Claims

1. A sensor for non-contact sensing of a physiological parameter of a body, the sensor comprising:

a waveguide, the waveguide comprises a metamaterial and is configured to receive a transmitted signal and to propagate the transmitted signal in a spoof surface plasmon mode along the waveguide to produce an evanescent electromagnetic field and to provide a received signal,

wherein the waveguide is placed at a predetermined distance away from the body for non-contact sensing of a perturbation produced by a physiological motion of the body using the evanescent electromagnetic field, the perturbation produces a phase shift between the transmitted signal and the received signal for use in determining the physiological parameter of the body.

2. The sensor of claim 1, wherein the waveguide comprises a sensing layer on a sensing side of the waveguide adapted to detect the perturbation produced by the physiological motion of the body, a grounding layer on an opposite side to the sensing side, and a non-electrically conductive layer sandwiched between the sensing layer and the grounding layer, wherein the grounding layer is configured to confine the evanescent electromagnetic field to the sensing side of the waveguide.

3. The sensor of claim 1 or claim 2, wherein the sensing layer comprises a comb-shaped rectangular strip, the comb-shaped rectangular strip having an elongated base and a plurality of teeth extending along and from the elongated base, wherein adjacent teeth of the plurality of teeth is separated by a gap.

4. The sensor of claim 3, wherein a height of the plurality of teeth measured from the elongated base is adapted to vary a degree of wavelength confinement of the spoof surface plasmon mode.

5. A system for non-contact sensing of a physiological parameter of a body, the system comprising one or more sensors according to any one of claims 1 to 4, and a software-defined radio (SDR) system configured to provide the transmitted signal and to receive the received signal.

6. The system of claim 5, wherein the SDR system includes a digital-to-analogue converter (DAC), the SDR system is configured to:

generate a digital complex baseband signal;

convert the digital complex baseband signal to form an analogue baseband signal using the DAC;

modulate the analogue baseband signal with a carrier signal to provide the transmitted signal;

demodulate the received signal to obtain in-phase and quadrature (IQ) components associated with the digital complex baseband signal; and

digitise the obtained IQ components.

7. The system of claim 6, wherein the SDR system is configured to perform complex conjugate multiplication of the digital complex baseband signal and the digitised IQ components to determine a phase shift signal associated with the phase shift between the transmitted signal and the received signal.

8. The system of claim 7, wherein the SDR system is configured to filter the phase shift signal with a low-pass filter and to down-sample the filtered phase shift signal to form a decimated phase shift signal.

9. The system of claim 8, wherein the SDR system is adapted to arctangent demodulate and unwrap the decimated phase shift signal to obtain a time-varying phase signal associated with the phase shift between the transmitted signal and the received signal.

10. The system of claim 9, wherein the physiological motion is associated with more than one physiological parameter, the system further comprises a processor and a data storage storing computer program instructions operable to cause the processor to:

process the time-varying phase signal with a bandpass filter to segregate the time-varying phase signal to individual components associated with each of the more than one physiological parameter.

11. The system of claim 10, wherein the one or more sensors includes a first sensor provided at a back of the body adapted to detect a respiration signal and a heart signal

associated with the body, and a second sensor provided at a wrist of the body adapted to detect a radial pulse signal associated with the body, the system further comprises a processor and a data storage storing computer program instructions operable to cause the processor to:

process a first time-varying phase signal associated with the first sensor with bandpass filters to segregate the first time-varying phase signal to a time-varying respiration phase signal and a time-varying heart phase signal; and

process a second time-varying phase signal associated with the second sensor with a bandpass filter to obtain a time-varying radial pulse phase signal.

12. The system of claim 11, wherein the data storage further stores computer program instructions operable to cause the processor to:

perform fast Fourier transform on first 15 seconds of each signal segment of the time-varying respiration phase signal to estimate a respiratory period;

calculate a moving-average curve by taking a mean of the time-varying respiration phase signal over a time window equivalent to two times of the respiratory period to generate each data point of the moving-average curve;

calculate intercepts between the moving-average curve and the time-varying respiration phase signal;

identify peaks on the time-varying respiration phase signal using the calculated intercepts, wherein each of the peaks is identified as a maximum between an intercept with a positive slope and an ensuing intercept with a negative slope; and

calculate a respiratory cycle as a time duration between two adjacent peaks.

13. The system of claim 11 or claim 12, wherein the data storage further stores computer program instructions operable to cause the processor to:

calculate a first time derivative waveform for each of the time-varying heart phase signal and the time-varying radial pulse phase signal;

set all negative values of the first time derivative waveform for each of the time-varying heart phase signal and the time-varying radial pulse phase signal to zero to form a resultant waveform for each of the time-varying heart phase signal and the time-varying radial pulse phase signal;

square the resultant waveform associated with each of the time-varying heart phase signal and the time-varying radial pulse phase signal to form a squared signal

associated with each of the time-varying heart phase signal and the time-varying radial pulse phase signal;

filter the squared signal using a moving-average filter with a predetermined time window to produce an integrated signal associated with each of the time-varying heart phase signal and the time-varying radial pulse phase signal;

detect peaks in the integrated signal associated with each of the time-varying heart phase signal and the time-varying radial pulse phase signal;

detect peaks in the time-varying heart phase signal and the time-varying radial pulse phase signal;

verify detected peaks in the time-varying heart phase signal and the time-varying radial pulse phase signal using the detected peaks in the integrated signal;

calculate beat locations in the time-varying heart phase signal and the time-varying radial pulse phase signal, each of the beat locations being a nearest preceding positive zero-intercept in relation to each verified peak of the time-varying heart phase signal and the time-varying radial pulse phase signal; and

calculate beat to beat intervals associated with each of the time-varying heart phase signal and the time-varying radial pulse phase signal, the beat to beat intervals being a time interval between successive beat locations, wherein the beat to beat intervals associated with the time-varying heart phase signal relates to a heart rate and the beat to beat intervals associated with the time-varying radial pulse phase signal relates to a radial pulse rate.

14. The system of any one of claims 11 to 13, wherein the data storage further stores computer program instructions operable to cause the processor to:

receive the time-varying heart phase signal and the time-varying radial pulse phase signal;

process the time-varying heart phase signal and the time-varying radial pulse phase signal to form a processed time-varying heart phase signal and a processed time-varying radial pulse phase signal;

generate, using a trained machine learning model, an aligned time-varying heart phase signal and an aligned time-varying radial pulse phase signal based on the processed time-varying heart phase signal and the processed time-varying radial pulse phase signal, wherein peaks of the aligned time-varying heart phase signal correspond to electrocardiography (ECG) R-wave peaks and peaks of the aligned time-varying

radial pulse phase signal corresponds to photoplethysmography (PPG) maximum first derivative (MFD) points;

calculate a pulse transit time (PTT) as a time delay between one of the peaks of the aligned time-varying heart phase signal and a corresponding one of the peaks of the aligned time-varying radial pulse phase signal; and

convert the calculated PTT to a systolic blood pressure value and a diastolic blood pressure value.

15. The system of claim 14, wherein the data storage further stores computer program instructions operable to cause the processor to:

search, within an ensuing time window of 0.15s to 0.4s of the one of the peaks of the aligned time-varying heart phase signal, a local maximum of the aligned time-varying radial pulse phase signal, the local maximum being the corresponding one of the peaks for use in calculating the PTT.

16. The system of claim 14 or claim 15, wherein the data storage further stores computer program instructions operable to cause the processor to:

receive training data comprising training time-varying heart phase signals and training time-varying radial pulse phase signals;

process the training data to form training processed time-varying heart phase signals and training processed time-varying radial pulse phase signals; and

train a machine learning model to form the trained machine learning model, wherein the data storage storing computer program instructions operable to cause the processor to train the machine learning model further stores computer program instructions operable to cause the processor to:

generate, using the machine learning model, training time-varying heart phase signal outputs and training time-varying radial pulse phase signal outputs based on the training processed time-varying heart phase signals and the training processed time-varying radial pulse phase signals; and

minimise, using a regression layer, a mean squared error (MSE) between each of the training time-varying heart phase signal outputs and training time-varying radial pulse phase signal outputs and corresponding target time-varying heart phase signals and time-varying radial pulse phase signals for forming the trained machine learning model.

17. The system of any one of claims 14 to 16, wherein the trained machine learning model includes a long short-term memory (LSTM) network followed by a fully connected (FC) layer for each of the time-varying heart phase signal and the time-varying radial pulse phase signal.

18. The system of any one of claims 14 to 17, wherein the data storage storing computer program instructions operable to cause the processor to process the time-varying heart phase signal and the time-varying radial pulse phase signal further stores computer program instructions operable to cause the processor to:

left-shift the time-varying heart phase signal by a predetermined amount of time to form the processed time-varying heart phase signal; and

differentiate the time-varying radial pulse phase signal with respect to time to generate a time derivative of the time-varying radial pulse phase signal to form the processed time-varying radial pulse phase signal.

19. The system of any one of claims 14 to 18, wherein the data storage further stores computer program instructions operable to cause the processor to:

identify epochs for blood pressure sensing, the identified epochs each being a time window having a predetermined time period during which both the time-varying heart phase signal and the time-varying radial pulse phase signal are present;

calculate a mean heart rate and a mean pulse rate for the identified epochs;

select, one or more candidate epoch among the identified epochs, wherein an absolute difference between the mean heart rate and the mean pulse rate of each of the one or more candidate epoch is less than two beats per minute;

calculate a signal quality metric (Q_e) for each of the time-varying heart phase signal and the time-varying radial pulse phase signal in each of the one or more candidate epoch as:

$$Qe = \frac{\frac{N}{t_e}}{\frac{1}{N-1}\sum_{t=1}^{N-1}\frac{60}{I(i)}}$$

where N is a number of detected beats of the time-varying heart phase signal or the time-varying radial pulse phase signal in each of the one or more candidate epoch, t_e is

a length of each of the corresponding one or more candidate epoch in minutes, and I is a beat-to-beat interval from each successive pair of the detected beats in seconds; and

selecting one or more detection epoch from among the one or more candidate epoch for continuous blood pressure detection, wherein the signal quality metric (Q_e) for each of the time-varying heart phase signal and the time-varying radial pulse phase signal in the one or more detection epoch is more than 0.5.

20. A method for non-contact sensing of a physiological parameter of a body using one or more sensors, wherein each of the one or more sensors comprises a waveguide, the waveguide comprises a metamaterial and is configured to propagate a transmitted signal in a spoof surface plasmon mode along the waveguide to produce an evanescent electromagnetic field and to provide a received signal, the evanescent electromagnetic field being used for non-contact sensing of a perturbation produced by a physiological motion of the body, the method comprising:

(i) placing the waveguide at a predetermined distance away from the body for non-contact sensing of the perturbation;

(ii) providing the transmitted signal to the waveguide;

(iii) receiving the received signal from the waveguide; and

(iv) processing the received signal and the transmitted signal to determine a phase shift between the transmitted signal and the received signal caused by the perturbation for determining the physiological parameter of the body.