The design of an intelligent image sensor based on two-dimensional cellular automata is presented in this paper. This intelligent sensor performs simple first stage pre-processing of the image in parallel with the sensing operation. The sensor is addressable like a dynamic memory, and hence techniques such as windowing can be performed rapidly without the large data redundancy that occurs with serially addressed sensors.

**Introduction**

The continuing progress in image-sensor technology has resulted in faster and, generally, better cameras, thus making available high quality image acquisition systems to be connected to a computer. Usually such systems comprise one or more cameras, a board with one or more analog-to-digital converter(s), a fair amount of memory to store the digitized pixel values that constitute the image, and possibly several boards containing specialized hardware to process the acquired images at high speed.

Considerable efforts have been devoted to research in computer algorithms for image processing [1], and the number of applications for such computer vision has been steadily growing over the past years.

Most of the difficulties in a traditional computer vision system still arise from the demanding requirements in terms of computing power and communication bandwidth between the camera and the image processor. This need for high computer power and communication bandwidth, exhibited by these computer vision systems, cannot be readily eliminated since it is inherent in the fact that they transmit and process raw data.

To overcome the above difficulties experienced in traditional computer vision systems, new techniques based on integrated sensors and processors on the same VLSI chip have very recently been developed (see for example [2-3]). This co-operation is very similar to the process which occurs in the human retina, where some kind of local computation takes place at the retinal level before sending the image to the brain for further processing.

An intelligent image sensor performing simple first stage pre-processing of the image concurrently with the sensing operation, based on an analogue technique, has very recently been described [4].

In this paper we present an alternative approach to the concurrent sensing and processing of images based on two-dimensional cellular automata. The overall architecture is the same as the analogue and digital image sensors is the same and has been described in the analogue case by Marriott [4]. The basic concept of this architecture is the placement of processing capabilities right beside the image sensors, in order to build an intelligent sensor, as opposed to dumb sensors, and/or faster processors. In each case the sensors perform the simplest function that can qualify for the term "intelligent", i.e. the sensors carry out spatial low pass filtering on the image, removing spurious spiky noise from the image. More specifically, the second section defines a two-dimensional cellular automaton, the third section the architecture of the sensor, and the fourth section draws conclusions from the results presented.

**Two-Dimensional Cellular Automata**

Traditionally, a two-dimensional cellular automaton is an NxN array of finite state machines (cells), all having the same local transition function, where the new state of a cell depends on the current state of the cell itself and the current states of its neighbours. In more practical terms, we can think of a cellular automaton as an array of identical processing elements each of which has a finite amount of memory, and all of which operate synchronously, in discrete time steps, in accordance with the same stored program.

Each processor initially receives a piece of input data, and at subsequent time steps, each processor accepts inputs from its neighbours. Figure 1 shows a two-dimensional cellular automaton, where each cell represents a pixel cell of the intelligent sensor described in the next section.

![Two-Dimensional cellular automaton interconnection scheme](image)

**Abstract**

The design of an intelligent image sensor based on two-dimensional cellular automata is presented in this paper. The intelligent sensor performs simple first stage pre-processing of the image in parallel with the sensing operation. The sensor is addressable like a dynamic memory, and hence techniques such as windowing can be performed rapidly without the large data redundancy that occurs with serially addressed sensors.

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There are several possible lattices and neighbourhood structures for two-dimensional cellular automata [5-6]. In this paper we exclusively consider square lattices, with the neighbourhood structure shown in Figure 1. Cellular automata with this neighbourhood structure are referred to as the Von Neumann cellular automata.

When a cellular automaton is used for image processing, or image analysis, the input data given to each processor is the grey level of a pixel, with neighbouring processors getting data from neighbouring pixels. In this paper we exclusively consider bilevel, or binary, images. When a grey level image is considered, this can be converted to a binary image by multiple thresholding [7]. After multiple thresholding, the binary image is processed by the use of logical, rather than numerical, transforms employing Boolean algebra. Finally, the grey level image is generated by arithmetic summation.

**Integrated Sensor Architecture**

Each pixel cell contains an image sensor, the design of which has been described by Marriott [4]. The simplest light detector is a photodiode, which is used as a sensor. In MOS technology a photodiode can be constructed by having an area of $N$ diffusion in a p-type substrate. If this diffusion is connected to a positive voltage, the p-n junction will be reverse biased and its junction capacitance charged to the same voltage. If now light is incident on the photodiode, photons are
absorbed and hole-electron pairs are generated with some reasonable quantum efficiency. The current generated by these hole-electron pairs has the effect of discharging the photodiode junction capacitance, the rate of discharging being proportional to the light intensity. Figure 2 shows the equivalent circuit of such a sensor. The capacitor shown is the inherent junction capacitance of the diffused area, and the p-channel transistor is used to precharge the photodiode capacitance. The cl signal resets the cell.

Figure 2: The circuit of the sensing element.

At this stage, in order to obtain a bitmap image, the thresholding operation needs to be performed locally at each pixel. The thresholding circuit is simply an inverter. The voltage on the capacitor C is used as an input to the inverter. If this voltage is above the inverter threshold (e.g. for a dimly illuminated pixel), the inverter output will be zero, whereas if it is below (e.g. for a brightly illuminated pixel), the inverter output will be one.

The intelligent sensor acts, in parallel with the sensing operation and that of thresholding, as a spatial low-pass filter on the image. The low-pass filtering operates to remove bright "spikes", which would incorrectly appear in the thresholded image. This function, although simple, is useful in the real world. Consider, for instance, a sensor for looking items on a conveyor belt \[4\]. Moreover, assume that the items are metallic and thus reflect light specularly. To provide maximum contrast, a dark conveyor is used together with bright lighting. Specular reflections from the objects could produce small, but bright, dots as seen by the sensor. These bright dots may be "seen" by whatever processor the sensor is attached to as objects in their own right. Conventionally, the processor would be programmed to remove these bright dots from the image before any other image processing is performed. But this takes time which could be used for other image processing tasks. In real time systems such time spent becomes important. The intelligent image sensor has already performed the bright dot removal and thresholding task in real time, concurrently with the sensing operation, thus saving time for the processor to do other tasks.

The low-pass filtering operation is performed by each pixel cell, which is connected to its four nearest neighbours only (von Neumann cellular automata). If the pixel cell finds that its value is different from the value of the majority of its neighbours (transition function), then it assumes that it is wrong and takes the value of the majority. Otherwise, its value remains the same. The circuit of the pixel cell, based on dynamic CMOS logic, is shown in Figure 3. In considering the VLSI layout of the pixel cell it should be noted that all transistors in the pixel cell must be shielded from the light. The availability of a second layer of metal allows this constraint to be achieved quite easily. The interconnections between the cells, being of short length, can be implemented in polysilicon, whereas the global signals should be routed in metal and metal2.

Figure 3: The circuit of a pixel cell of the intelligent image sensor. in1, in2, in3, and in4 represent the inputs from the neighbouring cells.

It is intended that the array of pixels should have a similar layout to that of a dynamic RAM, and, therefore, it is natural that similar addressing techniques can be used. A high level floorplan of the chip is shown in Figure 4 \[b\]. The main advantage of this RAM structure becomes apparent when windowing techniques are used. This is suitable when a small portion of the total image contains information of interest. The random access capability means that only this information is read from the sensor. Therefore, a great reduction in the amount of data read, as compared with serial readout sensors, is achieved.
Wafer-Scale Integrated Imaging Systems

Due to the massive processing hardware required by many image processing applications and/or the very large size of some images, the wafer-scale integrated processor approach can be used for intra-chip connections. Compared to conventional interconnection means, this technique offers large savings in speed, power, and cost. Since each wafer processed will have unpredictable defective cells, strategies should be devised to route the faulty ones. These strategies involve minimizing the total interconnection path and maximizing the size of the good array. The reconfigured array will have its own unique interconnection path. This approach can also be used for encoding and decoding techniques in parallel with other image processing applications (e.g. low-pass filtering).

Conclusions

The design of an intelligent image sensor, based on two-dimensional cellular automata, is presented in this paper. The described sensor acts, in parallel with the sensing operation and that of thresholding, as a spatial low-pass filter on the image. A photodiode is used as a sensing element. The thresholding circuit is simply an inverter. The low-pass filtering operates to remove bright "spikes", which would incorrectly appear in the thresholded image. This is performed by each pixel cell according to a local transition function, which takes into account the majority of the values of its four nearest neighbour pixels. Therefore, the intelligent sensor is able to perform on the same chip the thresholding task and the low-pass filtering in real-time concurrently with the actual sensing operation.

References