A 300x150 Single Photon Active Event Sensor

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VoxelSensors

Abstract. This paper introduces a novel sensor technology, Single Photon Active Event Sensors (SPAES), designed for the detection of sparse optical signals. SPAES is a new multi-modal sensor category that combines **Single Photon Avalanche Diodes (SPADs) and event-based sensing** to offer high detection bandwidth, single-photon sensitivity, and low power consumption. The sensor architecture incorporates in-pixel spatiotemporal filters that can distinguish active light from ambient light, enabling robust operation even in bright conditions. The output is a stream of x, y, and optionally t (time) events, providing accurate localization and timing of detected photons. This technology has the potential to revolutionize various applications, including 3D sensing and eye tracking, due to its **high sensitivity, low latency, low power consumption, and immunity to interference**. We present results of a first sensor implementation with 300x150 resolution fabricated in an FSI 40nm CMOS technology and associated 3D sensing system.

SPAES sits at the intersection of 2 recent trends in CMOS image sensing and optical sensing: the development of small CMOS-compatible SPADs (Single Photon Avalanche Diodes) and SPAD arrays and SPAD systems [1, 2, 3], driven by researchers such as Eduardo Charbon, Christiano Niclass, Robert Henderson, Neal Dutton, and many more, and the quest for neuromorphic vision sensors and the development of event-based sensing [4, 5, 6] originating from the neuromorphic sensing efforts from researches such as Carver Mead, Toby Delbruck, Christoph Posch and also many others.

With SPAES, we propose a new sensor architecture and sensing modality which leverages the unique properties of SPADs and the unique benefits of event-based or sparse sensing. SPADs offer high detection bandwidth and single photon sensitivity, and the recent advances in making these devices manufacturable with high yield (for example ST Microelectronics, Sony, ...). The sparse sensing offers a paradigm for low power sensing architectures.

To demonstrate the operational principle of SPAES, we developed a first prototype sensor. The sensor consists of an array of 300x150 pixels (Figure 1) and is fabricated in a 40nm CMOS process. Each pixel consists of a SPAD detector and filtering logic, with the goal of differentiating active from ambient photons.

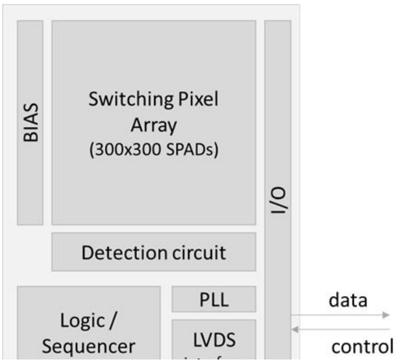

Figure 1 - Sensor Blockdiagram

The target of the filtering mechanism is to identify the photons originating from sparse active illumination, for example a laser dot projected on the scene. The filtering mechanism, which happens inside each pixel in parallel, will check the behavior of the detected photons with respect to an expected behavior. For example, the user may program an expected behavior describing that the detected laser beam should be detected on 2 neighboring pixels within a specific timeframe. The in-pixel filter circuit will then verify, when a trigger is generated from the SPAD, if a neighboring SPAD has triggered within the time window. If not, the trigger is ignored. If yes, the trigger is passed. A second filtering mechanism will check if this coincidence event is happening within a second neighborhood more than once within a larger window of time. Suppose the laser beam is moving because we are scanning the scene, the laser will stay on the pixel cluster for a defined moment of time. The user can program for example that at least 3 coincidence events must have happened in order to validate the event and pass it on for further processing, in other words the coincidence event must be persistent. These 2 filtering paradigms, coincidence and persistence, are the core of VoxelSensors SPAES. The in-pixel filters are programmable, and can be enabled and disabled.

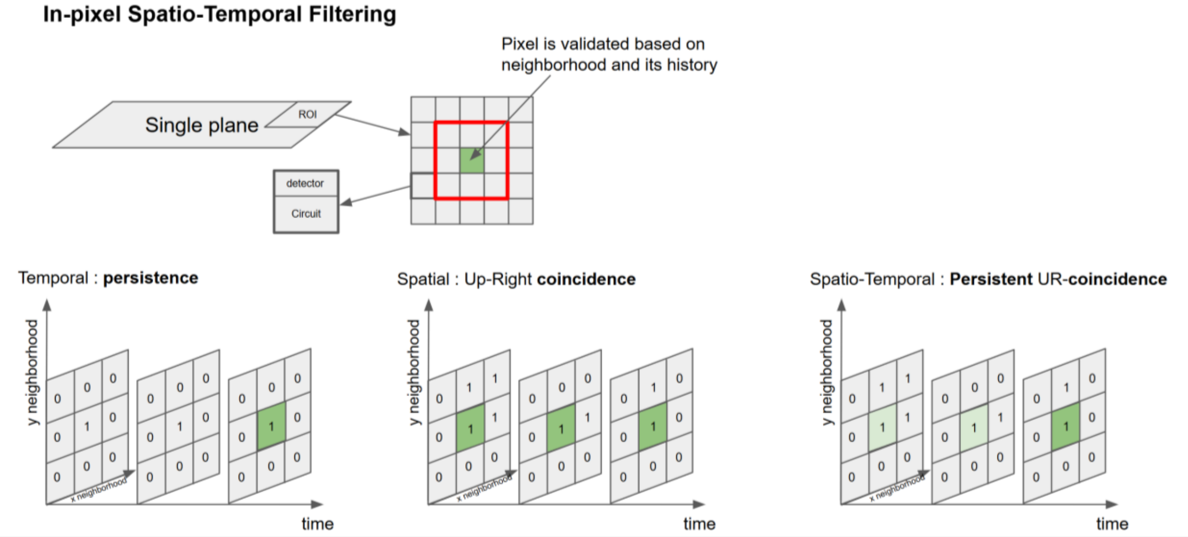

Figure 2 - In-pixel spatio-temporal filtering strategy

Figure 3 illustrates, the flow of events from left to right, starting with the optical input flux including a scanning active signal such as a laser beam which is the signal of interest. The SPAD array will trigger on each detected photon. In-pixel SpatioTemporal Filters (STFs) attempt to distinguish active light from ambient light.

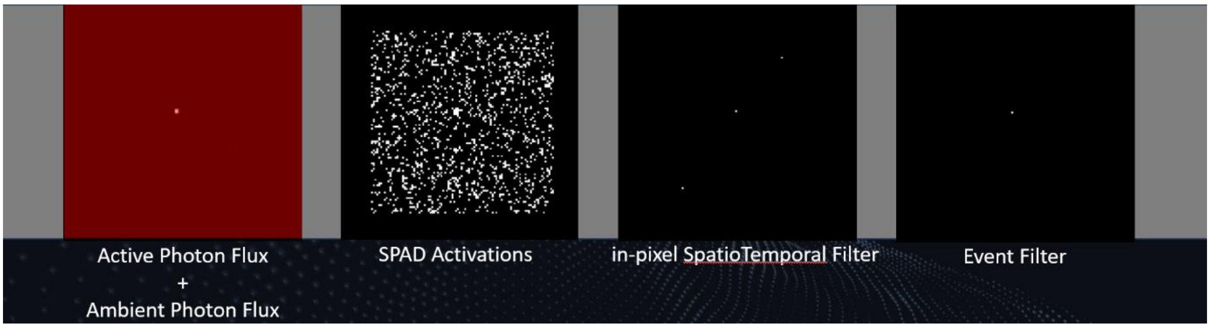

Figure 3 - SPAES signal flow from input flux to detected events.

Once events have been verified by the in-pixel filter, the events are brought to the periphery and further filtering can be applied to remove spatio-temporally isolated events. Lastly, for each observation cycle, the detected x,y positions are outputted by the sensor. In this proof-of-concept sensors this happens on a parallel LVDS bus.

To achieve **3D sensing**, the SPAES sensor is paired with a Laser Beam Scanner (LBS). The scanner scans at least 1 dot on the scene. The preferred scanning mechanism here is a dual-axis resonating MEMS to achieve fast scanning and high density of data in a short amount of time. The SPAES sensor is programmed to track the position of the scanning laser spot in the scene. Based on the coordinates of the spot in the image plane measured by the sensor, and the associated projection vector, for each time instance a 3D location of the laser spot can be triangulated. Below figures show the schematic representation of the 3D sensing method (Figure 4) and an example of the resulting 3D output data (Figure 5)

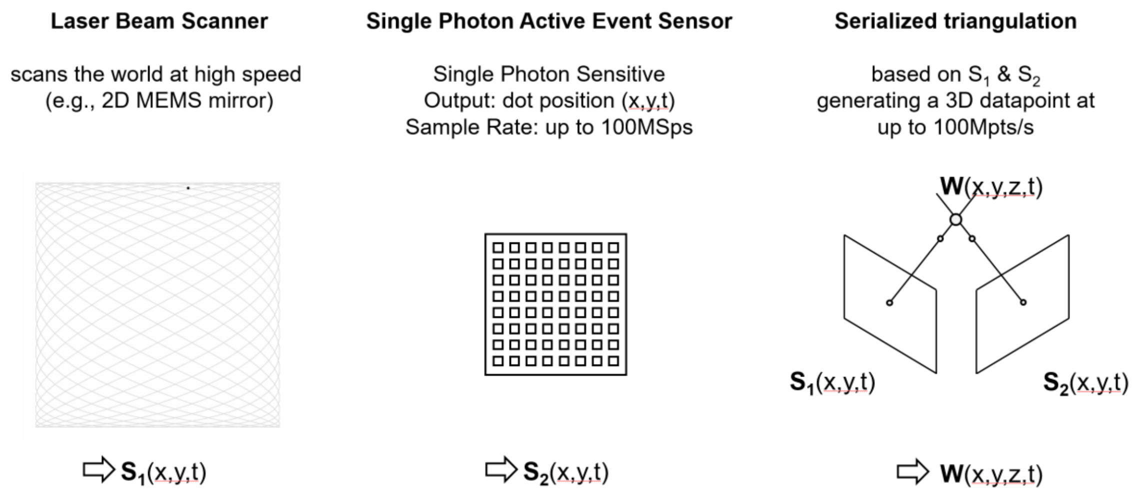

Figure 4 - 3D sensing scheme using Laser Beam Scanning, SPAES detection and triangulation.

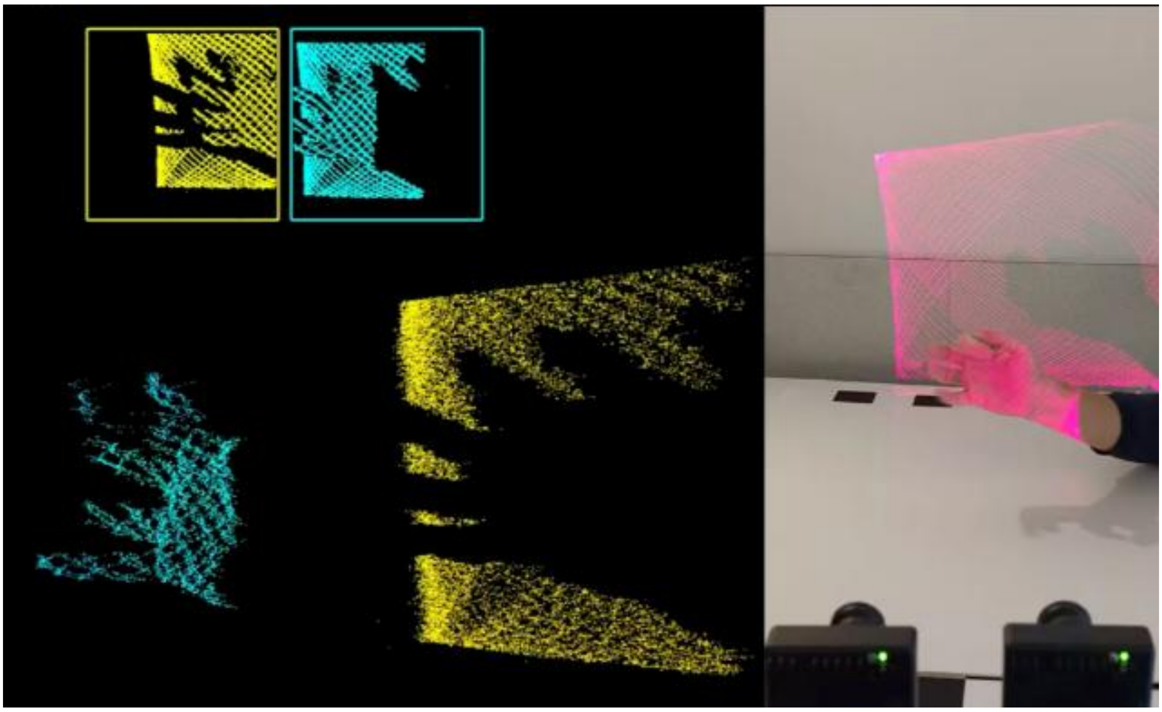

Figure 5 - Screenshot from the VXSDK visualiser

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