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Impact of Random Body Movements on 60-GHz Doppler Radar for Real-Time Monitoring of Vital Signs

Ting Zhang
UPMC Univ Paris 06, UR2,
L2E
Sorbonne Universités,
F-75005
Paris, France
ting.zhang@upmc.fr

Guido Valerio
UPMC Univ Paris 06, UR2,
L2E
Sorbonne Universités,
F-75005
Paris, France
guido.valerio@upmc.fr

Julien Sarrazin
UPMC Univ Paris 06, UR2,
L2E
Sorbonne Universités,
F-75005
Paris, France
julien.sarrazin@upmc.fr

Dan Istrate
CNRS, UMR 7338,
Biomechanics and
Bioengineering (BMBI)
Université de Technologie de
Compiègne
Compiègne, France
mircea-dan.istrate@utc.fr

ABSTRACT

We show the impact of random body movements when contactless detection of vital signs is performed with a 60-GHz Doppler radar. Since the monitoring should reveal dangerous events in real-time home-care scenarios, constraints is present on the durations of the observation windows. Body movements of different duration are here considered in connection with such a short-time signal observation.

Keywords

Non-contact vital-sign monitoring, Doppler radar, Optimization algorithm, 60 GHz

1. INTRODUCTION

Population aging is a major factor motivating the development of home-care services to reduce costs and improve the quality of life of patients [1], and the need for more reliable technical instrumentation for medical monitoring and diagnosis. Specifically, real-time estimation of vital signs is required to detect dangers and act accordingly.

In this framework, the use of continuous wave Doppler radar for non-contact monitoring of vital signs, namely heartbeat (HB) and respiration rates (RR), is a recently established technique. It is based on the detection of the Doppler frequency shift of a wireless signal scattered by the patient. While several applications are envisaged around 5 GHz [2],

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working at millimeter waves (i.e., around 60 GHz) provide a more robust estimation of the weaker HB signal [3].

On the other hand, current solutions do not specifically aim at reducing the duration of the observation window. When this duration becomes small (of the order of a few seconds compared with several tens of seconds often used in the existing literature), the estimation is more difficult and dependent on random body movements (RBM), which are not effectively averaged as in the long-duration window.

In this work, RBM of different durations are added to the usual chest movements, and the impact of these movements on the estimation of the vital signs of interest is studied with reference to reasonable accuracies required in this kind of applications.

2. FORMULATION OF THE PROBLEM

In CW Doppler radar presented here, a sinusoidal signal (here with frequency $f = 60$ GHz) is transmitted towards a person's chest, at an average distance d_0 (see Fig. 1). The reflected signal is phase-modulated by the signal $x(t) + x_d(t) = x_h(t) + x_r(t) + x_d(t)$, the sum of the heartbeat $x_h(t)$, the breathing $x_r(t)$, and a possible RBM $x_d(t)$. Each vital signal is a simple sinusoid: $x_h(t) = m_h \sin(2\pi f_h t + \phi_h)$, and $x_r(t) = m_r \sin(2\pi f_r t + \phi_r)$, whose amplitudes (m_r and m_h), frequencies (f_r and f_h), and initial phases (ϕ_r and ϕ_h) are unknown. The RBM is here a random signal with a prescribed maximum amplitude and time duration. The received signal is demodulated by an IQ quadrature receiver. The two baseband signals B_I and B_Q are of the form

$$B_{I/Q}(t) = \frac{\cos \left[\frac{4\pi x(t)}{\lambda} + \frac{4\pi x_d(t)}{\lambda} + \frac{4\pi d_0}{\lambda} \right]}{\sin \left[\frac{4\pi x(t)}{\lambda} + \frac{4\pi x_d(t)}{\lambda} + \frac{4\pi d_0}{\lambda} \right]} + n_{I/Q}(t), \quad (1)$$

λ being the wavelength at f . $n_{I/Q}(t)$ represent the Gaussian noise in the system. A complex demodulation is performed on the received signals, where the final baseband signal is $B_C(t) = B_I(t) + jB_Q(t)$.

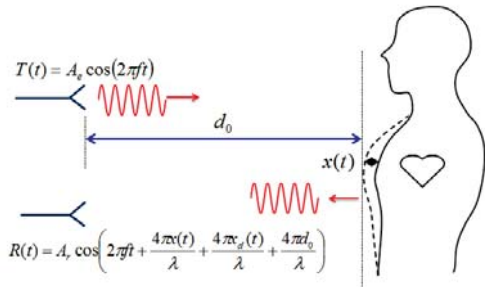


Figure 1: Representation of CW Doppler radar system for vital signs monitoring.

To achieve an accurate frequency estimation, we solve an optimization problem, consisting in finding all unknown parameter in the direct signal model $B_C(t)$ by minimizing the discrepancy between the measured signal and the estimated one. A particle swarm optimization (PSO), is executed in the time domain, where the signal length and the calculation time is fixed to 5 seconds for real-time capabilities.

3. NUMERICAL RESULTS

In this section we show the cumulative distribution functions (CDF) relative to 1000 estimation of the respiration and heartbeat frequencies f_r and f_h . For each simulation, amplitudes and frequencies take random values with Gaussian distribution, within realistic ranges, while the phases take uniformly distributed random values. A good estimation of phases grants more robust results for the frequencies, as highlighted by the authors in [4]. The SNR is set here to 20 dB, a typical value in practical systems proposed in the literature. Different RBM are considered, by varying both their maximum amplitudes and time durations.

Figs. 2 shows the CDF in the presence of a RBM of maximum amplitude of 1 cm ((a) and (b)) and 2 cm ((c) and (d)), having different durations. Three cases have been considered: a short movement (1 s), an average movement (2 s), and a long movement (5 s), where the short and long definitions should be meant with respect to the total observation duration (5 s). The presence of a RBM does not prevent a reasonably accurate estimation of the frequencies, as long as its duration is not comparable with the observation duration.

In the most critical scenario, the Doppler radar could wait until the patient is again at rest and proceed with a new estimation. Data processing based on the patient medical history should be employed in this limited case in order to conclude about its medical conditions and decide how to proceed (e.g., temporarily using longer observation windows).

4. CONCLUSIONS

We have discussed the impact of RBMs on the contactless monitoring of vital signs through Doppler radar at 60 GHz. Real-time applications are specifically targeted, where the observation window is very short and potentially sensitive to irregular movements. However, a good robustness of the proposed estimation technique has been assessed. Data processing algorithms should be employed in the worst-case scenarios where the detection loses precision due to strong and long-lasting movements.

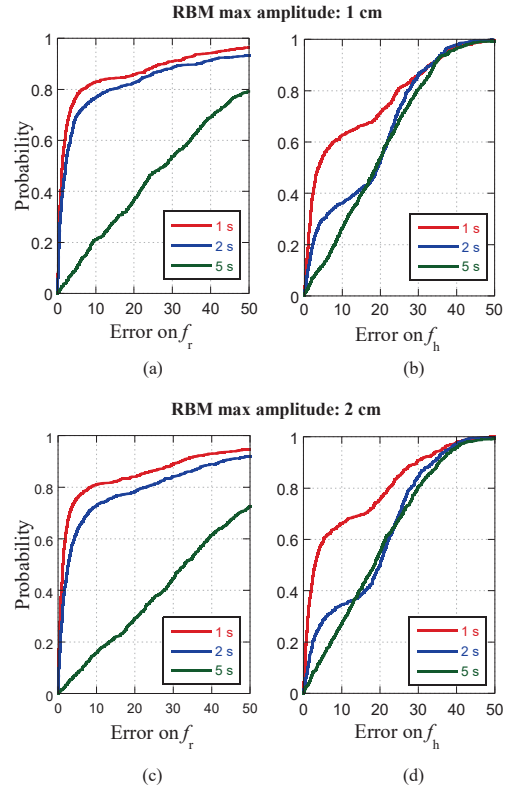


Figure 2: CDF obtained from the PSO optimization results, related to the frequencies f_h and f_r , in the presence of a RBM. (a) f_r with a RBM of 1 cm; (b) f_h with a RBM of 1 cm; (c) f_r with a RBM of 2 cm; (d) f_h with a RBM of 2 cm.

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