A Disdrometer based on ultra-fast SPAD Cameras

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Abstract: *We present a new environmental application of SPAD imagers, the continuous measurement of size and shapes of hydrometeors. A first 32x32 pixel prototype allows real-time operation at very low light levels, 6000 fps and 1:100 average data reduction.*

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1. Introduction

A disdrometer is an instrument designed to characterize the size (and shape for the most modern ones) distribution of hydrometeors (raindrops, snowflakes and hailstones). The resulting data help interpret weather radar images, as part of weather forecasts, and improve understanding of precipitation microphysics. Parameters of interest are fall speed, size/volume, shape (ellipsoidal, possibly changing over time) of hydrometeors.

2. Design Constraints

The top fall velocity is ~10m/s, while the target diameter is in the range 0.1–10mm. In addition, a disdrometer must be designed for autonomous and continuous outdoors use, often in very harsh conditions.

3. State-of-the-art

Imaging based techniques play an important role in the literature. Recent implementations include the use of multiple line-scan cameras [1] attaining resolutions of 0.1mm with a sampling area of 100cm^2. In general, it is important to achieve (1) high speed, (2) high dynamic range and sufficient SNR ratio, and (3) sufficiently high saturation levels to enable strong illumination.

4. Prototype

We have opted for a SPAD based imager, to achieve our main goals of sensitivity, speed, low power consumption, portability, and potentially low final system price. SPADs are a class of APDs operating above breakdown, in so-called Geiger-mode (Fig. 1). The RADHARD2 (RH2) system comprises a CMOS chip and an FPGA for rolling-shutter acquisition at 6000fps (Fig. 2a). A micrograph of the chip is shown in Fig. 2b [2].

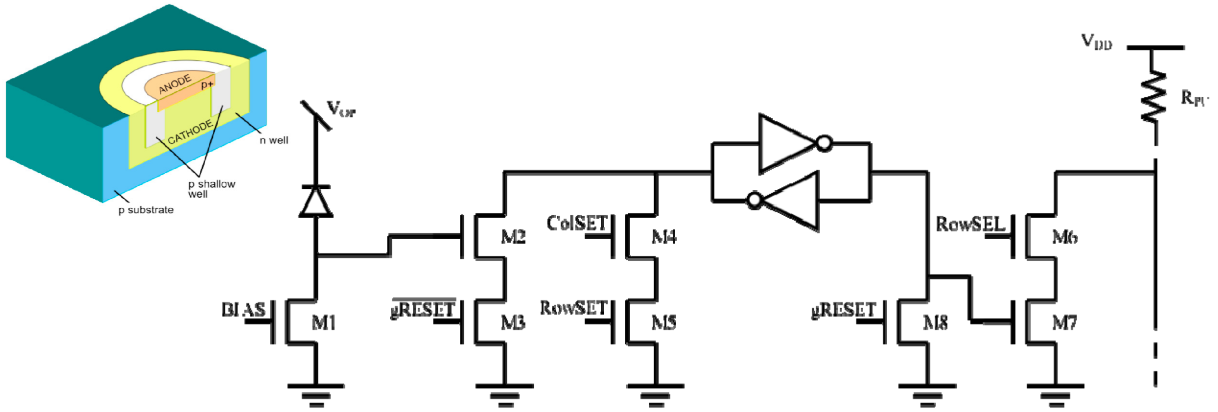

Fig. 1 RADHARD2 pixel: schematic diagram with passive quench and recharge circuitries (left), pulse shaping and an embedded counter (right) [2]. Inset: SPAD cross-section, conventional CMOS process.

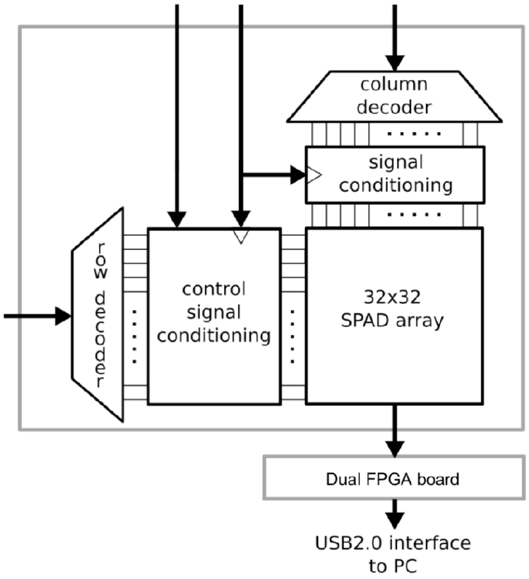

Fig. 2a RADHARD2 block diagram [2]. The chip is read out in rolling shutter mode as a sequence of 1-bit 32x32 pixel frames.

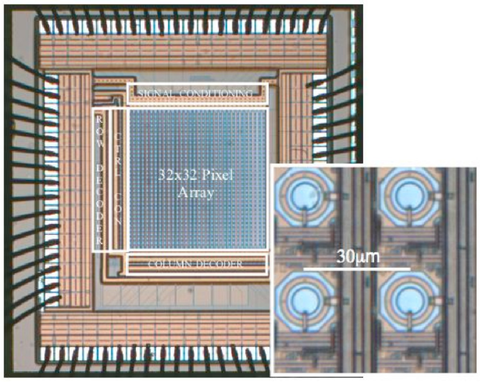

Fig. 2b Photomicrograph of RADHARD2, a 32x32 parallel-counting pixel array implemented in 0.35μm CMOS technology. [2]

5. Set-up and Processing

The RH2 camera observes the raindrops as they fall through an intake slid and pass in front of a LED illuminator. Processing is organised in a three-step hierarchical approach. First, we accumulate 1-bit frames so as to increase the pixel resolution to 4 bits. Second, using an event-driven technique, we recognize the presence of a hydrometeor in a frame, thus filtering those frames that do not contain any objects. A frame average is calculated, and only those frames above an empirically determined threshold are kept, resulting in less than 1% of the frames being stored. Third, the filtered stream is subsequently analyzed in the PC.

6. Results

The first lab tests involved glass spheres of 2mm mimicking medium-large hydrometeors (Fig. 3a). A typical image sequence of real raindrops is shown in Fig. 3b.

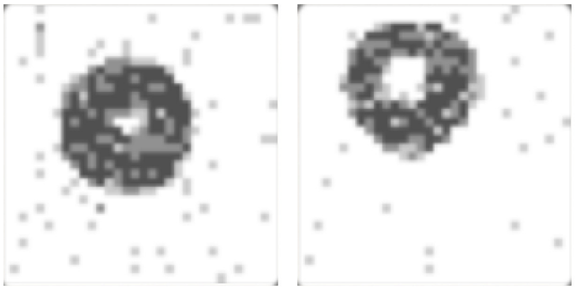

Fig. 3a Image of a glass sphere captured by RADHARD2 (left). Water drop observed by RADHARD2 under the same conditions (right). The intensity resolution was 4 bits in all experiments.

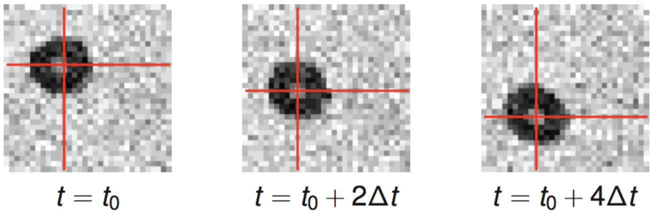

Fig. 3b Sequence of raindrops captured by RADHARD2 running at a 6kfps. The centre is determined and thus the velocity of the fall may be determined. In this case the estimated velocity was of 3.4m/s.

In order to train the system to recognize the raindrops within a range of possible geometries, RH2 follows a precise calibration procedure, involving determination whether the drop is in the focal plane, or its actual size, carried out using the drops as lenses [3] (Fig. 4). Once this calibration phase is completed, it becomes possible to estimate the actual diameter D of the raindrop (Fig. 5-Fig. 6). Several measurement campaigns have been carried out on real rainfall events. The raindrop is identified using standard pattern matching, where the training set is a known raindrop sequence and the reference patterns are the drop *soma* and its boundary (Fig. 7). In the future, the RH2 chip will be replaced with a larger format device. We also plan to move many of the functionalities from software to firmware.

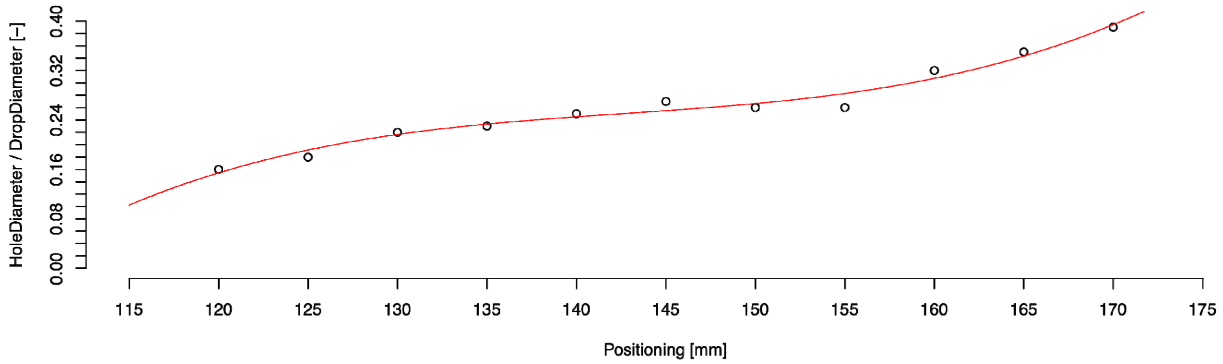

Fig. 4 Use of raindrops as lenses for calibration purposes: (*soma* diameter)/(drop diameter) ratio as a function of the drop location along the intake slid. The horizontal axis shows the distance of the raindrop to the main lens. The relation is cubic as shown by Jones [3]. (NB: soma: white hole in the drop image centre.)

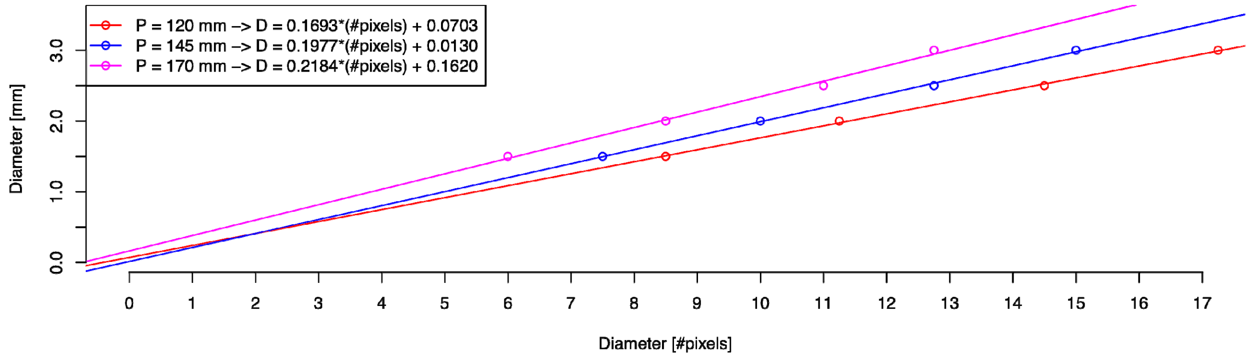

Fig. 5 Estimation of the raindrop diameter *D*, irrespective of distance of the raindrop to the main lens *p*. The accuracy of the estimation is given by the error of the linear fit.

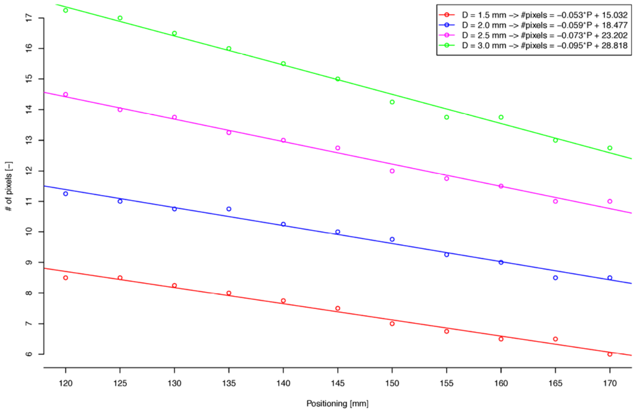

Fig. 6 Linear fit of raindrop diameter D in pixels vs the drop position on the optical axis for several values of the real drop diameter. The accuracy is given by the error of the fit.

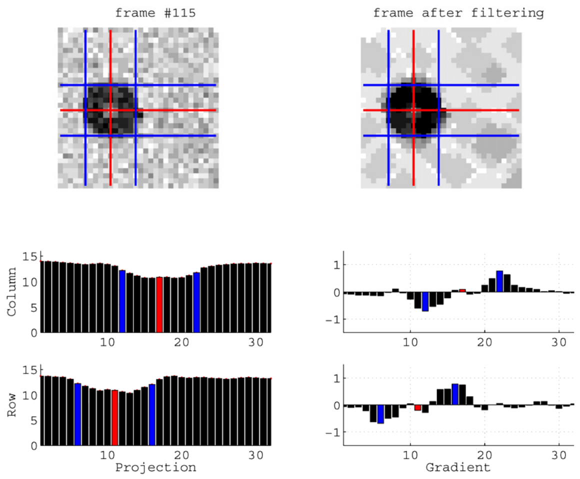

Fig. 7 Results after post-processing: raindrop raw image (top left), filtered image (top right). Bottom left: projection for each dimension, bottom right: gradient on this projection.

References

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