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(54) **OPTICAL THREE-DIMENSIONAL COORDINATE SENSOR SYSTEM AND METHOD THEREOF**

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(57) **ABSTRACT**

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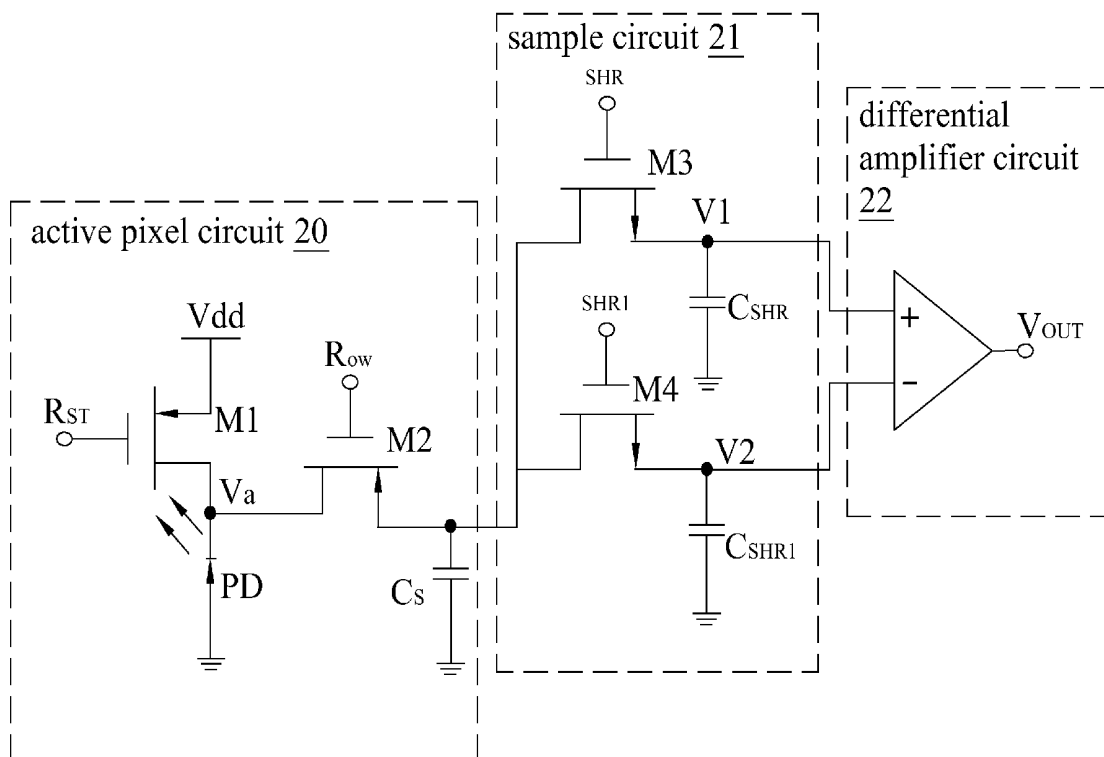
The present invention relates an optical three-dimensional coordinate sensor system and method thereof. A plurality of light-emitting modules produce a plurality of light signals, and then a plurality of reflected light signals reflected by an object are received by a plurality of photodetectors. After receiving the reflected light signals, the photodetectors generate a plurality of photocurrents. A plurality of active pixel circuits receive the photocurrents and transform the photocurrents to a plurality of reflective optical voltages. A plurality of differential amplifier circuits (DAC) compare the reflective optical voltages and the background voltages, and then output a plurality of DAC output voltages of the reflected light signals. Afterward, a processing module detects the DAC output voltages and uses an algorithm to calculate the top three of the DAC output voltages to determine the three-dimensional coordinate of the object.

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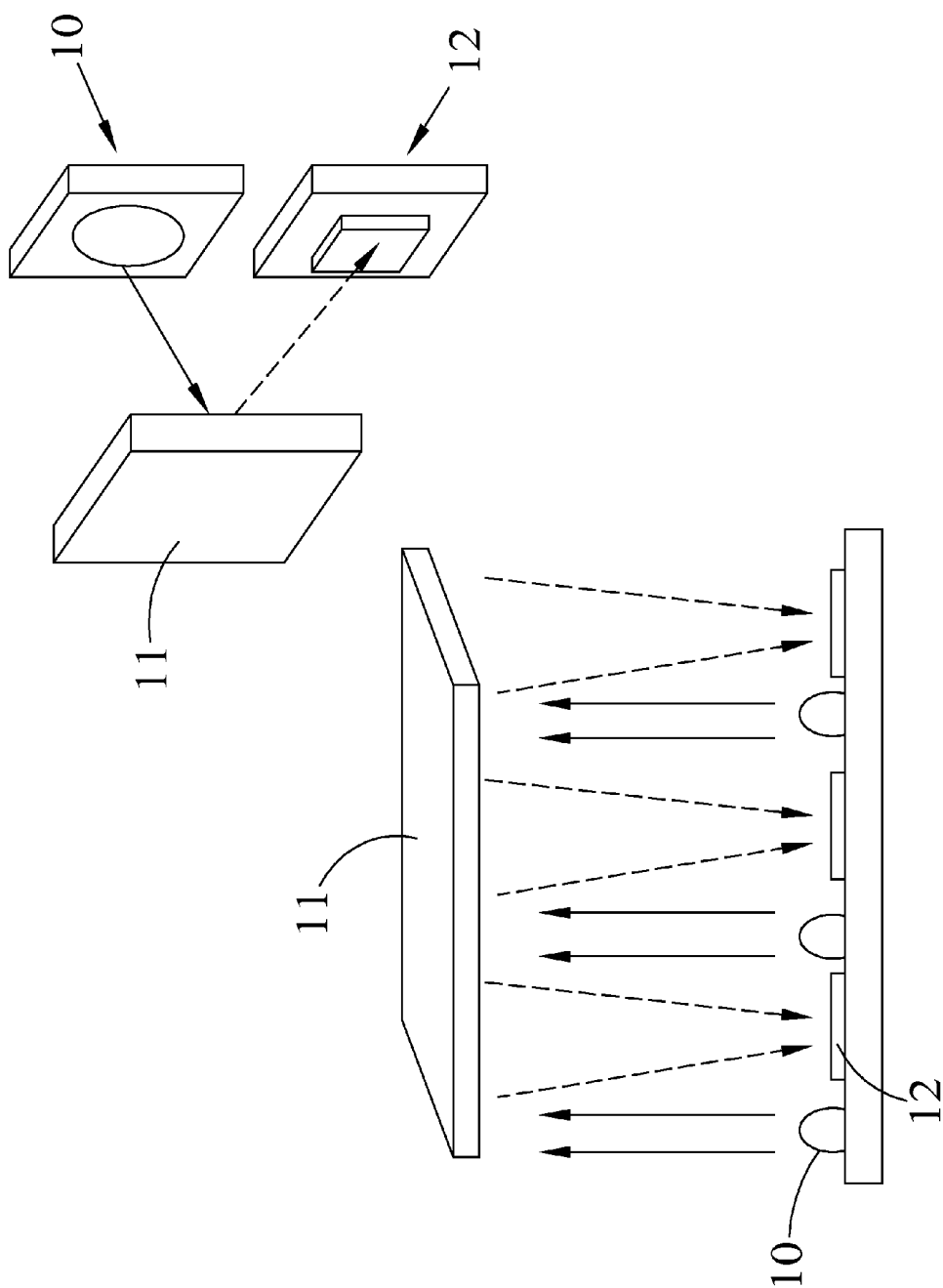


FIG. 1

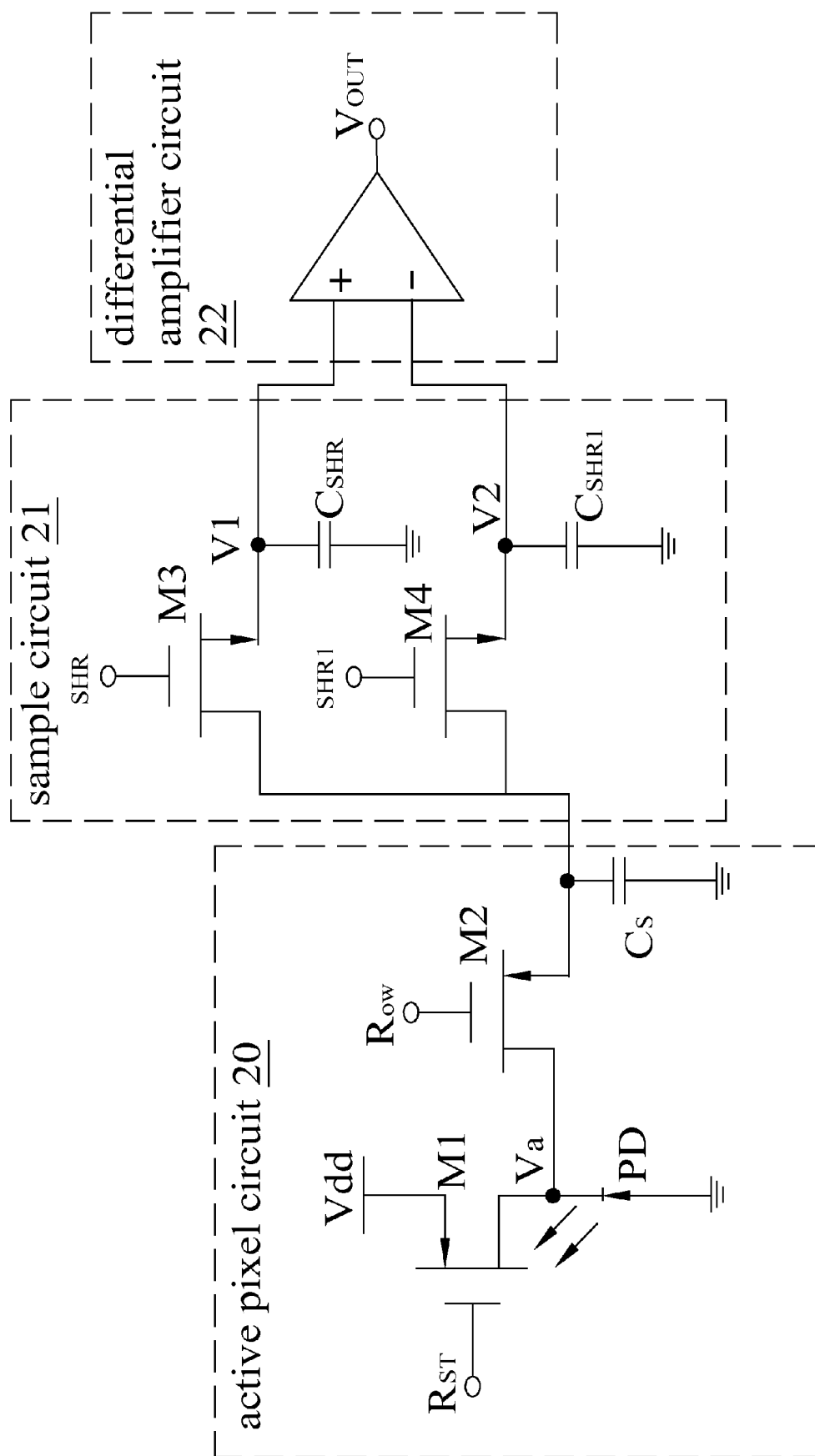


FIG. 2

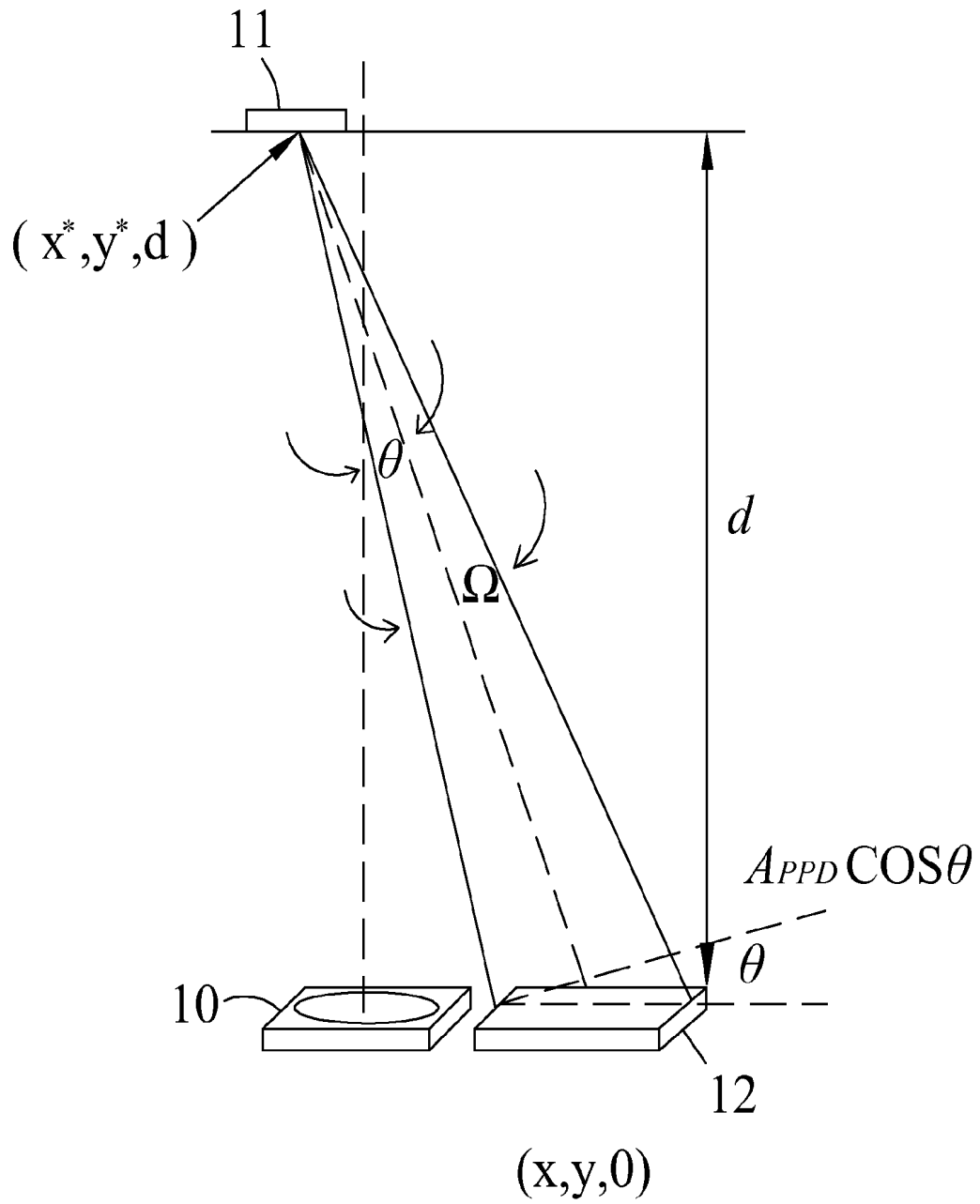


FIG. 3

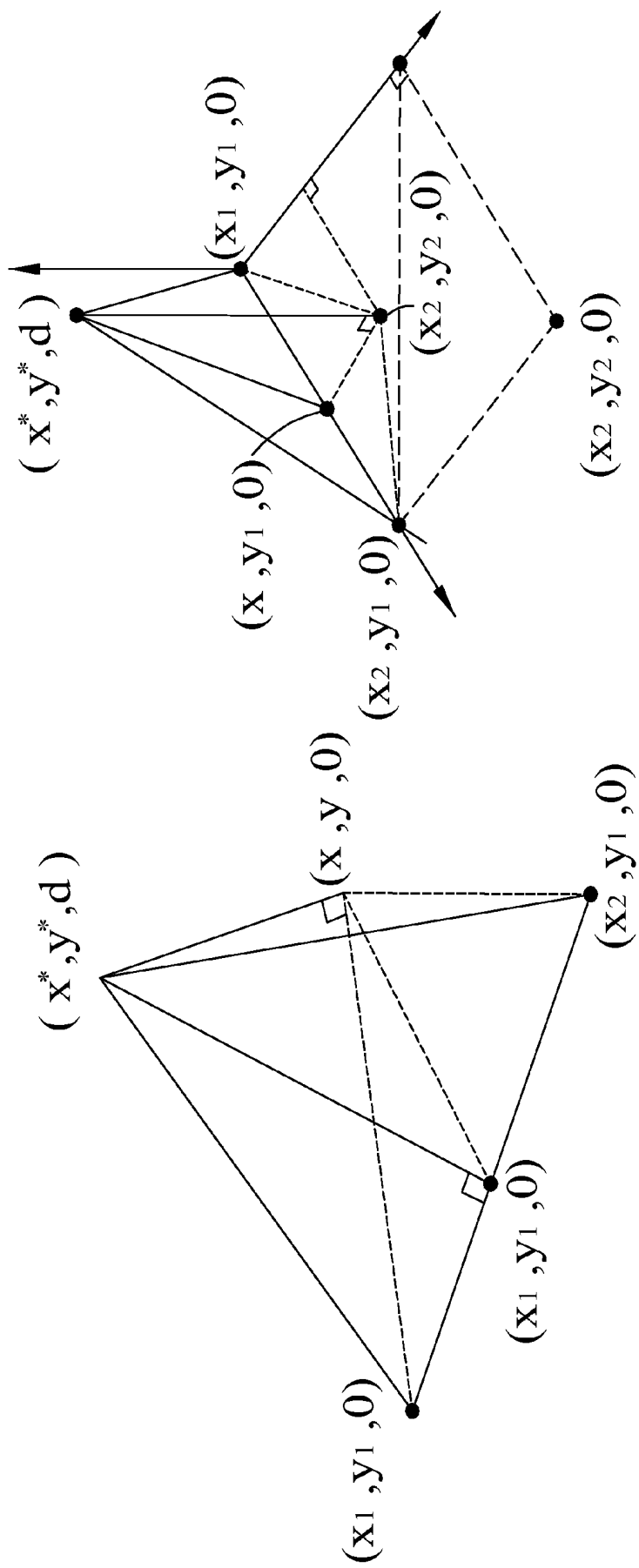


FIG. 4

## OPTICAL THREE-DIMENSIONAL COORDINATE SENSOR SYSTEM AND METHOD THEREOF

### FIELD OF THE INVENTION

[0001] The exemplary embodiment(s) of the present invention relates to a sensor system and the method thereof. More specifically, the exemplary embodiment(s) of the present invention relates to an infrared optical three-dimensional coordinate sensor system and the method thereof.

### BACKGROUND OF THE INVENTION

[0002] In recent years, the LED technology has big progress in the efficiency of brightness, and many applications for displays appear continuously. Also, the optical proximity sensor (OPS) is commonly used in wireless communications, bio-molecular sciences, environmental monitoring, and displays. The OPS is developed based on the light signal received by the photo-detector (PD) via the reflections of the measured object. The PD transfers the light signal to the electrical signal. By detecting the intensity of the electrical signal, the OPS can calculate the distance of measured object.

[0003] The conventional OPS is used mostly for switches; however, there are limited applications for OPS. Also, the OPS needs to comply with the specific color or shape to effectively detect the object, and it is easily affected by the ambient light or the dark current, which results in a wrong detection. In addition, the OPS has at most two-dimensional detection range (i.e. single plane detection range). Thus, it can not do a three-dimensional coordinate sensing of an object.

### SUMMARY

[0004] A primary object of the present invention is to provide an infrared optical three-dimensional coordinate sensor system and the method thereof, so as to improve the previous drawbacks of the conventional OPS and provide a better three-dimensional coordinate sensor system.

[0005] According to an object of the present invention, an optical three-dimensional coordinate sensor system is provided, comprising a plurality of light-emitting modules, a plurality of sensing modules, and a processing module. The light-emitting modules emit a plurality of light signals to an object. The sensing modules are formed from a plurality of photodetectors, a plurality of active pixel circuits (APCs), a plurality of sampling circuits, and a plurality of differential amplifier circuits (DACs). The photodetectors absorb a plurality of reflected light signals reflected by the object to generate a plurality of photocurrents. Each of the APCs comprises at least one active transistor within a pixel unit cell; the APCs connected to the photodetectors receive the photocurrents and transform the photocurrents to a plurality of reflective optical voltages. Each of the sampling circuits comprises a sampling transistor and a capacitor; the sampling circuits connected to the APCs sample and store the reflective optical voltages. The DACs connected to the sampling circuits receive the reflective optical voltages. Each of the DACs subtracts the reflective optical voltage from a background voltage and multiply a differential gain to the difference. Then, the DACs output a plurality of DAC output voltages of the reflected light signals. Next, the processing module connected to the sensing modules detects the DAC output volt-

ages and uses an algorithm to calculate the top three of the DAC output voltages to determine the three-dimensional coordinate of the object.

[0006] To achieve this object, a optical three-dimensional coordinate sensing method according to the present invention comprises the steps of emitting a plurality of light signals to an object by a plurality of light-emitting modules; absorbing a plurality of reflected light signals reflected by the object and generating a plurality of photocurrents by a plurality of photodetectors; receiving the photocurrents and transforming the photocurrents to a plurality of reflective optical voltages by a plurality of active pixel circuits (APCs); sampling and storing the reflective optical voltages by a plurality of sampling circuits; subtracting the reflective optical voltages from a plurality of background voltages and multiplying differential gains to output a plurality of DAC output voltages of the reflected light signals by a plurality of differential amplifier circuits (DACs); and detecting the DAC output voltages and using an algorithm by a processing module to calculate the top three of the DAC output voltages to determine the three-dimensional coordinate of the object.

[0007] Herein the APC may be a 2-transistor-APC (2T-APC). The 2T-APC comprises a reset transistor, a row select transistor and a storage capacitor. The source of the reset transistor is connected to a V<sub>dd</sub>, the drain of the reset transistor is connected to the drain of the row select transistor, and the source of the row select transistor is connected to the storage capacitor.

[0008] Herein the 2T-APC operates in three modes sequentially: reset, integration, and readout. In the reset mode, the reset transistor is switched ON and pre-charges the node Va to 3.3V. At the same time, the row select transistor is switched ON. In the integration mode, the reset transistor is switched OFF and the node Va drops because of the photo-carriers discharging a photocurrent capacitor C<sub>PD</sub>. In the readout mode, the row select transistor is switched OFF and an output voltage of the row select transistor is readout.

[0009] In summary of the aforementioned descriptions, the optical three-dimensional coordinate sensor system and the method thereof according to the present invention feature one or more of the following advantages:

[0010] (1) The sensing modules have the storage capability; they can reduce the incorrect positioning due to the influence of the background light or charge injection (charge injection).

[0011] (2) The system and method thereof reduce the cost of the sensor circuit. It only needs fewer APC to reach a larger area of detection.

[0012] (3) The algorithm significantly shortens the reaction time, thereby increases the speed of reaction to reach the required rapid rate of reaction of a wide range.

[0013] (4) The system and method thereof achieve low-cost, three-dimensional positioning, and low noise, which is practical for application.

[0014] With these and other objects, advantages, and features of the invention that may become hereinafter apparent, the nature of the invention may be more clearly understood by reference to the detailed description of the invention, the embodiments and to the several drawings herein.

### BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The exemplary embodiment(s) of the present invention will be understood more fully from the detailed description given below and from the accompanying drawings of various embodiments of the invention, which, however,

should not be taken to limit the invention to the specific embodiments, but are for explanation and understanding only.

**[0016]** FIG. 1 is the architecture of optical proximity sensor;

**[0017]** FIG. 2 is a block diagram of the optical three-dimensional coordinate sensor system according to the present invention;

**[0018]** FIG. 3 is a space side view of sensor and light source according to the present invention; and

**[0019]** FIG. 4 is a relationship of the position of the object and space coordinates.

#### DETAILED DESCRIPTION

**[0020]** Exemplary embodiments of the present invention are described herein in the context of the optical three-dimensional coordinate sensor system and method thereof.

**[0021]** Please refer to FIG. 1 which is the architecture of the optical proximity sensor (OPS) according to the present invention. As shown, the OPS comprises light-emitting diodes (LEDs) 10 and polymer photo-detectors (PPDs) 12. The LEDs 10 and the PPDs 12 are disposed side by side in the same plane to form the OPS. Light emitted by the LEDs 10 is reflected from the measured object 11 back onto the PPD pixels.

**[0022]** Please refer to FIG. 2 which is a block diagram of the optical three-dimensional coordinate sensor system according to the present invention. As shown, the readout circuit of the OPS comprises an active pixel circuit (APC) 20, a sampling circuit 21, a differential amplifier circuit (DAC) 22 and row decoders.

**[0023]** An APC 20 is defined as a sensor that has one or more active transistors within the pixel unit cell. In the embodiment, the 2-transistor-APC (2T-APC) 20 comprises a polymer photodiode (PPD), a reset transistor (M1), a row select transistor (M2) and a storage capacitor. M1 and M2 adopt PMOS structure. The 2T-APC 20 operates in three modes:

(1) Reset mode: The reset transistor (M1) is switched ON and pre-charges the node Va to 3.3V. The 2T-APC 20 with the storage capacitor can increase the electrical charge and storage ability. At the same time, the row select transistor (M2) is switched ON.

(2) Integration mode: After reset, M1 is switched OFF for an integration period ( $T_i$ ). During  $T_i$ , photodiode voltage (Va) drops because of the photo-carriers discharging  $C_{PD}$ .

(3) Readout mode: After integration, the M2 is switched OFF and the  $V_{out}$  is readout. Because the M2 acts as an ideal switch ( $V_{DS2}=0$ ), Va is equal to the output voltage of the M2. At the end of integration, the output voltage of the M2 can be expressed as

$$I = C \frac{dv}{dt}, \quad (1)$$

$$V_{out} = V_{DD} - \frac{T_i}{C_{in}} I_{PD}, \quad (2)$$

where  $T_i$  is the integration time and the capacitance  $C_{in}$  represents the photodiode capacitor in parallel with the equivalent capacitance  $C_{MOS}$  of MOS transistors seen at node A and storage capacitor  $C_S$

$$C_{in} = C_{PD} + C_{gd1} + C_{gd2} + C_S. \quad (3)$$

**[0024]** Each sampling circuit 21 comprises a sampling transistor (M3 or M4) and capacitor (CSHR or CSHR1). At first, the LED is switched OFF in the first reset cycle. The reset transistor (M1) is switched ON and pre-charges Va to 3.3V. At the same time, the row select transistor (M2) is switched ON. After reset, M1 is switched OFF for an integration period ( $t=t1$ ). During  $t1$ , PD generates photo-carriers discharging CPD by  $\Delta Q$  decreasing Va. Before M2 is switched OFF, V1 is sampled onto capacitor CSHR by pulsing M3 to VDD; V1 is behalf of the background voltage. Next, the LED is switched ON in the second reset cycle. The reset transistor (M1) is switched ON and pre-charges Va to 3.3V. At the same time, the row select transistor (M2) is switched ON. After reset, M1 is switched OFF for an integration period ( $t=t2$ ). During  $t2$ , PD generates photo-carriers discharging CPD by  $\Delta Q$  decreasing Va. Before M2 is switched OFF, V2 is sampled onto capacitor CSHR1 by pulsing M4 to VDD; V2 is behalf of the background voltage with the voltage of reflective light.

**[0025]** The differential amplifier circuit (DAC) 22 is connected to the sampling circuits 21 for subtracting V2 from V1 and multiplies a differential gain  $A_d$  to output the voltage of reflective light  $V_{out}$ ; the voltage of reflective light  $V_{out}$  satisfies the following condition:

$$V_{out} = A_d (V_{background} - V_{background+reflection}). \quad (3)$$

**[0026]** Row decoders are used to generate the signals used to scan rows during readout. The array architecture is assumed to be column-parallel so that an entire row can be read out simultaneously. Each column of the array has a column readout amplifier that generates an analog output voltage proportional to the intensity of the incident light.

**[0027]** Please refer to FIG. 3 which is a space side view of sensor and light source according to the present invention. As shown, the LED 10 is assumed to be a Lambertian emitter and the object to be a Lambertian reflecting surface. For a Lambertian emitter, the radiant flux that is detected by PPD 12 is proportional to  $\cos \theta \times \Omega$ , where  $\Omega = A_{PPD} \cos \theta / [d^2 + (x-x^*)^2 + (y-y^*)^2]$  is the solid angle spanned by the PPD 12 to the object 11, d is the distance between the object 11 and the sensor,  $\theta$  is the angle between the PPD 12 and the object 11,  $A_{PPD}$  is the area of the PPD 12 pixel and  $\alpha$  is a proportionality factor. Putting all together, one obtains the following expression for the photocurrent

$$I_i(x^*, y^*, d) = \frac{\alpha d^2}{[d^2 + (x_i - x^*)^2 + (y_i - y^*)^2]}. \quad (4)$$

The position of the PPD 12 is  $(x_1, y_1, 0) \dots (x_9, y_9, 0)$  in 3x3 PPD 12 array, and the position of the object 11 is  $(x^*, y^*, d)$ . When the object 11 approaches any pixel of array, nine pixels of the PPD 12 generate photocurrent. In addition, the current and the distance of the object 11 are inversely proportional. Thus,  $(x^*, y^*, d)$  and the photocurrent related equations are as follows

$$\sqrt{\frac{I_i}{\alpha} [d^2 + (x_i - x^*)^2 + (y_i - y^*)^2]} = d, \quad (5)$$

-continued

$$\text{Define } K_i = \sqrt{\frac{I_i}{\alpha}} \quad (i = 1 \sim 9), \quad (6)$$

$$K_i[d^2 + (x_i - x^*)^2 + (y_i - y^*)^2] = d$$

And (7)

$$V_{out,i} = \frac{A_d T_i}{C_{in}}(I_i),$$

$$\text{Define } \beta = \frac{\alpha A_d T_i}{C_{in}}, \quad (8)$$

$$V_{out,i} = \frac{\beta d^2}{[d^2 + (x_i - x^*)^2 + (y_i - y^*)^2]}.$$

The location of the object **11** ( $x^*, y^*, d$ ) will fall around the large output voltage of the PPD **12**. However, a photo-detector can only access a dimension of information, and the point of the space has three dimensions of information. Therefore, the positioning of the sensed object **11** needs three photo-detectors, which generate the largest output signals. The relationship of the position of the object and space coordinates shows in FIG. 4. The point of the maximum voltage and the remaining two points form a right triangle in the x-y plane. The sensed object **11** locates in the x-axis or y-axis is determined by the second large voltage. Then, it is necessary to calculate Eq. (9), Eq. (10) and Eq. (11) simultaneously in order to determine the location of the object precisely.

$$V_{out,largest} = \frac{\beta d^2}{[d^2 + (x_1 - x^*)^2 + (y_1 - y^*)^2]}, \quad (9)$$

$$V_{out,second} = \frac{\beta d^2}{[d^2 + (x_2 - x^*)^2 + (y_2 - y^*)^2]}, \quad (10)$$

$$V_{out,third} = \frac{\beta d^2}{[d^2 + (x_3 - x^*)^2 + (y_3 - y^*)^2]}. \quad (11)$$

Use these equations to obtain ( $x^*, y^*, d$ ). Finally, make use of the other equation to verify the correctness of the location.

**[0028]** In summary, the optical three-dimensional coordinate sensor system and the method thereof according to the present invention achieve low-cost, three-dimensional positioning, and low noise, which is practical for application.

**[0029]** While particular embodiments of the present invention have been shown and described, it will be obvious to those skilled in the art that, based upon the teachings herein, changes and modifications may be made without departing from this invention and its broader aspects. Therefore, the appended claims are intended to encompass within their scope of all such changes and modifications as are within the true spirit and scope of the exemplary embodiment(s) of the present invention.

What is claimed is:

1. An optical three-dimensional coordinate sensor system, comprising:

a plurality of light-emitting modules emitting a plurality of light signals to an object;

a plurality of sensing modules, comprising:

a plurality of photodetectors receiving a plurality of reflected light signals reflected by the object to generate a plurality of photocurrents;

a plurality of active pixel circuits (APCs) connected to the photodetectors for receiving the photocurrents and transforming the photocurrents to a plurality of reflective optical voltages, each of the APCs comprising at least one active transistor within a pixel unit cell;

a plurality of sampling circuits connected to the APCs for sampling and storing the reflective optical voltages, each of the sampling circuits comprising a sampling transistor and a capacitor; and

a plurality of differential amplifier circuits (DACs) connected to the sampling circuits for receiving the reflective optical voltages, each of the DACs subtracting the reflective optical voltage from a background voltage and multiplying a differential gain thereto, the DACs outputting a plurality of DAC output voltages of the reflected light signals; and

a processing module connected to the sensing modules for detecting the DAC output voltages and using an algorithm to calculate top three of the DAC output voltages to determine a three-dimensional coordinate of the object.

2. The optical three-dimensional coordinate sensor system as claimed in claim 1, wherein each of the APCs is a 2-transistor-APC (2T-APC), the 2T-APC comprising a reset transistor, a row select transistor and a storage capacitor; a source of the reset transistor is connected to a Vdd, a drain of the reset transistor is connected to a drain of the row select transistor, and a source of the row select transistor is connected to the storage capacitor.

3. The optical three-dimensional coordinate sensor system as claimed in claim 2, wherein the reset transistor and the row select transistor are PMOS transistors.

4. The optical three-dimensional coordinate sensor system as claimed in claim 2, wherein the 2T-APC operates in a plurality of modes sequentially.

5. The optical three-dimensional coordinate sensor system as claimed in claim 4, wherein the plurality of modes comprise a reset mode, in which the reset transistor is switched ON and pre-charges a node Va to 3.3V; also, the row select transistor is switched ON.

6. The optical three-dimensional coordinate sensor system as claimed in claim 5, wherein the plurality of modes comprise an integration mode, in which the reset transistor is switched OFF and the node Va drops because of a plurality of photo-carriers discharging a photocurrent capacitor  $C_{PD}$ .

7. The optical three-dimensional coordinate sensor system as claimed in claim 6, wherein the plurality of modes comprise a readout mode, in which the row select transistor is switched OFF and an output voltage of the row select transistor is readout.

8. The optical three-dimensional coordinate sensor system as claimed in claim 1, wherein each of the sensing modules is a 3x3 polymer photo-detector (PPD) array to realize the determination of the three-dimensional coordinate of the object.

9. The optical three-dimensional coordinate sensor system as claimed in claim 1, wherein the light-emitting modules are a plurality of light-emitting diodes (LEDs).

10. The optical three-dimensional coordinate sensor system as claimed in claim 8, wherein a radiant flux detected by the PPD is proportional to  $\cos \theta \times \Omega$ , where  $\Omega = A_{PPD} \cos \theta / [d^2 + (x - x^*)^2 + (y - y^*)^2]$  is a solid angle spanned by the PPD to the object, d is a distance between the object and the PPD,



$\theta$  is an angle between the PPD and the object,  $A_{PPD}$  is an area of the PPD pixel, and  $\alpha$  is a proportionality factor.

11. The optical three-dimensional coordinate sensor system as claimed in claim 10, wherein the photocurrent is proportional to the radiant flux, and the photocurrent satisfies the following condition:

$$I_i(x^*, y^*, d) = \frac{\alpha d^2}{[d^2 + (x_i - x^*)^2 + (y_i - y^*)^2]^2},$$

wherein  $(x_i, y_i, 0)$  is a position of the PPD in the 3x3 PPD array, and  $(x^*, y^*, d)$  is the three-dimensional coordinate of the object.

12. The optical three-dimensional coordinate sensor system as claimed in claim 11, wherein the top three of the DAC output voltages satisfy the following condition:

$$V_{out,i} = \frac{\beta d^2}{[d^2 + (x_i - x^*)^2 + (y_i - y^*)^2]^2},$$

$$\text{wherein } \beta = \frac{\alpha A_d T_i}{C_{in}}$$

and  $T_i$  is an integration time of a capacitance  $C_{in}$ .

13. An optical three-dimensional coordinate sensing method, comprising the following steps:

- emitting a plurality of light signals to an object by a plurality of light-emitting modules;
- receiving a plurality of reflected light signals reflected by the object and generating a plurality of photocurrents by a plurality of photodetectors;
- receiving the photocurrents and transforming the photocurrents to a plurality of reflective optical voltages by a plurality of active pixel circuits (APCs);
- sampling and storing the reflective optical voltages by a plurality of sampling circuits;
- subtracting the reflective optical voltages from a plurality of background voltages and multiplying differential gains thereto to output a plurality of differential amplifier circuit (DAC) output voltages of the reflected light signals by a plurality of differential amplifier circuits (DACs); and
- detecting the DAC output voltages and using an algorithm by a processing module to calculate top three of the DAC output voltages to determine a three-dimensional coordinate of the object.

14. The optical three-dimensional coordinate sensing method as claimed in claim 13, wherein the step of receiving the photocurrents and transforming the photocurrents further comprises the following step:

- providing a 2-transistor-APC (2T-APC) to operate in a plurality of modes sequentially.

15. The optical three-dimensional coordinate sensing method as claimed in claim 14, wherein the plurality of modes comprise a reset mode, in which the reset transistor is switched ON and pre-charges a node Va to 3.3V; also, the row select transistor is switched ON.

16. The optical three-dimensional coordinate sensing method as claimed in claim 15, wherein the plurality of modes comprise an integration mode, in which the reset transistor is switched OFF and the node Va drops because of a plurality of photo-carriers discharging a photocurrent capacitor  $C_{PPD}$ .

17. The optical three-dimensional coordinate sensing method as claimed in claim 16, wherein the plurality of modes comprise a readout mode, in which the row select transistor is switched OFF and an output voltage of the row select transistor is readout.

18. The optical three-dimensional coordinate sensing method as claimed in claim 13, wherein the step of calculating the three-dimensional coordinate further comprises the following step:

detecting a radiant flux by a polymer photo-detector (PDD), the radiant flux being proportional to  $\cos \theta \times \Omega$ , wherein  $\Omega = A_{PPD} \cos \theta / [d^2 + (x - x^*)^2 + (y - y^*)^2]$  is a solid angle spanned by the PPD to the object,  $d$  is a distance between the object and the PPD,  $\theta$  is an angle between the PPD and the object,  $A_{PPD}$  is an area of the PPD pixel, and  $\alpha$  is a proportionality factor.

19. The optical three-dimensional coordinate sensing method as claimed in claim 18, wherein the photocurrent is proportional to the radiant flux, and the photocurrent satisfies the following condition:

$$I_i(x^*, y^*, d) = \frac{\alpha d^2}{[d^2 + (x_i - x^*)^2 + (y_i - y^*)^2]^2},$$

wherein  $(x_i, y_i, 0)$  is a position of the PPD in a 3x3 PPD array, and  $(x^*, y^*, d)$  is the three-dimensional coordinate of the object.

20. The optical three-dimensional coordinate sensing method as claimed in claim 19, wherein the top three of the DAC output voltages satisfy the following condition:

$$V_{out,i} = \frac{\beta d^2}{[d^2 + (x_i - x^*)^2 + (y_i - y^*)^2]^2},$$

$$\text{wherein } \beta = \frac{\alpha A_d T_i}{C_{in}}$$

and  $T_i$  is an integration time of a capacitance  $C_{in}$ .

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