of the art for production airborne LIDAR systems is a 500 kHz effective pulse rate, this is still nowhere near the rate at which point cloud source data can be acquired when using an imaging system where nearly every pixel in a stereo pair will result in a measured point. For instance, the pixel acquisition rate of the Leica ADS80 is 12 MHz (i.e., a stereo pair of 12,000-pixel arrays operating at a maximum 1,000 Hz line rate)[4]. The effective match rate is roughly 80% on typical terrain, yielding up to 96 million points per second in the resulting point cloud. Although the processing time is much greater on a per-point basis, this processing is largely "hands-off". In combination with the relatively low cost of computing power, the resulting cost per point can be much less than that resulting from LIDAR-generated point clouds. The foregoing indicates the need to carefully select the acquisition sensor (image-based versus airborne LIDAR) for a given application.

5. REFERENCES

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