# SS-3 Commercial Applications of Laser Radar Technology

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**Introduction**

Optech is a company spun off from my research program at the Department of Physics at York University in Toronto. It was established in 1974 with its principal focus being the development of laser radar systems and applications. This year celebrating its 25th anniversary, Optech has prospered and grown by applying laser time-of-flight ranging technology to meet user needs in a variety of fields. Although the initial technical focus of the company has not changed, many of the present business activities were never anticipated at the outset. This is not really that surprising since most of the hardware and all of the software now in use was not available at all in the early years. In this paper I outline briefly the evolution of Optech's corporate activities and highlight the present business areas.

Optech has followed the pattern of many high-tech business ventures. It started essentially as a "technology-push" enterprise. From the university research it was evident that time-of-flight laser ranging technology had excellent potential for many commercial applications. However, there was almost complete ignorance of this potential in the outside world so at the beginning there was almost no "market pull" for this technology. It is a well-know fact that to be a successful business it is necessary to respond effectively to the needs of the marketplace. In present-day terminology, a company must provide value to its customers by offering solutions to their problems.

Over the years Optech has had to work at building this market pull and responding to it. To accomplish this it has been necessary to devote a large amount of time and resources towards: working closely with prospective customers to understand their problems and needs; ensuring that the technology really can provide them with a solution; educating potential users in the merits of the proposed solution; undertaking the R&D and engineering necessary to produce a high-quality and cost-effective product. In summary, it can be said that to introduce such new technology the ingredients for success must include:

- adequate R&D to support and advance the key technology, (Things change very rapidly)
- knowledgeable and collaborative users
- realistic promises (The laser applications field has often suffered from "overselling")
- dedication to customer education as well as selling
- strong after-sales support to ensure customer satisfaction and to derive performance feedback for product improvement.

Optech started out primarily as a producer of custom systems, tailored to meet the specific needs of individual customers. At the university we had developed laser radar (lidar) systems for atmospheric monitoring and for underwater probing. The atmospheric lidar was based on a ruby laser which at that time was the best candidate for the system. This van-mounted lidar had been used for a variety of field projects, both for graduate student research studies and for some practical applications under contract to a few users. One of these users, Ontario Hydro, a major power generation utility, was so pleased with the lidar performance in effluent plume tracking that it decided to procure its own system. A tender was issued and I decided to set up Optech to respond since there was no way that such a commercial undertaking could be sensibly handled within the university.

At the same time my initial university investigations on ship-borne underwater probing with lidar were being very positively viewed by the Canada Centre for Remote Sensing. As a result this agency decided to fund a study program to assess the capabilities of taking such lidar systems onto an airborne platform. Again Optech responded and was awarded this as its second start-up business activity.

An important element in my decision to start the company was the presence of a role model. One of my professor colleagues had started a company a year or so earlier and I benefited greatly from his enthusiastic encouragement and by seeing the (deceptively) apparent ease with which he got everything up and running. Another important factor supporting my decision was the fact that prior to coming to the university, I had spent several years leading a group in an industrial research laboratory. As a result I did have some background experience upon which to build.

These two initial projects were successfully completed. The lidar was built and operated by the Ontario Hydro as an atmospheric diagnostic tool for many years during the commissioning of a number of new generating stations. The early studies on the potential of airborne lidars for underwater applications convinced me that there were revolutionary capabilities to be achieved in this area. From this small beginning, with only three employees and two projects, Optech has progressed to become an international leader in the provision of systems, based on laser ranging technology, serving the needs of a diversity of users. Although about three quarters of Optech's business at the beginning was on atmospheric lidars, work in this area now represents only about five percent of our current business. This is still a significant level of activity, however, since the business volume to-day is more that two hundred times that at the beginning.

Optech is now principally a developer and manufacturer of products based on time-of-flight laser radar technology. Our customer base is truly international. Although we still develop one-of-kind systems customized to the needs of individual customers, the majority of our activities are associated with the provision of a line of more well-defined products. These products vary substantially in complexity and have prices ranging from a few thousand to several million dollars. The production volumes also vary considerably from the one-off systems to hundreds of units per year. In the following sections an overview is given of these successful commercial applications of laser radar technology. Optech is currently organized on the basis of four operating Divisions, each serving a particular market sector and the applications described below are presented on this basis. . There is a flow of technology among all of these areas and many subsystems have been developed which serve the needs of several products.

**Atmospheric Monitoring**

Optech's business in this area has continued to be based on the development and production of one-of-a-kind custom systems. Optech has never yet built two systems alike in this area. Every opportunity has involved a different set of specifications reflecting, in part, the continuing evolution of the technologies and the increasing sophistication of the user requirements. In spite of the increasing user acceptance of lidar systems for atmospheric applications, there has almost never been the development of a market such that it makes sense to develop anything approaching a standard product. Apart from some military systems, the one exception to this is the widespread use of laser ceilometers. A few manufacturers are now producing such devices as relatively standard units. The price and performance demands of ceilometers are quite rigorous and Optech has to date never viewed this as an attractive business area.

We have been quite successful in the development of a number of operational lidar systems. These have spanned a wide range of technologies including: scanning elastic backscatter for plume tracking, species specific Raman[1] and differential absorption lidar (DIAL)[2] systems, multifield-of-view systems for multiple scattering diagnostics. In the production of these systems Optech has developed an array of advanced hardware and software capabilities. Optech continues to offer its skills for the ddevelopment of atmospheric lidar systems and is prepared to respond to suitable opportunities in this area. At this time, however, we have no plans to pursue any product development in the atmospheric lidar field. Some of the lidar subsystems have been offered as products in the past but this is not viewed as a significant growth area.

As far as a business area, the field of atmospheric lidars displays a mixed array of future trends. On the positive side, the technology continues to advance rapidly. Many things, which were difficult to impossible a short time ago, are now quite achievable. In recent years there has also been a considerable increase in the level of activity in this field. More atmospheric lidars are now operating than ever before. This activity is providing an increasing spectrum of proven performance and an increasing level of user awareness. In addition, with the advancement of the technology there is an improving cost effectiveness in many areas. The utilization of lidars from space platforms has also been receiving considerable attention in recent years. The US Lidar In-Space Technology Experiment (LITE) and other planned lidar space missions augur well for increasing future activities in this area.. Optech for the last three years has been supporting the Canadian Space Agency in its assessment of a space-borne DIAL system for global ozone and aerosol measurements.

On the negative side, there is still very little market pull for commercial atmospheric lidar products. Since virtually all requirements are for custom systems, any system provider must include the cost of the development and engineering labour. Frequently the user finds it more cost effective to use in-house resources than to contract out the full procurement. As a result a large number of the existing atmospheric lidar systems were built by university or government research groups. In addition, atmospheric lidars still tend to be relatively complex systems with limited versatility. In many applications lidar cannot compete cost effectively with other technologies. As a result any application must be carefully selected to utilize the unique capabilities of lidar to optimize the cost-effectiveness.

Overall it would appear that atmospheric lidars present moderately expanding business opportunities with little prospect for any commercial "breakouts" in the near future. There seems to be little chance that there will be any sizeable market to provide economy of scale so there is minimal opportunity for substantial cost reduction. However there is a potential for significant niche and specialty applications which could provide good business opportunities. These should arise in applications such as: pollution and air quality remote sensing, global and regional monitoring networks for aerosols, clouds, water vapor and other selected atmospheric constituents. There should also be a continuing demand for custom and military systems.

**Process Monitoring and Control**

A rapidly expanding area of Optech's business is in the application of laser radar devices for relatively straightforward distance measurement. Our Industrial Products Division has developed a number of such products aimed at the provision of information on the location, size, shape or motion of targets of interest. The information derived from these devices is typically used as feedback into some operational control system for providing autonomous operation or overall process control.

The application of this technology has become widespread. A major market sector is that involving level measurement – that is, the measurement of the amount of material in a container. The level measurement market is very large and is currently being served by a number of diverse technical approaches. Contact sensors are still widely used as are non-contact sensors using ultrasonics, microwaves, nuclear radiation, capacitance devices etc. Laser devices are now finding their place in a number of niche level measurement applications in which other sensors are not suitable. The excellent space and time resolution capabilities of the laser devices and the capabilities for operating in environments forbidden to other sensors are advantageous attributes. At present Optech has hundreds of such devices in operation around the world in sectors such as mining, pulp and paper, wood mills, chemical, pharmaceutical, petroleum refining and wastewater handling. One associated application is in monitoring wave heights and water levels for bridge clearances. These applications present a rapidly expanding business area..

The technology for these systems is based on the use of low power diode lasers in both the infrared and visible regions of the spectrum. The units must be eyesafe, ruggedized to meet stringent environmental specifications and cost-effective. They have to beat the competition from the alternative technologies. They have to be packaged to interface readily with the industrial configurations of the users and they have to meet the formal regulatory standards associated with the particular application. The resolution and accuracy of these units are also very important specifications to be addressed in the final product design.

In addition to level measurement Optech has developed laser-ranging products for measuring the size and shape of excavations and bulk materials. One product, the Cavity Monitoring System (CMS) has been jointly developed by Optech and a major Canadian mining firm. This unit has a scanning laser rangefinder on the end of a boom about 10 m in length. The unit can be introduced into small openings or dangerous areas and operated to provide a full three-dimensional scan of the region within a few minutes and with spatial resolutions of a few centimeters. The output is logged as a digital signal in the unit's computer and this information is then available for processing in a variety of customer specified applications. Similar systems are useful for tunneling applications.

Optech is also involved in the airport automation industry. We have developed laser scanning-ranging units for automatic identification and positioning of aircraft approaching airport loading gates. Here the laser rangefinder is one component of an overall guidance system that monitors and displays to the pilot the necessary positional information to guide the aircraft to the gate. The application of such systems shows significant future potential as international airports move to increased automation. Similar laser systems are being applied for object locating and positioning in the materials handling industry.

**Lidar Bathymetry**

Optech has pioneered in the development of laser radar systems for underwater probing.. Since the first ship-borne demonstration at York University in 1973 Optech has continued to devote considerable effort towards the development of full operational airborne lidar bathymeters for water depth measurement. This work has proceeded quite successfully and there are now several of these systems in operation at sites around the world [3].

The operating principle of the bathymeter is quite simple. A high repetition rate laser in the blue-green spectral region is directed downward from an aircraft in a scanned pattern across the water surface. Return pulses are obtained from the surface and the bottom of the water body being interrogated. The time between these two pulses, along with the known velocity of light in water, provides a measurement of the water depth. Such bathymeters operate optimally in relatively clear waters to maximum depths of up to 40 or 50 meters. They are shallow water systems and complement the more conventional acoustic methods which can operate to much greater depths. The acoustic systems are typically ship-mounted and must have a sensor in the water. This in many applications presents a significant limitation. The airborne lidars can interrogate a water body remotely and with aircraft speed and agility. Thus they can readily cover shoals, reefs and other shallows that are inaccessible to surface craft and where acoustic measurements are difficult, impossible or not cost-effective. Since the majority of water depth studies involve the shallower water of coasts, rivers, harbors and shipping channels, the capabilities of airborne lidar bathymeters can be widely and cost-effectively applied.

The implementation of this simple concept is in fact far from simple. The airborne lidar bathymeter involves quite an array of complex and sophisticated technologies. The laser requirements are stringent since the wavelength, polarization, energy and pulse characteristics must be carefully controlled. The current laser of choice is the Nd:YAG, using both the fundamental (for surface detection) and doubled frequency output (for water penetration). There is also an array of special optical design specifications. The nature of the transmitted beam, the scan pattern and the beam entry angle into the water must be carefully controlled. The design of the receiving optics involves a number of trade-offs to optimize the weak signal and reject the large “noise” from the water column. Current bathymeters typically have multi-channel receiving optics to provide more reliable detection of surface and bottom returns, polarization and water Raman signals for unambiguous water/land discrimination and high and low gain channels to handle the large dynamic range of the signals. Since the laser beam expands considerably in the water, the optimization of the field-of-view and the spectral filter bandwidth demands careful attention. For optimal system operation aircraft altitudes are typically of the order of a few hundred meters.

The lidar system electronics must handle the wide range of signal characteristics involved. Usually the entire lidar return from the surface to the bottom is digitized with nanosecond resolution. The full lidar signal from top to bottom is usually only a few hundred nanoseconds in duration. Because of the scattering and attenuation losses in the water, the top and bottom return signals can differ by many orders of magnitude. As a result the signal detection has to have wide dynamic range (100db) and bandwidth (100 MHz). In addition, the electronics has to integrate all of the positional information of the aircraft, essentially in real time, so that the point of impingement of each pulse on the bottom can be located with sufficient absolute accuracy to meet the hydrographic survey specifications. This also involves the development of the algorithms needed to correct for the water surface structure, the beam spread and the bottom characteristics with sufficient accuracy.

All of the above requirements have been successfully met and cost-effective systems are now operational. As a business activity, lidar bathymeters also has a mixed array of attributes. On the positive side is the fact that lidars offer truly revolutionary capabilities compared to any other existing technologies. These capabilities have been amply demonstrated in the existing operational systems. For example, post-hurricane subsurface erosion studies have been completed in hours rather than weeks; shoals and reefs have been quantified with unprecedented detail; large area surveys have been completed in a very timely fashion[3,4]. Operational costs have been estimated to be one quarter to one third of those for comparative acoustic surveys. On the negative side is the relatively high capital cost and complexity of these systems. Current systems have price tags of several million dollars and the matching of current technology to the current user needs does not indicate any easy route to reduction of cost and complexity. At Optech work is underway to continue improving the technologies involved with a view to continual improvement in the cost-effectiveness of these systems.

**Terrestrial Surveying**

Many of the lidar bathymetry technologies at Optech have been extended and modified to serve the needs of the airborne terrestrial surveying field. For this application a scanning airborne lidar is used to provide accurate three-dimensional digital mapping of the surface features of terrestrial terrain. Many of the concepts and subsystems are similar to those developed for the bathymetric lidars. The system implementation for terrain surveying is considerably simpler, however, since the lidar signals are less complicated and the data processing procedures somewhat less demanding. However, the requirements for the terrain mapping systems are still quite challenging.

For terrain mapping full surface coverage is needed so that contiguous laser spot illumination is needed. In addition, vertical resolution of a few centimeters and horizontal resolution of a few tens of centimeters is often required. This translates into the need for high repetition rate laser firing and high precision time-of-flight measurements. For good area coverage the operating altitudes of up to several kilometers are often desired. These requirements place significant restrictions on the specifications of the lasers used. Diode-pumped solid state laser systems are attractive for their small size and lower power demands. Since the surface returns are relatively strong, small area receivers and scanners can be employed. The positional and orientational information of the system must also meet stringent requirements and these are met with a combination of global positioning system (GPS) and inertial navigation system (INS) technologies. High speed and large capacity data handling systems are needed.

Optech has developed a line of such Airborne Laser Terrain Mapping (ALTM) systems[5]. As with the lidar Bathymeters the ALTMs offer quite revolutionary capabilities compared to other existing technologies[6]. Many Optech ALTMs are now operating worldwide in a number of applications. Digital terrain mapping is used for topographic, site and corridor surveys and urban structure topography. One unique ALTM capability is the ability to survey land topography underneath forest and vegetation cover since there is statistically enough penetration of the leaf canopy by the laser beam. Using first and last pulse discrimination it is possible to measure both the ground topography and the tree height for forest inventory. Since these systems are compact they can be mounted in helicopters or fixed-wing aircraft to provide very high density of surface area coverage (typical surveys can provide several million points).

Another important application has been in the survey of power lines. With the high spatial resolution of the ALTM it is possible to detect and accurately locate the individual conductors and towers of a power line or the wires of communication lines. Already the ALTMs have flown thousands of kilometers of lines and have precisely located the wires and the towers. Of particular importance in this application is the location of the "danger trees", those growing so close to the power lines to permit arcing to the ground. Optech has developed software that accurately identifies and locates such trees to permit their efficient removal. Previously the lines had to be surveyed in a much more labour intensive manner, often by patrols on foot. Conductor sag resulting from thermal/current variations can be measured.

The precision and spatial density of measurements with the ALTM have permitted a wide range of new applications to be implemented. The fact that the data are generated directly in digital form obviates the need for many of the labour-intensive data reduction tasks. Comparison of measurements of mountain regions in summer and winter can provide snow-pack inventory and flood potential assessments. 3-D urban structures can be generated and used to support a number of applications such as cellular antenna locations. In general the capability for surveying in areas with difficult access has been found to be very valuable, as has the surveying of sand and snow-covered areas which are very difficult to do with photogrammetric measurements. Optech has found this area to be one of high future business potential

**Conclusion**

Optech's experience over 25 years has shown that there are excellent and expanding opportunities for commercial success in the application of laser radar technology. These opportunities involve applications in a diversity of markets and success depends upon a judicious matching of the technology with the needs of the customers. We are very optimistic about the future business prospects.

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