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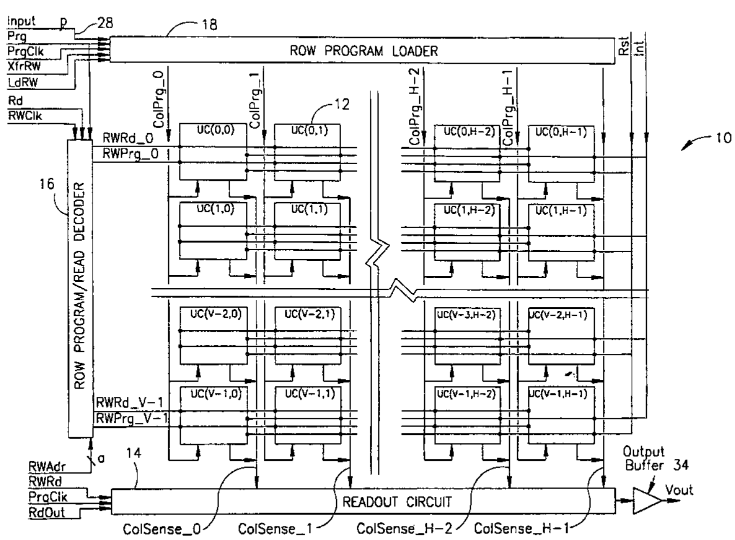
(54) Title: IMAGE-SENSOR ARCHITECTURE FOR PER-PIXEL CHARGE-INTEGRATION CONTROL



(57) Abstract: A sensor array that produces a captured image at the end of a time frame. The array includes a plurality of unit cells which sense the image with multiple within-frame charge-integrations, and control means which separately controls each of the unit cells. The unit cells are programmable multiple charge-integration unit cells with modes of photocurrent integration and non-integration. The control means includes means for separately controlling multiple charge-integrations in a single frame capture of each unit cell, independently of the charge-integrations of the other unit cells.

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IMAGE-SENSOR ARCHITECTURE FOR PER-PIXEL CHARGE-INTEGRATION CONTROL

FIELD OF THE INVENTION

The present invention relates to image sensor array architecture generally and, in particular, to logic control thereof.

BACKGROUND OF THE INVENTION

Image sensors are generally comprised of an array of sensing unit cells, wherein each unit cell comprises a pixel which is exposed to light, and produces an electrical response representative thereof. Hereinbelow are defined the basic terms used in relation to image-sensor technology and several known-in-the-art methods for the same.

The minimal signal that can be detected by an image sensor is defined as the minimal incident light intensity on the pixel that results in a recognizable, meaningful response signal above the noise level. Signals with light intensity below the noise level are considered to act in the image sensor's cutoff region.

The maximum signal that can be detected by an image sensor is defined as the maximal incident light intensity on an image sensor's pixel that results in a recognizable non-saturated response. Signals with light sensitivity above this level are considered to be in the saturation range.

The region between the cutoff region and the saturation range is defined as the image sensor's sensitivity range. Light signals with intensity in the image sensor's sensitivity range yield a response signal that corresponds to the incoming light intensity

The resolution and the minimum sensitivity determine the noise floor. Dynamic range (DR) performance is described in terms of the ratio between the highest intensity and the lowest intensity range limits. An image sensor's dynamic range is described in three equivalent ways.

In the first way, the dynamic range is described as the ratio:

(1) $$DR^1_L \equiv 10^n : 1$$

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where DR^1_L is the image sensor's dynamic-range performance and n is a positive number, normally rounded to an integer.

Hence, an image sensor with a dynamic range of $10^3 : 1$ can capture signals that are up to thousand times larger than its minimum signal.

The second way of describing the dynamic range is in a logarithmic fashion, where:

(2) $$DR^2_L \equiv 20 \cdot \log_{10} DR^1_L$$

The third way often used to describe the image sensor's dynamic range is by the number of bits required to describe the dynamic range in a binary number fashion. This number of bits is directly related to the dynamic range by the following formula,

(3) $$N_b \equiv \text{Intg}\,(\log_2 DR^1_L + 1),$$

where; N_b is the number of bits, and Intg is a function that extracts the integer part of its argument.

Ideally, the most desirable image sensor is one that imitates the human eye's performance and captures scenes with comparable performance to the human eye's retina. However, while the human eye's retina provides a dynamic range of $10^8 : 1$, commercially available image sensor's "silicon retinas" provide a dynamic range that is typically only $10^3 : 1$. Thus, in comparison to the human eye's dynamic-range performance, the silicon retina performs quite poorly.

Dynamic range is a central issue in image-sensor design research. The basis for the research is the understanding of the workings of the human eye's retina. The superb performance of the human eye's retina results from the fact that each retina's photoreceptor locally adjusts its sensitivity to the intensity of the incident light. Although the individual photoreceptors of the human eye's retina each have a dynamic range of less than $10^3 : 1$, the overall retina's performance is much better due to photoreceptor's capability to locally adjust its "quiescent point". Shifting the point of operation means that the photoreceptor, when exposed to a high intensity of light, reduces its sensitivity while, when exposed to a low light intensity, it increases its sensitivity.

The research into improvement of the artificial retina's dynamic range is intensive, and today takes one of the following forms:

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- Logarithmic Sensors: This type of sensor logarithmically compresses the dynamic range. The logarithmic compression is done by a logarithmically behaving photosensor, or a logarithmically responding circuit to an input photocurrent.

These circuits however, are quite sensitive to the manufacturing process, and slight variations in the manufacturing process may result in varying pixel-response sensitivities. Even adjacent pixels may significantly vary in their response sensitivity. This variance expresses itself in Fixed Pattern Noise (FPN), or in other ways that result in a poor quality image.

- Multiple Exposure Sensors: Several images at different exposures (charge-integration periods) are acquired and then combined into a single image. Typically, the combination of several different-exposure images is done on the image sensor's video output.

Due to image acquisition time, and to computing-intensive/time-consuming image-combination constraints, this method is typically restricted to the acquisition and processing of two images. The drawback of this method is that if the pair of acquired images differ substantially in their exposure times, the outcome can be image-color artifacts and edge artifacts.

- Autonomous/Per-Pixel Controlled-Exposure Time Sensors: For this approach, each pixel's exposure time is independently controlled and locally adjusted to the incident light's intensity. Efficient implementation of this method should yield the best results. Two noticeable attempts in this direction have been reported so far.

One reported method is based upon a unit cell that incorporates a static Set-Reset flip-flop. Resetting each pixel at a programmable point in time triggers the charge accumulation and thus controls the charge-integration time. Unfortunately the result is a large unit-cell area, a low fill factor, or both. Therefore, this unit cell is not suitable for small-pixel/high-resolution image sensors.

Furthermore, the image sensor's dynamic range is highly dependent on the column scan rate. Column-scan rate is limited by the programming rate of

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