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Remote 3D imaging using single photon detection

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A new method rapidly acquires depth scans at extended distances, paving the way for resolving low-signature targets at power levels safe for human eyes.

Obtaining 3D images of remote objects is of widespread interest in many disciplines, including manufacturing, geosciences, architecture, and defense. Although specific requirements may differ, many commonalities can be identified. These systems should produce an easily recognizable computer model of the scanned scenery, provide high resolution in all three dimensions, and operate over as long a transmission distance as possible. They also need to work in different environmental conditions, have tolerance for a high dynamic range of return signals, and require as little a priori knowledge about the target as possible. Short acquisition times become critical with moving objects. Ensuring that the system does not produce light intensities harmful to the human eye is often of paramount importance.

Past work has relied on many passive and active approaches. Passive systems—very much like the human eye—use one or more sensors to gather conventional, flat images which are then analyzed for depth cues. Active imagers emit spatial or temporal light patterns and reconstruct the scene based on the way these patterns are modulated on their return.[1] The latter approach is often less dependent on ambient lighting and can operate in many environmental conditions. We have developed an active imaging system using time-correlated single photon counting (TCSPC) to achieve the best possible light sensitivity, allowing us to produce detailed 3D models of objects kilometers away based on information from scattered return photons.

TCSPC[2] usually measures the time difference between a source emission and a received photon event, and it has traditionally been employed in fluorescence lifetime experiments. Each photon event recorded by the detector is timed with respect to the source event using sophisticated hardware. Typically, we record many of them for each measurement. Over many cycles, the timing difference between the laser emission and return photons from the target yields the averaged round-trip time, and therefore an accurate source-target distance. Picosecond resolution and photon statistics potentially allow for micrometer-scale overall depth resolution.[3]

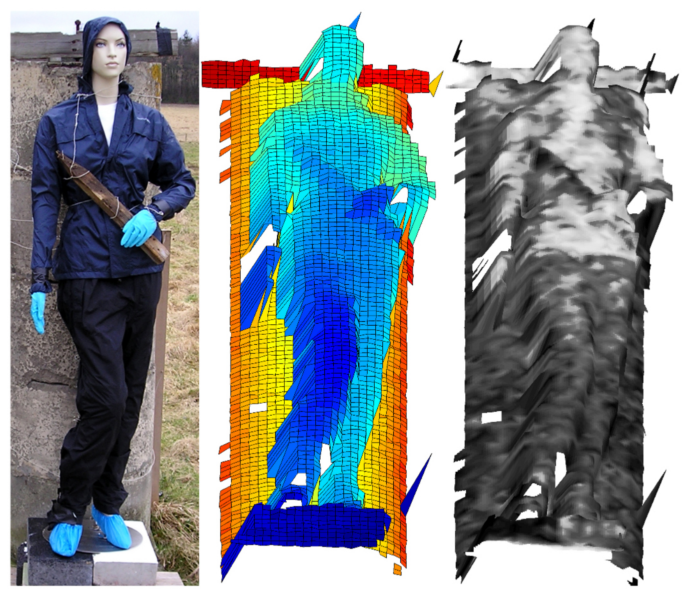

Figure 1. *Scan of a life-size mannequin at 325m distance. The return depth (middle) and intensity (right, interpolated) distributions of different target materials can reveal concealed objects.*

We designed, constructed, and characterized a scanning 3D imager using TCSPC, operating at MHz repetition rates and μW average power levels.[4] A 90ps pulse-width laser diode provides photon pulses at a wavelength of 842nm. Two computer-controlled galvanometer mirrors steer the laser beam over the target scene in a pixel-by-pixel raster scan pattern. A single-lens reflex camera objective both forms a small illumination spot on the target object and collects return photons. Polarization optics split the common transmit and receive beam path. The fiber-coupled single photon detector—usually a silicon single photon avalanche diode—connects to the receive channel.

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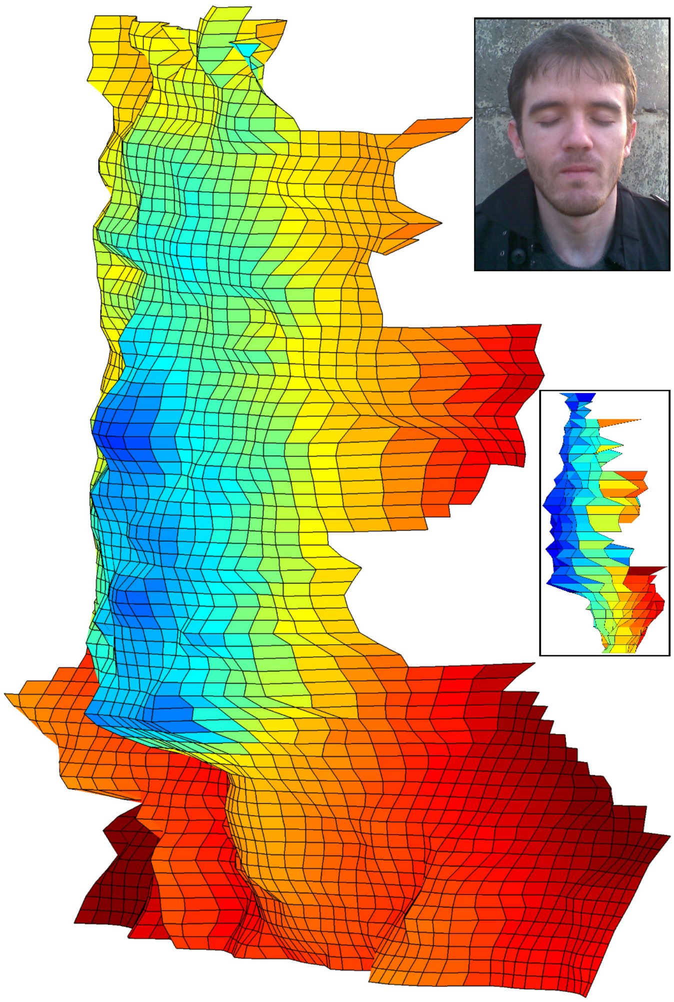

Figure 2. *Scan of a human head from 325m away. The system is completely safe for human eyes at all operating distances. Postprocessing can guide recognition of the target (Inserts: upper right: photo, right: raw data).*

We transferred the time-tagged photon and trigger events to a multi-core desktop computer, which converts them into time-of-flight histograms for each pixel. The software's multithreading capabilities enable real-time evaluation of completed histograms while the scanner acquires subsequent pixels. A fast-Fourier-transform cross-correlation algorithm determines the maximum target return for each pixel by comparing it with the known instrumental response shape. However, others have shown that identifying multiple target returns in one pixel via an adaptive reversible-jump Markov-chain Monte-Carlo algorithm can aid recognition by partially obstructing or reflecting materials such as foliage and glass—without a priori knowledge about the target.[3]

We can enhance visualization of acquired depth images depending on the nature of the object. Figure 1 shows a scan of a life-size mannequin at a range of 325m: the depth information is overlaid with a return intensity color map to enhance the contrast between different materials. Figure 2 shows a human head scan after a spatial cubic-spline interpolation, pronouncing and restoring the rounded and organic nature of the target.

The system can produce highly detailed 3D images at long ranges with minimal active illumination. This approach, coupled with the modularity of the design, allows for rapid adaptation to a wide range of applications. Next steps in our ongoing work include implementing novel detector technologies and revising the unit's optical design to decrease acquisition time and boost the target range.

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References

1. P. J. Besl, *Active, optical range imaging sensors*, **Machine Vis. Appl. 1** (2), pp. 127–152, 1988. doi:10.1007/BF01212277
2. W. Becker, **Advanced Time-Correlated Single Photon Counting Techniques**, Springer, Berlin, 2005.
3. G. S. Buller and A. M. Wallace, *Ranging and three-dimensional imaging using time-correlated single-photon counting and point-by-point acquisition*, **J. Sel. Top. Quantum Electron. 13** (4), pp. 1006–1015, 2007. doi:10.1109/JSTQE.2007.902850
4. G. S. Buller, R. J. Collins, N. J. Krichel, A. M. Wallace, and A. McCarthy, *Scanning of low-signature targets using time-correlated single-photon counting*, **Proc. SPIE 7320**, p. 732003, 2009. doi:10.1117/12.818645