

SYSTEM AND METHOD FOR BODY MOVEMENT DETECTION

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of priority of Singapore Patent Application No. 10202302632Q, filed 19 September 2023, the content of which is hereby incorporated by reference in its entirety for all purposes.

TECHNICAL FIELD

[0002] The present disclosure relates generally to systems and methods for body movement detection. In some embodiments, the disclosure may include using one or more radar sensors to detect body movement.

BACKGROUND

[0003] The following discussion of the background is intended to facilitate an understanding of the present disclosure. However, it should be appreciated that the discussion is not an acknowledgment or admission that any of the material referred to was published, known or part of the common general knowledge in any jurisdiction as at the priority date of the application.

[0004] Radar sensor(s) may be adopted for the detection of vital signals of a target body. However, such detection of vital signals may be complicated by random body movements. Such random body movements may have to be detected, compensated and/or removed, to obtain accurate vital signals detection.

[0005] Various approaches have been used for the detection of body movements (movement signals) and subsequent processing of such movement signals. One approach utilizes two radar sensors, one radar sensor positioned in front of the body and one radar sensor positioned at the back of the body, to cancel out the front-back body movement interference while enhancing vital signs. However, the challenge lies in its impracticality for real-world applications, especially with multiple targets in different locations.

[0006] Another approach utilizes a camera and integrates camera data to aid in canceling random body movements. However, this approach is limited due to privacy concerns and the unavailability of camera data in radar systems.

[0007] Another approach employs a deep neural network (DNN) to extract desired respiration signals from those mixed with body movement interference. This method requires extensive training with various body movement patterns, making it relatively less practical.

[0008] Another approach is a probabilistic deep learning model to separate vital signs from body movements, but its effectiveness requires substantial validation with real data.

[0009] Another approach is principled upon movement compensation techniques. Such movement compensation techniques focus on compensating for small and large body movements using threshold-based scaling and range-bin tracking, respectively. However, the assumptions of infrequent large movements may limit its effectiveness.

[0010] Another approach enhances heartbeat signals by matching and filtering against a clean template. The difficulty lies in selecting an appropriate template, especially with overlapping respiration and heartbeat rates.

[0011] Another approach uses adaptive noise cancellation (ANC), wherein ANC may be combined with polynomial fitting and discrete cosine transform to estimate and subtract body movements, although its effectiveness may be limited by the time-varying nature of body movement.

[0012] There exists a need to provide an improved body movement detection device, system, and method to alleviate one or more of the aforementioned limitations or drawbacks.

SUMMARY

[0013] This disclosure was conceptualized to provide one or more body movement detection devices, systems, and methods, in particular for low complexity body movement detection and compensation methods for reliable vital sign estimation. The body movement detection device may include one or more multiple-input multiple-output (MIMO) radar sensors. Compared to the existing solutions, the proposed approach has relatively low hardware and computational complexity, and may, in some embodiments, require only a single device. The proposed body movement detection and compensation, the MIMO radar may achieve more accurate detection of body movement and vital sign measurement.

[0014] According to an aspect of the present disclosure, there is provided, a method for detecting body movement of a target body, the method comprising emitting electromagnetic signals from a radar sensor towards the target body; receiving reflected signals from the target body at the radar sensor, the radar sensor arranged in data or signal communication with a

processor; processing, by the processor, the received reflected signals, wherein the processing comprises: calculating a difference of the received reflected signals between two time moments; comparing an absolute value of the difference with a first threshold; wherein in a positive determination that the absolute value of the difference is greater than or equal to the first threshold; comparing the absolute value of the difference with a second threshold; wherein in a positive determination that the absolute value of the difference is greater than or equal to the second threshold for a predetermined time window within the two time moments, concluding that body movement is present.

[0015] In one embodiment, the method further comprises defining a first edge function, and configuring the first edge function such that in the positive determination that the absolute value of the difference is greater than or equal to the first threshold, assigning the first edge function to the value of the difference, otherwise, assigning the first edge function value to zero.

[0016] In one embodiment, the method further comprises defining a second edge function, and configuring the second edge function such that in the positive determination that the absolute value of the difference is greater than or equal to the second threshold for the predetermined time window within the two time moments, maintaining the value of the second edge function to the value of the difference, otherwise, assigning the second edge function value to zero.

[0017] In one embodiment, the method further comprises compensating the body movement signal from the received reflected signals, by subtracting the first edge function value from the received reflected signal value between the two time moments.

[0018] In one embodiment, the method further comprises conducting high pass filtering on the compensated body movement signal.

[0019] In one embodiment, the target body possesses one or more vital signs, the one or more vital signs include at least one of heartbeat, breathing, and respiratory rate.

[0020] In one embodiment, the radar sensor comprises a multiple-input multiple-output (MIMO) radar.

[0021] In one embodiment, the radar sensor is integrated with the processor.

[0022] In one embodiment, the radar sensor is a single-chip mmWave radar sensor, and comprises one or more integrated antennas.

[0023] According to an aspect of the present disclosure, there is provided a system for detecting body movement of a target body, the system comprising a radar sensor, the radar sensor configured to emit electromagnetic signals towards the target body, and receive reflected signals from the target body; a processor configured to: calculate, between two time moments, a difference of the received reflected signals; compare an absolute value of the difference with a first threshold; wherein in a positive determination that the absolute value of the difference is greater than or equal to the first threshold; compare the absolute value of the difference with a second threshold; wherein in a positive determination that the absolute value of the difference is greater than or equal to the second threshold for a predetermined time window within the two time moments, concluding that body movement is present.

[0024] In one embodiment, the processor is configured to define a first edge function, and further configure the first edge function such that in the positive determination that the absolute value of the difference is greater than or equal to the first threshold, assign a value of the first edge function to the value of the difference, and, otherwise, assign the value of the first edge function value to zero.

[0025] In one embodiment, the processor is configured to define a second edge function, and further configure the second edge function such that in the positive determination that the absolute value of the difference is greater than or equal to the second threshold for the predetermined time window within the two time moments, maintain the value of the second edge function to the value of the difference, otherwise, assigning the second edge function value to zero.

[0026] In one embodiment, the processor is further configured to compensate the body movement signal from the received reflected signals, by subtracting the value assigned to the first edge function from the received reflected signals between the two time moments.

[0027] In one embodiment, the processor is configured to conduct high pass filtering on the compensated body movement signal.

[0028] In one embodiment, the target body possesses one or more vital signs, the one or more vital signs include at least one of heartbeats per unit time, and respiratory rate.

[0029] In one embodiment, the radar sensor comprises a multiple-input multiple-output (MIMO) radar.

[0030] In one embodiment, the radar sensor is integrated with the processor.

[0031] In one embodiment, the radar sensor is a single-chip mmWave radar sensor, and comprises one or more integrated antennas.

[0032] According to another aspect of the present disclosure there is provided a system for detecting body movement of a target body and compensating the detected body movement for vital sign estimation of the target body, the system comprising a radar sensor, the radar sensor configured to emit electromagnetic signals towards the target body, and receive reflected signals from the target body; a processor configured to: calculate, between two time moments, a difference of the received reflected signals; compare an absolute value of the difference with a first threshold; wherein in a positive determination that the absolute value of the difference is greater than or equal to the first threshold; compare the absolute value of the difference with a second threshold; wherein in a positive determination that the absolute value of the difference is greater than or equal to the second threshold for a predetermined time window within the two time moments, conclude that body movement is present; wherein the processor is further configured to remove the body movement signal from the received signals.

[0033] According to another aspect of the present disclosure there is provided a non-transitory computer-readable medium storing instructions that, when executed by a processor, cause the processor to perform a method comprising: obtaining signals from a radar sensor between at least two time moments, calculating a difference of the signals between the at least two time moments; comparing an absolute value of the difference with a first threshold; wherein in a positive determination that the absolute value of the difference is greater than or equal to the first threshold; comparing the absolute value of the difference with a second threshold; wherein in a positive determination that the absolute value of the difference is greater than or equal to the second threshold for a predetermined time window within the two time moments, determining that a body movement is present.

[0034] According to another aspect of the present disclosure there is provided a computer program, the computer program comprising instructions to execute the aforementioned method

BRIEF DESCRIPTION OF THE DRAWINGS

[0035] The disclosure will be better understood with reference to the detailed description when considered in conjunction with the non-limiting examples and the accompanying drawings, in which:

- FIG. 1 is a flow chart depicting a method for detecting body movement of a target body according to some embodiments.
- FIG. 2 is a flow chart depicting a method for body movement detection and compensation for vital sign estimation according to some embodiments.
- FIG. 3 is a system block diagram illustrating a system for detecting one or more body movements of a target body according to some embodiments.
- FIG. 4 shows simulation results of the method for body movement detection and compensation based on the method of FIG. 2.
- FIG. 5 shows actual results of the body movement compensation based on real measurements obtained from a target human body.

DETAILED DESCRIPTION

[0036] The following detailed description refers to the accompanying drawings that show, by way of illustration, specific details and embodiments in which the disclosure may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the disclosure. Other embodiments may be utilized and structural, and logical changes may be made without departing from the scope of the disclosure. The various embodiments are not necessarily mutually exclusive, as some embodiments can be combined with one or more other embodiments to form new embodiments.

[0037] Embodiments described in the context of one of the systems or methods are analogously valid for the other systems or methods.

[0038] Features that are described in the context of an embodiment may correspondingly be applicable to the same or similar features in the other embodiments. Features that are described in the context of an embodiment may correspondingly be applicable to the other embodiments, even if not explicitly described in these other embodiments. Furthermore, additions and/or combinations and/or alternatives as described for a feature in the context of an embodiment may correspondingly be applicable to the same or similar feature in the other embodiments.

[0039] In the context of various embodiments, the articles “a”, “an” and “the” as used with regard to a feature or element include a reference to one or more of the features or elements.

[0040] Throughout the specification, unless the context requires otherwise, the word "comprise" or variations such as "comprises" or "comprising", will be understood to imply the

inclusion of a stated integer or group of integers but not the exclusion of any other integer or group of integers.

[0041] Furthermore, throughout the specification, unless the context requires otherwise, the word "include" or variations such as "includes" or "including", will be understood to imply the inclusion of a stated integer or group of integers but not the exclusion of any other integer or group of integers.

[0042] As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

[0043] As used herein, the term "signal" may be understood to include information in any suitable analog or digital form, for example, provided as a data packet, a file, a portion of a file, a set of files, a stream, a portion of a stream, a set of streams, and the like. The term signal, however, is not limited to the aforementioned examples and may take various forms and represent any information as understood in the art. In some embodiments, a signal may be converted to digital form.

[0044] As used herein, the term "module" refers to, or forms part of, or includes an Application Specific Integrated Circuit (ASIC); an electronic circuit; a combinational logic circuit; a field programmable gate array (FPGA); a processor (shared, dedicated, or group) that executes code; other suitable hardware components that provide the described functionality; or a combination of some or all of the above, such as in a system-on-chip. The term module may include memory (shared, dedicated, or group) that stores code executed by the processor.

[0045] As used herein, the terms 'first', 'second', and so on, are used for purposes of clarity and do not imply order or precedence.

[0046] As used herein, the term "processor" refers to a circuit, including analog circuits or components, digital circuits or components, or hybrid circuits or components. Any other kind of implementation of the respective functions which will be described in more detail below may also be understood as a "circuit" in accordance with an alternative embodiment. A digital circuit may be understood as any kind of a logic implementing entity, which may be special purpose circuitry or a processor executing software stored in a memory, or a firmware.

[0047] As used herein, the term "obtain", as used herein, refers to the processor which actively obtains the inputs, or passively receives inputs from a user interface, one or more sensors. The term obtain may also refer to the processor that receives or obtains inputs from a

communication interface, e.g. a user interface. The processor may also receive or obtain the inputs via a memory, a register, and/or an analog-to-digital port.

[0048] As used herein, “vital sign(s)” broadly refers to at least one of a heartbeat signal and a breathing or respiration signal. Vital signs may correspond to tiny body displacements and can be sensed by a radar sensor **through micro-Doppler detection**. In some embodiments, vital sign detection may be conducted after object localization when a MIMO radar, or radar sensor, is used. In general, since random body movement may be significantly larger than the desired body displacement caused by vital signs, vital sign detection may be interfered by the random body movement significantly. Thus, identifying the random movement and further compensating its effect may be necessary to achieve reliable and accurate vital sign detections.

[0049] As used herein, “target body” may broadly include a body of a living being capable of moving and having one or more vital signs. The target body may be a living human being.

[0050] As used herein, “body movement” is to be distinguished from “vital sign(s)” as relatively larger movement of a target body, such as movement of one or more hands, one or more legs, a head, a torso, of the target body.

[0051] As used herein, an “edge function”, broadly includes a function, such as a step function, that increases or decreases abruptly from one constant value to another. In some embodiments, the edge function may be applied as a data filter, such as a high-pass filter, by effectively removing lower-frequency components of the data. For example, by applying a step function to the data signal, the DC component and any low-frequency noise components of the data may be removed. In some embodiments, the edge function may be software-coded and executed as a function by a processor, the processor configured to receive digital data input for processing. In some embodiments, the edge function may be implemented by one or more hardware components, such as, but not limited to, operational amplifiers with step response, diodes, and transistors, digital circuits, pulse generators, analog-to-digital converters (ADCs), step recovery diodes, sample-and-hold circuits, or various combinations of the aforementioned components.

[0052] According to an aspect of the present disclosure there is provided a method for detecting body movement.

[0053] FIG. 1 illustrates a flow chart depicting a method 100 for detecting body movement of a target body, the method 100 comprising:

[0054] step 102: emitting electromagnetic signals from a radar sensor towards the target body.

[0055] step 104: receiving, within a time period, (or between at least two time moments), reflected signals from the target body at the radar sensor, the radar sensor arranged in signal (data) communication with a processor.

[0056] step 106: processing, by the processor, the processing comprises

[0057] step 108: calculating a difference of the received reflected signals between the at least two time moments;

[0058] step 110: comparing an absolute value of the difference with a first threshold; wherein in a positive determination that the absolute value of the difference is greater than or equal to the first threshold;

[0059] step 112: comparing the absolute value of the difference with a second threshold;

[0060] step 114: wherein in a positive determination that the absolute value of the difference is greater than or equal to the second threshold for a predetermined time window within the two-time moments, concluding that body movement is present.

[0061] In step 112, where the comparison results in a negative determination, i.e. the absolute value of the difference is smaller than the second threshold, it may be concluded that body movement is not present.

[0062] In some embodiments, the proposed body movement detection of method 100 may be used in a compensation method for vital sign estimation.

[0063] In some embodiments, the second threshold may be greater than the first threshold. In some embodiments, the first threshold may be 0.45, and the second threshold may be 0.75. In some embodiments, the received reflected signals, which may be regarded as input signals, may undergo further processing, such as, but not limited to, digitalization and normalization. In some embodiments, the normalization may be based on a scale from 0 to 1 for a time interval, e.g. difference between the two time moments is 30 seconds.

[0064] Referring to FIG. 2, a method of body movement detection and compensation for vital sign estimation 200 may be depicted as a flow chart and with reference to operating a radar sensor, such as a MIMO radar sensor for detecting body movement of a target body based on the method 100.

[0065] In step 102, the radar sensor may include one or more multiple-input multiple-output (MIMO) radars. The emission of the electromagnetic signals from a multiple-input multiple-

output (MIMO) radar towards the target body may be done in accordance to a specific wavelength or frequency, for example, 60 gigahertz (GHz) to 64 GHz.

[0066] In step 104, the received reflected signals from the target body at the MIMO radar may be expressed mathematically in Equation (1) as follows:

$$r(t) = v(t) + m(t) \quad (1)$$

wherein $r(t)$ denotes the received reflected signal at a particular time t , $v(t)$ denotes the desired vital sign signal at the particular time t , and $m(t)$ denotes body movement signal. At the outset, it is appreciable $v(t)$ and $m(t)$ are unknown.

[0067] In some embodiments, the body movement signal may be mathematically expressed in Equation (2), as follows:

$$m(t) = \sum_{k=1}^K a_k u(t - T_k) \quad (2)$$

wherein $u(t)$ denotes an edge function, in the form of a unit step function, $T_1 < T_2 < \dots < T_K$, a_k is the strength of the k^{th} step. In general, Equation (2) is based on the principle that although the vital sign is continuously varying, its strength is relatively smaller compared with the body movement.

[0068] In a digital system having a sample duration denoted by Δ , a digital discrete signal can be expressed mathematically in Equation (3) as follows:

$$r(n) = v(n) + m(n) \quad (3)$$

wherein $r(n)$ is the value of the $r(t)$ at the time moment Δn . It may be appreciable that Equation (1) may be converted to Equation (3) using one or more analogue to digital converter (ADC).

[0069] It may be appreciable that any body movement of a target body received as reflected electromagnetic signals by the radar sensor may be represented as a suddenly large change of displacement, which may cause a jump of phase detection used to measure the vital sign(s). As such, any body movement picked up as reflected electromagnetic signals by the radar sensors are likely several magnitudes higher than typical vital signals of the target body, and any body movement may cause the received signal magnitude (level) to quickly increase and stay at new increased signal level for a short period. The received signal level may also have a wide frequency bandwidth with relatively strong signal power compared to the vital signals.

[0070] Based on the above assumption, body movement signals may drown out the desired weaker vital sign signals. To detect any body movement of the target body, a difference $d(n)$ of

the digital signal received at a current moment $r(n)$ and a last moment $r(n-1)$ may be mathematically expressed in Equation (4) as follows:

$$d(n) = r(n) - r(n-1) \quad (4)$$

[0071] After Equation (4) is defined, a first threshold tr_1 may be expressed mathematically in Equation (5) as follows:

$$tr_1 > vr \quad (5)$$

wherein vr is a max absolute value of the change slope (i.e. a rate of change) of the vital sign signal.

[0072] In some embodiments, the method 200 comprises a step 202 of defining a first edge function, and configuring the first edge function such that in a positive determination that the absolute value of the difference is greater than or equal to the first threshold, assigning the first edge function to the value of the difference, otherwise, assigning the first edge function value to zero.

[0073] The first edge function $e(n)$ may be expressed mathematically in Equation (6) as follows:

$$e(n) = \begin{cases} d(n), & \text{if } |d(n)| \geq tr_1 \\ 0, & \text{otherwise} \end{cases} \quad (6)$$

[0074] wherein in a positive determination that the absolute value of the difference $|d(n)|$ is greater than or equal to the first threshold tr_1 , the value of the first edge function $e(n)$ is assigned to the value of the difference $d(n)$, otherwise, the value of the first edge function value is assigned to zero. In principle, the first edge function seeks to detect (or identify) signals higher than the vital sign signal based on the first threshold tr_1 . The detected or identified signals may or may not be body movement signals of the target body. For example, the signals include interference signals to be subsequently removed. In summary, the signals identified by the first edge function $e(n)$ may include body movement signals and interference signals or noise signals. To isolate the body movement signals of the target body, knowledge of the body movement signal characteristic is required. In some embodiments, this may be based on the observation that typical body movement(s) of a target body may result in a continuous change for a time duration, with some occasional small changes or interference signals, including noise. In general, these may not pose a problem unless the change is too big, which corresponds to sharp location change. For the sharp location change, a second threshold tr_2 is defined. This second threshold may be larger than the first threshold tr_1 .

[0075] For the signal change within $|tr_2|$, only the signal portion with continuous changes during time n to $n + C - 1$ will be identified, where C is a sliding window size, and let n : $n + C - 1$ denotes the time serial (time period) n to $n + C - 1$. In some embodiments, the method 200 comprises a step 204 of defining a second edge function, and configuring the second edge function such that in a positive determination that the absolute value of the difference is greater than or equal to the second threshold for a predetermined time window within the two time moments, maintaining the value of the second edge function to the value of the difference, otherwise, assigning the second edge function value to zero.

[0076] The second edge function $e(n)$ may be expressed mathematically in Equation (7) as follows:

$$e(n) = \begin{cases} \text{no change} & \text{if } |d(n)| \geq tr_2 \\ \text{reset to 0,} & \text{if } \min\{|e(n:n+C-1)|\} = 0 \\ \text{otherwise} & \text{no change,} & \text{otherwise} \end{cases} \quad (7)$$

wherein the value of the second edge function is reset to 0 if the minimum of the signal within the time window n to $n + C - 1$ is determined to be 0, and is no change, otherwise.

[0077] Referring to Equation (7), the second edge function may be defined, such that in a positive determination the absolute value of the difference $|d(n)|$ is greater than or equal to the second threshold tr_2 for a predetermined time window (i.e. n to $n + C - 1$) within the two time moments, maintaining the value of the second edge function to the value of the difference, otherwise, assigning the second edge function value to zero.

[0078] Equation (7) concludes the process for detecting body movement signals. Advantageously, the definition of the first and second thresholds and the first and second edge functions enable body movement signals to be identified and noise signals to be removed.

[0079] The identified or detected body movement signals may then be further processed for compensation to obtain vital signs of the target body, and/or for subsequent determination of gestures, for example.

[0080] Step 210: In some embodiments as illustrated with reference to Equations (8) and (9), after the edge recording $e(n)$ is done for detection body movements of the target body, the compensation is conducted as below:

$$r'(n:\infty) = r(n:\infty) - e(n) \quad (8)$$

[0081] Step 220: For the new signal sequence $r'(n)$, high-pass filtering may be conducted, and the final compensated sequence $r''(n)$ is

$$r''(n) = hpf(r'(n)) \quad (9)$$

[0082] FIG. 3 is an embodiment of a system 300 for detecting body movement of a target body 390. The detected body movement may be compensated for a vital sign estimation, such as heartbeat signals over a time period, of the target body 390. The system 300 may include a radar sensor module 310 and a processor 320. The radar sensor module 310 may be used to emit electromagnetic signals towards the target body 390, and to receive reflected signals from the target body 390. The reflected signals from the target body 390 may then be sent to the processor 320 for further processing. The reflected signals may be converted to digital signals before processing by the processor 320.

[0083] The processor 320 may process the reflected signals to calculate a difference of the received reflected signals between two time moments; compare an absolute value of the difference with a first threshold; wherein in a positive determination that the absolute value of the difference is greater than or equal to the first threshold; compare the absolute value of the difference with a second threshold; wherein in a positive determination that the absolute value of the difference is greater than or equal to the second threshold for a predetermined time window within the two time moments, determine that body movement is present. If the comparison results in a negative determination, it may be concluded that body movement is not present. In some embodiments, the processor 320 may comprise a communication interface, a processing unit, and a memory.

[0084] In some embodiments, the radar sensor module 310 may be an evaluation module, for example, the TIIWR6843ISK evaluation module specifically designed for radar applications. The radar sensor module 310 may comprise a single-chip, mmWave radar sensor such as the IWR6843 sensor. The TIIWR6843ISK evaluation module may integrate a 60-64 GHz mmWave radar front end with an ARM Cortex-R4F processor and a C674x DSP, allowing for advanced signal processing and autonomous operation.

[0085] The radar sensor module 310 may include an Antenna on Package (AoP), which simplifies the design and reduces the size of the system. In some embodiments, the radar sensor module 310 may be configured for different use cases, such as long-range and short-range sensing.

[0086] In some embodiments, the radar sensor module 310 may include multiple data communication interfaces to support various communication protocols such as Universal Asynchronous Receiver/ Transmitter (UART), Serial Peripheral Interface (SPI), and Inter-

Integrated Circuit (I2C) for communication. In some embodiments, the radar sensor module 310 may include one or more general-purpose input/output (GPIOs) ports for additional control. The TIWR6843ISK module advantageously serves as a versatile and powerful platform for developing radar-based solutions, enabling quick prototyping and deployment.

[0087] In some embodiments, the radar sensor module 310 may be a BGT60TR13C radar board, which is a radar sensor evaluation board developed by Infineon Technologies. It is based on the BGT60TR13C, which is a highly integrated 60 GHz radar transceiver. The BGT60TR13C radar board may include a 60 GHz Radar transceiver, and may be configured as a fully integrated, microwave radar transceiver operating in the 60 GHz ISM band. The BGT60TR13C radar board may include transmit and receive channels, along with integrated antennas, making it suitable for compact radar systems. The BGT60TR13C radar board may be configured for motion sensing, so as to receive reflected signals from the target body. It is capable of detecting fine movements, including micro-motions, and can be used in smart home, automotive, and industrial applications. The BGT60TR13C radar board may be configured in Doppler mode, FMCW (Frequency Modulated Continuous Wave), and CW (Continuous Wave) for various sensing requirements. The BGT60TR13C radar board may include integrated antennas, eliminating the need for external antennas and simplifying the design process. The radar transceiver features on-chip signal processing capabilities, including an ADC (Analog-to-Digital Converter) and a motion detection engine, enabling complex radar signal processing directly on the chip.

[0088] In some embodiments, the radar board may be designed for low-power operation, making it suitable for battery-powered applications. The radar board may support interfaces like the SPI and GPIO, and may be compatible with various development tools, including software libraries and examples for radar signal processing.

[0089] The processor 320 may be a remote server, or may be a general-purpose computer capable of processing complex numbers. In some embodiments, the processor 320 may be integrated with the radar sensor module 310. The processor 320 may comprise wired and/or wireless data communication capabilities for the transmission of data with the radar sensor module 310. In some embodiments, the processor 320 may be part of a distributed computing network. In some embodiments, the processor 320 may comprise a built-in Digital Signal Processor (DSP) and a microcontroller (MCU) within the same chip, allowing for edge processing capabilities directly on the radar sensor. In some embodiments, the processor 320

may include a user interface for displaying the digital signals obtained from the target body, in real time.

[0090] It may be appreciable that with the present system and method to detect body movement, only one single radar device/sensor is required, and the present system and method do not require a pair of radar devices and precise positioning to work. In other words, the present method and system for body movement detection is relatively less complex in terms of hardware and operation.

[0091] It may be further appreciated that compared to solutions requiring additional imaging device(s), such as cameras, to assist in body movement detection, the present system and method may be relatively less complex. Notwithstanding the same, if required for further verification, testing, or calibration of the present system, one or more image capturing devices may be optionally added.

[0092] FIG. 4 shows a typical body movement effect and the compensation simulation, the simulation graphically expressed in five rows 402, 404, 406, 408, 410. Each of the five rows comprises a time domain graphical representation and a frequency domain representation.

[0093] The first row 402, labelled “**body movement**” comprises simulation result of an example body movement signals obtained by the radar sensors in time domain on the left side and frequency domain on the right side.

[0094] The second row 404, labelled “**vital sign**”, comprises the vital sign in time domain on the left side and frequency domain on the right side. It may be appreciable that the magnitude of the body movement signals is several times higher than the vital signals. In summary, it may be seen that the body movement signals has higher strength value and wider frequency band compared with vital sign signals in the second row.

[0095] The third row 406, labelled “**mixed**”, shows the simulation of the vital sign signals with body movement signals combined (i.e. reference Equation (1) and Equation (3)). It may be observed that without body movement compensation, the vital sign signals frequency will not be noticeable because it may be “submerged” in the body movement frequency components in the frequency domain. In other words, without the compensation to remove body movement signals, the vital sign signal detection may fail.

[0096] The fourth row 408, labelled “**movement detected**” shows the simulation of the body movement detection according to the defined first and second edge functions and corresponding first and second thresholds. After the body movement detection in the fourth

row, and processing based on steps 108, 110, 112, 114 above, the compensated signal in the fifth row 410, labelled “**compensated**”, the shape may be observed to be relatively similar as the original vital sign signal in the second row 404, in time domain. In frequency domain, the peak of the compensated signal matches the desired vital signal component relatively well, hence demonstrating well recovery of the vital sign signals.

[0097] FIG. 5 shows the body movement detection and compensation method of FIG. 2 applied to obtain real life measurement data, as a verification of the efficacy of the proposed method. In FIG. 5, the 1st row of graph plots 502, labelled “**bf compensation**”, “**breath bf compensation**” and “**heartbeat bf compensation**”, are the real measured data with body movement before compensation. The time domain waveform is on left side, the frequency domain waveforms for breathing and vital signs, in the form of heartbeats, are on the middle and right side, respectively. The ground truth breathing rate and heartbeat were 16 times/minute and 56 beats/minute, respectively.

[0098] However, due to body movement signals detected, the measured breathing was 21 time/minute and heartbeat was 62 beat/minute, which are quite different from the truth values. The second row 504 of FIG. 5 shows the body movement signals detected as an example of a real input signal (i.e. received reflected signals from a human being) before the proposed signal or data processing. The input signal may comprise a combination or mix of the desired vital sign signals and body movement signals. The ground truths of the vital signs are heart rate 56/min and breathing rate 16/min. The second row 504 is different from other rows, which comprise three columns.

[0099] In the third row 506, the time domain waveform after body movement compensation is on the left side. It may be observed that the changing due to body movement has been removed or compensated for. The middle and the right side plots are the frequency domain waveforms after body movement compensation. It may be observed that the detected breathing rate is 15 time/minute and heartbeat are 56 beat/minute, which are very close to the truth values.

[00100] The fourth row 508 illustrates a relatively simple way to handle body movement signals once identified, which is to discard the body movement signals in the movement period rather than applying any compensation. The remaining portion of the signal is then used for heartbeat and rate detection. Consequently, column 2 of the fourth row 508 displays the heartbeat detection results, while column 3 of the fourth row 508 presents the breathing rate detection results.

[00101] In some embodiments, a method for detecting vital signs with MIMO radar is presented. The method may comprise receiving, via a plurality of receiving antennas, signals transmitted from a plurality of transmitting antennas, wherein the signals comprise analogue and/or digital signals relating to body movements and signals relating to vital signs; calculating a difference between a signal at a discrete time and a signal at a preceding discrete time; determining the signals relating to body movements based on the difference; and determining the signals relating to vital signs by compensating the received signals with the signals relating to body movements; wherein calculating a difference between a signal at a discrete time and a signal at a preceding discrete time comprises applying an edge function with a first threshold so as to remove negligible interference signals, wherein the first threshold is greater than a max absolute value of a change slope of the signals relating to vital signals and wherein calculating a difference between a signal at a discrete time and a signal at a preceding discrete time further comprises applying the edge function with a second threshold so as to obtain the signals relating to body movements. The method further comprising correcting the received signal by removing the body movement effect as a function of time and compensating accordingly. The method further comprising conducting a high pass filtering on the compensated signals. Thereby resulting in a low complexity process for random body movement detection and its compensation, and that effectively achieving more accurate vital sign estimation.

[00102] It should be further appreciated by the person skilled in the art that variations and combinations of features described above, not being alternatives or substitutes, may be combined to form yet further embodiments falling within the intended scope of the invention.

[00103] In particular, although the described it may be appreciated that the separating the vital signs from the body movement includes applying a filtering technique to distinguish between low-frequency components associated with body movement and high-frequency components associated with vital signs.

[00104] In some embodiments, the processing of the received reflected signals obtained by the radar sensors may comprise constructing a range-Doppler map of the target body.

[00105] Although the present system and method can function with a single radar sensor with integrated processor without further hardware, it may be contemplated that additional devices, such as cameras and signal filters, may be added as necessary to enhance the accuracy of the body detection and/or vital sign estimation.

[00106] According to another aspect of the present disclosure there is provided a non-transitory computer-readable medium storing instructions that, when executed by a processor, cause the processor to perform a method comprising obtaining signals from a radar sensor between at least two time moments; calculating a difference of the signals between the at least two time moments; comparing an absolute value of the difference with a first threshold; wherein in a positive determination that the absolute value of the difference is greater than or equal to the first threshold; comparing the absolute value of the difference with a second threshold; and wherein in a positive determination that the absolute value of the difference is greater than or equal to the second threshold for a predetermined time window within the two time moments, determining that a body movement is present.

[00107] A computer program (also known as a program, software, software application, script, or code) can be written in any form of programming language, including compiled or interpreted languages, declarative or procedural languages, and it can be deployed in any form, including as a stand-alone program or as a module, component, subroutine, object, or other unit suitable for use in a computing environment. A computer program may, but need not, correspond to a file in a file system. A program can be stored in a portion of a file that holds other programs or data (e.g., one or more scripts stored in a markup language document), in a single file dedicated to the program, or in multiple coordinated files (e.g., files that store one or more modules, sub programs, or portions of code). A computer program can be deployed to be executed on one computer or on multiple computers that are located at one site or distributed across multiple sites and interconnected by a communication network.

[00108] Some of the processes and logic flows described in this specification can be performed by one or more programmable processors executing one or more computer programs to perform actions by operating on input data and generating output. The processes and logic flows can also be performed by, and device can also be implemented as, special purpose logic circuitry, e.g., an FPGA (field programmable gate array) or an ASIC (application specific integrated circuit).

[00109] While this specification contains many details, these should not be understood as limitations on the scope of what may be claimed, but rather as descriptions of features specific to particular examples. Certain features that are described in this specification or shown in the drawings in the context of separate embodiments can also be combined. Conversely, various

features that are described or shown in the context of a single embodiment can also be implemented in multiple embodiments separately or in any suitable sub-combination.

[00110] Similarly, while operations are depicted in the drawings in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. In certain circumstances, multitasking and parallel processing may be advantageous. Moreover, the separation of various system components in the embodiments described above should not be understood as requiring such separation in all embodiments, and it should be understood that the described program components and systems can generally be integrated together in a single device or packaged into multiple devices.

[00111] A number of embodiments have been described. Nevertheless, it will be understood that various modifications can be made. Accordingly, other embodiments and combinations of one or more of the described embodiments are within the scope of the following claims.

CLAIMS

1. A method for detecting body movement of a target body, the method comprising:
emitting electromagnetic signals from a radar sensor towards the target body;
receiving reflected signals from the target body at the radar sensor, the radar sensor arranged in data or signal communication with a processor;
processing, by the processor, the received reflected signals,
wherein the processing comprises:
calculating a difference of the received reflected signals between two time moments;
comparing an absolute value of the difference with a first threshold;
wherein in a positive determination that the absolute value of the difference is greater than or equal to the first threshold;
comparing the absolute value of the difference with a second threshold,
wherein in a positive determination that the absolute value of the difference is greater than or equal to the second threshold for a predetermined time window within the two time moments, concluding that body movement is present.
2. The method of claim 1, further comprising defining a first edge function, and configuring the first edge function such that in the positive determination that the absolute value of the difference is greater than or equal to the first threshold, assigning the first edge function to the value of the difference, otherwise, assigning the first edge function value to zero.
3. The method of claim 1 or 2, further comprising defining a second edge function, and configuring the second edge function such that in the positive determination that the absolute value of the difference is greater than or equal to the second threshold for the predetermined time window within the two time moments, maintaining the value of the second edge function to the value of the difference, otherwise, assigning the second edge function value to zero.
4. The method of claim 2 or 3, further comprising compensating the body movement signal from the received reflected signals, by subtracting the first edge function value from the received reflected signals between the two time moments.

5. The method of claim 4, further comprising conducting high pass filtering on the compensated body movement signal.
6. The method of any one of the preceding claims, wherein the target body possesses one or more vital signs, the one or more vital signs include at least one of heartbeat, breathing, and respiratory rate.
7. The method of any one of the preceding claims, wherein the radar sensor comprises a multiple-input multiple-output (MIMO) radar.
8. The method of any one of the preceding claims, wherein the radar sensor is integrated with the processor.
9. The method of claim 8, wherein the radar sensor is a single-chip mmWave radar sensor, and comprises one or more integrated antennas.
10. A system for detecting body movement of a target body, the system comprising:
 - a radar sensor, the radar sensor configured to emit electromagnetic signals towards the target body, and receive reflected signals from the target body;
 - a processor configured to:
 - calculate, between two time moments, a difference of the received reflected signals;
 - compare an absolute value of the difference with a first threshold;
 - wherein in a positive determination that the absolute value of the difference is greater than or equal to the first threshold;
 - compare the absolute value of the difference with a second threshold;
 - wherein in a positive determination that the absolute value of the difference is greater than or equal to the second threshold for a predetermined time window within the two time moments, concluding that body movement is present.

11. The system of claim 10, wherein the processor is configured to define a first edge function, and further configure the first edge function such that in the positive determination that the absolute value of the difference is greater than or equal to the first threshold, assign a value of the first edge function to the value of the difference, and, otherwise, assign the value of the first edge function value to zero.

12. The system of claim 10 or 11, wherein the processor is configured to define a second edge function, and further configure the second edge function such that in the positive determination that the absolute value of the difference is greater than or equal to the second threshold for the predetermined time window within the two time moments, maintain the value of the second edge function to the value of the difference, otherwise, assigning the second edge function value to zero.

13. The system of claim 11 or 12, wherein the processor is further configured to compensate the body movement signal from the received reflected signals, by subtracting the value assigned to the first edge function from the received reflected signals between the two time moments.

14. The system of claim 13, wherein the processor is further configured to conduct high pass filtering on the compensated body movement signal.

15. The system of any one of claims 10 to 14, wherein the target body possesses one or more vital signs, the one or more vital signs include at least one of heartbeats per unit time, and respiratory rate.

16. The system of any one of claims 10 to 15, wherein the radar sensor comprises a multiple-input multiple-output (MIMO) radar.

17. The system of any one of claims 10 to 16, wherein the radar sensor is integrated with the processor.

18. The system of any one of claims 10 to 17, wherein the radar sensor is a single-chip mmWave radar sensor, and comprises one or more integrated antennas.

19. A system for detecting body movement of a target body and compensating the detected body movement for vital sign estimation of the target body, the system comprising:

a radar sensor, the radar sensor configured to emit electromagnetic signals towards the

target body, and receive reflected signals from the target body;

a processor configured to:

calculate, between two time moments, a difference of the received reflected signals;

compare an absolute value of the difference with a first threshold;

wherein in a positive determination that the absolute value of the difference is greater than or equal to the first threshold;

compare the absolute value of the difference with a second threshold;

wherein in a positive determination that the absolute value of the difference is greater than or equal to the second threshold for a predetermined time window within the two time moments, conclude that body movement is present;

wherein the processor is further configured to remove the body movement signal from the received signals.

20. A non-transitory computer-readable medium storing instructions that, when executed by a processor, cause the processor to perform a method comprising:

obtaining signals from a radar sensor between at least two time moments,

calculating a difference of the signals between the at least two time moments;

comparing an absolute value of the difference with a first threshold;

wherein in a positive determination that the absolute value of the difference is greater than or equal to the first threshold;

comparing the absolute value of the difference with a second threshold;

wherein in a positive determination that the absolute value of the difference is greater than or equal to the second threshold for a predetermined time window within the two time moments, determining that a body movement is present.