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POF-based specklegram sensor post processing comparative: methods for extracting breath and heart rate

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ABSTRACT

Continuous patient monitoring has been evidenced as very beneficious for reducing degeneration[1]. Due to this, a POF specklegram sensor has been developed based on a previous work [2]. This work presents a comparative between analysis methods of the specklegram signal for achieving a precise and robust non-contact monitor system.

Two different techniques have been used: one based on the Fast Fourier Transform (FFT) and the other based on the Hilbert Transform (HT). Each technique has been employed with two different methods, for heart rate and breath rhythm. The different algorithms are tested on 10 volunteers of different ages and sex.

Keywords: speckle, monitoring, vital sings, optics, fiber optic, noninvasive

1. INTRODUCTION

A system based on speckle effect fiber sensors has been proved as a feasible, non-contact and low cost implementation for measuring heart rate[3]. This work compares FFT and HT techniques to obtain heart and, additionally, breath rates. The achieved results demonstrate that different processing techniques can improve the capabilities of this kind of devices presented in previous works.

1.1 Speckle effect in multimode fibers

The speckle effect in an optical fiber is induced by propagation of different modes with different phase velocities in a multimode fiber. These propagation modes are generated by a coherent light and each of them corresponds with a different optical path which changes the phase delay[4].

If a perturbation is applied to the optical fiber, the speckle pattern is affected and varies. This pattern is acquired as a temporal sequence with a CCD camera positioned at the end of the fiber. As demonstrated in [3], a differential processing method can be applied to calculate the relation between the speckle pattern variation and the external variation measured (ΔI_D) for every I'th pixel in successive frames (i):

$$\Delta I_D\{i\} = \frac{1}{K * MN} \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} \left| I_{nm}^{i-1} - I_{nm}^{i} \right| \qquad (1)$$

Where K is the full scale value of the speckle pattern color map and $I_{n,m}$ corresponds to the pixel of the n,m position (considering MxN pixels) of the I'th speckle pattern. The non-contact monitoring problem is now reduced to analyze the frequency of a differential speckle signal, which is obtained at sampling frequency of 50 Hz.

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2. MATERIALS AND METHODS

2.1 Reference methods

A conventional pulse oximeter placed in the thumb determines reference values of heart rate measured in beats per minute (bpm). For breath rate, the pattern is determined by the change of temperature on an NTC thermistor positioned in front of the noise when the patient breathes, measured in breaths per minute.

2.2 Inline Specklegram Processing

The differential specklegram signal is preprocessed before the algorithm is applied. The main objective of this is to reduce noise and high frequency components of the signal. This preprocessing consist of a downsampling and a mean filter. Two different methods have been compared, HT and FFT, in two contexts, one for heart beat and the other for breath rate. A sliding window simulates real time acquisition, with different sizes for heart rate and breath rate detection. Each scenario has his own downsampling factor and mean window size. Once the signal differential speckle is preprocessed, the two methods are applied:

FFT method: the first derivative is applied to the preprocessed differential speckle signal, then a FFT is used to detect the maximum frequency peak. This maximum peak is the breath or heart rate in their corresponding context.

HT method: the Hilbert transform induces a phase shift of pi/2 to every Fourier component of a function. This allows to reconstruct a signal with double amplitude and phase (2), which reduces noise.

$$X = C_{in} + iC_{quad} = Ae^{j\phi} \qquad (2)$$

Where $H(C_{in}) = C_{quad}$. At this point, the phase can be isolated (3) to reduce the noise of signal. Once it has been performed, the FFT is applied to phase of initial signal in order to detect maximum peaks, which are the desired frequencies[5].

$$\phi = \text{atan}\left(\frac{C_{in}}{C_{quad}}\right) \qquad (3)$$

3. RESULTS AND DISCUSSION

As previously explained, two different methods have been compared in two different contexts. The input is the differential speckle signal. In the frequency domain, it can be observed that the speckle signal is composed by two high carriers one related to heart rate and the other to breath rate, the frequency of those carriers corresponds to red dots in fig. 1. The computation time of both methods have been measured in a MATLAB implementation (MATLAB R2018b 64 bits, processor Intel core i5-8500, 8 Gb RAM), resulting in a mean computation time for each time window of 0.41782 ms for HT and 0.26878 ms for FFT.

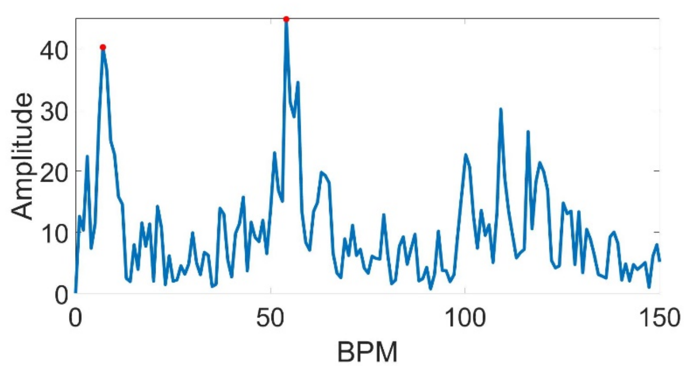

Fig. 1: Differential FFT specklegram signal.

The error is showed as absolute error, obtained by Eq (4).

$$e(t) = |Speckle(t)| - |Control(t)| \qquad (4)$$

3.1 Heart rate

In order to test the accuracy of the two proposed techniques, fig. 2 compares the different obtained hearts rates: the control, FFT analysis and Hilbert analysis signals of the specklegram signal.

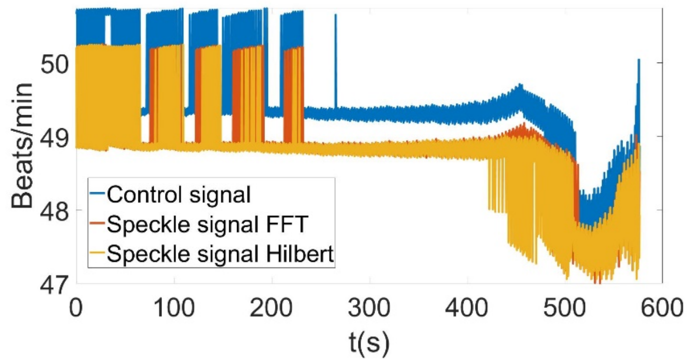

Fig. 2: Control pulse and obtained from processing specklegram signal with FFT and HT.

In order to check the accuracy of the obtained estimation from FFT and HT, fig. 3 shows the comparative of the absolute errors in each technique. The mean absolute error for all patients was 0.9818 bpm for FFT processing and 1.1163 for HT processing. The maximum mean error was 4.8732 BPM for FFT and 6.9028 BPM for HT.

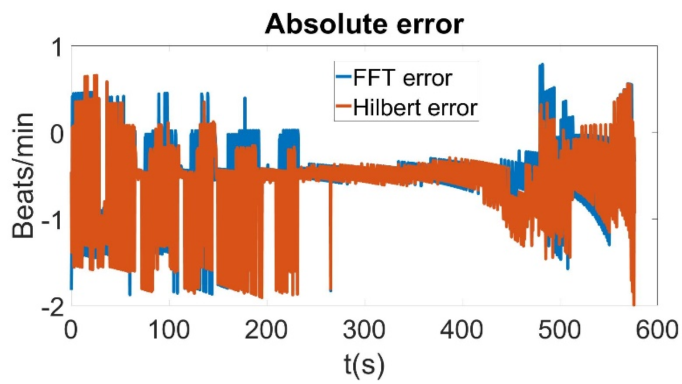

Fig 3: Absolute error of calculated pulse with FFT and HT techniques.

3.2 Breath rate

Fig 4 shows the breath rate obtained from the specklegram signal with the two methods described and the control breath rate.

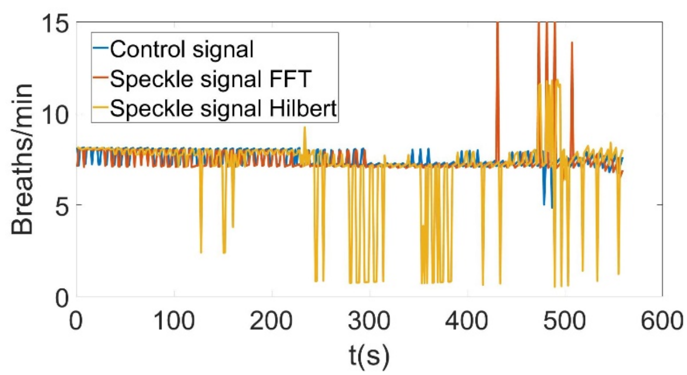

Fig. 4: Breath rate from control and obtained with FFT and HT from specklegram signal.

The absolute error is analyzed in fig. 5 for each time window. The mean absolute error of all patients was 2.71 breaths per minute with the FFT technique and 5.0663 with the HT technique.

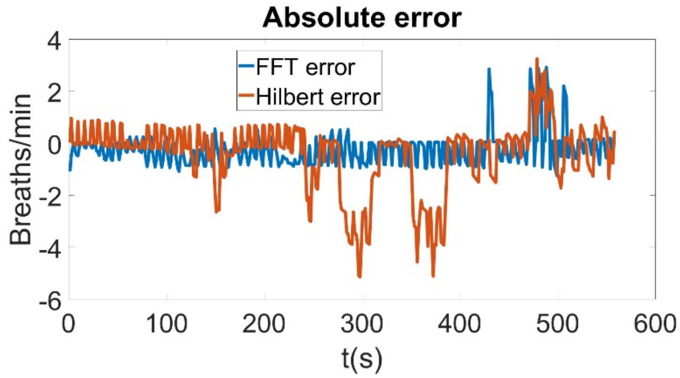

Fig 5: Absolute error of calculated breath rate with FFT and HT techniques.

4. CONCLUSION

A new method for extracting pulse and breath rates from the differential specklegram signal has been compared in this paper with a different solution showing good performance in previous works by other authors. Based on the obtained results, both perform similar but the differential FFT provides a slightly better accuracy and consumes less computation time (about a 25% less).

This methodology is suitable both for heart rate monitoring and for breath monitoring. It has more accuracy for heart rate due to the very low frequency of breath rate signal, in the order of 0.15 Hz.

This allows one single device to provide information of both parameters at the same time.

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