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# Lidar Imagery – From Simple Snapshots to Mobile 3D Panoramas

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## ABSTRACT

Lidar imagery is now providing unique 3D imaging capabilities for an expanding range of applications. Lidars are widely used for measuring the location, shape and structure of solid surfaces for applications in surveying, mapping, positioning and vehicle guidance. Lidars are also able to make sub-surface marine and hydrographic measurements for water depth measurements, water quality studies and identification of underwater resources. Such lidars can be operated from airborne, surface and underwater platforms. Lidars have also become the sensors of choice for an increasing number of atmospheric measurements including meteorological and air quality studies. Additionally lidar imaging has been used in a variety of space applications including planetary exploration as well as spacecraft landing, docking and rendezvous. This paper presents an overview of the highlights of these applications along with an outline of future trends and directions.

## 1. BACKGROUND CONCEPTS

It is interesting to note that one of the first lidar airborne terrain mapping studies was reported exactly 20 years ago at the 1991 Photogrammetric Week in a paper by Joachim Lindenberger entitled “Methods and Results of High-Precision Airborne Laser Profiling”. This study was carried out using an early version of an Optech rangefinder and the excellent results obtained stimulated Optech to develop the new ALTM line of instrumentation dedicated to Airborne Lidar Terrain Mapping. This area has now grown to be one of the major business areas of the company. In addition, Joachim went on to develop a commercial airborne survey service that has played a leading role in the development of the lidar airborne survey field.

Lidar is able to measure the location and other properties of a remote region by using the reflected signal from the region when it is illuminated by laser radiation. Lidar is an active optical remote sensing system, “active” because it provides its own source of radiation unlike “passive” optical remote sensors which rely on ambient illumination or thermal emission from the region of interest. The development of lidar has arisen from the discovery of lasers in 1960 and the rapid development of these unique light sources.

Lasers provide the ability to generate highly controlled optical radiation in a variety of pulsed or modulated continuous wave (CW) modes. With lasers it is possible to specify and control:

- Wavelength and wavelength spread, [$\lambda$ and $\Delta\lambda$]
- Wavelength tunability [$\lambda(t)$]
- Pulse width and repetition frequency ($\Delta\tau$ and PRF)
- Output beam direction and beam spread, $\Delta\theta$ and $\theta(t)$
- Degree of polarization
- Level of optical coherence
- Output intensity
- 3D location of the remote region of interest
- Irradiance (power per unit area) on that remote region.

Lidar systems can make use of all of these capabilities to provide unique illumination signatures. Combining this detailed knowledge of the illumination with a comprehensive analysis of the optical and temporal properties of the reflected signal gives lidar many capabilities not accessible with passive optical analyses.

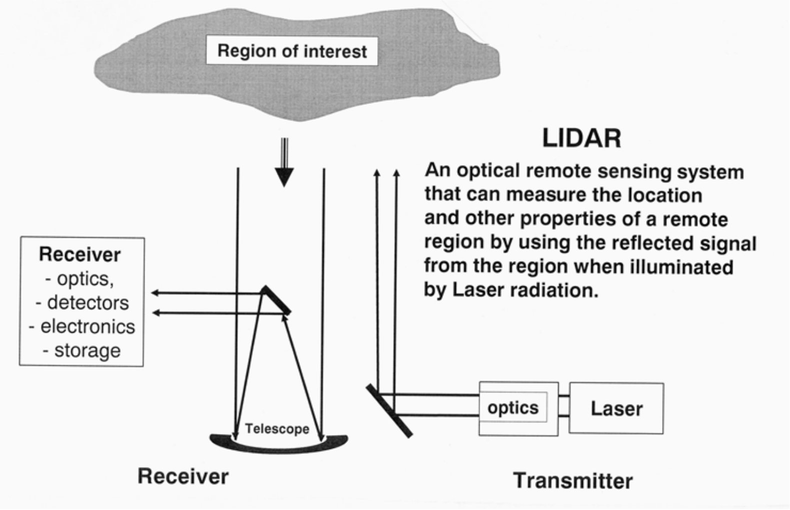

Figure 1: Lidar schematic

Current lidar systems have a wide variety of capabilities and hardware configurations in response to the particular requirements of the application involved. All lidars, however, have the basic configuration shown in Figure 1 with a telescope located to observe the signal scattered (reflected) from the outgoing beam by the environment. The transmitted beam can be pulsed or CW with modulation to allow range information to be derived from the time delay associated with the two-way transit time at the velocity of light. Although CW lidars are widely employed in a number of applications, they typically operate over much shorter ranges than those using pulsed laser sources. In this overview I will be focusing my attention on the properties and applications of pulsed lidar systems. For such systems laser pulses of the order of a few nanoseconds or less are transmitted. Although the lidar transmitted beam output is a very short pulse, the temporal structure of the reflected signal can vary greatly depending upon the nature of the environment into which the beam is sent. If there is reflection from only a single solid target the return signal will be a pulse essentially identical to the one transmitted. However, if there is any scattering in the region between the lidar and the target, the return signal will cover a more extended time period. In fact the temporal structure of this extended return carries information on the properties of the entire region. This feature is widely used in the application of lidars for atmospheric and marine applications.

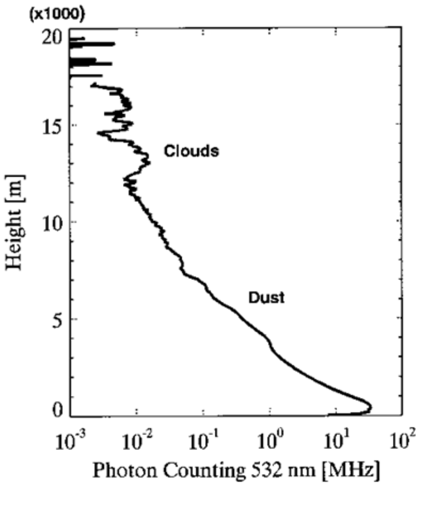

Figure 2: Basic lidar signature

An example of such a return is seen in Figure 2. Optech developed the first lidar on Mars for the 2007 NASA mission *Phoenix,* and the figure shows the first lidar signal reflected from the atmosphere of Mars with this lidar. This lidar had a fixed vertical viewing direction and operated at a repetition rate of 100 Hz with 5-ns pulses. As seen in the figure, the return signal extends over the entire atmosphere up to an altitude of about 20 km. This signal diminishes approximately as the square of the distance, and contains information on the structure of the atmosphere indicating the locations and extent of dust and clouds in the atmosphere. Thus each point of the lidar signal carries four pieces of information: the three positional coordinates and the intensity of the reflected signal. These provide the basic ingredients needed to produce a high-quality 3D image.

This figure exemplifies the fact that the basic “imaging” capability of lidar is a spatially resolved 1-dimensional line trace of the region probed by the transmitted beam. The spatial location of all points along the line can be accurately determined from the time delay of the reflected signal. This basic imaging capability is quite different from the 2-dimensional image obtained with camera systems. Thus it could be said that with a single measurement (“exposure”) a camera directly provides *X* and *Y* spatial information. To get the *Z* information it is necessary to utilize a number of different camera measurements. Conversely, a single lidar measurement can be said to directly provide the *Z* information. To provide the X and Y information additional lidar measurements are required. One immediate and important conclusion that can be drawn from this comparison is the fact that the most sensible and effective means of deriving full 3-D information is to employ both of these techniques synergistically, an approach that we have been using at Optech in all of our systems.

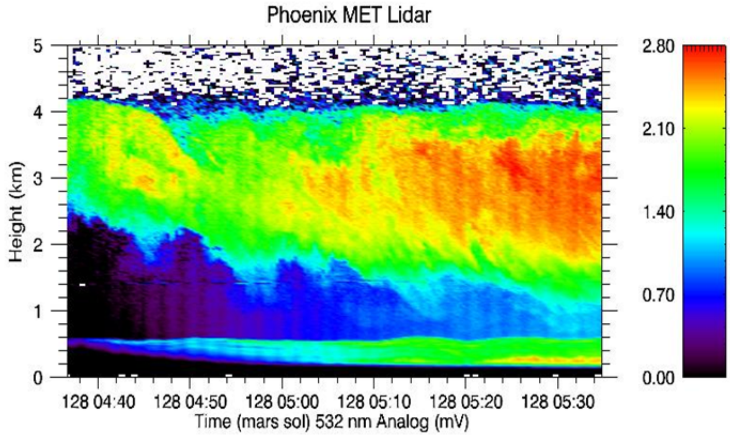

Figure 3: Sample lidar image of the Martian atmosphere

Figure 3 illustrates how a simple image can be generated from a series of lidar line traces. The intensity of the reflected signal along the line is coded into the amplitude (or colour) of the line and a continuous series of these lines are displayed. The example of Figure 3 shows a 1 hour collection of the traces such as shown in Figure 2 for the lidar reflections from the Martian atmosphere. Even with a fixed viewing direction the lidar displays very useful information on the characteristics and behaviour of the atmosphere as it moves across the lidar beam. In fact this display shows our discovery of snowfall on Mars, a previously unknown feature of the Martian atmosphere. In this very simple form of lidar image the location and spatial evolution of the cloud layer and the descent of the snow below the cloud are clearly displayed along with the development of a low-level fog layer.

Photogrammetry based on photographic images is a highly developed technology as old as modern photography, dating back to the mid-nineteenth century. The photogrammetric use of lidar imagery is a much more recent technology which has been developing rapidly mainly over the last few decades. As mentioned earlier, photography is a *passive* remote sensor while lidar is an *active* remote sensor. The various aspects of these sensors are summarized in the table below.

| **Passive Sensor** | **Active Sensor** |
|---|---|
| • Uses reflection of ambient light or thermal emission | • Supplies its own illumination |
| • Limited control over ambient illumination | • High level of illumination control |
| • Illumination is generally multi-wavelength | • Illumination is generally monochromatic |
| • Reflections are multi-angle | • Backscattering dominates (no shadows in basic signature) |
| • Direct X, Y information | • Direct Z information |
| • Day/night limitations | • Day & night operation |
| • Sun angle and shadow considerations | • Reduced atmospheric limitations |
| • Atmospheric limitations (haze, clouds) | • Image X, Y, information requires multi-measurements |
| • Image Z information requires multi-measurements | |

The lidar signal can contain much more information than just the location of the target region. Since the transmitted beam can have highly controlled and well known optical properties, the changes of these properties in the reflected signal carry significant information about the region producing the reflection. Rayleigh, Mie and surface scattering produce the major components of the reflected signal. These elastic scattering processes produce reflections at the same wavelength as the transmitted laser beam. However, depending on the nature of the scattering medium in the target region, there could also be inelastic Raman scattering or fluorescence that would produce components of the reflected signal at different wavelengths. Spectral analysis of the lidar return signal can provide qualitative and quantitative information about the material in the target region. Raman scattering has been used widely in lidars for studies in the atmosphere and in marine environments. Raman spectral signatures provide species-specific information about the scattering (reflecting) medium. Raman scattering cross-sections are small so the lidar Raman signal is typically very weak, but with appropriate system design the Raman signal can be separately and accurately detected by the lidar.

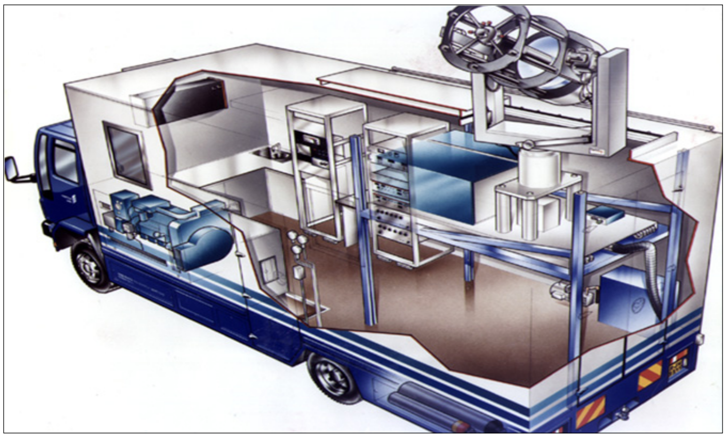

Figure 4: Raman lidar for natural gas detection

Figure 4 shows a Raman lidar constructed to monitor the effluent from natural gas pipelines. This system was designed to monitor the concentration of methane in the atmosphere out to ranges of 1 km even in ambient full sunshine. The laser transmits pulses in the ultraviolet with filters in the receiver to selectively measure the methane Raman signal. Comparing this signal with the Raman return from atmospheric nitrogen allows the quantitative computation of the methane concentration. Mechanical scanning of the lidar pointing direction provides 3D mapping of the plume of methane gas to identify regions in which explosive concentrations exist. Raman spectral information can also be used to uniquely identify liquid water in mixed maritime environments and to provide temperature measurements.

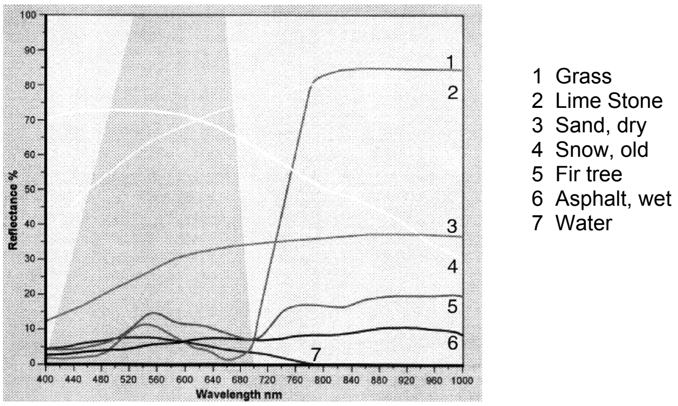

Figure 5: Selective reflectance examples

Lidars can use multiple wavelengths to provide species-specific information on the material in the target region. This can be achieved by utilizing spectral differences in both reflection and absorption. It is well known that the reflectance of many materials is strongly wavelength-dependent. A few examples are shown in Figure 5. By choice of appropriate lidar wavelengths, the reflected signal from different species can be selectively enhanced. This procedure is also widely used in passive imagery.

The Differential Absorption Lidar (DIAL) is widely used in lidar studies of the atmosphere. In this mode of operation the lidar simultaneously transmits two wavelengths. The first is chosen to be at a strong absorption feature of

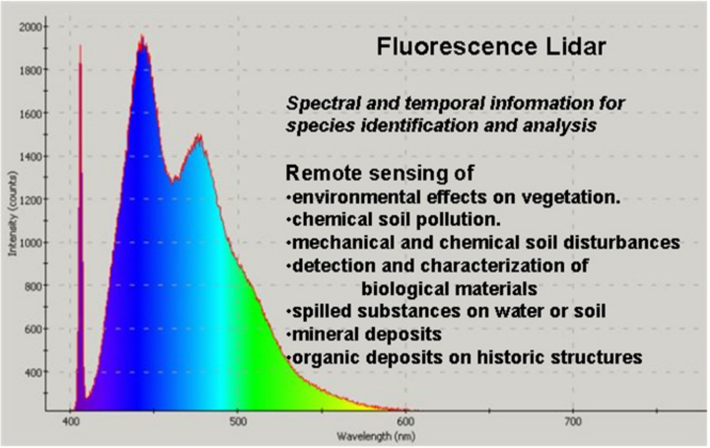

Figure 6: Fluorescence lidar uses

the gas of interest, and the second is generally selected to be at a nearby wavelength that is weakly absorbed by that gas. As the pulses at these two wavelengths propagate, the first is strongly attenuated wherever the gas is located while the second is not. Comparison of this differential absorption can be utilized to quantitatively map out the region containing the gas of interest. This is widely used for studying the distribution of important atmospheric constituents such as water vapour and ozone. In fact ground-based lidars are routinely used to study the ozone in the stratosphere to monitor the evolution of the highly important ozone hole in the polar regions.

Fluorescence of material in the target region can also be used to provide additional information in the reflected lidar signal. There is, however, generally a time delay between the lidar illumination and the fluorescence signal. Because of this it is no longer possible to use the time delay of the fluorescent signal as a measure of the distance to the target region. In such lidar systems the range is measured with the signal at the transmitted wavelength and the spectral information in the fluorescence is used to provide additional information on the scattering region. Fluorescence lidar measurements have been widely used for a variety of applications, as indicated in Figure 6. As well as this spectral information, the time-dependent behaviour of the fluorescence signal provides additional information on the target material. This feature has been used to differentiate the types of oils in ocean surface spills.

## 2. AIRBORNE LIDAR TERRAIN MAPPING

Optech began its activities with airborne lidar mapping in the early 1970s. We undertook the development of an Airborne Laser Ice Profilometer, and at that time there was no access to the Global Positioning System (GPS) so airborne topographic survey capabilities were quite limited. However, the interest was mainly in the statistics of the surface roughness of the ice, since experience had shown that this information was of high value in understanding the nature of an arctic ice field. Thus knowledge of the absolute positional information was not mandatory for the lidar ice profilometer. This situation offered a unique opportunity for our entry into the airborne laser survey field almost two decades ahead of the availability of GPS in the 1990s.

Figure 7: Operating scenario for airborne laser terrain mapping

Figure 7 shows a schematic representation of an airborne lidar terrain mapper. The downward-pointing lidar beam scans across the field of view and at each pulse measures the distance from the lidar to the surface. For each distance measurement the GPS provides the position of the lidar and the inertial navigation system (INS) provides the orientation of the transmitted beam, so that the 3D point of impingement of the pulse on the ground can be accurately determined.

There are a number of key parameters involved in the lidar generation of an accurate topographic image. The GPS and INS requirements are similar for both the camera and lidar images. With the lidar there are several other important considerations. The Z resolution depends upon the pulse configuration and the precision of the time interval measurement between the time of transmission and the reception of the reflected pulse. If the target is spatially varying in the Z direction the lidar detector system has to be capable of measuring the details of the time-resolved signal such as shown in Figure 2. The time interval resolution required to do this is typically in the region of picoseconds (e.g., a 1-cm distance corresponds to a lidar time interval of 67 ps).

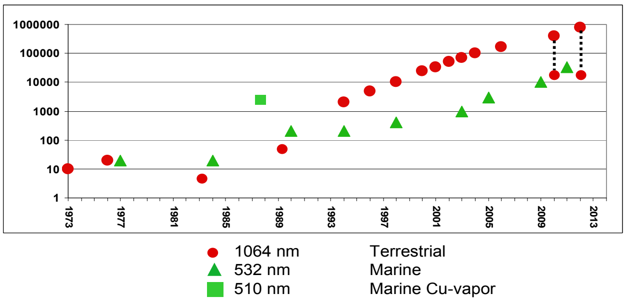

Figure 8: Optech lidar PRF history

The X,Y spatial resolution of the lidar image of the surface terrain depends on the laser spot size, the lidar pulse repetition rate and the characteristics of the lidar scanner (e.g., scanning rate, scan configuration, scanner calibration). These parameters and the distance to the target will control the areal density of laser spots on the target. Current lidar systems typically provide a wide range of control over these parameters, so the target spot density can typically vary from a few to many hundred points per square metre, depending on the particular conditions involved.

Laser PRFs have increased markedly. This is illustrated in Figure 8, which shows the evolution of the PRFs in our lidar systems from 1973 to the present. The10-Hz rates of our early single-laser lidars have now increased to variable rates of up to 1 MHz in present multiple-laser lidar systems. Similarly, scanner technology has advanced rapidly with enhanced scan pattern control that can significantly increase the efficiency of the point density and distribution.

The lidar spot size at the target region is controlled by the optical parameters of lidar transmitter. For a monochromatic laser source, the minimum spot size will be produced with a diffraction-limited source. In this case the beam divergence is approximately $\lambda/D$, where $\lambda$ is the laser wavelength and D is the diameter of the transmitter aperture. For a laser output wavelength at 1 μm and an exit aperture of 1 cm the beam divergence is $\sim 10^{-4}$ radians. Thus for an aircraft altitude of 1 km the spot size on the ground would be about 10 cm. Varying the lidar transmission optics provides wide control over the spot sizes available. At the same time this capability provides control over the laser intensity per unit area falling on the target surface, and hence the signal-to-noise in the reflected signal with respect to ambient sunlight illumination.

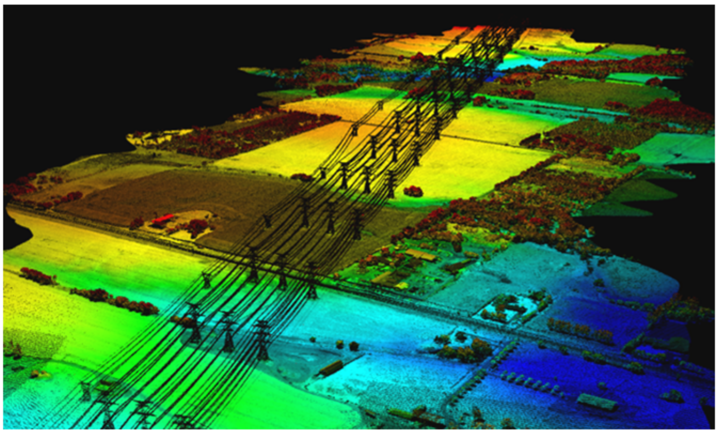

Figure 9: Lidar data collected over power line corridors include conductors and various ground features, roads, structures, vegetation (Orion M data, 1-km AGL, colour-coded elevation)

These special capabilities of lidars are well demonstrated in studies of power lines where the 3D location of each conductor and its surrounding can be measured with high precision, as shown in Figure 9. The resolution of the image is accurate enough to monitor the catenary curvature of the conductors to note the changes resulting from the temperature effects of changing current flow. "Danger trees" encroaching too close to the power lines can be specifically identified for remedial action. All of these features can be augmented considerably by the use of multi-beam lidars, which are now avail-able. At the same time the technology has permitted rapid improvements in the reduction of size, mass and power requirements of airborne lidar systems, so that they can now operate in aircraft with quite modest capabilities.

These airborne lidar mapping systems provide a number of unique advantages compared to passive photogrammetric measurements. Because of the direct 3D information available from lidar data, orthorectification is a straightforward process. In addition, lidar topographic information is readily obtained over featureless terrain such as sand and snow where accurate photogrammetry is typically very difficult. Most unique, however, is the capability of lidar to obtain topographic information of fully forested terrain by the ability to spatially separate the terrain surface return from that of the forest canopy. This capability has been clearly demonstrated even in dense jungle environments. The lidar-derived structural information on the tree cover has also been used for remotely assessing the quality and quantity of the vegetation cover.

## 3. AIRBORNE LIDAR MARINE MAPPING

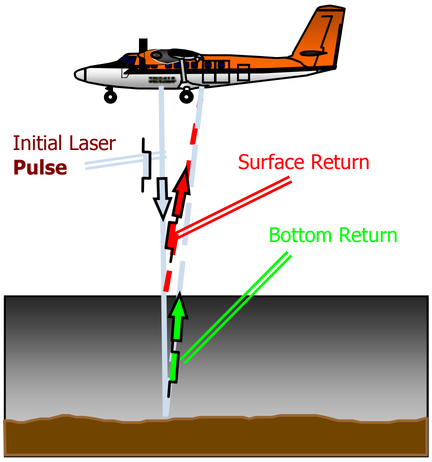

Figure 10: Scanning Hydrographic Operational Airborne Laser Survey (SHOALS)

My research as a professor at York University in Toronto included the development of a ship-borne lidar bathymeter for water depth studies in Lake Erie in 1973. The success of this work led to the establishment of Optech as a commercial venture, and the development of an airborne lidar bathymeter was the first project undertaken by Optech in 1974. The general principle of a marine lidar is shown in Figure 10. It is basically an airborne terrain mapping lidar with certain special features. It is designed to operate at a wavelength that will penetrate water (typically in the blue-green spectral region) so that the transmitted pulse will pass through the air-water interface and penetrate into the water volume. The detection system is designed to record the time difference between the signal reflected from the surface and the water bottom.

The scattering caused by the turbidity of the water restricts the penetration depth of the lidar signal. Under optimum conditions of low ambient light and the clearest open ocean water, penetrations of up to 50 metres are obtained. Penetration depths are much less in murky river and harbour waters. However, operational statistics show that the majority of coastal marine survey work is done in waters less than about 15 metres deep. As a result airborne lidar marine systems are proving to be highly effective new tools for studies of the littoral zone. SHOALS lidars are now providing surveys of coastal and inland waters at a rate of several tens of square kilometers per hour and with rapid data turnaround.

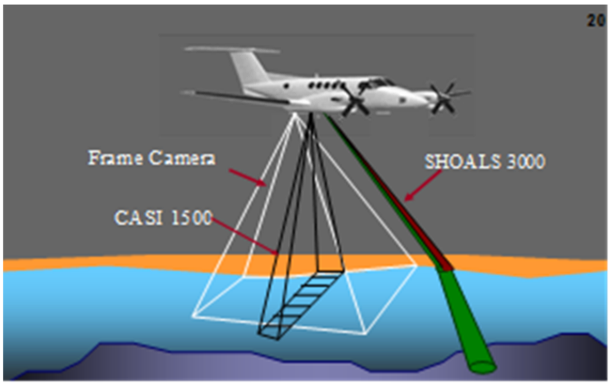

Figure 11: Active-passive data fusion

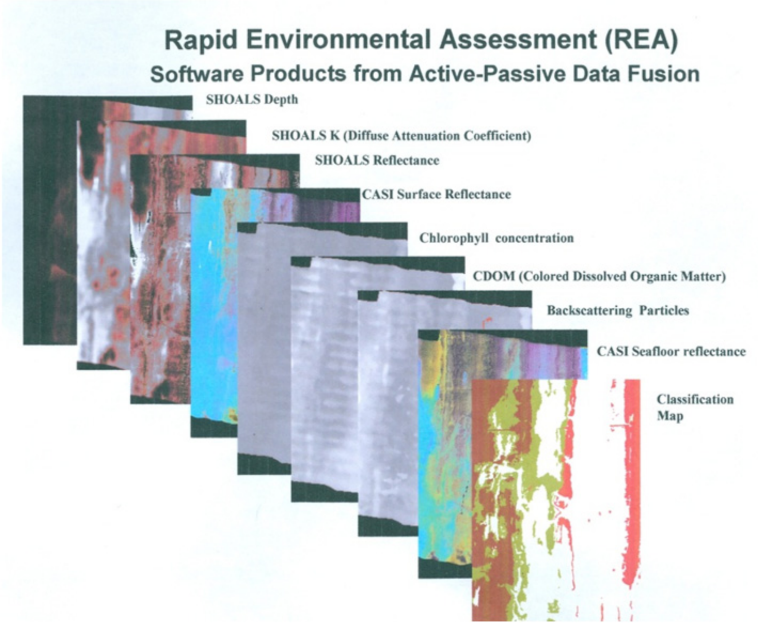

Figure 12: Software products from Active-Passive Data Fusion

A marine lidar has significantly greater technical requirements than those needed for a terrestrial survey system. The short penetration depth means that the full duration of the lidar signal is generally only in the range of about a microsecond. In order to measure very shallow waters and probe the spatial variations of the water column, the marine lidar must employ nanosecond digitization capabilities as well as wide dynamic range signal acquisition, since the signal in water typically can vary by five or six decades between the surface and the bottom. Our current systems include dual-wavelength beams (green for water transmission and infrared for surface detection), separate detectors optimized for shallow and deep water, as well as the capability to measure Raman scattering from water.

The capabilities of marine lidar systems are greatly enhanced with the incorporation of passive sensors such as illustrated in Figure 11. This shows the combination of a lidar along with a frame camera and a hyperspectral system. The two passive systems provide wideband capability for measuring the spectral reflectance of the observed area. Such hyperspectral capabilities are already well developed for applications, in a variety of terrain studies. Incorporation of the lidar extends these capabilities to marine applications since the lidar signal provides spatially resolved information on the characteristics of the water column. With such information it is possible to separate the passive reflectance signals emanating from the water column and the water bottom terrain. Using this information, Optech has developed Rapid Environmental Assessment (REA) software that can provide a wealth of new information on marine environments. A sample set of information derived from such active-passive data fusion is shown.

This combined information provides seamless shoreline/bathymetric topographic images as well as quantitative information on seafloor reflectance, and 3D images of water attenuation, chlorophyll concentration, and suspended sediments. In addition it provides the information necessary for automated sea floor and land cover classification. This entire package of instrumentation and software is now incorporated in CZMIL, Optech's Coastal Zone Mapping and Imaging Lidar. CZMIL has been developed under the auspices of the U.S. Army Corps of Engineers and the Joint Airborne Lidar Bathymetry Technical Center of Expertise. It provides a complete coastal zone mapping and imaging lidar system with very high spatial resolution and excellent performance in shallow and turbid water.

## 4. "SURFACE-BASED" LIDAR IMAGING SYSTEMS

Lidar imaging technology is also being employed for an increasing variety of non-airborne applications. Lidars are now used for measurements previously the domain of total station survey instruments. The most common configuration is a readily portable tripod-based instrument. These lidars operate with pulse rates up to 50 kHz and make use of a variety of scanning methods to generate a 3D image with sub-centimeter resolution of remote regions of interest. They operate mainly in the infrared and can make measurements up to distances over 2 km. Eye safety is a major consideration with these systems, since they generally operate in close proximity to personnel. Most commercial units meet laser safety Class 1, which means that they are safe under all conditions of normal use.

With integrated digital cameras, these instruments provide high quality 3D colour images. They are already widely used as systems for 3D as-built imaging of complex structures and commercial surveys for engineering and mining applications. They are also being used for vehicle guidance and monitoring of industrial processes. The long range capabilities of these systems have demonstrated unprecedented performance for accurate quantitative volume measurements of material extracted in open pit mining operations. They also offer new capabilities for characterizing rock face structure and monitoring motion associated with rock fall dynamics. Recent Optech studies with the U.S. National Park Service have clearly demonstrated the value of such lidars for improved public awareness of rock fall hazards.

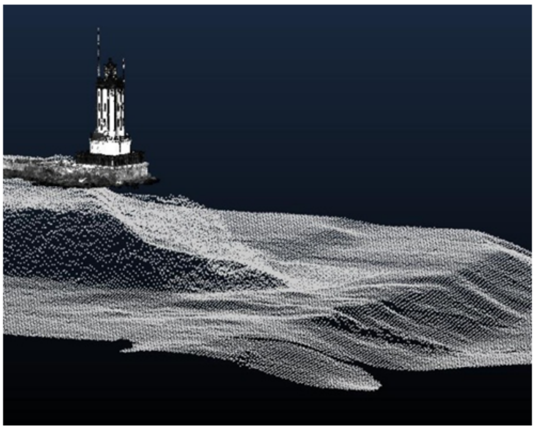

Figure 13: Integrated lidar and sonar data

These lidars are also able to be used on a moving platform, which enables the collection of precise dynamic motion-compensated 3D data sets. When integrated with GPS and IMU systems, these small lidars can provide georeferenced data sets in many novel and unique situations. Our ILRIS system has been used on boats, trucks and airships to provide information not accessible with other surveying methods. Figure 13 shows an example of an interesting collaboration with the U.S. Coastal Resources Management Council (CRMC). We participated in a study that demonstrates the capability of integrating lidar XYZ surface point position data with high-resolution subsurface sonar imaging of the sea floor and sedimentary profiles beneath the sea floor. The lidar was installed on the sonar-equipped boat to simultaneously measure the above-surface structures of the harbor of Providence, Rhode Island, while sub-surface bathymetric information was being collected with the sonar. This combined information can provide valuable new data for use in shoreline stability analysis and change-detection studies.

## 5. LIDAR MOBILE MAPPING SYSTEMS

The newest addition to the lidar imaging family is the development of the Lidar Mobile Mapper, lidars mounted on mobile vehicles that are capable of collecting survey-quality data from vehicles moving at speeds up to 100 km/hr. These recent arrivals are already viewed as a disruptive technology causing a sea-change in traditional surveying and engineering methods and workflows. They can be mounted on road, rail and all-terrain vehicles as well as watercraft to provide full 3D images of the surrounding environment. The widespread use of these mobile lidars shows that critical decision-makers no longer have to depend on out-dated "as-designed" engineering documents, but can make quick and accurate decisions based on up-to-date field conditions.
These mobile mappers are now providing a complementary approach to airborne surveys. Nowadays it is appropriate to consider both approaches before deciding on the right tool for a particular survey.

Airborne lidars:
- Provide high-speed coverage of large areas
- May incur fewer GPS signal drop-outs caused by multipath interference at ground level in dense urban environments
- Provide a "bird's-eye" view that in some cases can be advantageous
- Can survey terrain inaccessible to land vehicles (e.g., ravines, mountains, wetlands)

Mobile lidars:
- Operation at shorter ranges concentrates laser points, producing extremely high-density data.
- With multi-sensor configurations can produce virtually no shadowing
- Provide a "from-the-ground-up" perspective that has distinct advantage in many field applications (e.g. cityscapes, power corridor infrastructure, bridges, tunnels)
- Offers access to areas inaccessible to aircraft (e.g., restricted airspace surrounding busy airports)

Figure 14: A 500-kHz Lynx image

Optech's Lynx Mobile Mapper has been used for many applications that clearly demonstrate the excellent quality of the images available (Figure 14) and the high value of mobile mapping systems. After the greatest electrical outage in U.S. history, the North American Electrical Reliability Corporation (NERC) issued an industry-wide requirement for all suppliers to provide information on the in-field conditions of their power lines. A survey crew using an SUV-mounted Lynx drove along the transmission corridor right-of-way while scanning the surrounding towers, cables and related infrastructure. High-density georeferenced XYZ images were produced that achieved NERC compliance. An enduring benefit of such lidar scanning data is that it enables the utility to develop a georeferenced and searchable database of all in-field assets that is easily accessible for future analyses and change-detection studies. In a similar study, an SUV-mounted Lynx was used after Hurricane Katrina to drive along the top and survey a 2-km

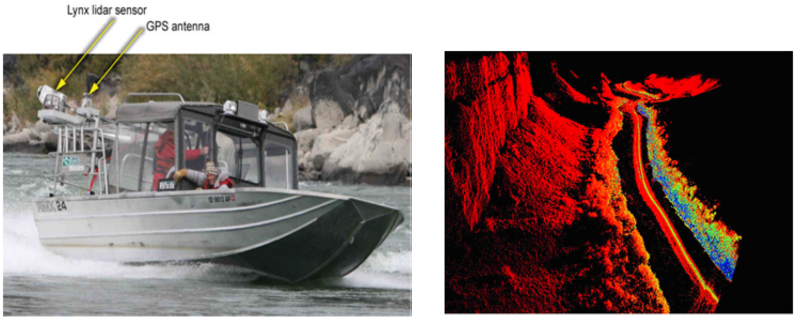

Figure 15: Snake River Canyon survey

levee. It provided centimeter-level resolution of the levee and the surrounding areas in a collection time of less than one hour.

As shown in Figure 15, Lynx has also been successfully used for marine mobile surveys from a high speed jet boat. Using this approach WHPacific successfully surveyed the Snake River Hells Canyon in Idaho. Despite the remote and hazardous terrain, a 2-mile stretch of the river was surveyed at speeds of 40 to 48 km/hr. The georeferenced spatial data obtained provided unprecedented 3D detail (5-cm accuracy, 1-cm resolution) of the shoreline and surrounding cliffs. At present these mobile lidar imaging systems are finding a rapidly expanding array of applications.

## 6. CONCLUSION

Lidar is already the system of choice for an increasing number of survey, mapping and 3D imaging requirements. In this short overview I have touched on only a few of the highlights. I have hardly mentioned the widespread use of lidar in atmospheric studies, and in many respects the applications of atmospheric lidars are several years ahead of the lidar survey work outlined in this summary. Ground-based, airborne and mobile lidar systems are being used world-wide for atmospheric monitoring and research. In these activities lidar is providing innovative atmospheric mapping capabilities and an unprecedented array of new and unique measurements.

Space applications of lidar are also well advanced. Lidars have been flying on spacecraft for many years and are still passing overhead every day. These are being widely used for global atmospheric studies, including mapping the structure and distribution of clouds, aerosols and ozone. Such a system has been used to accurately map the surface topography of Mars from an orbiting spacecraft. The Mars Orbiter Laser Altimeter (MOLA), an instrument aboard NASA's Mars Global Surveyor, generated a high-resolution map of Mars from over 27 million elevation measurements gathered in 1998 and 1999. The data were assembled into a global grid where elevation points are known with accuracies down to a few metres.

Optech has been involved in a number of space lidar programs for atmospheric studies, spacecraft location, tracking and rendezvous applications, as well as the development of systems for selecting and mapping spacecraft planetary landing sites. Our most exciting space venture to date was with the team providing a Canadian-supplied lidar for the NASA 2007 Mars mission “Phoenix” as mentioned above. In May of this year Optech was selected as part of a team to provide a lidar for the NASA mission OSIRIS-Rex. This mission is to retrieve samples from a small asteroid, with the lidar to provide accurate surface topography and landing site selection.

The future of lidar imagery is very bright. The pace of lidar development to date has been mainly controlled by the advances in the key technologies involved. Central are the improving capabilities of lasers along with the detectors and associated electro-optical systems. In recent years the rapid advances in these components have been instrumental in lidar development. Additional factors have been the increasing availability of compact, large-capacity memories and the development of the software and algorithms needed for the optimum acquisition and analysis of the massive amount of data being produced by modern lidars.

For survey work it is increasingly clear that an important first step in any project is to assess the several technologies available and to decide on the optimum approach to adopt. Not only is it worthwhile to consider the airborne active/passive trade-offs, but also to consider the possible benefits of combining both airborne and ground-based mobile capabilities. Experience to date shows that the most effective way to use active lidar imaging is in collaboration with appropriate passive imaging systems. This has been true with our airborne systems from the very beginning and is now generally the best approach with all lidar systems. In my view it is important to spread to the user community the good word on the high value of this collaborative active-passive approach. The future for lidar applications seems now to be limited mainly by the creative imagination of the user.