Smart Readout Technique based on Temporal Redundancies Suppression Designed for Logarithmic CMOS Image Sensor

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Abstract: We present in this paper a new readout technique designed in order to control the dataflow outgoing from a logarithmic image sensor. It is based on the reduction of the temporal redundancies in the streaming video frames. The main idea is to distribute the sensor into blocks of NxN pixels, then each block generates the mean value of the luminosities signals of all its pixels, this mean values are converted and stored in a digital memory. A comparison between two averages vectors of two successive images point out the addresses of the blocks that must be entirely read and updated in the following frame.

Introduction:

Recent advancements in CMOS technologies have induced a big progress in the field of image sensors especially in terms of resolution since the technology is going to miniaturization. This leads to minimize more and more the pixel area and then considerably increase the resolution of the whole sensor. This rise of resolution put on the foreground the challenge of the efficient transmission and processing of the video rate data especially in cost and power constrained environments. Conventional readout technique (Fig.1) requires scanning all the pixels of the matrix whether their luminosities signals have changed or not since last read image. This leads to high level of temporal redundancies and then to a high dataflow, a high power dissipation and a limited frame rate.

On the other hand, advanced technologies have allowed the integration of several processing functionalities on a single chip beside the image sensor's core or further inside it, which is an opportunity regarding the challenge previously mentioned. Hence emerges the need to seek and implement new techniques so as to handle the readout and reduce the redundant data.

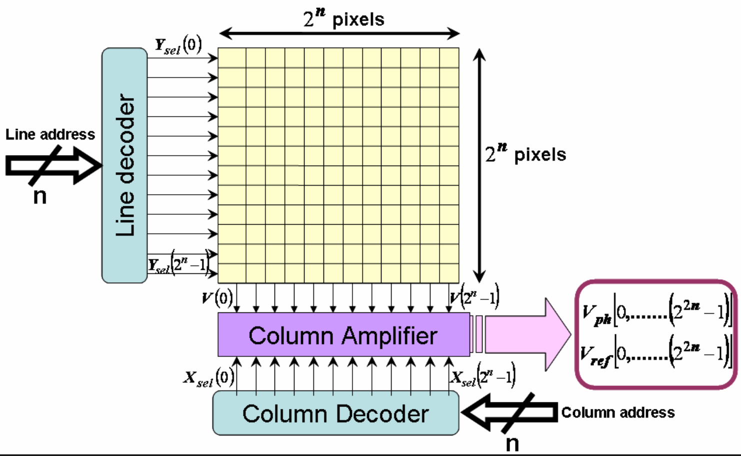

Figure1: Block diagram of a standard imager with conventional readout mode

Several researches have been undertaken in order to overcome this problematic; [1] presents an asynchronous temporal contrast sensor based on continuous time logarithmic pixel. It could be considered as a complete frame-free transient vision sensor. The main disadvantage of this sensor is that it implements 26 transistors and 3 capacitors in the pixel so it has a 40x40µm² of pixel area and only 8.1% of Fill Factor (FF). [2] also presents the same disadvantage with more than 50 transistors and 1 capacitor per pixel. The work of [3] ends with 30 transistors per pixel with a FF of about 1.8%. In addition, we can mention the works of [4] and [5] that present another disadvantage: a limited dynamic Range (DR) <50dB. [6]'s work presents a better FF but also a limited DR of 51dB.

Proposed Solution :

That is why we propose a new readout method that aims to reduce the dataflow outgoing from the sensor while maintaining an acceptable pixel area and FF. We propose to distribute the matrix into sub-blocks of NxN interconnected logarithmic pixels. The dimensions (N) of these sub-blocks should be defined according to the desired resolution of the imager in a way to conserve the image quality. Matlab codes have been developed for this purpose; the details of the criteria that control this choice are given later. Each pixel of these blocks provides two important analogue values; the first is its local luminosity signal and the second is the mean value of the block luminosities. The schematic and the layout views of the pixel are given in the figure 2:

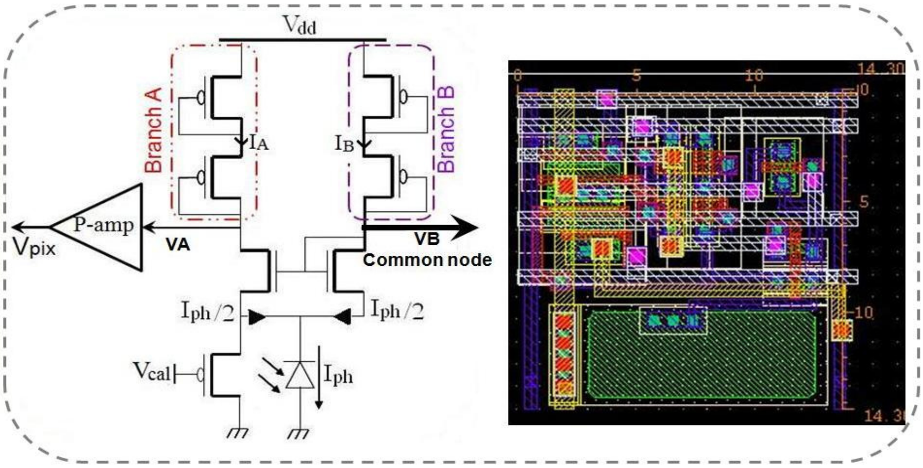

Figure2: Schematic and layout views of the proposed architecture pixel

Through the branch A of the circuit, flows a current of Iph/2, where Iph is the photogenerated current induced by the photodiode, while VA is a logarithmic function [8] of this current:

$$V_A = V_{dd} - n(n+1)U_t \ln\left(\frac{Iph}{2I_0}\right) \tag{1}$$

n and I0 being process dependent parameters. The second symmetric branch B is dedicated to contribute in the generation of the average voltage of the block. The node VB is connected to all the (VB)s of all the pixels of a block. So why, the current that passes through the branch B of each pixel of a block is the mean value of all the photogenerated currents by all the photodiodes of the block.

$$I_B = \frac{\sum_{i=1}^{16} I_{ph,i} / 2}{N * N} \tag{2}$$

So the voltage VB which is given by $V_B = V_{dd} - n(n+1)U_t \ln\left(\frac{I_B}{I_0}\right)$ is the average voltage of the block.

This pixel implements a calibration method [7] that provides a 2.1% of FPN. The layout of the pixel has been designed. It gives a total pixel area of 14.3x14.3µm² with photosensitive part of 36µm2 so a Fill Factor of 17.6%.

The averaging simulation results are given in the Fig.3, so as the DC simulation that shows the high dynamic range (DR) and output voltage swing (OVS) of our designed pixel.

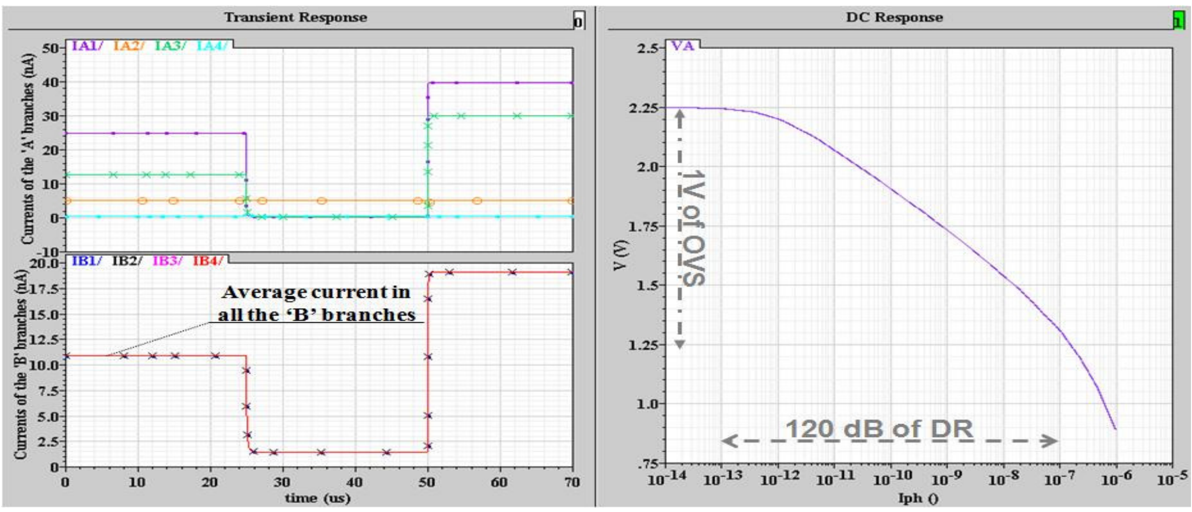

Figure3: Transient response showing the averaging scheme, and DC response showing the DR and the OVS of the pixel

The second step of the readout mode will be the sequential scan of the mean values of all the blocks. These analogue values should be converted and then memorized in a digital memory array. So for the next frame, we rescan, convert and store the new mean values and then compare them to the previous one by one. Only the blocks that have changed mean values enable the generation of their X and Y addresses. All the pixels of these blocks will be scanned, and then updated in the following image so why we do not lose the resolution of the imager. Figure4 shows the corresponding block diagram:

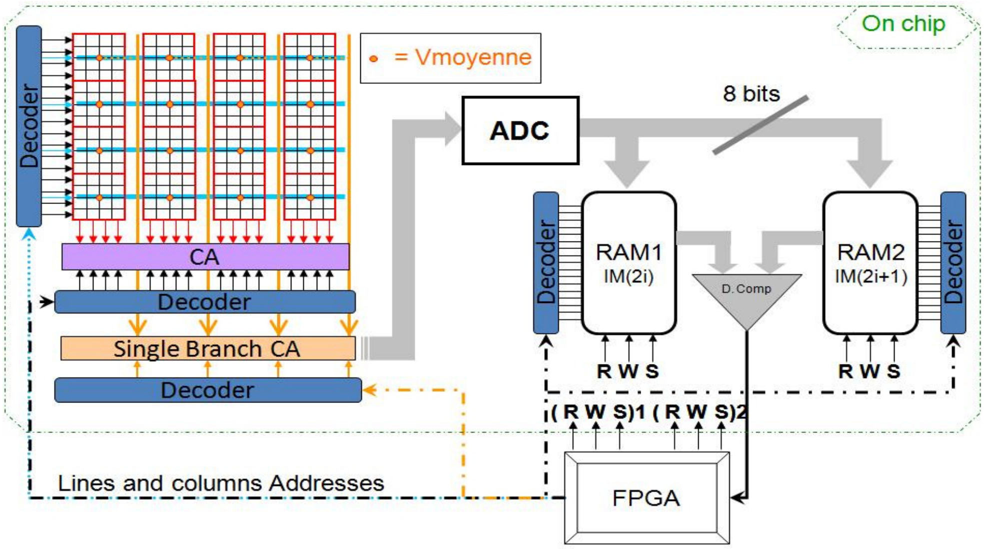

Figure4: Block diagram of the proposed system

MATLAB emulation of the method proves its efficiency. We applied our algorithm on two different sequences of 50 images (768x576 pixels) token from two different videos. In the first one, we have a fixed camera that films a moving object, while in the second; we have a moving camera that films a static scene. So if we take a sub-block of 4x4 pixels, we obtain for the first sequence a dataflow reduction of 57% and for the second sequence a value of ~65%. As for the data loss we got about 6% of loss for the first sequence and 4.7% for the second. This term of data loss is defined by the number of pixels that have been changed without being read divided by the total number of pixels of the imager. We know that these values are completely dependent of the scene dynamics but at the same time these numbers can give a clear idea about the efficiency of the method. In fact we propose to do this simulation in order to choose the size of the sub-blocks, regarding the desired imager resolution. A comparative table is given below. It shows for each block size, the obtained dataflow reduction and the information loss. We must mention that “MRR” signifies “Means Redundancy Rate” which means the rate of the unchanged averages between two successive frames. Otherwise, REF is the rate of the data that must be read at each frame. These data are the averages provided by all the blocks. As for the “IL” it represents the rate of the unread pixels although they have changed their values:

Averaging		2x2	4x4	8x8	16x16
SEQ1 Fixed camera	MRR	69.48%	63.7%	57.06%	50.3%
SEQ2 Moving camera	MRR	76.14%	72.75%	69.05%	65.5%
REF		25%	6%	1.5%	0.4%
Dataflow reduction (MRR – REF)	SEQ1	44.5%	**57.7%**	55.56%	49.8%
	SEQ2	51.14%	**66.75%**	67.55%	65%
Information Loss “IL”	SEQ1	2.54%	**6. 5%**	10.08%	12.7%
	SEQ2	1.91%	**4.7%**	7.18%	9.31%
PSNR (dB)	SEQ1	58.2	**54.3**	52.4	51.2
	SEQ2	57.7	**53.7**	51.3	49.4

Table1: Matlab emulation results

From this table, we can figure out that we obtain maximal dataflow reduction and acceptable loss of information for the sub-blocks of 4x4 pixels. As well, in the figure5, we can clearly see the difference between the quality of the image obtained after the processing by blocks of 4x4 pixels and the one with 16x16. We can perceive a "square effect" that affects the 16x16 image.

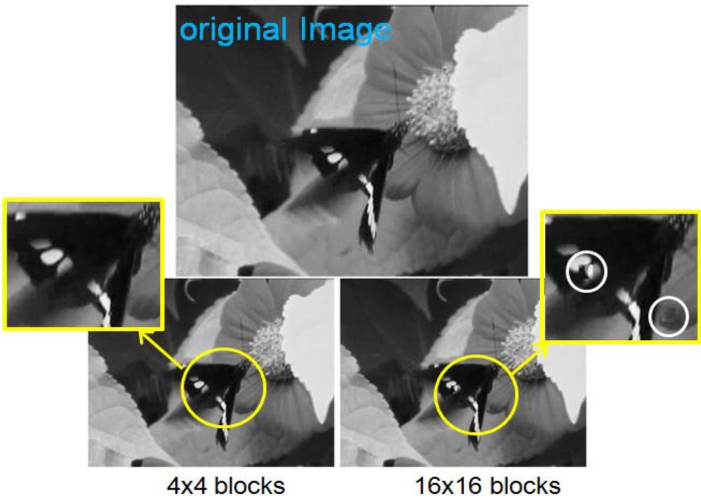

Figure5: original and processed images results

Conclusion and Perspectives:

In this paper we present a new architecture designed in order to control the massive dataflow outgoing from the logarithmic image sensor and going through the ADC.

This architecture is based on the temporal redundancy suppression. We present the schematic and the layout views of the designed pixel so as for the total algorithm of the method. A MATLAB emulation of the method justifies our choices and proves the efficiency of the method. A dataflow reduction more than **55%** is expected, which is a huge gain in terms of power consumption or readout speed. The layout of the pixel has been designed. It gives a total pixel area of 14.3x14.3µm² with photosensitive part of 36µm2 so a Fill Factor of 17.6%. A complete prototype of the sensor has been designed and going to be fabricated. A comparison with previous work in the domain is also presented and resumed in the table2:

Reference	[1]	[2]	[3]	[4]	[5]	[6]	Our work
Pixel area (µm²)	40x40	69x69	37.5x34.8	34x40	9.4x9.4	25x25	**14.3x14.3**
Fill factor	8.1%	9%	1.8%	14%	15%	17%	**17.6%**
(Transistors, capacitors)/pixel	26 trans 3 cap	>50 trans 1 cap	30 trans 0 cap	38 trans 0 cap	37 trans 0 cap	6 trans 2 cap	**8trans 0 cap**
Fixed Pattern Noise	2.1% contrast	2% contrast	High in weak luminosities	1-2 decades	0.8% of full scale before off-chip digital CDS	0.5% of APS full scale 2.1% change	2.1%
Dynamic Range (dB)	120	120	104	~50	~45	51	**120**

Table2: Comparison with previous work

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