US010149659B1

(12) **United States Patent**
Schwartz et al.

(10) **Patent No.: US 10,149,659 B1**
(45) **Date of Patent: Dec. 11, 2018**

(54) **HAND-HELD X-RAY SENSOR WITH GESTURE-ACTIVATED WAKE FUNCTION**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **15/719,568**

(22) Filed: **Sep. 29, 2017**

(51) **Int. Cl.**
A61B 6/00 (2006.01)
G03B 42/00 (2006.01)

(52) **U.S. Cl.**
CPC ***A61B 6/56*** (2013.01); ***G03B 42/00*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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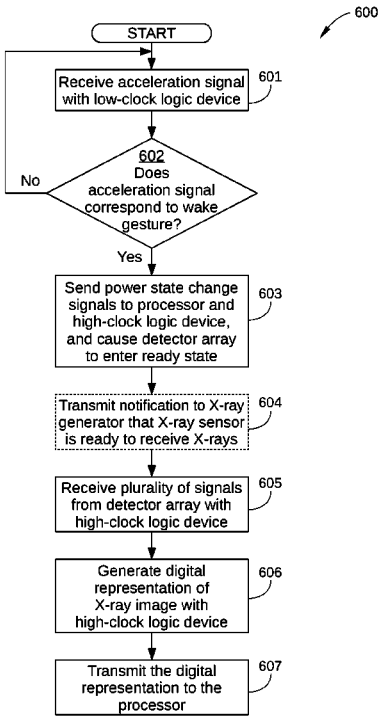
(57) **ABSTRACT**

An X-ray sensing apparatus includes a detector array configured to generate a plurality of signals in response to x-rays incident on the detector array during an exposure period; a high-clock logic device communicatively coupled to the detector array; a low-clock logic device communicatively coupled to the high-clock logic device; an accelerometer communicatively coupled to the low-clock logic device; and a processor communicatively coupled to the high-clock logic device. The low-clock logic device is configured to receive an acceleration signal from the accelerometer; determine that the acceleration signal corresponds to a wake gesture; and, in response to determining that the acceleration signal corresponds to the wake gesture, send a first power state change signal to the processor and a second power state change signal to the high-clock logic device.

20 Claims, 6 Drawing Sheets



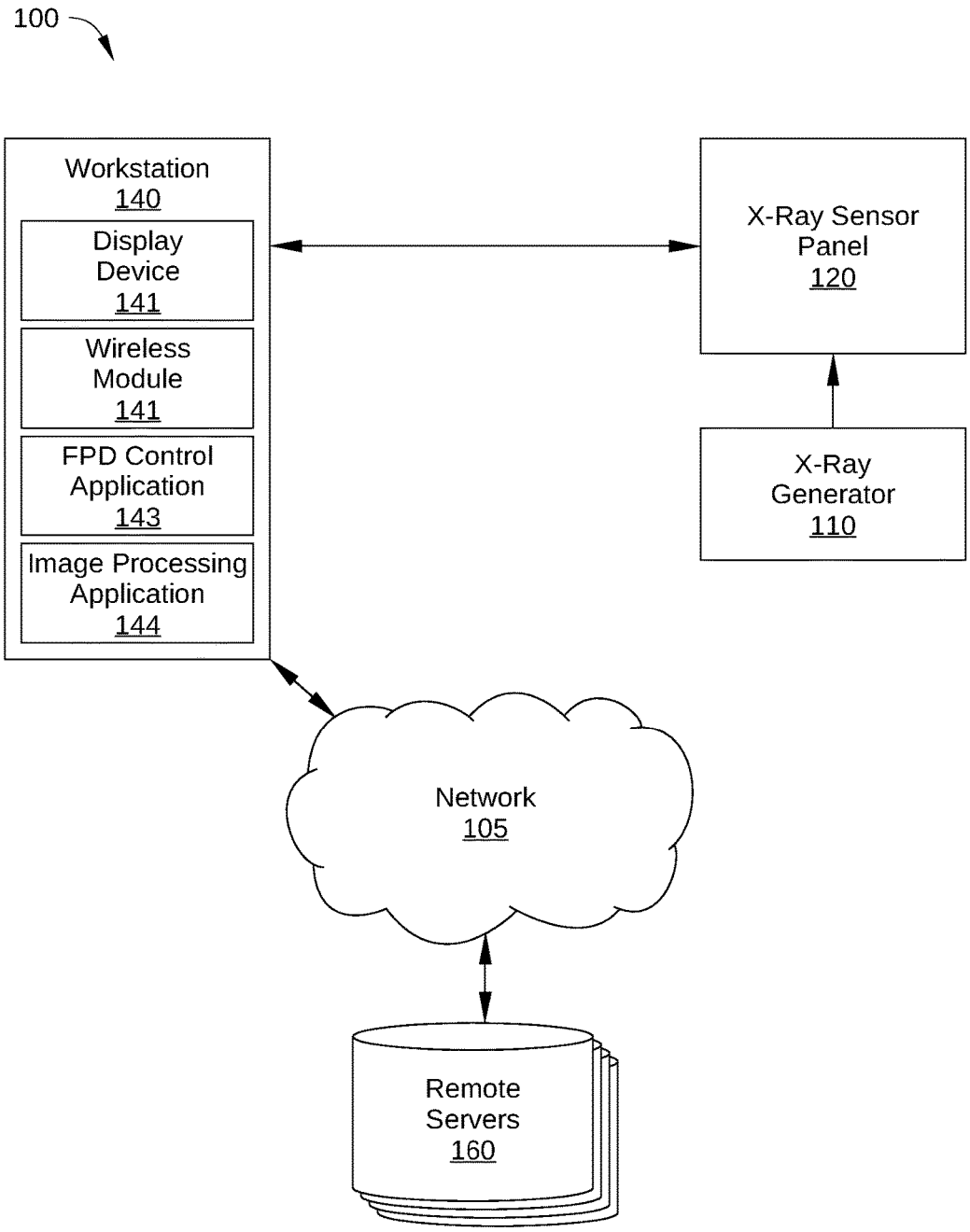

100
Workstation
140
Display
Device
141
Wireless
Module
141
FPD Control
Application
143
Image Processing
Application
144
X-Ray Sensor
Panel
120
X-Ray
Generator
110
Network
105
Remote
Servers
160

FIG. 1

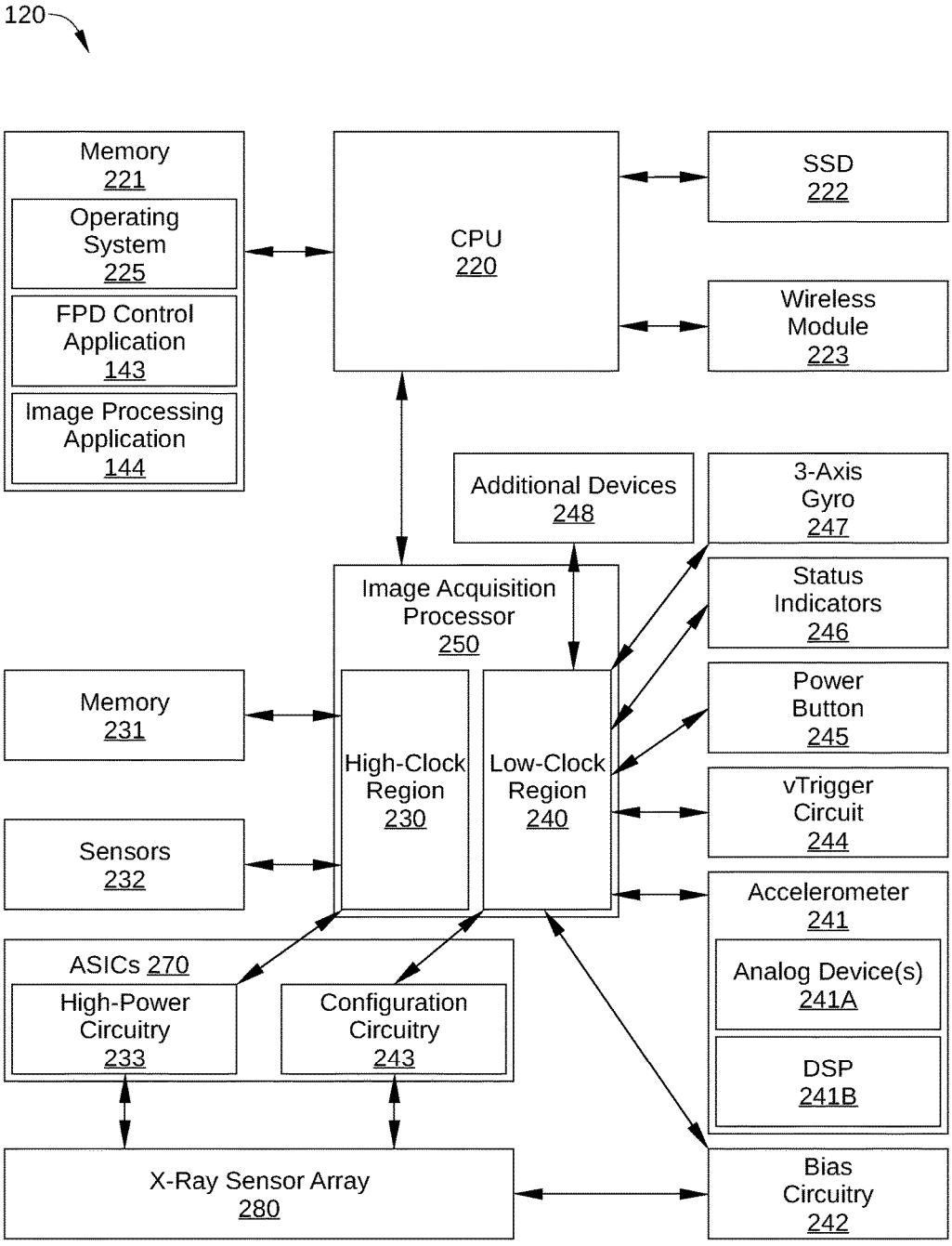

120
Memory
221
Operating System
225
FPD Control Application
143
Image Processing Application
144
CPU
220
SSD
222
Wireless Module
223
Additional Devices
248
3-Axis Gyro
247
Image Acquisition Processor
250
Status Indicators
246
Memory
231
High-Clock Region
230
Low-Clock Region
240
Power Button
245
vTrigger Circuit
244
Sensors
232
Accelerometer
241
ASICs 270
High-Power Circuitry
233
Configuration Circuitry
243
Analog Device(s)
241A
DSP
241B
X-Ray Sensor Array
280
Bias Circuitry
242

FIG. 2

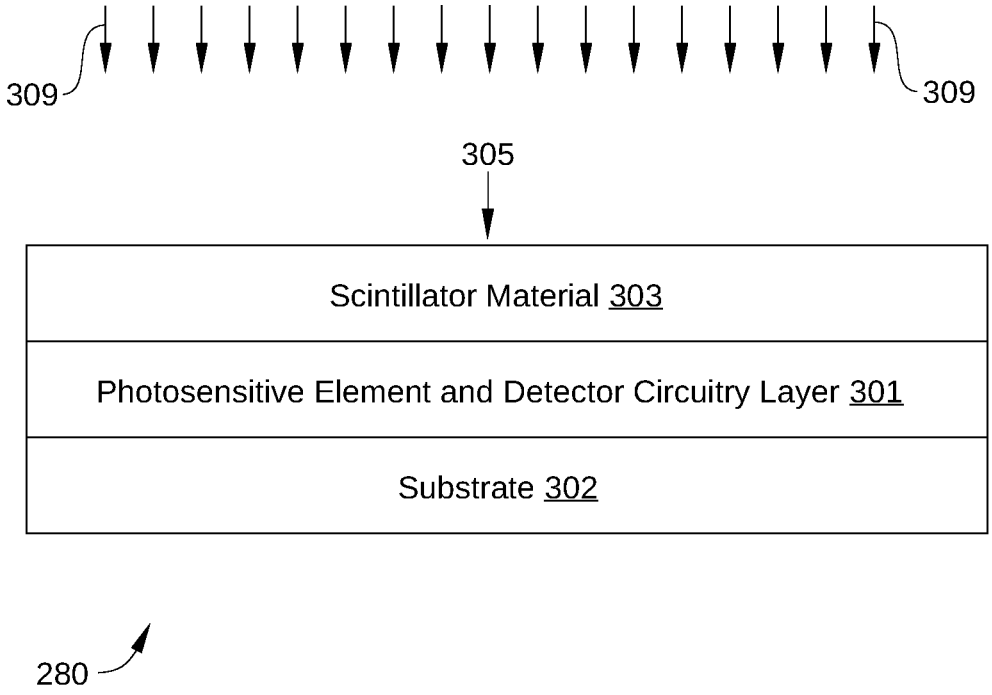

309
309
305
Scintillator Material 303
Photosensitive Element and Detector Circuitry Layer 301
Substrate 302
280

FIG. 3

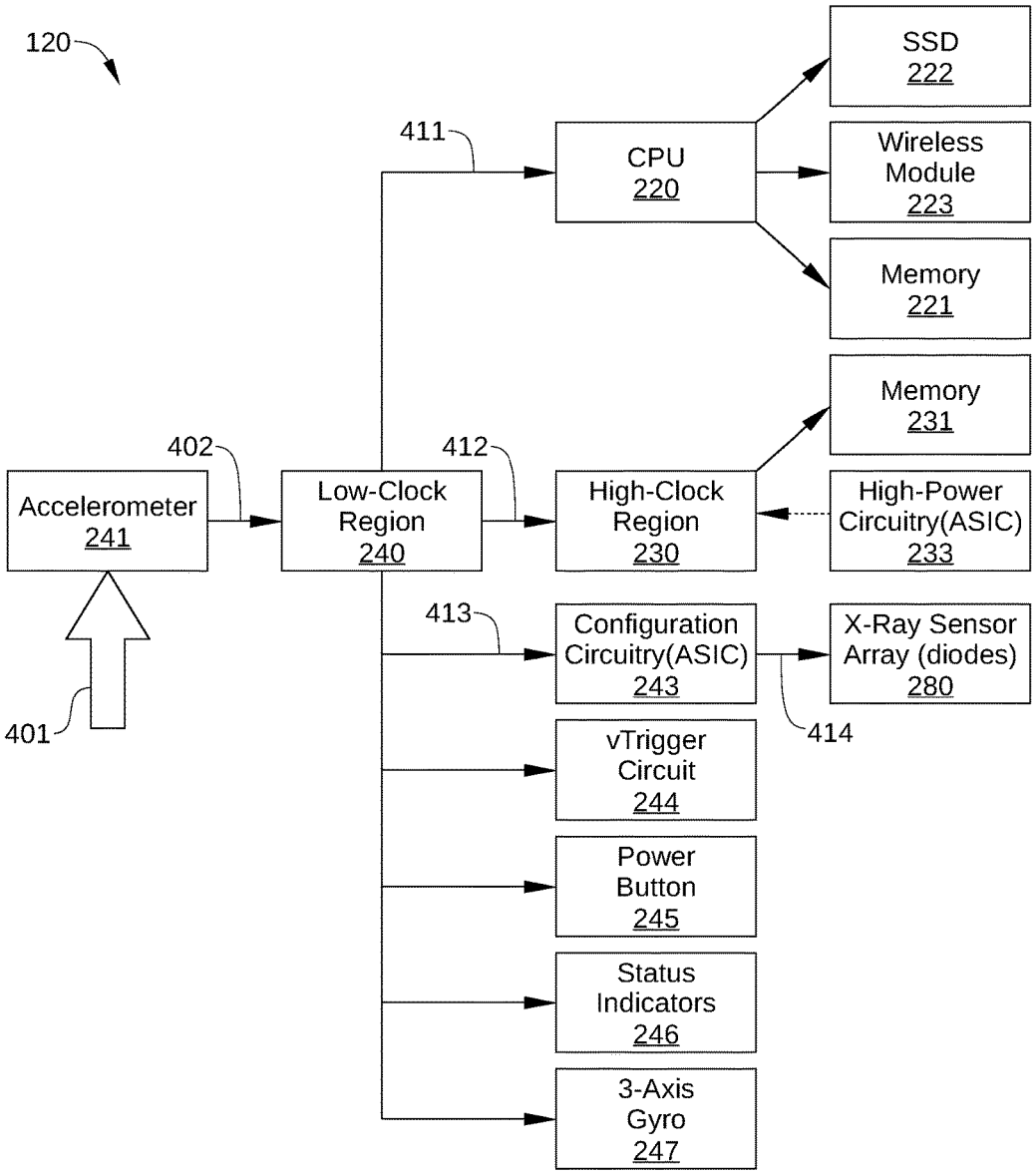

120
411
CPU
220
SSD
222
Wireless
Module
223
Memory
221
Memory
231
402
412
Accelerometer
241
Low-Clock
Region
240
High-Clock
Region
230
High-Power
Circuitry(ASIC)
233
413
Configuration
Circuitry(ASIC)
243
X-Ray Sensor
Array (diodes)
280
414
401
vTrigger
Circuit
244
Power
Button
245
Status
Indicators
246
3-Axis
Gyro
247

FIG. 4

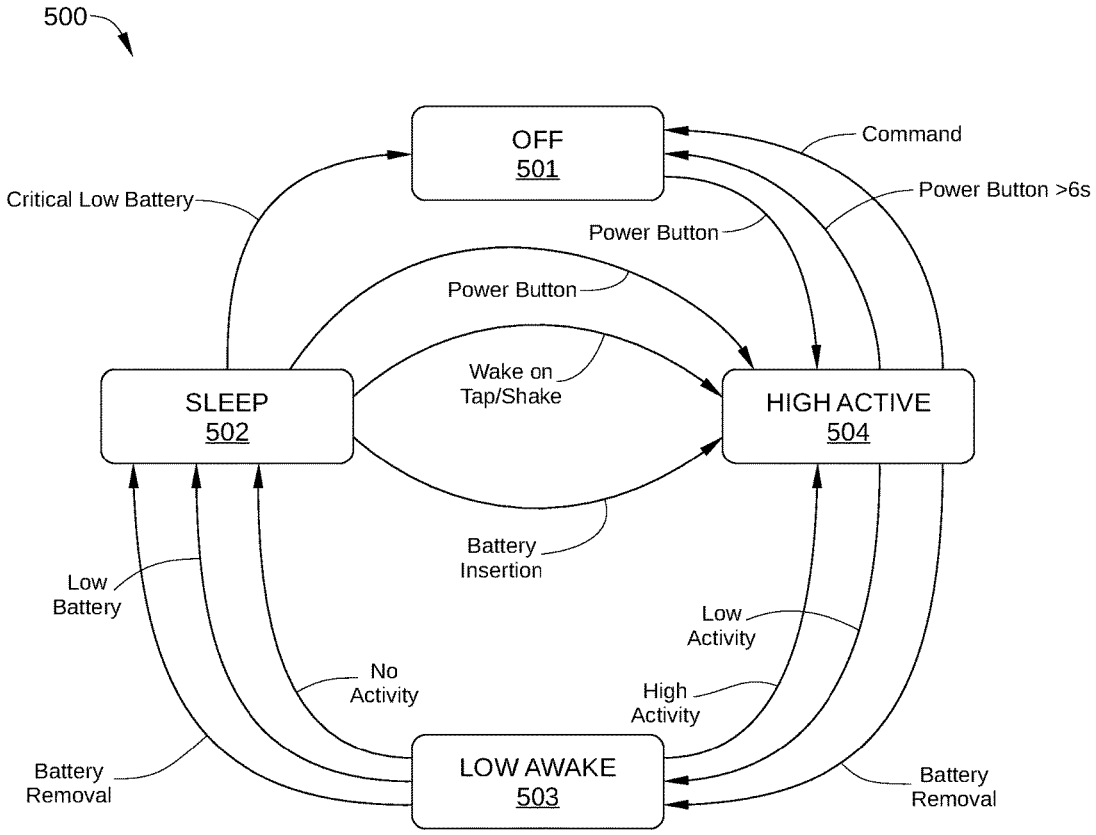

500
OFF
501
SLEEP
502
HIGH ACTIVE
504
LOW AWAKE
503
Command
Power Button >6s
Power Button
Power Button
Critical Low Battery
Wake on
Tap/Shake
Battery
Insertion
Low
Battery
Low
Activity
No
Activity
High
Activity
Battery
Removal
Battery
Removal

FIG. 5

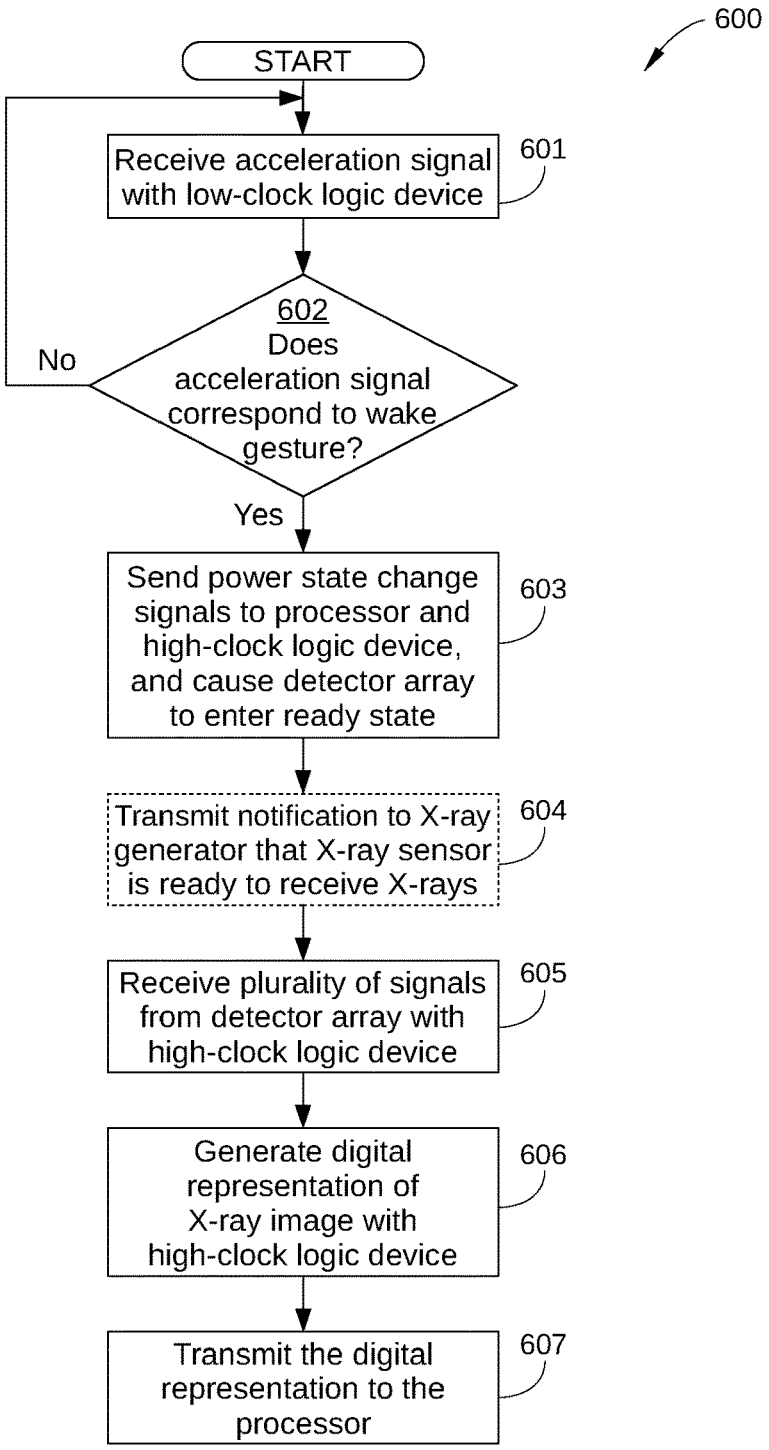

600
START
Receive acceleration signal with low-clock logic device
601
602
Does acceleration signal correspond to wake gesture?
No
Yes
Send power state change signals to processor and high-clock logic device, and cause detector array to enter ready state
603
Transmit notification to X-ray generator that X-ray sensor is ready to receive X-rays
604
Receive plurality of signals from detector array with high-clock logic device
605
Generate digital representation of X-ray image with high-clock logic device
606
Transmit the digital representation to the processor
607

FIG. 6

HAND-HELD X-RAY SENSOR WITH GESTURE-ACTIVATED WAKE FUNCTION

BACKGROUND

Unless otherwise indicated herein, the approaches described in this section are not prior art to the claims in this application and are not admitted to be prior art by inclusion in this section.

Digital radiography is a form of X-ray imaging in which digital X-ray sensors are used to generate digital X-ray images, and has multiple advantages over traditional film-based techniques. By bypassing chemical processing, digital radiography is more time efficient, provides digital images for immediate image preview, facilitates image enhancement, and generally requires less radiation to produce an image of similar contrast.

Digital radiography is now used in many applications, including medical diagnostics, veterinary care, dental imaging, industrial inspection, and security. Each of these applications could benefit from a completely portable implementation of a flat panel X-ray acquisition system, i.e., a battery-powered device with full image acquisition, enhancement, and data storage capabilities. Consequently, flat panel display X-ray sensors have been developed with a form factor that can be easily carried and employed as a self-contained, battery powered device. However, the power requirements of such hand-held X-ray sensors can severely limit how long they can be operated without being charged, limiting the utility of the hand-held configuration.

To address this issue, some hand-held X-ray sensors are configured with a sleep function that causes the X-ray sensor to enter a lower power state after a certain time interval has elapsed in which the X-ray sensor remains idle. Thus, when the X-ray sensor is not in use, power consumption of the X-ray sensor is greatly reduced. An important drawback to such a sleep function is that waking the X-ray sensor can be time-consuming and inconvenient. For example, in veterinary applications, the X-ray sensor is typically not in use while an animal to be X-rayed is made ready for imaging, the X-ray sensor is correctly positioned near the animal, and an image acquisition computer external to the X-ray sensor is set up for receiving image data. As a result, there are extended periods of time during which the X-ray sensor can remain in a lower power consumption state, such as an idle state or a sleep state, without impacting the user. Unfortunately, waking the X-ray sensor from such a state can involve a user interrupting a current task (e.g., minding the animal, positioning the X-ray sensor, or positioning the X-ray generator), walking to the image acquisition computer, paging through one or more menus on the image acquisition computer and performing one or more input operations, and returning to the interrupted task. Thus, while the sleep function can extend battery life of a hand-held X-ray sensor, the added inconvenience of such a feature can overshadow its benefits.

SUMMARY

In accordance with at least some embodiments of the present disclosure, a computer-implemented method for changing a power state in a hand-held X-ray sensing apparatus that includes a processor, an accelerometer, a high-clock logic device, a low-clock logic device, and a detector array, includes receiving an acceleration signal from the accelerometer, determining with the low-clock logic device that the acceleration signal corresponds to a wake gesture, and, in response to the determining, sending, from the low-clock logic device, a first power state change signal to the processor and a second power state change signal to the high-clock logic device, and causing the detector array to exit a stand-by state and enter a ready state in which image acquisition can be performed.

In accordance with at least some embodiments of the present disclosure, an X-ray sensing apparatus includes a detector array configured to generate a plurality of signals in response to x-rays incident on the detector array during an exposure period, a high-clock logic device communicatively coupled to the detector array, a low-clock logic device communicatively coupled to the high-clock logic device, an accelerometer communicatively coupled to the low-clock logic device, and a processor communicatively coupled to the high-clock logic device. The low-clock logic device is configured to receive an acceleration signal from the accelerometer, determine that the acceleration signal corresponds to a wake gesture, and, in response to the determining, send a first power state change signal to the processor and a second power state change signal to the high-clock logic device, and cause the detector array to exit a stand-by state and enter a ready state in which image acquisition can be performed.

The foregoing summary is illustrative only and is not intended to be in any way limiting. In addition to the illustrative aspects, embodiments, and features described above, further aspects, embodiments, and features will become apparent by reference to the drawings and the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other features of the present disclosure will become more fully apparent from the following description and appended claims, taken in conjunction with the accompanying drawings. These drawings depict only several embodiments in accordance with the disclosure and are, therefore, not to be considered limiting of its scope. The disclosure will be described with additional specificity and detail through use of the accompanying drawings.

FIG. **1** is a block diagram of a digital radiographic X-ray acquisition system, according to one or more embodiments of the present disclosure.

FIG. **2** schematically illustrates a hand-held detector of the digital radiographic X-ray acquisition system in FIG. **1**, according to one or more embodiments of the present disclosure.

FIG. **3** schematically illustrates a cross-sectional view of an X-ray sensor panel of the X-ray detector of FIG. **2**, according to one embodiment of the disclosure.

FIG. **4** is an operational block diagram of the flat-panel detector of FIG. **2**, according to one or more embodiments of the present disclosure.

FIG. **5** is a power state diagram for the flat-panel detector of FIG. **2**, according to various embodiments of the present disclosure.

FIG. **6** sets forth a flowchart summarizing an example method for waking a flat-panel detector from a sleep state, according to one or more embodiments of the present disclosure.

DETAILED DESCRIPTION

In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, similar symbols typically identify similar

components, unless context dictates otherwise. The illustrative embodiments described in the detailed description, drawings, and claims are not meant to be limiting. Other embodiments may be utilized, and other changes may be made, without departing from the spirit or scope of the subject matter presented here. It will be readily understood that the aspects of the disclosure, as generally described herein, and illustrated in the figures, can be arranged, substituted, combined, and designed in a wide variety of different configurations, all of which are explicitly contemplated and make part of this disclosure.

In light of the issues set forth in the background, there is a need in the art for a battery-powered X-ray sensor that addresses the above limitations of conventional X-ray sensors. According to embodiments of the present disclosure, a flat panel detector for a digital radiographic X-ray acquisition system is configured with a sleep or suspend function that reduces power consumption of certain components of the flat panel detector when idle, and a gesture-activated wake function that enables these components. In some embodiments, the wake gesture is a specific number of physical taps on an external surface of the X-ray panel sensor by the user, and the taps are detected by a low-power sensor that remains on in the sleep state, such as an accelerometer. Thus, the flat panel detector can be quickly brought out of the sleep state by a user while holding the flat panel detector. Consequently, delays and interruptions that result from maintaining the flat panel detector in a sleep state are minimized or otherwise reduced.

FIG. **1** is a block diagram of a digital radiographic X-ray acquisition system **100**, according to one or more embodiments of the present disclosure. Digital radiographic X-ray acquisition system **100** is a digital radiography system that is configured to generate raw digital X-ray image data based on incident X-rays, and generate digital images based on the raw digital X-ray image data. As shown, digital radiographic X-ray acquisition system **100** includes an X-ray generator **110** and an X-ray sensor panel **120** that is wirelessly connected to a workstation **140**, which in turn can connect to remote servers **160** via a network **105**. In some embodiments, workstation **140** connects to remote servers **160** via a wireless access point (not shown). Alternatively or additionally, in some embodiments, X-ray sensor panel **120** is configured to wirelessly connect to remote servers **160** directly via network **105** and/or a wireless access point.

Network **105** may be any technically feasible type of communications network that allows data to be exchanged between digital radiographic X-ray acquisition system **100** and remote servers **160**. Examples of network **105** may include a wide area network (WAN), a local area network (LAN), a wireless (WiFi) network, and/or the Internet, among others.

X-ray generator **110** can be any suitable X-ray source for emitting X-ray photons, such as an X-ray tube. Generally, X-ray generator **110** is controlled by workstation **140** or other computing device, via a wired or wireless connection. Specifically, workstation **140** enables selection of X-ray attributes suitable for a specific image acquisition or acquisition session. For example, workstation **140** can control the power supply of X-ray generator **110**, thereby producing a desired peak kilovoltage (kVp), current, and duration of exposure.

Remote servers **160** are computing devices in which reside information pertinent to operation of X-ray sensor panel **120**, such as user data, patient data, previously performed studies, and previously acquired images associated therewith. For example, in some embodiments, remote servers **160** include one or more Digital Image and Communications in Medicine (DICOM) servers, such as a DICOM picture archiving and communication system (PACS) storage server and/or a DICOM PACS review workstation. Such servers provide storage and convenient access to medical images from multiple modalities, thereby enabling a user of X-ray acquisition system **100** to immediately access previously generated medical images and/or studies associated with a particular patient or project.

Workstation **140** may be any technically feasible computing device that includes a display device **141**, for displaying a user interface (UI) and is capable of wirelessly connecting to X-ray sensor panel **120**, such as a (touch-sensitive or conventional) display screen. For example, in some embodiments, workstation **140** may be desktop or laptop computer that is configured to interact with (e.g., receive output from and provide input to) X-ray sensor panel **120**. In other embodiments, workstation **140** may be a suitably programmed mobile computing device, such as a smartphone, a wearable computing device, or an electronic tablet. In either case, workstation **140** includes a wireless module **142** for enabling communication with X-ray sensor panel **120**, and is programmed with one or more FPD control applications **143** that enable user interactions with X-ray sensor panel **120**, such as configuring X-ray sensor panel **120**, operating X-ray sensor panel **120**, and performing FPD calibration procedures. In addition, in some embodiments, workstation **140** is programmed with an image processing application **144** for processing image data received from X-ray sensor panel **120**. Image processing application **144** includes one or more applications for processing image data received from X-ray sensor panel **120** to generate a digital image. For example, in some embodiments, image processing application **144** may be configured to convert a digital representation or other image data into a digital image in a specific image file format and/or to modify the resultant digital image. Alternatively or additionally, in some embodiments, image processing application **144** may provide image processing capability for radiographic (still-picture X-ray) applications and/or fluoroscopic (video X-ray) applications. Alternatively or additionally, in some embodiments, image processing application **144** can include patient study editing software, image review and/or annotation software, image reprocessing software, and the like. Thus, once a digital representation is received from X-ray sensor panel **120**, image generation and post-processing can be performed independently from the operation of X-ray sensor panel **120**.

In some embodiments, workstation **140** may be further configured to query, over a network, a list of patients and studies to be performed, such as a DICOM Modality Worklist Server or other remote server **160**; to locally store a list of patients and studies to be performed, similar to a DICOM Modality Worklist Server; to provide a user interface to access a locally stored patient/study list; to maintain a local record of studies performed and images acquired, such as a panel-resident version of a DICOM PACS; to provide a user interface to view and/or review such studies; and to transmit studies performed, including images, directly to one or more of remote servers **160**.

X-ray sensor panel **120** is a battery-powered, wireless, radiographic flat panel detector that has a power state architecture that includes a sleep state for significantly reducing power consumption of X-ray sensor panel **120** when X-ray images are not being acquired. Specifically, upon entering the sleep state, certain components of X-ray sensor panel **120** are powered down, while other components of X-ray sensor panel **120** operate in a lower power

state than when X-ray sensor panel **120** is in an active power state. In addition, X-ray sensor panel **120** includes a wake function that enables a user holding X-ray sensor panel **120** to cause X-ray sensor panel **120** to exit the sleep state via a wake gesture. By contrast, a user generally releases a conventional FPD from a sleep state by accessing a particular application on a workstation associated with X-ray sensor panel **120** and performing one or more input operations in the application. On embodiment of X-ray sensor panel **120** is illustrated in FIG. **2**.

FIG. **2** is a block diagram of X-ray sensor panel **120**, according to one or more embodiments of the present disclosure. As shown, X-ray sensor panel **120** includes a central processing unit (CPU) **220**, an image acquisition processor **250** with a high-clock region **230** and a low-clock region **240**, and a plurality of application-specific integrated circuits (ASICs) **270** coupled to an X-ray sensor array **280**. CPU **220** is communicatively coupled to various devices, including one or more of a memory **221**, a solid-state drive (SSD) **222** or other non-volatile data storage medium, and a wireless module **223**. High-clock region **230** of image acquisition processor **250** is communicatively coupled to a memory **231**, sensors **232**, and high-power circuitry **233** of ASIC **270**. Low-clock region **240** of image acquisition processor **250** is communicatively coupled to an accelerometer **241**, bias circuitry **242**, configuration circuitry **243** of ASIC **270**, a voltage trigger (vTrigger) circuit **244**, a power button **245**, one or more status indicators **246**, a three-axis gyro **247**, and one or more additional devices **248**.

CPU **220** may be any suitable processor implemented as a CPU, an application-specific integrated circuit (ASIC), a field programmable gate array (FPGA), any other type of processing unit, or a combination of different processing units. In some embodiments, CPU **220** is a Smart Mobility Architecture (SMARC) ×86-based processor. In general, processing unit **220** may be any technically feasible hardware unit capable of processing data and/or executing software applications residing in memory **221**, including an operating system (OS) **225**, and, in some embodiments, FPD control application **143** and image processing application **144**. CPU **220** is configured to read data from and write data to memory **221**. Memory **221** may include a random access memory (RAM) module, a flash memory unit, any other type of memory unit, or a combination thereof. Memory **221** includes various software programs that can be executed by CPU **220** and application data associated with said software programs, including OS **225**. In some embodiments, FPD control application **143** and/or image processing software **144** reside in memory **221**. In the embodiment illustrated in FIG. **2**, memory **221** is depicted as a separate device from CPU **220**, but in other embodiments memory **221** can be included in CPU **220**.

OS **222** supports the functions of CPU **220**, including scheduling tasks and executing FPD control application **143** and/or image processing software **144**, sending commands to SSD **222** and wireless module **223**, and managing the power state of CPU **220**.

SSD **222** provides non-volatile storage for previously acquired data or medical images, studies associated with a particular patient or project, and/or software applications. Wireless module **223** may be any technically feasible wireless chips, cards, or other devices that enable X-ray sensor panel **120** to communicate wirelessly with workstation **140** in FIG. **1** and/or with network **105** in FIG. **1**. Examples of devices suitable for use as wireless module **223** include a WiFi module, a WLAN module, a 3G module, and the like. For example, in some embodiments, wireless module **223** is a 802.11ac/n device capable of providing a WiFi Direct connection to workstation **140**. Alternatively or additionally, in some embodiments, wireless module **223** is a device capable of providing a Bluetooth connection to workstation **140**. Thus, in some embodiments, wireless module **223** includes two antennas and is capable of both WiFi and Bluetooth operation simultaneously.

In some embodiments, image acquisition processor **250** is a separate processor from CPU **220** that controls and otherwise interacts with the image acquisition hardware of X-ray sensor panel **120**. As such, image acquisition processor **250** may be any suitable processor implemented as a CPU, an ASIC, an FPGA, any other type of processing unit, or a combination of different processing units. In general, image acquisition processor **250** may be any technically feasible hardware unit capable of controlling the image acquisition hardware of X-ray sensor panel **120**, receiving signals from the readout electronics of X-ray sensor array **280**, generating a digital representation of an x-ray image based on the received signals, and transmitting the digital representation to CPU **220** for image processing. In other embodiments (not shown), image acquisition processor **250** is integrated with CPU **220**.

In some embodiments, image acquisition processor **250** is an FPGA that includes high-clock region **230** and low-clock region **240**. In such embodiments, the functionality of image acquisition processor **250** as described herein is implemented as image acquisition firmware that resides in high-clock region **230**, low-clock region **240**, or a combination of both. High-clock region **230** is a high-clock-rate logic device that performs time-dependent and/or computationally intensive actions, such as receiving signals from ASICs **270** during image acquisition, storing image-acquisition data in memory **231**, processing image-acquisition data, etc. Low-clock region **240** is a low-clock-rate logic device that performs less computationally intensive and/or less time-sensitive operations, such as changing the current configuration of ASICs **270** via configuration circuitry **243** and controlling and/or processing signals from accelerometer **241**, vTrigger circuit **244**, power button **245**, status indicators **246**, 3-axis gyro **247**, and/or other devices **248**. In some embodiments, high-clock region **230** and low-clock region **240** are different portions of a single integrated circuit (IC) chip. In other embodiments, high-clock region **230** and low-clock region **240** are each implemented as separate IC logic chips.

Low-clock region **240** operates at a significantly lower clock rate and consumes significantly less power than high-clock region **230**. For example, in one embodiment, low-clock region **240** operates at a clock-rate of about 24 MHz and consumes on the order of about 0.3 W while in typical operation, while high-clock region **230** operates at a clock-rate of about 200-400 MHz and consumes on the order of about 3-5 W while in typical operation, such as during image acquisition. Thus, low-clock region **240** can remain powered during a sleep or an idle mode without significantly reducing the useful battery life of X-ray sensor panel **120**. It is noted that high-clock region **230** generally performs functions of image acquisition processor **250** that are only used in an active state and are not employed while X-ray sensor panel **120** is in a sleep state, such as image acquisition functions. Thus, high-clock region **230**, and the functions of X-ray sensor panel **120** performed thereby, can be powered down while X-ray sensor panel **120** is in a sleep state without affecting the functionality of X-ray sensor panel **120**.

Accelerometer **241** may be any technically feasible accelerometer configured to detect acceleration of X-ray sensor

panel **120** and to generate and transmit a corresponding acceleration signal to image-acquisition processor **250**. In some embodiments, accelerometer **241** is configured to detect acceleration of X-ray sensor panel **120** along one axis. Alternatively or additionally, accelerometer **241** is configured to detect acceleration of X-ray sensor panel **120** along two and/or three axes. In some embodiments, accelerometer **241** includes one or more analog devices **241**A that generate an analog signal indicating a measured acceleration of X-ray sensor panel **120** along one or more axes, such as a microelectromechanical systems (MEMS) accelerometer. In other embodiments, accelerometer **241** includes one or more additional devices (not shown) that generate a digital signal indicating a measured acceleration of X-ray sensor panel **120** along one or more axes. Thus the acceleration signal generated by accelerometer **241** can be an analog or digital signal.

In some embodiments, accelerometer **241** further includes a digital signal processor (DSP) **241**B or other processor configured to perform one or more filtering functions on the acceleration signal generated by analog device(s) **241**A. Thus, in such embodiments, the acceleration signal generated by accelerometer **241** can be a filtered signal. Such filtering functions can modify the acceleration signal so that accelerations resulting from a wake gesture can be more readily distinguished by suitable logic located in DSP **241**B or in low-clock region **240**.

According to various embodiments, a wake gesture performed by a user includes a specific number of physical taps on an external surface of X-ray sensor panel **120** by the user. For example, in such embodiments, the wake gesture may be a double-tap that occurs within a specified time interval, e.g., one second. Alternatively or additionally, in some embodiments, the wake gesture includes physically tapping a surface of the X-ray sensor panel **120** against an external object, such as a wall or floor, for a specific number of times within a specified time interval, e.g., one second. Alternatively or additionally, in some embodiments, the wake gesture includes shaking X-ray sensor panel **120** for a specified time interval. It is noted that other causes of acceleration of X-ray sensor panel **120** generally have a different rise time, magnitude, harmonic profile, and/or other detectable characteristics than a tap-based wake gesture, and therefore can be eliminated or reduced from an acceleration signal by the filtering functions performed by DSP **241**B. For example, accidentally bumping X-ray sensor panel **120** against an object, dropping X-ray sensor panel **120**, or transporting X-ray sensor panel **120** in a motor vehicle can all cause significant accelerations of X-ray sensor panel **120**. However, filtering function included in DSP **241**B can reduce the likelihood that such accelerations are erroneously determined to indicate a user-initiated wake gesture. Thus, when DSP **241**B performs these filtering functions, detection of the accelerations typical of a user performing a wake gesture is greatly facilitated.

In some embodiments, DSP **241**B may also be configured with logic to determine whether accelerations measured by analog device(s) **241**A indicate that a user has performed a wake gesture, such as when X-ray sensor panel **120** is tapped against an object by a user, or when a user manually taps a surface of X-ray sensor panel **120**. In such embodiments, the acceleration signal transmitted to low-clock region **240** by accelerometer **241** is an indicator signal that notifies low-clock region **240** that a wake gesture has been identified. Alternatively, in other embodiments, such logic is included in low-clock region **240**. In such embodiments, the acceleration signal from accelerometer **241** may be an analog or digital signal indicating accelerations experienced by X-ray sensor panel **120**.

Bias circuitry **242** is configured to apply a small negative voltage, for example approximately −1 V, to the light-detecting diodes of X-ray sensor array **280** when X-ray sensor panel **120** is in a sleep mode. With this low voltage applied thereto, the light-detecting photodiodes of X-ray sensor array **280** can be quickly brought to an active state in which image acquisition can be performed in response to incident X-ray photons. In addition, bias circuitry **242** is configured to apply a higher negative bias to the photodiodes of X-ray sensor array **280** (for example −3 to −5 V) to increase the response time and signal output of the photodiodes. Biasing the photodiodes in this way increases the signal output by modifying the conditions experienced by the diodes when incident X-ray photons are received.

VTrigger circuit **244** is configured to detect incident X-rays on X-ray sensor array **280** when the photodiodes of X-ray sensor array **280** are in a low-power, ready state, i.e., when bias circuitry **242** applies a voltage to the photodiodes of X-ray sensor array **280**. In addition, vTrigger circuit **244** is configured to send a notification to low-clock region **240** that incident X-rays have been detected. Low-clock region **240** then triggers image acquisition by causing the photodiodes of X-ray sensor array **280** to enter an active state via bias circuitry **242** and configuration circuitry **243**.

Power button **245** enables various user inputs to control the power state of CPU **220**, image acquisition processor **250**, and/or X-ray sensor panel **120** as a whole. For example, in some embodiments, when X-ray sensor panel **120** is off, pressing power button **245** for more than a certain time interval, such as one second, results in image acquisition processor **250** turning on and booting up. In some embodiments, when X-ray sensor panel **120** is operating in an active state, pressing power button **245** for a longer time interval, for example between one and three seconds, results in X-ray sensor panel **120** exiting any lower power state, such as an idle state or a sleep state, and entering a normal operating power state. In some embodiments, when X-ray sensor panel **120** is operating in an active state, pressing power button **245** for a still longer time interval, for example between three and six seconds, results in X-ray sensor panel **120** attempting to shut down. In some embodiments, when X-ray sensor panel **120** is operating in an active state, pressing power button **245** for an even longer time interval, for example greater than six seconds, results in CPU **220** and image acquisition processor **250** immediately shutting down. In other embodiments, any other technically feasible user input scheme may be employed in conjunction with power button **245** to cause FDP **120** to enter a certain power state.

Status indicators **246** include visual indicators, such as one or more color-coded light-emitting diodes (LEDs) and/or audible indicators, such as one or more buzzers or speakers. Status indicators **246** can provide information to a user associated with one or more of current power state, battery state, wireless communication state, system state, completion of a current image acquisition, and the like.

3-axis gyro **261** indicates the precise orientation of X-ray sensor panel **120** during X-ray image acquisition, even when there is motion of X-ray sensor panel **120** at that time. Thus, metadata indicating up/down/left/right for a particular image can be collected at the time of image acquisition. In some embodiments, accelerometer **241** can also indicate when X-ray sensor panel **120** has been bumped, thereby preventing signals generated by X-ray sensor array **280** during such

a bump from being interpreted as an image signal generated in response to incident X-rays.

Other devices may also be included in X-ray sensor panel **120** and communicatively coupled to low-clock region **240**, including one or more digital-to-analog converts (DACs) and/or analog-to-digital converters (ADCs), a power monitor, a shock sensor, a battery or supercapacitor, temperature sensors, and the like.

ASICs **270** include the readout electronics and analog devices for measuring voltage generated by the amorphous silicon photodiodes of X-ray sensor array **280**. For example, in some embodiments, ASICs **270** include analog ASIC devices that each generate a voltage that is proportional to incident visible light on a particular pixel region of X-ray sensor array **280**. As shown, ASICs **270** include high-power circuitry **233** and configuration circuitry **243**. High-power circuitry **233** is energized during image acquisition to read out charge generated by the photodiodes of X-ray sensor array **280**. Configuration circuitry **243** connects each ASIC in ASICs **270** with image acquisition processor **250** to enable changing the power state and otherwise controlling each ASIC in ASICs **270**. For example, in some embodiments, configuration circuitry **243** includes a configuration bus. High-power circuitry **233** is energized during image acquisition, but is not powered when X-ray sensor panel **120** is in a ready state, i.e., ready to receive incident X-rays, or when X-ray sensor panel **120** is in a sleep state. By contrast, configuration circuitry **243** is generally energized when X-ray sensor panel **120** is in the ready state or in a sleep state.

X-ray sensor array **280** includes a glass plate with a matrix or array of pixel detector elements formed thereon that each convert incident X-ray photons to electrical charge. In embodiments in which X-ray sensor panel **120** is configured as an indirect flat panel detector, a scintillator material in X-ray sensor panel **120** is excited by incident X-rays and emits light, which is detected by a plurality of photodiodes. Each photodiode generates a signal (e.g., a voltage that is proportional to incident light intensity) for a different pixel of what will eventually become a digital image. An encoder (which may be, for example, included in high-clock region **230**) then interprets each of these voltages and assigns a value to each that is proportional to the voltage. One such embodiment of X-ray sensor array **280** is illustrated in FIG. **3**.

FIG. **3** schematically illustrates a cross-sectional view of X-ray sensor array **280**, according to one embodiment of the disclosure. As shown, X-ray sensor array **280** includes a photosensitive element and detector circuitry layer **301** formed on a substrate **302** and a layer of scintillator material **303** formed on photosensitive element and detector circuitry layer **301**. Also shown are incident X-rays **309** that have passed through a patient, sample, or other object of interest after being generated by X-ray generator **110**. Together, photosensitive element and detector circuitry layer **301**, substrate **302**, and scintillator material **303** form an X-ray imaging matrix **305**. It is noted that photosensitive element and detector circuitry layer **301** is generally formed from a plurality of processing layers, and that X-ray imaging matrix **305** may include additional material layers not illustrated in FIG. **3**.

Photosensitive element and detector circuitry layer **301** generally includes a plurality of photosensitive elements, such as photodiodes, photogates, phototransistors, or any other suitable circuitry suitable for operation as pixel detector elements in X-ray sensor array **280**. For example, photosensitive element and detector circuitry layer **301** may also include thin-film transistors (TFTs) for reading out the digital signals from the pixel detector elements. Scintillator material **303** may include one or more material layers including, but not limited to, gadolinium oxisulfide (Gd_2O_2S:Tb), cadmium tungstate ($CdWO_4$), bismuth germanate ($Bi_4Ge_3O_{12}$ or BGO), cesium iodide (CsI), or cesium iodide thallium (CsI:TI)), among others.

In the embodiment illustrated in FIG. **3**, X-ray sensor array **280** is depicted as an indirect flat panel detector, in which X-ray photons are converted to other light photons that are in turn detected and converted into charge. In other embodiments, X-ray sensor array **280** can be a direct flat panel detector. In a direct FPD, incident X-ray photons are converted directly into charge in an amorphous selenium layer, and the resultant charge pattern therein is read out by suitable hardware, such as a thin-film transistor (TFT) array, an active matrix array, microplasma line addressing, or the like.

FIG. **4** is an operational block diagram of X-ray sensor panel **120** waking from a sleep state in response to a wake gesture, according to one or more embodiments of the present disclosure. The sleep state is a power conserving state in which some or most components of X-ray sensor panel **120** are not powered. The sleep state can be substantially equivalent to the S3 sleep state in embodiments in which X-ray sensor panel **120** is a Windows-based system, the sleep mode or hibernate mode 0 in embodiments in which X-ray sensor panel **120** is a MacOS-based system, or the suspend mode in embodiments in which X-ray sensor panel **120** is a Linux-based system. Such a power state is referred to generically herein as a "sleep state".

As shown, when accelerometer **241** receives a wake gesture **401** while in a sleep state, accelerometer **241** sends an acceleration signal **402** to low-clock region **240**. Low-clock region **240** determines, based on acceleration signal **402**, that a wake gesture has been performed by a user on X-ray sensor panel **120**, and transmits a first power state change signal **411** to CPU **220**, such as a Peripheral Component Interconnect Express (PCIe) wake signal, and a second power state change signal **412** to high-clock region **230**. In addition, low-clock region **240** causes the photodiodes of X-ray array **280** to exit a stand-by state and enter a ready state in which image acquisition can be performed. For example, in some embodiments, low-clock region **240** transmits a ready panel signal **413** to configuration circuitry **243**. Configuration circuitry **243** then biases the photodiodes of X-ray array **280** with a higher negative voltage **414** than when in the stand-by state, thereby making X-ray sensor array **280** ready to generate image data when X-ray photons are incident thereon. In some embodiments, in response to determining that a wake gesture has been performed by the user on X-ray sensor panel **120**, low-clock region **240** also transmits one or more additional power state change signals, such as activation signals, as shown, to one or more of vTrigger circuitry **243**, power button **245**, status indicators **246**, and three-axis gyro **247**.

In response to receiving first power state change signal **411**, CPU **220** enters a higher power state than the sleep state, and activates one or more of memory **221**, SSD **222**, and wireless module **223**. For example, in embodiments in which CPU **220** receives the first power state change signal **411** while in an S3 sleep state, in response CPU **220** enters a higher power consumption state than the S3 sleep state, such as a low-power-but-active power consumption state (e.g., an S0 low awake state in a Windows-based system), or a high active state (e.g., an S0 high active state in a Windows-based system). In such embodiments, in the low-

power-but-active power consumption state, CPU **220** is awake and ready to receive image data and/or to perform image data processing, whereas in the high active state, CPU **220** operates in a standard operating state, and is generally receiving image data from high-clock region **230** and/or processing such image data.

In response to receiving second power state change signal **412**, high-clock region **230** changes from a lower-power state, such as an un-powered state, to a higher power state, such as a ready state or an active state. For example, in some embodiments, in the ready state, high-clock region **230** is ready to receive signals from high-power circuitry **233** of ASICs **270** in response to incident X-rays striking X-ray sensor array **280**. In addition, in the active state, high-clock region **230** is receiving and processing such signals from ASICs **270**.

FIG. **5** is a power state diagram **500** for X-ray sensor panel **120**, according to various embodiments of the present disclosure. As shown, X-ray sensor panel **120** operates in four different power states: an off state **501**, a sleep state **502**, a low awake state **503**, and a high active state **504**.

In sleep state **502**, no software is operating in CPU **220**, memory **221** is in a refresh mode, and SSD **222** and wireless module **223** are powered down. In addition, high-clock region **230** of image acquisition processor **250** is powered down, as well as memory **231**, other sensors **232**, and high-power circuitry **233** of ASICs **270**. By contrast, **502**, low-clock region **240**, configuration circuitry **243**, and bias circuitry **242** are powered on in sleep state **502**. In addition, the photodiodes of X-ray sensor array **280** have a low negative bias applied thereto (for example −1 V), and can be quickly made ready to receive light generated by X-ray photons incident on X-ray sensor array **280**.

In some embodiments, sleep state **502** is substantially similar to an S1, S2, or S3 sleep state for CPU **220**. In such embodiments, X-ray sensor panel **120** enters high active state **504** when power button **245** is depressed for a particular duration of time (for example, one to three seconds), when a battery insertion event is detected (for example by low-clock region **240**), or when a wake gesture is detected by low-clock region **240**. In some embodiments, when a wake gesture is detected by low-clock region **240**, low-clock region **240** employs a PCIe wake mechanism to cause CPU **220** to enter high active state **504** from sleep state **502**. X-ray sensor panel **120** enters sleep state **502** from low awake state **503** in response to low battery detection, detection of a battery removal event, or no activity for more than a maximum time threshold, for example 30 seconds. X-ray sensor panel **120** enters off state **501** from sleep state **502** when a critical battery power is detected.

In low awake state **503**, CPU **220** operates in a low-power-but-active power consumption state. For example, for Windows-based systems low awake state **503** may be substantially similar to an S0 low awake state or a Deepest Runtime Idle Platform State (DRIPS). Thus, low awake state **503** is a lower power consumption state than a normal operating state, such as high active state **504**, but CPU **220** is awake and ready to receive image data and/or to perform image data processing. As such, operating system **225** executes on CPU **220**, but power consumption by operating system **225** is minimized or otherwise reduced relative to when CPU **220** is in high active state **504**. In some embodiments, one or more cores included in CPU **220** may be parked or otherwise powered down in low awake state **503**. In some embodiments, SSD **222** and wireless module **223** are also powered on in low awake state **503**. In addition, in low awake state **503**, high-clock region **230**, low-clock region **240**, memory **231**, and vTrigger circuit **244** are powered on and active. Further, the photodiodes of X-ray sensor array **280** have a negative bias applied thereto (for example −3 to −5 V) and are ready to receive light generated by X-ray photons incident on X-ray sensor array **280**. In some embodiments, one or more additional components of X-ray sensor panel **120** are also powered on in low awake state **503**, including power button **245**, one or more status indicators **245**, 3-axis gyro **247**, and additional devices **248**. Alternatively, in some embodiments, one or more of the above-described additional component of X-ray sensor panel **120** are not powered on in low awake state **503**, and are instead only powered on in high active state **504**.

X-ray sensor panel **120** enters low awake state **503** from high active state **504** in response to low activity detection. Low activity detection can be performed by CPU **220** or by image acquisition processor **250**, and can occur when: no user inputs are received for a time interval exceeding a predetermined threshold; the activity level of CPU **220** is such that one or more cores of CPU **220** can be parked or otherwise powered down; and/or image acquisition processor **250** completes transmission of image data to CPU **220**. In some embodiments, X-ray sensor panel **120** also enters low awake state **503** upon detection of a battery removal event. X-ray sensor panel **120** exits low awake state **503** and enters high active state **504** when high activity is detected. Such high activity detection can be performed by CPU **220** or by image acquisition processor **250**, and can occur when: user inputs are received via wireless module **223** from workstation **140**; image acquisition processor **250** begins transmission of image data to CPU **220**; and/or the activity level of CPU **220** is such that one or more cores of CPU **220** need to be powered up or otherwise activated, such as when image data are being received from image acquisition processor **250**, documents or image data are being received or transmitted via wireless module **223**, image processing is being performed with CPU **220**, etc.

In high active state **504**, CPU **220** operates in a standard operating state, such as an S0 high active state. Thus, high active state **504** is a higher power consumption state than low awake state **503**, and CPU **220** is awake and receiving image data and/or performing image data processing. In addition, in high active state **504**, high-clock region **230**, low-clock region **240**, memory **231**, high-power circuitry **233**, and vTrigger circuit **244** are powered on and active. Further, the photodiodes of X-ray sensor array **280** have a larger negative bias applied thereto (for example −3 to −5 V) and are ready to receive light generated by X-ray photons incident on X-ray sensor array **280**, and/or are receiving such light.

X-ray sensor panel **120** enters high active state **504** from off state **501** in response to power button **245** being depressed, and from low awake state **503** in response to detecting a high activity level, as described above. X-ray sensor panel **120** enters off state **501** from high active state **504** in response to power button **245** being depressed for an extended time interval, such as greater than six seconds, or in response to a software command, for example via a user input to workstation **140**. According to various embodiments, X-ray sensor panel **120** enters high active state **504** from sleep state **502** in response to determining that a wake gesture is performed by a user. Specifically, X-ray sensor panel **120** enters high active state **504** from sleep state **502** when low-clock region **240** receives an acceleration signal from accelerometer **241** and determines that the acceleration signal corresponds to a wake gesture. In some embodiments,

X-ray sensor panel **120** also enters high active state **504** from sleep state **502** in response to power button **245** being depressed.

As illustrated by power state diagram **500**, X-ray sensor panel **120** is configured to minimize or otherwise reduce power consumption when in sleep state **502**, and to quickly enter high active state **504** based on a wake gesture. Specifically, by reducing power consumption of CPU **220** and powering off non-essential components of X-ray sensor panel **120** in sleep state **502**, battery life of X-ray sensor panel **120** is extended. It is noted that for a typical processor, power consumption in high active state **504** may be on the order of about 20 W, power consumption in low awake state **503** may be on the order of about 5 W, and power consumption in sleep state **502** may be on the order of about 0.5 W. In addition, by powering components of X-ray sensor panel **120** in sleep state **502** that enable detection of a wake gesture that is performed by a user, X-ray sensor panel **120** can be quickly and conveniently brought to high active state **504**. Thus, a user can wake X-ray sensor panel **120** without using inputs via workstation **140**

FIG. **6** sets forth a flowchart summarizing an example method for waking a flat-panel detector from a sleep state, according to one or more embodiments of the present disclosure. The method may include one or more operations, functions, or actions as illustrated by one or more of blocks **601-607**. Although the blocks are illustrated in a sequential order, these blocks may be performed in parallel, and/or in a different order than those described herein. Also, the various blocks may be combined into fewer blocks, divided into additional blocks, and/or eliminated based upon the desired implementation. Although the method is described in conjunction with digital radiographic X-ray acquisition system **100** of FIGS. **1-5**, persons skilled in the art will understand that any suitably configured radiographic system is within the scope of the invention.

Prior to the method step, X-ray sensor panel **120** enters sleep state **502**. In some embodiments, X-ray sensor panel **120** enters sleep state **502** in response to a user entering a sleep command via workstation **140** to X-ray sensor panel **120** while X-ray sensor panel **120** is in low awake state **503**. In some embodiments, X-ray sensor panel **120** enters sleep state **502** in response to detecting that no activity has occurred for a time interval that exceeds a predetermined duration, for example 30 seconds. In such embodiments, no activity is considered detected when no image data from x-ray sensor array **280** is received by image acquisition processor **250** and no image data processing (including sending and receiving image data) is performed by CPU **220**. It is noted that accelerometer **241** and low-clock region **240** are both activated in sleep state **502**.

A method **600** begins at step **601**, in which low-clock region **240** receives an acceleration signal from accelerometer **241**.

In step **602**, low-clock region **240** determines whether the acceleration signal received in step **601** corresponds to a wake gesture being performed by a user on X-ray sensor panel **120**. If no, method **600** proceeds back to the start and low-clock region **240** continues to listen for an acceleration signal; if yes, method **600** proceeds to step **603**. As noted above, a wake gesture can include a specified number of taps (for example, two), within a specified time interval (for example, one second) on a surface of X-ray sensor panel **120**. Alternatively or additionally, a wake gesture can include tapping of X-ray sensor panel **120** against an object for a specified number of times within a specified time interval. Alternatively or additionally, a wake gesture can include shaking X-ray sensor panel **120** for a minimum number of back-and-forth iterations or for a time interval greater than a minimum time duration.

In step **603**, low-clock region **240** sends a first power state change signal to CPU **220** and a second power state change signal to high-clock region **230**, and causes the photodiodes of X-ray array **280** to exit a stand-by state and enter a ready state in which image acquisition can be performed. In the ready state, a higher negative bias is applied to the photodiodes of X-ray sensor array **280** than in the stand-by state.

In optional step **604**, X-ray sensor panel **120** transmits a notification to X-ray generator **110** via wireless module **223** that X-ray sensor panel **120** is ready to receive X-rays.

In step **605**, high-clock region **230** receives a plurality of signals from ASICs **270** in response to X-ray photons incident on X-ray sensor array **280**.

In step **606**, high-clock region **230** generates a digital representation of an X-ray image. For example, the digital representation may include an intensity value for each pixel of X-ray sensor array **280**, as well as suitable metadata associated with the intensity values. In some embodiments, some or all of the digital representation is temporarily stored in memory **231** until transmitted to CPU **220**.

In step **607**, high-clock region **230** transmits the digital representation of the X-ray image to CPU **220** for subsequent data processing or transmission to workstation **140**.

In sum, a flat panel detector for a digital radiographic X-ray acquisition system is configured with a sleep function that reduces power consumption of certain components of the flat panel detector when idle, and a gesture-activated wake function that enables these components. In some embodiments, the wake gesture includes a specific number of physical taps on an external surface of the X-ray panel sensor by the user, which can be detected by a low-power sensor that remains on in the sleep state, such as an accelerometer. Thus, the flat panel detector can be quickly brought out of the sleep state by a user while holding the flat panel detector. Consequently, delays and interruptions that result from maintaining the flat panel detector in a sleep state are minimized or otherwise reduced.

While various aspects and embodiments have been disclosed herein, other aspects and embodiments will be apparent to those skilled in the art. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope being indicated by the following claims.

We claim:

1. A computer-implemented method for changing a power state in a hand-held X-ray sensing apparatus including a processor, an accelerometer, a high-clock logic device, a low-clock logic device, and a detector array, the method comprising:

receiving an acceleration signal from the accelerometer;

determining with the low-clock logic device that the acceleration signal corresponds to a wake gesture; and

in response to determining that the acceleration signal corresponds to the wake gesture, sending, from the low-clock logic device, a first power state change signal to the processor and a second power state change signal to the high-clock logic device.

2. The computer-implemented method of claim **1**, wherein the first power state change signal comprises a wake signal that causes the processor to change from a lower-power sleep state to a higher-power active state.

3. The computer-implemented method of claim **2**, wherein, in the higher-power active state, the processor activates at least one of a non-volatile memory associated

with the processor and included in the hand-held X-ray sensor, and a wireless communication module associated with the processor and included in the hand-held X-ray sensor.

4. The computer-implemented method of claim **2**, wherein, in the higher-power active state, the processor executes an application configured to receive image data from the high-clock logic device.

5. The computer-implemented method of claim **1**, further comprising, in response to determining that the acceleration signal corresponds to the wake gesture, causing the detector array to exit a stand-by state and enter a ready state in which image acquisition can be performed.

6. The computer-implemented method of claim **1**, wherein the second power state change signal causes the high-clock logic device to change from a power off state to a power on state.

7. The computer-implemented method of claim **6**, further comprising, in response to the high-clock logic device receiving a plurality of signals from the detector array while the high-clock logic device is in the power on state:

generating, with the high-clock logic device, a digital representation of an X-ray image based on the plurality of signals; and

transmitting the digital representation from the high-clock logic device to the processor while the processor is in a higher-power active state.

8. The computer-implemented method of claim **7**, further comprising, in response to receiving the digital representation from the high-clock logic device, generating with the processor a digital image based on the digital representation.

9. The computer-implemented method of claim **1**, wherein causing the detector array to exit the stand-by state and enter the ready state comprises causing charge reading elements in the detector array to enter a high-power state in which electric charge generated by incident X-rays can be measured.

10. An X-ray sensing apparatus, comprising:

a detector array configured to generate a plurality of signals in response to x-rays incident on the detector array during an exposure period;

a high-clock logic device communicatively coupled to the detector array;

a low-clock logic device communicatively coupled to the high-clock logic device;

an accelerometer communicatively coupled to the low-clock logic device; and

a processor communicatively coupled to the high-clock logic device,

wherein the low-clock logic device is configured to:

receive an acceleration signal from the accelerometer;

determine that the acceleration signal corresponds to wake gesture; and

in response to determining that the acceleration signal corresponds to the wake gesture, send a first power state change signal to the processor and a second power state change signal to the high-clock logic device.

11. The X-ray sensing apparatus of claim **10**, wherein the first power state change signal comprises a wake signal that causes the processor to change from a lower-power sleep state to a higher-power active state.

12. The X-ray sensing apparatus of claim **11**, wherein, in the higher-power active state, the processor activates at least one of a non-volatile memory associated with the processor and included in the hand-held X-ray sensor, and a wireless communication module associated with the processor and included in the hand-held X-ray sensor.

13. The X-ray sensing apparatus of claim **11**, wherein, in the higher-power active state, the processor executes an application configured to receive image data from the high-clock logic device.

14. The X-ray sensing apparatus of claim **10**, wherein the processor is further configured to cause the detector array to exit a stand-by state and enter a ready state in which image acquisition can be performed.

15. The X-ray sensing apparatus of claim **10**, wherein the second power state change signal causes the high-clock logic device to change from a power off state to a power on state.

16. The X-ray sensing apparatus of claim **15**, wherein the high-clock logic device is configured to, in response to receiving a plurality of signals from the detector array while in the power on state:

generate a digital representation of an X-ray image based on the plurality of signals; and

transmit the digital representation to the processor while the processor is in a higher-power active state.

17. The X-ray sensing apparatus of claim **10**, wherein the low-clock logic device and the high-clock logic device are included in a single integrated circuit chip.

18. The X-ray sensing apparatus of claim **10**, wherein the acceleration signal comprises a notification from a processor included in the accelerometer that the acceleration signal corresponds to a wake gesture, and determining with the low-clock logic device that the acceleration signal corresponds to the wake gesture comprises receiving the notification.

19. The X-ray sensing apparatus of claim **10**, wherein the acceleration signal comprises an analog or digital output from the accelerometer that is generated when the wake gesture is performed by a user, and determining with the low-clock logic device that the acceleration signal corresponds to the wake gesture comprises performing an algorithm with the low-clock logic device.

20. An X-ray sensing apparatus, comprising:

a processing means;

an image acquisition means, communicatively coupled to the processing means and a detector array, wherein

the detector array is configured to generate a plurality of signals in response to x-rays incident on the detector array during an exposure period, and

the image acquisition means is configured to generate a digital representation of an X-ray image based on the plurality of signals that is communicatively coupled to the detector array; and

an accelerometer communicatively coupled to the image acquisition means, wherein the image acquisition means is further configured to:

receive an acceleration signal from the accelerometer;

determine that the acceleration signal corresponds to a wake gesture; and

in response to determining that the acceleration signal corresponds to the wake gesture, send a first power state change signal to the processing means and a second power state change signal to the image acquisition means.

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