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Inventor(s)	Smit; Philip C. et al.

Systems and methods for non-contact respiratory monitoring

Abstract

Methods and systems for non-contact monitoring of a patient to determine respiratory parameters such as respiration rate, tidal volume, minute volume, oxygen saturation, and other parameters such as motion or activity. The systems and methods receive a first, video signal from the patient and from that extract a distance or depth signal from the relevant area to calculate the parameter(s) from the depth signal. The systems and methods also receive a second, light intensity signal from an IR feature projected onto the patient, and from that calculate the parameter(s) from the light intensity signal. The parameter(s) from the two signals can be combined or compared to provide a qualified output parameter.

Inventors: **Smit; Philip C. (Hamilton, GB), Addison; Paul S. (Scotland, GB), Jacquel; Dominique (Edinburgh, GB)**

Applicant: **Covidien LP** (Mansfield, MA)

Family ID: **1000008767641**

Assignee: **Covidien LP (Mansfield, MA)**

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Primary Examiner: Weare; Meredith

Attorney, Agent or Firm: Draft Masters IP, LLC

Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) The present application claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application No. 63/142,298, entitled “Systems and Methods for Non-Contact Respiratory Monitoring”, filed Jan. 27, 2021, the entirety of which is incorporated herein by reference.

BACKGROUND
(1) Many conventional medical monitors require attachment of a sensor to a patient in order to detect physiologic signals from the patient and transmit detected signals through a cable to the monitor. These monitors process the received signals and determine vital signs such as the patient's pulse rate, respiration rate, and arterial oxygen saturation. For example, a pulse oximeter is a finger sensor that may include two light emitters and a photodetector. The sensor emits light into the patient's finger and transmits the detected light signal to a monitor. The monitor includes a processor that processes the signal, determines vital signs (e.g., pulse rate, respiration rate, arterial oxygen saturation), and displays the vital signs on a display.
(2) Other monitoring systems include other types of monitors and sensors, such as electroencephalogram (EEG) sensors, blood pressure cuffs, temperature probes, air flow measurement devices (e.g., spirometer), and others. Some wireless, wearable sensors have been developed, such as wireless EEG patches and wireless pulse oximetry sensors.
(3) Video-based monitoring is a new field of patient monitoring that uses a remote video camera to detect physical attributes of the patient. This type of monitoring may also be called “non-contact” monitoring in reference to the remote video sensor, which does not contact the patient.
SUMMARY
(4) The present disclosure is directed to methods and systems for non-contact monitoring of a

patient to determine respiratory parameters such as respiration rate, tidal volume, minute volume, oxygen saturation, and other parameters such as motion and activity. The systems and methods utilize a first, video signal received from the patient and from that extract a distance or depth signal from the relevant area to calculate the parameter(s) from the depth signal. The systems and methods also receive a second, light intensity signal, such as from an IR feature projected onto the patient, and from that calculate the parameter(s) from the light intensity signal. The parameter(s) from the two signals can be combined or compared to provide a qualified output parameter.
(5) One particular embodiment described herein is a method qualifying a respiratory parameter of a patient by combining two measurements or calculations of that parameter. The method includes determining the respiratory parameter of the patient using depth information determined by a non-contact patient monitoring system in a region of interest (ROI), over time, between the patient and the monitoring system. The method also includes determining the respiratory parameter of the patient using light intensity information in the ROI, over time, from the patient, which is done by: projecting a feature onto the patient in the ROI; measuring a first reflected light intensity from the feature at a first time; measuring a second reflected light intensity from the feature at a second time subsequent to the first time; and comparing the first reflected light intensity and the second reflected light intensity to determine a change in position or location of the feature over time. The two parameters, the respiratory parameter of the patient using depth information and the respiratory parameter of the patient using light intensity information, are combined to provide or qualify a combined respiratory parameter.
(6) This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used to limit the scope of the claimed subject matter.
(7) Other embodiments are also described and recited herein.

Description

BRIEF DESCRIPTION OF THE DRAWING
(1) FIG. **1** is a schematic diagram of an example non-contact patient monitoring system according to various embodiments described herein.
(2) FIG. **2** is a schematic diagram of another example non-contact patient monitoring system according to various embodiments described herein.
(3) FIG. **3**A and FIG. **3**B are schematic diagrams showing two embodiments using the example non-contact patient monitoring system of FIG. **2**.
(4) FIG. **4** is a block diagram of a computing device, a server, and an image capture device according to various embodiments described herein.
(5) FIG. **5**A is a photograph of a patient being monitored by a non-contact patient monitoring system according to various embodiments described herein, with a region of interest delineated; FIG. **5**B is an enlarged portion of the region of interest of FIG. **5**A; FIG. **5**C is a graphical representation of data from a non-contact patient monitoring system according to various embodiments described herein; and FIG. **5**D is a graphical representation of additional data from a non-contact patient monitoring system according to various embodiments described herein.
(6) FIG. **6** is a stepwise method of an example method of using a non-contact patient monitoring system according to various embodiments described herein.
(7) FIG. **7** is a stepwise method of another example method of using a non-contact patient monitoring system according to various embodiments described herein.
DETAILED DESCRIPTION
(8) As described above, the present disclosure is directed to medical monitoring, and in particular,

non-contact, video-based monitoring of respiratory parameters, including respiration rate, tidal volume, minute volume, oxygen saturation, and other parameters such as motion or activity. Systems and methods are described for receiving a video signal view of a patient, identifying a physiologically relevant area within the video image (such as a patient's forehead or chest), extracting a distance or depth signal from the relevant area and also a light intensity signal from the relevant area, filtering those signals to focus on a physiologic component, calculating a vital sign from the signals, measuring the vital sign from the signals, and comparing the calculated vital sign to the measured vital sign.

(9) The signals are detected by a camera or camera system that views but does not contact the patient. With appropriate selection and filtering of the signals detected by the camera, the physiologic contribution by the detected depth signal can be isolated and measured. Additionally, the light intensity signal is detected by at least one camera that views but does not contact the patient. With appropriate selection and filtering of the signal detected, the physiologic contribution can be estimated or calculated.

(10) This approach has the potential to improve patient mobility and comfort, along with many other potential advantages discussed below.

(11) Remote sensing of a patient with video-based monitoring systems presents several challenges. One challenge is due to motion or movement of the patient. The problem can be illustrated with the example of conventional, contact, pulse oximetry, which utilizes a sensor including two light emitters and a photodetector. The sensor is placed in contact with the patient, such as by clipping or adhering the sensor around a finger, toe, or ear of the patient. The sensor's emitters emit light of two particular wavelengths into the patient's tissue, and the photodetector detects the light after it is reflected or transmitted through the tissue. The detected light signal, called a photoplethysmogram (PPG), modulates with the patient's heartbeat, as each arterial pulse passes through the monitored tissue and affects the amount of light absorbed or scattered. Movement of the patient can interfere with this contact-based oximetry, introducing noise into the PPG signal due to compression of the monitored tissue, disrupted coupling of the sensor to the finger, pooling or movement of blood, exposure to ambient light, and other factors. Modern pulse oximeters use filtering algorithms to remove noise introduced by motion and to continue to monitor the pulsatile arterial signal.

(12) However, movement in non-contact pulse oximetry creates different complications, due to the extent of movement possible between the patient and the camera. Because the camera is remote from the patient, the patient may move toward or away from the camera, creating a moving frame of reference, or may rotate with respect to the camera, effectively morphing the region that is being monitored. Thus, the monitored tissue can change morphology within the image frame over time. This freedom of motion of the monitored tissue with respect to the detector introduces new types of motion noise into the video-based signals.

(13) Another challenge is ambient light. In this context, “ambient light” means surrounding light not emitted by components of the camera or the monitoring system. In contact-based pulse oximetry, the desired light signal is the reflected and/or transmitted light from the light emitters on the sensor, and ambient light is entirely noise. The ambient light can be filtered, removed, or avoided in order to focus on the desired signal. In contact-based pulse oximetry, contact-based sensors can be mechanically shielded from ambient light, and direct contact between the sensor and the patient also blocks much of the ambient light from reaching the detector. By contrast, in non-contact pulse oximetry, the desired physiologic signal is generated or carried by the ambient light source; thus, the ambient light cannot be entirely filtered, removed, or avoided as noise. Changes in lighting within the room, including overhead lighting, sunlight, television screens, variations in reflected light, and passing shadows from moving objects all contribute to the light signal that reaches the camera. Even subtle motions outside the field of view of the camera can reflect light onto the patient being monitored.

(14) Non-contact monitoring such as video-based monitoring can deliver significant benefits over

contact monitoring if the above-discussed challenges can be addressed. Some video-based monitoring can reduce cost and waste by reducing use of disposable contact sensors, replacing them with reusable camera systems. Video monitoring may also reduce the spread of infection, by reducing physical contact between caregivers and patients. Video cameras can improve patient mobility and comfort, by freeing patients from wired tethers or bulky wearable sensors. In some cases, these systems can also save time for caregivers, who no longer need to reposition, clean, inspect, or replace contact sensors.
(15) The present disclosure describes methods and systems for non-contact monitoring of a patient to determine respiratory parameters such as respiration rate, tidal volume, minute volume, oxygen saturation, and other parameters such as motion and activity. The systems and methods receive a first, video signal from the patient and from that extract a distance or depth signal from the relevant area to calculate the parameter(s) from the depth signal. The systems and methods also receive a second signal, a light intensity signal reflected from the patient, and from that calculate the parameter(s) from the light intensity signal. The parameter(s) from the two signals can be combined or compared to provide a qualified output parameter. In some embodiments, the light intensity signal is a reflection of an IR feature projected onto the patient, such as by a projector.
(16) The depth sensing feature of the system provides a measurement of the distance or depth between the detection system and the patient. One or two video cameras may be used to determine the depth, and change in depth, from the system to the patient. When two cameras, set at a fixed distance apart, are used, they offer stereo vision due to the slightly different perspectives of the scene from which distance information is extracted. When distinct features are present in the scene, the stereo image algorithm can find the locations of the same features in the two image streams. However, if an object is featureless (e.g., a smooth surface with a monochromatic color), then the depth camera system has difficulty resolving the perspective differences. By including an image projector to project features (e.g., in the form of dots, pixels, etc.) onto the scene, this projected feature can be monitored over time to produce an estimate of changing distance or depth.
(17) In the following description, reference is made to the accompanying drawing that forms a part hereof and in which is shown by way of illustration at least one specific embodiment. The following description provides additional specific embodiments. It is to be understood that other embodiments are contemplated and may be made without departing from the scope or spirit of the present disclosure. The following detailed description, therefore, is not to be taken in a limiting sense. While the present disclosure is not so limited, an appreciation of various aspects of the disclosure will be gained through a discussion of the examples, including the figures, provided below. In some instances, a reference numeral may have an associated sub-label consisting of a lower-case letter to denote one of multiple similar components. When reference is made to a reference numeral without specification of a sub-label, the reference is intended to refer to all such multiple similar components.
(18) FIG. **1** shows a non-contact patient monitoring system **100** and a patient P according to an embodiment of the invention. The system **100** includes a non-contact detector system **110** placed remote from the patient P. In this embodiment, the detector system **110** includes a camera system **114**, particularly, a camera that includes an infrared (IR) detection feature. The camera **114** may be a depth sensing camera, such as a Kinect camera from Microsoft Corp. (Redmond, Washington) or a RealSense™ D415, D435 or D455 camera from Intel Corp. (Santa Clara, California). The camera system **114** is remote from the patient P, in that it is spaced apart from and does not physically contact the patient P. The camera system **114** includes a detector exposed to a field of view F that encompasses at least a portion of the patient P.
(19) The camera system **114** includes a depth sensing camera that can detect a distance between the camera system **114** and objects in its field of view F. Such information can be used, as disclosed herein, to determine that a patient is within the field of view of the camera system **114** and determine a region of interest (ROI) to monitor on the patient. Once an ROI is identified, that ROI

can be monitored over time, and the change in depth of points within the ROI can represent movements of the patient associated with, e.g., breathing. Accordingly, those movements, or changes of depth points within the ROI, can be used to determine, e.g., respiration rate, tidal volume, minute volume, effort to breathe, etc.

(20) In some embodiments, the field of view F encompasses exposed skin of the patient. In other embodiments, the field of view F encompasses a portion of the patient's torso, covered by a blanket, sheet, or gown.

(21) The camera system **114** operates at a frame rate, which is the number of image frames taken per second (or other time period). Example frame rates include 20, 30, 40, 50, or 60 frames per second, greater than 60 frames per second, or other values between those. Frame rates of 20-30 frames per second produce useful signals, though frame rates above 100 or 120 frames per second are helpful in avoiding aliasing with light flicker (for artificial lights having frequencies around 50 or 60 Hz).

(22) The distance from the ROI on the patient P to the camera system **114** is measured by the system **100**. Generally, the camera system **114** detects a distance between the camera system **114** and the surface within the ROI; the change in depth or distance of the ROI can represent movements of the patient, e.g., associated with breathing.

(23) In some embodiments, the system **100** determines a skeleton outline of the patient P to identify a point or points from which to extrapolate the ROI. For example, a skeleton may be used to find a center point of a chest, shoulder points, waist points, and/or any other points on a body. These points can be used to determine the ROI. For example, the ROI may be defined by filling in the area around a center point of the chest. Certain determined points may define an outer edge of an ROI, such as shoulder points. In other embodiments, instead of using a skeleton, other points are used to establish an ROI. For example, a face may be recognized, and a chest area inferred in proportion and spatial relation to the face. In other embodiments, the system **100** may establish the ROI around a point based on which parts are within a certain depth range of the point. In other words, once a point is determined that an ROI should be developed from, the system can utilize the depth information from the depth sensing camera system **114** to fill out the ROI as disclosed herein. For example, if a point on the chest is selected, depth information is utilized to determine the ROI area around the determined point that is a similar distance from the depth sensing camera **114** as the determined point. This area is likely to be a chest.

(24) In another example, the patient P may wear a specially configured piece of clothing that identifies points on the body such as shoulders or the center of the chest. The system **100** may identify those points by identifying the indicating feature of the clothing. Such identifying features could be a visually encoded message (e.g., bar code, QR code, etc.), or a brightly colored shape that contrasts with the rest of the patient's clothing, etc. In some embodiments, a piece of clothing worn by the patient may have a grid or other identifiable pattern on it to aid in recognition of the patient and/or their movement. In some embodiments, the identifying feature may be stuck on the clothing using a fastening mechanism such as adhesive, a pin, etc. For example, a small sticker or other indicator may be placed on a patient's shoulders and/or center of the chest that can be easily identified from an image captured by a camera. In some embodiments, the indicator may be a sensor that can transmit a light or other information to the camera system **114** that enables its location to be identified in an image so as to help define the ROI. Therefore, different methods can be used to identify the patient and define an ROI.

(25) The ROI size may differ according to the distance of the patient from the camera system. The ROI dimensions may vary linearly with the distance of the patient from the camera system. This ensures that the ROI scales according with the patient and covers the same part of the patient regardless of the patient's distance from the camera. This is accomplished by applying a scaling factor that is dependent on the distance of the patient (and the ROI) from the camera. In order to properly measure the depth changes, the actual size (area) of the ROI is determined and movements

of that ROI are measured. The measured movements of the ROI and the actual size of the ROI are then used to calculate the respiratory parameter, e.g., a tidal volume. Because a patient's distance from a camera can change, e.g., due to rolling or position readjustment, the ROI associated with that patient can appear to change in size in an image from a camera. However, using the depth sensing information captured by a depth sensing camera or other type of depth sensor, the system can determine how far away from the camera the patient (and their ROI) actually is. With this information, the actual size of the ROI can be determined, allowing for accurate measurements of depth change regardless of the distance of the camera to the patient.

(26) In some embodiments, the system **100** may receive a user input to identify a starting point for defining an ROI. For example, an image may be reproduced on an interface, allowing a user of the interface to select a patient for monitoring (which may be helpful where multiple humans are in view of a camera) and/or allowing the user to select a point on the patient from which the ROI can be determined (such as a point on the chest). Other methods for identifying a patient, points on the patient, and defining an ROI may also be used.

(27) However, if the ROI is essentially featureless (e.g., a smooth surface with a monochromatic color, such as a blanket or sheet covering the patient P), then the camera system **114** may have difficulty resolving the perspective differences. To address this, the system **100** includes a projector **116** to project individual features (e.g., dots, crosses or Xs, lines, individual pixels, etc.) onto the ROI; the features may be visible light, UV light, infrared (IR) light, etc. The projector may be part of the detector system **110** or the overall system **100**.

(28) The projector **116** generates a sequence of features over time on the ROI from which is monitored and measured the reflected light intensity. A measure of the amount, color, or brightness of light within all or a portion of the reflected feature over time is referred to as a light intensity signal. The camera system **114** detects the features from which this light intensity signal is determined. In an embodiment, each visible image projected by the projector **116** includes a two-dimensional array or grid of pixels, and each pixel may include three color components—for example, red, green, and blue. A measure of one or more color components of one or more pixels over time is referred to as a “pixel signal,” which is a type of light intensity signal. In another embodiment, when the projector **116** projects an IR feature, which is not visible to a human eye, the camera system **114** includes an infrared (IR) sensing feature. In another embodiment, the projector **116** projects a UV feature. In yet other embodiments, other modalities including millimeter-wave, hyper-spectral, etc., may be used.

(29) The projector **116** may alternately or additionally project a featureless intensity pattern (e.g., a homogeneous, a gradient or any other pattern that does not necessarily have distinct features). In some embodiments, the projector **116**, or more than one projector, can project a combination of a feature-rich pattern and featureless patterns on to the ROI.

(30) For one projector **116** or multiple projectors, the emission power may be dynamically controlled to modulate the light emissions, in a manner as commonly done for pulse-oximeters with LED light.

(31) The detected images and diffusion measurements are sent to a computing device **120** through a wired or wireless connection **121**. The computing device **120** includes a display **122**, a processor **124**, and hardware memory **126** for storing software and computer instructions. Sequential image frames of the patient P are recorded by the video camera system **114** and sent to the processor **124** for analysis. The display **122** may be remote from the camera system **114**, such as a video screen positioned separately from the processor and memory. Other embodiments of the computing device **120** may have different, fewer, or additional components than shown in FIG. **1**. In some embodiments, the computing device may be a server. In other embodiments, the computing device of FIG. **1** may be additionally connected to a server. The captured images (e.g., still images, or video) can be processed or analyzed at the computing device and/or at the server to determine the parameters of the patient P as disclosed herein.

(32) FIG. **2** shows another non-contact patient monitoring system **200** and a patient P. The system **200** includes a non-contact detector **210** placed remote from the patient P. In this embodiment, the detector **210** includes a first camera **214** and a second camera **215**, at least one of which includes an infrared (IR) camera feature. The cameras **214**, **215** are positioned so that their ROI at least intersect, in some embodiments overlap. The detector **210** also includes an IR projector **216**, which projects individual features (e.g., dots, crosses or Xs, lines, or a featureless pattern, or a combination thereof etc.) onto the ROI. The projector **216** can be separate from the detector **210** or integral with the detector **210**, as shown in FIG. **2**. In some embodiments, more than one projector **216** can be used. Both cameras **214**, **215** are aimed to have the features projected by the projector **216** to be in the ROI. The cameras **214**, **215** and projector **216** are remote from the patient P, in that they are spaced apart from and do not contact the patient P. In this implementation, the projector **216** is physically positioned between the cameras **214**, **215**, whereas in other embodiments it may not be so.
(33) The distance from the ROI to the cameras **214**, **215** is measured by the system **200**. Generally, the cameras **214**, **215** detect a distance between the cameras **214**, **215** and the projected features on a surface within the ROI. The light from the projector **216** hitting the surface is scattered/diffused in all directions; the diffusion pattern depends on the reflective and scattering properties of the surface. The cameras **214**, **215** also detect the light intensity of the projected individual features in their ROIs. From the distance and the light intensity, at least one physiological parameter of the patient P is monitored.
(34) FIG. **3**A and FIG. **3**B both show a non-contact detector **310** having a first camera including an IR detection feature **314**, a second IR camera including an IR detection feature **315**, and an IR projector **316**. A dot D is projected by the projector **316** onto a surface S, e.g., of a patient, via a beam **320**. Light from the dot D is reflected by the surface S and is detected by the camera **314** as beam **324** and by the camera **315** as beam **325**.
(35) The light intensity returned to and observed by the cameras **314**, **315** depends on the diffusion pattern caused by the surface S (e.g., the surface of a patient), the distance between the cameras **314**, **315** and surface S, the surface gradient, and the orientation of the cameras **314**, **315** relative to the surface S. In FIG. **3**A, the surface S has a first profile S**1** and in FIG. **3**B, the surface S has a second profile S**2** different than S**1**; as an example, the first profile S**1** is during an exhale breath of a patient and the second profile S**2** is during an inhale breath of the patient. Because the surface profiles S**1** and S**2** differ, the deflection pattern from the dot D on each of the surfaces differs for the two figures.
(36) During breathing (respiration), the light intensity reflection off the dot D observed by the cameras **314**, **315** changes because the surface profile S**1** and S**2** (specifically, the gradient) changes as well as the distance between the surface S and the cameras **314**, **315**. FIG. **3**A shows the surface S having the surface profile S**1** at time instant t=t.sub.n and FIG. **3**B shows the surface S having the surface profile S**2** at a later time, specifically t=t.sub.n+1, with S**2** being slightly changed due to motion caused by respiration. Consequently, the intensity of the projected dot D observed by the cameras **314**, **315** will changed due to the changes of the surface S. In FIG. **3**A, a significantly greater intensity is measured by the camera **315** than the camera **314**, seen by the x and y on the beams **324**, **325**, respectively. In FIG. **3**B, y is less than y in FIG. **3**A, whereas x in FIG. **3**B is greater than x in FIG. **3**A. The manner in how these intensities change depends on the diffusion pattern and its change over time. As seen in FIGS. **3**A and **3**B, the light intensities as measured by the cameras **314** and **315** have changed between FIGS. **3**A and **3**B, and hence, the surface S has moved. Each camera will generate a signal because of the change of the intensity of dot D when the surface profile changes from time instant t=t.sub.n to t=t.sub.n+1 due to movement.
(37) In some other embodiments, a single camera and light projector can be used. For example, in FIGS. **3**A and **3**B, the camera **315** is not present or is ignored. It is clear that the camera **314** will still produce a change in light intensity from time instant t=t.sub.n to t=t.sub.n+1 due to movement.

This embodiment will therefore produce only a single signal as opposed to the two signals generated by the embodiment discussed in the previous paragraph.

(38) FIG. **4** is a block diagram illustrating a system including a computing device **400**, a server **425**, and an image capture device **485** (e.g., a camera, e.g., the camera system **114** or cameras **214**, **215**). In various embodiments, fewer, additional and/or different components may be used in the system.

(39) The computing device **400** includes a processor **415** that is coupled to a memory **405**. The processor **415** can store and recall data and applications in the memory **405**, including applications that process information and send commands/signals according to any of the methods disclosed herein. The processor **415** may also display objects, applications, data, etc. on an interface/display **410**. The processor **415** may also or alternately receive inputs through the interface/display **410**. The processor **415** is also coupled to a transceiver **420**. With this configuration, the processor **415**, and subsequently the computing device **400**, can communicate with other devices, such as the server **425** through a connection **470** and the image capture device **485** through a connection **480**. For example, the computing device **400** may send to the server **425** information determined about a patient from images captured by the image capture device **485**, such as depth information of a patient in an image.

(40) The server **425** also includes a processor **435** that is coupled to a memory **430** and to a transceiver **440**. The processor **435** can store and recall data and applications in the memory **430**. With this configuration, the processor **435**, and subsequently the server **425**, can communicate with other devices, such as the computing device **400** through the connection **470**.

(41) The computing device **400** may be, e.g., the computing device **120** of FIG. **1** or the computing device **220** of FIG. **2**. Accordingly, the computing device **400** may be located remotely from the image capture device **485**, or it may be local and close to the image capture device **485** (e.g., in the same room). The processor **415** of the computing device **400** may perform any or all of the various steps disclosed herein. In other embodiments, the steps may be performed on a processor **435** of the server **425**. In some embodiments, the various steps and methods disclosed herein may be performed by both of the processors **415** and **435**. In some embodiments, certain steps may be performed by the processor **415** while others are performed by the processor **435**. In some embodiments, information determined by the processor **415** may be sent to the server **425** for storage and/or further processing.

(42) The devices shown in the illustrative embodiment may be utilized in various ways. For example, either or both of the connections **470**, **480** may be varied. For example, either or both the connections **470**, **480** may be a hard-wired connection. A hard-wired connection may involve connecting the devices through a USB (universal serial bus) port, serial port, parallel port, or other type of wired connection to facilitate the transfer of data and information between a processor of a device and a second processor of a second device. In another example, one or both of the connections **470**, **480** may be a dock where one device may plug into another device. As another example, one or both of the connections **470**, **480** may be a wireless connection. These connections may be any sort of wireless connection, including, but not limited to, Bluetooth connectivity, Wi-Fi connectivity, infrared, visible light, radio frequency (RF) signals, or other wireless protocols/methods. For example, other possible modes of wireless communication may include near-field communications, such as passive radio-frequency identification (RFID) and active RFID technologies. RFID and similar near-field communications may allow the various devices to communicate in short range when they are placed proximate to one another. In yet another example, the various devices may connect through an internet (or other network) connection. That is, one or both of the connections **470**, **480** may represent several different computing devices and network components that allow the various devices to communicate through the internet, either through a hard-wired or wireless connection. One or both of the connections **470**, **480** may also be a combination of several modes of connection.

(43) The configuration of the devices in FIG. **4** is merely one physical system on which the disclosed embodiments may be executed. Other configurations of the devices shown may exist to practice the disclosed embodiments. Further, configurations of additional or fewer devices than the ones shown in FIG. **4** may exist to practice the disclosed embodiments. Additionally, the devices shown in FIG. **4** may be combined to allow for fewer devices than shown or separated such that more than the three devices exist in a system. It will be appreciated that many various combinations of computing devices may execute the methods and systems disclosed herein. Examples of such computing devices may include other types of medical devices and sensors, infrared cameras/detectors, night vision cameras/detectors, other types of cameras, radio frequency transmitters/receivers, smart phones, personal computers, servers, laptop computers, tablets, RFID enabled devices, or any combinations of such devices.
(44) The method of this disclosure utilizes depth (distance) information between the camera(s) and the patient to determine a respiratory parameter such as respiratory rate. A depth image or depth map, which includes information about the distance from the camera to each point in the image, can be measured or otherwise captured by a depth sensing camera, such as a Kinect camera from Microsoft Corp. (Redmond, Washington) or a RealSense™ D415, D435 or D455 camera from Intel Corp. (Santa Clara, California) or other sensor devices based upon, for example, millimeter wave and acoustic principles to measure distance.
(45) The depth image or map can be obtained by a stereo camera, a camera cluster, camera array, or a motion sensor focused on a ROI, such as a patient's chest. In some embodiments, the camera(s) are focused on visible or IR features in the ROI. Each projected feature may be monitored, less than all the features in the ROI may be monitored or all the pixels in the ROI can be monitored.
(46) When multiple depth images are taken over time in a video stream, the video information includes the movement of the points within the image, as they move toward and away from the camera over time.
(47) Because the image or map includes depth data from the depth sensing camera, information on the spatial location of the patient (e.g., the patient's chest) in the ROI can be determined. This information can be contained, e.g., within a matrix. As the patient breathes, the patient's chest moves toward and away from the camera, changing the depth information associated with the images over time. As a result, the location information associated with the ROI changes over time. The position of individual points within the ROI (i.e., the change in distance) may be integrated across the area of the ROI to provide a change in volume over time.
(48) For example, movement of a patient's chest toward a camera as the patient's chest expands forward represents inhalation. Similarly, movement backward, away from the camera, occurs when the patient's chest contrasts with exhalation. This movement forward and backward can be tracked to determine a respiration rate.
(49) Additionally, the changes in the parameter can be monitored over time for anomalies, e.g., signals of sleep apnea or other respiratory patterns.
(50) In some embodiments, the depth signal from the non-contact system may need to be calibrated, e.g., to provide an absolute measure of volume. For example, the volume signal obtained from integrating points in a ROI over time may accurately track a patient's tidal volume and may be adjusted by a calibration factor or factors. The calibration or correction factor could be a linear relationship such as a linear slope and intercept, a coefficient, or other relationships. As an example, the volume signal obtained from a video camera may under-estimate the total tidal volume of a patient, due to underestimating the volume of breath that expands a patient's chest backward, away from the camera, which is not measured by the depth cameras, or upward orthogonal to the line of sight of the camera. Thus, the non-contact volume signal may be adjusted by simply adding or applying a correction or calibration factor. This correction factor can be determined in a few different ways, including measuring the actual parameter to obtain a reference value to use as a baseline.

(51) In some embodiments, demographic data about a patient may be used to calibrate the depth or volume signal. From a knowledge of the patient's demographic data, which may include height, weight, chest circumference, BMI, age, sex, etc., a mapping from the measured volume signal to an actual volume signal may be determined. For example, patients of smaller height and/or weight may have less of a weighting coefficient for adjusting measured volume for a given ROI box size than patients of greater height and/or weight. Different corrections or mappings may also be used for other factors, such as whether the patient is under bedding, type/style of clothing worn by a patient (e.g., t-shirt, sweatshirt, hospital gown, dress, v-neck shirt/dress, etc.), thickness/material of clothing/bedding, a posture of the patient, and/or an activity of the patient (e.g., eating, talking, sleeping, awake, moving, walking, running, etc.).
(52) As indicated above, in addition to the methodology of this disclosure utilizing depth (distance) information between the camera(s) and the patient to determine a respiratory parameter, the method also uses reflected light intensity from projected IR features (e.g., dots, grid, stripes, crosses, squares, etc., or a featureless pattern, or a combination thereof) in the scene to estimate the depth (distance).
(53) FIG. **5**A shows an IR image from a subject patient. A region of interest (ROI) **500** is indicated on the image by the boxed (rectangular) region, although the ROI could have other, e.g., non-rectangular, shapes. The ROI **500** is shown enlarged in FIG. **5**B with a pattern of projected IR features **510** readily visible in the figure. It can be readily seen that the features **510** have a varying intensity across the ROI **500**. In addition, the intensity of the features **510** varies over time as the ROI **500** moves, e.g., during a respiratory cycle.
(54) This change of intensity over time of each of the projected features is used to produce a respiratory waveform plot. The waveform is formed by aggregating all the pixel values, at an instant in time, over time, from across the ROI **500** to generate a pattern signal shown in FIG. **5**C. In some embodiments, less than all the projected features in the ROI **500** are monitored; for example, only a random sampling of the projected features is monitored, or for example, every third feature is monitored. In some embodiments, each feature reflection over time is monitored only for a predetermined duration, to determine which projected features provide an accurate or otherwise desired light intensity signal, and then those selected features are monitored to obtain the signal. In some embodiments, each pixel in the ROI is monitored and the light intensity signal obtained.
(55) The respiratory modulations over time, extracted from the varying intensity of the projected features, closely match those obtained from the respiration depth (distance) measured by the depth camera(s) (shown in FIG. **5**D).
(56) It should be noted that the phase of the intensity pattern signal (FIG. **5**D) may be 180 degrees out of phase with that of the respiration modulation signal (FIG. **5**C). This would be due the direction of the movement of the surface (e.g., exhale versus inhale) and gradient of the surface as well as orientation of the camera(s) relative to the surface, all which play a role in modulating the reflected light.
(57) Across the whole ROI **500**, some features (e.g., dots or each pixel) may produce “in phase” modulations and some may be “out of phase.” These may be combined separately to produce two signals. Light returning from each of these features may be combined to produce a single respiratory signal, for example by inverting or phase-shifting by 180 degrees so where necessary to produce all in phase and then combining to get a combined pattern signal.
(58) This method for producing a respiratory signal, i.e., from the intensity of the light diffusion, is independent from the depth data used to produce a signal representative of the respiratory parameter. This secondary pattern signal, from the light intensity, can be used to enhance or confirm the measurement of the respiratory parameters from the depth data.
(59) For example, the calculation of respiratory rate (determined from, e.g., a plot such as FIG. **5**C) can be combined with a similar plot of the respiratory rate obtained from the depth camera

(RR.sub.depth). This may be done, e.g., by computing respiratory rate from each signal and then averaging the two numbers, or, with a more advanced method, such as Kalman filtering. FIG. **6** shows a method **600** for combining the data from the depth measurements with the data from the light intensity measurements to provide a combined parameter. In FIG. **6**, the method **600** is particularly directed to respiratory rate, whereas in other embodiments a similar method is used to provide a different respiratory parameter.
(60) The method **600** includes a first branch **610** that derives a respiratory parameter (specifically for this example, the respiratory rate (RR.sub.irp)) from the light intensity measurements and a second branch **620** that calculates the respiratory parameter (specifically for this example, the respiratory rate (RR.sub.depth)) from the depth measurements. The method **600** combines the derived respiratory rate (RR.sub.irp) from the first branch **610** with the calculated respiratory rate (RR.sub.depth) from the second branch **620**.
(61) For the respiratory rate (RR.sub.irp) derived from the light intensity measurements, the method **600** includes a step **612** where the IR images are acquired of the surface being monitored. The features within the desired ROI are inspected in step **614** for their light intensity and change in light intensity over time. From the intensity information obtained in step **614**, a respiratory pattern signal is calculated in step **616**. From this patterned signal, the respiratory rate (RR.sub.irp) is derived.
(62) For the respiratory rate (RR.sub.depth) derived from the depth measurements, the method **600** includes step **622** where the depth image stream of the surface is acquired from a depth camera. A respiratory signal (e.g., volume) is derived from the depth stream in step **624**, from which a respiratory rate (RR.sub.depth) is calculated in step **626**.
(63) In step **630**, the derived respiratory rate (RR.sub.irp) from step **618** is combined with the respiratory rate (RR.sub.depth) calculated in step **626**. The two rates may be averaged (e.g., simple average or mean, median, etc.), added, or combined in any other manner. Either individual patterns or the combined pattern can be inspected for anomalies, e.g., signals of sleep apnea or other respiratory patterns.
(64) FIG. **7** shows another method **700** for combining the data from the depth measurements with the data from the light intensity measurements to provide a combined parameter; the method **700** is also directed to respiratory rate.
(65) The method **700** includes a first branch **710** that derives a respiratory pattern from the light intensity measurements and a second branch **720** that calculates the respiratory parameter from the depth measurements. The method **700** combines the calculated respiratory pattern from the first branch **710** with the calculated respiratory signal from the second branch **720**.
(66) The method **700** includes a step **712** where the IR images are acquired of the surface being monitored. The features (e.g., dots) within the desired ROI are inspected in step **714** for their light intensity and change in light intensity over time. From the intensity information obtained in step **714**, a respiratory pattern signal is calculated in step **716**.
(67) For the respiratory signal derived from the depth measurements, the method **700** includes step **722** where the depth image stream of the surface is acquired from a depth camera. A respiratory signal (e.g., respiratory volume) is derived from the depth stream in step **724**.
(68) The calculated respiratory pattern signal (from step **716**) and the derived respiratory signal (from step **724**) are combined in step **730**, prior to calculating the respiration rate. The signals can be added, average, or otherwise combined in step **730** and then used to calculate a respiration rate in step **732** from the combined signal of step **730**.
(69) In both the method **600** of FIG. **6** and the method **700** of FIG. **7**, the respiratory signal from the depth stream is combined with one respiratory signal obtained from the light intensity. In other embodiments, multiple light intensity signals may be obtained, e.g., one from IR features, one from visible features, one from UV features, etc., so that the respiratory signal from the depth stream is combined with multiple respiratory signals from multiple light intensity measurements.

(70) Returning to and with respect to FIG. **2** and FIGS. **3**A and **3**B above, it is described that a system **200** with two cameras **214**, **215** or a system **300** with two cameras **314**, **315** can be used, the two cameras **214**, **215** and **314**, **315** providing a stereo property for one or both of the depth signal and the light intensity signal. When two cameras are used, although both cameras will produce very similar results, they each have their own noise characteristics. The noise, which is added to the respiratory signal, is generally uncorrelated and the overall noise component is therefore reduced by combining the results of two cameras. Thus, each camera produces a respiratory pattern and the results may then be, for example, averaged. Note that more than two cameras may be used to further improve the performance. Additionally, e.g., other, more advanced, methods for combining/fusing the different respiratory signals may be used including Kalman and particle filtering.
(71) Thus, described herein are methods and systems for non-contact monitoring of a patient to determine respiratory parameters by utilizing a distance or depth signal from the patient to the system to calculate the parameter(s) from the depth signal and by utilizing a reflected light intensity signal from projected IR features to derive the same parameter(s). The parameter(s) from the two signals are combined or compared to provide an output parameter value or signal.
(72) The above specification and examples provide a complete description of the structure and use of exemplary embodiments of the invention. The above description provides specific embodiments. It is to be understood that other embodiments are contemplated and may be made without departing from the scope or spirit of the present disclosure. The above detailed description, therefore, is not to be taken in a limiting sense. For example, elements or features of one example, embodiment or implementation may be applied to any other example, embodiment or implementation described herein to the extent such contents do not conflict. While the present disclosure is not so limited, an appreciation of various aspects of the disclosure will be gained through a discussion of the examples provided.
(73) Unless otherwise indicated, all numbers expressing feature sizes, amounts, and physical properties are to be understood as being modified by the term “about,” whether or not the term “about” is immediately present. Accordingly, unless indicated to the contrary, the numerical parameters set forth are approximations that can vary depending upon the desired properties sought to be obtained by those skilled in the art utilizing the teachings disclosed herein.
(74) As used herein, the singular forms “a”, “an”, and “the” encompass implementations having plural referents, unless the content clearly dictates otherwise. As used in this specification and the appended claims, the term “or” is generally employed in its sense including “and/or” unless the content clearly dictates otherwise.

Claims

1. A method of qualifying a respiratory parameter of a patient, comprising: positioning an infrared detector and an infrared projector exposed to a region of interest (ROI) of a patient; projecting, by the infrared projector, an infrared feature onto the patient in the ROI; measuring, by the infrared detector and utilizing the projected infrared feature, depth information comprising a distance between the patient and the infrared detector; determining a first respiratory modulation signal of the patient comprising the depth information over time; determining a second respiratory modulation signal of the patient using light intensity information in the ROI, over time, from the patient, wherein the second respiratory modulation signal is independent of the first respiratory modulation signal and is determined by: measuring, by the infrared detector, a first reflected light intensity from the projected infrared feature at a first time; measuring, by the infrared detector, a second reflected light intensity from the projected infrared feature at a second time subsequent to the first time; and aggregating reflected light intensity information over time to create the second respiratory modulation signal; and combining the first and second respiratory modulation signals to

qualify a respiratory parameter of the patient, wherein the respiratory parameter comprises respiration rate.

2. The method of claim 1, wherein projecting the infrared feature onto the patient comprises: projecting a pattern of individual features.

3. The method of claim 1, wherein projecting the infrared feature onto the patient comprises: projecting a plurality of infrared features onto the patient.

4. The method of claim 1, wherein projecting the infrared feature onto the patient comprises: projecting a grid or array of infrared features onto the patient in the ROI.

5. The method of claim 1, wherein the infrared camera comprises stereo first and second cameras, and wherein determining the second respiratory modulation signal comprises: measuring the first reflected light intensity and the second reflected light intensity from the feature in stereo with the first camera and the second camera.

6. The method of claim 5, wherein measuring with the first camera and the second camera comprises: comparing the first reflected light intensity measured by the first camera and the second camera to the second reflected light intensity measured by the first camera and the second camera.

7. The method of claim 1, further comprising phase-shifting the first or second respiratory signals prior to combining.

8. The method of claim 1, wherein the second respiratory modulation signal comprises an amount, color, or brightness of light over time.

9. A method of qualifying a respiratory rate of a patient, comprising: positioning first and second infrared cameras and an infrared projector exposed to a region of interest (ROI) of a patient; projecting, by the infrared projector, an IR feature pattern onto the ROI; acquiring, from the first and second infrared cameras, a depth image stream comprising depth images of the ROI over time; deriving a first respiratory signal from the depth image stream; acquiring, from at least one of the first and second infrared cameras, an IR light intensity stream comprising a light intensity of the projected IR feature pattern over time; calculating a second respiratory signal from the IR light intensity stream; and combining the first and second respiratory signals to provide an output respiratory rate.

10. The method of claim 9, wherein acquiring the IR light intensity stream comprises: measuring a first reflected light intensity from an IR feature at a first time; measuring a second reflected light intensity from the IR feature at a second time subsequent to the first time; and comparing the first reflected light intensity and the second reflected light intensity.

11. The method of claim 10, wherein measuring the first reflected light intensity and the second reflected light intensity comprises measuring the first reflected light intensity and the second reflected light intensity from the IR feature in stereo with the first camera and the second camera.

12. The method of claim 10, wherein acquiring the IR light intensity stream comprising the projected IR feature pattern comprises acquiring the IR light intensity stream from the non-contact patient monitoring system in the ROI.

13. The method of claim 12, wherein the non-contact patient monitoring system calculates the respiratory rate and derives the respiratory rate.

14. A method of determining a respiratory rate of a patient, comprising: projecting a pattern of infrared features onto a region of interest (ROI) of a patient, within a field of view of an infrared detector; acquiring a depth signal by measuring a distance between the ROI and the infrared detector, the depth signal comprising the measured distance over time; detecting, by the infrared detector, a light intensity of the projected pattern of infrared features and acquiring a light intensity signal comprising the detected light intensity over time; and combining the light intensity signal and the depth signal to calculate a respiratory rate.

15. The method of claim 14, wherein the infrared detector comprises a first camera and a second camera, and wherein detecting the light intensity of the projected pattern of infrared features comprises measuring a first reflected light intensity and a second reflected light intensity from the

IR feature in stereo with the first camera and the second camera.

16. The method of claim 14, wherein: acquiring the light intensity signal and acquiring the depth signal comprises acquiring both signals from the infrared detector.