The effects of interpixel capacitance in a pixilated array may be measured by first resetting all pixels in the array to a first voltage, where a first image is read out, followed by resetting only a subset of pixels in the array to a second voltage, where a second image is read out, where the difference in the first and second images provide information about the interpixel capacitance. Other embodiments are described and claimed.
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FIG. 1
SET ALL PIXELS TO $V_0$
OR
ILLUMINATE ALL PIXELS TO CHARGE $Q_0$

ACQUIRE IMAGE

SET SUBSET OF PIXELS TO $V_1$
OR
ILLUMINATE SUBSET OF PIXELS TO CHARGE $Q_1$

ACQUIRE NEW IMAGE
FORM DIFFERENCE IMAGE

SHIFT SUBSET

FIG. 3
MAPPING ELECTRICAL CROSSTALK IN PIXELATED SENSOR ARRAYS

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a divisional of U.S. patent application Ser. No. 12/009,959, filed on Jan. 18, 2008, and incorporated herein by reference in its entirety.

GOVERNMENT INTEREST

The invention claimed herein was made in the performance of work under a NASA contract, and is subject to the provisions of Public Law 96-517 (35 USC 202) in which the Contractor has elected to retain title.

BACKGROUND

For some systems employing pixilated sensor arrays or MEMS (Micro-Electrical-Mechanical Systems) arrays, it is desirable to measure the capacitance at each element (pixel) in the array. For example, the detection of electromagnetic radiation comprises several steps, including photon capture, collection of photo-generated charges, and sensing the corresponding voltages. Capacitive coupling between pixels may induce errors in their corresponding sensed voltages, which may lead to inaccurate image values. This capacitive coupling may affect the electronic gain and linearity of each pixel. Capacitive coupling causes the photo-generated charge on a pixel to induce a voltage on one or more adjacent or nearby pixels, leading to cross-talk when the voltages are sensed.

For some systems employing pixilated sensor arrays or MEMS (Micro-Electrical-Mechanical Systems) arrays, it is desirable to measure the capacitance at each element (pixel) in the array. For example, the detection of electromagnetic radiation comprises several steps, including photon capture, carrier diffusion, collection of photo-generated charges, and sensing the corresponding voltages. Capacitive coupling between pixels may induce errors in their corresponding sensed voltages, which may lead to inaccurate image values. This capacitive coupling may affect the electronic gain and linearity of each pixel. Capacitive coupling causes the photo-generated charge on a pixel to induce a voltage on one or more adjacent or nearby pixels, leading to cross-talk when the voltages are sensed.

It is desirable to provide a map of capacitive coupling for all elements in a pixeled array, which may be useful in calibration procedures.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates an array of pixels and controller according to an embodiment.

FIG. 2 illustrates a subset of pixels with associated cells and annuli according to an embodiment.

FIG. 3 illustrates a procedure according to an embodiment.

DESCRIPTION OF EMBODIMENTS

In the description that follows, the scope of the term “some embodiments” is not to be so limited as to mean more than one embodiment, but rather, the scope may include one embodiment, more than one embodiment, or perhaps all embodiments.
Suppose the index $i$ ranges over the integer set $\{1, 2, \ldots, N\}$, and the index $j$ ranges over the integer set $\{1, 2, \ldots, M\}$. To make the notation concise, these integer sets may be denoted as $I$ and $J$, respectively. Accordingly, the set $\{v_{ij}, i \in I, j \in J\}$ may be considered an image, and likewise for the pixels that had the second reset voltage applied. To provide an ensemble of voltages $v_{oi}(i,j)$ and $v_{i}(i,j)$, followed by averaging to provide an average of $v_{oi}(i,j)$ over the ensemble and an average of $v_{i}(i,j)$ over the ensemble. Additional notation could be added to $v_{oi}(i,j)$ and $v_{i}(i,j)$ to denote their averages, but for ease of presentation such additional notation will not be introduced. In light of this, it should be noted that when considering the description below, that for some embodiments, $v_{oi}(i,j)$ and $v_{i}(i,j)$ may represent averages over an ensemble of measurements. A difference $v_{oi}(i,j)-v_{i}(i,j)$ may be calculated for each index pair $(i,j)$ to provide a set of differences. This set of differences, which may be termed a difference image, is indicative of the capacitive coupling between pixels, and may depend upon the particular choice of subset of pixels that were reset to the voltage $v_{oi}$. It is convenient to denote this dependence by introducing $s$ to represent a subset of pixels. The difference $d_{i,j}(s)=v_{oi}(i,j)-v_{i}(i,j)$ may then be calculated for each pair $(i,j)$ for some subset $s$. This gives a set of differences $\Delta(s)\{d_{i,j}(s), i \in I, j \in J\}$. A family of such sets may be provided by performing the above-described procedure for a family of subsets. The family of subsets may be chosen to cover the entire array.

As a particular example, a subset may be chosen such that each pixel in the subset is separated from its nearest neighbor by 6 pixels. That is, we might choose a subset comprising pixels at positions $\{(i, j), 1=1, 7, 14, 21, \ldots; j=1, 7, 14, 21, \ldots\}$. There will be edge effects, so for simplicity assume that $N$ and $M$ are multiples of 7. This subset may be denoted as $s_1$. Another subset may be chosen by shifting this subset by one position, either in a row direction or a column direction, unless of course the edge of the array has already been bumped into. For example, a second subset may be the set of positions $\{(i, j), i=2, 8, 15, 22, \ldots; j=1, 7, 14, 21, \ldots\}$. This subset may be denoted as $s_2$. This process may be repeated, each time shifting a subset to obtain a new subset, so that the family of all subsets covers the entire array.

In the absence of a gradient in either the first or second reset voltages across the imager, or alternatively, in the presence of an identical gradient in both the first and second reset voltages, the voltage coupling for each pixel may be directly determined from the difference image, $\Delta(s)\{d_{i,j}(s), i \in I, j \in J\}$. For the ideal case in which there is no capacitive coupling, the image would only have the difference voltage for the pixels that had the second reset voltage applied. If coupling is present, then this difference image will directly give the sum of the coupling voltages from all coupling interactions, in pixels surrounding the reset pixel. Thus, there is not only the effect of the reset pixel on the nearest neighbor pixels, but also the sum of the change in the nearest neighbors and the central reset pixel on the next-nearest-neighbor, and vice versa.

There may be embodiments for which a gradient in the first reset image is not cancelled out by the second reset image, or vice versa. If the gradient is in voltage only, the resulting image still gives the voltage-to-voltage coupling accurately, but at voltage differences that correspond to the gradient. If the gradient is in the illumination, then the voltage-to-voltage coupling may be analyzed by an iterative solution that uses the preferred electronic gain calculation to convert the gradient in illumination to a voltage, followed by calculating the induced coupling, and then re-calculating the correct electronic gain, per pixel. This procedure may be repeated until convergence is achieved. This latter approach should also be performed if there is significant non-linearity in the output voltage of the pixels, relative to the two pixel values in the before and after images.

For some embodiments, the set $\Delta(s)\{d_{i,j}(s), i \in I, j \in J\}$ may be processed to mitigate effects due to local spatial variation in the array. For some embodiments, this procedure may be described as follows. The array may be divided into a contiguous family of cells, each cell being a contiguous set of pixels that includes one and only one pixel belonging to the subset $s$. That is, there is a one-to-one correspondence between the pixels in the set $s$ and the set of cells. Except near the edges of the array, for some embodiments the center of a cell may be the pixel in that cell belonging to $s$. Generally, given a pixel position $(k,l)$ that belongs to the subset $s$, the cell associated with $(k,l)$ and $(i,j)$ for which the distance between $(k,l)$ and $(i,j)$ is less than or equal to the distance between $(i,j)$ and any other pixel in the subset $s$. FIG. 2 illustrates this, where the dots in array 201 represent a portion of the subset of pixels that are reset to $v_{oi}$. The dashed lines divide the array into cells. (Not all cells are shown.)

About each pixel belonging to the subset $s$, a locus of pixels may be defined, where the locus is inside the cell associated with the pixel. For example, locus 202 is drawn around pixel 204 in FIG. 2. Of course, the locus is not continuous, but is meant to represent the set of pixels within a cell that are at some given distance from the pixel in the cell belonging to the subset $s$. For cells near the edge, the corresponding locus may be truncated by the edge.

For any pixel position $(i,j)$, there is one and only one cell containing $(i,j)$, and that cell contains a pixel position that also belongs to the subset $s$. Denote this pixel position as $(i^*, j^*)$. It depends also upon the choice of subset $s$. Note that if the pixel position $(i,j)$ belongs to the subset $s$, then $i^*=i$ and $j^*=j$. For the particular example in FIG. 2, $(i^*, j^*)$ is in the center of the shown cells. For the cell containing $(i,j)$, an average over the locus associated with that cell may be calculated. More specifically, for any pixel position $(i,j)$, let $\alpha(i^*, j^*, s)$ denote the average of the values $d(m,n,s)$ on the locus of points $(m, n)$ associated with the cell containing $(i,j)$. With this notation in mind, some embodiments provide the values

$$\hat{d}(i, j, s) = \frac{d(i, j, s) - \alpha(i^*, j^*, s)}{d(i^*, j^*, s) - \alpha(i^* - 1, j^*, s)}$$

Note that $d(i,j,s)$ is normalized to be less than or equal to one, and that $d(i^*, j^*, s)=1$.

For each subset $s$, the set $\hat{\Delta}(s)\{\hat{d}(i,j,s), i \in I, j \in J\}$ may be calculated as discussed above. Furthermore, a family of these sets may be calculated for a family of subsets $s$ that cover the array. This family of sets may provide information about the capacitive coupling among pixels in an array, and to what degree capacitive coupling is important as a function of intra pixel distance. For example, for a particular subset $s$, all $d(i,j,s)$ for which $(i,j)$ and $(i^*, j^*)$ are nearest neighbors provides information about the capacitive coupling among...
nearest neighbors; all \( d(i,j,s) \) for which \((i,j) \) and \((i^*,j^*)\) are
next-to-nearest neighbors provides information about the
capacitive coupling among next-to-nearest neighbors; and
so forth. As a result, histograms may be generated based
upon this family of sets, yielding information about
the degree of capacitive coupling. For some arrays, such histo-
grams may show that capacitive coupling is not important
for sufficiently large intra pixel distance. For example, for
some embodiments, capacitive coupling has been found to
be important only for nearest neighbors.

Some embodiments may provide a voltage-to-voltage
coupling factor for next neighbors and next-to-nearest
neighbors. For example, for a regular two dimensional array
(ignoring edge effects), pixel \((i,j)\) has four nearest neighbors,
pixels \((i-1,j), (i+1,j), (i,j-1), \) and \((i,j+1)\), and four next-to-
nearest neighbors, pixels \((i-1,j-1), (i+1,j-1), (i-1,j+1), \) and
\((i+1,j+1)\). Let \( k \) and \( l \) denote relative pixel index values such that
\( d_{k,l}(k,l,s) \) references voltage differences for the nearest
and next-to-nearest neighbors to pixel \((i,j)\). That is, the \( (k,l) \)
index pairs \((-1,0), (1,0), (0,-1), \) and \((0,1)\) delineate the
nearest neighbors to pixel \((i,j)\), and the \( (k,l) \) index pairs
\((-1,1), (-1,-1), (1,-1), \) and \((1,1)\) delineate the next-to-
nearest neighbors to pixel \((i,j)\). With this notation, some
embodiments may provide coupling factors \( D_{k,l}(k,l,s) \) where

\[
D_{k,l}(k,l,s) = \frac{d_{k,l}(k,l,s)}{d_{k,l}(k,l,s)}.
\]

Clearly, this scheme may be extended for all \( n^{th} \)-nearest
neighboring pixels for all pixels \((i,j)\) in an array, with
appropriate truncation at the edges of the array.

One may obtain ratios for the coupling capacitors, relative
to their adjacent diode capacitors, for the pixel array of
interest using the set of coupling factors, even for the general
case where all of the diode capacitances and all of the
coupling capacitances are assumed to vary among each other.
One may use iterative algorithms (e.g. simulated annealing) to independently calculate the capacitance values.
There may be simpler algorithms (e.g. perturbation methods) for more restricted assumptions, such as for the
assumption of equal diode capacitances and equal coupling capacitances. An imager average nodal capacitance may be
available from conversion gain measurements. Deviations of
diode capacitance values may be small, relative to the
average, and coupling capacitance values may be small,
relative to the diode capacitances.

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diode capacitances and equal coupling capacitances. An imager average nodal capacitance may be available from
conversion gain measurements. Deviations of diode capacitance values may be small, relative to the average, and
coupling capacitance values may be small, relative to the
diode capacitances.

Green's function methods or matrix inversion methods
may be used to calculate both diode and coupling capaci-
tances under more constrained experimental conditions,
such as for example a uniform flat field, only single pixel
reset, and uniformity of all coupling capacitances, and
separately, uniformity of all diode capacitances. Separate
kernels may be used to obtain the corresponding charge-to-
voltage coupling factors.

Various modifications may be made to the disclosed
embodiments without departing from the scope of the inven-
tion as claimed below. For example, instead of setting all the
pixels to the first voltage \( v_0 \) before selectively setting a
subset to the second voltage \( v_1 \), for some embodiments a flat
field may be imagined so that all the pixels accumulate a first
charge \( g_0 \). For such embodiments, one may perform an
iterative analysis where to calculate an implied voltage
coupling, calculate the implied capacitance correction, then
perform a localized background subtraction to remove il-
mination non-uniformities, and then re-calculate the voltage
coupling until convergence of the calculated coupling value.
Furthermore, for some embodiments, instead of setting the
subset of pixels to the second voltage \( v_1 \), a beam spot may
be used to illuminate only the pixels in the subset, once at
a time, or a patterned beam may be used to evenly illuminate
the pixels in the subset, more than one at a time so that the
subset accumulates a second charge \( q_1 \). Similar remarks as
discussed with respect to analysis for the flat field also apply
to the analysis of the subset of pixels.

Furthermore, some embodiments may not utilize a flat
illumination field, and for some embodiments, the subset of
pixels need not be a regular spaced sub-array.

Some of these procedures are illustrated in the flow
diagram of FIG. 3, where in process 302 all the pixels are set
to the first voltage \( v_0 \), or in the case of a different procedural
mode, all the pixels are instead illuminated with a flat field
so that all the pixels accumulate the first charge \( g_0 \). In
process 304, the image is acquired. In process 306, some
pre-selected subset of the pixels in the array are set to the
second voltage \( v_1 \), or in the case of a different procedural
mode, the pixels in this subset are instead illuminated to
accumulate the second charge \( q_1 \). In process 308, a new
image is acquired, and a difference image is formed by
taking the difference between the previously acquired image
and the new image. In process 310, the subset of pixels is
shifted, as discussed earlier, and control is brought back to
process 302. The procedure stops when the family of all
subsets has covered the array.

Throughout the description of the embodiments, various
mathematical relationships are used to describe relationships
among one or more quantities. For example, a mathematical
relationship or mathematical transformation may express a
relationship by which a quantity is derived from one or more
other quantities by way of various mathematical operations,
such as addition, subtraction, multiplication, division, etc.
Or, a mathematical relationship may indicate that a quantity
is larger, smaller, or equal to another quantity. These
relationships and transformations are in practice not satisfied
exactly, and should therefore be interpreted as “designed for”
relationships and transformations. One of ordinary skill
in the art may design various working embodiments to
satisfy various mathematical relationships or transforma-
tions, but these relationships or transformations can only be
met within the tolerances of the technology available to the
practitioner.

Accordingly, in the following claims, it is to be under-
stood that claimed mathematical relationships or transforma-
tions can in practice only be met within the tolerances or
precision of the technology available to the practitioner, and
that the scope of the claimed subject matter includes those
embodiments that substantially satisfy the mathematical
relationships or transformations so claimed.
What is claimed is:

1. A system comprising: an array of pixels, each pixel operating substantially at a same wavelength; and a controller coupled to the array of pixels, the controller configured to: acquire a first image based on illuminating each pixel in the array to accumulate a first charge; acquire a second image based on illuminating only those pixels in a subset of the array to accumulate a second charge, the subset being less than an entirety of pixels in the array of pixels and comprising pixels spaced two or more pixel-distance apart; and form a difference image based on the first and second images.

2. The system as set forth in claim 1, the controller configured to acquire a first family of images based on illuminating each pixel in the array to accumulate the first charge and acquire a second family of images based on illuminating only those pixels in a subset of the array to accumulate the second charge.

3. The system as set forth in claim 2, where the family of subsets covers the array.

4. The system as set forth in claim 1, wherein the first image is based on an average of voltage readouts by the controller based on illuminating each pixel in the array to accumulate the first charge, and the second image is based on an average of voltage readouts by the controller based on illuminating only those pixels in a subset of the array to accumulate the second charge.

5. The system as set forth in claim 1, wherein the subset comprises next-nearest neighbor pixels.

6. The system as set forth in claim 2, wherein the controller is further configured to acquire each image of the second family of images based on illuminating a different subset of pixels for each image of the second family of images.

7. The system as set forth in claim 6, wherein the controller is further configured to acquire one image of the second family of images based on illuminating nearest-neighbor pixels in a first subset, and another image of the second family of images based on illuminating next-nearest-neighbor pixels in a second subset.

8. The system as set forth in claim 6, wherein the controller is further configured to acquire one image of the second family of images based on illuminating pixels in a first subset, the pixels in the first subset being spaced six pixel-distance apart.

9. The system as set forth in claim 1, wherein the controller is further configured to:

   5. acquire a plurality of additional images based on illuminating only those pixels in additional subsets of the array to accumulate a second charge, the subset being less than an entirety of pixels in the array of pixels and comprising pixels spaced two or more pixel-distance apart; and
   10. form a plurality of difference images each based on a difference between the first and each of the additional images, wherein each additional subset is different from other additional subsets.

10. The system as set forth in claim 1, wherein the controller is further configured to calculate a capacitance of each pixel of the array of pixels, based on the difference image.

11. The system as set forth in claim 9, wherein the controller is further configured to calculate a capacitance of each pixel of the array of pixels, based on the plurality of difference images.

* * * * *