LETTERS

100-×100-pixel CMOS retina for real-time binary pattern matching

L. F. C. Lew Yan Voon
I.U.T. Le Creusot
Laboratoire LE2I
12, rue de la fonderie
71200 Le Creusot, France

Guy Cathebras
Universite Montpellier II
LIRMM
161 rue Ada
34392 Montpellier Cedex 5
France

Bernard Lamalle
Patrick Gorria
B. Bellach
O. Aubreton
I.U.T. Le Creusot
Laboratoire LE2I
12, rue de la fonderie
71200 Le Creusot, France

Abstract. We present a 100-×100-pixel retina that can detect differences between an image under analysis and a reference image. The retina is realized in standard 0.6-μm CMOS technology with three layers of metal from Austria Micro Systems. Its total area is 34 mm^2 with a fill factor of about 37%.
[DOI: 10.1117/1.1468229]

Subject terms: silicon retina; image sensors; pattern recognition; image processing.

Paper OEL02002 received Jan. 4, 2002; revised manuscript received Feb. 15, 2002; accepted for publication Feb. 18, 2002; appeared online Feb. 19, 2002.

1 Working Principle of the Retina

A silicon retina is an image sensor in which a signal processing circuitry is integrated next to the photosensitive device so as to allow some low-level processing to be done on the image signals before they are made available at the output of the circuit.[1]

In this letter we present a CMOS retina that can detect differences between an image under analysis and a reference image in real time.[2] By differences we mean that the images are either different or identical but spatially shifted. Let us consider, for example, the two images represented in Fig. 1. The reference image is first transformed into a binary image as shown in Fig. 2(a) and stored in latches in the circuit by assigning the logic value 0 to a black pixel and the logic value 1 to a white pixel. Next, the image under analysis is projected on the retina and the currents produced by all the black and white pixels are respectively summed, converted to voltages, and read out at the output of the circuit.

Now, if we compute the black and white pixel currents, or black and white currents for short, for both the reference image (I_{white} and I_{black}) and the one under analysis (I'_{white} and I'_{black}), we would obtain the same white current but a different black current. Indeed, the pixels involved in the computation of the currents are the same in the case of the I_{white} and I'_{white} currents and different in the case of the I_{black} and I'_{black} currents due to the presence of the bright triangle as shown in Figs. 2(c) and 2(d). By comparing the black and white currents, we can conclude that the images of Figs. 1(a) and 1(b) are different. For this example, only the black current is involved in the discrimination of the two images. In general, both the black and white currents contribute to the discrimination of the images.

To summarize, the matching method that is implemented in the retina is based on a logical AND between two images and on current summation. It may thus fail under certain conditions that will be discussed in Sect. 3.

2 The Retina

The retina is mainly constituted of an array of pixels whose block diagram is shown in Fig. 3. During the programming mode the reference image is thresholded using the current comparator that furnishes a binary value 0 or 1 according to whether the photodiode current due to the luminous flux is smaller or greater than a threshold current I_{th} (I_{th} is by default the mean current in the array of pixels). This binary value is stored in a latch and used during the normal operation mode to set the position of the switch so as to connect together all the cathodes pertaining to the same type of photodiodes. In this way the I_{black} and I_{white} currents are obtained by hardwiring.

The layout of the pixel, realized in standard 0.6-μm CMOS technology with three layers of metal from Austria Micro Systems, is shown in Fig. 4(a). It is a 50.6-×50.6-μm-square pixel with a fill factor of about 37%, which is rather a high value for a silicon retina. The layout of the retina is shown in Fig. 4(b). It consists of a 100-×100-pixel array and some devices for allowing the threshold current to be set to a value different from the default mean current value and for converting the I_{black} and I_{white} currents to voltages V_{black} and V_{white}. Its total area is 34 mm^2.

3 Experimental Results

The experimental setup is composed of the retina fixed in a case with a 25-mm lens and located at a distance of 45 cm from a 150-W backlight source on which the test images are placed. With such a setup the view area is about 16 ×16 cm.

The retina was first characterized with respect to the smallest detectable surface area that represents both the smallest detectable pattern and the smallest detectable dif-

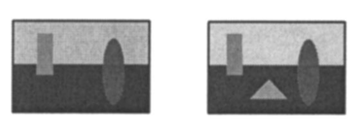

Fig. 1 Reference image and image under analysis.

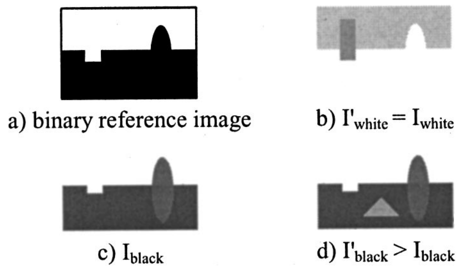

Fig. 2 (a) Binary reference image; (b) pixels involved in the computation of the I_{white} and I'_{white} currents; (c) I_{black} current; (d) I'_{black} current.

ference between the image under analysis and the reference image. This is achieved using patterns of decreasing areas until the corresponding output voltage is about 20 mV, the dark voltage obtained by measuring the output voltage with the retina placed in the dark. The smallest detectable surface area is equal to 60 pixels under our experimental conditions.

Secondly, we have tested the ability of our retina to detect differences between binary patterns using a test set composed of images of both simple and complex geometrical shapes with a surface area greater than 60 pixels. Any one of the images is first used both as the reference image that is memorized in the circuit and as the image under analysis so as to determine the reference black and white voltages denoted by V_{b0} and V_{w0}. Next, for each of the other images, the corresponding V_{black} and V_{white} voltages are measured and the matching error ε computed according to the following equation:

$$\varepsilon = |V_{\mathrm{white}} - V_{w0}| + |V_{\mathrm{black}} - V_{b0}|$$

The image under analysis and the reference image are the same if $\varepsilon < V_{\mathrm{eth}}$, a matching error threshold voltage whose value is set according to an acceptable matching failure rate.

In theory, for binary images, matching should never fail since the black and white currents depend only on the number of black and white pixels resulting from the logical AND, the intensity of the image being a constant. However, in practice it can fail due to the fact that the intensity of the image is not a constant but depends on the light source. Thus, it may happen that two identical binary images do not produce the same black and white currents due to different illumination conditions. In this case, depending on

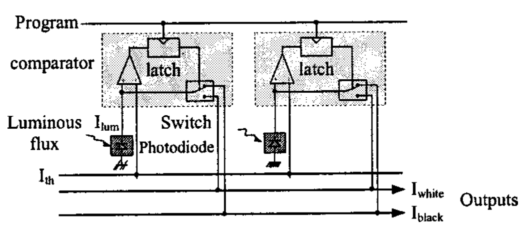

Fig. 3 Block diagram of the pixel.

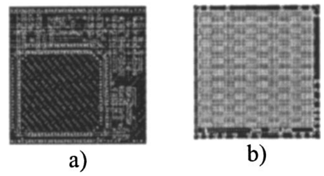

Fig. 4 Layout of the (a) pixel and (b) retina.

the choice of the matching error threshold voltage, matching may fail. This has been verified using our test set under different illumination conditions. We have also verified that under stable illumination conditions all the patterns are correctly discriminated.

Concerning gray-level images the intensity and contrast of the images is an additional parameter that may cause matching failure due to the following two causes. The use of low-contrast images as reference images may result in incorrect memorization of the image due to the disparities in the pixel's characteristics. Indeed, the circuit fabrication process cannot guarantee that all the pixels will have the same characteristics. Any shift in the characteristics would result in a random classification into black or white pixels of all the pixels whose current value is close to the threshold current. Moreover, since pattern matching is based on the summation of the currents produced by, respectively, the black and white pixels resulting from the logical AND, all gray level images that give the same I_{black} and I_{white} currents will be considered as being the same image although they may be different. This is due to the fact that by considering the sum of the currents (related to the gray level) the spatial information is lost.

4 Conclusions

We have presented a 100-×100-pixel programmable retina that can detect differences between binary images in real time as long as the image under analysis is different from the reference image by at least 60 pixels and the illumination is stable. If the illumination is not the same for the reference image and the one under analysis then the matching operation may fail. This is due to the fact that it is based on a logical AND between the images and on current summation that depends on the illumination since the photodiode current is proportional to the luminous flux falling on it.

The retina is fabricated in standard 0.6-μm CMOS process with three layers of metal from Austria Micro Systems. Its total area is 34 mm^2 and the fill factor is 37%.

Industrial applications for which our retina can be useful are, for example, the production of 3-D parts from plane materials by press machines. Our retina can be, in these types of processes, used to stop the machine if the material is not correctly positioned under the press in order to avoid damage to the machine.

References

1. A. Moini, *Vision Chips*, Kluwer Academic Publishers, Norwell, MA (2000).
2. L. F. C. Lew Yan Voon, G. Cathebras, B. Bellach, B. Lamalle, and P. Gorria, "Silicon retina for real-time pattern recognition," *Proc. SPIE* **4306**, 168–177 (2001).