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Evaluation of Doppler Signal Analysis Algorithms for Heart Rate Estimation

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Abstract

This paper presents an analytical evaluation of the post processing algorithms of a radar signal coming from a human subject. The purpose is to estimate the heart rate and its variability from the analysis of the time domain variation of the phase of the reflected signal.

1. Introduction

Breathing and heartbeat are vital parameters that represent an important reference for assessing a person's health. Their monitoring is part of normal clinical practice as indicators of the patient's pathology or even predictions of future health problems. In [1] it has been shown, for example, that there is a strong correlation between nocturnal apnea and future cardiovascular complications.
In recent years, interest in the continuous monitoring of these two parameters outside hospitals has increased in particular for active and healthy ageing. The possibility of continuous, non-invasive and simple monitoring would lead to a reduction in hospital costs and a greater self awareness of the patient's health status.
The use of electromagnetic (EM)sensors for remote respiration monitoring has proved to be very effective [2-3]. This type of sensor is very promising for domestic use as it respects the subject's privacy, it has an excellent ability to penetrate the fabrics and therefore it can be used even when the subjects are dressed.
The sensor is based on the detection of the subject's chest movements during breathing. The sensor is a radar that send an EM signal toward the patient's chest that reflect back the signal modulated by this movement. The analysis of the modulated signal allows the extraction of respiratory frequency information.
The same sensor could also be used to extract information about heart rate(HR) and its variability (HRV). In fact, the contraction of the hearth transmits on the chest surface a slight oscillation. This imperceptible movement can be detected by a high-frequency electromagnetic sensor. Appropriate design of the sensor in terms of frequency and power, as well as post processing of the signal, would allow both parameters to be obtained with the same sensor.
The use of a Doppler radar is very well studied in literature. The main problem that needs to be addressed, in order to obtain cardiac information, is the very low signal-to-noise ratio (SNR) that occurs in the signal reflected by the monitored body. Several algorithms have been proposed, also recently [4] but each of them suffers from different limitations. Depending on the type of subject or environment surrounding the monitored subject, the different systems are more or less accurate.
In this paper we present a preliminary theoretical analysis of different approaches that can be used to estimate the heart rate using a Doppler Radar. The algorithms chosen are all very simple to implement and therefore all respond to the need to limit the computational aspect and therefore cost and memory of a system suitable for home monitoring.

2. Formulation of the problem

The Doppler Radar realized in [3] allows to determine the complex S21 parameter between the transmitting and the receiving antenna. The received signal is modulated both in amplitude and phase by chest movement. From its demodulation it is possible to derive the respiratory and heart rate.
In this work we focus on the phase of the S21 and in particular we work with an analytical signal that simulates the phase of the signal reflected by a subject monitored through Doppler radar. It has the same periodical characteristics. The signal used is as follows:

$$s(t) = \cos(\omega_B t) + A_H \frac{g(t)}{\max(g(t))} + A_N rand(t) \quad (1).$$

where the respiration is simulated as a sinusoid of angular frequency ω_B, while the heart signal is simulated as a series of pulses g(t)=$e^{-\tau_r t} - e^{\tau_d t}$, with amplitude A_H. A numerical noise created with a random series of A_N amplitude samples is added. Heart signal and noise amplitudes are modified to analyze different types of SNR.
The signal is subjected to different post-processing algorithms. In particular:
1) Signal filtering and subsequent frequency analysis: Fourier transform
2) Signal filtering and subsequent analysis over time: peak detection
3) Correlation with various signals consisting of Gaussian pulses at different intervals from 30 to 200 pulses per minute.

3. Results

Tables I and II show the results obtained with the abovementioned algorithms as the amplitude of the AH cardiac signal varies, for two different heart rate values: 80 beat per minute (bpm) and 120 bpm. The parameters used are: $\omega_B=2\pi\cdot 0,3$ corresponding to a breathing rate of 18 breaths per minute, $\tau_r=15$, $\tau_d=60$, while the A_N noise amplitude is 0,15.

Table I Results for a cardiac signal at 80 bpm

Peak detection (bpm)	**Fourier transfom (bpm)**	**Correlation HR (bpm)**	A_H
80	80	80	0,5
80	80	80	0,15
80	80	**77**	0,05
73	80	**76**	0,01

Table II Results for a cardiac signal at 120 bpm

Peak detection (bpm)	**Fourier transform (bpm)**	**Correlation HR (bpm)**	A_H
115	120	120	0,5
111	120	120	0,15
109	120	120	0,05
91	120	120	0,01

In the first two algorithms the signal is filtered a first time to eliminate background noise and to obtain the respiratory rate, and a second time to eliminate the respiratory signal.

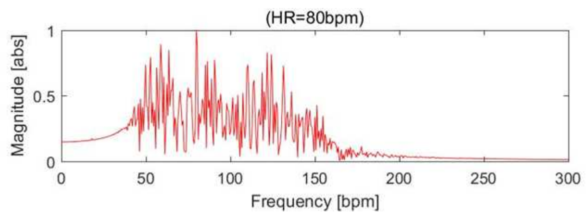

Figure 1. Amplitude of the Fourier transform of the filtered signal with an amplitude cardiac signal A_H=0.01.

As the results show, algorithms do not always give good results. Frequency analysis would seem to always give the correct response, but there are uncertainties in the frequency estimation. In fact, figure 1 shows the amplitude of the signal Fourier transformer amplitude in the case of HR=80bpm and A_H=0.01. As we can see in the figure, the peak frequency at 80 bpm is not so high compared to the others.
This is a particularly difficult case to estimate because the other two algorithms give different results and therefore it is not possible to decide with certainty what the heart rate is.

5. Conclusions

A preliminary analysis of algorithms for the estimation of heart rate from signals obtained with Doppler radar was presented. The study is purely analytical, and therefore the algorithms themselves will have to be subsequently evaluated on real signals. From this initial approach, however, it is immediately evident that a good algorithm for some situations may not always be as good for others. The application of these algorithms to real signals will give answers to the possibility to estimate the heart rate on the basis of the results obtained with all algorithms and not only with one of them, and therefore estimating as true the most frequent result.

7. References

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