SPAD LiDAR with Radar target prediction

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UNIVERSITÄT DUISBURG ESSEN

Open-Minded

A. Henschke[1], H. Fletcher[2], A. Utz[1], M. Ligges[1]

1) Fraunhofer Institute for Microelectronic Circuits and Systems IMS

2) University of Duisburg-Essen, Department of Electronic Components and Circuits

Light Detection and Ranging (LiDAR) system range performance is often limited by the presence of ambient light or other environmental disturbances in the channel. While Radio Detection and Ranging (RADAR) and LiDAR operate in different areas of the electromagnetic spectrum a combined approach can result in an overall system performance increase exceeding the bare combination of the individual results. In this approach the RADAR information is used in a low-level fusion strategy to calculate the appropriate time-gate window before the distance conversion to improve the detection statistic.

Idea

Low-level fusion strategy by using the RADAR target prior for the time-gate window calculation before the LiDAR distance conversion **(Fig. 1)**. This leads to the following advantages for the overall system.

1. Improvement in **stray light immunity and measurable range**
2. Increase of **noise suppression** and **detection statistics**

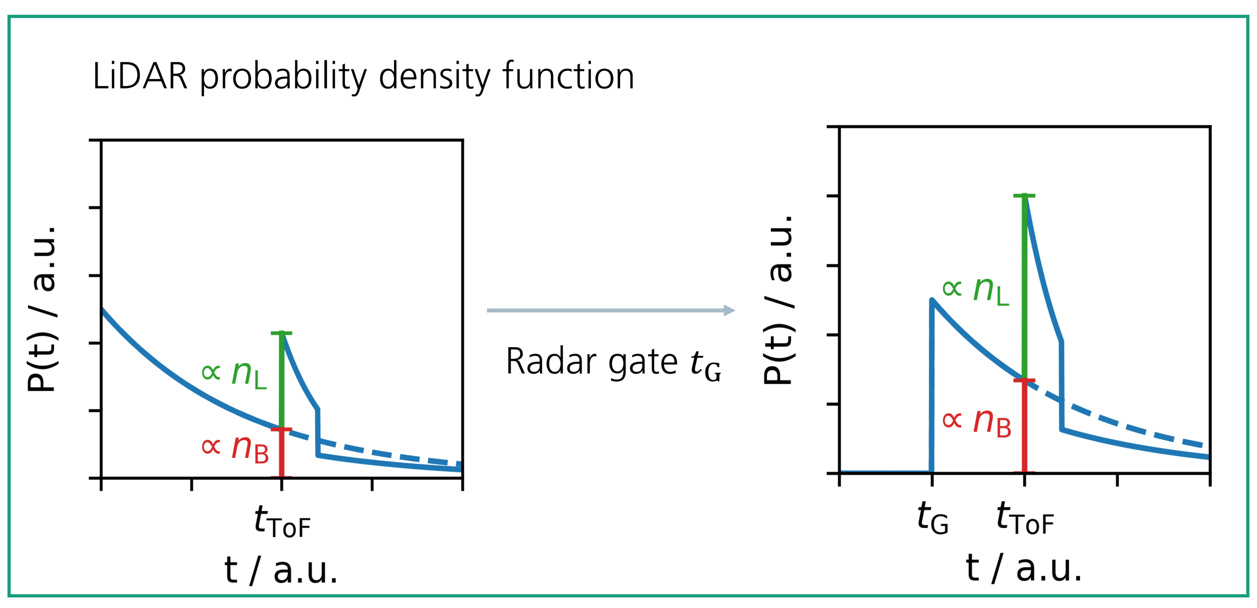
Fig. 1 *Low-level fusion algorithm for the combination of LiDAR and RADAR. Coarse time corresponds is 6.25 ns (system clock) while fine time is stepped with 250 ps accuracy (delay line).*

Improving detection statistics by gating

The arrival of photons at the SPAD sensor can be modeled by a Poisson process. The probability density function (PDF) $P(t)$ with the momentary rate $r(t)$ for first-photon detection is shown in (1) [1].

$$P(t) = r(t) \cdot \left(1 - \int_0^t P(\tau)\, d\tau\right) = r(t) \cdot e^{\int_0^t -r(\tau) d\tau} \qquad (1)$$

For simplification, the discussion is limited to a rectangular temporal laser pulse model. Assuming constant ambient illumination and a rectangular pulse with detection rate leads to the PDF shown in **Fig. 2 a)**.



a) *Example of the PDF without the use of a radar prior*

b) *Signal improvement through applying a gate time t_G*

Fig. 2 *Example of the PDF with and without the use of a gate time t_G*

The arrival of the laser pulse constitutes a local increase in momentary signal, while earlier arriving photons result in an exponential decay which suppresses the laser generated signature. By enabling the SPAD after a gate time t_G, shortly before the laser pulse arrival, early triggering from ambient photons can be prevented and the ratio of detected laser and ambient photons can be improved **(Fig. 2 b))**.

Proof of concept demonstrator

- RADAR sensor OmniPresense OPS 243-C
  - FMCW measurement principle
  - Range up to 60 m and 16 targets
- Fraunhofer Direct Time-of-Flight LiDAR "CSPAD3K" [2]
  - 3072 SPAD-Pixels (2x2 SPAD per pixel)
  - Flash LiDAR measurement principle
  - SPAD-based first-photon sensor

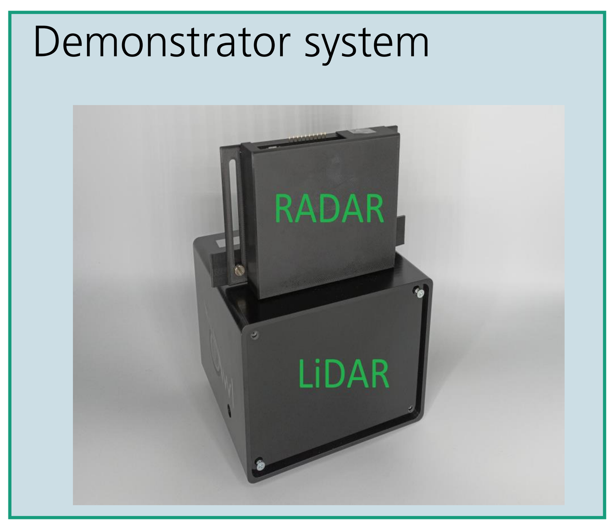


Fig. 3 *Demonstrator with the combination of LiDAR and RADAR.*

Experiment and results

The demonstrator setup is used to measure a static target with a reflectivity of 15 % at 5.8 m. Stray light influence is emulated by a halogen light source.

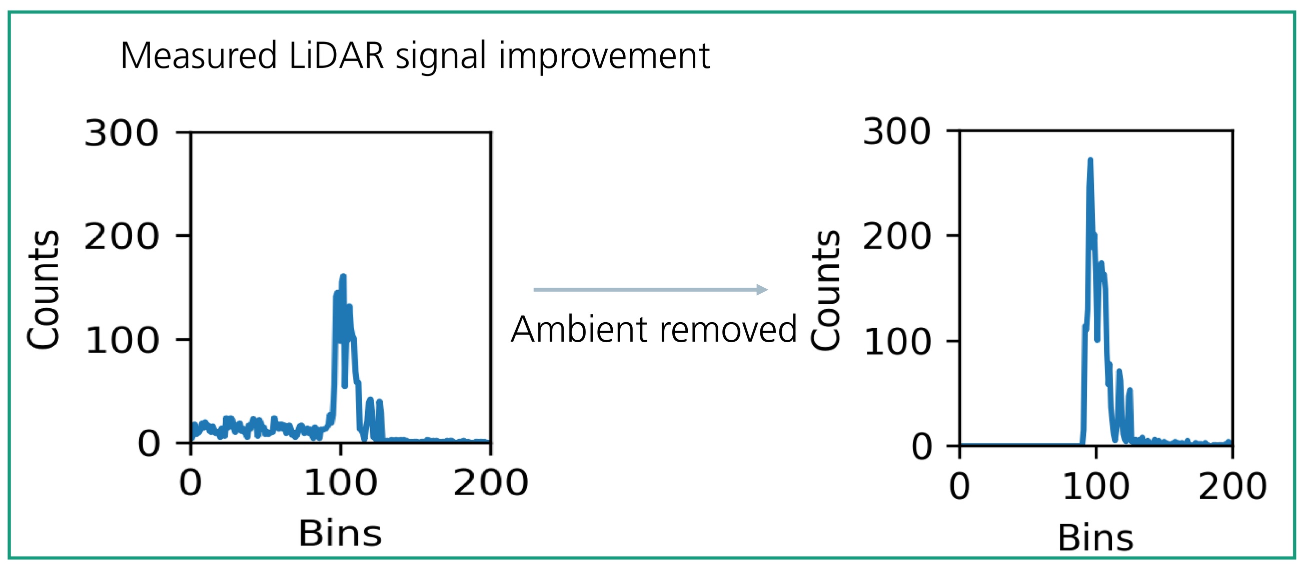
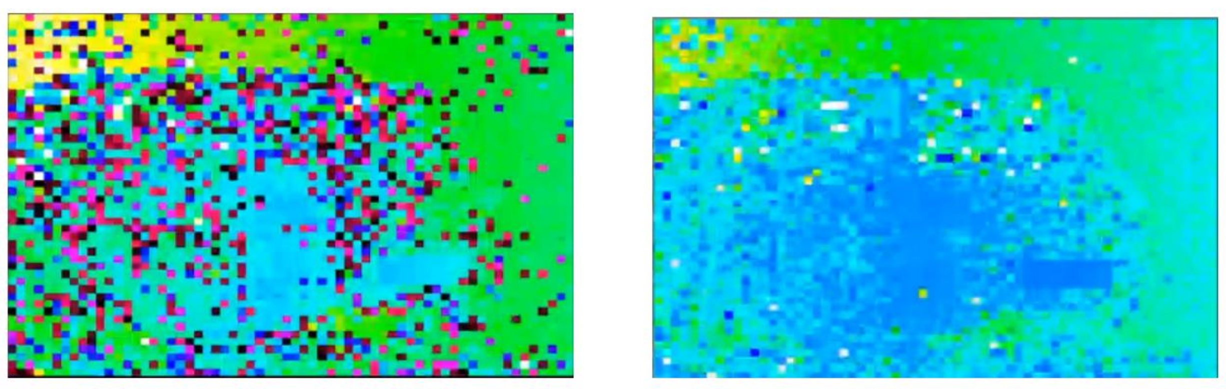


Fig. 4 *Example histograms of a target pixel for the RADAR improved distance measurement*

The histograms with the employment of the RADAR low-level fusion strategy show an increase in signal quality for single-photon LiDAR systems **(Fig. 4)**. The improvement becomes visible when applying the algorithm to the 3D pointcloud for the scene in **Fig. 5.**

Fig. 5 *Scene of a car with stray light influence*

In **Fig. 6 a)** many pixels output false distance information due to the stray light influence. With the RADAR prediction **(Fig. 6 b))**. the shape of the object is clearly visible and false distance information is suppressed.



a) Car scene with pixels saturated through stray light

b) Car scene with suppressed saturation through target prediction

Fig. 6 Measured scene of the car with and without using the RADAR target prediction

The proposed approach improves LiDAR signal quality under stray light influence, but it should be applicable to other environmental impacts as well. However it is not free from drawbacks. Optical systems detect way smaller objects than RADAR and when the RADAR misses an object, the fusion algorithm hides this subarea of the measured range. The approach can further be improved by analyzing LiDAR data and selectively using the RADAR gate only when LiDAR detection becomes impossible.

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2 J. Ruskowski, C. Thattil, J. Drewes, and W. Brockherde, "64x48 pixel backside illuminated spad detector array for lidar applications," in Quantum Sensing and Nano Electronics and Photonics XVII, 2020

Contact

andre.henschke@ims.fraunhofer.de

hendrik.fletcher@uni-due.de

www.ims.fraunhofer.de

Fraunhofer IMS, 47057 Duisburg, Germany

University DuE, 47057 Duisburg, Germany