Mapping Matters

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Your Questions Answered
The layman's perspective on technical theory and practical applications of mapping and GIS

Question: I heard about a new technology in lidar called Geiger mode, what is it?

Anonymous Reader

Dr. Abdullah: The principle behind the operation of current lidar systems is based on a pulsed laser beam that is sent in a specific direction until it hits an object in its path. The pulsed light then interacts with molecules of the object and scatters in various directions with a portion reflected back (backscattered) towards its origin (the lidar system). The backscattered light sent in the direction of the sensor is collected by telescopes and conducted into a detection unit (detector or receiver). After passing through filters, the signal (represented by photons) is received by a single element (i.e., non-pixilated) detector that detects and processes multi-photon returns.

The new technology that you refer to differs from conventional lidar systems by splitting each pulse into an array of sub-pulses, each of which is considered to be a pulse on its own. Therefore, the main difference between the conventional lidar technology and lidar operating in Gieger mode (photon counting) technology is in the forms and methods that the back scattered light (or reflected signal) is received and processed. Conventional lidar systems use lasers with sufficient energy per pulse, in combination with optics of sufficient aperture, to work with return signals of thousands of photons per shot. The high signal level approach requires laser repetition rates of hundreds of thousands of pulses per second to obtain contiguous coverage of the terrain at sub meter spatial resolution. Such requirements impact the design parameters of these systems and limit scalability in terms of power and hardware.

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In the last decade, a new paradigm in lidar design has evolved, utilizing the Geiger mode photon counting detector technology. The concept of Geiger mode, or photon counting-based lidar, is centered on creating an array of lidar point clouds from a single emitted laser pulse. The foundation of Geiger mode lidar is very light-sensitive, solid-state photodetectors. These devices are able to detect a low intensity incident flux of light (down to the single photon) and provide precise information on the number of photons arriving at the detector and their arrival time. In these lidar sensors, a relatively low energy laser (few micro joules) transmits in the form of sub nanosecond pulses at a high rate. The transmitted pulse then illuminates a ground surface area with a size that is dependent on flying altitude and laser aperture. The backscat-

ter from the illuminated ground area is focused by a diffraction-limited telescope, or Diffractive Optical Element (DOE), and then projected onto a segmented single-photon-threshold Geiger-mode detector (receiver). The size, in terms of pixels, of the segmented anode can be tailored for each instrument. Some designs for the photon counting system are based on locating the DOE after the laser leaves the transmitter, resulting in multiple sub-pulses hitting the target. Each of these back-scattered sub-pulses is then directed by a telescope onto a single-photon-threshold Geiger-mode detector within the segmented (array) of detectors (See Figure 1).
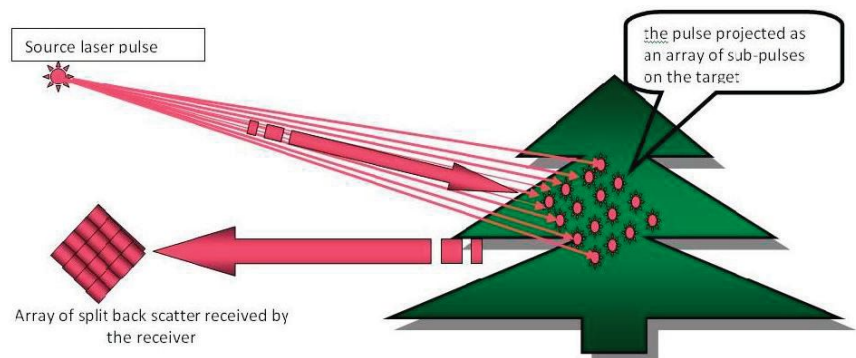

Figure 1. Principles of operation of photon counting lidar.

In summary, instead of providing a single element detector, as is the case with the conventional lidar system, a Geiger or photon counting system splits the backscatter from a single pulse into an array of sub-pulses resulting in very dense point clouds. Figures 1 and 2 illustrate the principal operation for this type of lidar system.

This new technology provides multiple advantages:

1. It requires very low energy to operate with the transmitter using few micro joules.
2. It uses diffractive optics that can be designed according to the user's need. This enables the system to split each pulse into an array of sub-pulses or spots, which result in a very dense point cloud. As an example, a system with 10 kHz repetition rate (10,000
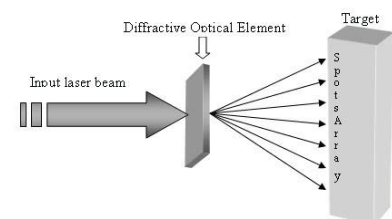

Figure 2. Principal of Diffractive Optical Element (DOE).

pulse per second or pps) results in a total of 10,240,000 sub-pulse per second or 10,240 kHz if it uses a 1024 channel Detector and Range Receiver (an array of 32x32 pixels). Such density provides tremendous capability in mapping densely vegetated areas.

3. Due to the high detector sensitivity (only one photon), the system can be flown from very high altitudes. The high point density coupled with the high altitude capability results in very efficient data acquisition.

4. Some of the photon counting lidar systems can be used not only as topographic lidar, but also for shallow water bathymetry, if it uses green light.

The Geiger mode system was originally proposed for mapping from space vehicles. However, airborne versions of the system were developed by Lincoln Laboratory at the Massachusetts Institute of Technology (MIT). The system, which is referred to as the "Airborne Ladar Imaging Research Testbed (ALIRT)" was flown for the first time for disaster relief in Haiti. MIT researchers responded to USSOUTHCOM's request to deploy and fly ALIRT to support U.S. military relief efforts after an earthquake devastated the small island of Haiti. The performance of the system was effective in aiding multiple emergency response missions, including:

- Determining conditions of roads and bridges (Figure 3)
- Analyzing flood zones to help in selecting temporary housing
- Selecting helicopter landing zones
- Assisting in counting the number of refugee camp occupants and supply distribution through volumetric computations or modeling.

Finally, I would like to call attention to the following concerns regarding this new technology.

1. The system does not generate intensity images. However, the high density point cloud can be colorized using a video or digital imagery to emulate, to a certain degree, the intensity image generated by conventional lidar systems.

2. Because it is not used commercially by the mapping community, very little is known about its accuracy and reliability. Until adequate metrics are available about the performance, caution should be practiced when dealing with this new technology. In the near future we may see some systems that are manufactured and utilized for commercial mapping purposes.

3. Due to the high sensitivity and low energy requirement, there are some concerns about noise generated from the background photon rate from the sunlit surfaces surrounding the target area. Careful consideration in design parameters of the laser system such as polarization type of output, good beam divergence, spectral width, and wavelength stability may minimize the solar effect and therefore elevate such concerns.

Figure 3. Sample data collected over Haiti using the ALIRT system (Image courtesy, Lincoln Laboratory, MIT).

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Once the capabilities of the Geiger mode-based lidar are explored and commercialized, it is anticipated that it will be widely used among the mapping community in the coming decade.

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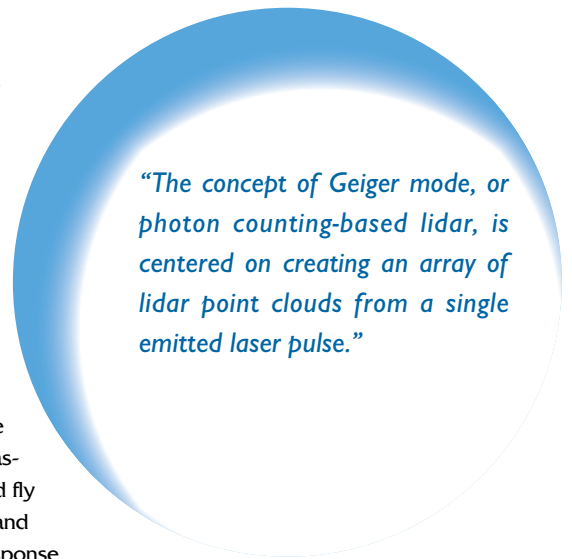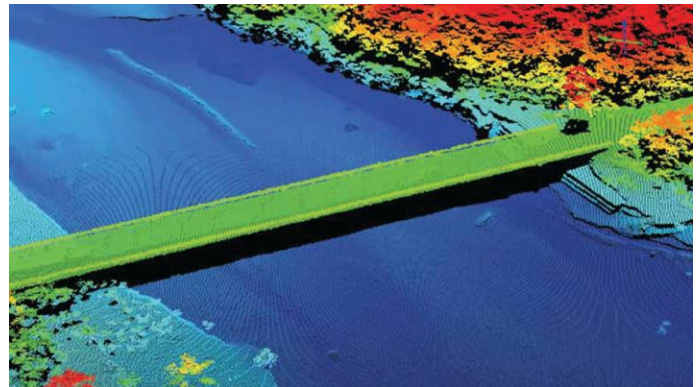

Correction

In the October 2011 "Mapping Matters", the following equations were erroneously published and should be corrected as follow:

$B = h \cdot \tan(FOV)$ should be $= 2 \cdot h \cdot \tan(FOV/2)$

$\Delta H\omega$, $\Delta H\varphi$ should be $= B/2 \cdot \tan(\Delta\varphi) = h \cdot \tan(FOV/2) \cdot \tan(\Delta\varphi)$

Thanks to the anonymous reader who brought it to our attention.