Current Developments in the Technology

Airborne Topographic Laser Scanners

The recent Intergeo 2010 conference and trade fair and the ELMF 2010 forum and exhibition have both served to highlight the many new developments that have been taking place in airborne topographic laser scanners. Indeed, as a result of all of this activity and innovation, airborne laser scanning is a booming sector of the mapping industry and a flourishing area for the system suppliers. This article discusses the main advances that are occurring in the technology and presents an overview and survey of those systems that are operational and are currently available on the market.

By Gordon Petrie

Introduction

After a rather long and quite slow period of development from the mid-1990s onwards, over the last five or six years, airborne laser scanning has seen big advances in its technology. So much so that it has become a mainstream mapping technology alongside airborne digital imaging. Indeed, nowadays, these two complementary airborne technologies are often used in combination for mapping purposes, producing the digital elevation and image data that are required for many topographic mapping applications. Thus, for example, many orthophotos are now produced from this particular combination of data. Based on information from both published and private sources, I would estimate that there are well over four hundred airborne laser scanners in operational use world-wide at the present time. Given that the cost of a single full-blown airborne laser scanner system (including its obligatory GNSS/IMU unit and its optional digital camera) lies in the range $500,000 to $1.3 million, in total, this amounts to an enormous capital investment in the technology by the mapping industry.

However, although the airborne laser scanner is now well established as a mapping tool, the technology is still being developed apace with the prospect of a further considerable improvement in performance, especially with regard to the density of points that can be measured over the ground. Many users, especially in the engineering field, are requesting very high densities of accurately measured elevations – as high as several tens of points per square metre for elevation data having height accuracies in the sub-decimetre class – and apparently they are willing to pay for such detailed and accurate 3D data. At the other end of the mapping scale, e.g. in the context of regional or statewide terrain modelling and other large-area surveys, there are calls for ever greater coverage of the terrain from a single flight – which, in practice, means that this type of laser-derived elevation data has to be acquired and measured from ever greater flying heights.

On the hardware side, there has been a continuous development of laser rangefinder technology in order to generate the power that is needed for scanner operations from ever higher altitudes and at pulse rates that meet the needs for ever higher point densities. Other interesting developments include the extension of the wavelengths that are used by airborne laser scanners from the near infra-red (NIR) [\(\lambda = 0.7 \text{ to } 1.4 \, \text{µm}\)], which has mostly been used in the past, to the blue-green part of the spectrum [\(\lambda = 400 \text{ to } 550 \, \text{nm}\)] and to the short wavelength infra-red (SWIR) [\(\lambda = 1.4 \, \text{µm} \text{ to } 3 \, \text{µm}\)]. Those laser rangefinders that are using these shorter and longer wavelengths exhibit quite different characteristics, e.g. in terms of water penetration and eye-safety respectively, to those in the NIR part of the spectrum that we have become used to.
I – Technological Aspects & Components

Overall Concept & Principal Components

The overall concept of the airborne laser scanner is that (i) the position, height and attitude of the airborne platform (together with that of the scanner which is mounted on it) are being measured continuously in-flight by an on-board GPS/IMU or GNSS/IMU unit with specific reference to a nearby GPS ground base station or a wide-area correction service such as OmniSTAR. (ii) Simultaneously a dense series of ranges and the corresponding scan angles from the platform to the ground are being measured very rapidly across the terrain in the cross-track direction by the laser rangefinder and by the angular encoder that is attached to the scanning mechanism. (iii) Combining these two sets of measurements results in the determination of a line of elevation values at known positions (with X, Y, Z coordinates) forming a profile across the terrain in the cross-track direction [Fig. 1]. The successive series of these measured profiles that are acquired in parallel as the airborne platform flies forward forms a digital terrain model or 3D point cloud of the terrain area that has been scanned. Besides the measurement of the slant range values using a very precise clock, the scanner detectors will also measure the intensity (or energy) value of the returned pulse. However this latter information is often very ‘noisy’ and difficult to interpret or to utilize. Up till now, the intensity values appear to be of limited interest to most users of airborne laser scan data, whose interest and attention is usually focussed on the positional and elevation data that is provided by the laser scanner.

The main hardware components of a typical scanner are shown in Fig. 2. The slant range to each successive point along the ground profile is determined through the very accurate measurement of the time-of-flight (TOF) between the emission of the pulse that has been fired by the laser rangefinder and its reception back at the rangefinder after reflection from the ground. Obviously the rate at which the laser rangefinder fires its successive pulses – the pulse repetition frequency (or PRF) – and the rate at which the ground is being scanned while the profiles are being measured – the scan rate – are vital parameters in determining the actual density of the points that are being measured on the ground.

Multiple Pulses

However the matter of the number of pulses that are being fired towards the ground is not dependent purely on the rate at which the laser rangefinder can operate, but also on the flying height (H) of the airborne platform from which it is being operated. Thus, for a flying height of 1,000 m, each individual pulse that is fired by the laser rangefinder in the nadir direction will travel a distance of 2,000 m (2 km) to the ground and back. So the total elapsed time for this return trip to the ground and back will amount to 2/300,000,000 seconds = 6.7 µs (microseconds) – where the speed of light is 300,000 km/sec. Thus, in earlier types of airborne laser scanner, this time period had to elapse before the next pulse could be fired towards the ground. This meant that the maximum PRF value that could be achieved from that specific flying height of 1 km was 150,000 Hz (= 150 kHz) – even though the laser rangefinder itself could fire its pulses at much greater rates. If higher flying heights were being used – for example to acquire greater ground coverage from a single flight – then the elapsed time of travel for each pulse would be greater and the effective pulse rate of the rangefinder would need to be lowered accordingly. The increase in the slant range as the scan angle increases away from the nadir direction must also be taken into account.

This particular limitation has now been overcome to a considerable extent with the introduction by all the major laser system suppliers of the technique of having multiple pulses measured in the air simultaneously within a single profile scan. This feature is called “multiple-pulses-in-the-air” (MPIA) by Leica Geosystems; “continuous multipulse” (CMP) by Optech; and “multiple time around” (MTA) by RIEGL. Irrespective of these differences in the name, their common adoption of this particular technique means that the laser rangefinder can fire a new pulse towards the ground without having to wait for the arrival of the reflection of the previous pulse at the instrument. Thus more than one measuring cycle can be taking place at any specific moment of time. It is not clear from the suppliers’ literature how many of these cycles may be used simultaneously. In practice, there must be a maximum figure depending on the flying height at which the scanner is being operated. However the use of up to three such cycles has been reported in the case of RIEGL’s latest LMS-Q680i scanner. With the introduction of this technique, maximum pulse rates have risen to 200 kHz and beyond – though the actual value that is used will still be dependent on the flying height.

Scan Patterns & Scan Rates

The matter of the scan patterns and scan rates that are being used in a particular model of scanner is also of considerable importance in achieving the desired point density and coverage of the terrain. Both the Optech and...
Leica laser scanners achieve their ground coverage through the bi-directional scanning of the terrain using oscillating mirrors controlled by galvanometers or servo motors. This means that the mirrors have to slow down and stop (at the turning points) before reversing their direction of scan and accelerating away on the return sweep. The mirrors need to be very light weight but very stiff in order to achieve the high scan rates that are needed. The resulting scan pattern over the ground is saw-toothed in the case of the Optech ALTM scanners [Fig. 3 (a)] and sinusoidal in the case of the Leica ALS scanners [Fig. 3 (b)]. In both cases, the maximum scan rate that can be achieved using bi-directional scanning is inversely proportional to the field of view (FOV) that is being employed. Obviously a narrow FOV can have a higher scan rate than can be achieved with a wide FOV. For example, a maximum scan rate of 100 Hz can be achieved with the Leica ALS60 scanner with a narrow FOV of 15 degrees, falling to 40 Hz at the ALS60’s maximum FOV value of 75 degrees.

In the case of the RIEGL scanners, a continuously rotating optical polygon is used to provide a unidirectional scan at a constant rotational velocity over the ground. This arrangement provides high scan rates – 200 Hz maximum in the case of the Optech ALTM scanners [Fig. 3 (a)] and sinusoidal in the case of the Leica ALS scanners [Fig. 3 (b)]. In both cases, the maximum scan rate that can be achieved using bi-directional scanning is inversely proportional to the field of view (FOV) that is being employed. Obviously a narrow FOV can have a higher scan rate than can be achieved with a wide FOV. For example, a maximum scan rate of 100 Hz can be achieved with the Leica ALS60 scanner with a narrow FOV of 15 degrees, falling to 40 Hz at the ALS60’s maximum FOV value of 75 degrees.

Yet another scanning pattern, which is used in the TopEye Mk II, TopEye Mk III and AHAB DragonEye laser scanners that are manufactured in Sweden, is the so-called Palmer scan. This pattern was first utilized in NASA’s ATM and AOL laser scanners from the 1990s. It makes use of a nutating mirror to produce a continuous series of overlapping elliptical scans over the ground surface as the airborne platform flies forward [Fig. 5]. As with the RIEGL scanners, the scan mirrors of the TopEye Mk II and Mk III and the AHAB DragonEye rotate continuously and do not have to slow down and stop, as is the case in those scanners that employ bi-directional scanning over the ground. The advantage of this configuration is that each point on the ground is scanned twice from different directions. This allows measurements to be made to those points that were occluded during the first pass. The reported disadvantage is the complexity involved in processing the two sets of measurements for each ground point that have been obtained with a certain time difference between them from different positions and with different orientations in the air. However AHAB has assured me that, in practice, this has proven not to be a problem.

Dual (or Multiple) Pulse Streams

Since it is difficult to envisage substantial increases in the scan rate, the three major system suppliers have all been exploring the possibilities of increasing still further the density of points being measured on the ground. This is being done using dual streams of laser pulses to carry out range measurements between the scanner and the ground simultaneously. In the case of RIEGL, its BP-560 system utilizes twin LMS-Q560 laser scanners [Fig. 6 (a)] which are mounted on a frame which is installed in a specially built carbon-fibre belly pod [BP] that is attached to the underside of a Diamond DA42 MPP [Multi-Purpose Platform] twin piston-engined aircraft [Fig. 6 (b)]. The two laser scanners are operated simultaneously, both firing their pulses in a coordinated manner. This allows both the scan rate and the pulse rate to be doubled when both laser scanners are being operated simultaneously in a nadir pointing configuration. This dual scanner arrangement results in two streams of laser pulses reaching the ground in parallel, instead of the single stream that will result from the use of a single scanner. The two RIEGL scanners that are being used in the BP-560 system share a common GPS/IMU sub-system, which can be supplied either by IGI or...
Applanix. So far, only a very few of these systems have come into operation. A limitation is that the BP-560 system with its specially built belly pod was designed specifically for use with the Diamond DA42 MPP aircraft and is not available for use with other survey aircraft.

In the case of Optech, the company has developed its Pegasus airborne laser scanner system. Again this employs dual scanner units, but with shared electronics as well as a shared Applanix GPS/IMU position and orientation system. Only a few Pegasus scanner systems have been operated till now. However it is possible to envisage further scanner units - say one or two more - being added to this modular system, so increasing the scan rate and pulse measurement rate still further. With regard to Leica, the company has just announced its "Point Density Multiplier" technology at the recent Intergeo 2010 trade fair. This new technology is being implemented in its newly announced ALS70 airborne laser scanner. This will retain the single laser scanner of the previous ALS50 and ALS60 models, but it features a more powerful laser rangefinder that will generate twin pulses simultaneously using a beam splitter. One of the two streams of laser pulses is tilted slightly from the nadir direction so that the two streams of pulses cover the ground in parallel. Again this effectively doubles both the scan rate and the pulse measurement rate to ensure the acquisition of a greater density of elevation values over the ground.

**Laser Rangefinders**

The laser rangefinder (LRF) is a major component in the overall airborne laser scanner system. While its operational characteristics (PRF, scan rate, etc.) appear on the data sheets published by the system suppliers, information about the actual types of laser, the wavelengths being used, etc. is seldom released by the system suppliers. Yet, at the same time, the various manufacturers of the actual lasers are not slow to proclaim that their lasers are being used in airborne laser scanners. The difficulty lies in matching the two – which lasers are being used on which scanners? Only NASA with its research laser scanners is willing to give detailed information on this matter. From this source, it is well known that powerful Q-switched solid state lasers using Nd:YAG and Nd:VO<sub>4</sub> rods (that emit their pulses at \( \lambda = 1064 \) nm) and Nd:YLF rods (that utilize \( \lambda = 1046 \) nm) have been used in the laser rangefinders that are employed in certain airborne laser scanners. However other types of solid state lasers are in use in certain other scanners, as are semi-conductor diode lasers.

In general terms, more powerful lasers need to be employed as the operational flying heights get higher. In which case, eye safety becomes a matter of increasing concern. In this context, it is interesting to note the increasing use of fibre lasers on airborne laser scanners. These lasers employ a special type of optical fibre doped with a rare earth such as erbium which emits its pulses at wavelengths around \( \lambda = 1540 \) nm in the short wavelength infra-red (SWIR) part of the spectrum – with wavelengths above \( \lambda = 1400 \) nm being reckoned to be ‘eye-safe’. These optical fibres can be quite long, but can be coiled up to form a very compact laser that is pumped by a relatively inexpensive diode laser and uses fibre Bragg gratings on the fibre ends as internal reflectors [Fig. 7 (a)]. These fibres exhibit excellent thermal dissipation when used in a high powered operation. Indeed, at the ELMF 2010 exhibition held recently in The Hague, fibre lasers of this type for use in laser scanners were being shown by the Manlight company from Lannion in France [Fig. 7 (b)]. It was only too apparent that the system supplier who utilizes these fibre lasers in its airborne laser scanner products had a stand that was located only a few metres away from the Manlight booth.

**Detectors & Data Recording**

Most earlier types of airborne laser scanner only detected and recorded single echoes (the first return) or two echoes (the first and last returns) from the returning signals reflected from the ground objects that have been struck by the laser pulse. However, many of the more recently introduced models have the capability of recording multiple (usually three or four) discrete echoes or returns, e.g. those from trees and branches as well as the ground – which can be useful when mapping vegetation or forests. Other scanners have also been developed to carry out full waveform digitizing and recording by which the complete analogue waveform showing the intensities of the reflected pulse from its leading edge to its trailing edge is digitized and recorded for each successive pulse that is emitted by the scanner and strikes the ground objects. Thus the entire return signal for each pulse is being measured in terms of intensity values as a function of time. In the case of the RIEGL LMS-Q560 and LMS-Q680i series, this capability is an integral part of the scanner. With the Leica ALS scanners, it takes the form of an additional waveform digitizer module (WDM65). The digitization is carried out with a recording interval of 1 or 2 ns, so the use of this technique demands enormous data storage. It is not clear that the resulting data is of value outside the research domain and certain forestry applications. Nevertheless, the three main system suppliers – RIEGL (with its DR560 and DR680 data recorders), Leica (with its DLM65 recorder)
and Optech – all now offer a waveform recorder based on the use of removable solid state drives as an option for attachment to the appropriate models in the range of airborne laser scanners that each of them offers [Fig. 8].

Within this particular area, it is also interesting to note that NASA is using photon detectors in its experimental SIMPL (Swath Imaging Multi-Polarization Photon-counting Lidar) project. This is a prototype airborne laser scanner instrument which is intended to focus on its potential to carry out (i) the mapping of land topography; (ii) the mapping of glaciers and large areas of land and sea ice, and (iii) vegetation mapping. The photon detectors have the ability to detect and count the individual photons reflected by the terrain surface from the very short pulses that are generated by small fibre lasers [Fig. 9 (a)]. These lasers can generate short low energy pulses at a high repetition rate that have a small ground footprint. The underlying concept behind the SIMPL project is that, once the basic technology is proven, it will use multiple examples of these fibre lasers, which will be operated in a pushbroom configuration. Essentially, if this scheme proves to be successful, then a fully developed instrument would carry out swath mapping of the ground with multiple lasers and detectors operating in a fan configuration producing elevation profiles in parallel in the along-track direction [Fig. 9 (b)]. This would eliminate the use of scanning mirrors which is a feature of all current airborne laser scanners. [N.B. It is not too different a concept to that of the multi-beam sonar which is used in underwater bathymetric mapping, but, in this case, with the airborne laser scanner sending multiple light pulses through the air simultaneously instead of the sonar emitting multiple acoustic pulses underwater simultaneously!]

Imaging

The intensity values that are returned by the laser pulses that are being reflected from the topographic features produce a rather ‘noisy’ or grainy image on which is often difficult to interpret and precisely delineate the individual ground objects. Indeed much of the information content that is provided by a dedicated imaging device cannot be duplicated or matched by the intensity image from the laser scanner. Thus almost all airborne topographic laser scanner systems are equipped with a supplementary imaging device or sub-system that can generate much higher quality images in terms of their resolution and texture as well as their colour content. Originally very small-format video cameras were used in this role. One or two users have also used pushbroom imaging line scanners for this purpose. However, nowadays, the imaging device is almost always a medium-format digital frame camera with a format that can range from 16 to 60 Megapixels. The camera and the laser scanner are usually mounted rigidly together on a common base plate or mount [Fig. 10]. The spatial relationship of the two devices is then determined very exactly through measurement during calibration. For operational use, the two devices are closely integrated and they will normally share flight management and control sub-systems in common, together with a single shared GNSS/IMU sub-system.

Given the number of airborne laser scanners that are in current operation, when added together, the total number of cameras that have been supplied as part of a laser scanner system form a very large segment of the airborne medium-format digital frame camera market. Previously these cameras were mostly supplied to the laser scanner system integrators and suppliers by Applanix and RolleiMetric, both of which have been acquired by Trimble. However, more recently, the main suppliers of laser scanner systems have moved to ensure that these cameras are produced in-house under their own control and to their own profit, rather than being bought in from a commercial rival. By doing this, the servicing and support arrangements for the cameras can also be simplified.

Thus, in 2007, Leica Geosystems first started to fit its own RCD105 camera – which it sourced from Geospatial Systems Inc. (GSI) in the U.S.A. – to its range of ALS laser scanners. At Intergeo 2010, Leica introduced its new RCD30 medium-format digital frame camera, which it builds in-house in its factory in Heerbrugg. This camera can also be integrated with its ALS laser scanners. Similarly, Optech acquired DiMAC Systems earlier this year (in June 2010) and will now build the range of DiMAC medium-format cameras in its manufacturing facility in Vaughan, Ontario with a view to fitting them to its laser scanners. In a recent further development (in December 2010), Optech has also pur-
of the measured data, the position and attitude values that are provided by the GNSS/IMU sub-system have certain accuracy limitations. Indeed these form the biggest part of the overall error budget of an airborne laser scanner system. The GNSS or GPS receiver is the primary source of the absolute positional data and is supplemented by that provided by the IMU, which also supplies the attitude data. In this context, three different categories of IMU can be distinguished in terms of their performance and price.

(i) A “high end” navigation grade IMU is usually based on Ring Laser Gyros (RLG). These are very expensive, so their use is confined to only the most demanding applications in terms of accuracy.

(ii) A tactical or medium grade IMU is usually based on the use of Fibre Optic Gyros (FOG), which are somewhat less expensive in terms of cost and are widely used in the GNSS/IMU sub-systems employed in airborne laser scanner systems.

(iii) Commercial consumer level IMUs are based on the use of MEMS (Micro Electro-Mechanical System) gyros. They are much less expensive, but also less accurate, although some MEMS gyros are now approaching the quality of FOGs.

Applanix POS/AV – Absolute Accuracy Specifications – RMSE Values

<table>
<thead>
<tr>
<th>Model No.</th>
<th>210</th>
<th>310</th>
<th>410</th>
<th>510</th>
<th>610</th>
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<td>0.05 – 0.3</td>
<td>0.05 – 0.3</td>
<td>0.05 – 0.3</td>
<td>0.05 – 0.3</td>
</tr>
<tr>
<td>Velocity (m/s)</td>
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<td>0.075</td>
<td>0.005</td>
<td>0.005</td>
<td>0.005</td>
</tr>
<tr>
<td>Roll &amp; Pitch (degrees)</td>
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<td>0.015</td>
<td>0.008</td>
<td>0.005</td>
<td>0.0025</td>
</tr>
<tr>
<td>True Heading (degrees)</td>
<td>0.08</td>
<td>0.035</td>
<td>0.015</td>
<td>0.008</td>
<td>0.005</td>
</tr>
</tbody>
</table>

Relating these general remarks about IMUs to the present discussion about airborne laser scanners, and taking the Applanix POS AV GNSS/IMU devices that are widely used as sub-systems in airborne laser scanners as examples, the POS AV 610 uses RLG gyro; the POS AV 510 uses FOG gyro; while the POS AV 410, 310 and 210 all use MEMS quartz gyro. The accuracy specifications which are offered by the different versions of the POS AV system that have been used in conjunction with the Optech ALTM airborne laser scanners are summarized in the table given above, which is based on data published by Optech and Applanix.

II - Airborne Topographic Laser Scanner System Suppliers

As mentioned above, there are three main commercial suppliers of airborne laser scanners – Optech Inc., Leica Geosystems and RIEGL. A smaller supplier is AHAB from Sweden. Besides which, two of the largest providers of mapping services world-wide – Fugro and Blom – have both (and quite independently) constructed a substantial series of laser scanners in-house that they operate routinely in commercial service. Furthermore, quite a number of individual (one-off) custom-built systems have been constructed and operated in North America, Western Europe and Japan. This last group will not be discussed here, nor will airborne bathymetric laser scanners.

Fig. 12 – (a) An Optech ALTM Gemini system with the laser scanner unit at right rear and the control electronics cabinet at left rear. In front is the laptop computer that is used to control the overall system and a small system display monitor. (b) The compact Optech Odon laser scanner and its accompanying digital camera are mounted rigidly together on a tiltable base plate at left. The laptop computer used as controller and a small display monitor are at right. (Source: Optech)

Fig. 13 – The Optech Pegasus HD400 multi-laser system with the scanner unit at right. The control electronics cabinet is at left with a laptop computer and a system display monitor sitting on top of it. (Source: Optech)
laser rangefinder operating at $\lambda = 1064$ nm and has a pulse repetition rate of up to 200 kHz. The rangefinder in the C200 model operates at $\lambda = 1541$ nm with an emphasis on eye safety, having regard to the very low altitudes at which it may potentially be operated. The M200 model utilizes the higher grade Applanix POS AV 510 system as its geo-referencing system, while the C200 is fitted with a POS AV 410 unit as its GNSS/IMU sub-system.

As discussed above, the Pegasus scanner is the latest product in the Optech ALTM family with its design based on the use of multiple laser rangefinders operating at $\lambda = 1064$ nm; a single shared scanner mechanism; and a single Applanix POS AV 510 GNSS/IMU sub-system [Fig. 13] Operating in combination, a twin rangefinder version of the Pegasus can produce PRF values up to 400 kHz, giving rise to the initial commercial version which is called the Pegasus HD400. This configuration ensures its operation from medium altitudes (up to 2.5 km) and/or its production of a high density of elevation values on the ground. It is also possible to configure the instrument so that one stream of scanner pulses is nadir pointing while the other points in a forward direction. This allows better coverage of the vertical sides of cliffs and buildings and will also aid the detection of the masts and wires that are so important for aircraft safety and will appear on airport approach charts.

**Leica Geosystems**

Leica Geosystems first entered the airborne laser scanner market in January 2001 through its purchase of the Azimuth Corporation, a small American company based in Massachusetts that had developed its Aeroscan laser scanner. This system was rebranded and sold by Leica as its ALS40 scanner. In 2003, a new and much smaller and more compact design called the ALS50 was introduced. This was followed, in 2006, by an improved version called the ALS50-II which introduced multiple pulse technology to the range, allowing pulse rates to be increased up to 150 kHz. Shortly afterwards, production was switched from Massachusetts to Leica’s main manufacturing plant in Heerbrugg, Switzerland. In 2007, Leica introduced its Corridor Mapper design [Fig. 14 (a)], which, as the title suggests, is designed for corridor and other types of mapping at large scales from lower altitudes up to 1,000 m above ground level. This was followed by the introduction of the ALS60 model which represented a still further upgrade of the ALS50-II design with pulse repetition rates of up to 200 kHz [Fig. 14 (b)].

Although the ALS40 and, initially, the ALS50 systems both incorporated the Applanix POS AV GPS/IMU as their geo-referencing sub-system, in 2004, the Applanix company was acquired by Trimble, one of Leica Geosystems’ main competitors across the whole field of surveying and mapping instrumentation. This led to Leica’s purchase of the small Terramatics company based in Calgary, Canada in 2005. This company had already developed its IPAS (Inertial Position & Attitude System) GPS/IMU product and this was quickly adapted and incorporated into the ALS50 scanner and its successors. As with the Optech
ALTM scanners, the performance of the successive models in the Leica ALS series has been steadily augmented and improved over the years. With the ALS60 model that was introduced at the ISPRS Congress in 2008, the pulse rate had risen to a maximum of 200 kHz employing multi-pulse technology, while the maximum scan rate had increased to 100 Hz. The very latest ALS70 model—which has only just been introduced to the market by Leica Geosystems—is offering a still higher performance employing its “Point Density Multiplier” technology. As discussed above, this model will generate two streams of laser pulses simultaneously using a single laser rangefinder and scanning mechanism in combination with a beam splitter and a multiple pulse operating regime. The initial announcement mentions a maximum effective pulse rate of 500 kHz being attainable from a flying height of 1,000 m above ground level and a 200 Hz scan rate using the dual stream of laser pulses.

### RIEGL Laser Measurement Systems

Although RIEGL was already a well-established manufacturer of laser measuring instruments such as distance and speed meters, ground-based laser rangefinders and scanners, aircraft altimeters and anti-collision devices, the company did not enter the field of airborne laser scanning until 2003. However it has done so in a very different manner to that of Optech and Leica, who are suppliers of complete systems. Instead RIEGL has chosen to develop within the airborne scanning field principally as an OEM supplier of laser scanning engines, each comprising a laser rangefinder and scanning mechanism, together with the associated timing circuitry and control electronics. These laser scanning engines have been supplied to a number of systems suppliers and commercial mapping service providers, who have added a GNSS/IMU sub-system, developed the appropriate software and integrated all these hardware and software components to create the final complete airborne scanning systems. Although this activity as an OEM supplier forms a very large part of RIEGL’s business within the airborne laser scanner sector, RIEGL has also built and supplied a number of complete systems to customers, albeit on a much smaller scale.

The main LMS-Qxxx series of RIEGL laser scanner engines that have been built for use in airborne systems have been developed along two main lines. The first of these, comprising the LMS-Q140 and the later LMS-Q240 laser scanning engines, have been designed specifically for use from relatively low altitudes, e.g. for corridor mapping or power line surveys, and are normally operated from a helicopter. The other main line, comprising the LMS-Q280 and the later LMS-Q560 engines, were designed to act as the basis for laser scanner systems that are being operated from higher altitudes and mounted on fixed-wing aircraft. The latest and most powerful model in this LMS-Qxxx series is the LMS-Q680i which was announced early this year (2010) [Fig. 15 (a)]. This features a maximum laser pulse repetition rate of 400 kHz using RIEGL’s multiple pulse technology (with 3 pulses in the air simultaneously) together with a maximum scan rate of 200 Hz over a 60 degree FOV. This performance is claimed to produce an effective measurement rate of 266,000 coordinated points per second. A special version of this scanner is the NP680i which can be supplied as a complete system (not just a laser scanner engine), including a GNSS/IMU unit and a medium-format digital frame camera, and is designed to be fitted into the new “universal nose” of the Diamond DA42 MPP aircraft [Fig. 16]. This replaces the previous LMS-S560 product which utilized a single LMS-Q560 scanner in the belly pod that can be mounted on the Diamond DA42 MPP aircraft, as already discussed above.

Another new development from RIEGL has been the introduction of its new “V-Line” series of compact and lightweight laser scanner engines in the autumn of this year (2010). So far, two models—the VQ-480 and VQ-580—have appeared in this series [Fig. 15 (b)]. A comparison of the data sheets for these two products reveals an almost identical performance, including a maximum laser pulse repetition rate of 300 kHz; a maximum scan rate of 100 Hz; and an effective measurement rate of 150,000 coordinated points per second. The maximum operating altitude for both of these scanner engines is circa 1,000 m above ground level. The VQ-480 scanner is intended for lower-altitude applications such as corridor mapping and power line inspection, while the VQ-580 is said by RIEGL to be “especially designed to measure on snow and ice”.

### RIEGL-Based Systems

A number of German system suppliers have based their airborne laser scanner products on the laser engines that have been supplied to them by RIEGL on an OEM basis. One of the principal system suppliers and system integrators is the IGI company with its range of LiteMapper airborne laser systems. To the basic RIEGL laser scanner engine, IGI then adds its own CCNS (Computer Controlled Navigation System) for flight navigation and precise data acquisition and its AEROcontrol GNSS/IMU for direct geo-referencing. The laser scanner engine and these sub-systems are then integrated together with IGI’s purpose-built LMcontrol unit and various software modules that have been developed in-house by IGI. Currently the systems that result from the integration of all these hardware and software modules include the LiteMapper 4800 (based on the new RIEGL VQ-480 scanner engine); the LiteMapper 5600 (based on the LMS-Q560) [Fig. 17]; and the LiteMapper 6800-400 (based on the LMS-Q680i). Besides which, IGI’s DigiCAM medium-format digital frame camera and DigiTHERM digital thermal IR camera are both optional items that can be added to a LiteMapper scanner system.
A very similar range of laser scanner systems is also available from the GeoSpatial Division of Trimble, which acquired TopoSys, another German system supplier, in September 2008. In this way, Trimble entered the airborne laser scanner business, having acquired the TopoSys Harrier product line. These Harrier laser scanners parallel the IGI products, but, in each case, the IGI sub-systems are replaced by the equivalent products – e.g. the POS AV GNSS/IMU for geo-referencing and the POSTrack integrated flight management system – from Applanix, which is also part of the Trimble organisation. Either a Trimble (Applanix) DSS digital camera or a Trimble Aerial Camera can also be fitted to any of the Harrier laser scanners as an additional optional item. Currently Trimble offers its Harrier 48 [based on the RIEGL VQ-480 scanner engine], Harrier 56 [based on the LMS-Q560] [Fig. 18]; and Harrier 68i [based on the LMS-Q680i] models in this particular field.

Besides the systems that are sold to customers by IGI and Trimble, RIEGL has also supplied its OEM laser scanner engines direct to a number of mapping service providers in North America who have carried out the integration of these engines and their development into fully operational laser scanner systems in-house. Examples of these include (i) Lidar Services International (LSI) in Calgary, Canada, which operates three of its Helix systems – two helicopter-based and one mounted in a Cessna fixed-wing aircraft – all of which are equipped with RIEGL laser scanner engines; (ii) the three ALMIS-350 helicopter-borne systems developed by the Terrapoint division of the Ambercore company, which has its headquarters in Ottawa, Canada and operational bases in Houston, Texas and Calgary, Alberta; and (iii) Tuck Mapping Solutions from Virginia with its three ‘eagleye’ systems, all operated from Bell helicopters.

AHAB

The Airborne Hydrography AB (AHAB) company, which is located in Jonkoping, Sweden, is best known for its development of the HawkEye-II airborne bathymetric laser scanner system, three of which are in current operation worldwide with Pelydryn Ltd., based in Newport, South Wales in the U.K. AHAB also developed the laser rangefinders and scanners that formed part of the upgrade of the original Blom TopEye systems into the TopEye Mk. II systems. However AHAB has also developed a very compact topographic laser scanner system for operation from lower altitudes (up to 1 km) over land surfaces, called DragonEye [Fig. 19 (a)]. This system is equipped with a laser rangefinder having a maximum PRF of 300 kHz at H = 200 m and 200 kHz at H = 500 m and detectors that can record up to four return echoes per pulse. The DragonEye has a Palmer scan mechanism that generates an elliptical scanning pattern over the ground at scan rates up to 100 Hz [Fig. 19 (b)]. The GNSS/IMU sub-system that is currently used in the DragonEye is the iTraceRTF200-E manufactured by iMAR in Germany, which utilizes a FOG (Fibre Optic Gyro)-based IMU. Like all other topographic laser scanners, the DragonEye can be supplied with either video or digital frame cameras to generate the accompanying imagery.
Article

III – Custom-Built Laser Scanner Systems

Fugro

According to the Fugro company’s Web site, currently it operates eight of its in-house developed FLI-MAP systems, mainly through two of its subsidiary companies – John L. Chance Associates in the U.S.A. and Fugro Aerial Mapping BV based in the Netherlands. Development of the original FLI-MAP (Fast Laser Imaging Mobile Airborne Platform) began in 1993 and it entered operational service in 1995. The FLI-MAP-I and FLI-MAP-II models that followed all date from the late 1990s, while the later FLI-MAP 400 systems have all been built during the present decade. All of these scanner systems have been mounted on helicopter platforms and have been used primarily for corridor surveys from low altitudes. However the newest model in the series, called FLI-MAP 1000, is designed for use from higher altitudes and is mounted on fixed-wing aircraft.

The FLI-MAP 400 (Fig. 20) employs a laser rangefinder with a maximum PRF of 225 kHz, which is used in conjunction with a continuous rotating four-faced polygon mirror that allows forward and backward scans as well as nadir pointing scans. These provide a raster-based ground pattern over the ground at a maximum scan rate of 150 Hz. The position and orientation system is somewhat unusual, comprising four Trimble GPS receivers. One is used as the primary navigation receiver, while the data from the other three secondary receivers and a vertical gyro are used to derive the values of the heading, roll and pitch of the platform (and the laser scanner system). With the FLI-MAP 1000 system, the PRF of the laser rangefinder has been increased to 375 kHz; the scan speed has been doubled; and a multiple-pulse-in-the-air technology has been implemented, all of these improvements allowing 250,000 elevation points to be acquired per second. All of the FLI-MAP systems employ various types and configurations of video and digital frame cameras to provide the images that supplement the elevation data acquired by the laser scanners. However, for its wider area operations from higher altitudes, the Fugro EarthData company uses Leica ALS50-II and ALS60 scanners.

Blom

The Blom TopEye airborne laser scanners originated with Saab starting in 1993, with the first TopEye scanners becoming operational from the mid-1990s onwards. After a number of changes in ownership, the TopEye company operating the instruments was bought by Blom in 2005 and, since then, it has become one of the main operational elements of Blom Sweden, based in Gothenburg. The original TopEye Mk-I scanners featured oscillating mirrors producing a Z-shaped pattern of coverage over the ground, similar to that of the Optech ALTM scanners. However the instruments were re-built (and re-designated as the TopEye Mk-II) from 2004 onwards. The very substantial upgrade included the installation of fibre lasers operating at λ = 1064 nm with a selectable output energy and an effective pulse rate of 50 kHz. The TopEye Mk-II also employed avalanche photo diodes as detectors that can record both the first and last echoes together with the full intensity waveform of the returning pulse after its reflection at the ground. The rebuilt scanners were also fitted with rotating mirrors that produced an overlapping elliptical (Palmer scan) pattern over the ground. The flight altitude envelope stretched from 60 to 960 m above ground level.

The latest model in the series is the TopEye Mark III which incorporates a proprietary dual-scan technology using (i) a laser rangefinder operating at 210 kHz in conjunction with a Palmer (elliptical) scan mechanism; and (ii) a RIEGL LMS-Q560 (linear/roaster) laser scanner. The reflected pulse echo data is again being captured as a full intensity waveform. Not only does this dual scanner arrangement provide higher density data over the ground (Fig. 21 [a]), it also acquires its data at two quite different wavelengths – λ = 1064 nm (NIR) and λ = 1550 nm (SWIR) respectively. All the TopEye laser scanners are designed to be operated from helicopters flying at low altitudes (Fig. 21 [b]). Seven of these TopEye scanners have been built, with five being operated by the Blom group and a further two with the Aerotec company in the U.S.A. For higher-altitude operations, the Blom group uses both Optech ALTM and Leica ALS60 laser scanners. Furthermore the Blom CGR company based in Italy has recently ordered one of the new Optech Pegasus HD400 scanners.

Conclusion

Laser scanning from airborne platforms has already established itself as one of the standard methods that can be used for the acquisition of digital elevation data which is accurate and reliable enough for many mapping and visualization purposes, though not all. However, as this article has shown, airborne laser scanner technology is still being developed apace. It will be very interesting to see what impact these new developments will have on the overall aerial photogrammetric scene, especially with regard to the possible full integration of airborne imaging and laser scanning technologies.

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Fig. 20 – (a) This helicopter is equipped with a FLI-MAP 400 laser scanner system, which is mounted in a frame that is attached to the underside of the aircraft. Note also the two outrigger pylons, each supporting a GPS antenna. (b) A CAD drawing of the frame that carries the FLI-MAP laser scanner and the system’s video and digital frame cameras. This is fitted externally to the underside of the helicopter. (Source: Fugro)

Fig. 21 – (a) Showing the respective ground patterns – elliptical (in red) and raster (in black) – that are being measured by the dual laser scanners of the Blom TopEye Mk. III system. (b) The TopEye Mk. III laser scanner system is mounted in the box that is fitted to the underside of this helicopter. (Source: Blom)