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Heart-rate Monitoring of Moving Persons Using 79GHz Ultra-wideband Radar Sensor

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Abstract:

This paper presents a 79 GHz ultra-wideband sensor monitoring the instantaneous heart-rate (HR) of moving persons. The sensor uses three approaches for the instantaneous HR monitoring: block-based motion/movement compensation of multiple persons, multiresolution analysis and Burg method for instantaneous HR analysis. The first approach normalizes and/or compensates for motion/movement of moving persons where the consecutive received signal, called radar range-profile, is stored on a block-by-block basis and the motion/movement within each block is then normalized as stationary. The second approach uses multi-resolution analysis (MRA) in order to remove most of the breathing signal from the received vital-sign waveform (HR and breathing). And the third approach estimates the instantaneous HR using Burg method. Measurement was conducted in order to investigate the usefulness of our suggested HR monitoring system including the above three approaches. The estimated HR is also compared with an optical pulse wave sensor (finger PPG) in order to confirm the accuracy.

Keywords: millimeter-wave, radar sensor, heart-rate, health-care

Classification: Sensing

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1. Introduction

Heart-rate signal, especially instantaneous heart-rate (HR), is one of very important vital-signs which indicates daily health state of person such as stress evaluation and falling asleep forecast [1]. The HR signal would be variable at every beat of our heart due to the influence of the autonomic nervous. For example, stress evaluation and falling asleep forecast can be estimated from the instantaneous HR. Therefore, HR monitoring systems such as wearable and wireless RF sensor have attracted considerable attention. However, the wearable sensor may require repeated placement and removal of the sensor device including the battery placement, thereby limiting the long-term use. The wireless RF sensor would be preferable, but it is challenging to monitor the instantaneous HR without body contact because the HR component included in the received signal is much weaker as compared with the breathing component [2]-[5]. There have been so far several papers regarding the HR monitoring system with ultra-wideband (UWB) radar, but these assumes relatively ideal conditions, that is, on a single person who is motionless (seated or lying down, for example) [3][5].

In this paper, we suggest a millimeter-wave UWB sensor which can be used to monitor the instantaneous HR of moving persons. It uses three approaches for instantaneous HR monitoring: block and storage-based motion/movement compensation of moving persons, multi-resolution analysis (MRA) and instantaneous HR analysis using Burg method. The first approach normalizes and/or compensates for motion/movement of moving persons where the consecutive received signal, called radar range-profile, is stored on a block-by-block basis and the motion/movement within each block is normalized as stationary. The second approach uses an MRA in order to remove most of the breathing signal from the received vital-sign waveform (HR and breathing). And the third approach estimates the instantaneous HR using Burg method. The use of FFT is not generally appropriate for instantaneous HR since the HR is variable. A normal, healthy heart does not tick evenly like a metronome, but instead, when looking at the milliseconds between the HR interval, there is constant variation. Therefore, the motion/movement normalized signal is separated into HR and breathing component by the MRA and the instantaneous HR is then estimated accurately using Burg method. Measurement was conducted in order to investigate the usefulness of our suggested HR monitoring system. The estimated HR is also compared with an optical pulse wave sensor (finger PPG) in order to confirm the accuracy. It has been found from the measurement results that the estimated HR is in good agreement with the finger PPG sensor (the correlation coefficient is 0.96 ~ 0.98).

2. Heart-rate monitoring sensor robust to motion/movement

Fig.1 shows the block diagram of our suggested monitoring scheme. The sensor uses three approaches for instantaneous HR monitoring: block-based motion/movement compensation of multiple persons, multi-resolution analysis for removing the respiration signal and Burg method for instantaneous HR analysis.

The consecutive received signal is divided into blocks each of which is stored at the data size of a block (block time duration of approximately 1 second) and the motion/movement within each block of radar range-profiles (radar range-profile as a function of time) is tracked and then compensated and/or normalized as stationary as shown in Fig.1. The compensation process is repeatedly executed until the error is less than a given value as shown in Fig.1. And the above operation is recursively conducted from block to block. Therefore, the sensor is capable of compensating for the body motion/movement of each moving person and monitoring the HR. For multiple persons, the above operation is conducted one by one. The motion compensated signal is then applied to the following MRA. It is noted that the use of FFT is not appropriate for the HR monitoring since the HR signal is not constant. A normal, healthy heart does not tick evenly like a metronome, but instead, when looking at the milliseconds between heart beats, there is constant variation. The monitoring accuracy is largely affected by breathing signal since the HR component included in the received signal is much weaker than the breathing component. Therefore, The MRA is employed to remove the breathing component where that orthogonal wavelets are employed. The HR and breathing signals generally exist at the frequency components around 0.75 Hz to 1.6 Hz and around 0.1 Hz to 0.5 Hz respectively. Therefore, the HR signal is reconstructed using detail coefficients from level 6 to level 7 to remove the breathing signal [3]. And the HR interval is estimated from the power spectral density (PSD) calculated by Burg method to calculate the AR coefficient at the approximately 4 second data window. The AR model is shown as

$$y_n = -\sum_{i=1}^{M} a_i y_{n-1} + x_n$$

where, y_n is observed signal, a_i is AR coefficients, x_n is white Gaussian noise and M is order of the AR model.

The relationship between the AR coefficients a_k and the power spectral density (PSD) is shown as

$$P(\omega) = \frac{\sigma^2}{\left|1 + \sum_{k=1}^{M} a_k e^{-j\omega k}\right|^2}$$

where σ^2 is the estimated variance of residuals.

It is important to determine an optimum order of the AR model. Some algorithms for determining the optimum order have been suggested such as Akaike's Information Criterion (AIC) and Final Prediction Error (FPE), but it is not easy to determine the optimal order of AR model every time. Therefore, we select the order using the histogram generated by the optimal order of the AR model of the 1000 sets of received signal [3].

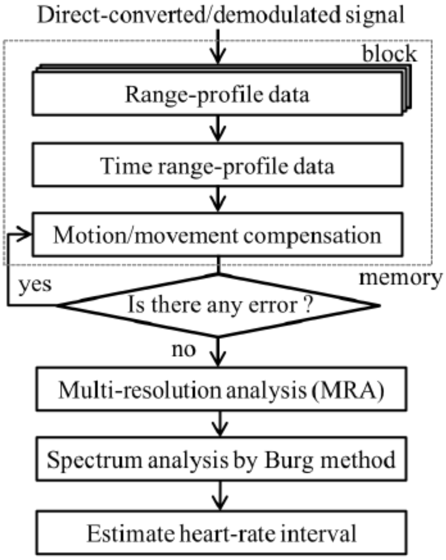


Fig.1 Block diagram of the heart rate monitoring scheme

3. Measurement result

A. Measurement set-up

The measurement was conducted using a 79GHz UWB sensor with 3GHz bandwidth, 0dBm transmitted power and 30° antenna beam-width (Texas Instruments IWR1443 radar module). The sensor offers high range-resolution and anti-multipath fading capability as compared with 24GHz and 76GHz sensor. The sensor is based on a FCM (fast-chirp modulation) architecture where it transmits a series of 1000 FCM waveforms per a frame time, while the echo signals received from some object are then mixed with the transmitted signal to produce beat signal which will give the distance and Doppler of the object. The resulting beat signal, called IF signal, is transformed into time-domain range-profile data using a FFT demodulator. A photoplethysmography (PPG) sensor for continuous monitoring beat-to-beat pulsation is attached to a finger of each subject and the measured HR is used as a reference.

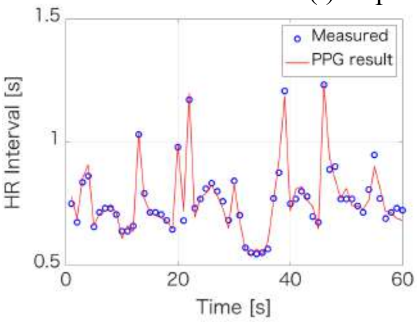
B. Measurement result

The measurement was conducted for three scenarios as shown in Fig.2: (a) two subjects remained seated in each chair without backrest as usual, therefore some body movements were seen, (b) subject was typing on PC keyboard involving body movement, and (c) subject was sitting a few seconds, and afterwards walking slowly toward the sensor antenna. The sensor antenna was directed towards subjects. The measurement was conducted for three graduate-student (subjects) under a protocol approved by the University of Kitakyushu and the informed consent was obtained for all subjects.

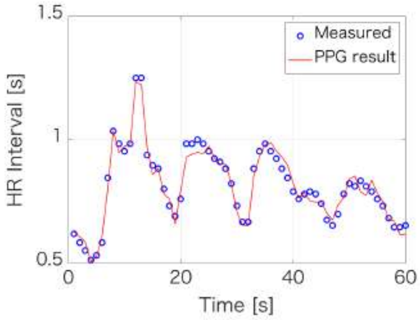
The estimated HR intervals for scenario 1 to 3 are shown in Fig.2(a)-(c), respectively, where each PPG result is also superimposed. Fig.2(a) presents the HR results measured simultaneously for two subjects at 1m and 1.1m away from the sensor respectively. It is seen that their HR intervals are in good agreement with the PPG as a reference. Fig.2(b) shows the HR interval of subject typing on

PC keyboard. The result indicates that the HR interval also falls in line with the PPG.

(i) Experiment environment 1



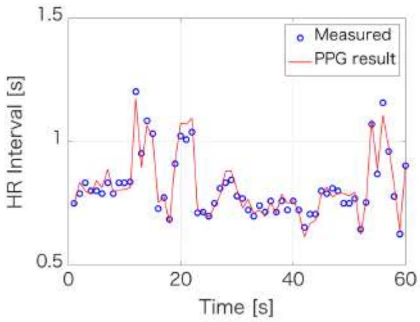
(ii) Result 1 (Subject A)



(iii) Result 1 (Subject B)

(a) Scenario 1 (two subjects seated)

(i) Experiment environment 2

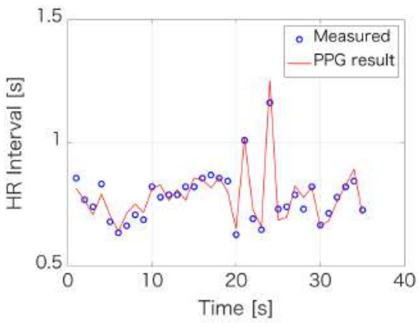


(ii) Result 2

(b) Scenario 2(typing on PC keyboard)

(i) Experiment environment 3 (sitting)

(ii) Experiment environment 3 (walking)

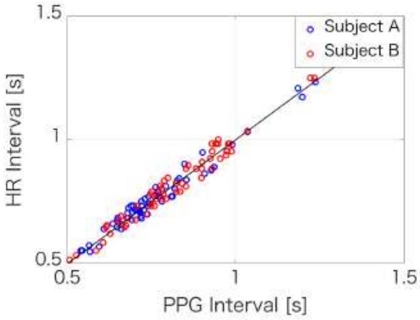


(iii) Result 3

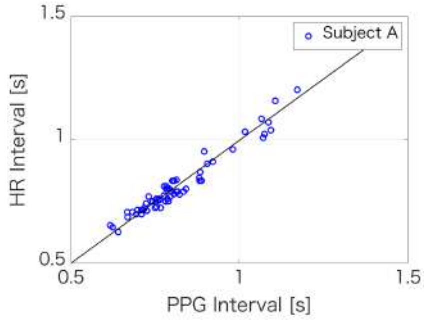
(c) Scenario 3 (start walking from a sitting position)

Fig.2 Measurement scenarios and results of HR intervals

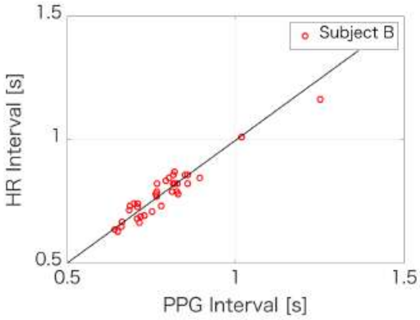
Next, Fig.2(c) shows the HR of a walking subject. It is seen that the movement was compensated successfully in the block by block operation and the result approximately matches the PPG. It may be interesting to show the scattered diagram of the HR interval which are estimated from our suggested sensor and PPG data. Fig.3 shows the scattered diagram of HR intervals derived from our suggested sensor and PPG for the three scenarios. It is seen from Fig.3 that the correlation coefficient is observed to be 0.96～0.98 and our suggested monitoring scheme is found to be effective for moving person and multiple persons.



(a) Scenario 1



(b) Scenario 2



(c) Scenario 3

Fig.3 Scatter diagram of HR intervals

4. Conclusions

This paper has presented a 79 GHz UWB sensor monitoring the instantaneous heart-rate of moving persons. The sensor uses three processes for instantaneous HR monitoring: block-based motion/movement compensation of moving persons, multi-resolution analysis and Burg method for instantaneous HR analysis. The first process normalizes and/or compensates for some motion/movement where the consecutive radar range-profile is stored at the data size of a block and the motion/movement within each block is normalized as stationary. The second one uses a MRA in order to remove most of the breathing signal from the received vital-sign signal (HR and breathing). The third one estimates the instantaneous HR using Burg method. The measurements for three scenarios including multiple persons and moving person were conducted. As a result, it has shown that our suggested sensor can estimate the instantaneous heart-rate accurately.

We envision that the sensor can be applied to various practical situations, such as home health-care, medical care and driver monitoring system.