Optimisation Algorithm for 60-GHz Non-Contact Human Vital-Sign-Monitoring

Ting Zhang, Julien Sarrazin, Guido Valerio, Dan Istrate

Optimization Algorithm for 60-GHz Non-Contact Human-Vital-Sign Monitoring

Ting Zhang[1,2], Julien Sarrazin, Guido Valerio

Sorbonne Universités, UPMC Univ Paris 06[1]
UR2, L2E, F–75005, Paris, France
ting.zhang, guido.valerio, julien.sarrazin@upmc.fr

Dan Istrate
Biomechanics and Bioengineering (BMBI)[2]
CNRS UMR 7338, Sorbonne Universités
Université de Technologie de Compiègne
F–60200, Compiègne, France
mircea-dan.istrate@utc.fr

I. Theory

Doppler radar has been widely applied in the medical domain in the recent years [1]. This non-contact technique is very popular and interesting since no sensor needs to be placed on the body. In a Continuous Wave (CW) Doppler detection system for vital signals, a sinusoidal signal $T(t) = A_e\cos(2\pi f t)$ at carrier frequency f is transmitted towards a human body, and then reflected by the chest which moves according to physiological movements. These movements can be detected and evaluated by measuring the frequency shift of the reflected signal according to the well known Doppler-effect law. The reflected signal is demodulated by an IQ quadrature receiver to avoid detection issues due to lack of reception during certain intervals of time [2]. The complex baseband signal is modulated by tiny physiological movements $x(t)$ of the human body. Here, two principal physiological movements (heartbeating and respiration) are represented by a single tone sinusoidal signal, respectively, $x(t) = x_r(t)+x_h(t) = m_r\sin(\omega_r t + \phi_r) + m_h\sin(\omega_h t + \phi_h)$, where m_r and m_h describe the amplitudes of respiration and heartbeat movement, respectively, ω_r and ω_h represent the movement frequencies, ϕ_r and ϕ_h are the initial phases.

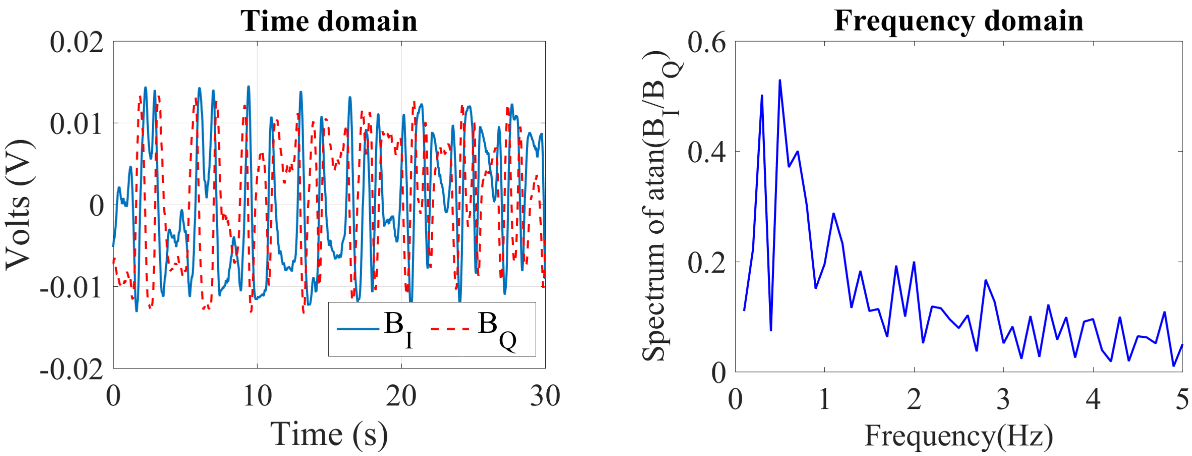
The exponential term of the reflected baseband signal can be expanded using Fourier series [1],

$$B(t) = \sum_{n=-\infty}^{+\infty}\sum_{k=-\infty}^{+\infty} J_n\left(\frac{4\pi m_h}{\lambda}\right) J_k\left(\frac{4\pi m_r}{\lambda}\right)\exp\left[j\left(n\omega_h t + k\omega_r t\right)\right]\exp\left[j\left(n\phi_h + k\phi_r\right)\right]\exp\left(j\psi\right), \qquad (1)$$

where J_n is the n-th order Bessel function of the first kind. $\lambda = c/f = 5$ mm is the working wavelength of the CW radar at 60 GHz. ψ is defined as the total residual phase of the system. This complex baseband signal in the frequency domain is represented by a sum of harmonic components, which causes not only creation of harmonic frequencies for each physiological movement signal itself, but also generates intermodulated frequencies between the two movements [3]. Due to the nonlinear nature of the Doppler phase modulation, undesired intermodulations of harmonic components are present [1]. A direct peak detection from the spectral analysis is therefore no more reliable, since ambiguities can arise when interpreting the different peak locations. This communication presents an approach to estimate body movements related to vital activities by means of a 60 GHz Doppler radar, using robust optimization algorithms.

II. Experimental measurement

Fig. 1 shows the measured time–domain and frequency–domain breathing signal, superimposed with the heartbeat of a human body, at 1 m distance in front of one emitting and one receiving antenna. The emitting power is about -2.5 dBm and the pyramidal horn antenna gain is 24 dBi. The recording time is 30 seconds. To obtain the spectrum shown in Fig. 1 (b), the acquisition time is taken for 10 seconds, and the sampling frequency is $F_s = 100$ Hz. We can deduce that the first peak in the spectrum in Fig. 1 (b) corresponds to the fundamental of respiration. However, the heartbeat fundamental is not visible, hence the direct spectral analysis does not work at all, as the spectrum depends on several unknown parameters, f_r, f_h, m_r, m_h, ϕ_r, and ϕ_h, which persuades us to find a better spectrum–estimation algorithm.



(a) (b)

Figure 1. Representation of measured signal in the time domain and frequency domain.

Table I
OPTIMIZATION RESULTS

		f_r (bpm)	f_h (bpm)	m_r (mm)	m_h (mm)		f_r (bpm)	f_h (bpm)	m_r (mm)	m_h (mm)
Front	0-5 s	15.6	80	1.1	0.05	5-10 s	16.2	49.2	0.81	0.25
	10-15 s	16.8	52.2	1.3	0.22	15-20 s	15.6	69.6	1.9	0.13
	20-25 s	17.4	102.6	1.8	0.05	25-30 s	18	48	1.6	0.12
Back	0-5 s	12	90	1.0	0.07	5-10 s	22.8	62.4	0.13	0.14
	10-15 s	21	76.2	0.16	0.05	15-20 s	22.8	49.2	0.37	0.05
	20-25 s	24	48	0.77	0.22	25-30 s	27.6	48	0.53	0.26
No breath	0-5 s	12	70.2	0.19	0.08	5-10 s	X	82.8	0	0.05

To estimate body movements using an optimization algorithm, we propose the Particle Swarm Optimization (PSO). In our case, the PSO is used to optimize a defined cost function, which describes the discrepancy between the measured baseband signal spectrum and the one calculated by a direct signal model, where the baseband signal is defined as the same form as (1). The optimization procedure is executed on the measured signal with a recording time of every five seconds. The optimization results are given in Table I. Different scenarios are measured, including the detection from the front of the body, from the back of the body, and also an emergency situation, where the person has no breath. Note that for all these scenarios, we succeeded to get accurate respiration and heartbeating rates. Moreover, the amplitudes of induced displacements are also estimated and could be used as a complementary information for vital sign monitoring. The calculated time of this optimization procedure is limited to 5 s, which is reasonable for real–time monitoring. The optimization algorithm, compared to the direct spectrum analysis, is proved to be more robust to estimate simultaneously two physiological movements.

REFERENCES

[1] C. Li, M. Lubecke, O. Boric-Lubecke, and J. Lin, “A Review on Recent Advances in Doppler Radar Sensors for Noncontact Healthcare Monitoring”, *IEEE Trans. Microw. Theory Tech.*, vol. 61, pp. 2046-2060, May 2013.

[2] AD. Droitcour, O. Boric-Lubecke, VM. Lubecke, JS. Lin, and GTA. Kovacs, “Range Correlation and I/Q Performance Benefits in Single-chip Silicon Doppler Radars for Noncontact Cardiopulmonary Monitoring”, *IEEE Trans. Microw. Theory Tech.*, vol. 52, pp. 838–848, Mar 2004.

[3] T. Zhang, J. Sarrazin, G. Valerio, and D. Istrate, “Non-Contact Estimation at 60 GHz for Human Vital Signs Monitoring Using a Robust Optimization Algorithm”, *2016 IEEE International Symposium on Antennas and Propagation and North American Radio Science Meeting*, Fajardo, Puerto Rico, 26 June - 1 July, 2016.