# Photon Counting Technology

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As the need to transmit and receive the maximum amount of information in the fastest and most secure manner possible has grown over the last decades, scientists and technologists have been working to exploit the quantum properties, or quantum states, of the most fundamental information-bearing object, the photon. By encoding information in the form of the quantum states of photons, it is possible to achieve the highest levels of compression and security in optical communication on one hand, and sensitivity in optical sensing on the other hand. Two vital factors which have led to the growth of this field of research, and which could ultimately lead to practical use of these concepts in deployed systems, are the advancements in the generation and detection of quantum states of photons, as well as the creation of methods of encoding the information into the quantum states of photons.

A key requirement for the implementation of any quantum information system is the ability to reliably detect and count photons. To address this need, research into photon-counting techniques and technologies has grown steadily over the past two decades, and the applications have expanded well beyond quantum communication to include quantum-enhanced sensing, quantum information processing, fluorescence sensing, light detection and ranging (LIDAR), and 3D imaging. Many of the detection requirements in these emerging areas remain similar to those of quantum communications: high detection efficiency; low background levels; very low jitter; and, increasingly, a very high data rate capability.

In this special section, we present five technical articles that report on advancements in various aspects of photon-counting technology and their applications in depth imaging and florescence sensing. The first article, by Gustav Tolt et al., provides a study on time-correlated single-photon counting for three-dimensional LIDAR systems. The authors present six peak-detection approaches and compare their performance in terms of range accuracy, sensitivity to sparse sampling and the number of outliers, and their ability to detect two distinct scattering surfaces within the instantaneous field of view.

Next, the problem of long-range depth profiling for camouflaged targets using single-photon detection is addressed in the article authored by Rachael Tobin et al. This excellent article focuses on the reconstruction of depth and intensity profiles from data acquired using a custom-designed time-of-flight scanning transceiver; the system is based on the time-correlated single-photon counting technique using a Peltier-cooled InGaAs/InP single-photon avalanche diode detector operating at a wavelength of 1.55 $\mu$m.

Massimo Ghioni et al. contribute substantially to improving a well-known challenge in the use of parallel time-correlated single-photon counting (TCSPC) detectors, that is the transfer of picosecond resolution data at high rates from the detector array to the processor. Specifically, they present an elegant routing algorithm that enables a smart connection between a $32 \times 32$ detector array and five shared high-performance converters able to provide an overall conversion rate up to 10 Gbit/s.

In their article, Matthew Edgar et al. introduce a method for real-time computational photon-counting LIDAR with the much-appreciated ultimate aim of developing a low-cost real-time LIDAR system. The authors describe a prototype LIDAR system that utilizes a single high-sensitivity photon-counting detector and fast-timing electronics to recover millimeter-resolution three-dimensional images in real time.

Finally, in their article on fluorescence-decay data analysis, Matthias Patting et al. present a method for correcting the problem of detector pulse pile-up, a long-term issue limiting the performance of fluorescence-decay data analysis at very high count rates. Their work therefore offers quantitatively accurate fluorescence lifetime imaging at very high frame rates.

We hope that this special section helps to highlight some of the advancements in photon-counting technologies and some of their applications. We would also like to take this opportunity to thank the contributing authors and the staff of *Optical Engineering* in helping to compile this special section on photon counting technology.

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