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LOW COST SINGLE CHIP CMOS CAMERA FOR AUTOMOTIVE APPLICATION

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ABSTRACT

Non-integrating CMOS image sensors have a higher dynamic range than alternative designs which make them more suitable for automotive applications. Unfortunately, gain and offset non-uniformities in the photosensors and active elements on the focal plane generate fixed-pattern noise in the received image, which limit the resolution and sensitivity of the vision system. In this work we present a solution based on an adaptive algorithm for online correction of spatial non-uniformity. Furthermore, we demonstrate on chip intensity histogram equalization by using the same adaptive algorithm and we achieve high bandwidth without compromising the gain output by using a native transistor. In order to prove our concept a VLSI prototype has been realized using $0.35\mu m$ *CMOS technology.*

1. INTRODUCTION

After a period of incubation, the CMOS image sensor has become one of the fastest growing imaging technologies in today's digital imaging market. CMOS based imagers offer significant advantages over CCD's such as system on chip capability, low power consumption and lower cost.

This work concerns a subset of CMOS sensor technology, namely logarithmic imagers. Unlike a linear pixel, a logarithmic pixel continuously converts incident photons into voltage that is proportional to the logarithm of the light intensity. The main advantage of a logarithmic sensor is that, over five decades of illuminance, ten bits of resolution are sufficient to sense illuminance with one percent accuracy, making these type of sensors very attractive for automotive application [1]. Unfortunately, large variations between the responses of individual pixels can obscure all the details within the scene and allow only gross features to be observed. To solve this problem it has been suggested an off chip solution to digitally remove these variations [1]. However, this solution will only increase the cost of the final camera.

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2. ALGORITHM

The offset and gain correction system can be described by the following equations, where f and $f^{'}$ are the input with unknown offset θ and φ is the applied offset correction. λ and β are related to the gain correction

$$f = x + \theta + \varphi \tag{1}$$

$$f^{'} = \lambda\beta x^{'} \tag{2}$$

The condition for offset compensation

$$\theta + \varphi = Const \tag{3}$$

By transforming Eq. (2) to the log domain we can determine the sufficient condition for gain non-uniformity correction

$$\ln f^{'} = \ln\lambda + \ln\beta + \ln x^{'} \tag{4}$$

$$\Longrightarrow \ln\lambda + \ln\beta = Const \tag{5}$$

A stochastic gradient descent adaptive rule is introduced to achieve (3) and (5)

$$\Delta\varphi_{ind(k)} = -\alpha sign(f_{ind(k)} - f_{ind(k-1)}) \tag{6}$$

$$\Delta\lambda_{ind(k)} = -\alpha\lambda_{ind(k)} sign(f^{'}_{ind(k)} - f^{'}_{ind(k-1)}) \tag{7}$$

The algorithms in Eq. (6) & (7) for non-uniformity correction can also be used to achieve histogram equalization. This is possible if we code the image by comparing $f_{ind(k)}$ and $f_{ind(k-1)}$.
If $f_{ind(k)} > f_{ind(k-1)}$, the output is "1", else "0" We can describe this operation by the following equation,

$$F(f_{ind(k)}) = sign(f_{ind(k)} - f_{ind(k-1)}) \tag{8}$$

The technique we are using for histogram equalization can be described as a statistical technique in an oversampling representation.

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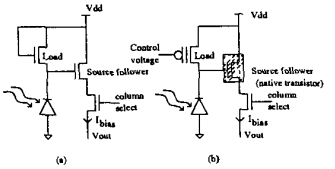

Figure 1: Logarithmic pixel circuit.

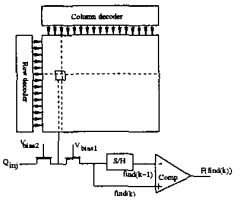

Figure 2: Complete architecture.

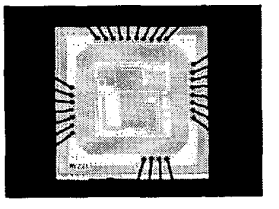

Figure 3: Micrograph of the chip.

3. VLSI IMPLEMENTATION

In the conventional architecture shown in Fig. 1 (a), the response of the pixel to light is logarithmic since the load transistor is operating in weak inversion, in this condition the drain source current of the load transistor is

$$i_{ds} = \frac{W}{L} i_{d0} \exp(\frac{v_{gs}}{nV_T}) \tag{9}$$

It can be shown that,

$$v_P = v_{bias} - nV_T \ln(\frac{L}{W}\frac{i_{ds}}{i_{d0}}) \tag{10}$$

In order to integrate the algorithm we described in the previous section a new type of logarithmic pixel circuit shown in Fig 1(b) is proposed where a floating gate device is used as the load within each pixel and a native transistor is used as a source follower. For a floating gate device with a total capacitance of C_t the change in pixel voltage ΔV caused by a change of photocurent ΔI_{ph} can be expressed as

$$\Delta V = \frac{C_t}{C_{gd}} \frac{nkT \ln \Delta I_{ph}}{q} \tag{11}$$

Where C_{gd} is the overlap capacitance between the drain and the floating gate. It is obvious that the geometry of the floating gate device can be used to vary the ratio $\frac{C_t}{C_{gd}}$ which controls the gain of the pixel. Furthermore, the programmable threshold voltage of this floating gate device can be used to trim each pixel to remove variation between pixels. Once the pixel array has been trimmed at a particular temperature, the large gain of the pixel will prevent the uniformity of the pixel responses from being degraded by changes of temperature. To achieve a high gain without compromising the bandwidth of the pixel output, we suggest the use of a native transistor as a source follower. This native transistor is based on a low threshold voltage implant available in some standard CMOS technologies[2]. Figure. 2 describes the architecture of the sensor. After uniform illumination we select a column and row address $ind(k)$. We open the switch M1 and close M2, we compare the voltage $f_{ind(k)}$ and $f_{ind(k-1)}$ if $F(f_{ind(k)}) = 0$ we open M2 and close M1, we inject a small negative charge onto the floating gate, if $F(f_{ind(k)}) = 1$ we continue randomly selecting a new pixel. The output bits accumulated due to the comparator operation constitutes a histogram representing the intensity equalized image.

4. CONCLUSION

An array of 16×16 adaptive CMOS imager has been fabricated in $0.35\mu m$ CMOS technology. The micrograph of the prototype fabricated is shown in Fig. 3. Such high dynamic range sensors are able to adapt to different lighting conditions without frame delay and operate in different temperature environments ideally suited to the cost sensitive automotive consumer market.

5. REFERENCES

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