TP 6.4: A CMOS Motion Detector System for Pointing Devices

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The blocks of an optical motion detection microsystem are: a ball with a printed pattern of spots that contrasts with the background color; LEDs to illuminate part of the ball; a lens to focus an image onto the surface of a chip; a CMOS chip composed of an array of photodetectors and processing circuits outputting signals to a microprocessor; a microprocessor to establish the protocol for communications with the personal computer and to generate required interrupts (Figure 1).

The approach presented here improves on previously-proposed solutions by reducing the system power consumption by at least two orders of magnitude, increasing the tracking resolution to 800dpi, and by requiring only a random-size, -shape and -position pattern printed on the surface of the ball instead of a precise regular pattern that is difficult to manufacture [1, 2, 3].

To reduce total power consumption, mainly from current in the LED used for illumination, 10µs pulses of light illuminate the surface of the ball at 1kHz. The image is spatially sampled by an array of photodiodes (300µm pitch) in the x and y directions as in previous CMOS image sensors and also sampled at regular time intervals [4, 5]. Relevant information about displacement of the two-level intensity image can only be carried by spot edges passing over a photodiode between two input pulses, as shown in Figure 2. If a random-size and -shape spot is moved exactly the distance between two photodiodes in the x direction, all the vertical edges present between photodiodes laid out in the x direction would have moved in the displacement direction. Conversely, if the spot is moved by less than the pitch between photodiodes, only a fraction of the edges have a probability to move over a photodiode. An estimation of the displacement between two pulses is given by:

Δx = (number of vertical edges moving right - number of vertical edges moving left) / (number of vertical edges) (1)

Δy = (number of horizontal edges moving up - number of horizon tal edges moving down) / (number of horizontal edges) (2)

Δx and Δy are estimates of the displacement in the x and the y directions, between two pulses, under the condition that the image of the ball on the surface of the chip has not moved more than the pitch between photodiodes. The higher the number of edges on the image, the more precise the estimation of the displacement of the ball will be on average. Spot density, as well as minimum size of spots on the ball take into account the pitch between two photodiodes (300µm) and is designed to comply with a speed-detection-range of 0-10 inches/s and a tracking resolution above 800dpi.

Figure 3 is a micrograph of the circuit implementing image acquisition and displacement estimation. Its core is a matrix of 75-pixels between the 93-photodiodes array. The schematic of the pixel (38-analog transistors and 102-digital transistors) is shown in Figure 4. Each pixel is composed of an n-well photodiode and a current amplifier and is able to capture up to a 1000 snapshots of the ball surface per second for an illumination range of 100-500mW/m^2.

Current mirrors and current comparators are used for detecting the presence of a vertical edge (E_x) between the pixel photodiode and its right neighbor pixel photodiode, respectively an horizontal edge (E_y) between its photodiode and its upper neighbor photodiode. The sign of the gradient of the edge seen from the pixel (S) is determined to differentiate between negative and positive edges at two consecutive light pulses. To avoid analog problems related to transistor mismatch and noise in the comparators, edges are defined between two photodiodes when the ratio between their respective photocurrents is higher than a given factor a (respectively lower than a factor 1/a). For this given application, a is 2, complying with a measured minimum ratio of 3 between the reflectance of the two color zones on the ball. A latched current comparator allows information about the position of the edges to be kept after illumination is switched off. The comparator is reset before the next pulse of light. Three latches controlled by the shift signal are used to store the previous information about the edges (oE_x, oE_y, oS).

At a given time, a switch-logic block computes a local estimation of the displacement of a vertical edge (E_x) to the right (R) or to the left (L), respectively an horizontal edge (E_y) to up (U) or down (D) directions, as shown in Figure 5. For example, on a given pixel, an edge E_x with a gradient sign S has moved right if E_x with the same gradient was on the left pixel (oE_{xl}, oS_l) at the previous pulse of light. A calibrated current of 100nA is injected when the output is true on a 6-wire analog bus accessed by all the pixels in parallel. Thus, the total current value on each wire determines the total number of edges present on the image and the number of edges that have moved. The six wires are combined to compute Δx and Δy displacements as given by (1) and (2) and converted to two 5b digital words that can be read by the external microprocessor.

Other blocks implemented on chip are a current reference source and a state machine providing control signals needed in the pixel matrix and in the chip test procedure. Each pixel is tested by injecting a current I_{test} in parallel with the output of the current amplifier. The calculation circuits on-chip are tested by imposing a sequence of images through column and row registers controlled by the state machine. Also implemented for test purposes are means to scan out the digital values of E_x, E_y and S and the analog values of the photodetectors. Figure 6 shows a typical output.

The chip (4.4x4.3mm^2 without scribe lines) is implemented in a 2µm CMOS low-power, low-voltage technology, to allow an operating voltage range of 2.4 to 5.5V. Thanks to the use of a bidirectionnal in/out pad, only 4 pads are needed (2 for supply voltages, 1 for clock and 1 for data in/out). In the idle mode, the circuit consumes less than 3µA.

References:

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[3] Gottardi, M., W. Yang, "A CCd/CMOS Image Motion Sensor," ISSCC Digest of Technical Papers, pp.193-194, Feb., 1993.

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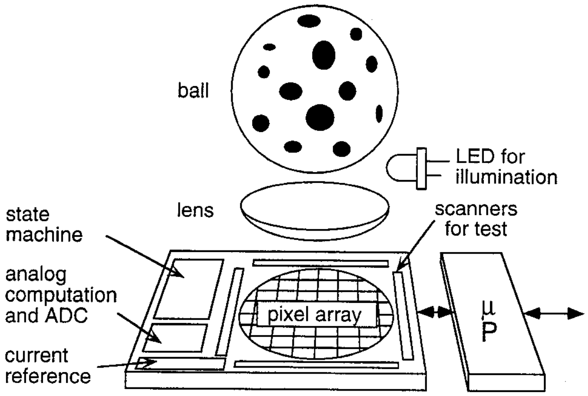

Figure 1: Pointing device microsystem.

Figure 3: See page 426.

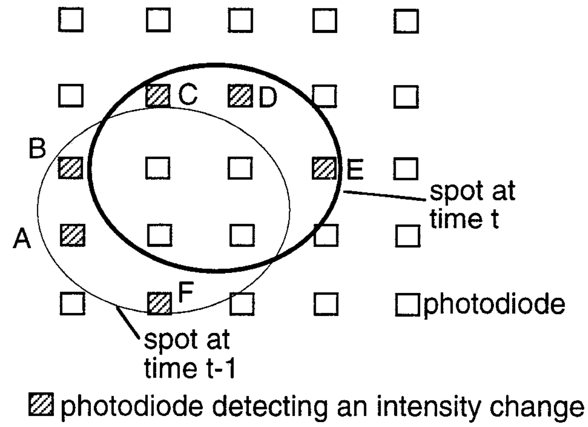

Figure 2: Photodiodes A to F output different intensity currents at t and t-1. Changed ratio of output to neighbor current indicates edge motion.

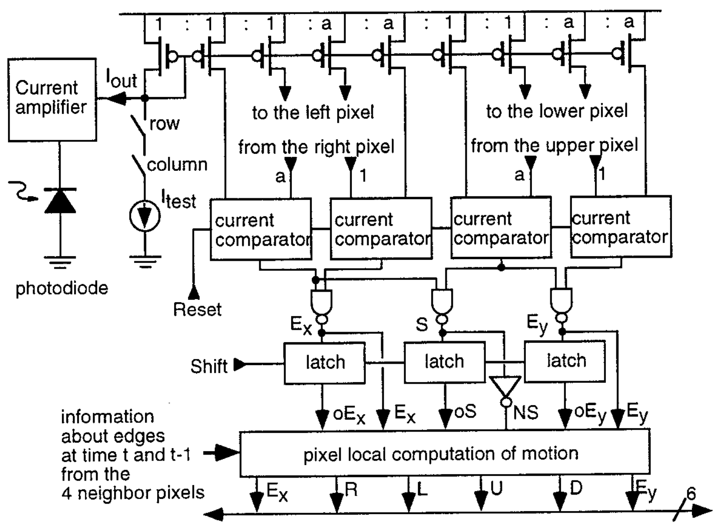

Figure 4: Pixel block diagram.

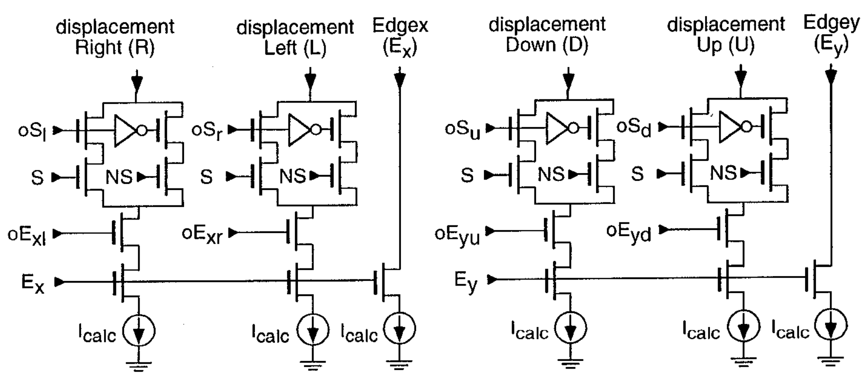

Figure 5: Local motion calculation circuit.
Figure 6: See page 426.

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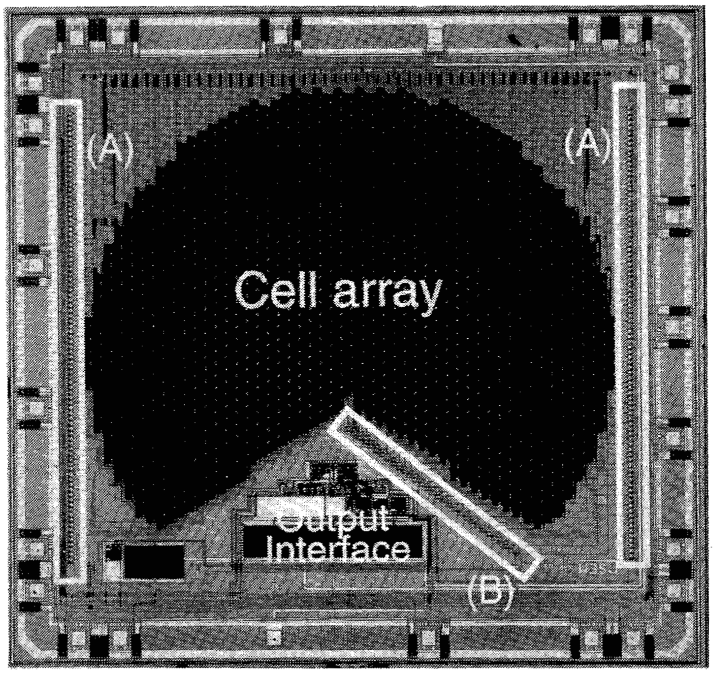

Figure 1: Chip micrograph. Boxes show 1-D transistor networks that determine angular (A) and radial (B) coordinates.

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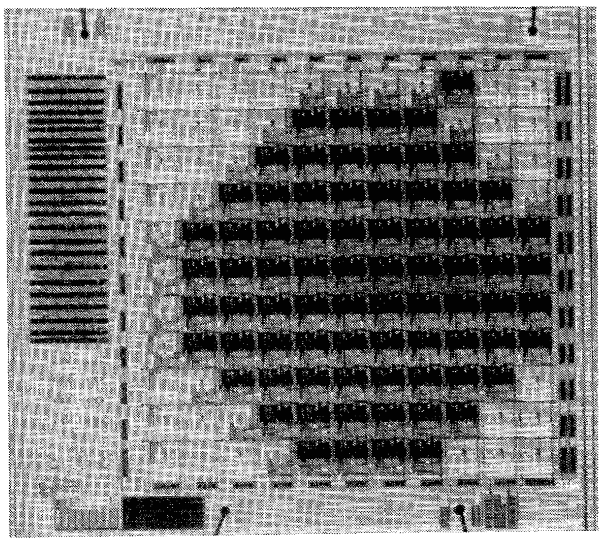

Figure 6: Measured output of Ex, Ey and S.

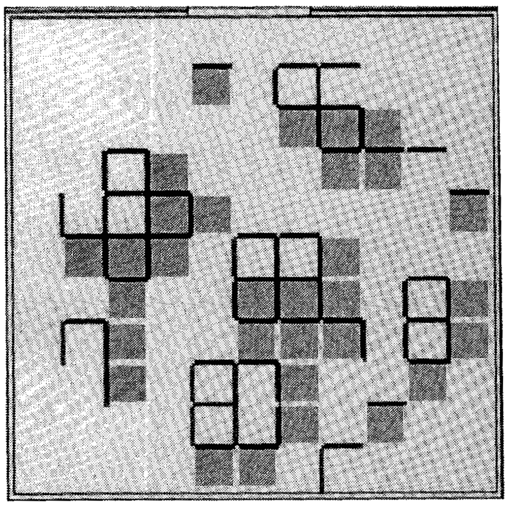

Figure 3: Chip micrograph. Key areas shown in Figure 1.