METHODS AND SYSTEMS FOR CONTACTLESS HEALTH MONITORING

RELATED APPLICATIONS

[0001] This application is a continuation in-part of the U.S. application No. 18/113,314 which was filed on February 23, 2023. The U.S. application No. 18/113,314 is a continuation of the U.S. application No. 17/887,489 which was filed on August 14, 2022. The U.S. application No. 17/887,489 is a continuation of the U.S. application No. 17/222,031 which was filed on April 5, 2021. The U.S. application No. 17/222,031 is a continuation-in-part of the U.S. application No. 17/153,851 which was filed on January 20, 2021. The U.S. application No. 17/222,031 claims priority from the U.S. provisional patent application No. 63/005,371 filed on April 5, 2020. The U.S. application No. 17/153,851 is a continuation of the U.S. application No. 15/650,850 which was filed on July 15, 2017. The U.S. application No. 15/650,850 claims priority from the U.S. provisional patent application No. 62/363,230 filed on July 16, 2016. The U.S. applications No. 18/113,314, No. 17/887,489, No. 17/222,031, No. 17/153,851, No. 15/650,850 as well as the U.S. provisional patent applications No. 62/363,230 and No. 63/005,371 are incorporated herein by reference in their entirety.

BACKGROUND OF THE INVENTION

[0002] Typically, data related to vital physiological processes such as pulse and respiration within a human body are collected using a range of contact devices and methodologies. Certain non-contact methods are also available, including those employing video cameras.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] FIG. **1** shows example data obtained using an example embodiment of a system and an example implementation of a method according to the technology disclosed in this patent document.

[0004] FIG. **2** shows a result of a fast Fourier transform applied to a part of the data shown in FIG. **1**.

[0005] FIGS. **3**A-**3**C show that application of the additional light texture to a person's body by a system or a device according to the technology disclosed herein can lead to a significant increase of the components of the data collected by the system or the device that are related to the respiration and heart activity of the person.

[0006] FIGS. **4**A-**4**B show that systems, devices, and methods according to the technology disclosed in this patent document can be used to detect heartbeats and respiration of a person even when the person is completely covered by a thick blanket.

[0007] FIGS. **5**A-**5**B show that systems, devices, and methods according to the technology disclosed in this patent document can be used to detect heartbeats and respiration of a sleeping person during nighttime without use of additional lighting or illumination.

[0008] FIG. **6** shows example data obtained by a system according to the disclosed technology using an implementation of a method according to the technology disclosed herein.

[0009] FIG. **7** shows a person sitting on a chair.

[0010] FIGS. **8**A-**8**B show that systems, devices, and methods according to the technology disclosed in this patent document can be used to obtain temporal profiles of heartbeats of a person from different parts of the person's body in a non-contact fashion and with high temporal resolution.

[0011] FIG. **9** shows example variations, associated with the respiration and/or pulse of a person, of the elements of additional light texture created according to an embodiment of the technology disclosed in this patent document.

[0012] FIG. **10** shows other example variations of the elements of the additional light texture associated with the respiration and/or pulse of a person.

[0013] FIG. **11** shows example data obtained using an embodiment of a system and an implementation of a method according to the technology disclosed herein.

[0014] FIG. **12** shows another example data obtained using an embodiment of a system and an implementation of a method according to the technology disclosed in this patent document.

[0015] FIGS. **13**A-**13**B show an example dependence of the data obtained by a system according to the technology disclosed in this patent document using a method according to the technology disclosed herein on the distance of the system from a person.

[0016] FIGS. **14**A-**14**B show another example dependence of the data obtained by a system according to the technology disclosed in this patent document using a method according to the technology disclosed herein on the distance of the system from a person.

[**0017**] FIG. **15** illustrates an example video frame captured by a system according to the disclosed technology and showing a person lying on a firm surface.

[**0018**] FIG. **16** shows a plot of example data obtained by a system according to the disclosed technology for the person shown in FIG. 15.

[**0019**] FIG. **17** shows another plot of example data produced by a system according to the disclosed technology for the person shown in FIG. 15.

[**0020**] FIG. **18** illustrates an example video frame captured by a system according to the disclosed technology and showing a person lying in a bed and covered by a blanket.

[**0021**] FIG. **19** shows a plot of example data generated by a system according to the disclosed technology for the person shown in FIG. 18.

[**0022**] FIG. **20** shows another plot of example data obtained by a system according to the disclosed technology for the person shown in FIG. 18.

[**0023**] FIG. **21** illustrates an example video frame captured by a system according to the disclosed technology and showing a person lying on a bed.

[**0024**] FIG. **22** shows a plot of example data obtained by a system according to the disclosed technology for the person shown in FIG. 21.

[**0025**] FIG. **23** shows a schematic diagram of an example device according to the disclosed technology.

[**0026**] FIG. **24** shows a flowchart of an example method according to the disclosed technology.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[**0027**] The capability to gather data related to vital physiological processes—such as pulse and respiration—within a person's body (here, "person" may refer to an adult, child, infant, or a fetus within a mother's or female’s body or a fetus within an artificial womb or an artificial uterus) in a non-contact fashion, has significant potential in numerous medical fields. These include sleep medicine, cardiology, maternal-fetal medicine, and in situations where direct contact for the purpose of obtaining these measurements is either undesirable or not possible.

[**0028**] This patent document presents devices, systems, and methods capable of non-contact acquisition of information related to at least one physiological parameter of a person. These parameters can include, but are not limited to, respiration rate, heart rate, blood pressure, respiration rate variability, heart rate variability, temporal characteristics of at least a portion of a heartbeat or respiration cycle, a stage of sleep, or the duration of a blood pressure pulse's transit time from one point or area of the body to another. The latter is also known as pulse wave transit time. The aforementioned physiological parameters are subsequently referred to as the "group of physiological parameters". Any individual parameter within this group is referred to as a "physiological parameter" in the text that follows.

[**0029**] The technology disclosed in this patent document enables the calculation of the duration of the blood pressure wave's transit time between two distinct points on the body, for instance, a human body. This duration can be used to determine the pulse wave velocity (PWV) of the blood pressure wave propagation by dividing the distance between the two points by the duration. This distance might be the length of a straight line between the points or the length of an actual or hypothetical path between them. The calculated PWV can subsequently be utilized to ascertain a value related to the person's blood pressure, either systolic and/or diastolic.

[**0030**] For instance, the non-contact methods, devices, and systems for monitoring physiological parameters disclosed in this patent document can be beneficial in a variety of contexts. These include respiration and/or pulse gating for medical imaging techniques such as Magnetic Resonance Imaging (MRI) or X-ray Computed Tomography, sleep studies that necessitate non-contact monitoring of the aforementioned physiological parameters during a person's sleep, and non-contact tracking of the mechanical activity of an adult's heart or a fetus's heart within the mother's womb or withing an artificial uterus, among others.

[0031] The technology disclosed in this patent document comprises three core elements in a system or a device: 1) A light source element configured to illuminate one or more areas of a person's body. These areas, collectively referred to as a set of areas in this document, may be partially or fully covered by items such as clothing, a blanket, or other covering materials. 2) A video camera element configured to capture one or more video frames of at least a portion of the areas illuminated by the system's or device’s light source. These frames are referred to as a set of video frames or video frames set in this patent document. 3) A computing element configured to perform computations on at least part of the video frames set. These system or device components and their respective functions are described in greater detail later in this document.

[0032] When we use terms such as "a person's body", "a part of a person's body", "an area of a person’s body", "one or more areas of a person’s body", "a set of areas of a person’s body", "two areas of a person’s body", "any number of areas of a person’s body" and similar phrases, it should be understood that these could refer to any part or area or areas of a person's body, regardless of whether they are fully covered, partially covered, or not covered at all.

[0033] Furthermore, when an area of the body is covered partially or completely by any number of covering items, phrases like “the light source is illuminating the area” or “the light source is projecting light on the area” or “the light source is creating light spots on the area” or “the light source is creating elements of a light texture on the area” should be interpreted as the light source's ability to illuminate or create light spots on the covering items and/or on the uncovered parts of the body area. This applies, for example, when the area refers to a skin surface.

[0034] In this patent document, a video frame is generally defined as a numeric value or a set, group, or array of numeric values that correspond to one or more pixels (also referred to as sensing elements or areas) of a sensor or detector. These pixels can be physical or virtual, the latter of which may combine multiple physical pixels. This set of pixels, which may originate from the video sensor of a camera, can range from a single pixel to all sensor pixels.

[**0035**] Alternative terms for a video sensor's "pixel" (or, more generally, for a light sensor’s or detector’s pixel) could include "photosite," "sensel," "photosensor element," "sensing element," or "sensing area".

[**0036**] The set of numeric values associated with a video frame can contain more than one numeric value corresponding to the same pixel of a video sensor. For instance, the set of numeric values could include an array of numeric values corresponding to a single sensor pixel.

[**0037**] Herein, a pixel of a video frame is defined as one or more numeric values corresponding to a single pixel of a video sensor. These sensor pixels could be physical sensing elements or areas, or virtual pixels comprising one or more physical pixels of various sizes, locations, and internal structures.

[**0038**] These pixel values are typically contained in the video frame data, which may include numeric values representing the intensities of color components such as red, green, blue, or cyan, magenta, yellow, and black. Each of these color intensity values could correspond to a "red," "green," or "blue" pixel of the video sensor used to produce the video frame.

[**0039**] Just as physical sensor pixels can be arranged in a two-dimensional array or matrix, the numeric values of a video frame can be arranged in various data structures. These structures could be one-dimensional arrays, two-dimensional arrays, arrays of more than two dimensions, trees, lists, and other types of data structures.

[**0040**] When we refer to "an area of a video frame" or "a part of a video frame" or "a section of a video frame" or "a segment of a video frame" or use similar terms in this patent document, we generally mean either an area, part, section, or segment of an image captured in the video frame as it could be viewed by a person, or a part of the video frame data that may correspond to that area, part, section, or segment of the image.

[0041] In the context of this patent document, the key effect of a light source element is to add an additional layer of light texture, beyond existing natural or artificial ambient light, to the objects surrounding it. This could include parts of a person's body. We refer to this additional light texture as the "artificial light texture" or "ALT". This added texture, produced by the light source element, ideally comprises one or more distinct illuminated areas, termed its "elements". For instance, a light source element of a system, in accordance with the technology disclosed here, may create one or more light spots on a person's body. These light spots, collectively referred to as a set of light spots, form the aforementioned ALT, with each individual light spot serving as an element of this texture.

[0042] Generally, a light spot created by a light source element of a system, as per the technology disclosed in this patent document, represents illumination produced on a specific area of an object. This illuminated area is typically surrounded by areas that are either not illuminated by the light source or have lower levels of illumination due to the light source. In some cases, these surrounding areas may be significantly less illuminated compared to the area with the light spot. If the light source element is the only source of light in a scene, the light spots it produces on surrounding objects would appear (to an observer or in an image obtained by a camera) as brightly lit areas contrasted by darker, or in some cases, completely dark areas.

[0043] Thus, a light spot can also denote an area where illumination is produced by the light source element. This area, which could be part of an object illuminated by the light source or a section of a video frame capturing that object, is typically surrounded by or adjacent to other areas with lower levels of illumination from the light source. The level of illumination—or more broadly, the level of electromagnetic radiation—created by the light source within the light spot can be characterized by measures such as irradiance or illuminance. These measures evaluate the flux or intensity of electromagnetic radiation on, or passing through, the light spot's surface. Furthermore, the spatial distribution of irradiance or illuminance from the light source on the light spot's area can also be used to measure or characterize this level of illumination.

[0044] For instance, the irradiance of light from the light source element on the area covered by the light spot could exhibit a variety of spatial distributions. These distributions could be uniform, follow a normal or Gaussian pattern, be irregular, be random, or exhibit a repeating pattern, at least on a portion of the light spot.

[**0045**] The shape of the light spot can be also variable. It may be essentially circular, elliptical, rectangular, or possess an arbitrary or amorphous shape.

[**0046**] Illumination of a person’s body areas by the light source element, such as by creating one or more light spots on these areas, can increase the illumination of these areas relative to others. This effect enhances the illumination contrast between areas illuminated by the light source element and those not, as observed in the video frames captured by a system's video camera element. This illumination contrast can be measured using video frame data.

[**0047**] Such illumination forms elements of the additional light texture, with each illuminated area (e.g., a light spot) serving as an individual element of the texture.

[0048] Movements of a person's body, including those associated with respiration and heartbeats, can result in changes or variations in the curvature, shape, position, tilt, or size of the body's surfaces, or any items covering the body. These changes can in turn lead to variations in one or several properties of the additional light texture produced by a light source on these surfaces and/or items. These properties include illumination, shape, size, location of the texture's elements, distribution of illumination within or among the texture's elements, distribution of shapes, sizes, locations of the texture's elements, and the number of these elements.

[**0049**] These variations are observed and captured by a video camera element in a system built or configured in accordance with the technology disclosed in this document, as depicted in video frames collected by the camera element (see, e.g., FIGS. **9** and **10** and the related description below).

[**0050**] Subsequently, or in parallel with the video frame capture, these frames are processed by a computing element. This processing results in one or more numeric values, collectively referred to as the "ALT data" in this patent document. This data is related to or representative of the information relevant to at least one physiological parameter of the person. This data can be further processed to obtain numeric values which are also related to or representative of the information relevant to at least one physiological parameter of the person. The ALT data can be presented through various forms of representation, such as a two-dimensional or three-dimensional plot, an alphanumeric representation, or an audio-based or audio-visual representation.

[0051] The application of the additional light texture can significantly enhance the illumination contrast in a scene observed by a video camera. This effect is especially prominent in low ambient light environments, such as those typically present during nighttime. As we will demonstrate, the additional light texture can act as an amplification medium for small body movements. Applying this texture to a person's body can lead to a substantial increase in components of the ALT data related to the person's heart activity and respiration. This increase can be orders of magnitude greater compared to scenarios where no additional light texture is present—for instance, when the ALT-generating light element is switched off—under otherwise equivalent data collection and processing procedures and conditions (see FIGS. **3**A-**3**C and the related description below).

[0052] The additional light texture created by a light source element can also cover parts of objects that are in direct or indirect contact with a person's body, such as a chair, a blanket, a bed, the floor, or walls. Movements or changes in the shape, size, or position of these objects, resulting from movements of the person's body, can also be captured in the ALT data if these objects are within the field of view of a system's video camera element, as per the technology disclosed here.

[**0053**] This capability enables the detection of heartbeats and respiration events, such as an inhale-exhale sequence, as well as various forms of normal, abnormal, or disordered breathing patterns even when a person is completely hidden under a thick blanket, as demonstrated later in this document (see FIGS. **4**A-**4**B and the related discussion below).

[**0054**] Furthermore, the technology disclosed in this patent document can also facilitate the detection of a fetus's heartbeats within, for example, a female's body.

[0055] In a system according to the technology disclosed in this patent document, the light source element, the video camera element, and the computing element may or may not be housed in a common enclosure. Additionally, any of these elements of a system according to the disclosed technology can also be a part, either physically or functionally, of a device or system other than the ones according to the technology disclosed herein.

[**0056**] For instance, a laptop computer's processing unit (acting as a computing element), an infrared (IR) camera of an Intel RealSense R200 unit (serving as a video camera element), and the IR projector of the R200 unit (functioning as a light source element) could collectively form a system as per the disclosed technology. This can be achieved when, for example, they are configured to perform the function of obtaining information related to at least one of the mentioned physiological parameters, in accordance with a method specified in this patent document.

[**0057**] Such a system's central unifying element could be a non-transitory storage medium—like the laptop computer's hard drive, an external hard drive, a remote hard drive, an optical disk, or a flash drive. This medium would store one or more processor-executable instructions, which, when executed, prompt a processor (e.g., the laptop computer's processing unit) to illuminate an object's area using a light source (e.g., the IR projector of the R200 unit), collect video frames using a camera (e.g., the infrared (IR) camera of the R200 unit), and perform computations on these frames in line with a method disclosed herein.

[**0058**] This non-transitory storage medium can be part of the computing element in a system or could be located externally. It can also be physically or communicatively connected to the computing element and/or other elements of the system, such as, e.g., the video camera element.

[**0059**] The processing unit of the laptop computer could include a processor, a graphics processing unit (GPU), or both.

[0060] Consider another example, where a mobile device, such as a phone, tablet, or laptop, houses the computing element. In this scenario, a depth-sensing camera embedded into the device (or an IR camera which is a part or a component of the embedded depth-sensing camera) could serve as the video camera element, and its light emitter could act as the light source element. Configured to gather information related to one or more of the aforementioned physiologic parameters using a method as per the disclosed technology, these components together form a system in line with the technology described in this patent document.

[**0061**] The mobile device might contain a non-transitory storage medium that stores processor-executable code. When executed by a processor—such as the device's processor or processing unit—this code instructs the processor to direct the light source element (e.g., the emitter of the embedded depth-sensing camera) to illuminate one or more areas of an object (such as a person). It further commands the video camera element (e.g., the infrared camera of the embedded depth-sensing camera) to collect or obtain one or more video frames. The code also guides the processor to perform computations according to some steps of a method outlined in this patent document.

[**0062**] The processing unit of the mobile device can include a processor, a graphics processing unit (GPU), or both, or any number of other types of computing elements, electronic or electrical components or circuits (e.g., the ones mentioned in this patent document).

[0063] In another example, a mobile device such as a phone—e.g., a smartphone—or a tablet can serve as the computing element. The device's camera can act as the video camera element, and a separate light emitter associated with the mobile device can serve as the light source element. This light source element might be physically attached to the mobile device or exist as an independent unit. Together, when configured to gather information related to one or more of the aforementioned physiologic parameters using a method as per the disclosed technology, these components form a system in line with the technology described in this document.

[**0064**] The light emitter can be controlled by the mobile device, allowing the device—using its processing unit, for instance—to activate, deactivate, power, or adjust the output power or any other property such as, e.g., wavelengths of the light emitted by the light emitter.

[**0065**] In some cases, the light emitter could be embedded in a protective case or cover or keyboard of the mobile device. It might connect to the mobile device through a communication port (e.g., USB) and/or a power port, such as a charging port.

[**0066**] The processing unit of the mobile device could include a processor, a graphics processing unit (GPU), both, or any number of other computing elements, electronic or electrical components or circuits (e.g., the ones mentioned in this patent document).

[0067] In an embodiment of a system according to the technology disclosed herein—referred to as "the first embodiment"—the light source element is the infrared projector of a Microsoft Kinect for Xbox 360 system (Microsoft Corporation, U.S.). The computing element is a Raspberry Pi single-board computer (Raspberry Pi Foundation, UK), and the video camera element is a Pi NoIR camera (Raspberry Pi Foundation, UK) connected to the Raspberry Pi single-board computer.

[**0068**] An optical bandpass filter can be used with the Pi NoIR camera to reduce the effects of ambient light intensity variations. These variations can be slow or fast, compared, for example, to a typical duration of a heartbeat or an inhale/exhale sequence. One such source of variations could be the light from incandescent bulbs, which flicker at a frequency of 60 Hz in the U.S. or 50 Hz in Europe.

[**0069**] The use of the bandpass filter could be important when incandescent light bulbs are the only light source for a scene. It's also important when the rate of video frame collection by the camera is different from the frequency of the electric grid or integer fractions of that frequency. For instance, in the U.S., these frequencies might be 60 Hz, 30 Hz, 15 Hz, or 6 Hz.

[0070] An implementation of a method according to the technology disclosed in this patent document (referred to as “the first method” below), comprises the steps described in paragraphs [**0071**]-[**0074**] below:

[0071] The infrared projector of the Microsoft Kinect for Xbox 360 system projects a set of light spots onto the objects of a scene, including the body of a person, observed by the Pi NoIR camera, thus adding artificial light texture to the objects of the scene observed by the Pi NoIR camera. The infrared projector of the Microsoft Kinect for Xbox 360 system is turned on or off by the Raspberry Pi single-board computer.

[0072] Video encoding of the video frames captured by the Pi NoIR camera using, for example, H.264 or any other video encoding or video compression standard and using a video encoder (software and/or hardware) is performed using the Raspberry Pi single-board computer and functionality provided by Picamera library (documentation for the library is available at picamera.readthedocs.io).

[0073] A set of the sum of absolute differences (SAD) numeric values is obtained for at least one of the encoded video frames using the motion vector data generated by the video encoder (e.g., H.264 based one) for at least some of the encoded video frames using the Raspberry Pi single-board computer and functionality provided by the Picamera library. In digital image processing, a sum of absolute differences (SAD) value is a measure of similarity between image blocks (e.g., two image blocks) within a video frame or between a first image block in a first video frame and a second image block in a second video frame. It is obtained by calculating, for each pixel in a first image block, an absolute difference between that pixel and a corresponding pixel in a second image block being used for comparison with the first image block. These differences are summed to create a metric of block similarity, referred to as the L_1 norm of a difference image or Manhattan distance between two image blocks.

[0074] For at least one of the encoded video frames for which a set of SAD values was obtained, and for at least one part of the set of SAD values, a sum of the SAD values in the part is calculated to obtain a numeric value referred to as the “sSAD” value below using the Raspberry Pi single-board computer. If the part contains a single SAD value, then that SAD value is provided as the sSAD value. The part of the SAD values set corresponds to the area (or part) of the video frame which was used to obtain the SAD values belonging to the part. The sSAD value or values obtained for a single video frame or for several video frames form a set of the ALT data values referred to above. A sSAD value represents a measure of motion in a video frame or in its part for which the sSAD value was computed. By choosing different parts of the set of SAD values, multiple sSAD values can be computed for the same frame, and those sSAD values may, in turn, correspond to different parts or areas of the frame.

[0075] Python code that implements the aforementioned video frames capture and processing steps can be found in LISTING 1 below. This code operates on a Raspberry Pi single-board computer connected to a Pi NoIR camera. In this case, the sum of the

SAD values is calculated for the entire set of SAD values. Note that the methods disclosed in this patent document can be applied to whole video frames or to any part(s) thereof without any limitations.

[0076] The computed sSAD values contain information about the respiration, heartbeats, and other movements of a person. They can also account for movements of any objects, animate or inanimate, that are in direct or indirect contact with the person, or even objects that are not in contact with the person. This information pertains to the time period captured by the video frames used to derive the sSAD values.

[**0077**] Numeric values representative of the respiration rate and/or heart rate of the person for that time period can be obtained by, e.g., performing Fourier analysis. For example, we can use the Fast Fourier Transform (FFT) on the sSAD values (refer to FIG. **2** and the related description below for more information).

[**0078**] We can also derive numeric values representing heart rate variability (HRV) and/or respiration rate variability. This can be achieved by identifying the positions of the peaks corresponding to heartbeats and/or respiration events, such as inhalation and/or exhalation, in the sSAD data. By determining the durations of the time intervals between successive heartbeat and/or respiration peaks, we can create a series of time interval duration values for heartbeats and/or respiration.

[**0079**] Furthermore, we can perform statistical calculations on this series of time interval duration values. This could involve producing a histogram of these values and/or determining parameters such as the mean value and/or the standard deviation of the distribution of these values. As such, we can obtain information about the variation in these time interval durations over the time period covered by the said video frames.

[**0080**] For example, sSAD values or more generally ALT data can be used to generate RMSSD (Root Mean Square of Successive Differences) metric of the heart rate variability. RMSSD measures the variability in the time series of successive differences between time positions of successive heartbeats. It is typically used to estimate the vagal (parasympathetic) mediated changes reflected in the HRV and it's a good indicator of short-term components of HRV.

[**0081**] An example procedure for computing RMSSD values using sSAD or any other type of ALT data according to the technology disclosed herein can be as follows.

Identify Peaks: Detect the peaks in the sSAD signal. These peaks may, for example, correspond to the systolic upstroke of each cardiac cycle. For peak detection, one can use, for example, the derivative of the sSAD signal and detect where it crosses zero.

Calculate Intervals: Once the peaks are identified, determine the time between successive peaks. These time intervals represent the time between successive heartbeats.

Calculate RMSSD:

Find the difference between successive time intervals. If the intervals are T_1, T_2, T_3,..., T_n, then calculate the differences as (T_2-T_1), (T_3-T_2), ..., (T_n-$T_{[n-1]}$).

Square each of these difference values. This is done to remove the sign of the difference and focus on the magnitude of change.

Find the mean (average) of these squared differences.

Take the square root of the result.

Mathematically, this can be represented as:

$$RMSSD = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n-1}(T_{i+1} - T_i)^2}$$

Where T_{i+1} and T_i are successive intervals, and n is the total number of intervals.

[0082] As a practical starting point, the Kinect system can be placed approximately 5 feet away from the person, with the Pi NoIR video camera located near the Kinect. In this setup, the Kinect functions as the light source element. The distance between the Kinect and/or the video camera and the person can influence the intensity of the heartbeat signal during respiration events (see, e.g., FIGS. **1**, **5**A, **13**A-**13**B, and **14**A-**14**B, and the associated description). If the camera and/or the Kinect is placed too far from the person, the pulse and/or respiration signal in the ALT data may become virtually undetectable. Bringing the Kinect and/or the camera closer to the person typically reduces the prominence of the heartbeat signal component in the ALT data during respiration events. Fine-tuning the positioning of the Kinect (light source) and/or the video camera can be done, for example, by monitoring visualizations of the collected ALT data.

[0083] All the data depicted in the following figures were collected in the absence of any significant body movements from the subject, other than those associated with the subject's respiration and heartbeats.

[0084] FIG. **1** presents an example of the ALT data obtained from the first embodiment of a system as previously described, utilizing the first method in accordance with the technology disclosed in this patent document. The ALT data collection took place during daytime at a rate of 49 data points per second. This rate corresponds to a video capture setting of 49 frames per second on the Pi NoIR camera (refer to LISTING 1). Simultaneously, High Definition (HD) video at 720p was recorded. The video frame size was established at 1280x720 pixels. The subject was positioned at a distance of 1.5 meters (approximately 5 feet) from the Pi NoIR camera, with the camera capturing the upper two-thirds of the subject's body.

[0085] In this instance, the H.264 video encoder generated both I-type and P-type video frames at a ratio of one I-type video frame for every 59 P-type video frames. As the motion vector data for I-type video frames is zero, and consequently, the sSAD values for I-type video frames are zero as well, we replaced each I-type frame's zero sSAD value with the sSAD value of the preceding P-type video frame in the sSAD data shown in FIGS. **1**, **4**A, **5**A, **8**A, and **8**B.

[0086] By setting the appropriate parameter for its operation, the H.264 video encoder can be instructed to produce a single I-type video frame followed only by P-type video frames (see LISTING 1). The three main picture types used in various video algorithms are I, P, and B. They each exhibit different characteristics: I-frames are the least compressible but don't require other video frames for decoding. P-frames can use data from previous frames to decompress and are more compressible than I-frames. B-frames can use both previous and forward frames for data referencing, allowing for the highest level of data compression.

[0087] In FIG. **1**, each data point **100** signifies the sSAD value for a specific encoded video frame. The sSAD values are plotted on the vertical axis **110**. Time progresses from left to right, with earlier captured frames on the left and later ones on the right. These sSAD value data points are interconnected by straight lines.

[0088] The section marked **120** approximates one full respiration cycle of the subject, comprising an inhale followed by an exhale. The sSAD values in this area encapsulate both the individual's respiration and heartbeat.

[0089] The region denoted as **130** pertains to a timeframe when the subject did not breathe. Therefore, the sSAD values within this segment solely illustrate the subject's heartbeat.

[0090] In FIG. **1**, the region labeled as **140** comprises 2048 sSAD data points. This data was used to generate the frequency spectrum depicted in FIG. **2**. The duration of interval **140** in FIG. **1** is approximately 42 seconds.

[0091] To prepare the data for the frequency spectrum, the average value of the sSAD data points in region **140** of FIG. **1** was subtracted from each individual sSAD value in the same region. Subsequently, a fast Fourier transform (FFT) was applied to the resulting average-corrected sSAD values.

[0092] The frequency peaks in FIG. **2**, labeled as **210** (0.24 Hz) and **220** (1.12 Hz), correspond respectively to the person's respiration rate and heart rate during the time interval represented by region **140** in FIG. **1**. The frequency values of peaks **210** and **220** equate to 14 respiration cycles per minute and 67 heartbeats per minute, respectively.

[0093] To exemplify the amplifying effect of the additional light texture, we collected ALT data during daytime using the aforementioned first system embodiment and method, at a rate of 90 data points per second. This rate corresponds to a video capture setting of 90 frames per second on the Pi NoIR camera. The video frame size was set to 640x480 pixels, and the subject was positioned approximately 1.3 meters (4.3 feet) away from the camera, which captured roughly half of the individual's body.

[0094] Frequency spectra depicted in FIGS. **3**A and **3**B were obtained similarly to FIG. **2**, through fast Fourier transformation of the sSAD value data sets. Both sSAD data sets used to generate the spectra in FIGS. **3**A and **3**B were of the same length, corresponding to one minute of data collection under identical ambient lighting conditions (excluding any additional illumination created by the light source element).

[0095] During the collection of the sSAD data set corresponding to FIG. **3**A, the light emitter of the Microsoft Kinect for Xbox 360 unit was active (switched ON). Conversely, during the collection of the sSAD data set for FIG. **3**B, the light emitter was inactive (switched OFF). Note that FIGS. **3**A and **3**B use the same scale on the vertical axis.

[0096] FIG. **3**C presents the same data as FIG. **3**B, but the maximum value of its vertical axis is one hundred times smaller than the maximum values of the vertical axes in FIGS. **3**A and **3**B (2.0E+11 in FIG. **3**C versus 2.0E+13 in FIGS. **3**A and **3**B). Consequently, frequency components **310** and **320** in FIG. **3**A, which correspond to the subject's respiration and heartbeats respectively, are at least one hundred times larger than the frequency components in the same regions of the spectra depicted in FIGS. **3**B and **3**C. The horizontal axis numbers in FIGS. **3**A, **3**B, and **3**C correspond to the frequency bin numbers of the FFT.

[0097] Hence, the data presented in FIGS. **3**A, **3**B, and **3**C illustrates that the implementation of the additional light texture results in an amplification of the frequency components corresponding to an individual's respiration and heartbeats. This amplification is by at least two orders of magnitude when compared to the scenario without any additional light texture.

[0098] It should be noted that both respiration rate and heart rate can be deduced from the same sSAD data. This is exemplified above with reference to the sSAD data presented in FIG. **1**.

[0099] It should be noted that the "baseline" or base level of the sSAD values can potentially be within the range of hundreds of thousands, as exemplified in FIG. **1**. Even with the application of the artificial light texture on a person's body, the amplitude of the respiration and/or heartbeat components within the sSAD signal may constitute only a few percentage points relative to this baseline.

[0100] FIGS. **4**B, **5**B, **7**, **9**, and **10** depict images that were captured by a Pi NoIR camera and subsequently converted into grayscale images.

[0101] To illustrate the ability of the systems, devices, and methods disclosed in this patent document to detect heartbeats and respiration even when a person is entirely enveloped by a thick blanket, ALT data collection was conducted using the first system embodiment and the first method previously described. This data gathering occurred at night, with a rate of 49 data points per second (which corresponds to the Pi NoIR camera's video capture setting of 49 frames per second). The video frame size was established at 1280x720 pixels.

[0102] FIG. **4**B illustrates a person reclining in an armchair, entirely enveloped by an "IKEA 365+ MYSA" quilt/blanket, which has a "warmth rate" of 6. This classification signifies a "thick and heavy" quilt measuring 150x200 cm with a filling weight of 1730 g. To the human eye, the room depicted in FIG. **4**B appeared almost entirely dark because human vision is primarily insensitive to the near-infrared light emitted by the Kinect projector. Any residual illumination in the room, discernible to a person, was due to distant streetlights and the LEDs of electronic equipment within the room. It should be noted that ALT is also effective in daylight, as demonstrated, for example, by the data in FIGS. **1**-**3**.

[0103] FIG. **4**A presents ALT data gathered from the individual enveloped in the blanket shown in FIG. **4**B. The dataset duration in FIG. **4**A spans about one minute. Both respiration and pulse signals are clearly discernible in FIG. **4**A. The arrows labelled **410** in FIG. **4**A mark several consecutive heartbeats. Each of the five regions of ALT data bracketed and labelled with arrows **420**, **430**, **440**, **450**, and **460** in FIG. **4**A corresponds to a respiration cycle, comprising an inhale followed by an exhale. It's noteworthy that there was a pause in breathing between the respiration cycles denoted by **440** and **450**. Additionally, following this breath hold, the person took a relatively quick inhale during the subsequent respiration cycle, **450**. This action is manifested in the rate of change and amplitude of the ALT data for that cycle as shown in FIG. **4**A.

[0104] FIG. **5**B displays an image of an individual asleep under a blanket on a bed, captured by a Pi NoIR camera during nighttime. The light spots produced by the light emitter of a Kinect for Xbox 360 unit, which provided the majority of the scene's illumination, are clearly visible. These light spots create distinct areas of illumination, which form the elements of the artificial light texture produced by the light emitter. The specifics of the artificial light texture elements visible in FIG. **5**B will be further examined later (refer to FIG. **10** and associated discussion). In this scenario, the minimum distance between both the Pi NoIR camera and the Kinect unit and the closest point of the person's body was approximately 2.3 meters, or 7.5 feet.

[0105] The ALT data depicted in FIG. **5**A were gathered using the first embodiment of a system and the first method as per the technology disclosed herein, both described above, at a rate of 49 samples per second. The video captured by the Pi NoIR camera was set to a frame size of 1280x720 pixels. Thin black lines marked as **510** in FIG. **5**A join the sSAD data points. The ALT data in FIG. **5**A mirror both the respiration and heartbeats of the individual. Moreover, a moving average of 49-points was computed for the sSAD values shown in FIG. **5**A, to accentuate the respiration process captured in the ALT data. The thick black line labeled **520** in FIG. **5**A traces the points derived from these moving average calculations, revealing that there were four complete respiration cycles captured in the ALT data depicted in FIG. **5**A. In total, there were 27 heartbeats captured in the ALT data displayed in FIG. **5**A.

[0106] As previously mentioned, the application of additional light texture can significantly enhance the illumination contrast in the scene captured by a video camera. This is particularly effective in low ambient light environments, such as those typically found during the night. FIG. **5**B serves as a strong demonstration of this principle. In the absence of illumination produced by the Kinect's light emitter, the scene in FIG. **5**B would appear nearly uniformly pitch-black.

[0107] For instance, if 'n' represents the number of bits used to denote the shades of gray in a grayscale image like the one displayed in FIG. **5**B, the minimum ratio (comparing the larger value to the smaller one) of grayscale pixel values across two areas or parts of a person's body in the image would be $1 + 1/(2^n - 2)$. When n equals 16, this ratio approximates 1.000015. The ratio of grayscale pixel values echoes the illumination levels ratio for the body parts depicted by those pixels in the image, and can be used as a gauge of illumination contrast between different sections of the image or video frame captured by a video camera as well as a measure of illumination contrast between the body parts or areas depicted by those pixels. In the same vein, the grayscale value of a pixel can be used as a measure of illumination (or illumination level or intensity) of the body part or area corresponding to that pixel as well as a measure of illumination of a section or part of the image or video frame containing the pixel.

[**0108**] In a video frame captured by a video camera, the measure of illumination of a specific area of an object can be deduced from the pixel values that represent that area. In the context of grayscale video frames, each pixel's value, typically ranging from 0 (black) to 255 (white), directly indicates the intensity of light reflected from the corresponding part of the object. A higher pixel value indicates greater illumination, and conversely, a lower value suggests reduced illumination for the pixel, as well as for the part or area of an object corresponding to the pixel. For RGB video frames, each pixel has three components: red, green, and blue, with each component's value typically ranging from 0 to 255. The illumination intensity for a pixel, as well as for the corresponding part or area of an object captured in a video frame, can be indicated by the sum, average, or a weighted combination of these RGB values. For a more generalized measure across an entire area, one might average the illumination values of all the pixels within that region. Additionally, in some contexts, converting RGB values to luminance or brightness using established color models can provide a representation of the perceived illumination of the area in question.

[**0109**] Methods, devices, and systems according to the technology disclosed in this patent document can use pixel values or values derived using numeric values or data associated with the pixels of video frames or images as measures of illumination of those areas of objects in a scene captured in the images and/or video frames which correspond to the pixels.

[0110] If a light source element, such as, e.g., the one used in the first system embodiment discussed in this patent document, serves as the sole or major source of illumination for a scene captured by a video camera (as, e.g., in FIGS. **4**B and **5**B), then objects lit by the light source as well as video frames captured by the video camera will showcase areas with significantly divergent illumination levels. This leads to high illumination contrast values between those areas (for instance, $2^n - 1$ between pixels possessing the minimum non-zero grayscale level of 1 and the maximum grayscale level of $2^n - 1$; with n equalling 16, the ratio is 65535, for example). In contrast, when the observed scene lacks any illumination (say, when the light source is switched off), the illumination contrast would equal 1.

[0111] The number of bits, represented by 'n', in a binary representation of any numeric value linked to a video frame pixel or otherwise related to a video frame, can be any integer. For example, the number of bits used to denote shades of gray in a grayscale image could be 8, 16 (as mentioned above), 32, 64, 128, 256, 512, 1024, etc. (these values do not necessarily have to be powers of two).

[0112] It should be noted that an additional light source, providing relatively spatially uniform illumination of the scene as viewed by the video camera element, can be employed alongside the light source element that generates the additional light texture.

This can be particularly helpful when such added uniform illumination can improve a person's ability to discern the elements of the scene captured in the video frames by the video camera element. This is especially applicable in cases when the light source element generating the additional light texture is the primary or sole source of illumination for a scene, as exemplified in FIG. **5**B. In certain implementations, the light source element that creates the additional light texture may also produce the aforementioned spatially uniform illumination.

[0113] In the methods disclosed in this patent document, we utilize measures of motion in at least a part of a video frame, such as those based on the sSAD value. Other measures of motion in at least a part of a video frame can be employed within the methods according to the disclosed technology. For instance, one could calculate the absolute values of the motion vector components, generated by a video encoder (e.g., an H.264-based one), for a macroblock of a video frame (the components of said motion vector are referred to as the X-component and Y-component) and compute the sum of the absolute values of the components of motion vectors for at least a part of the macroblocks of at least a part of the video frame. This measure of motion is referred to as XYabs in the text below.

[0114] Furthermore, a motion measure based on the sum of the lengths of the motion vectors, calculated using motion vector components generated by a video encoder (e.g., one adhering to the H.264 standard or any other video encoder), for at least a part of the macroblocks in at least a part of a video frame can also be used. Another possibility involves using a measure of motion based on the sum of the lengths of motion vectors, which are generated through an optical flow type of analysis of the video frames (e.g., of a sequence of video frames).

[0115] In the scenario where an optical flow-based measure of motion is used, the elements of the artificial light texture, created by a light source element of a system according to the disclosed technology, can be considered as the objects whose motion is tracked in the video frames using optical flow or an optical flow-based method. Optical flow-based methods of video analysis can be applied to these artificial light texture elements created through the operation of a light source element, according to the technology disclosed herein.

[0116] The XYabs values depicted in FIG. **6** are computed for the same video frames used to produce the sSAD data shown in FIG. **5**A. The lines denoted as **610** in FIG. **6** connect the XYabs data points. Similar to the sSAD values for I-type video frames, the XYabs values for the I-type video frames are set to zero. An arrow marked as **620** in FIG. **6** indicates an XYabs value (zero) for one of the I-type video frames from the set used to generate the data shown in FIGS. **5**A and **6**.

[0117] As with FIG. **5**A, a 49-point moving average was calculated using the XYabs values to emphasize the captured respiration process, specifically the cycle of inhalation followed by exhalation. The thick black line, labeled **630** in FIG. **6**, traces the points resulting from these moving average calculations, revealing four complete respiration cycles captured within the displayed ALT data. Notably, FIG. **6** presents the same number of heartbeats, 27, as shown in FIG. **5**A.

[0118] An XYabs value represents a measure of motion in a video frame or its part for which the XYabs value was computed.

[0119] Systems, devices, and methods according to the technology disclosed herein enable the simultaneous capture of pulse, respiration, and other information pertaining to the mechanical motion of various parts of a person's body. This data can be collected with high temporal resolution and with high spatial resolution by processing respective segments of the captured video frames.

[0120] FIGS. **7**, **8**A, and **8**B demonstrate that the technology disclosed in this patent document can be utilized to obtain detailed information about the intricate mechanical movements of the heart in a non-contact manner. The ALT data depicted in FIGS. **8**A and **8**B were gathered during daytime using the first embodiment of a system and the first method in line with the technology disclosed herein.

[0121] The image in FIG. **7** displays a portion of a person's upper body. Rectangle **710** outlines the area observed by the Pi NoIR camera and illuminated by the light emitter of a Kinect for Xbox 360 unit. It is important to note that the portion of the image within rectangle area **710** in FIG. **7** was captured separately from the rest of the image and overlaid on top of it to provide a clearer representation of the location of the imaged areas of the person’s body.

[0122] The camera's frame size was configured to 640x480 pixels. The data depicted in FIGS. **8**A and **8**B was gathered by the Pi NoIR camera operating at a rate of 90 frames per second. This yields an 11 milliseconds time interval between data points, assuming that the Pi NoIR camera’s video capture parameters remained constant during the acquisition of the video frames used to generate the sSAD data values displayed in FIGS. **8**A and **8**B (as per LISTING 1 below).

[0123] Both the Pi NoIR camera and the Kinect unit were approximately 0.6 m (~ 2 feet) from the person when the image within area **710** and the data presented in FIGS. **8**A and **8**B were collected.

[0124] FIG. **8**A illustrates ALT data for three heartbeats, gathered from processing the entire video frames captured by the Pi NoIR camera (set to a resolution of 640x480 pixels, corresponding to rectangle **710** in FIG. **7**). The data in FIG. **8**B correlate to the same heartbeats as depicted in FIG. **8**A. The ALT data in FIG. **8**B were acquired for the areas surrounding the person’s heart, marked by rectangle **720** in FIG. **7**. This was done by processing parts of the complete video frames captured by the Pi NoIR camera, which correspond to rectangle **720** in FIG. **7**, using the first method as per the technology disclosed in this patent document. Note that the vertical axes in FIGS. **8**A and **8**B have different scales, which are not specified.

[0125] As demonstrated in FIGS. **8**A and **8**B, the ALT data gathered from the smaller regions denoted by rectangle **720** near the person's heart (as shown in FIG. **8**B) display a higher resolution of the heartbeat profile details when compared to the ALT data from the entire area within rectangle **710** in FIG. **7** (as shown in FIG. **8**A).

[0126] The data presented in FIGS. **8**A and **8**B illustrate that systems, devices, and methods in accordance with the technology disclosed in this patent document can be utilized to extract information specific to different parts of the body. This can be achieved through processing distinct segments or areas of the video frames captured by a video camera element. Collection of ALT data can occur at a high temporal resolution; e.g., the time interval between the data points in FIGS. **8**A and **8**B is 11 milliseconds, limited by the maximum frame rate of the utilized video camera element.

[0127] These capabilities, as offered by the systems and methods under the technology disclosed in this patent document, could prove valuable in various applications, particularly in medical imaging. Here, the tracking of pulse, heartbeats, respiration, and other body movements across the whole body and/or any specific areas thereof is typically required.

[0128] As demonstrated by FIGS. **8**A and **8**B, the systems, devices, and methods in accordance with the disclosed technology can be seen as a non-contact counterpart to the seismocardiography and/or ballistocardiography methods, both of which monitor the mechanical activity of the heart and the vascular system. This non-contact counterpart is not just a simple alternative; it represents a sophisticated and non-obvious solution, with the potential to revolutionize the way we monitor the heart and vascular system, enhancing the convenience and ease of use of the technology due to its contactless nature as well as enhancing the depth and breadth of the data it provides.

[0129] The systems, devices, and methods disclosed within this patent document can be utilized to extract information related to the temporal characteristics of at least a portion of a heartbeat, or a segment of a respiration cycle. This can be achieved through various means. For instance, determining the temporal positions of sSAD values or their maxima in relation to a fixed time point or in relation to one another. Or, it could involve determining the duration for which sSAD values remain above a certain level or within a specific numeric value range.

[0130] Another method could comprise identifying temporal positions of points or intervals of extreme variation—be it a maximum or a minimum, local or global—in the sSAD or, more generally, ALT data values. Moreover, it's possible to establish a time dependence or a function—such as a discrete function—for the sSAD values that corresponds to at least a portion of a heartbeat or a segment of a respiration cycle. This established time dependence can subsequently be utilized to identify the temporal durations and/or positions of various features of this time dependence, including but not limited to the ones mentioned previously.

[0131] FIG. **9** presents images **910** and **920**. These were acquired by a system constructed according to the first embodiment of the disclosed technology. The system's Pi NoIR camera was focused on the same area of an individual's body as indicated by rectangle **710** in FIG. **7**. Both images **910** and **920** were captured under the same conditions as the image within rectangle **710** in FIG. **7**.

[0132] In FIG. **9**, white rectangles **930** and **940** encircle specific areas within images **910** and **920**, respectively. These specific areas are further detailed in images **970** and

980, corresponding to rectangles **930** and **940** respectively. Both rectangles **930** and **940** occupy the same relative position in images **910** and **920**, which share identical dimensions.

[0133] As evidenced in images **910**, **920**, **970**, and **980** of FIG. **9**, the light emitter element of the system—consistent with the first embodiment of the technology detailed here—produces light spots of various shapes on distinct areas of a person's body. Shapes of the light spots may include circular, elliptical, rectangular, triangular, hexagonal, having fuzzy borders, or arbitrary ones. These light spots, separate from the surrounding areas marked by their relatively lower illumination, create the elements of what is termed as the additional or artificial light texture generated by the system. Two such light spots are indicated by arrows **950** and **960** in FIG. **9**.

[0134] Whenever this patent document uses a verb such as "illuminates", “produces”, “captures”, “processes”, etc. to describe an action carried out by a device or system according to the disclosed technology or to describe an action carried out by a part or an element of a device or system according to the disclosed technology, it is implied that the device or system and/or their part(s) or element(s) can be configured to perform the action in question or that the device or system and/or their part(s) or element(s) are capable of performing the action in question or that the device or system and/or their part(s) or element(s) are configured or designed or bult to perform the action in question.

[0135] The image **910**, and its corresponding part **970**, were captured in the interim between the heartbeats of the person, during a moment of breath cessation. Conversely, image **920**, and its associated part **980**, were taken around the midpoint of the person's respiration cycle.

[0136] A comparison of images **910** and **920**, as well as their respective segments **930** and **940** displayed in images **970** and **980** of FIG. **9**, illustrates how bodily movements such as respiration, heartbeats, and other internal or external movements can induce changes in the illumination, shape, size, and position of the individual elements comprising the artificial light texture. Moreover, these movements can affect the number of these elements present between images **910** and **920**, and between their segments **930** and **940** shown in images **970** and **980**. Additionally, the movement can lead to variations in the distribution of characteristics such as illumination (e.g., average level or intensity of illumination) within a single element or among different elements, the shape of elements, the size of elements, and the location or position of elements. These variations are at least partially captured by a video camera element in a sequence of video frames. These frames are processed by a computing element according to the disclosed technology, resulting in a set of numeric values or ALT data. The ALT data either already represents the information related to a parameter within the mentioned group of physiologic parameters or can be further processed to obtain values representing the information related to that parameter within the mentioned group of physiologic parameters. Also, at least a part of this set of numeric values can be graphically represented, such as in a 2D plot, as exemplified in FIGS. **8**A and **8**B.

[0137] FIG. **10** displays images **1010** and **1020**, which were procured by a system conforming to the first embodiment delineated in this patent document. In this system, the Pi NoIR camera was oriented towards the same scene depicted in FIG. **5**B. The procurement of images **1010** and **1020** occurred under the same conditions as those for FIG. **5**B.

[0138] In FIG. **10**, the white rectangles **1030** and **1040** respectively enclose areas of images **1010** and **1020**, which are correspondingly displayed in greater detail as images **1050** and **1060**. Both rectangles **1030** and **1040** maintain the same relative positioning within their respective images, **1010** and **1020**, which share identical dimensions. Rectangles **1030** and **1040** encapsulate the chest and abdomen regions of an individual shrouded by a blanket.

[0139] As displayed in FIG. **10** by images **1010**, **1020**, **1050**, and **1060**, the light emitter element in the system, conforming to the first embodiment of the technology disclosed herein, projects a multitude of light spots onto different areas of an individual's body. These light spots, which are captured by a video camera element, can adopt a variety of shapes and are interspersed with areas of the body that receive less illumination. These light spots constitute the elements of the additional or artificial light texture created by the first embodiment of the system.

[0140] The image **1010**, and correspondingly, its segment **1030** as shown in image **1050** from FIG. **10**, were captured during a period of rest between the person's heartbeats, when the individual was not breathing. Conversely, image **1020** and, by extension, its segment **1040** displayed in image **1060** from FIG. **10**, were acquired during a respiration cycle of the individual.

[0141] Upon examining images **1010** and **1020**, along with their corresponding segments displayed in images **1050** and **1060** in FIG. **10**, it's clear that under the conditions under which these images were captured, respiration, heartbeats, and/or other bodily movements primarily induce variations in the distribution of illumination among the artificial light texture elements as well as within individual elements. In contrast, under the conditions associated with images **910** and **920** and their corresponding segments displayed in images **970** and **980** in FIG. **9**, physiological activities such as respiration and heartbeats induce not only variations in the distribution of illumination among and within the elements of the artificial light texture, but also variations in their shape, size, and location distributions, as well as variations in the total number of artificial light texture elements.

[**0142**] It's worth noting that the light source element and the camera element were positioned at a larger distance from the person in the case illustrated in FIG. **10** (~ 2.3 m minimum distance) compared to the case presented in FIG. **9** (~ 0.6 m).

[**0143**] The aforementioned variations are captured, at least in part, by a video camera element in a set of video frames. These frames are processed by a computing element according to a method detailed in this patent document, resulting in at least one set of numeric values or ALT data. This ALT data, once obtained, is already representative of or indicative of the information related to the physiologic parameters of the person from the specified group of physiologic parameters. If necessary, this data can be further processed for additional insights. These numeric values or ALT data can also be displayed using a graphical representation such as a 2D or 3D plot, as exemplified in FIGS. **5**A and **6**.

[0144] Let's consider the scenario where the light source element and the video camera element are placed virtually at the same location. When the distance between the light source and the camera element on one hand, and the person on the other, is sufficiently large, the elements of the additional light texture generated by the light source element on the person's body's surfaces, as viewed by the video camera element, are relatively small. In this case, these elements occupy a single pixel or a small cluster of a few pixels in the video frames captured by the video camera element (this first case generally corresponds to the situations depicted in FIGS. **5**B and **10**). In this distance scenario, movements of the person's body, including those associated with heartbeats and respiration, primarily result in changes in the distribution of illumination among the ALT elements, as captured by the video camera element.

[0145] As the distance between the video camera element and/or the light source element on one hand, and the person on the other, decreases, the observed size and/or density of the ALT elements increases (this second case generally corresponds to the scenarios shown in FIGS. **4**B, **7**, and **9**). In this latter case, movements of the person's body, including those linked to heartbeats and respiration, usually result in changes not only in the distribution of illumination among or within the ALT elements, as captured by the video camera element, but also in changes in one or more of the position, shape, size, or number of the ALT elements in the video frames captured by the video camera element.

[0146] The comparison of data depicted in FIG. **5**A (which corresponds to the first distance scenario described above) and FIGS. **1** and **4**A (which correspond to the second distance scenario) highlights that as the distance between a person and the light source and/or the camera elements of a system, as disclosed in this patent document, decreases, the respiration process becomes more evident in the ALT data. This increased prominence of the respiration process in the ALT data when comparing the second distance scenario to the first one suggests that the relative contribution of changes in characteristics of the ALT elements such as illumination, position, shape, size, or number, which are associated with respiration, also increases as the distance between the person and the light source and/or camera elements of a system, according to the technology disclosed herein, decreases.

[0147] While the patterns of Kinect-generated light spots (ALT elements) presented in FIGS. **4**B, **5**B, **7**, **9**, and **10** were not generated through observation of a single laser spot with its corresponding (e.g., subjective) speckles, interference phenomena, akin to those responsible for forming a speckle pattern when a singular laser beam and its accompanying laser light spot are employed, can influence the illumination distribution within each discrete element of the additional light texture, as documented by the video camera element. Moreover, geometric attributes, including tilt and curvature, along with a host of physical properties, such as optical characteristics inherent to different parts and surfaces of a human body, can also impact the illumination distribution within each element as well as among the elements of the additional light texture (also referred to as ‘artificial light texture’ in this patent document).

[0148] In the following sections, we will discuss additional example embodiments of the devices and systems as per the technology disclosed in this patent document.

These examples will focus on the use of Intel RealSense cameras, a product of Intel Corporation, U.S.

[**0149**] In this patent document, 'example embodiments' and/or ‘example aspects’ refer to specific implementations or instances, and should not be construed as limiting the scope of the disclosed technology to these particular examples.

[0150] RealSense cameras from Intel can have their light emitters serve as light source elements in various embodiments of devices and systems as per the technology disclosed in this patent document. The RealSense cameras can themselves be utilized as video camera elements for capturing video frames in systems and devices adhering to the disclosed technology. Alternatively, another camera, such as, e.g., a Raspberry Pi NoIR camera, can be employed as the video camera element.

[0151] Systems, devices, and methods aligned with the technology disclosed in this patent document can operate with diverse types of static light patterns generated by a variety of devices. Examples include the Microsoft Kinect for Xbox 360 (as discussed above and demonstrated in FIGS. **4**B, **5**B, **7**, **9**, and **10**), and the Intel RealSense R200 cameras (as detailed below and in FIGS. **11** and **13**A-**13**B). Notably, each R200 includes an infrared texture projector with a fixed pattern designed to be high-contrast and appear as random dots. Furthermore, the disclosed technology can operate with dynamically projected patterns, such as, for example, those generated by Intel RealSense F200 cameras, as described below and shown in FIGS. **12** and **14**A-**14**B.

[0152] It is noteworthy that the diverse light patterns employed by the systems, devices, and methods pursuant to the technology disclosed in this patent document share a common feature. This feature involves the illumination of a set of areas (one or more areas) on an object, such as a person's body. This illumination results in either the creation or increase of light within these areas, relative to other areas of the object. This can be understood as enhancing the illumination contrast between the areas illuminated by the light source element and those not illuminated by it, as observed in the video frames captured by a video camera element of a system or device under the disclosed technology. The illumination or contrast thereof may be measured using video frame data, as previously discussed.

[0153] This illumination creates elements of the additional light texture, such as, e.g., light spots, as evidenced, for instance, in images **970** and **980** in FIG. **9** by light spots **950** and **960**. As mentioned earlier, movements of the person's body, including those related to respiration and/or heartbeats, can trigger variations in the illumination, shape, size, or position/location of the elements of the additional light texture, as captured by a video camera element. These movements can also lead to alterations in the illumination distribution, shape distribution, size distribution, location distribution, or the number of these elements, as captured by a video camera element (as seen, for example, in FIGS. **9** and **10** and associated discussion).

[0154] These variations are at least partially captured by the video camera element in a set of video frames. These frames are processed by a computing element as per a method aligned with the technology disclosed in this patent document, resulting in a set of numerical values, known as the "ALT data". In some embodiments, these data can be further processed to derive numerical values that are indicative of, or contain information related to a physiological parameter of the person. At least part of this data set and/or at least part of the derived numerical values can also be displayed using a graphical representation such as a 2D or 3D plot, an alphanumeric representation, or any other form of visual, audio, or audio-visual representation.

[0155] The ALT data, its features, or numeric values derived from it, can be conveyed in multiple ways according to the technology disclosed in this patent document. For instance, they can be translated into corresponding levels or variations in the pitch, volume, or repetition rate of an audio signal. This signal can be created (e.g., in real time) or recorded (e.g., based on the specific ALT data), and then played back to represent these levels and/or variations.

[0156] Similarly, these data can be converted into corresponding variations or levels in the brightness, color, or contrast of an image. These images can be displayed on a screen or projected by a light projector onto the surface of an object, such as a wall. The data could also be used to control the brightness or color of light emitted by a light source.

[0157] In the same vein, audio and visual representations of the ALT data, or its derived numeric values, can be produced either simultaneously or at different times. This approach offers a multisensory representation of the data, allowing users to perceive and interpret the data in various ways.

[0158] For instance, consider a setting such as a meditation room or a yoga studio equipped with a system according to the disclosed technology. The system captures ALT data for a person in meditation or relaxation, which contains information about the person's heartbeats. Variations in the amplitude of the ALT data correspond with the person's heartbeat, and the person's heart rate can be derived by further processing the ALT data.

[0159] These heartbeat-induced variations in the ALT data could be converted into variations in the volume of a sound played through speakers in the studio or through headphones (e.g., wireless ones) worn by the person. This could create an immersive, real-time biofeedback experience, with the sound volume fluctuating in sync with the person's heartbeat. Alternatively, a heartbeat sound could be played at a repetition rate that corresponds to the determined frequency of the person's heartbeats, providing an audible representation of the individual's heart rate.

[0160] The possibilities extend beyond sound. For example, one could utilize visuals to illustrate the same ALT data. The frequency or amplitude of the person's heartbeat could correspond to a level of or changes in the brightness and/or color of a light in the room, creating a dynamic visual experience connected to the person's physiological state. This could help create an environment that is responsive to the person's physiological state, thereby enhancing their relaxation or meditation experience.

[0161] This type of data representation can be particularly valuable in settings such as meditation studios or wellness centers, where real-time physiological feedback can enhance a user's awareness of their body and mind connection, potentially improving their wellness practices. The disclosed technology thus provides versatile and innovative methods for representing and utilizing physiological data.

[0162] Visual and audio representations of ALT data can be utilized as an innovative tool for assisting those with sleep-related challenges, including difficulties falling asleep or forms of insomnia. As per the technology disclosed herein, the ALT data, which contains information about a person's physiological parameters such as heart rate or respiration, can be converted into soothing sounds or calming visual effects that may promote relaxation and sleep.

[0163] For instance, the rhythm of a person's heartbeats and/or respiration, as derived from the ALT data, could be translated into a gentle, rhythmic sound that mimics the ebb and flow of the ocean waves or a soft lullaby that syncs with the person's heartbeats and/or respiration. This rhythmic pattern could help calm the mind and lull the person to sleep. Similarly, the individual's respiration captured in the ALT data (e.g., as variations in the amplitude of the ALT data corresponding to inhales and exhales) or respiration rate derived from the ALT data could be represented as the rising and falling of a calming visual image, such as a slowly undulating landscape or the soft glow of a light. As the person's respiration slows down, so would the movement of the image and/or the brightness of the light, encouraging the person to synchronize their breathing with these soothing visual cues, promoting relaxation and facilitating sleep.

[0164] These representations can be particularly beneficial for those with sleep issues. By translating physiological signals into a soothing audio-visual language, the technology disclosed in this patent document can provide real-time feedback that helps users modulate their breathing and heart rate, potentially promoting a state of relaxation conducive to sleep.

[0165] Moreover, over time, these biofeedback mechanisms can enhance an individual's awareness of their own physiological state and its correlation with their feelings of relaxation or tension. This could potentially aid individuals in developing better control over their physiological responses to stress or anxiety, which are common culprits for sleep problems. Consequently, the technology disclosed herein might not only assist in falling asleep faster but may also help in enhancing the overall quality of sleep.

[0166] As previously discussed, one possible approach to implementing a method according to the technology disclosed in this patent document involves obtaining the Sum of Absolute Differences (SAD) numeric values generated by a video encoder for the video frames captured by a video camera. The ways to compute SAD numeric values which can be implemented in the devices and methods according to the disclosed technology are not confined to utilizing video encoder data. As detailed below, this computation can be performed in alternative ways.

[0167] A possible implementation of the SAD-generating calculations can comprise an iterative process over pixels within a specific captured video frame. For each pixel, a difference is calculated between a numeric value associated with that pixel and a numeric value linked to a corresponding pixel in another captured video frame.

[0168] The associated numeric value could, for example, be included in the data of the video frame itself (such as the pixel's grayscale level or the intensity of blue, red, or green color), or could be obtained as a result of calculations involving one or more numeric values in the video frame data. If the pixel contains a single numeric value, such as the grayscale level, the associated numeric value could be this single numeric value itself, or it could be obtained through computations involving that single numeric value, such as computing an average of the grayscale levels of the pixel and its neighboring pixels or scaling the grayscale level using a factor, for example.

[0169] After determining the difference between the numeric values associated with corresponding pixels, an absolute value of that difference is calculated and added to the cumulative sum of absolute values previously calculated in the iterative process. This sum of absolute differences, referred to as the "mSAD" value, is analogous to the sSAD value derived from video encoder data.

[0170] Two pixels from different video frames can be considered corresponding if they occupy the same position in terms of row and column within their respective frames, though alternative rules may apply, allowing for corresponding pixels to occupy different rows and/or columns. This mSAD value can be computed for any part of a video frame, ranging from the entirety of the frame down to a single pixel, following the aforementioned procedure.

[0171] The mSAD value, calculated for an entire captured video frame as previously described, serves as a basic measure of similarity between that video frame and another video frame, referred to as the "reference" video frame. The calculation of the mSAD value uses the data from the reference video frame, thus providing a "Manhattan distance" or total absolute difference between the two video frames, computed using the numeric values associated with the pixels in the frames. The mSAD value calculated for a video frame, or a portion of it, represents a quantification of motion within that frame or its part. This quantification offers insight into changes or movements taking place in the scene captured by the frame.

[**0172**] The Manhattan distance (also referred to as taxicab distance), D, between vector **p** having coordinates of its end point (p_1, p_2, …, p_n) and vector **q** having coordinates of its end point (q_1, q_2, …, q_n) in an *n*-dimensional real vector space with a (fixed) Cartesian coordinate system (the origin points of both vectors **p** and **q** are at the center of the coordinate system, (0, 0, …, 0)), is the sum of the lengths of the projections of the line segment between the end point of the vector **p** and the end point of the vector **q** onto the coordinate axes of the coordinate system. More formally, $D(\mathbf{p}, \mathbf{q}) = \|\mathbf{p} - \boldsymbol{q}\|_1 = \sum_{i=1}^{n} |p_i - q_i|$. For example, the Manhattan (taxicab) distance between (p_1, p_2) and (q_1, q_2) is $|p_1 - q_1| + |p_2 - q_2|$.

[**0173**] Generally, a pixel of a video frame corresponds to one or more numeric values, representing a physical pixel or a group of pixels from the sensor of the video camera that captured the frame, such as the video camera element of a system developed according to the technology disclosed in this patent document.

[**0174**] Consider two video frames, labeled P and Q. For frame P, we assign a corresponding vector **p**. The coordinates of vector **p** align with the numeric values associated with one or more pixels in video frame P. For example, these numeric values can be sourced directly from the frame data, provided by the camera that captured the frame. Each coordinate p_i of vector **p** equals the numeric value associated with a particular pixel of video frame P.

[**0175**] Similarly, for frame Q, we assign a corresponding vector **q**. The coordinates of vector **q** align with the numeric values associated with one or more pixels in video frame Q. These numeric values can, for example, also be sourced directly from the frame data, provided by the camera that captured the frame. Each coordinate q_i of vector **q** equals the numeric value associated with a particular pixel of video frame Q.

[**0176**] In both cases, the video frame data can be received from the video camera by a computing element of a system developed according to the technology disclosed in this patent document.

[0177] The Sum of Absolute Differences (SAD) value, generated by a video encoder such as an H.264-based one, for a macroblock of a video frame, serves as a measure of similarity between that macroblock and a corresponding macroblock from another video frame, termed the reference video frame. This is essentially the "Manhattan distance" between these two macroblocks. Consequently, the sSAD value can be considered as the "Manhattan distance" between two video frames, calculated using data generated by the video encoder.

[0178] The computation of the SAD value generated by a video encoder for a macroblock of a video frame can follow a similar procedure to the mSAD computation previously described. For each pixel of the macroblock, it can involve the calculation of an absolute difference between a numeric value associated with the pixel and a numeric value associated with a pixel from a corresponding macroblock of the reference video frame. The sum of these absolute difference values forms the SAD value.

[0179] It should be noted that the corresponding macroblocks, the correspondence of which is usually established by a video encoder, may not necessarily hold the same position within the video frames containing the macroblocks. Furthermore, the two pixels for which an absolute difference is calculated between numeric values associated with them, may not hold the same positions within the macroblocks containing them. In an implementation of a method in line with the technology disclosed in this patent document, whether it uses data generated by a video encoder or not, the two pixels used in the absolute value calculation may occupy the same or different positions within the corresponding video frames containing them.

[0180] In an implementation of a method according to the disclosed technology, the numeric value associated with a pixel within a video frame can be derived directly from the pixel's data in the video frame (e.g., the pixel’s grayscale level or color values such as blue, red, green, cyan, yellow, magenta, or black). Alternatively, it can be calculated using one or more of the video frame data values for that pixel and/or other pixels within the same or different video frames (e.g., an average of the grayscale level values of the pixel and either all or a selection of its neighboring pixels within the video frame).

[0181] Note that while, in general, methods in accordance with the disclosed technology typically use the immediately preceding video frame as the reference frame for calculating SAD, XYabs, sSAD, or mSAD values for any captured video frame, any captured video frame can function as the reference video frame for any other captured video frame when generating data using any method per the disclosed technology.

[0182] Furthermore, by allowing a reference video frame to be separated from a given video frame within the set of video frames by one or more video frames, one can obtain SAD, XYabs, sSAD, or mSAD data corresponding to different timescales or effective frame rates. For instance, if video frames are captured at a rate of 100 frames per second (fps), which corresponds to a 10 ms time interval between consecutive video frames given fixed camera settings such as exposure duration (see, e.g., LISTING 1), a 30-second capture would result in a set of 3000 video frames. One could process this entire set by selecting the immediately preceding frame as the reference video frame for each video frame for which a SAD, XYabs, sSAD, or mSAD value is to be obtained, yielding SAD, XYabs, sSAD, or mSAD data corresponding to a 10 ms interval between video frames, or a capture rate of 100 fps. Alternatively, one could form a subset of the collected video frames by selecting every 10th frame from the set. Processing this entire subset by selecting the immediately preceding frame within the subset as the reference video frame for each video frame from the subset for which a SAD, XYabs, sSAD, or mSAD value is to be obtained would yield SAD, XYabs, sSAD, or mSAD data corresponding to a 100 ms interval between SAD, XYabs, sSAD, or mSAD data points, or an effective capture rate of 10 fps.

[0183] Respiration, heartbeats, and/or other body movements of a person can induce additional variations in the "Manhattan distance" between captured video frames, compared to scenarios without body movements or movements of objects within the scene caused by the body. Consequently, the computed sSAD and/or mSAD values, both indicative of the "Manhattan distance" between captured video frames, may contain information about the person's respiration, heartbeats, and/or other movements over the time span covered by the captured video frames.

[0184] The application of an artificial light texture according to the technology disclosed in this patent document to a person's body and/or surrounding objects can notably amplify variations in the "Manhattan distance" between captured video frames, which are associated with the person's respiration, heartbeats, and/or other movements. This amplification is notable compared to scenarios without the artificial light texture, such as when the ALT-generating light emitter is switched off, given identical data collection and processing steps.

[0185] Assuming that video frames are captured at equal time intervals, the computed sSAD and/or mSAD values can be interpreted as the integral, or sum, of the rate of change of the numeric values associated with the pixels in the video frames. These numeric values are used in the computation of the sSAD and/or mSAD values.

[0186] It should be noted that the methods outlined in this patent document, according to the disclosed technology, can employ SAD, XYabs, mSAD, sSAD values, or any other suitable measure of motion. These measures could include, for instance, the calculation of the sum of lengths of motion vectors for a video frame or part of it. This could be achieved using data generated by a video encoder or through an optical flow-based method. These measures can be used irrespective of the type of additional light texture (be it static or dynamic, or the nature of the illumination pattern) created by the systems or devices according to the disclosed technology.

[0187] It's worth highlighting that the primary reason for utilizing the absolute value of the difference between two numeric values, associated with video frame pixels in some implementations of the methods according to the disclosed technology, is the interest in the magnitude of change between these values rather than the direction (positive vs. negative) of this change. Therefore, the absolute value calculation operation can be substituted with another operation that achieves the same objective, providing information about the magnitude (absolute or relative) or extent or degree rather than the direction of change between the numeric values associated with the pixels of the video frames, in alternative implementations of the methods according to the disclosed technology. For example, one might opt to compute the square of the difference, denoted as $difference^2$, rather than its absolute value, $|difference|$, in an implementation of a method according to the disclosed technology.

[0188] The raw mSAD ALT data are depicted in FIGS. **11**, **12**, **13**A-**13**B, and **14**A-**14**B as lines connecting data points (represented as dots, these are the computed mSAD values for the captured video frames). Snapshots of the scenes captured by the video camera elements are presented below the corresponding data plots in FIGS. **11** and **12**. In the computation of the mSAD values shown in FIGS. **11**, **12**, **13**A-**13**B, and **14**A-**14**B, two pixels were assigned as corresponding to one another if they were located in the same numbered pixel rows and columns within two different video frames. The grayscale level of a pixel was used as the numeric value associated with that pixel in the mSAD value computations. For every given video frame, we used the one immediately preceding it as the reference video frame for the computation of the mSAD values presented in FIGS. **11**, **12**, **13**A-**13**B, and **14**A-**14**B.

[0189] The mSAD data depicted in FIG. **11** were obtained using the light emitter and IR video stream of an R200 Intel RealSense camera, operating at a capture rate of 60 frames per second. A snapshot of the scene, taken from the R200 IR video stream, is displayed below the mSAD data plot in FIG. **11**. In the scene, an individual is sitting in an armchair approximately 3 feet away from the R200 camera. The mSAD data in FIG. **11** capture four complete respiration cycles of the individual, as well as a small portion of a fifth respiration cycle at the beginning of the dataset. Numeric values for the heart rate and/or respiration rate of the individual can be derived, for instance, through Fourier analysis of the mSAD data or a correlation-type analysis of the mSAD data (such as an auto-correlation of a single series of mSAD data values).

[0190] The mSAD data displayed in FIG. **12** were gathered utilizing the light emitter and IR video stream of an F200 Intel RealSense camera, which operates at a capture rate of 100 frames per second. A snapshot of the scene from the F200 IR video stream is presented beneath the mSAD data plot in FIG. **12**. The individual in the scene is sitting on a chair approximately 3 feet from the F200 camera. The mSAD data in FIG. **12** capture four complete respiration cycles of the individual.

[0191] The computing element, a desktop PC, was running the same video frame processing algorithm described above to generate real-time mSAD data for both R200 and F200 cameras (FIGS. **11** and **12**, respectively).

[0192] In the instance of dynamically projected patterns, illustrated by the use of a F200 Intel RealSense device (FIG. **12**; “dynamic” projection in the case of the F200 device means that F200 projects a series of light patterns, one after another, over the span of a projection period after which the projection sequence repeats itself), movements of the body, including those associated with heartbeats and respiration, result in alterations to the non-uniform illumination distribution of the scene created by the F200 device. This distribution, dynamically created by the light emitter of the F200 device, is captured by the device's infrared camera. This captured non-uniform (in space and/or time), dynamic (changing over time) illumination distribution forms the artificial light texture, as observed in the captured video frames.

[0193] It is worth noting that the mSAD data in FIG. **12** exhibits a higher noise level compared to the mSAD data in FIG. **11**. This elevated noise level can be attributed to a lack of synchronization between the pattern generation by the F200 camera's light emitter and the individual's heartbeats and respiration. This lack of synchronization means that consecutive heartbeats and/or respiration cycles can correspond to varying average exposure of the body areas to the camera's dynamically projected light patterns. Furthermore, different sections of a heartbeat time interval and/or of a respiration cycle duration, even when of equal duration, can correspond to different exposure of the body areas to the camera's patterns.

[0194] Similar to the first embodiment of a system according to the disclosed technology, the distance between the F200 or R200 device and the individual can impact the prominence of the heartbeat signal during respiration events. Generally, as the device gets closer to the individual, the heartbeat signal component in the ALT data becomes less pronounced during respiration events. It is also important to note that at a sufficiently large distance between the device and the individual, the pulse or respiration signal in the ALT data may be virtually indiscernible. Adjustments to the device's position relative to a subject can be made based on the observation of visualizations of the collected ALT data, for instance. Note that both the light emitter and camera elements in F200 and R200 devices are housed in the common relatively small enclosure.

[0195] FIGS. **13**A and **13**B present mSAD data acquired using the IR light emitter and IR video stream of a R200 Intel RealSense device operating at a 60 frames per second rate, corresponding to two different distances between the R200 device and an individual seated in an armchair, as depicted in FIG. **11**. FIG. **13**A corresponds to a distance of approximately 152 cm (60 in) between the R200 device and the backrest of the armchair, while FIG. **13**B corresponds to a distance of about 102 cm (40 in). In both FIGS. **13**A and **13**B, four complete respiration cycles of the individual were captured in the mSAD data. Raw mSAD data are represented in FIGS. **13**A and **13**B by gray lines connecting the mSAD data points. Black lines **1310** and **1320** in FIGS. **13**A and **13**B, respectively, represent 24-points moving averages of the raw mSAD data. The data in FIGS. **13**A and **13**B illustrate that the variations in the mSAD data associated with heartbeats are less prominent during respiration cycles in FIG. **13**B compared to FIG. **13**A. This indicates that the relative contribution of respiration to the mSAD data increases as the distance between the individual and the camera and light source elements of the R200 device decreases (note that in this instance, both elements are housed within the same enclosure of the R200 unit).

[0196] FIGS. **14**A and **14**B illustrate mSAD data obtained using the IR light emitter and IR video stream of a F200 Intel RealSense device running at a rate of 100 frames per second. These figures correspond to two different distances from the F200 device to a person seated on a chair, as shown in FIG. **12**. FIG. **14**A corresponds to a distance of approximately 119 cm (47 in) between the F200 device and the backrest of the chair, while FIG. **14**B corresponds to a distance of around 81 cm (32 in). Both FIGS. **14**A and **14**B capture four complete respiration cycles of the individual in the mSAD data. Raw mSAD data are displayed in FIGS. **14**A and **14**B by gray lines connecting the mSAD data points. Black lines **1410** and **1420** in FIGS. **14**A and **14**B, respectively, depict 20-points moving averages of the raw mSAD data. The data in FIGS. **14**A and **14**B show that the variations in the mSAD data linked to heartbeats are less noticeable during respiration cycles in FIG. **14**B compared to FIG. **14**A. This suggests that the relative contribution of respiration to the mSAD data increases as the distance between the person and the video camera and light source elements of the F200 device decreases (in this scenario, both of these elements are housed within the common enclosure of the F200 unit).

[0197] The example embodiments of the technology disclosed in this patent document, as detailed above, indicate that the systems, devices, and methods according to the technology disclosed herein don't rely on any specific type of light pattern, be it static or dynamic. The data shown in FIGS. **1** and **5**A, **13**A and **13**B, and **14**A and **14**B all exhibit the same qualitative dependence on the distance between an individual and the video camera element and/or the light source element. This dependence pertains to changes in how the elements of the additional light texture respond to the individual's body movements, including those associated with heartbeats and/or respiration, as captured by a video camera element. These changes occur with alterations in the distance between the individual and the light source element and/or the video camera element, as illustrated above for one of the system embodiments disclosed herein (refer to FIGS. **9** and **10** and the associated discussion).

[0198] As demonstrated, embodiments of systems and devices following the technology disclosed in this document can utilize cost-effective hardware components, such as a Raspberry Pi single-board computer and a Pi NoIR camera. They are also compatible with light emitters from various consumer electronics devices traditionally used for depth-sensing applications, such as, e.g., Kinect for Xbox 360 and Intel RealSense R200 and F200 cameras. These devices generate light patterns with vastly different spatial and temporal characteristics.

[0199] As illustrated earlier, methods in accordance with the technology detailed in this patent document can deploy algorithms founded on differential data processing between video frames and various measures of motion within a video frame relative to another frame. It should be noted that these methods can apply to both "raw" video frames that haven't undergone video encoder processing, and "encoded" video frames that have. These methods facilitate the use of economical video camera and computing elements while maintaining a high degree of compatibility with, and independence from, the specific spatial and temporal characteristics of light patterns generated by diverse light sources.

[0200] Moreover, to gather information associated with the mentioned group of physiological parameters, some embodiments of the systems, devices, and methods according to the technology disclosed in this patent document do not require, produce, or extract any depth or distance data or values that are encoded in the light patterns projected by light emitters and captured by camera elements of depth-sensing devices. Examples of such devices include Kinect and RealSense cameras used in some embodiments. Similarly, some embodiments of the systems, devices, and methods according to the technology disclosed in this patent document do not utilize, produce, or extract any other depth or distance information or values related to or associated with any object, including a person's body or any part of it, within a scene captured or observed by a video camera, or within the field of view of a camera. To gather information associated with the specified group of physiological parameters, some embodiments do not require, produce, or extract any information about any distance.

[**0201**] As additionally highlighted earlier, to acquire information pertaining to the aforementioned group of physiological parameters, some embodiments of the systems, devices, and methods according to the technology disclosed in this patent document do not utilize, produce, or extract any information, numeric values, or data related to the position (such as coordinates and/or distances) of any element of an image of a scene within the image of the scene, where the image is captured in a video frame by a video camera.

[**0202**] Furthermore, for the purpose of obtaining information connected to the mentioned group of physiological parameters, some embodiments of the systems, devices, and methods according to the technology disclosed in this patent document don't use, generate or extract any information, numeric values, or data related to the position (e.g., coordinates and/or distances) of any feature of any function computed, calculated, or otherwise obtained using data from any video frame captured by a video camera.

[**0203**] As outlined above, some measures of motion employed by the systems, devices, and methods in accordance with the technology disclosed herein utilize distance values. For instance, these could be the lengths of motion vectors or projections of a motion vector onto one or more axes of a coordinate system. These values associate an element of a first video frame (for instance, a pixel or macroblock of the first video frame) with an element of a second video frame (like a pixel or macroblock of the second video frame).

[**0204**] Furthermore, it has been demonstrated that the systems, devices, and methods in accordance with the disclosed technology do not necessitate a subject's skin area to be exposed to a camera or any other device. The camera, within a system or device as per the disclosed technology, may be directed towards any part of the subject's body or even towards areas beyond the confines of the body, such as regions located at a certain distance from the body. These parts, areas, or regions could be entirely cloaked by one or more covering items, such as a blanket or clothing, including loose-fitting garments. For instance, the camera may be focused on the back or legs of a subject, even if clothing entirely covers these areas. Hence, certain embodiments of the systems, devices, or methods in line with the disclosed technology do not use, produce, or procure any data or information regarding changes in a person's skin color. Such changes, which, for example, can be observed by a person or captured by a video camera when the skin is uniformly illuminated by white light, may be prompted by the individual's heartbeats or another physiological process. In essence, some embodiments of the systems, devices, and methods according to the disclosed technology abstain from procuring, producing or utilizing any information about heartbeat-induced variations in a subject's (e.g., a person's) skin color.

[**0205**] In some example embodiments, methods, systems, and devices according to the technology disclosed in this patent document do not use and/or do not produce any information or data which describe position or location, be it a relative or absolute position or location, of an area or areas of open skin (e.g., skin not covered by clothing; e.g., skin which can be observed by a naked eye of a person) of a subject (e.g., a person) in any of the video frames captured by the video camera element of a system or a device built or configured in accordance with the technology disclosed herein. In some example embodiments, methods, systems, and devices according to the technology disclosed in this patent document do not use and/or do not produce any information or data which describe position or location of an area or areas of open skin of a subject regardless of the way and/or means by which the position or location can be used and/or produced. Some example embodiments of the methods, systems, and devices according to the technology disclosed in this patent document identify and/or use identification of position or location of an area or areas of open skin in one or more video frames captured by a video camera which may or may not be a part of a device or a system according to the technology disclosed in this patent document.

[**0206**] In some example embodiments, methods, systems, and devices according to the technology disclosed in this patent document do not identify the face or any element of the face of a subject in any of the video frames captured by a video camera of a device or a system configured or built in accordance with the technology disclosed herein. In some example embodiments, methods, systems, and devices according to the technology disclosed in this patent document do not identify and/or do not use identification of the face or any element of the face of a subject in any of the video frames captured by a video camera which may or may not be a part of a device or a system according to the technology disclosed in this patent document. In some example embodiments, methods, systems, and devices according to the technology disclosed in this patent document do not identify the face or any element of the face of a subject and/or do not use such an identification regardless of the way this identification can be made and/or used and/or regardless of the means and/or media which can be employed for such an identification. Some example embodiments of the methods, systems, and devices according to the technology disclosed in this patent document identify and/or use identification of the face or an element of the face of a subject in one or more video frames captured by a video camera which may or may not be a part of a device or a system according to the technology disclosed in this patent document.

[**0207**] In some example embodiments, methods, systems, and devices according to the technology disclosed in this patent document do not identify any open skin area or open skin element of a head, face, hand, arm, leg, foot or any other body part of a subject in any of the video frames captured by a video camera of a device or a system built or configured in accordance with the technology disclosed herein. In some example embodiments, methods, systems, and devices according to the technology disclosed in this patent document do not identify and/or do not use identification of any open skin area or open skin element of a face, head, arm, hand, leg, foot, or any other body part of a subject in any of the video frames captured by a video camera which may or may not be a part of a device or a system according to the technology disclosed in this patent document. In some example embodiments, methods, systems, and devices according to the technology disclosed in this patent document do not identify any area or element of open skin on a head, face, arm, hand, leg, foot or any other body part of a subject and/or do not use such an identification regardless of the way this identification can be made and/or used and/or regardless of the means and/or media which can be employed for such an identification. Some example embodiments of the methods, systems, and devices according to the technology disclosed in this patent document identify and/or use identification of an area or element of open skin on a head, face, arm, hand, leg, foot or any other body part of a subject in one or more video frames captured by a video camera which may or may not be a part of a device or a system according to the technology disclosed in this patent document.

[**0208**] Furthermore, systems, devices, and methods in accordance with the technology disclosed in this patent document also do not require a subject to be within a camera's line of sight.

[0209] The preferred embodiment of a system under the technology disclosed in this patent document comprises a light source element. This element is configured to illuminate one or more areas of a person's body by creating light spots on these areas. Additionally, the light source element may have at least one of the following capabilities: changing the distance between at least two light spots, altering the size of at least one light spot, modifying the shape of at least one light spot, or adjusting the illumination intensity of at least one light spot.

[0210] This preferred embodiment also comprises a video camera element, which possesses at least one of the following capabilities: changing the rate of video frame acquisition, adjusting the size of the video frames, or modifying the exposure duration of at least one video frame.

[0211] Furthermore, the preferred embodiment comprises a computing element capable of calculating SAD, sSAD, mSAD, or XYabs numeric values, or the sum of the lengths of motion vectors. These vectors may be generated using a video encoder or produced through an optical flow-based method of video frame analysis, applicable to the video frames captured by the video camera element. Preferably, the computing element can conduct at least part of these computations using a graphics processing unit (GPU).

[**0212**] The computing element in a system or device, as per the technology disclosed herein, may encompass or include elements such as an integrated circuit, a processor, a microprocessor, a multi-core processor, a controller, a microcontroller, a graphics processing unit (GPU), an application-specific integrated circuit (ASIC), or a field-programmable gate array (FPGA).

[**0213**] The video camera element of a system or device according to the disclosed technology may include or be at least one of the following: an infrared camera (for instance, a camera, device, light detector, or sensor that is capable of generating electrical signals using (or in response to) light or photons of one or more wavelengths above approximately 600 nm, or light within the range between approximately 600 nm and approximately 1000 nm, or photons of wavelengths between approximately 600 nm and approximately 1 mm) or a visible-spectrum camera (for instance, an RGB camera, light sensor, light detector, or device that can generate electrical signals using (or in response to) light or photons with one or more wavelengths between approximately 400 nm and approximately 700 nm).

[**0214**] The measures of motion, such as SAD, sSAD, mSAD, XYabs, or a sum of the lengths of the motion vectors in at least a part of a video frame used by some methods, devices, and systems according to the disclosed technology, serve as measures of variations in one or more of the illumination, shape, size, or location of the additional light texture elements, as well as measures of variations in their count. These measures, as observed by a video camera element of a device or a system according to the disclosed technology, are not the only ones and any other measure of motion in a video frame, or a portion of it, can be utilized within the methods, systems, and devices according to the disclosed technology.

[**0215**] Moreover, any measures, quantities or functions which capture or reflect or are related to variations in one or more of the illumination, shape, size, location, or number of the elements of an artificial light texture produced by a device or a system according to the disclosed technology can be utilized within the methods, systems, and devices according to the technology disclosed herein.

[**0216**] The mentioned features of systems, devices and methods under the disclosed technology can be utilized to obtain information related to a person's cardiovascular system functionality. Specifically, information regarding the duration of the time interval for a blood pressure wave or pulse propagation between two points or areas of a subject, pulse wave velocity (PWV) characteristics of the subject's cardiovascular system, and/or the subject's blood pressure (systolic and/or diastolic), can be obtained in a non-contact and continuous manner.

[**0217**] Pulse wave velocity (PWV) refers to the speed at which a pressure pulse, or a wave of blood, travels through an organism's circulatory system, such as a human's. This system may comprise an artery or a combined length of arteries. Clinically, PWV is utilized as an indicator of arterial stiffness. Currently, the preferred method for PWV measurements is through calculating the carotid to femoral PWV (cfPWV). This method involves measuring the duration of a blood pressure pulse's propagation from a point on a person's carotid artery to a point on their femoral artery using contact measuring equipment. cfPWV is highly reproducible and can forecast future cardiovascular incidents and overall mortality, independently of conventional cardiovascular risk factors. Recognized by the European Society of Hypertension, cfPWV serves as an indicator of potential organ damage and a valuable supplementary test in the investigation of hypertension.

[**0218**] A system or a device as per the technology disclosed in this patent document, designed to ascertain the duration or length of a time interval for the propagation of a blood pressure pulse (or wave) from one area, point, or part of a body (e.g., the body of a subject or person) to another, is henceforth referred to as a PWV system. In some embodiments, a PWV system may also be used to determine pulse wave velocity values or related data, as well as information regarding blood pressure (e.g., systolic and/or diastolic blood pressure values or data).

[**0219**] A PWV system may comprise, for instance, a light source element (such as the light emitter of an Intel RealSense device (typically referred to as 'Intel RealSense camera') like the D435, D435i, D435f, D435if, D455, D455f, or D457), a video camera element (for example, one or more of the infrared (IR) cameras of the Intel RealSense device), and a computing element (such as a Microsoft Surface Go tablet or another type of computer). The video camera element and/or the light source element of a PWV system can be connected to the system's computing element through either wired or wireless connection(s). In general, any system or device according to the disclosed technology could be considered a PWV system or PWV device, respectively.

[**0220**] To acquire information relating to a person's pulse wave velocity and/or blood pressure characteristics, the light source element of a system according to the disclosed technology is designed or configured to illuminate one or more areas on a person's body, for example by projecting a number of light spots onto these areas. As previously detailed, this illumination establishes elements of the additional or artificial light texture (ALT) on at least part of the person's body.

[**0221**] Movements of the individual, including those associated with heartbeats and respiration, as well as movements triggered by the propagation of a blood pressure pulse along the person's body (for example, from a first to a second point or area), can induce changes in the illumination, shape, size, or location of the additional light texture's elements, as captured by a video camera element, in accordance with the disclosed technology. They can also alter the quantity of these elements, as captured by a video camera element, in accordance with the disclosed technology.

[**0222**] Such changes can be at least partially recorded in one or more video frames collected by the video camera element. These frames can be processed by a computing element of the system using a method according to the technology disclosed herein, resulting in numerical values, or "ALT data". This data contains information related to the duration of blood pulse propagation, as well as the person's pulse wave velocity and/or blood pressure. This data can, for example, be further processed to yield numerical values representing information related to the duration of blood pulse propagation and/or the person's pulse wave velocity and/or blood pressure.

[**0223**] To acquire information related to the characteristics of blood pressure pulse propagation (e.g., duration, velocity) in a person's cardiovascular system, video frames can, for example, be processed in the following manner:

[**0224**] Two distinct areas within each video frame from a number of video frames captured by a video camera element of a system consistent with the disclosed technology, are chosen or selected. These areas are henceforth referred to as the first area and the second area.

[**0225**] For at least one of the selected first areas in the video frames, a first numerical value is computed. This value corresponds to, or is related to, a measure of motion in that area. The measure of motion for the first area might be determined relative to an area from a different video frame.

[**0226**] Similarly, for at least one of the selected second areas in the video frames, a second numerical value is computed. This value corresponds to, or is related to, a measure of motion in that area. This or any other measure of motion in the second area can be computed relative to an area from a different video frame or areas within several video frames. These may have the same or different positions within the video frames.

[**0227**] Every measure of motion mentioned in this patent document, as well as any other measure of motion, can be employed to derive the aforementioned first and second numerical values. These values pertain to movements of a person's body due to their heartbeats (including blood pressure waves initiated by those heartbeats) and/or respiration, as long as such movements are captured (directly or indirectly (e.g., via movements of other objects)) in the mentioned first and second areas of the video frames.

[**0228**] The numerical values derived for the first areas within the video frames are denoted as the first set of motion values. Similarly, the numerical values obtained for the second areas within the video frames are referred to as the second set of motion values.

[**0229**] A segment of the first set of motion values and a segment of the second set of motion values, both corresponding to the same heartbeat, are identified or selected.

[**0230**] Portions of the first and second sets of motion values are considered to correspond to the same heartbeat if, for instance, that heartbeat has an identical serial number in both the first and second sets of motion values. This is when the heartbeats are counted from a shared time reference for both sets of motion values. Portions of the first and second sets of motion values might be considered to correspond to the same heartbeat if they relate to the same time interval, such as when they were obtained using video frames with timestamps within that interval.

[**0231**] Within the indicated portion of the first set of motion values, at least one motion value is identified or selected (referred to as the first motion value below), along with its corresponding video frame. Likewise, within the specified part of the second set of motion values, at least one motion value is chosen (referred to as the second motion value below), as well as its corresponding video frame.

[**0232**] A video frame may correspond to a motion value within the first or second set of motion values, if that motion value was ascertained for the first or second area of that video frame, respectively. The video frame linked to the first motion value is hereafter referred to as the first frame, while the video frame associated with the second motion value is denoted as the second frame.

[**0233**] These first and second frames are utilized to ascertain a time interval corresponding to the duration of a blood pressure wave's propagation. This wave moves between an area of the individual's body captured in at least one of the first areas of the video frames and an area of the body captured in at least one of the second areas of the video frames.

[**0234**] The time interval may be equivalent to the time interval between the first and second frames. This can be determined using the time stamps of the first and second frames, which can be provided by the camera that captured the frames, or by a computing element within a system as per the disclosed technology that received these frames from the camera. Alternatively, or additionally, the time interval could be derived from calculations involving time positions (including but not limited to the aforementioned time stamps) of one or more video frames, which may or may not include the first and second frames.

[**0235**] A numeric value representative of pulse wave velocity can be determined using the time interval previously identified, as well as a numeric value associated with the distance between the area of the person's body captured in at least one of the first areas of the video frames and the area captured in at least one of the second areas. This may be a direct distance (along a line or curve), an effective distance, or a virtual distance. By dividing the distance-associated numeric value by the determined time interval, the pulse wave velocity can be calculated.

[**0236**] In some embodiments, the first motion value might correspond to a minimum motion value in the first set of motion values, which can be a local or global minimum. In other embodiments, the first motion value could correspond to a maximum motion value in the first set, whether local or global.

[**0237**] In some instances, the first motion value may correspond to a maximum value, a minimum value, a rate of change, or a slope of a function. This could be, for example, a maximum or a minimum value of a function, such as moving average or another type of averaging or filtering function, derived from the motion values in the first set. This function may depend on various parameters such as the video frame number or the frame's timestamp. In some embodiments, the first motion value might correspond to a motion value in the first set or to a value of a function of the motion values in the first set.

[**0238**] In some example embodiments, the second motion value could correspond to a minimum motion value in the second set, whether it is a local or a global minimum. In other example embodiments, the second motion value might correspond to a maximum value, either local or global, within the second set of motion values.

[**0239**] In some instances, the second motion value might correspond to a maximum value, a minimum value, a slope, or a rate of change of a function. This function could be a function derived from the motion values in the second set, such as, for example, a moving average function or another type of averaging or filtering function. This function might depend on various parameters, including the video frame number or the timestamp of the frame from which the motion value was derived. In some embodiments, the second motion value may correspond to a motion value in the second set, or to a value of a function of the motion values in the second set.

[**0240**] For the purpose of obtaining data related to the characteristics of blood pressure wave propagation in the cardiovascular system of a person, such as duration and velocity, video frame processing can be conducted in the following manner in certain embodiments of the technology disclosed in this patent document:

[**0241**] In every video frame within a selected set—this set comprising one or more video frames—two areas are selected or identified. These areas will be referred to as the first and second areas. Alternatively, a first area is identified in each of a certain number of video frames, and a second area is identified in each of a different set of video frames. In this scenario, at least some of the frames in which the first area is selected are distinct from those where the second area is chosen.

[**0242**] For at least one of the first areas identified in the video frames, a numeric value is derived that corresponds to a specific measure of motion within the area. This measure of motion in the first area of a video frame could be established in relation to, or using an area from, a different video frame. Similarly, for at least one of the second areas selected in the video frames, a numeric value is obtained that corresponds to a measure of motion within the area. This measure of motion in the second area of a video frame could be determined in relation to, or using an area from, another video frame.

[**0243**] Any measure of motion discussed in this patent document, as well as any other measure of motion, can be utilized to derive these numeric values. These values are indicative of the movements of a person's body caused by heartbeats, including the resulting blood pressure waves, and/or respiration, as far as such movements are captured (directly or indirectly (e.g., via movements of other objects)) within the first and second areas of the video frames.

[**0244**] The numeric values derived for the first areas within the video frames are collectively referred to as the first set of motion values. Similarly, those computed for the second areas within the video frames form the second set of motion values. From each set, a subset of motion values corresponding to the same heartbeat is identified or selected. The subsets from the first and second sets of motion values can be considered as corresponding to the same heartbeat if, for instance, the heartbeat has the same serial number in both sets when heartbeats are numbered starting from a common time reference. Alternatively, or additionally, these subsets from the first and second sets of motion values can be considered as corresponding to the same heartbeat if they relate to the same time interval.

[**0245**] In certain example embodiments, time markers or indicators are assigned to the motion values in both the first and second sets. These time markers can be obtained, e.g., using timestamps or other time-related indicators of the video frames. For example, these timestamps could be assigned to the video frames by a camera which captured those frames or by a computer, such as the computing element of a system as per the disclosed technology.

[**0246**] In some embodiments, the assigned time markers can be acquired using the timestamps of the video frames corresponding to the motion values. For instance, a video frame corresponds to a motion value in the first or second set of motion values if the motion value was determined for the corresponding area of the video frame. In specific embodiments, a time marker for a motion value from the first or second set of motion values may match the timestamp of the video frame for which the motion value was determined.

[**0247**] These operations result in a first set of time markers, corresponding to the first set of motion values, thus establishing a first correspondence or a first discrete function between a motion value in the first set and a time marker in the corresponding set. Similarly, a second set of time markers, corresponding to the second set of motion values, establishes a second correspondence or a second discrete function.

[**0248**] Some embodiments of the disclosed technology might further involve interpolating the first discrete function between at least two motion values in the first set and their corresponding time markers to yield an interpolated first discrete function. Similarly, interpolation might also be performed on the second discrete function between at least two motion values in the second set and their corresponding time markers, resulting in an interpolated second discrete function.

[**0249**] Any method of interpolation can be applied in the described scenario, such as, for example, linear, polynomial, or spline interpolation. In some embodiments, interpolation might generate additional motion values along with corresponding time markers, located between the points where the interpolation was performed.

[**0250**] In some example embodiments, a first time value can be derived or selected using either the first discrete function or the interpolated first discrete function. Similarly, a second time value can be derived or selected using either the second discrete function or the interpolated second discrete function. In some embodiments, a time interval can be determined using the first and second time values. This interval might be equivalent to the difference between the first and second time values. In some embodiments, this interval might be a function of the difference between the first and second time values.

[**0251**] The determined time interval can correspond to the duration of propagation of a blood pressure pulse from an area of the subject's body, captured in or otherwise associated with at least one of the first areas of the video frames, to an area of the subject's body, captured in or otherwise related to at least one of the second areas of the video frames.

[**0252**] A numeric value representing the pulse wave velocity (PWV) characteristic of the subject's cardiovascular system could be determined using the previously computed time interval and another numeric value that is associated with the distance between an area or part of the subject's body captured in or otherwise associated with at least one of the first areas of the video frames, and another area or part of the subject's body captured in or otherwise related to at least one of the second areas of the video frames. For instance, this calculation might involve dividing the numeric value associated with the distance by the computed time interval.

[**0253**] In some embodiments, the first time value might correspond to a minimum (be it local or global) motion value of either the first discrete function or the interpolated first discrete function. In other embodiments, this first time value might correspond to a maximum (local or global) motion value of the first discrete function or the interpolated first discrete function. Still, in other cases, the first time value could correspond to a maximum or minimum value of a slope or rate of change of the first discrete function or interpolated first discrete function. Yet in other embodiments, the first time value could simply correspond to a value from the first discrete function or the interpolated first discrete function.

[**0254**] In some embodiments, the second time value might correspond to a minimum (be it local or global) motion value of either the second discrete function or the interpolated second discrete function. In other embodiments, this second time value might correspond to a maximum (local or global) motion value of the second discrete function or the interpolated second discrete function. Still, in other cases, the second time value could correspond to a maximum or minimum value of a slope or rate of change of the second discrete function or interpolated second discrete function. Yet in other embodiments, the second time value could simply correspond to a value from the second discrete function or the interpolated second discrete function.

[**0255**] Note that in any method, device or system according to the technology disclosed herein, a given transformation, modification, or function can be applied to any of the following: the first discrete function, the interpolated version of the first discrete function, the second discrete function, or the interpolated version of the second discrete function. Furthermore, the first and second time values can be ascertained using characteristic points or features, such as, e.g., maxima, minima, or points with the maximum or minimum rate of change (slope) from the resultant transformed or modified discrete functions (whether interpolated or not). For instance, one or more operations (e.g., applied in a sequence of operations) like averaging (e.g., moving average or exponential moving average), smoothing, filtering (e.g., median, Gaussian, high-pass, low-pass, band-pass, or band-stop filtering), computation of a derivative, or application of a transform (e.g., Fourier, wavelet, Hilbert, histogram equalization, z-score normalization, or min-max scaling) can be utilized on the first or second discrete functions, as well as their respective interpolated versions.

[**0256**] FIG. **15** illustrates one of the infrared (IR) video frames (video frame **1500**) captured by the video camera element of a PWV system in line with the disclosed technology. The frame depicts a person lying on a solid surface. The first area of the video frame, as shown in FIG. **15**, is the region between lines **1510** and **1520**. The second area is between lines **1530** and **1540**. As depicted in FIG. **15**, both the first and second areas of the video frame include parts of the individual's body and portions of the surrounding objects. This specific example does not limit the breadth of the technology disclosed here. Other scenarios are plausible, where both or only one of these video frame areas capture solely a section or multiple sections of the person's body, or only a section or sections of the surrounding objects.

[**0257**] Also, the shape of either the first or second area can be circular, elliptical, hexagonal, polygonal, have fuzzy borders or be arbitrary and does not necessarily need to be rectangular, as shown in FIG. **15**. For instance, an area's shape or boundary (like that of the first or second area) may follow the contour of the person's body or an object near the person. The first area's shape may differ from the second area's shape. The first area's size may also be different from the second area's size. Additionally, any of the first or second areas of the video frame can constitute any portion of the video frame. The second area may have a different position within the video frame than the first area, and it might also overlap with the first area, at least in part. The first or second area within the video frame may either be a single contiguous region or comprise multiple, possibly overlapping or non-overlapping, regions of the video frame.

[0258] The first area, having the same position within the frame as the first area shown in FIG. **15**, was also chosen in a number of additional video frames captured by the PWV system's video camera element. Similarly, the second area, sharing the same position within the frame as the second area shown in FIG. **15**, was chosen in each of these additional video frames where the first area was also selected. The video frames in which both the first and second areas were selected are hereafter referred to as a set of PWV video frames.

[0259] For each of the first areas in the set of PWV video frames, an mSAD value, serving as a measure of motion, was calculated, resulting in the first set of motion values. Similarly, an mSAD value, another measure of motion, was calculated for each of the second areas in the set of PWV video frames, yielding the second set of motion values.

[0260] Any computations utilizing a motion value from the first set of motion values can yield a numeric value, which then represents a measure of motion in the corresponding first area of a video frame. For instance, an average value can be computed, whether it be a weighted average, arithmetic average, exponential average, or any other type or combination of averaging methods, of an mSAD value and any other *k* (where *k* is an integer) mSAD values within the first set. The average values derived from the first set of motion values are henceforth referred to as the first set of average motion values.

[0261] In a similar vein, computations utilizing a motion value from the second set of motion values can produce a numeric value, which also represents a measure of motion in a second area of a video frame (for instance, the second area for which the motion value was computed). The calculations performed using the motion value from the second set of motion values could be the same or different in nature compared to the calculations performed using the motion value from the first set. For instance, an average value can be computed, whether it be a weighted average, arithmetic average, exponential average, or any other type or combination of averaging methods, of an mSAD value and any other *n* (where *n* is an integer) mSAD values within the second set. The average values derived from the second set of motion values are henceforth referred to as the second set of average motion values.

[0262] Apart from, or in addition to, applying an averaging operation to the set(s) of motion values (or to any number of motion values within these sets), any other operation can be performed, or any function or operator applied, to any number of motion values in any of these sets. For example, a frequency filter (such as a band-pass, band-stop, high-pass, low-pass filter or any combination of these) can be applied to one or more motion values in one or more of the sets of motion values.

[0263] Any value from a set of average motion values is referred to as an mSADaverage value. Similar to any mSAD value, an mSADaverage value represents a measure of motion in a video frame area.

[0264] The data plots of mSADaverage values displayed in FIGS. **16** and **17** used a value of 14 for both *k* and *n*. The mSADaverage values were calculated as an arithmetic average of an mSAD value and *k* (or *n*) preceding mSAD values in a set of mSAD motions values, where "preceding" refers to values obtained from frames with timestamps earlier than that of the frame used to derive the mSAD value. The particular choice of values for *k* and/or *n* does not limit the scope of the technology disclosed in this patent document.

[0265] Applying filters or averaging operations to motion values can potentially result in time shifts of the adjusted values relative to the original ones. These time shifts are typically caused by phase changes induced by the filtering or averaging process, and are more pronounced when dealing with non-linear or complex filters. The magnitude and direction of the shift often depend on the characteristics of the original signal, including its frequency content and its variability over time.

[0266] To address these time shifts, corrective operations can be implemented. These operations essentially adjust the timestamps of the modified values, thus compensating for the introduced shifts. The specific nature of the corrective operations can depend on the type and severity of the shift, as well as the particular filter or averaging operation used.

[0267] For instance, if the shifts are constant and known, a simple offset can be applied to the timestamps of the filtered or averaged values. If the shifts vary with frequency (a common occurrence with certain types of filters), a more complex corrective operation, possibly involving an inverse filtering operation, may be needed.

[0268] In some cases, an estimation of the shift can be obtained by comparing (e.g., correlating) the filtered or averaged values with the original ones, and this estimate can then be used to adjust the timestamps. Alternatively, one might use predictive models or machine learning algorithms to anticipate and correct for the shifts.

[0269] FIG. **16** illustrates a plot of an example first set of average motion values. These values were derived from the first areas of numerous video frames, all of which share the same position within their respective frames as the first area (between lines

1510 and **1520**) of video frame **1500** depicted in FIG. **15**. However, in some implementations, any two of these first areas may have different positions, sizes, structures, or shapes within their respective video frames.

[0270] FIG. **17**, on the other hand, depicts a plot of an example second set of average motion values. These were derived from the second areas of video frames in a series of video frames, the same series used for obtaining the first set of average motion values. As previously discussed, the first and second sets of (average) motion values may share all, some, or none of the same video frames. Each of the second areas used shares the same position within its respective frame as the second area (between lines **1530** and **1540**) of video frame **1500**, as shown in FIG. **15**. In certain implementations, any two of the said second areas may have different positions, sizes, structures, or shapes within their respective video frames.

[0271] The mSADaverage points depicted in both FIG. **16** and FIG. **17** are connected by lines. The horizontal axes in both figures represent the assigned numbers of the video frames from which the mSADaverage values were calculated. These frame numbers can be converted into time values, or time markers, utilizing values of time intervals between the frames or the time stamps of the video frames. These time interval values or time stamps can be generated by either the video camera element or the computing element of the PWV system, including its hardware or operating system.

[0272] The vertical axes in FIG. **16** and FIG. **17** display the mSADaverage values. It should be noted that the plots shown in FIGS. **16**, **17**, **19**, and **20** are purely illustrative. Systems, devices, and methods according to the technology disclosed in this patent document can utilize any kind of numeric values, whether averaged, filtered, or processed in any other manner, that represent a measure of motion in a video frame area.

[0273] The data points falling within the bracket **1610** in FIG. **16** were chosen as corresponding to a heartbeat of the individual shown in FIG. **15**. The data points within the bracket **1710** in FIG. **17** were selected as matching the same heartbeat.

[0274] Within the defined heartbeat (the section of data under bracket **1610** in FIG. **16**), the mSADaverage data point **1620** was chosen for the first set of motion values. This point corresponds to the maximum mSADaverage value recorded for the heartbeat as seen in the first set of motion values. Similarly, within the same heartbeat (the section of data under bracket **1710** in FIG. **17**), the mSADaverage data point **1720** was selected for the second set of motion values. This point corresponds to the maximum mSADaverage value within the heartbeat as recorded in the second set of motion values.

[0275] While points corresponding to the maximum (whether local or global) value of a motion measurement within a heartbeat can be selected for any set of motion values, alternatives are possible. For instance, a point corresponding to the maximum rate of change (e.g., rate of increase or decrease) of a motion measurement during the systolic phase (or any other phase) of a heartbeat, or during the entire heartbeat, can be selected. For example, within the defined heartbeat, point **1630** from FIG. **16** could be selected from the first set of motion values. This point corresponds to the maximum rate of change in mSADaverage values during the systolic phase of the heartbeat identified within bracket **1610**. Similarly, point **1730** from FIG. **17**, representing the maximum rate of change in mSADaverage values during the systolic phase of the heartbeat identified within bracket **1710**, could be selected for the second set of motion values.

[0276] For another instance, a point corresponding to the 'foot' of a heartbeat peak could be selected. This could also be a point corresponding to a centroid of a peak, or a point corresponding to a centroid of a section of a peak. As another example, the point **1640** from FIG. **16**, corresponding to the minimum mSADaverage value within the heartbeat marked by bracket **1610**, could be chosen within that heartbeat for the first set of motion values. Similarly, point **1740** from FIG. **17**, which corresponds to the minimum mSADaverage value within the heartbeat marked by bracket **1710**, could be chosen for the second set of motion values.

[0277] It should be noted that the choice of a specific type of point (minimum, maximum, centroid, etc.) does not limit the scope of the disclosed technology. For the first and second sets of motion values, different types of points can be selected. For instance, the point chosen for the second set of motion values could be of a different type than the point chosen for the first set. For example, for the first set of motion values, a point corresponding to the maximum value of a motion measure within a heartbeat could be chosen, while for the second set, a point corresponding to the maximum rate of change (for example, rate of increase or decrease) of a motion measure during a certain part (e.g., systolic part) or during the entire heartbeat could be chosen.

[0278] Furthermore, the first set of motion values could include motion values of a particular type (e.g., mSAD values), while the second set could consist of a different kind of motion values (for instance, values corresponding to the sum of the lengths of motion vectors in a section of a video frame, or values derived from an optical flow analysis of video frames).

[0279] The video frames corresponding to the mSADaverage data points **1620** and **1720** were identified and are henceforth referred to as the first and second video frames, respectively.

[0280] The time interval, which represents the duration of propagation of a blood pressure wave between an area of the subject's body captured in the area of video frame **1500** displayed in FIG. **15** between lines **1510** and **1520** (the first body area), and another area of the subject's body captured in the area of video frame **1500** shown in

FIG. **15** between lines **1530** and **1540** (the second body area), was chosen to be equal to the time interval between the first and second video frames. This interval was calculated to be 0.12 seconds by computing the difference between the timestamps of the first and second video frames.

[**0281**] In addition to, or as an alternative to the methods described above for determining the duration of blood pressure wave propagation between two points, areas, or parts of a body (e.g., a human body) using the time interval between a first characteristic point within a heartbeat as captured in a set of first video frame areas, and a second characteristic point within the same heartbeat as captured in a set of second video frame areas, the time interval corresponding to the duration of blood pressure wave propagation between two points, areas, or parts of a body (e.g., a human body), can be ascertained using a correlation function between a first set of motion values derived from the first set of video frame areas and a second set of motion values derived from the second set of video frame areas.

[**0282**] For instance, a correlation function, whether discrete or continuous, can be calculated between the aforementioned sets of motion values. In order to determine the time interval, a point on this function that corresponds to a maximum value (such as a local maximum) of the correlation function can be identified and used to determine the time interval in question. This method provides an alternative or complementary approach to obtaining an accurate representation of blood pressure wave propagation times.

[**0283**] According to some example embodiments, the process of determining the time interval, or duration, of blood pressure wave propagation between two points, areas, or parts of a body, or acquiring data or information related to any of the mentioned physiologic parameters of a person, does not necessitate the use or acquisition of information regarding any distance related to any element or object of a scene captured in any video frame obtained by a video camera element of a system or device according to the disclosed technology. This statement, as well as other statements related to the term “distance” made in this patent document, apply also to any term synonymous with "distance," such as "displacement", "length", "shift", "space", "span", "gap", "interval", "separation", "interspace", "extent", "stretch", "width", "height", "depth", "range", and the like.

[**0284**] In certain embodiments, deriving the duration of the time interval for blood pressure wave propagation between two points, areas, or parts of a body, as well as acquiring data or information related to any of the stated physiologic parameters of a person, does not involve the use or acquisition of any information about any distance at all.

[**0285**] In some embodiments, determining the duration of blood pressure wave propagation between two points, areas, or parts of a body, along with obtaining data (such as numeric values) or information related to any physiologic parameters of the person mentioned in this patent document, does not require the use or acquisition of any information about the position of any element or feature of an image within that image. In such embodiments, the image, for instance, can be contained in a video frame captured by a video camera element of a system or device according to the disclosed technology or in any other video frame captured by any other camera. In this case, the terms “image” and “frame” (or “video frame”) are in the same conceptual relationship to each other as the terms “painting” and “canvas” on which that painting is painted.

[**0286**] According to certain example embodiments, the calculation of the time interval, or duration, of blood pressure wave propagation between two points, areas, or parts of a body, as well as the acquisition of data or information related to any of the physiologic parameters of an individual mentioned in this patent document, does not involve the use or collection of any information about the position of any feature of a function calculated using an image, within said image or within any other image. This applies to situations where the image is, for instance, captured in a video frame obtained by a video camera element of a system or device per the disclosed technology.

[**0287**] In other words, certain embodiments of the disclosed technology refrain from collecting or using any information or data about any distance or position of any object, feature or part thereof, or a feature of a function, or an image element for the purpose of determining the duration of blood pressure wave propagation between two points, areas, or parts of a body. The same applies when obtaining data or information related to any of the mentioned physiologic parameters of the person.

[**0288**] Some embodiments of the systems, devices, and methods as per the disclosed technology do not use or collect any data (for example, numeric values) related to skin color or changes in skin color of a subject. This includes not using or collecting any information about color changes in the skin (in any area) of the subject (such as a person) that are caused by the subject's heartbeats, including the blood pulses or waves generated by these heartbeats.

[**0289**] These color changes, for instance, can be observed by a human eye or captured by a video camera when the skin is uniformly illuminated with white light as changes in the red and/or green and/or blue component of the skin color.

[**0290**] Certain embodiments of the systems, devices, and methods according to the technology disclosed in this patent document intentionally avoid or refrain from acquiring, generating, or utilizing any information about any changes or variations in a subject's skin color. This includes avoiding any data or information related to color fluctuations in the skin of a subject, such as a human, that might be induced by the subject's heartbeats.

[**0291**] According to some example embodiments, the determination of the time interval or duration of blood pressure wave propagation between two points, areas, or parts of a body, and the acquisition or generation of data, for example numeric values, or information pertaining to any of the physiologic parameters mentioned in this patent document, do not involve the use or acquisition or production of information about color changes in any area of a subject's skin. This applies even when such changes are caused by the subject's heartbeats, including the blood pulses or waves produced by these heartbeats.

[**0292**] For the purpose of obtaining the time interval or duration of blood pressure wave propagation between two points, areas, or parts of a body, as well as acquiring or producing data or information related to any of the physiologic parameters mentioned in this patent document, some example embodiments explicitly avoid or refrain from using or collecting information about any color changes in any skin area of a subject. This remains the case even if these changes are, for example, induced by the subject's heartbeats, including the blood pulses or waves generated by these heartbeats.

[**0293**] In some example embodiments of the technology disclosed in this patent document, there are specific restrictions related to the handling of positional information and identification of certain features:

[**0294**] No Position or Location Information: The methods, systems, and devices according to such example embodiments do not use, produce, or obtain any information or data describing the position or location—whether relative or absolute—of an area or areas of open skin (e.g., skin not covered by clothing; skin observable by the naked eye) of a subject, such as a person, in any video frames captured by the corresponding video camera element.

[**0295**] No Face Identification: The methods, systems, and devices according to such example embodiments do not identify the face or any element of the face of a subject in the captured video frames. The methods, systems, and devices according to such example embodiments can also refrain from or avoid using such identification, regardless of how it may be made or used, or the means or media that might be employed for such identification.

[**0296**] No Identification of Open Skin Areas: The methods, systems, and devices according to such example embodiments do not identify and do not use the identification of any open skin area or element on a head, face, arm, hand, leg, foot, or any other body part of a subject in the captured video frames. This applies regardless of whether the video camera that captured the video frames is part of a specific device or system or not, and regardless of how the identification may be made or used, or the means or media that might be employed.

[0297] The above-determined duration of blood pressure wave propagation was utilized to calculate a Pulse Wave Velocity (PWV) value. A distance of 0.7 m was determined between the first and the second body areas by employing a ruler to measure the physical space separating these sections of the person's body. The same distance value could be ascertained using depth data, captured using the depth-sensing capabilities of an Intel RealSense camera or another depth-sensing camera compatible with or separate from the disclosed systems or devices. Note that, as discussed above, in order to determine the said duration of blood pressure wave propagation, no distance or positional data or information are produced or used by some example embodiments of the technology disclosed herein.

[0298] The calculated PWV value was derived by dividing the measured distance value (0.7 m) by the determined time interval duration (0.12 s), resulting in a value of 5.8 m/s. These computations, while demonstrated here for a single heartbeat, can be replicated for multiple heartbeats. PWV values obtained from multiple heartbeats could then be employed to extract statistical data related to the pulse wave velocity characteristic of a person's cardiovascular system. For instance, an average and/or a histogram of the calculated PWV values could provide valuable insights.

[0299] The process of calculating a PWV value from a single heartbeat, as delineated above, can be replicated across multiple heartbeats. In order to minimize the impact of random heartbeat-to-heartbeat variations in pulse wave velocity, which could potentially arise from noise in the ALT data, statistical calculations can be performed using multiple PWV values. For instance, an average value, whether arithmetic, weighted, or another type, can be computed using the PWV values obtained from several heartbeats. These particular examples of statistical calculations, however, do not confine the scope of the disclosed technology. Any form of calculation can be executed using one or multiple PWV values by systems and devices in accordance with the disclosed technology, or employing methods outlined herein.

[0300] The technology disclosed in this patent document can be utilized to obtain information related to the pulse wave velocity characteristic of a person's cardiovascular system, even when the individual is wearing clothes or is partially or fully covered by one or more items, such as a blanket. This unique capability of the disclosed technology is further elucidated with reference to FIGS. **18**-**20**, as described in the following sections.

[0301] FIG. **18** displays one of the IR video frames (video frame **1800**) that have been captured by the video camera element of a PWV system designed or built or configured in accordance with the technology disclosed in this patent document. This frame depicts a person lying in a bed, covered by a blanket.

[0302] Within video frame **1800**, as seen in FIG. **18**, the first area is delineated by the lines **1810** and **1820**, while the second area is found between the lines **1830** and **1840**.

[0303] The processing of these captured video frames, including both the video frame processing and data processing steps, was conducted in the same manner as was used to generate the data presented in FIG. **16** and FIG. **17**. This processing of the video frames captured by the PWV system for the scene depicted in FIG. **18** resulted in the data shown in FIG. **19** and FIG. **20**. Specifically, FIG. **19** illustrates a plot representing an example first set of average motion values. These values were obtained for the first areas of multiple video frames, with all of these first areas maintaining the same position within their respective frames as the first area between lines **1810** and **1820** in video frame **1800**, as shown in FIG. **18**. Similarly, FIG. **20** portrays a plot of an example second set of average motion values. These were secured for the second areas of numerous video frames (for example, the very frames for which the first set of average motion values was obtained), and all of these second areas were positioned consistently within their respective frames, mirroring the second area between the lines **1830** and **1840** in video frame **1800**, as depicted in FIG. **18**. In the plots displayed in FIG. **19** and FIG. **20**, the mSADaverage points are interconnected by lines.

[0304] The ability of a system or a device, using a method in accordance with the disclosed technology, to obtain data that captured the pulse of a person from the second areas of video frames—corresponding to a part of the individual's body completely covered by a blanket, as illustrated in FIG. **18**—underscores that devices, systems, and methods consistent with the disclosed technology are not dependent on observing exposed areas of skin (e.g., uncovered skin) or specific features such as the eyes or head of the individual. This is a marked departure from the requirements common to other technologies.

[0305] In FIG. **19**, data points falling under bracket **1910** were selected (or identified) as associated with a heartbeat of the person depicted in FIG. **18**. Likewise, data points under bracket **2010** in FIG. **20** were selected (or identified) as pertaining to the same heartbeat.

[0306] Within the mentioned heartbeat, mSADaverage data point **1920** (as seen in FIG. **19**) was chosen for the first set of average motion values, and mSADaverage data point **2020** (as illustrated in FIG. **20**) was selected for the second set of average motion values. Alternatively, point **1930** which corresponds to a maximum slope of the mSADaverage dependence within the heartbeat under the bracket **1910** in FIG. **19** or point **1940** which corresponds to a minimum mSADaverage value within the same heartbeat can be selected for the first set of average motion values. Also, point **2030** which corresponds to a maximum slope of the mSADaverage dependence within the heartbeat under the bracket **2010** in FIG. **20** or point **2040** which corresponds to a minimum mSADaverage value within the same heartbeat could be selected for the second set of average motion values instead of the point **2020**.

[0307] The video frames that correspond to mSADaverage data points **1920** and **2020** were pinpointed and are subsequently referred to as the first and the second video frames, respectively.

[0308] The time interval that represents the duration of propagation of a blood pressure pulse between two areas of the person's body was determined. The first area is captured in the section of video frame **1800** between lines **1810** and **1820**, as displayed in FIG. **18**, while the second area is captured in the section of video frame **1800** between lines **1830** and **1840**, as displayed in FIG. **18**. The time interval was chosen to be equal to the time difference between the first and the second video frames and was calculated to be 0.1 seconds, based on the subtraction of the timestamps of these frames.

[0309] To calculate the PWV (Pulse Wave Velocity) value, the previously determined duration of blood pressure wave propagation (0.1 s) was used. The distance between the first and second areas of the body, corresponding to the mentioned sections of video frame **1800**, was measured at 0.71 meters using a ruler. This distance value can also be ascertained using depth data captured using the depth-sensing functionality of a suitable depth-sensing camera.

[0310] The pulse wave velocity was calculated by dividing the measured distance value (0.71 m) by the time interval (0.1 s), resulting in a PWV value of 7.1 m/s.

[**0311**] FIG. **21** displays video frame **2100**, captured by a video camera of a system according to the disclosed technology, showing a person lying on a bed. In the video frame **2100**, areas **A** between lines **2110** and **2120** correspond to a series of heartbeats. These heartbeats are represented by a dotted line **2210** in FIG. **22**, reflecting a series of mSAD data values collected from the areas **A** of a first set of video frames.

[**0312**] The same series of heartbeats were also captured from areas **B**, shown between lines **2130** and **2140** in FIG. **21**, of a second set of video frames and are depicted by the solid line **2220** in FIG. **22**. The video frames used to obtain the data for line **2210** and the video frames used to obtain the data for line **2220** can be from the same or different sets of video frames, either completely or partially.

[**0313**] To display the mSAD data sets for lines **2210** and **2220** on the same amplitude scale, the data corresponding to line **2210** was scaled prior to plotting in FIG. **22**. Each mSAD number in the set was multiplied by a scaling number, and a shift number was then added to the multiplication result. This enabled the two data sets to be represented within the same amplitude interval along the vertical axis of the plot shown in FIG. **22**.

[**0314**] In FIG. **22**, the horizontal "time" axis illustrates the progression of time, highlighting a clear time shift between the series of heartbeats captured in areas **A** and **B** of the video frames, as represented by lines **2210** and **2220** respectively. The data clearly demonstrate the temporal discrepancy between the heartbeats in the two areas.

[**0315**] There is a time shift observable for each individual heartbeat between different series of captures. Specifically, the time profile of a heartbeat as captured in the areas **B** of the video frames is shifted towards longer times compared to its profile as captured in the areas **A**. These time shifts mirror the durations of blood wave propagation between specific parts or areas of the body of the person depicted in FIG. **21**. The parts in question include those captured in the area **A** of video frame **2100**, as shown in FIG. **21**, and corresponding parts captured in the area **B** of video frame **2100**. The magnitudes of these time shifts can be determined using any method consistent with the technology disclosed herein.

[**0316**] FIG. **23** provides a schematic diagram of a device **2300** in accordance with the disclosed technology. This device comprises three key components: a light source **2310**, a video camera **2320**, and a computing element **2330**. Double-ended arrows **2351**, **2352**, and **2353** in FIG. **23** signify possible communication and/or control connections or links between these elements, with the direction of the arrows denoting the flow of communication messages, control commands, or data. These control and/or communication connections or links can be either wired or wireless.

[**0317**] In certain example implementations, the light source **2310** can be configured to illuminate one or more areas as described in this patent document. The video camera **2320** may be configured to capture one or more video frames. The computing element **2330** may be configured to perform any computations outlined in this patent document, including those specifically mentioned in connection with any method, system, or device consistent with the disclosed technology.

[**0318**] FIG. **24** illustrates a flowchart for an example embodiment of method **2400** in line with the technology disclosed in this document. Method **2400** comprises the following steps:

[**0319**] Step **2410** involves illuminating a first area and a second area with a light source. Step **2420** involves obtaining a set of video frames, including at least a first video frame and a second video frame, using a camera. Step **2430** involves obtaining a first numeric value and a second numeric value by employing a processor to perform computations with the first and second video frames. Step **2440** involves determining the duration of a time interval for blood pulse propagation between a first point and a second point of a subject, utilizing the first and second numeric values.

[**0320**] The pulse wave velocity values derived for a person using devices, systems, and methods in accordance with the technology disclosed in this patent document can be employed to gather information and/or data, such as numeric values, related to the individual's blood pressure. This can be achieved, e.g., through establishing a correlation between a pulse wave velocity value and a blood pressure value, whether systolic and/or diastolic.

[**0321**] For instance, a numerical value for blood pressure can be ascertained by employing a functional relationship that correlates blood pressure (systolic and/or diastolic) with pulse wave velocity. Methods for achieving this relationship can be found, for instance, in the work titled “Relation between blood pressure and pulse wave velocity for human arteries” by Ma et al. (DOI: https://doi.org/10.1073/pnas.1814392115), which is incorporated into this document by reference.

[**0322**] The functional relationship may be exemplified by a quadratic relationship between a pulse wave velocity value (*pWV*) and a blood pressure value *P* (e.g., diastolic or systolic): $P = a(pWV)^2 + b$, where a and b are numeric coefficients. Specifically, the numeric coefficient a might have a value around 0.046 $kPa \cdot s^2 \cdot m^{-2}$, and the numeric coefficient b might be about 5.1 kPa in some cases. In other cases, the numeric coefficient a might have a value around 0.18 $kPa \cdot s^2 \cdot m^{-2}$, and the numeric coefficient b might be about 2.7 kPa. In general, the values of the numeric coefficients a and b of the quadratic dependence mentioned above can be determined using measured values of pulse wave velocity (pWV) and corresponding systolic or diastolic blood pressure P by fitting a quadratic dependence (e.g., $P = a(pWV)^2 + b$) into those values.

[**0323**] In cases where there is an interest in tracking the relative changes of pulse wave velocity and/or blood pressure in a person, the duration of pulse wave propagation between two areas, points, or parts of the person's body can be determined using the methods in accordance with the technology disclosed in this patent document. Instead of measuring the distance between the specified areas, points, or parts of the person's body (which may be challenging for the individual to measure reliably or with high accuracy) and then dividing this distance by the determined duration, an alternative approach could be used.

[**0324**] One can divide the person's known height (which can be measured with relatively high accuracy, even by the person themself) by the determined duration of pulse wave propagation to yield a height-related ratio. This ratio is referred to as a height-related velocity value. From this value, a blood pressure value can be obtained.

[**0325**] The changes in the height-related velocity values, whether absolute or relative, can accurately reflect shifts in the person's blood pressure and/or "real" pulse wave velocity values. A calibration function may be determined and/or utilized to translate these height-related velocity values into systolic and/or diastolic blood pressure values for the person or to actual pulse wave velocity values. This function can serve as a translation tool to interpret the individual's blood pressure or pulse wave characteristics more precisely.

[**0326**] When tracking changes in pulse wave velocity and/or blood pressure characteristics of a person's cardiovascular system using these height-related velocity or systolic and/or diastolic blood pressure values, it's advisable to consistently measure the pulse wave transit time between the same areas or points on the person's body.

[**0327**] An example aspect of the disclosed technology involves a method of acquiring information pertaining to one or more of the following attributes: a person's respiration rate, heart rate, variability in respiration rate, variability in heart rate, a temporal characteristic of a portion of a heartbeat (or of the whole heartbeat), a temporal characteristic of a part of a respiration cycle (or of the whole respiration cycle), or a stage of sleep. The method comprises the following steps described in paragraphs [**0328**]-[**0331**] below:

[**0328**] Illuminating a Set of Areas: This comprises illuminating (either directly or indirectly) a person's body, an object in contact (either direct or indirect) with the person's body, a body that may refer to a female/mother or an artificial womb harboring a fetus when the method aims to gather information regarding the fetus or if the individual is the fetus, or an organ such as a heart or lung, which may be at different stages of the organ growth or development and which may be at least partially enclosed in a living body or a growth environment or medium. Here, the term "person" broadly encompasses an adult, child, infant/baby, or fetus inside the body of a female/mother or inside an artificial uterus. Thus, in the context of this patent document, the phrase "person's body" and the like could be replaced by "object" or "body" or “organ.”

[**0329**] Collecting Video Frames: Capturing a set of video frames (one or more video frames) for at least one of the illuminated areas using a video camera.

[**0330**] Performing Initial Computations: Processing at least two video frames from the set, using a processor or computer, to derive a collection or set of numerical values associated with the set of video frames.

[**0331**] Performing Further Computations or Display: This step involves additional calculations on at least part of the set of numeric values to derive numerical values related to the attributes mentioned earlier (e.g., a person's respiration rate, heart rate, respiration rate variability, heart rate variability, temporal characteristic of at least part of a heartbeat, temporal characteristic of at least part of a respiration cycle, or a stage of sleep). Alternatively, or additionally, it may involve displaying at least part of the set of numeric values through a graphical or audio or audio-visual representation, or generating or saving or recording a graphical or audio or audio-visual representation of at least part of the set of numeric values.

[**0332**] The described method offers a robust approach for tracking essential physiological characteristics with applications ranging from monitoring adult health to fetal assessments.

[**0333**] Continuing from the method outlined earlier, the “Performing Initial Computations” step in it can be further broken down into a series of sub-steps according to some example embodiments: i) Computing Numeric Values for Each Video Frame: For at least one video frame of the set, the following computations are performed: a) Associating Numeric Values with Pixels: For each pixel in at least part of a video frame, a numeric value is associated with the pixel using data from that video frame. b) Associating Numeric Values with Pixels in Another Frame: Similar to step a, but for pixels in at least part of another video frame within the set. c) Calculating Differences: For each pixel in at least part of the video frame, a difference is computed between the numeric values associated with that pixel and a corresponding pixel in at least part of another video frame. d) Calculating Numeric Values from Differences: For each pixel in at least part of the video frame, a numeric value is calculated which is equal to or is proportional (e.g., directly or inversely proportional) to or is a function of at least one of the following: the difference calculated for the pixel, an absolute value of the difference calculated for the pixel, or a squared value of the difference calculated for the pixel. e) Calculating a Sum: The numeric values calculated in step d) are summed for the pixels in at least part of the video frame, resulting in a final numeric value for the video frame.

[**0334**] In the context of methods, devices, systems, and media related to the technology disclosed in this patent document, the act or step of "associating" a numeric value with a pixel, or "assigning" a numeric value to a pixel, encompasses situations where any numeric value or values from the video frame data, or any other numeric value, is used in a computation concerning that pixel. This means that if such values are involved in calculations pertaining to the pixel, they are considered as being assigned to or associated with that pixel. As an example, if the video frame data for a pixel provides a grayscale value representing its intensity, and if this grayscale value is utilized in calculations by any method, device, system, or media as per the technology disclosed herein, then that specific grayscale value is deemed to have been associated with or assigned to the pixel.

[**0335**] In the context of methods, devices, systems, and media pursuant to the technology disclosed in this patent document, steps or actions such as "associating" values with one or more pixels, "assigning" values to one or more pixels, "allocating" specific values to pixels, or "linking" numeric data to specific pixel points, and the like might be integrated into certain embodiments. However, it is imperative to note that any of these steps or actions, including but not limited to the aforementioned examples, can be omitted or bypassed in any embodiment or aspect of the methods, devices, systems, and media in accordance with the technology disclosed herein.

[**0336**] Furthermore, in some example embodiments of the method (as well as other methods, systems, mediums, or devices according to the disclosed technology), there is no use or acquisition of information about any distance related to any element or object of a scene captured in any video frame of the said video frames set. Additionally, in some embodiments, there is no use or acquisition of information about the position of any element of an image of a scene, captured in any video frame of the said video frames set, within the said image.

[**0337**] These detailed steps reinforce the method's ability to interpret complex video data without requiring specific spatial information, providing a flexible and robust approach to various applications.

[**0338**] In some example embodiments, certain limitations apply to the computations for at least one video frame of the set:

[**0339**] No Distance Information Used: Computations resulting in the set of numeric values for the video frames, and further computations leading to numeric values related to various physiological characteristics of the person (such as the respiration rate, heart rate, respiration rate variability, heart rate variability, temporal characteristics of heartbeat or respiration cycle, or stages of sleep), or the graphical or audio or audio-visual representation of these numeric values, do not utilize or generate any information about distances related to any element of a scene or any object in the scene captured in any video frame within the set. This includes not using information associated with or assigned to such elements or objects.

[**0340**] No Position Information Used: Similar to the first limitation, the computations do not use or produce any information about the position of any element within an image of a scene captured in any video frame within the set.

[**0341**] In some example embodiments, the referred-to set of video frames contains at least three video frames. In certain example embodiments, each video frame within this set consists of no fewer than two pixels.

[**0342**] In specific example embodiments, the execution of step “Illuminating a Set of Areas” (see above) leads to some areas of the person's body receiving a greater quantity of photons during the exposure time period for any frame within the set of video frames, as compared to the number of photons that the same areas of the person's body would have received during the exposure time period for any frame within the same set, had step “Illuminating a Set of Areas” not been performed, and assuming all other conditions remained identical.

[**0343**] In some example embodiments, the ratio of the larger average illumination to the lower average illumination for two specific areas of the person's body, as captured in a frame within the video frames set, is at least $1+1/(2^n-2)$. Here, *n* represents the number of bits in a binary representation of a numeric value associated with a pixel in that frame, contained within the video frame data of that specific frame. The said ratio can be calculated using the numeric values associated with pixels corresponding to the two areas of the person's body within the frame. In certain example embodiments, *n* is equal to one of the following values: 8, 16, 32, 64, 128, 256, 512, 1024, 2048, 4096, or 8192 (with *n* not required to be an even number or a power of two).

[**0344**] According to various example embodiments, the ratio of the larger average illumination to the lower average illumination for two areas of the person's body, as captured in a frame of the video frames set, may be greater than at least one of the following values: 1.000001, 1.001, 1.01, 1.1, 10, 100, 1000, 10000,100000, or 1000000.

[**0345**] In some example embodiments, the numeric values associated with each pixel of at least part of a video frame, as well as the numeric values associated with each pixel of at least part of another video frame in step i) of “Performing Initial Computations” step, are obtained using the same set of rules. In certain example embodiments, the pixel row number for a particular pixel of the video frame is equal to the pixel row number for the corresponding pixel of another video frame in step c) of step i) of “Performing Initial Computations” step. Similarly, the pixel column number for that pixel of the video frame is equal to the pixel column number for the corresponding pixel of another video frame in step c) of step i) of “Performing Initial Computations” step. In some example embodiments, the particular pixel of another video frame in step c) of step i) of “Performing Initial Computations” step is selected by a video encoder.

[**0346**] According to certain example embodiments, “Performing Initial Computations” step comprises the action of replacing at least one numeric value in the set of numeric values for the video frames set with another numeric value from the same set of numeric values for the video frames set. In some embodiments, the graphical representation of at least part of the set of numeric values takes the form of a two-dimensional plot.

[**0347**] In some example embodiments, the method additionally involves saving or recording or transmitting at least one video frame from the video frames set to a local or remote storage medium. In some example embodiments, the method also comprises saving or recording or transmitting at least one numeric value from the set of numeric values for the video frames set to a local or remote storage medium. The mentioned storage medium can belong to at least one of the following types: Hard Disk Drives (HDD), Solid State Drives (SSD), Optical Discs (CDs, DVDs, Blu-rays), Flash Drives, Memory Cards (SD cards, microSD cards), Magnetic Tapes, Floppy Disks, Network Attached Storage (NAS), Storage Area Network (SAN), Cloud Storage, RAM (Random Access Memory), ROM (Read-Only Memory), or Hybrid Storage Solutions.

[**0348**] In some example embodiments, the method involves transferring or transmitting at least one video frame from the video frames set over a communications network. In some example embodiments, the method comprises transferring or transmitting at least one numeric value from the set of numeric values for the video frames set over a communications network. The mentioned communications network can be of at least one of the following types: Personal Area Network (PAN), Local Area Network (LAN), Metropolitan Area Network (MAN), Wide Area Network (WAN), Global Area Network (GAN), Ethernet Network, Wireless LAN (WLAN), Cellular Network, Optical Network, Star Network, Mesh Network, Bus Network, Ring Network, Intranet, Extranet, Virtual Private Network (VPN), Content Delivery Network (CDN), Peer-to-Peer Network (P2P), Client-Server Network, or Hybrid Network.

[**0349**] According to certain example embodiments, the method comprises saving or recording at least one numeric value related to at least one of the following: the person's respiration rate, heart rate, respiration rate variability, heart rate variability, temporal characteristic of at least part of a heartbeat, temporal characteristic of at least part of a respiration cycle, or a stage of sleep. These numeric values are saved or recorded to a local or remote storage medium, which, in certain example embodiments, is a non-transitory storage medium.

[**0350**] In some example embodiments, numeric values associated with each pixel of at least part of a video frame in step i) of “Performing Initial Computations” step are derived using a first set of rules (comprising one or more rules). Simultaneously, numeric values associated with each pixel of at least part of another video frame in step i) of “Performing Initial Computations” step are derived using a second set of rules (comprising one or more rules). Here, the second set of rules differs from the first set of rules. This difference may exist between any rule within the first set of rules and any rule within the second set of rules, signifying that the first set of rules can contain rules different from those in the second set of rules. Also, the first set of rules can include a different number of rules compared to the second set of rules.

[**0351**] Another example aspect of the disclosed technology pertains to a system designed or configured to obtain information related to one or more of the following: a person's respiration rate, heart rate, respiration rate variability, heart rate variability, temporal characteristic of at least part of a heartbeat, temporal characteristic of at least part of a respiration cycle, or a stage of sleep. This system comprises (see paragraphs [**0352**]-[**0354**] below):

[**0352**] A light source element, configured to illuminate a set of areas on the person's body (where the set can include one or more areas).

[**0353**] A video camera element, configured to capture a set of video frames (which may include one or more video frames) pertaining to at least one of the illuminated areas.

[**0354**] A computing element and a non-transitory storage medium readable by the computing element. The storage medium stores instructions that, when executed by the computing element, prompt it to: i) Perform computations on at least two video frames from the set of video frames, resulting in a set of numeric values for the set of video frames. ii) Carry out computations on at least part of the set of numeric values to achieve at least one of the following outcomes: obtaining one or more numeric values connected to the respiration rate, heart rate, respiration rate variability, heart rate variability, temporal characteristic of part of a heartbeat, temporal characteristic of part of a respiration cycle, or a stage of sleep of the person, or displaying at least part of the set of numeric values through a graphical or an audio or an audio-visual representation of said part of the set of numeric values, or producing or generating and/or saving a graphical or an audio or an audio-visual representation of at least part of the set of numeric values. In some example embodiments, the produced or generated or saved graphical or audio or audio-visual representation of said part of the set of numeric values can be in the form of an image (e.g., a JPEG (.jpg), PNG (.png), GIF (.gif), BMP (.bmp), TIFF (.tif), PSD (.psd), AI (.ai), SVG (.svg), WEBP (.webp), or HEIF (.heif) image) or an audio file (e.g., an MP3 (.mp3), WAV (.wav), FLAC (.flac), AAC (.aac), OGG (.ogg), AIFF (.aiff), M4A (.m4a), WMA (.wma), ALAC (.m4a), or MIDI (.midi) file) or a video file with or without an audio track in it (e.g., an MP4 (.mp4), AVI (.avi), MKV (.mkv), MOV (.mov), WMV (.wmv), FLV (.flv), WEBM (.webm), MPEG (.mpeg), 3GP (.3gp), or TS (.ts) file).

[**0355**] In some example embodiments, step i) involves performing computations for at least one video frame of the set, including at least the following steps:
a) For each pixel of at least part of a video frame within the set, associating a numeric value with that pixel using data from the video frame itself.
b) Similarly, for each pixel of at least part of another video frame within the set, associating a numeric value with that pixel using data from that other video frame.
c) For each pixel within the specified part of the video frame, calculating a difference between the numeric value associated with that pixel and the numeric value associated with a corresponding pixel in the other video frame.
d) For each pixel within the specified part of the video frame, calculating a numeric value which is equal or proportional (e.g., directly or inversely proportional) to or is a function of at least one of the following: the difference calculated for the pixel, an absolute value of the difference calculated for the pixel, or a squared value of the difference calculated for the pixel.
e) Calculating a sum of the numeric values determined in step d) for the pixels within the specified part of the video frame, resulting in a numeric value for that video frame.

[**0356**] In this patent document, the numbering or lettering of steps in a method or elements and parts of a device or system (e.g., "a)", "i)", "1)", "2.", etc.) is implemented solely to facilitate reference to those specific steps, parts, or elements. The use of these letters or numbers does not prescribe or imply a sequential order in which the method steps must be performed. Likewise, it does not suggest any hierarchy, order of importance, or interconnection among the parts or elements of a device or system according to the disclosed technology.

[**0357**] In some example embodiments, any of the computations performed by the computing element (as well as any or some computations used in other embodiments of methods, systems, mediums, or devices according to the disclosed technology) exclude and/or do not produce and/or do not use any information about any distance related to any element of a scene or any object in the scene captured in any video frame within the set of video frames. In some example embodiments, any of the computations performed by the computing element (as well as any or some computations used in other embodiments according to the disclosed technology) exclude and/or do not generate and/or do not use any information about the position of any element of an image of a scene captured in any video frame within the set, specifically within the image itself.

[**0358**] In some example embodiments, the computing element may be of at least one of the following types: a processor (e.g., a multi-core processor), a computer, a single-board computer, a tablet, or a smartphone. In certain embodiments, the computing element is equipped with or is coupled or connected to (e.g., physically and/or mechanically and/or electrically and/or communicatively) a graphics processing unit (GPU), and in some cases, at least part of the computations is performed utilizing this GPU.

[**0359**] In some example embodiments, the computing element can belong to one or more of the following types: Desktop Computers, Laptop Computers, Tablet Computers, Smartphones, Single-board Computers, Mainframe Computers, Workstation Computers, Server Computers, Embedded Systems, Supercomputers, Wearable Devices, Gaming Consoles, Virtual Machines, Quantum Computers, Hybrid Computers, Thin Clients, Palmtop Computers, or Personal Digital Assistants (PDAs).

[**0360**] In certain embodiments, the light source element possesses a distribution of wavelengths characterized by a maximum exceeding 700 nm. In some embodiments, the light source element can emit light at one or more wavelengths above 700 nm. In some instances, the light source element may have a wavelength distribution with a peak (e.g., a local or a global maximum) between approximately 350 nm and 750 nm, or it may be capable of emitting light at one or more wavelengths within this range. In certain embodiments, the light source element is a laser, or includes a laser among its components. In some embodiments, the light source element may be a light-emitting diode (LED) or include an LED in its structure.

[**0361**] In this patent document, references to an "example embodiment" or "example aspect," or to an "embodiment" or "aspect," or “instance,” are made to illustrate various elements of the disclosed technology. Such terminology should not be construed as limiting the scope of the disclosure. Whether the term "example" is used or not in connection with an "aspect" or "embodiment" does not imply a difference in importance, quality, or any other characteristic of the described "aspect" or "embodiment." All embodiments and aspects, whether labeled as "example" or not, are pertinent to the understanding and implementation of the disclosed technology.

[**0362**] In some example embodiments, the light source element is configured to illuminate surface areas by creating one or more light spots on those areas. These light spots may have distinct illumination maxima, separated by some distances from each other either within a single light spot or between different light spots. For instance, the distance between at least two illumination maxima within a light spot may be at least 0.1 nm in some embodiments. In some embodiments, this separation might be at least 1 nm, 10 nm, 100 nm, 1000 nm, 10000 nm, 100000 nm, 1 mm, 10 mm, 100 mm, 1000 mm, or 10000 mm. For instance, the distance between the illumination maxima belonging to two different light spots may be at least 0.1 nm in some embodiments. In other embodiments, this separation might be at least 1 nm, 10 nm, 100 nm, 1000 nm, 10000 nm, 100000 nm, 1 mm, 10 mm, 100 mm, 1000 mm, or 10000 mm.

[**0363**] In some example embodiments, the light source element's configuration for producing one or more light spots includes having a first light spot with a first illumination maximum and a second light spot with a second illumination maximum. The separation between the locations of these illumination maxima might be at least 0.1 nm. In various instances, this distance may be extended to at least 1 nm, 10 nm, 100 nm, 1000 nm, 10000 nm, 100000 nm, 1 mm, 10 mm, 100 mm, 1000 mm, or 10000 mm, depending on the specific embodiment or application of the disclosed technology.

[**0364**] In some example embodiments, the light source element is configured or designed to illuminate the areas by generating light spots on those areas. These light spots are distinguished from one another by sections of the person's body that exhibit lower illumination compared to the light spots themselves. According to some example embodiments, the light source element is configured to create one or more light spots on each specified area, where at least two of these light spots are separated by a region of the person's body that has lower illumination relative to either of the two light spots.

[**0365**] In further example embodiments, the light source element is configured to illuminate surface areas by forming light spots on them. Additionally, this light source element has the ability to modify at least one of the following: the distance between at least two of the light spots, the size of at least one of the light spots, the shape of at least one of the light spots, or the illumination intensity of at least one of the light spots.

[**0366**] According to certain example embodiments, the act of illuminating a set of areas involves generating light spots on those areas. The light spots are set apart from one another by portions of the person's body that have a lower level of illumination in comparison to the light spots.

[**0367**] An example aspect of the disclosed technology pertains to a method of obtaining information related to at least one of the following: a respiration rate of a person, a heart rate of the person, a respiration rate variability of the person, a heart rate variability of the person, a temporal characteristic of at least a portion of a heartbeat of the person, a temporal characteristic of at least a part of a respiration cycle of the person, or a stage of sleep of the person (e.g., identification or labeling of that stage). This method comprises the following steps:

1. Illuminating at least one area of the person's body using a light source.
2. Collecting a set of video frames using a video camera. The set includes at least a first video frame and a second video frame.
3. Processing the set of video frames using a processor or computer. The processing involves:

   a. Associating a numeric value with each pixel of a portion of the first video frame.

   b. Associating a numeric value with each pixel of a portion of the second video frame.

   c. Calculating a difference for each pixel of the portion of the second video frame. This difference is between the numeric value associated with the pixel and the numeric value associated with a corresponding pixel of the portion of the first video frame.

   d. Calculating a numeric value for each pixel of the portion of the second video frame. This numeric value is equal or proportional (e.g., directly or inversely proportional) to or is a function of at least one of the following: the difference calculated for the pixel, an absolute value of the difference calculated for the pixel, or a squared value of the difference calculated for the pixel.

   e. Generating a first numeric value by summing the numeric values calculated for the pixels of the portion of the second video frame in step “d”.

[**0368**] Any numeric value or quantity mentioned in this patent document (hereafter referred to as the "original numeric value or quantity") can be substituted with another numeric value or quantity (hereafter referred to as “substitute numeric value or quantity”) which is proportional to the said original numeric value or quantity with a proportionality coefficient which is either larger than 1.0, smaller than 1.0, or equal to 1.0 and any method, device, or system according to the disclosed technology which uses and/or produces the said original numeric value or quantity may use and/or produce the substitute numeric value or quantity and will remain to be the method, device, or system according to the disclosed technology. Similarly, any original numeric value or quantity mentioned in this patent document can be substituted by a substitute numeric value or quantity which is a function of the said original numeric value or quantity and any method, device, or system according to the disclosed technology which uses or generates the said original numeric value or quantity may use or generate the substitute numeric value or quantity and will remain to be the method, device, or system according to the disclosed technology.

[**0369**] In some example embodiments, the method does not utilize or acquire information pertaining to any distance related to any element of a scene or object in the scene captured within any video frame of the specified set of video frames. This includes a stipulation that the processing of the set of video frames using a processor or computer is free from using or obtaining or producing any information about such distances. Moreover, in some embodiments, the method (or any other method consistent with the disclosed technology) explicitly comprises a step of abstaining from obtaining or utilizing or generating any distance-related information concerning any element or object in a scene captured in any video frame of the specified set.

[**0370**] Similarly, in some example embodiments, the method avoids using or acquiring information about the position of any element within an image of a scene captured in any video frame of the specified set of video frames. This position-related information is not used or obtained or generated during the processing of the set of video frames with a computer or processor. In accordance with some example embodiments, the method (or any other method in line with the disclosed technology) specifically comprises a step of refraining from using or obtaining or producing information about the position of any element of an image of a scene captured in any video frame of the specified set, within the image itself.

[**0371**] In some example embodiments, the methods according to the technology disclosed in this patent document refrain or abstain from obtaining, generating, or utilizing any distance-related information concerning any element or object in a scene captured in any video frame of the specified set. Additionally, or alternatively, they may abstain from using, producing, or obtaining information about the position of any element of an image of a scene captured in any video frame of the specified set, within the image itself.

[**0372**] These features emphasize such method's deliberate lack of reliance on specific spatial information, such as distance or position, regarding elements or objects within the scenes as well as elements of images of the scenes, captured in the video frames.

[**0373**] In some example embodiments, the process of associating a numeric value with each pixel of a part of the first video frame is performed using the video frame data of that first video frame. According to some example embodiments, this association of a numeric value with the pixel of the part of the first video frame is executed using only the video frame data of the first video frame itself.

[**0374**] In some example embodiments, the process of associating a numeric value with each pixel of a part of the second video frame is conducted using the video frame data of the second video frame. According to some example embodiments, this association of a numeric value with the pixel of the part of the second video frame is executed using only the video frame data of the second video frame itself.

[**0375**] In some example embodiments, the specific pixels of the parts of the first and second video frames used in calculating the difference are such that the pixel row numbers of the corresponding pixels in the first and second video frames are equal and the pixel column numbers of the corresponding pixels in the first and second video frames are equal.

[**0376**] In some example embodiments, the specific pixels of the parts of the first and second video frames used in calculating the difference are such that either the pixel row numbers of the corresponding pixels in the first and second video frames are different, or the pixel column numbers of the corresponding pixels in the first and second video frames are different, or both.

[**0377**] In some example embodiments, a video encoder selects both the part of the first video frame and the part of the second video frame. In some example embodiments, a video encoder selects either the part of the first video frame or the part of the second video frame.

[**0378**] In some example embodiments, the method comprises encoding either the first video frame, the second video frame, or both, using a video encoder. The video encoder may be, according to different example embodiments, a H.261 encoder, a H.262 encoder, a H.263 encoder, a H.264 encoder, a H.265 encoder, a H.266 encoder, a H.267 encoder, a H.268 encoder, a H.269 encoder, a H.270 encoder, a MPEG-1 encoder, a MPEG-2 encoder, or a MPEG-4 Part 2 encoder.

[**0379**] In some example embodiments, the method involves the computer or processor obtaining a second numeric value derived using the first numeric value. According to some example embodiments, this second numeric value is associated with at least one of the following: respiration rate of the person, heart rate of the person, respiration rate variability of the person, heart rate variability of the person, temporal characteristic of at least part of a heartbeat of the person, temporal characteristic of at least part of a respiration cycle of the person, or a stage of sleep of the person.

[**0380**] An example aspect of the disclosed technology pertains to a system for obtaining data related to one or more of the following: respiration rate of a person, heart rate of the person, respiration rate variability of the person, heart rate variability of the person, a temporal characteristic of at least a part of a heartbeat of the person, a temporal characteristic of at least a part of a respiration cycle of the person, or a stage of sleep of the person. This system comprises:

1. A light source element, configured to illuminate at least one area of the person's body.
2. A video camera element, configured to collect a set of video frames, including at least a first video frame and a second video frame.
3. A computing element, coupled with a non-transitory storage medium readable by the computing element. The storage medium stores instructions which, when executed by the computing element, enable the following computations:

a. For each pixel of a part of the first video frame, a numeric value is associated with the pixel.

b. For each pixel of a part of the second video frame, a numeric value is associated with the pixel.

c. For each pixel of the part of the second video frame, a difference is calculated between the numeric value associated with the pixel and the numeric value associated with a corresponding pixel of the part of the first video frame.

d. For each pixel of the part of the second video frame, a numeric value is calculated, which is equal to or proportional to (e.g., via a proportionality coefficient which can be larger than 1, equal to 1, or smaller than 1) or is a function of at least one of the following: the difference calculated for the pixel, an absolute value of the difference calculated for the pixel, or a squared value of the difference calculated for the pixel.

e. A first numeric value is obtained using a sum of the numeric values calculated for the pixels of the part of the second video frame in step d.

[**0381**] In some example embodiments, none of the computations performed by the computing element utilize or obtain (both in the meaning of “produce” and in the meaning of “receive”) or generate information about any distance related to, associated with, or otherwise corresponding to any element of a scene or any object in a scene captured in any video frame within the specified set of video frames. According to some example embodiments, data concerning any of the physiological parameters referenced in this patent document may be produced or acquired without relying on or employing information (e.g., numeric values) related to any distance connected to or corresponding to any element (e.g., an object) of a scene captured in any video frame of the specified set.

[**0382**] In some example embodiments, none of the computations performed by the computing element utilize or obtain or generate information regarding the position or coordinates of any element or feature within an image of a scene captured in any video frame of the specified set. According to some example embodiments, information or data (e.g., numeric values) pertaining to any of the physiological parameters mentioned in this patent document can be obtained without acquiring or producing or using any information related to the position or location or coordinates or distance of any element or object or feature detected or captured or generated by a sensor of a video camera (e.g., a video camera element of a system according to the disclosed technology) or without employing information related to the position or distance of any feature of a function computed using one or more images detected by a sensor of a video camera (e.g., a video camera element of a system according to the disclosed technology).

[**0383**] In this patent document, any of the terms “video camera”, “video camera element”, or “camera” can be replaced with any of the following terms: CCD (Charge-Coupled Device) sensor, CMOS (Complementary Metal-Oxide-Semiconductor) sensor, webcam, smartphone camera, tablet camera, DSLR (Digital Single-Lens Reflex) camera, mirrorless camera, action camera, drone with a camera, infrared camera, thermal camera, pinhole camera, digital cinematography camera, CCTV (Closed-Circuit Television) camera, photomultiplier tube, or image intensifier. All mentioned terms are related to the device types that can capture images or generate electrical signals in response to light (or photons).

[**0384**] According to some example embodiments, the computing element may be at least one of the following or may include at least one of the following: a processor (e.g., a processor having one or more than one computational core), a computer, a single-board computer, a tablet, or a smartphone. In certain embodiments, the computing element includes or is connected to or is coupled with (either via a wired or wireless connection or both) a graphics processing unit (GPU). According to some embodiments, at least part of the computations is performed using this GPU.

[**0385**] In some example embodiments, the light source element is an infrared light source. Such an infrared light source may be configured to (or may be configurable to) emit, produce, or generate light (or may be capable of emitting, producing, or generating light) with a wavelength falling within approximately 600 nm to approximately 10 mm. This infrared light source may be designed or configured to create light with multiple spectral components, encompassing one or more wavelengths between approximately 600 nm and approximately 10 mm. In some example embodiments, the light source element may be configured to emit, produce, or generate light (or may be capable of emitting, producing, or generating light) at one or more wavelengths in a range from approximately 0.1 nm to approximately 10 meters (10 m). According to further embodiments, the light source element may be configured or adjusted to produce light in the visible part of the electromagnetic spectrum, such as light at wavelengths between about 200 nm and about 750 nm. Specific configurations may allow the light source element to produce blue light (approximately 450 nm to 485 nm), green light (approximately 500 nm to 565 nm), or red light (approximately 625 nm to about 700 nm).

[**0386**] According to some example embodiments, the aforementioned video camera element may be an infrared camera. An infrared camera, for instance, could be a camera, light detector, light sensor, or device that is configured to (or is configurable to) register or detect (or is capable of registering or detecting) light or photons with a wavelength between approximately 600 nm and approximately 10 mm. It may be a camera, light detector, light sensor, or device specifically able to obtain (or configured or configurable to obtain) images using light of one or more wavelengths within this range (between approximately 600 nm and approximately 10 mm). According to some embodiments, the video camera element may be a camera, light detector, light sensor, or device that can obtain (or is configured or configurable to obtain) images using light with a wavelength between approximately 0.1 nm and approximately 10 m. It might be a camera, light detector, light sensor, or device set up, configured, or configurable to register or detect light of one or more wavelengths within this same wavelength range (between approximately 0.1 nm and approximately 10 m).

[**0387**] In certain example embodiments, the aforementioned light source element is designed or configured or is configurable to illuminate at least one surface area by creating a light spot on that area. This light spot has illumination originating from the light source element that is more intense than the illumination produced by the light source element on the surrounding areas.

[**0388**] According to some example embodiments, the light source element may be arranged or configured or be capable to illuminate the at least one surface area by forming distinct light spots on that area. These light spots are separated from each other by regions of the surface area (e.g., an area on a person's body) that receive lower illumination from the light source element compared to the illumination (e.g., an average illumination) within the light spots themselves.

[**0389**] In certain example embodiments, the specified light source element is designed or configured or is configurable to illuminate at least one area by generating multiple light spots on that area. In this context, at least a first light spot and a second light spot among these light spots are configured or structured such that the maximum illumination point of the first light spot is separated from the maximum illumination point of the second light spot by a distance of at least 0.1 nm or at least 1nm or at least 10 nm or at least 100 nm or at least 1000 nm or at least 10000 nm or at least 100000 nm or at least 1 mm or at least 10 mm or at least 100 mm or at least 1 m or at least 10 m. According to some example embodiments, the light source element is structured or configured or is configurable to illuminate an area by producing light spots on it where the center of a first light spot (e.g., a geometric center or a center ascertained through the distribution of illumination within the light spot) is spaced from the center of a second light spot by at least 0.1 nm. In certain embodiments, the mentioned distance might be at least 1nm or at least 10 nm or at least 100 nm or at least 1000 nm or at least 10000 nm or at least 100000 nm or at least 1 mm or at least 10 mm or at least 100 mm or at least 1 m or at least 10 m.

[**0390**] In some example embodiments, the light source element is tailored or configured or is configurable to illuminate an area (e.g., an area on a person's body) by forming light spots on it, and possesses the capability to alter at least one of the following characteristics: the distance between at least two of the light spots, the size of at least one of the light spots, the shape of at least one of the light spots, or the illumination intensity of at least one of the light spots.

[**0391**] In some example embodiments, the specified light source element is designed or built or configured or is configurable to illuminate a set of areas (one or more areas) on a person's body. This illumination creates or enhances the contrast (e.g., the illumination contrast) between these areas and other regions of the person's body, as visible in video frames captured by the video camera element or as evidenced by the data of the video frames captured by the video camera element.

[**0392**] Another aspect of the disclosed technology pertains to a non-transient computer-readable storage medium. This medium contains or stores instructions that, when executed by a computer or one or more processors, trigger actions which comprise: directing a light source to illuminate at least one area of a subject, object, or a person's body; instructing a video camera to capture one or more video frames; and executing, by the computer or one or more processors, computations according to a method consistent with the technology detailed in this patent document.

[**0393**] An example aspect of the disclosed technology pertains to a non-transient computer-readable storage medium containing instructions. When executed by a computer or one or more processors, these instructions direct the computer or processor(s) to perform at least the following actions:

1. Command a light source to illuminate at least one area of an object;
2. Instruct a video camera to collect a set of video frames, including at least a first and a second video frame;
3. Execute computations involving the following steps:

a. For each pixel within a portion of the first video frame, assign a numeric value to the pixel or associate a numeric value with the pixel;

b. For each pixel within a portion of the second video frame, assign a numeric value to the pixel or associate a numeric value with the pixel;

c. For each pixel within the portion of the second video frame, calculate a difference between the numeric value associated with or assigned to that pixel and the numeric value associated with or assigned to a corresponding pixel in the portion of the first video frame;

d. For each pixel within the portion of the second video frame, compute a numeric value that equals at least one of: an absolute value of the difference calculated for that pixel, or a squared value of the difference calculated for that pixel, or compute a numeric value that is proportional to at least one of: the difference calculated for that pixel, the absolute value of the difference calculated for that pixel, or the squared value of the difference calculated for that pixel with a proportionality coefficient which is greater than 1.0, equal to 1.0, or smaller than 1.0, or compute a numeric value that is a function of at least one of: the difference calculated for that pixel, the absolute value of the difference calculated for that pixel, or the squared value of the difference calculated for that pixel;

e. Obtain a first numeric value by summing the numeric values computed for the pixels within the portion of the second video frame in step “d” or by summing the difference values calculated for the pixels of the portion of the second video frame in step “c”.

[**0394**] In the context of methods, devices, systems, and media according to the technology disclosed in this patent document, the action or step of “associating” a numeric value with a pixel or “assigning” a numeric value to a pixel as well as any similar step or action implies that if a numeric value or values from the video frame data or any other numeric value or values is/are used in any computation for that pixel or in any computations involving the pixel or related to the pixel, then such value or values are deemed to have been assigned to or associated with the pixel. As an example, if the video frame data for a pixel provides values for its red, green, and blue components, and if the green component's value is utilized in calculations by any method, device, system, or media as per the technology disclosed herein, then that specific green component value is deemed to have been associated with or assigned to the pixel.

[**0395**] In certain embodiments, the computer or one or more processors include a Graphics Processing Unit (GPU).

[**0396**] In some embodiments, associating a numeric value with a pixel involves either assigning a value to the pixel or selecting or generating a value from or for the pixel. In certain contexts, this value may be embedded within a pixel of a video frame which may be represented by a set of numeric values corresponding to a pixel of a video sensor. In some embodiments, association may comprise or may consist of obtaining the pixel from a camera or a computer's memory or hard drive, or using one or more numeric values of the pixel in a calculation or computation.

[**0397**] In various embodiments of methods, devices, systems, and mediums according to the disclosed technology, any steps that comprise associating a numeric value with a pixel of a video frame may be optional and therefore omitted from those specific embodiments.

[**0398**] For instance, an aspect of the disclosed technology might relate to a method of acquiring or producing information or data pertaining to at least one of the following: a person's respiration rate, heart rate, variability in respiration rate, variability in heart rate, a temporal characteristic of at least part of a heartbeat, a temporal characteristic of at least part of a respiration cycle, or a sleep stage. This method comprises:

Illuminating at least one area of the person's body, using a light source;

Capturing a set of video frames, including at least a first video frame and a second video frame, using a video camera;

Processing this set of video frames, using a computer or a processor. The processing comprises:

Calculating, for each pixel of a part of the second video frame, a difference between a numeric value linked to that pixel and a numeric value linked to a corresponding pixel of a part of the first video frame;

Determining, for each pixel of the part of the second video frame, a numeric value equal to an absolute value of the difference calculated for the pixel or a squared value of that difference, or determining, for each pixel of the part of the second video frame, a numeric value proportional to at least one of: the difference calculated for the pixel, an absolute value of the difference calculated for the pixel, or a squared value of the difference calculated for the pixel with a coefficient of proportionality which is greater than 1.0, equal to 1.0, or smaller than 1.0, or determining, for each pixel of the part of the second video frame, a numeric value which is a function of at least one of: the difference calculated for the pixel, an absolute value of the difference calculated for the pixel or a squared value of the difference calculated for the pixel;

Obtaining or generating a first numeric value using a sum of the numeric values determined for the pixels of the part of the second video frame.

[**0399**] In specific implementations of the disclosed technology, either an absolute value of a numeric value *b* or its squared value can be substituted by the numeric value raised to any power (or exponent) *m*, denoted as b^m. For instance, the power (or the exponent) *m* could be an integer, floating-point, or fractional number. Furthermore, in certain implementations, the absolute or squared value of the numeric value, or the numeric value raised to the power *m*, can be replaced by a result derived from calculations or computations involving any of these values.

[**0400**] In some example embodiments, any portion of the video frame(s) obtained by a system or device in accordance with the disclosed technology, or any data acquired, produced, or computed by that system or device, can be saved on either local or remote storage mediums. A local storage medium might be one that is integrated into the device or system, directly connected to the device or system via a wired link like USB or Ethernet, or located within the same computer network as the device or system. Conversely, a remote storage medium may be what's commonly referred to as "in the cloud," or located in a segment of a computer network other than the local network or sub-network that houses the device or system. These video frames and/or data can be transmitted to the storage medium through various connections or communication links, such as Wi-Fi, Ethernet, Bluetooth, LTE, the Internet, etc., and using various communication protocols, including but not limited to TCP/IP.

[**0401**] In some example embodiments of the disclosed technology, devices, systems, or storage mediums designed, configured, or built according to the disclosed technology can be integrated into other devices or systems. For instance, a system in accordance with the disclosed technology might be built into a floor lamp or any other illumination source. Similarly, a system or a device according to the disclosed technology could be embedded within a bed, such as in the bed's headboard. According to certain implementations, the technology disclosed in this patent document encompasses an article of manufacture that comprises a device, system, or computer-readable storage medium in line with the technology disclosed herein.

[**0402**] An example aspect of the disclosed technology pertains to a method of determining the duration or length of a time interval for blood pulse or blood wave propagation between two points of a subject, referred to as the first point and the second point. These points may also be described as first and second areas or parts of the subject. The method comprises the following steps:

1. Illuminating: Illuminating a first area near the first point and a second area near the second point using a light source.
2. Obtaining Video Frames: Using a camera to capture a set of video frames, comprising at least a first video frame and a second video frame.
3. Computations: Performing calculations using a processor. These calculations comprise:

a. First Part Calculations: For each pixel in a first part of the second video frame, calculating a difference between a numeric value associated with the pixel and a corresponding numeric value related to a first part of the first video frame; for each pixel in the first part of the second video frame, deriving a numeric value using the difference calculated for the pixel; and generating a first numeric value using the numeric values derived for the pixels of the first part of the second video frame.

b. Second Part Calculations: For each pixel in a second part of the second video frame, calculating a difference between a numeric value associated with the pixel and a corresponding numeric value related to a second part of the first video frame; for each pixel in the second part of the second video frame, deriving a numeric value using the difference calculated for the pixel; and generating a second numeric value using the numeric values derived for the pixels of the second part of the second video frame.

c. Duration Calculation: Utilizing the first and second numeric values to determine the duration of the time interval for blood pulse or blood wave propagation between the first and second points of the subject.

[**0403**] In some example embodiments of the disclosed technology, illuminating either the first area or the second area (referred to below as the "target area," and all statements applicable to the first area are also applicable to the second area) or both of these areas may involve specific techniques. These comprise:

1. Illuminating Sub-Areas: The target area may include one or more sub-areas. A sub-area can be defined as a part, section, or region of the target area. Illumination of these sub-areas is carried out according to one of the following criteria:

a. Surrounding Illumination Contrast: Any of the illuminated sub-areas is at least partially surrounded by or encompassed by a part of the target area that has lower illumination in comparison to the sub-area itself; or

b. Proximity to Lower Average Illumination: Any of the illuminated sub-areas is situated proximate to a part of the target area characterized by lower average illumination compared to the average illumination of the sub-area.

2. Average Illumination Definitions: Average illumination can be determined in different ways such as, for example:

a. Spatial Averaging: An average illumination of an area, part, or sub-area of the target area is the illumination averaged over the spatial extent of the area, part, or sub-area; or

b. Temporal Averaging: In some embodiments, the average illumination might also be considered over time, such as over a specified time interval, for the area, part, or sub-area of the target area.

3. Relation to Other Measures: In certain embodiments, the illumination is related to other physical measures. Specifically, illumination may be proportional to, equal to, or a function of irradiance, illuminance, or any other metric that quantifies the flux or level of electromagnetic radiation produced by a light source on or through an area (e.g., sub-area(s) or other part(s) of the target area).

[**0404**] Within the context of this patent document, any statement or description that applies to a 'first' entity (such as a 'first area,' 'first frame,' 'first set,' ‘first pixel,’ etc.) can be equivalently applied to the corresponding 'second' entity (such as a 'second area,' 'second frame,' 'second set,' ‘second pixel,’ etc.), and vice versa. The terms 'first' and 'second' are thus interchangeable, and the principles, actions, steps, features, or functions etc. described for one are equally applicable to the other.

[**0405**] In some example embodiments, illuminating the first area involves lighting one or more sub-areas within the first area. Any illuminated sub-area may be at least partially surrounded by a portion of the first area that receives (e.g., on average, (e.g., timewise (e.g., per unit of time (e.g., 1 second)) and/or area-wise (e.g., per unit area))) a lower amount (or level) of light from the light source compared to the light received by the sub-area itself. The amount of light in some embodiments is proportional to, or equivalent to, or is a function of the irradiance, illuminance, or any other measure of the flux or level or amount of electromagnetic radiation produced or emitted by the light source on or through a given area, such as a sub-area or any other part of the first area.

[**0406**] In certain example embodiments, illuminating the first area comprises lighting one or more sub-areas in the first area such that any of the illuminated sub-areas is at least partially surrounded by an area receiving a lower irradiance from the light source than the irradiance which the sub-area itself is receiving from the light source.

[**0407**] In some example embodiments, illuminating the first area involves lighting one or more sub-areas within the first area so that any of the illuminated sub-areas is at least partially surrounded by or is proximate to an area or part of the first area receiving a lower average irradiance from the light source (e.g., averaged over the surface of that part of the first area) compared to the average irradiance (e.g., averaged over the surface of the sub-area) which the sub-area is receiving from the light source.

[**0408**] In some example embodiments, illuminating the first area involves directing photons from the light source to a sub-area within the first area. This can be done while avoiding or refraining from directing photons to an adjacent area or region that may be proximate to, at least partially surrounding, encompassing, or in contact with the said sub-area. This can also be done by directing a lower quantity or amount or number of photons (compared to the quantity or amount or number of photons directed to the sub-area within the first area) to an adjacent area or region that may be proximate to, at least partially surrounding, encompassing, or in contact with the said sub-area.

[**0409**] In some example embodiments, the process of illuminating the first area comprises creating or producing one or more distinct light spots on that area. According to some implementations, a particular light spot among these may be defined as described in this patent document or as illustrated in the accompanying Figures.

[**0410**] In certain example embodiments, the light source is configured to provide illumination to a sub-area in the first area, with the level of illumination being *K* times higher compared to that of another part, section, or area of the first area that is distinct from the sub-area. Depending on the embodiment, the value of *K* may vary:

In some embodiments, *K* is larger than 1, including specific cases where *K* is larger than $1+10^{-100}$, $1+10^{-6}$, $1+10^{-3}$, $1+10^{-2}$, $1+10^{-1}$, 2, 5, 10, 100, 1000, 10000, 100000, 1000000, 1000000000, or 1000000000000.

In some embodiments, *K* may be smaller than some of these values, specifically smaller than 1000000000000, 1000000000, 1000000, 100000, 10000, 1000, 100, 50, 10, 5, or 2.

[**0411**] These variations in *K* may correspond to different configurations or operating conditions for the light source or the areas being illuminated.

[**0412**] In certain example embodiments:

The first and/or the second area may be located on the subject. This could include areas on the subject's body such as the skin, or on external elements like the clothes the subject wears or a blanket covering the subject. Specifically, a part of the subject's body might be beneath the first and/or the second area when viewed from the camera's perspective (e.g., when the first and/or the second area is/are on the clothes or the blanket covering (e.g., at least partially) the subject).

At least one of the first or the second area may not be directly on the subject. For instance, from the camera's viewpoint, no part of the subject's body would be underneath such an area.

Both the first and the second area can be located on any section of the subject or on any segment of objects other than the subject.

The first area might be situated proximate to the carotid artery in the subject's neck and/or can encompass a portion of the neck. The first area could be located proximate to the subject's heart and/or can cover a part of the chest or thorax.

The second area could be proximate to the femoral artery in the subject's groin and/or might include a segment of the subject’s hip or thigh.

Both the first and second areas are versatile in terms of size and shape, which can be any size relative to the subject. The illumination directed at these areas can span any part or any fraction of them, ranging from minimal coverage to the entirety of the said areas.

[**0413**] In some example embodiments, the numeric value derived for a pixel in the first part of the second video frame can be equal, for example, either the absolute value of the difference or the squared value of the difference for the pixel or both. Similarly, in some example embodiments, the numeric value derived for a pixel in the second part of the second video frame can be determined in the same manner, being equal, for example, to either the absolute value of the difference or the squared value of the difference for the pixel, or both.

[**0414**] In some embodiments, the first numeric value corresponds to the total of the numeric values derived for all pixels in the first part of the second video frame. According to some example embodiments, the second numeric value is the sum of the numeric values derived for all pixels in the second part of the second video frame.

[**0415**] Furthermore, in certain example embodiments, the first and second parts of both the first and second video frames, as well as any part, area, or section of any video frame mentioned in this patent document, can possess unique characteristics. These characteristics can comprise any position, location, coordinates, or indices, as well as any other identification labels or information associated with the part, area, or section within a video frame. Additionally, these elements can have any shape and/or size, including sizes relative to the overall video frame.

[**0416**] The numeric value derived for a pixel in the first part of the second video frame can be determined using the difference calculated for that pixel in a number of ways, according to the technology disclosed in this patent document. Some of the example ways comprise:

Application of a Function to the Difference: Once the difference is calculated for the pixel, it is then processed through a mathematical function. Two example functions which can be used in the methods, devices, systems, mediums, and articles of manufacture according to the technology disclosed herein are the absolute value function and the squaring function.

Absolute Value of the Difference: One approach to processing the difference is to take its absolute value. The absolute value ensures that all resulting values are non-negative, regardless of whether, e.g., the pixel became darker or lighter from one frame to the next. This can be particularly useful when the direction of the change (e.g., increase or decrease in pixel value or quality) is not as important as the magnitude of the change.

Squared Value of the Difference: Another approach is to square the difference. This amplifies larger differences and minimizes (e.g., in a relative sense) smaller ones, providing a sort of weighted emphasis on more significant changes between frames. This can be useful when minor fluctuations between frames (due to noise, for instance) are deemed less important than more pronounced changes. Thus, the squaring function can be applied to emphasize larger differences and minimizes smaller ones in some embodiments.

Using the Difference Value Itself: In some embodiments, the steps or actions of “computing a numeric value using the difference” or “deriving a numeric value using the difference” and the like can be omitted or skipped or bypassed and the difference value itself can be further used in such embodiments instead of, e.g., the absolute value of the difference which is used in some other embodiments according to the technology disclosed herein.

[**0417**] The choice between the absolute value and the squared value, or other functions, would depend on the specific requirements for the application or method according to the technology disclosed in this patent document. It might be influenced by the need to emphasize certain characteristics of the data, the desire for computational efficiency, or other considerations relevant to the particular implementation or method.

[**0418**] According to the technology disclosed herein, once the difference is calculated for a pixel, it can be further processed to generate or derive a numeric value that may be useful for various video analysis purposes, such as motion detection, change detection, or other computational video analyses. By generating or deriving a numeric value for each pixel using the difference value computed for the pixel, a detailed map of changes between the two video frames is created. This map can be used for various applications like detecting movement, changes in light, or other alterations between frames.

[**0419**] Within the scope of this patent document, any numeric value or quantity (hereafter referred to as the "original numeric value or quantity") may be replaced with another numeric value or quantity (hereafter referred to as the "substitute numeric value or quantity") in at least two distinct ways:

Proportional Substitution: The substitute numeric value or quantity may be proportional to the original numeric value or quantity, with a proportionality coefficient that may be larger than 1.0, smaller than 1.0, or equal to 1.0. In such a case, any method, device, medium, article of manufacture, or system according to the disclosed technology, which utilizes or produces the original numeric value or quantity, may equivalently use or produce the substitute numeric value or quantity, without departing from the disclosed technology.

Functional Substitution: Similarly, the substitute numeric value or quantity may be a function of the original numeric value or quantity. This function could encompass any mathematical relationship that takes the original numeric value or quantity as an input and produces the substitute numeric value or quantity. Any method, device, medium, article of manufacture, or system that employs or generates the original numeric value or quantity may, in turn, use or generate the substitute numeric value or quantity, while still conforming to the method, device, medium, article of manufacture, or system as delineated within the disclosed technology.

[**0420**] These provisions allow for flexibility and adaptability in the implementation of the disclosed technology, ensuring that variations in numeric values or quantities used do not alter the fundamental nature or categorization of the methods, devices, or systems disclosed herein.

[**0421**] The technology detailed in this patent document eliminates a commonly encountered requirement in other technologies to expose an area of the subject's skin (e.g., a person's skin) to a system or device for the purpose of measuring heart rate. Unlike other systems, a device or system employing the technology disclosed in this patent document does not necessitate observation of any skin areas or the head or eyes of the subject.

[**0422**] Methods, systems, and devices aligned with the disclosed technology can function even when the person is entirely covered by one or more items, such as clothing or blankets. For example, they can operate when the person is dressed in any attire, including loose-fitting garments covering the entire body, or when completely enveloped by one or more blankets that fully obscure all body parts. These methods remain functional as long as movements related to the person's respiration and/or heartbeats are at least partially transferred to the aforementioned items (e.g., to a surface area of any such items that a video camera element of a system observes, as per the technology disclosed herein).

[**0423**] Further elaboration on various examples within this patent document demonstrates that information concerning the physiological parameters of a person (e.g., the ones mentioned above) can be determined, according to the technology disclosed in this patent document, without direct observation of the person by the video camera element of a system or device designed or configured according to the disclosed technology. The camera does not need to have the person, or even the spatial region occupied by the person and/or their clothing, within its view.

[**0424**] Instead, the video camera element can focus on objects surrounding the person. A light source element of the system can impart additional light texture to one or more of these objects, according to the disclosed technology. A computing element of the system can execute computations in line with a method of the disclosed technology to acquire numeric values or other forms of information pertinent to the person's physiological parameters. This approach enhances flexibility and adaptability in capturing physiological data without requiring direct observation of the subject or contact with the subject.

[**0425**] The monitoring without requiring direct observation of the subject or contact with the subject disclosed in this patent document is facilitated by the propagation of mechanical movements from the subject's body to surrounding objects. For example, features of devices, methods, and systems in accordance with the technology disclosed herein allow for the detection of a fetus's heartbeats within a female's body.

[**0426**] For instance, a light source element of a system designed or configured according to the disclosed technology may illuminate one or more areas of the mother's body. A video camera element of the system can capture one or more video frames of those areas, and a computing element can perform computations on the collected video frames. This process, adhering to the methods according to the disclosed technology, generates numeric values (referred to as ALT data) that encompass information regarding not only the fetal heartbeats and fetal movements but also the mother's heartbeats and respiration.

[**0427**] Notably, in some implementations, the video camera element doesn't even have to directly observe the mother's body. Instead, it can focus on one or more objects in the mother's vicinity, capturing video frames of those objects. In such scenarios, the system's light source illuminates specific areas on those objects. Remarkably, the same algorithms applicable when the camera directly observes the mother's body can be utilized to derive numeric values (ALT data) containing information about the fetal and maternal heartbeats, as well as the mother's respiration.

[**0428**] In a similar vein, while monitoring a baby's heartbeats and respiration, the camera element of a system or device conforming to the disclosed technology doesn't need to keep the baby within its field of view. The camera can instead be trained on a specific object, such as the crib or cradle where the baby is sleeping, effectively utilizing the technology in a manner that provides flexibility in monitoring without direct observation of the subject.

[**0429**] An example aspect of the technology disclosed in this patent document pertains to a system designed or configured to determine the duration of a time interval for the propagation of a blood pressure wave between a first point (or area or part) and a second point (or area or part) of a subject. This system comprises the following components:

1. A Light Source: Configured to illuminate a first area proximate to the first point and a second area proximate to the second point.
2. A Camera: Configured to capture a set of video frames, including at least a first video frame and a second video frame.
3. A Processor and a Non-Transient Processor-Readable Storage Medium: Storing one or more instructions that, upon execution by the processor, facilitate at least the following operations:

a. Calculating a difference, for each pixel of a first part of the second video frame, between a numeric value linked to the pixel and a numeric value associated with a corresponding pixel in a first part of the first video frame.

b. Computing, for each pixel of the first part of the second video frame, a numeric value utilizing the difference calculated for the pixel.

c. Obtaining a first numeric value by summing at least some of the numeric values computed for the pixels in the first part of the second video frame.

d. Calculating a difference, for each pixel of a second part of the second video frame, between a numeric value linked to the pixel and a numeric value associated with a corresponding pixel in a second part of the first video frame.

e. Computing, for each pixel of the second part of the second video frame, a numeric value utilizing the difference calculated for the pixel.

f. Obtaining a second numeric value by summing at least some of the numeric values computed for the pixels in the second part of the second video frame.

g. Determining the duration of the time interval for the blood pressure wave propagation between the first and second points of the subject using the first and second numeric values.

[**0430**] In certain example embodiments, the processor may be or may include one or more of the following: an electric circuit, a microprocessor, a computer, a single-board computer, a tablet, a phone, a GPU (Graphics Processing Unit), an ASIC (Application-Specific Integrated Circuit) chip, or an FPGA (Field-Programmable Gate Array) chip.

[**0431**] In some embodiments, the light source referred to is an infrared light source. In some embodiments, the light source is configured to emit light, or is capable of emitting light, at one or more wavelengths within the range from approximately 0.1 nanometer (0.1 nm) to approximately 10 meters (10 m).

[**0432**] According to certain example embodiments, the mentioned camera is an infrared camera. An infrared camera can be defined as a camera, light detector, light sensor, or device that is configured or capable of registering or detecting light or photons at one or more wavelengths within specific wavelength ranges. These ranges can include, for example, approximately 0.1 nm to 10000 mm, 200 nm to 750 nm, 200 nm to 800 nm, 200 nm to 850 nm, 200 nm to 900 nm, 200 nm to 950 nm, or 200 nm to 1000 nm.

[**0433**] In some embodiments, the camera in question can be any device, including a camera, light detector, light sensor, or another device or system which is capable of registering or detecting light or photons with one or more wavelengths below approximately 10 m, 1 mm, 1000 nm, 900 nm, or 800 nm.

[**0434**] In some embodiments, the camera in question can be any device, including a camera, light detector, light sensor, or another device or system which is capable of obtaining images using light or photons with one or more wavelengths within a range between approximately 200 nm and approximately 10 m, or which is configured to register or detect light or photons with a wavelength within this same range.

[**0435**] In some embodiments, the camera in question can be any device, including a camera, light detector, light sensor, or another device or system capable of obtaining images using light or photons with a wavelength within a range between approximately 0.1 nm and approximately 200 nm, or configured to register or detect light or photons with a wavelength within this same range.

[**0436**] In certain embodiments, the aforementioned light source is designed or configured to illuminate the first area by forming a first light spot thereon. The illumination intensity of this first light spot, due to the light source, surpasses the illumination intensity produced by the same light source on regions of the first area surrounding (or adjacent to, at least partially encircling, or bordering) the first light spot, as can be determined using pixel data of a video frame captured by a camera, as described above. Similarly, in some embodiments, the light source is configured or crafted to shine upon the second area by creating a second light spot on it. The illumination intensity of this second light spot, as may be determined using data of an image captured by a camera, as discussed above, resulting from the light source, is greater than the illumination the light source imparts on portions of the second area neighboring (or contiguous with, at least partially surrounding, or bordering) the second light spot. Note that, in the text of this patent document, the word “illumination” (typically refers to the amount of light incident on a surface) when used by itself as well as when it is used in, e.g., the phrases “illumination intensity” or “level of illumination” and similar phrases can be replaced by the word “brightness” (typically refers to the intensity of light emitted or reflected from a source or surface) without departure from the technology disclosed in it.

[**0437**] According to some example embodiments, the said light source is configured to illuminate the first area by creating light spots on the first area, wherein the light spots are separated from each other by regions or parts of the first area having lower illumination due to the light source compared to the illumination of the light spots due to the light source. According to some example embodiments, the said light source is configured to illuminate the second area by creating light spots on the second area, wherein the light spots are separated from each other by regions or parts of the second area having lower illumination due to the light source compared to the illumination of the light spots due to the light source.

[**0438**] In specific embodiments, the designated light source is configured or designed to cast light upon both the first and second areas, forming light spots on each. On the first area, there exists at least one pair of light spots—a first and a second light spots—where the peak illumination of the first light spot is at least 0.1 nm away from that of the second. Similarly, on the second area, at least one pair—a third and a fourth light spots—have their peak illuminations separated by a minimum of 0.1 nm.

[**0439**] In some embodiments, the specified distance between peak illuminations of the light spots can be at least 1 nm, 1 micrometer, 1 mm, 10 mm, 20 mm, 50 mm, or 100 mm. Alternatively or simultaneously, this distance might be less than 1 m, 50 cm, 30 cm, 15 cm, 10 cm, 5 cm, or 1 cm. Distances between peak illumination points of light spots on different areas can be different.

[**0440**] In some embodiments, the light source is configured to project or cast light spots on both the first area and the second area such that the separation between the light spots is based on the centers of the spots. For the first area, the centers (which could be geometric or determined by or using the light source's illumination distribution within the spot) of at least one light spot pair—a first and a second light spots—are distanced by a minimum of 0.1 nm. Likewise, for the second area, the centers of at least one pair—a third and a fourth light spots—are separated by at least 0.1 nm.

[**0441**] In some embodiments, the specified distance between light spot centers can be at least 1 nm, 1 micrometer, 1 mm, 10 mm, 20 mm, 50 mm, or 100 mm. Alternatively or simultaneously, this distance might be less than 1 m, 50 cm, 30 cm, 15 cm, 10 cm, 5 cm, or 1 cm.

[**0442**] In certain embodiments, the designated light source is configured to illuminate both the first and second areas by generating light spots on them. This light source is configured or designed to modify, or possesses the capability to adjust, one or more of the following: the distance between at least two light spots on the first or second area; the dimensions of a light spot; the form of a light spot; or the illumination intensity of a light spot.

[**0443**] In some embodiments, the light source is configured to illuminate a number of sections within the first and second areas. This illumination accentuates the contrast between these sections and the remaining portions of the first and second areas. Such contrasts can be evident in the video frames captured by a camera or through the data of the video frames captured by the camera, as, for example, described above.

[**0444**] A further aspect of the disclosed technology pertains to a non-transient computer-readable storage medium. This medium stores directives that, when executed by a computer or a processor or multiple processors, result in at least the following actions: activating or directing a light source to illuminate one or more areas proximate to a first point and to illuminate one or more areas proximate to a second point;

instructing a video camera to record one or several video frames; and undertaking any of the computations detailed in this patent document.

[**0445**] A specific facet of the technology detailed herein pertains to a non-transient computer-readable storage medium. This medium contains instructions that, when implemented by a computer or one processor or multiple processors, enable at least the following actions:

1. Direct a light source to illuminate areas near a first point on a subject and to illuminate areas near a second point on the subject.
2. Instruct a camera to capture a sequence of video frames, including at least an initial frame and a subsequent frame.
3. Execute a series of computations, comprising:

a. For each pixel in a first segment of the subsequent frame, determine a difference between a numeric value of the pixel (or a numeric value associated with the pixel, or a numeric value linked to the pixel) and a numeric value of a corresponding pixel (or a numeric value associated with the corresponding pixel, or a numeric value linked to the corresponding pixel) in a first segment of the initial frame.

b. For each pixel in the first segment of the subsequent frame, derive a numeric value based on the difference determined for the pixel in step 3a.

c. Sum these numeric values derived for the pixels of the first segment of the subsequent frame to obtain a primary numeric value.

d. For each pixel in a second segment of the subsequent frame, determine a difference between its numeric value (or a numeric value associated with the pixel, or a numeric value linked to the pixel) and a numeric value of a corresponding pixel (or a numeric value associated with the corresponding pixel, or a numeric value linked to the corresponding pixel) in a second segment of the initial frame.

e. For each pixel in the second segment of the subsequent frame, derive a numeric value based on the difference determined for the pixel in step 3d.

f. Aggregate these numeric values derived for the pixels of the second segment of the subsequent frame to obtain a secondary numeric value.

g. Using both the primary and secondary numeric values, calculate a duration representing the time interval of a blood pressure wave's propagation between the first point and the second point on the subject.

[**0446**] In the context of this patent document, the term "proximate" may be interchanged with or substituted by any of its synonyms such as "near," "adjacent," "close," "neighboring," or "contiguous", and, vice versa, any of the terms "near," "adjacent," "close," "neighboring," or "contiguous" may be interchanged with or substituted by “proximate”.

[**0447**] In certain example embodiments, when determining the time interval (or duration) of blood pressure wave propagation between two points, areas, or parts of a body according to the disclosed technology, there's no reliance on information related to the distance, displacement, or depth linked to any element or object within a captured scene from any video frame obtained by a system's video camera element, as per this technology. Additionally, in some embodiments, the process of determining this time interval doesn't involve any information concerning distance, displacement, or depth whatsoever. Furthermore, there are embodiments where the determination of the time interval does not encompass acquiring or utilizing data about the position of any element in an image of a captured scene within that image, wherein the image is taken or produced by the video camera component in a system or device aligned with the disclosed technology. In yet further embodiments, the determination of the time interval excludes the use or acquisition or generation of information regarding the position of any characteristic or feature of a function, one that's calculated using an image (e.g., captured in a video frame by a video camera component of a system in line with the disclosed technology), within that particular image.

[**0448**] In some example embodiments, the process of determining the time interval (or duration) of blood pressure wave propagation between two points, areas, or parts of a body, as per the disclosed technology, avoids using or obtaining:

Any data about color changes in a subject's (e.g., a person’s) skin area resulting from their heartbeats or about variations in the subject's skin hue, especially changes tied to their heartbeats, which includes the blood pulses or waves created by those heartbeats;

and/or any information concerning distances;

and/or any information about the presence of exposed skin areas on the subject;

and/or any details regarding the identification or recognition of the subject's face, head, or eyes.

[**0449**] Furthermore, in certain embodiments, the executing instructions and related computations do not prompt a processor, computer, or any computational component to gather, generate, or utilize:

Any data concerning distances;

and/or any details about changes in the subject's skin color, specifically those linked to or induced by the subject's heartbeats, encompassing blood pressure waves or pulses resulting from the heartbeats;

and/or any information regarding exposed skin areas on the subject;

and/or any specifics about spotting or discerning the subject's face, head, or eyes.

[**0450**] Although the methods related to the disclosed technology are described with specific sequences or numbered steps for convenience in reference, these arrangements do not impose any limitations. The steps of any method discussed in this patent document can be executed in any order. Additionally, steps can be performed or executed either sequentially or concurrently with other steps from the same or different methods according to the disclosed technology. Any method related to the disclosed technology, including any of the methods described in this patent document, can also encompass additional steps. Furthermore, any step can be omitted from any method. A step, a part, or a feature of a method according to the technology disclosed in this patent document can be included into another method according to the technology disclosed herein. Any step can be carried out by any component, system, or device related to the disclosed technology, such as, e.g., a computing element. Any feature, element, part, or component of a device, medium, article of manufacture, or system as per the disclosed technology can be utilized by any other device, medium, article of manufacture, system, element, part, or component within the same technological scope.

LISTING 1

```
#!python3

#Please see picamera.readthedocs.io for the 'picamera' library documentation.
import picamera
import numpy as np
import picamera.array
import time
import datetime
import os


experimentDurationHours = 0.5 #Duration of the ALT data collection, hours.
timeSliceDurationMinutes = 6 #The whole 'experimentDurationHours' time is split into
                             # 'timeSliceDurationMinutes' minutes long intervals (‘time
                             # slices’).
experimentDir = "./experiment/" #Location where ALT data, video, etc. will be saved.
                                # Each 'time slice' has its own sub-folder, see below.

os.makedirs(experimentDir)

class ALT(picamera.array.PiMotionAnalysis):

    def analyse(self, a):

        #This is the “sSAD” value referred to above:
        sSAD = np.sum(a['sad'])
        sSADs.append(sSAD)
```

```
    #Note that the sSAD value for an I-frame in the captured video data stream will be
    # equal to zero. Please consult documentation for the 'start_recording()' method of
    # the 'picamera.PiCamera' class
    # (picamera.readthedocs.io/en/release-1.12/api_camera.html#picamera.PiCamera.start_recording).
    # Particularly, setting the 'intra_period' parameter of the 'start_recording()' method
    # to zero will cause "the encoder to produce a single initial I-frame, and then only
    # P-frames subsequently". If you would like to keep I-frames in the captured video
    # stream, you can adjust the 'intra_period' parameter accordingly (or leave it at its
    # default value). A way to process the I-frame sSAD values would be to replace
    # them with the sSAD value of the previous frame, as the following 'pseudo code'
    # shows:

    #if sSAD != 0:
        #sSADsNoZeros.append(sSAD)
    #else:
        #if len(sSADsNoZeros) >= 1:
            #sSADsNoZeros.append(sSADsNoZeros[-1])


with picamera.PiCamera() as camera:

    with ALT(camera) as mvdOutput: # motion vector data (mvd) output

        camera.resolution = (1280, 720)
        camera.framerate = 49
        camera.exposure_mode = 'night'
        camera.awb_mode = 'auto'
        camera.iso = 1600
        camera.sharpness = 100
```

```
camera.contrast = 100

while camera.analog_gain <= 1:
    time.sleep(0.1)

#'seep' delays below give you some time before the camera parameters are locked
# and video recording and ALT data collection start
# which might be helpful, for example, if you start ALT before going to sleep
# so that there is time for you to turn off the lights and let the camera adjust to
# low-light environment.
print('Preparing ...')
print('60 ...')
time.sleep(45)
print('15 ...')
time.sleep(5)

#Fixing the camera's video acquisition parameters:
camera.shutter_speed = camera.exposure_speed
camera.exposure_mode = 'off'
g = camera.awb_gains
camera.awb_mode = 'off'
camera.awb_gains = g

print('10 ...')
time.sleep(5)
print('5 ...')
time.sleep(5)

print('RUNNING ...')
```

```
for t in range(int(experimentDurationHours*60/timeSliceDurationMinutes)):

    startDateTime = datetime.datetime.now()

    timeSliceDir = experimentDir + str(startDateTime) + "/"
    print('timeSliceDir = ', timeSliceDir)
    os.makedirs(timeSliceDir)

    sSADs = []
    sSADsfile = open(timeSliceDir + 'SADs.txt', 'w')

    #Note that the 'quality' parameter of the 'start_recording()' method might be
    # useful to keep the size of the captured video files reasonably low.
    # Please see
    # picamera.readthedocs.io/en/release-1.12/api_camera.html#picamera.PiCamera.start_recording
    # for details.
    camera.start_recording(timeSliceDir + '1280x720.h264', format = 'h264',
    motion_output = mvdOutput)
    camera.wait_recording(timeSliceDurationMinutes*60)
    camera.stop_recording()

    #Note that saving ALT data into a file and stopping/restarting video recording will
    # cause a short time 'gap' between the consecutive “time slices”
    for i in range(len(sSADs)):
        sSADsfile.write(str(i + 1) + ": " + str(sSADs[i]) + "\n")

    sSADsfile.close()
```

ABSTRACT

Methods, systems, devices, mediums, and articles of manufacture for non-contact acquisition of information associated with one or more of: respiration rate, heart rate, blood pressure, variability in respiration rate, variability in heart rate, temporal aspects of a segment of a heartbeat, temporal aspects of a segment of a respiration cycle, a stage of sleep, or the duration of a blood pressure pulse's propagation from one point, area, or part of the body to another.