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High-Precision 3D Imaging with Single-Photon Lidar

RESEARCHERS

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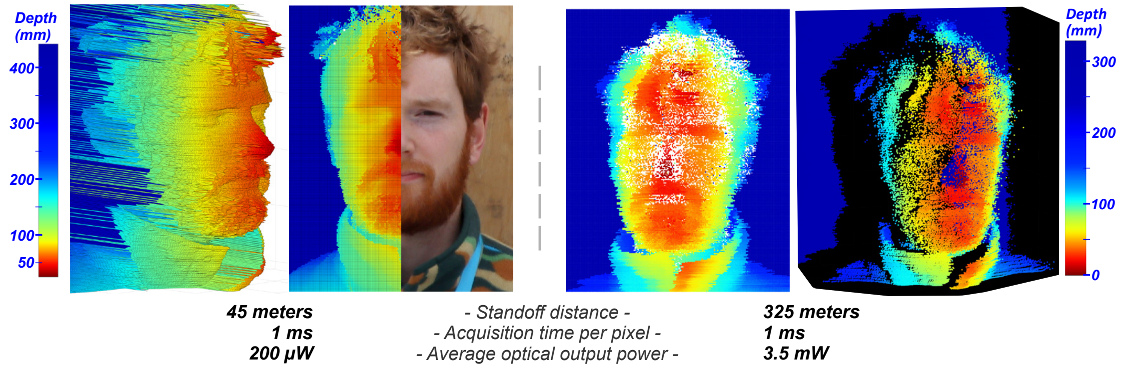
Light detection and ranging (lidar) systems based on direct time-of-flight measurements and time-correlated single-photon counting (TCSPC) offer a versatile approach for remote, noncontact depth imaging at low optical power illumination levels. This single-photon approach has proven effective in a wide variety of applications, providing robust flexibility in the trade-off between standoff distance, laser output power levels, data acquisition time and depth resolution. It has the potential to achieve high-resolution three-dimensional imaging over long ranges.

Single-photon lidar systems using an illumination wavelength of around 1550 nm offer advantages over systems operating at wavelengths below 1400 nm. They can use significantly higher output optical powers while still being eye-safe, and they benefit from lower solar background levels and higher atmospheric transmission. Superconducting nanowire single-photon detectors (SNSPDs) are an excellent option for systems operating in the shortwave infrared spectral region due to their low timing jitter and high detection efficiency.[1]

In recently published work,[2] we fiber-coupled a state-of-the-art, high-efficiency and ultra-low-timing-jitter SNSPD[3] to the receive channel of our custom-designed single-pixel monostatic scanning transceiver optimized for operation at a wavelength of 1550 nm. A commercially available (1550 nm wavelength) fiber laser connected to the transceiver transmit channel provided the pulsed illumination. The detector, operated at a temperature of 850 mK, achieved a single-photon detection efficiency of 65% at 1550 nm. When combined with a high-performance TCSPC data acquisition module, the overall system exhibited an instrumental response function of just under 13 ps, corresponding to a time-of-flight distance of approximately 4 mm (or 2 mm in depth). Compared with previously reported similar single-pixel lidar systems at this wavelength, our configuration achieved approximately twice the detection efficiency and a 10-fold improvement in timing resolution.

Coupled with the transceiver's spatial and spectral filtering and high optical throughput, this enabled 1-mm-depth features on a reference board and a human head to be clearly resolved when measured by the system in broad daylight at distances of 45 m and 325 m using per-pixel acquisition times between 0.25 and 1 ms. Millimeter-scale depth and lateral resolution were maintained at distances of up to 1 km using average optical output powers of ≤3.5 mW, meaning that the illumination beam exiting the transceiver was eye-safe at all distances.

This work demonstrates the deployment of advanced low-jitter SNSPDs in photon-counting lidar systems capable of kilometer-scale operation and highlights their potential for high-resolution, eye-safe 3D remote imaging. OPN



Oblique and face-on views of the measured depth profiles of a coauthor (G.G. Taylor) acquired in daylight at two standoff distances. The color scale represents the variation in depth across the reconstructed 3D surface.