Gaussian Pyramid Extraction with a CMOS Vision Sensor

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Abstract—This paper addresses a CMOS vision sensor with 176 × 120 pixels in standard 0.18 μm CMOS technology that computes the Gaussian pyramid. The Gaussian pyramid is extracted with a double-Euler switched-capacitor network, giving RMSE errors below 1.2% of full-scale value. The chip provides a Gaussian pyramid of 3 octaves with 6 scales each with an energy cost of 26.5 nJ at 2.64 Mpx/s.

I. INTRODUCTION

The Gaussian pyramid is a set of images extracted from the input scene that provides computer vision algorithms with scale robustness, i.e., the ability of an algorithm to give the same response regardless of the distance of the object to the camera. Scale Invariant Feature Transform (SIFT) is an example of feature detector that includes the Gaussian pyramid computation to minimize the non-linearity of a conventional RC filter [3]. In this context, the analog domain is very suitable for Gaussian pyramid computation. In particular, RC or switched-capacitor networks naturally compute the Gaussian kernel [4], [5]. The circuit addressed in this paper implements a switched-capacitor network. This minimizes the non-linearity of a conventional RC network, and it allows for a more accurate control of σ.

II. CHIP DESIGN

The chip comprises an array of 88 × 60 processing elements (PEs). Every PE contains 4 nwell/p-sub photodiodes configured as 3T structures, along with the circuitry for in-PE A/D conversion, in-PE CDS and a double-Euler switched-capacitor configuration along the 4 cardinal directions. The chip is fabricated within an area of 5 × 5 mm² in 0.18 μm CMOS technology. The chip gives the scales of the Gaussian pyramid or the input scene as 8-bit digital words. The image is read out through two frame buffers outside the PE array. Each PE is shorted to two 8-bit registers in their assigned frame buffer. This permits to read out pixels outside the chip as they are being read in from the PE array [6].

Fig. 1 shows the micrograph of the chip along with a schematic of a PE. Every PE occupies 44 × 44 μm². The area of the nwell/p-sub photodiode is 7.4 × 6.7 μm². The 4 3T pixels share the same current source drawing 1 μA. Both the A/D conversion of the input image (176 × 120 pixels) and the CDS operation are time-multiplexed throughout 4 cycles. The gain stages –K for CDS and the one for the offset-compensated comparator labeled EcC in Fig. 1 during A/D conversion are double-cascode inverters with 65 dB gain and 1 μA of bias current. The capacitance C in Fig. 1 is used during CDS and A/D conversion. The output of CDS is stored at every capacitor C pep in every PE. Subsequently, the Gaussian pyramid is computed with the double-Euler network displayed in Fig. 1 [7]. Capacitors C pep are laid down as MiM structures during Gaussian kernel computation in order to minimize feedthrough and injection errors. The Gaussian pyramid computation is controlled by the two non-overlapped signals φ1 and φ2 shown in Fig. 1, which combined define a clock cycle.

III. DEMO SETUP AND EXPERIMENTAL RESULTS

Fig. 2 is a picture of the experimental setup. Fig. 3 shows the chip with the lens, the carrier board, and an FPGA. The chip has a PGA120 package. It rests on a carrier board of 15 × 6 cm². A DE0 Terasic FPGA provides the control signals.
for the chip. A Raspberry-Pi with an ARM processor is used for display purposes.

Fig. 3 shows different Gaussian-filtered images throughout the pyramid for the first three octaves (O1, O2, and O3). RMSE errors by comparing our chip measurements with pure software implementations are below 1.2% with respect to the full-scale value. The chip consumes 70 mW with scene acquisition and the Gaussian pyramid of 3 octaves and 6 scales each. The Gaussian pyramid takes 8 ms (A/D conversions included), with 200 μs per A/D conversion, and 150 ns as the clock cycle for the switched-capacitor network, rendering 26.5 nJ/px at 2.64 Mpx/s. Real-time tests will be performed during the conference.

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