Three silicon retinas for simple consumer applications

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This paper describes three silicon retina chips which are each specialized to measure a different quality of a changing scene. The first retina detects image change anywhere in its field of view, and is intended as a presence detector. The second retina detects a blob of motion moving in one direction, and is intended for automatic door openers. The third retina measures image sharpness, and is intended for use in autofocus systems.

All three chips use the same circuit elements. The differences between the chips lie in their architecture. The basic circuit elements I use are an adaptive photoreceptor and a dissimilarity circuit – the "bump" circuit.

I like to call these chips "pseudo products." There is no specific customer in mind, but I did have practical applications in mind that I knew how to do, efficiently and robustly, with minimal power, area, or chip complexity. These chips consume on the order of 100µA (they run for more than a month continuously on a 9V battery), have on-chip bias generators, and are all fabricated as MOSIS[8] TinyChips $(2.2\text{mm})^2$ in an ancient 2µm or 1.2µm process. The chips also have microcontroller-compatible logic or pulse frequency modulated outputs. In large volume, together with a single-element molded plastic lens, the system costs would be around a dollar.

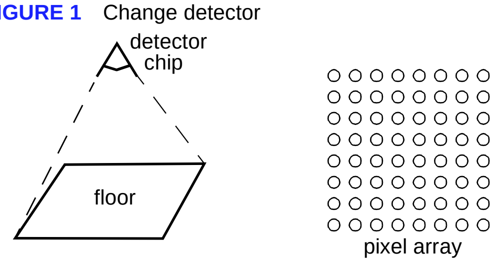
THE CHIP ARCHITECTURES

I start by describing the architectures of the three chips: the change detector, the door opener, and the focus detector. In the next section, I will describe the elements used in the chips.

Change detector

The idea is that this chip sits on the ceiling or wall, looking at a patch of floor or hallway. A rectangular array of pixels each independently measures change in the local illumination (Figure 1). These independent change signals are summed globally. The sum is compared with a threshold to signal a change somewhere in the field of view. Movement of a subject with sufficient contrast across any part of the field of view activates the change detector output.

FIGURE 1 Change detector



Each pixel has an adaptive photoreceptor and an antibump circuit. The antibump circuit computes the absolute difference between the local receptor output and the receptor adaptation level. The adaptation level is essentially an average over the last few seconds of receptor output, so each pixel computes a value that increases whenever the local illumination changes away from its average over the past.

This chip was built in a 2µm MOSIS CMOS process. Each pixel in the 15 by 15 array measures $(100\mu\text{m})^2$.

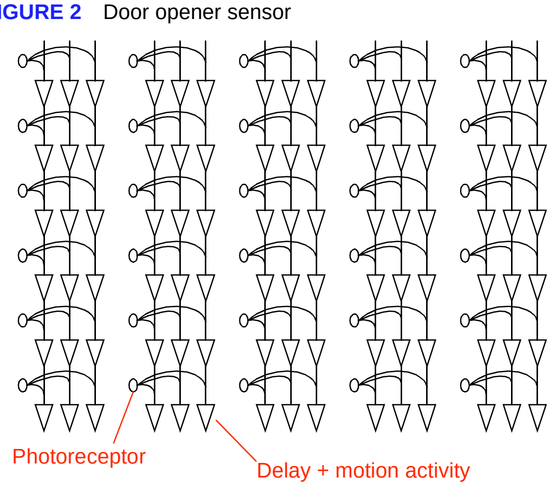
Door opener sensor

The idea here is to look at the area in front of an automatic door for a blob of motion activity towards the door. Sufficient activity generates a logic output that tells the door to open.

A set of direction selective motion detectors[3] shown in Figure 2 look for motion in one direction (towards the door). Each motion detector is a follower-integrator delay line. Photoreceptors capacitively couple into the delay line. When image motion is matched to the delay line speed, activity builds up on the delay line. Antibump circuits measure the activity on the delay line. All delay line activity is summed globally on the chip. When activity exceeds a threshold level, a logic signal tells the door to open. Each linear motion detector has three delay lines, each of which is tuned to speeds that are about an octave apart. This is intended to mimic cortical characteristics, where people see motion sensitive cells tuned to a range of speeds.

The door opener chip is built in a 1.2µm MOSIS process. Each cell in the array of 7 high by 19 wide motion cells measures 85µm by 150µm.

FIGURE 2 Door opener sensor

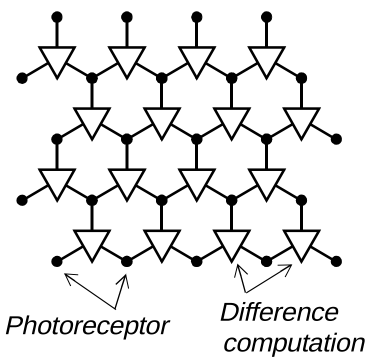


Focus sensor

This chip measures the absolute sharpness of the image. The idea is to use this sensor in the image plane of a camera system, to provide an absolute measure of image sharpness for use in autofocus[4]. This measure could be an advantage over the split-image focus sensors used in present SLR film cameras, which require a vertically or horizontally oriented sharply defined edge, and are confused by periodic patterns.

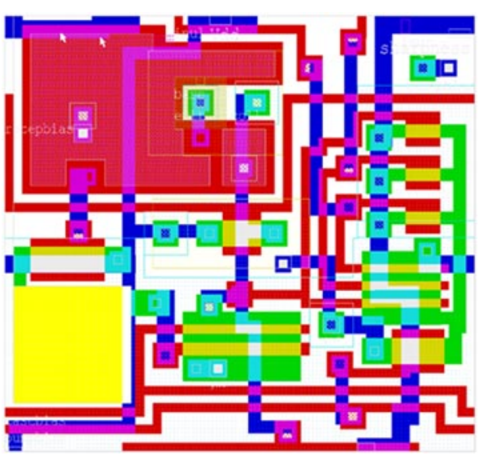
Figure 3 shows how the pixels are arranged in a hexagonal array. Each pixel has an adaptive photoreceptor and a 3-input antibump circuit. The antibump circuit computes an *expansive* measure of the absolute differences between three neighboring pixels. The sharper the image, the bigger these differences. The expansive measure means that sharp images (where pixel differences are greater) result in larger sharpness measure.

FIGURE 3 Focus sensor



Each pixel in the 25 by 26 array measures (60μm)^2; the chip is built in a 1.2μm MOSIS process. One pixel is shown in Figure 4

FIGURE 4 Focus sensor pixel



THE CIRCUIT ELEMENTS

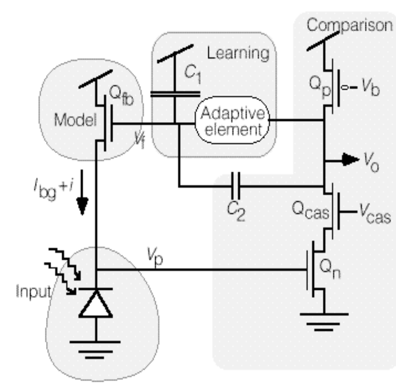
All three chips use the same core circuit elements: an adaptive photoreceptor[1] and an antibump circuit[2]. I summarize their characteristics here.

In addition, each chip includes a bias generator and an output circuit that produces either a logic output or a pulse-frequency modulated output.

Adaptive photoreceptor[1]

The photodiode current I_{bg} in Figure 5 is compared with a low-pass filtered photocurrent level V_f. The output of the receptor V_o is the amplified difference. V_o is referenced around the past history of the illumination, and has a gain determined by C_2/C_1 of about 1 volt/decade. Over a range of 6-7 decades of illumination, the photoreceptor outputs a signal whose variations in response to scenes with varying reflectivity are nearly invariant to illumination level. The receptor adapts its gain and integration time automagically to do this detection, much like biological photoreceptors. The lower limit of illumination is determined by dark current and desired response speed; in practice it is presently useful down to bright moonlight conditions.

FIGURE 5 Adaptive photoreceptor.

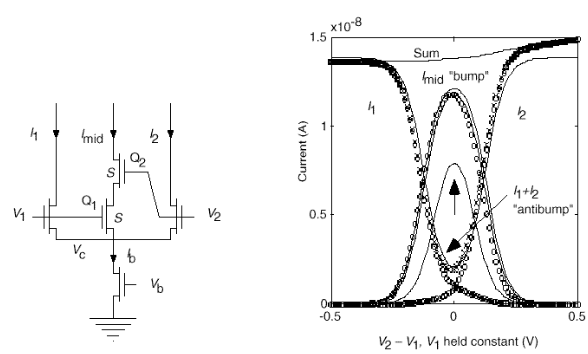


Antibump circuit[2]

The original bump/antibump circuit shown in Figure 6 takes two input voltages. The antibump output current grows large only when the two inputs differ sufficiently.

In the focus sensor, an additional leg (two transistors) is added to the bump circuit. The antibump output codes differences between any two (or all three) inputs. For small differences, the function is approximately quadratic in the differences. This quadratic characteristic is essential in computing an image sharpness measure that increases as the image becomes sharper.

FIGURE 6 Bump/antibump circuit.



Bump/Antibump circuit   Characteristics

Output circuits

The output circuit on each chip is similar. In the presence detector and door opener chips, the globally summed current computed by the core of each chip is compared with a reference current. This result of this comparison is input to a Schmidt trigger, whose output is the decision made by the chip.

In the focus detector chip, the focus signal current computed by the chip core is input to a pulse frequency generator. A simple ADC may be formed by connecting the resulting pulse train to the external counter clock input on a microcontroller. Between program loop cycles, the microcontroller measures relative image sharpness by counting the focus chips pulses.

Bias generator

These chips all have a common bias generator that generates all internal bias currents and reference voltages, so that they are nearly independent of threshold voltage, supply voltage and temperature. The bias circuit is based on a beta-multiplier "Vittoz loop" that generates a known master reference current[5] using a single external carbon resistor. A combination of on-chip diffusion resistance and off-chip carbon resistance – with opposite temperature coefficients – provides a degree of temperature compensation. A Vittoz pseudo-resistive divider[6] derives the other bias currents from this master current.

CONCLUSIONS

These chips represent the extreme low end of vision system complexity. Despite their simplicity, I believe that they compute useful image metrics that would require a much more complex traditional approach (imager + frame memory + DSP).

I believe it is in the arena of low cost, small die area, low power designs, which compute a simple measure of the image, that analog vision chips can make a practical impact over the next few years. I am still hoping that an enterprising firm will take up this interesting challenge.

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