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A novel method of micro-Doppler parameter extraction for human monitoring terahertz radar network

Kun Tian, Jin Li*, Xiaobo Yang

School of Electronic Engineering, University of Electronic Science and Technology of China, Chengdu, Sichuan 611731, China

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ABSTRACT

Human target characteristic parameter extraction is an important approach of behavior monitoring. The extraction of the characteristic can be applied in various backgrounds, such as sanatorium and hospital. Therefore, this technology is widely studied. Towards extracting physiological characteristic parameters and motion characteristic features of human target, a novel human parameter extraction algorithm is proposed in this paper which has high detection accuracy. The high accuracy detection is achieved by combining the time-frequency analysis and image processing algorithm. Besides that, the utilization of short wavelength and evident micro-motion features inherent with terahertz radar also contributes the improvement of detection accuracy. Simulations test the effectiveness of proposed the algorithm, and illustrate its performance of high extraction precision and insensitivity to noise. For comparison, the simulations are also performed in X-band radar. Via the thorough simulations, we can clearly find the advantage of our proposed algorithm in human target characteristic parameter extraction.

1. Introduction

Physiological and motion characteristic parameters are important vital signals. Physiological signals include the features caused by breath and heartbeat. The stride frequency and stride are important motion parameters. The precise extraction [1–2] of the human target characteristic parameters has wide applications such as health caring in sanatorium and hospital, security checking, safety protection and battle reconnaissance field. We can use multiple radars to build a network for monitoring of human target. An example of this type of radar networks is presented in Fig. 1.

Diverse technologies have been applied in vital signal detections. Ultrasonic wave or X radiographic inspection [3] are one of the major technologies. However, the measurement precision is low and coverage is small. Terahertz radar [4] is another valid tool which can satisfy the requirements on detection range and measurement precision [5,6]. Human target has radial motion corresponding to radar, and meanwhile, the cardiopulmonary and joints also have micro-motion, which may regulate the radar echo, namely the micro-Doppler [7] phenomenon. Generally, the radar working at the higher frequency is able to image micro-Doppler feature more clearly and achieve more accurate extraction [8]. Consequently, human characteristic parameter extraction can be of high precision in terahertz frequency band.

In 2002, J. L. Geisheimer and W. S. Marshall [9,10] working in Sensors and Electromagnetic Applications Laboratory in Georgia Institute of Technology used a full coherent X-band radar system to obtain the data induced by a moving body. This work can used in the gait analysis. In 2004, the group led by V. C. Chen [7,8,11,12] in American Naval Research Laboratory researched the phenomenon of micro-Doppler produced by the vibration of arms and legs when human walk. They used X-band radar system to detect human movement and extracted its micro-Doppler signature by time-frequency analysis. In 2007, T. Thayaparan, S. Abrol and E. Riseborough [13,14] in Defense R&D Canada measured human walk by radar system and used joint wavelet and time-frequency method to extract the micro-Doppler signature of human body. The parameters of human movement are successfully obtained. At the same time, C. P. Lai, Q. Ruan and R. M. Narayanan [15] in Pennsylvania State University used Hilbert-Huang Transform (HHT) to distinguish micro-Doppler signature from the noise. This method could be helpful in movement pattern recognition compared with traditional time-frequency methods.

In this paper, we use terahertz radar to constitute a monitoring radar network. The physiological characteristic model of breath and heartbeat and the joint micro-motion characteristic model [16] are established by considering the micro-motion of human target in terahertz frequency band. The time-frequency feature of the target is extracted through the image processing. Besides that, micro-motion characteristic parameter of human target is also obtained.

* Corresponding author.
E-mail address: flavicidin@vip.163.com (J. Li).

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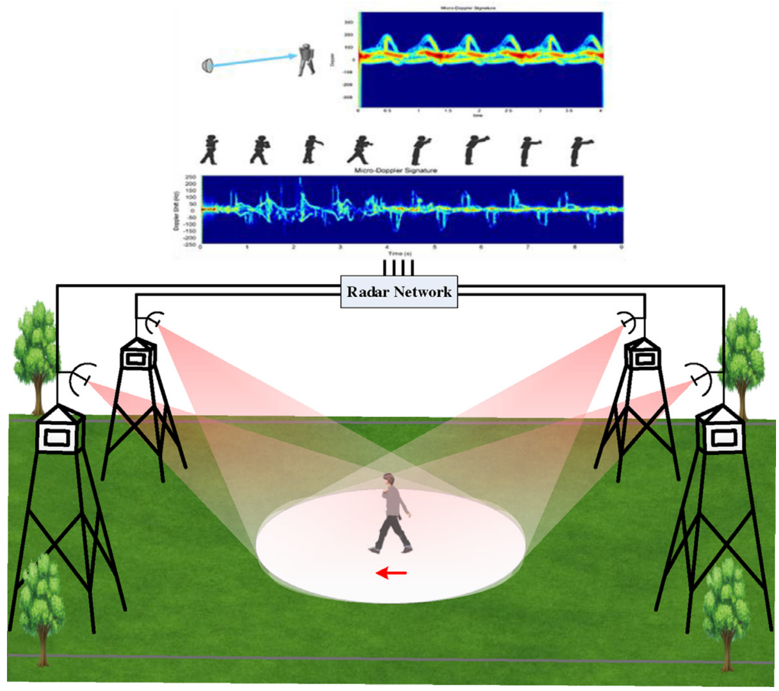

Fig. 1. The scene of human monitoring radar network.

According to the simulation results, this algorithm has high parameter extraction precision and good anti-noise performance.

2. Modeling of target echo and time-frequency distribution

Suppose that human target takes radial motion along the radar, and the instantaneous distance is $R_{b0}(t)$. The micro-motion caused by the lung during breathing can be approximated with sine function [17], namely the relation between the chest fluctuation caused by the lung and human center is:

$$R_{b1}(t) = r_{b1}\sin(2\pi f_{b1}t), \tag{1}$$

where r_{b1} is the fluctuation of lung and f_{b1} is the respiratory rate.

The heartbeat is approximated with the impulse function of sharp pulse:

$$R_{b2}(t) = r_{b2}\delta(f_{b2}t - \tau) \tag{2}$$

where r_{b2} is the amplitude of heartbeat; f_{b2} is the heartbeat frequency; τ is the heartbeat deviation, and $\delta(t)$ is:

$$\delta(t) = \frac{1}{1-2a}\left(\left|t - \frac{1}{2} - \lfloor t\rfloor\right| - a + \left|\left|t - \frac{1}{2} - \lfloor t\rfloor\right| - a\right|\right) \tag{3}$$

where $a = 1/2 - rf_{b2}$, r is the heartbeat range.

The above two kinds of micro-motion shall be brought in the human echo wave model, so the instantaneous distance between human target and radar is:

$$R_b(t) = R_{b0}(t) + r_{b1}\sin(2\pi f_{b1}t) + r_{b2}\delta(f_{b2}t - \tau) \tag{4}$$

The human motion characteristic model [18] is usually approximated with the sine model and modified function. In this paper, the parameter extraction method is studied. For analysis simplicity, a sine function is taken to approximate the joint motion. Since the joint distance is relatively huge, different joints can be considered as independent scattering center. Similarly, suppose human target conducts radial motion along the radar, the instantaneous distance is $R_{m0}(t)$, and the joint model is:

$$R_{mk}(t) = R_{m0}(t) + r_{mk}\sin(2\pi f_{mk}t + \varphi_{mk}), k = 1, 2, 3\ldots \tag{5}$$

where r_{mk}, f_{mk}, φ_{mk} stand for the swing amplitude, frequency and initial phase of the kth joint respectively.

Generally, if human body moves coordinately, it can be considered that the joint swing frequency is the same. The simulation of human target physiologic characteristic and motion characteristic model simulation is shown in Fig. 2.

As for the single frequency signal, the echo of the physiological characteristic model is:

$$S_b(t) = \sigma_b \exp\left[-\frac{j4\pi f_0}{c}(R_{b0}(t) + r_{b1}\sin(2\pi f_{b1}t) + r_{b2}\delta(f_{b2}t - \tau))\right] \tag{6}$$

where σ_b is the scattering coefficient, f_0 is the radar frequency, and c is the speed of light.

The echo of the motion characteristic model is:

$$S_m(t) = \sum_{k=0}^{N}\sigma_k \exp\left[-\frac{j4\pi f_0}{c}R_{mk}(t)\right] \tag{7}$$

where N is the number of scattering centers, σ_k is the scattering coefficient of the kth joint, f_0 is the frequency of radar, c is the speed of light. When $k = 0$, it is the echo signal of human body.

3. Human body parameter extraction algorithm based on micro-Doppler

The frequency modulation of radar echo caused by the micro-motion of objects is called the micro-Doppler effect. The motion characteristics of object, such as the amplitude, period, speed, etc. are included in such modulation. The instantaneous frequency of radar echo can be represented as:

$$f_{Doppler} = \frac{d}{dt}\left(-\frac{2R(t)}{\lambda}\right) = -\frac{2\dot{R}(t)}{\lambda} \tag{8}$$

where λ is the wavelength of radar, and $R(t)$ is the instantaneous distance between the target and radar.

The extraction of micro-Doppler frequency can achieve the characteristic of target speed changes, as well as the frequency and amplitude. It can be seen from Eq. (8) that frequency resolution is

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