Single-Photon LiDAR 3D Imaging in Degraded Visual Environments

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Light Detection and Ranging (LiDAR) is a methodology that uses the time of flight of reflected light from a pulsed laser source to determine distances and perform imaging of a target object [1]. Integrating single-photon detection with LiDAR offers greater sensitivity at extremely low signal levels than conventional high-energy pulsed systems based on avalanche photodiodes (APDs). Furthermore, single-photon avalanche diode (SPAD) detectors allow the use of low average optical power for target illumination [2]. Quantum LiDAR's inherent single-photon sensitivity gives it advantages over conventional optical imaging methodologies in degraded visual environments (DVEs), where visibility is compromised by mist, fog, haze and smoke. Imaging and ranging measurements in DVEs could support various applications, such as autonomous driving, airborne navigation and target recognition in adverse weather conditions [3].

Here we propose and demonstrate a single-photon LiDAR capable of intensity and depth measurements through a challenging DVE scenario. The comparison with a commercial LiDAR sensor under the same conditions reveals that our SPAD-based system maintained detectable returns while the classical LiDAR was fully saturated by the first fog layer encountered, preventing reliable target reconstruction. Moreover, these experimental results are supported by the development of a GPU-accelerated Monte Carlo simulation framework, which simulates photon propagation at the single-photon level. This enables the estimation of scattering and absorption probabilities, as well as the angular scattering distributions as a function of the encountered particle size and laser wavelength. The experimental setup is based on a coaxial design, comprising a pulsed laser emitting at 1550 nm, a galvanometer mirror system and an InGaAs/InP SPAD detector. The Time Correlated Single Photon Counting (TCSPC) module enables time-of-flight measurements and synchronizes the laser with the scanning system. As illustrative examples, measurements acquired with the experimental setup are reported in Fig. 1 showing target visibility under severe DVE conditions.

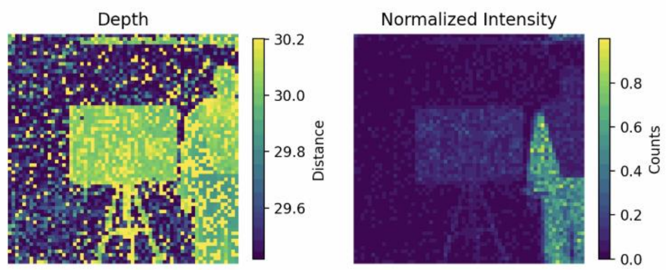

Fig. 1: *SPAD depth and intensity images in an artificial fog scenario under severe fog conditions.*

In conclusion, we demonstrated the 3D imaging capabilities of a single-photon LiDAR operating at 1550 nm in severe fog conditions, and the compact size of our system gives us confidence in the future integration of this LiDAR with unmanned aerial vehicles (UAVs) and, subsequently, helicopters.

References

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