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CMOS pixel sensors with on-chip Neural Network: A new horizon for embedded systems?

Since the early 1990's, CMOS Pixels Sensors (CPS) have become the most successful member of the family of Monolithic Active Pixel Sensors (MAPS), consisting in an array of pixel sensors and on-the-chip circuitry (e.g. preamplifier and digitization) on the same silicon substrate. They are now widely used in a large panel of applications, from visible light detection in cell phone camera or digital single-lens reflex, X-rays detection and imaging, up to charged particles detection in high energy physics. Besides integrating the sensor and the signal treatment in the same substrate, this technology offers several advantages: small achievable granularity, sensitivity to different type of radiations, possible thinning down to 50 µm to reduce material budget, and competitive radiation tolerance. Furthermore, CPS have been sustained by constant progress in the industry allowing to reduce costs.

Recently, new technologies have become available, reaching a deep sub-micronic feature size (from 180 nm down to 65 nm and even lower), offering various properties (e.g. high resistivity epitaxial layers) and various advanced features (e.g. quadruple-well implant). This allows to add more and more elaborated functionalities in a given area. Finally, integrating more signal treatment on the pixel itself and/or the chip periphery, allows to consider more complex operations both on the analog signal and on the digital output, in order to compactify the useful information in the output. This should translate into an output bandwidth reduction, a possible enhancement of the read-out speed and at last but not least a power consumption reduction.

In another domain belonging to Information Science, signal treatment and image analysis made very significant progress in the last decade thanks to algorithms based on bioinspired network models. Advanced techniques (e.g. deep learning, h-max algorithms) allow considering more and more applications for embedded systems in various applications (pattern recognition, face recognition, clustering, robotics to assist handicapped persons, etc.). However severe limitations still exist (robustness, adaptability to various environments, power consumption, maximum footprint, etc.). These constraints represent real technological obstacles.

One way to overcome these issues is to combine the progress of the two domains mentioned above (CPS and bio-inspired neural network). This leads to the concept of smart CMOS sensors using neural networks integrated on the chip. The expected added value is to allow both an advanced treatment of the data and a reduction of the bandwidth in the same time. At last but not least, this should enhance the adaptability of the technology counterbalancing the inherent rigidity of any very integrated system. One expects that this will open the door for a wide range of new applications. For instance, in particle physics, one could investigate how the vertex detector of the International Linear Collider (ILC) could use this feature to reject the hits generated by the beam background, taking advantage of their particular cluster shape they create on the matrix of the sensor.

One will give a short overview of the state of the art of CPS technology and describe the expected challenges of the described idea. Finally one will briefly explore the potential applications of CPS integrating neural networks in various fields.

Summary

Continuous and recent progress in CMOS pixelated sensor technology allows to integrate more and more signal treatment and functionalities in the chip itself. Secondly, neural networks algorithms are extensively used in embedded systems but with some technical limitations in terms of integration. One will present the concept of smart CMOS sensors using neural networks integrated on the chip which could overcome these limitations.

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