Illuminating New Territory with Lidar

FEATURE

by Jennifer Ouellette

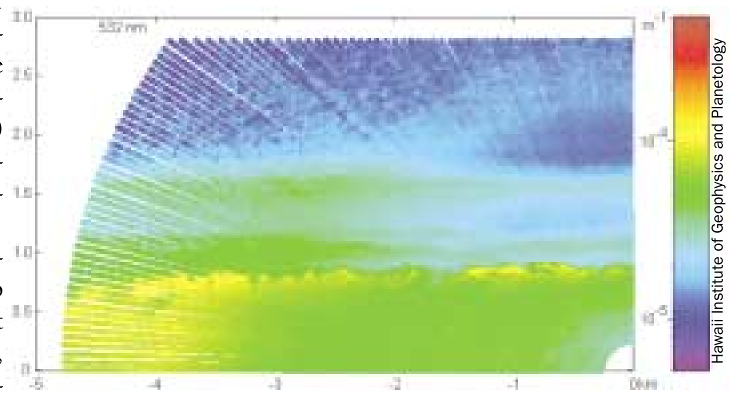
Rapid laser pulses improve airborne mapping

While the world was still reeling from the shock of the September 11th terrorist attacks, a small twin-propeller airplane spent several days flying 5,000 feet above Ground Zero in Manhattan and over the Pentagon near Washington, DC. It carried a laser-based instrument called lidar, which bounced pulses of infrared laser light off the shattered buildings and debris below.

The aircraft belonged to a company called EarthData (Gaithersburg, MD), which used the data collected during the flights to make topographic images of the sites. The images aided rescue workers in navigating the mounds of debris by identifying areas that could shift or collapse. Other instruments provided by the National Oceanographic and Atmospheric Administration (NOAA), the Army Joint Precision Strike Demonstration, the University of Florida, and Optech (Toronto, Canada) took aerial photographs and measured thermal radiation emanating from the surface to track underground fires.

The digital surface models produced from the various images enabled building and utility workers to determine the location of the foundation-support structures, elevator shafts, basement storage areas, and utility connections, so rescue workers could concentrate their efforts in the proper locations. The images also provided accurate height measurements as the recovery effort descended into the basement, mitigated the risk of flooding from nearby river waters by assessing the integrity of subsurface walls, and determined the volume of debris and the reach needed by cranes to remove it.

Once used primarily for atmospheric science studies (Figure 2), lidar has carved a niche for itself in the commercial marketplace over the past decade. Lidar, which stands for **light detection and ranging**, uses the same basic principle as radar. The instrument transmits light to a target, and the parts of the spectra that are not absorbed by the target are reflected or scattered back to it, where they are collected and analyzed. The changes in the properties of the light enable the user to determine specific properties of the target. In airborne topographical mapping, for example, up to 33,000 laser pulses/s are transmitted and received, enabling users to accurately



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calculate elevations of targets by measuring the round-trip travel time of the laser pulse from the aircraft to the ground (Figures 3 and 5).

There are three basic types of lidar, each operating at different wavelengths. **Range-finder lidar** measures the distance from the instrument to a solid target. **Differential absorption lidar** determines the concentrations of chemicals in the atmosphere—such as ozone, water vapor, and pollutants—and enables underwater mapping in shallow areas. **Doppler lidar** measures the velocity of a target by using the Doppler shift effect.

"As a rule, lidars made to work over water do not work as well over land, and vice versa," says Robert Fowler, manager of sales and marketing for Lasermap Image Plus (Montreal, Canada), which specializes in lidar-mapping services. This is because only specific wavelengths (usually at the blue-green end of the spectrum) can penetrate water, which absorbs most of the infrared

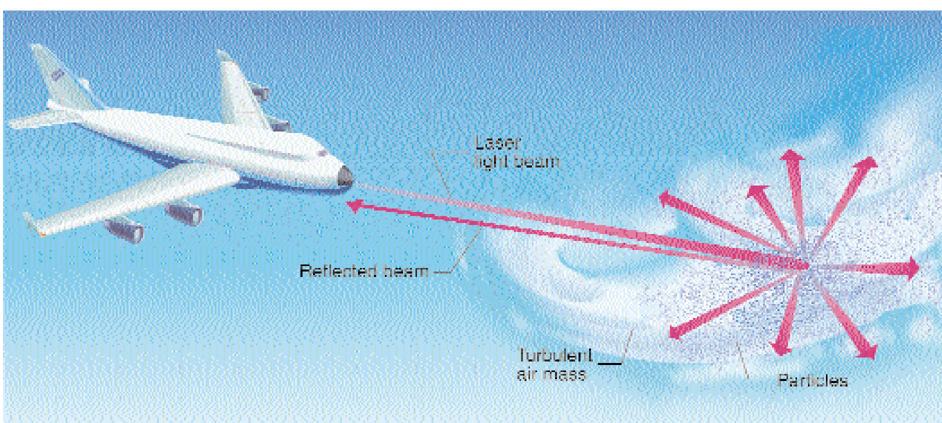

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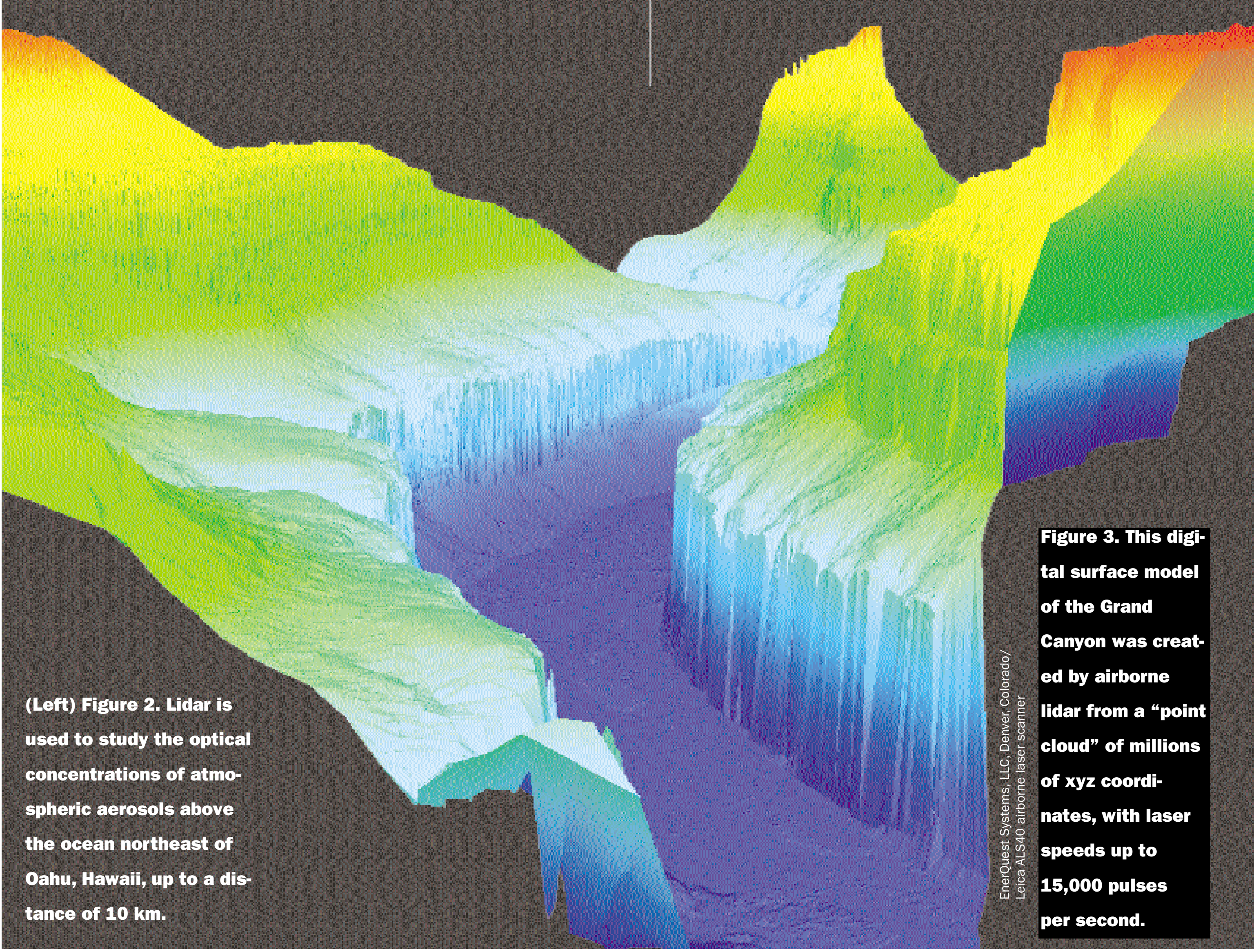
Figure 1. Airborne coherent lidar for advanced in-flight measurement of previously undetectable clear air turbulence has been flight-tested by a NASA/industry team to reduce the leading cause of in-flight injuries to passengers and crews.



(Left) Figure 2. Lidar is used to study the optical concentrations of atmospheric aerosols above the ocean northeast of Oahu, Hawaii, up to a distance of 10 km.

EnerQuest Systems, LLC, Denver, Colorado/ Leica ALS40 airborne laser scanner

Figure 3. This digital surface model of the Grand Canyon was created by airborne lidar from a "point cloud" of millions of xyz coordinates, with laser speeds up to 15,000 pulses per second.

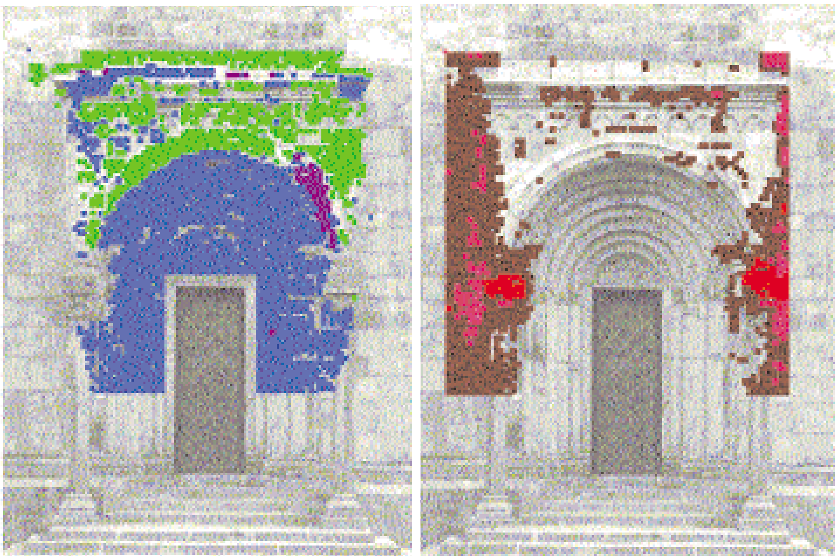
and near-infrared wavelengths favored for terrestrial mapping. Similarly, "if a lidar is made to cover large areas at high-level flying altitudes, unless the characteristics are changed, it will be too powerful to use on low-level flights," Fowler adds.

Enabling technologies

Lidar was developed shortly after the invention of the laser in 1958, but only in the past decade have advances in several related fields enabled its use in more commercial applications. Chief among these advances is the Global Positioning System (GPS). "Laser systems, even airborne laser systems, have been around for a long time, and the accuracy to which they can measure has been in the centimeter range for almost that long," says Fowler. "But absolute accuracy in the centimeter range has been true only of lasers fixed on the ground. Once you place a laser on a moving platform, the position of the platform becomes the limiting factor. Until GPS satellites were launched, there was no way of knowing exactly where a moving object was in relation to any ground-based coordinate system."

Another critical advance is the implementation of high-accuracy inertial measurement units (IMUs), another military technology that has found useful application in the commercial sector. IMUs exploit a law of physics that states that objects spinning at a high rate tend to keep their relative position in space. They consist of several gyroscopes, each of which spins a globular mass within a gimbal or cage, from which one can measure the angle of tilt. The gyroscopes are coupled with an accelerometer to measure velocity effects and calculate acceleration and distance. "The inertial system can now tell us how far, how fast, and in what direction we are moving relative to the point where we started," says Fowler.

Finally, lidar owes its current popularity in airborne topographical mapping to advances in laser technology, especially the emergence of solid-state diode-pumped lasers, which are now widely available commercially. "None of the laser ranging techniques we use are particularly innovative or new. It is just that 15 years ago, people were doing them with flash-lamp-pump and water-cooled lasers," says Martin Flood, chief technology officer of Airborne 1 Corp. (Los Angeles, CA). He notes that the size, weight, and power requirements of such lasers made it difficult to mount them on aircraft. In



Lund Institute of Technology, Sweden/Optics.org

Figure 4. Image of the Lund Cathedral created with lidar and multispectral image processing of fluorescence signals identifies stones from the 12th (blue) and 19th (green) centuries along with incipient algae stains (red).

comparison, diode-pumped lasers are rugged and compact, with lower power consumption and lower cost, making them ideal for airborne lidar applications.

To those three advances, Optech's Phil Arsenault adds the rapid increase in the speed of affordable computing. He points out that Optech's latest introduction into laser imaging uses core elements created as far back as 1992. "But at the time, we were using a Silicon Graphics workstation that cost more than most people wanted to pay for a computer, plus custom developed software that cost more than the computer," he says. "Today, my notebook computer has more than a gigahertz of processing speed and half a gigabyte of RAM. Access to inexpensive computing has driven people's desire to process more information."

Applications

For remote sensing applications, lidar data collection involves mounting an airborne laser-scanning system onto an aircraft with a GPS receiver to track its exact location and altitude, and an IMU to provide the pitch and roll of the aircraft. That data is combined to give an elevation accurate to within 6 in.

In addition to its usual engineering maps for construction development, utilities, and other city planning, Airborne1 once conducted a rapid lidar survey for a Hollywood studio to help it obtain a high-resolution digital topographic map to support special-effects modeling of a large outdoor film location. NOAA has used lidar to assess poststorm damage to beaches, cities, and buildings and to measure tree heights in timber stands. Lidar even found an application in space: The National Aeronautics and Space Administration installed a lidar system on the Mars Polar Lander to glean new information about the Martian atmosphere and terrain. The craft, however, crashed while landing on the planet in 1999.

A team of scientists from Sweden and Italy are using lidar to image the different types of stone used to build the Lund Cathedral in Sweden, a 12th century edifice that is the largest Romanesque building in northern Europe (Figure 4). The researchers found that they could also tell which of the walls had biological growth, making lidar a useful technique for detecting organisms that discolor walls, such as algae and lichens, before they can be detected by eye or by other means.

In oceanography, researchers from the University of Newcastle upon Tyne in England are using a compact airborne spectrographic imager to survey two damaged coral reefs off French Polynesia. The damage occurred in 1997 and 1998, when an El Niño swept across the South Pacific, increasing ocean temperatures in its path and killing up to 99% of coral on some reefs. Researchers at the Instituto Superior Tecnico (Lisbon, Portugal) have used a simple lidar system to detect small forest fires up to distances of 6.5 km. The team is also developing lidar algorithms for automatic recognition of smoke signatures, which it has patented in hopes of commercializing the technique.

Companies are increasingly turning to lidar for their mapping needs because it offers several critical advantages. First, unlike standard aerial photography, lidar data can be collected at night. Second, it is possible to quickly obtain data that could have taken months to collect if one were using traditional aerial photography and ground-survey techniques.

Third, lidar data is collected digitally, which eliminates the interpretation errors that sometimes occur with traditional elevation-data compilation. "Because lidar is direct to digital, you get extremely high accuracy," says Arsenault. "Other competing technologies are slower and more costly, and are not direct to digital." And finally, some lidars have such narrow footprints—1 m or less—that they can map the floor underneath a forest canopy or the urban canyons between tall buildings.

Despite these advantages, Fowler does not expect lidar to eclipse traditional aerial photography in the near future, although it will likely replace older technologies in some applications. "It's a complementary technology," he says. "While some people might say that lidar will do anything and everything for you, I prefer to ignore the hype and ask people to look upon lidar as another tool or sensor that will help solve a specific problem."

And lidar is still somewhat cost-prohibitive. The average lidar system for airborne mapping costs between \$600,000 and \$1.3 million, and the bathometric systems used for underwater surveying from the air typically cost between \$3 million and \$5 million. However, George Gorman, president of EarthData, says that sys-

Figure 5. This digital elevation model of Austin, Texas, was computed to a resolution of 1 m × 1 m from more than 180 million elevation points.

tems are becoming more affordable, especially as users gain a better understanding of the technology and how best to use it. Lidar can provide rapid, accurate surveys in situations for which it is particularly well suited, such as satellite imagery, radar surveys, photogrammetry, and ground surveys. “Basically, it gives you the ability to make a fairly accurate three-dimensional product right out of the can,” says Gorman.

Future

The next step in lidar is intensity recording, according to Fowler and Gorman. Optech and L-H Systems (Westford, MA) both manufacture systems that record the intensity of the return. This technology not only measures the distance between the system and the target but also provides a reading of the brilliance (or strength) of the return signal, which itself can be turned into an image. Each reflective surface has a specific reflectance level. For example, a concrete block reflects well because of its light color, but leafy vegetation absorbs more light and hence returns a weaker signal. Thus, users can assign certain signal strengths to specific types of objects to get automatic feature recognition. “In the remote sensing field, everybody is looking for an easy way to get feature recognition so that map production becomes more automated,” says Fowler. “I think the future is going to be in a more integrated system where you have more than just positions and elevations.”

Fowler also foresees important software developments. Several companies have created sophisticated processing algorithms that combine lidar elevation data with satellite imagery, for example, to create maps and make data analysis automatic.

As the market matures, so do the users, who are making ever-more sophisticated demands on the technology. This is driving a trend toward correlating different kinds of information and overlaying them on a topographical map generated by lidar. Systems that include digital imagery, digitized analog films, and satellite and digital photography collect data concurrently with the lidar data. Customers are also looking for multiwavelength data, or what Arsenault terms “hyperspectral data.” Because of this demand, Flood foresees lidar systems moving toward multifrequency lasers, combining green and infrared or ultraviolet wavelengths to capture additional information during mapping.

Faster laser pulses are also desirable. “Most of our customers want to go faster, faster, faster, because that way they can collect data on a tighter grid,” says Arsenault. The industry is moving toward faster data collection to increase the density, and thus the resolution, of objects on the ground or to increase the flight speed at which aircraft can collect data. “That allows for larger survey areas to be conducted in a shorter amount of time, provided the data density is acceptable at coarser samples.” Optech’s most recent products boast data collection speeds of 50 kHz, compared with only 2 kHz for its first products introduced in 1994.

Airborne 1’s system uses infrared lasers operating at 25 kHz with roughly 200 μJ of energy per pulse. And because lidar is so closely tied to developments in the diode-pumped laser, Flood expects that “as that technology advances and the price comes down, those improvements will be transferred to our mapping applications.” In fact, he reports that 50-kHz systems are in field-testing and 100-kHz systems will likely emerge within two years. “That increase in rep rate is a primary figure of merit for our industry because it determines the density of the data you can collect, or you can collect equally dense data from a higher altitude, and that trades off into operational efficiency,” he says.

Lidar is not just a useful tool, but an example of successfully commercializing a high-end scientific tool, says Flood. “It can go from something as mundane as mapping a condominium development to mapping the surface of Mars or characterizing global biomass for environmental studies,” he says. “It is the same tool being applied to these very diverse challenges, and that is part of the excitement for those of us in this industry. It’s science, but with practical uses in the private sector.” Ω