High-Resolution LIDAR with the SPC-QC-104

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Abstract: We describe LIDAR with a bh SPC-QC-104 TCSPC module and a bh BDS-SM 640-nm picosecond diode laser. The beam of the laser was directed to a distant target, photons scattered back from the target were collected by a Meade LX90 20-cm telescope, detected by a bh PMC-150-20 PMT module, and recorded by the TCSPC device. Using a laser pulse repetition rate of 250 kHz and no more than 10 µW of average power we obtained a clean backscattering signal from a tree 160 meters away. By increasing the pulse repetition rate to 50 MHz, we were able to detect fluorescence decay curves from the chlorophyll in the leaves.

Basic Principle

The distance to a distant objet can be measured by sending laser pulses to it, detecting light reflected or scattered at the object and determining the propagation time of the pulses to the object and back. The technique is called Light Detection and Ranging, or LIDAR. The principle is illustrated in Fig. 1.

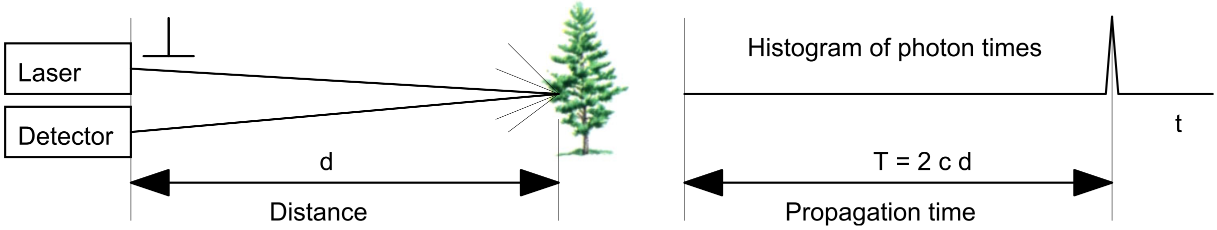

Fig. 1: Principle of LIDAR

The intensity of the light reaching the detector decreases with the distance of the object. For distances in the 100-m range and above and moderate laser power the intensity quickly drops to the single-photon level. A histogram of the photon times then shows a peak at a time T = 2 c d after the laser pulse, see Fig. 1, right. Time-correlated single photon counting (TCSPC) or related techniques are then the techniques of choice [1, 2].

The instrument-response function (IRF) of a TCSPC-based LIDAR system is given by the convolution of the laser pulse shape, the transit-time spread function of the detector, and the electrical instrument-response function of the TCSPC device. Even with medium-speed TCSPC devices, medium-speed detectors, and picosecond diode lasers an IRF width below 100 ps (FWHM, full width at half maximum) or 40 ps (RMS, root mean square) can be reached. Ultra-fast TCSPC devices with high-speed detectors can be 5 times faster than that [1, 3].

The actual resolution of a LIDAR experiment can be even higher. The reason is that not only one photon is used to build up the histogram shown in Fig. 1. The standard deviation of the measured propagation time then decreases (and the accuracy increases) with the square root of the number of photons. For example, for a system IRF of 40 ps (RMS) and 10,000 photons the standard deviation of the transit time becomes 0.4 ps, and the standard deviation of the distance is 60 µm. With a resolution that high not only the distance can be determined very accurately, but also optical properties, such as surface texture, photon migration times within the object, or fluorescence lifetimes the can be determined.

Experiment Setup

To demonstrate LIDAR with a TCSPC device we used a bh SPC-QC-104 module [4]. The SPC-QC-104 has an electrical IRF of 38 ps FWHM, or about 18 ps RMS. The advantage of the SPC-QC compared with faster SPC-150N or 180N modules is that it can record more than one photon within the start-stop time [4]. The possible detection of background photons therefore does not suppress the detection of a target photon at later times. As a light source we used a bh BDS-SM 640 nm ps diode laser. The laser was pulsed externally at a repetition rate of 250 kHz. The average power at this repetition rate is less than 10 µW, the pulse energy is about 40 pJ. Photons from the target were collected by a Meade LX90 (20 cm) telescope and detected by a bh PMC-150-20 photomultiplier module attached to the eyepiece holder. A photo of the optical setup is shown in Fig. 2.

Fig. 2: Optical setup

The low laser power and the low pulse energy used in our setup helps avoid laser-safety problems. However, it creates a problem with the pickup of environment light. The experiments were therefore performed at night. Even at night, light pollution turned out to be a problem. The pickup of ambient light was therefore reduced by a bandpass filter in front of the detector.

Results

Distance Measurement

A result is shown in Fig. 3. Despite the low laser power of the diode laser a clean signal was picked up from the target. The bump on the left is from the side-lobes of the laser beam diffusely scattered at a nearby tree, the peaks after the main peak are from trees behind the primary target.

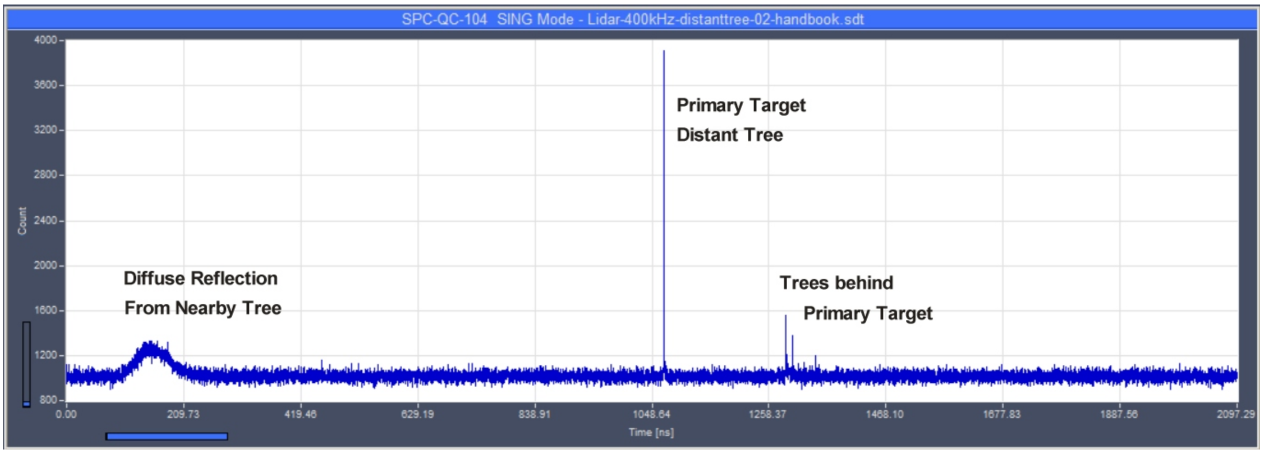

Fig. 3: LIDAR result obtained with the setup shown in Fig. 2. Laser repetition rate 250 kHz, laser pulse energy 40 pJ.

A zoom into the data around the target peak is shown in Fig. 4. The time of the maximum of the peak is 1070.21 ns, corresponding to a distance of 160.53 m.

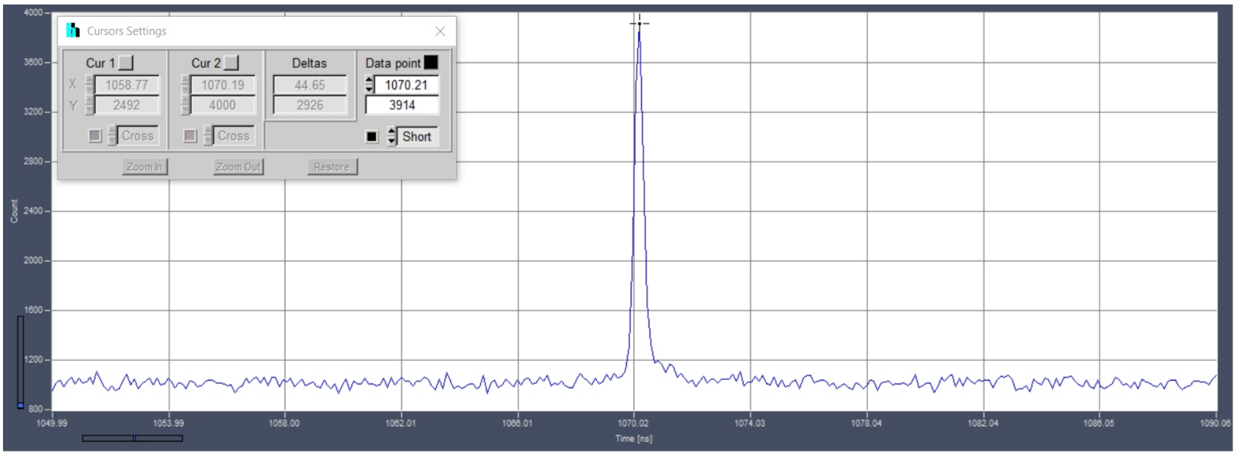

Fig. 4: Zoom into the region around the primary-target peak. The peak time is 1070.21 ns, corresponding to a target distance of 160.53 m.

Fluorescence-Lifetime Measurement

The success in recording scattered light from trees over a distance of more than 160 m prompted us to try recording of fluorescence decay functions of chlorophyll over the same distance. For a given average laser power, the intensity of fluorescence is several orders of magnitude lower than that of scattered laser light. However, the loss in intensity can be compensated by increasing the laser pulse repetition rate. There is no need of low repetition rate to avoid ambiguity, as in the case of distance measurement. The laser can therefore be run at its nominal repetition rate of 50 MHz, effectively increasing the average power by a factor of 200. The bandpass filter was replaced with a 680-nm long-pass filter, and the TCSPC recording-time window decreased to 16 ns. The time-channel width was set to 4 ps, and the number of time channels to 4096. The result was striking: The count rate increased to about 300,000 photons per second, and fluorescence decay curves showed up almost instantly. An example is shown in Fig. 5.

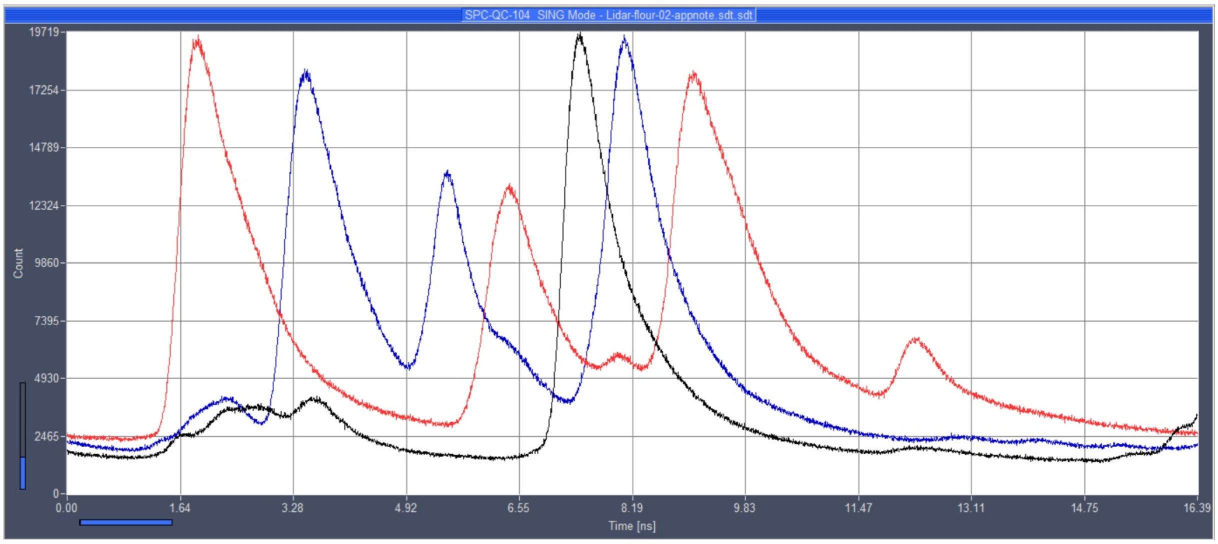

Fig. 5: Fluorescence decay curves of chlorophyll recorded from a tree 160 m away. The three curves were recorded from slightly different locations. The laser beam illuminated several leaves simultaneously, therefore several decay profiles are present in each curve.

Three curves (red, blue and black) were recorded from slightly different spatial locations. Moreover, the laser beam hit several leaves in slightly different distance. Therefore, several overlaid decay profiles are visible in each curve.

An attempt to de-convolute a decay curve with SPCImage NG [6] is shown in Fig. 6. The black curve of Fig. 5 was sent to SPCImage NG, and the fit range restricted to the decay curve in the centre. A double-exponential model and a synthetic IRF were used for the fit. The fit of the rising edge is not perfect, probably because there are small signal contributions from leaves in different distances. Nevertheless, reasonable decay times and amplitudes are obtained. The decay components are shown in the insert in the upper right of the figure.

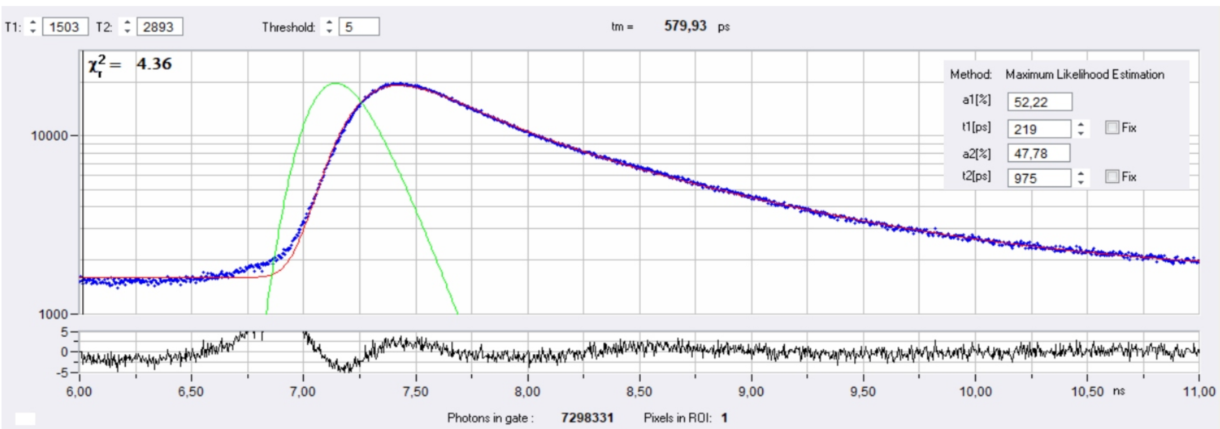

Fig. 6: De-convolution of the decay in the middle of the black curve in Fig. 5. Double-exponential model, synthetic IRF. Decay components shown in the insert upper right. The green curve is the IRF.

The decay times of the two components are t1 = 219 ps and t2 = 975 ps, the amplitude-weighted lifetime is tm = 580 ps. This is a short lifetime for chlorophyll. The short lifetime explains by the fact that the leaves are fully dark adapted, and the excitation power density is extremely low. Under these conditions, the photosynthesis channels are fully open, and the fluorescence is quenched by photosynthesis reactions.

Summary

We described LIDAR with a bh SPC-QC-104 TCSPC module and a bh BDS-SM 640-nm picosecond diode laser. The beam of the laser was directed to a distant target, photons scattered back from the target were collected by a Meade LLX19 20-cm telescope, detected by a bh PMC-150-20 PMT module, and recorded by the TCSPC device. Using a laser pulse repetition rate of 250 kHz and no more than 10 µW of average power we obtained a clean backscattering signal from a tree 160 meters away. By increasing the pulse repetition rate to 50 MHz, we were able to detect fluorescence decay curves from the chlorophyll in the leaves. The results show that TCSPC-based LIDAR not only delivers distances to remote objects but also reveals information on the objects themselves.

References

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