POF-based specklegram sensor for continuous patient monitoring

L. Rodriguez-Cobo[1]*, A. Rodriguez-Cuevas[1], E. Real[1], J.M. Lopez-Higuera[1], M. Lomer[1]

1 Photonics Engineering Group, University of Cantabria, 39005, Santander (Spain)

*Corresponding author: luis.rodriguez@unican.es

Abstract: In this work, different schemes to detect vital signs of bedding patients are proposed and experimentally verified. Employing speckle in multimode polymer optical fibers as sensing element, the fiber is placed under the bed linen to collect the small movements provoked by the patient. This kind of sensor takes advantage of the remarkably high sensitivity exhibited by fiber specklegram sensors. Based on a proper sizing of the employed multimode fiber, it can be placed in different locations trying to favour the detection of heart beating or movement. When the patient does not exhibit any conscious movement (e.g. while he is sleeping) its heart rate can be measured.

1. Introduction

At the present time, 24h-monitoring only occurs in the ICU (Intensive Care Units) even in the most developed countries. Nonetheless several studies have found strong evidences that continuous monitoring methods, as compared to conventional ones, can be more effective to avoid health deterioration of hospital patients, especially those cases related to heart conditions [1, 2]. Cardiac arrest is, in most cases, preceded by an abnormal breathing and heartbeat frequencies and therefore in many cases can be detected on time before it takes place, therefore patients can be transferred from their regular hospital rooms to the more prepared ICU and proceed to a further health evaluation. Eventually an important reduction in average recovering time of hospital patients can be achieved, reducing long-term economic cost as well.

Optical fiber based techniques have grown in importance for the non-contact monitoring field due to their versatility and the possibility of being used into singular environments such as magnetic resonance imaging scans, where placing metal or common electronic components is not an option since it can cause them to heat up and malfunction [3]. Among these techniques, fiber specklegram sensors have emerged as very promising methods to monitor of heartbeat and motion due to its high sensitivity and relative low cost. In this regard one of the first test was made in the University of Virginia in 2004 and it concludes that these types of sensors have the potential to become into a cost effective way of automating long term monitoring of patients[4]. After this test, similar experiments have been carried out in different institutions[5].

In this work, different speckle-based optical fiber sensors are employed to detect and measure the movement and heart rate of patients lying on a bed. Proposed devices are placed without direct contact to the patients and are able to measure those parameters when lying in different positions. The achieved results proved the applicability of these kind of sensors to be employed in real scenarios.

2. Sensor design

Three Polymer Optical Fibers (POF) with core diameters of 50 μm, 240 μm and 980 μm were tested in combination with several different support materials including thin wooden boards, silicone supports, soft plastics, bare fiber, cotton fabric and other textiles. Later, several fiber geometries were tested as well. Based on sensitivity and noise compromise, two sensors were selected: Band sensor and Ring sensor. Both sensors consisted of a semiconductor laser emitting at 638nm wavelength, a CCD camera which produces data at a rate of 30 frames per second, and a plastic fiber optic 200cm long and 240μm diameter core.

In the case of the Band sensor, the POF was set inside two lateral seams of cotton fabric of 7 cm wide and 80 cm long. In the Ring sensor, the POF was rolled creating 10 laps of an average diameter of 6cm and was set inside two cotton fabrics of 10cm of side.

2. Processing scheme

There is a model [6] that determines the relation between the speckle pattern variation and the perturbation to be measured. This model is limited to small perturbations and in order to extract this information, a differential processing method can be applied, being able to obtain the desired perturbation as the sum of the absolute value of the changes in all the signals [7]. Thus, consequently, The first step in every processing method was to compute the differential sequence. The value of each pixel of the frame n-1 is subtracted from the value of the equivalent pixel of the frame n (the next frame) and add them in absolute value. This sequence is then buffered using a 6 seconds window to analyse both movement and heart rate.

2.1 Motion detection

Next step is devoted to analyze the amount of movement detected by the specklegram sensor, to avoid its misunderstanding with the vital signs of the patient. The buffer size is divided in two sections: the recent time window, comprehending the 20% most recent points, and the oldest time window, comprehending the previous 80% (Fig. 1a). Both sections are averaged by the number of points in each section, in order to obtain the mean intensity level of the recent and old status. The ratio among recent and old takes values near 1.0 when the signal is similar, but varies strongly when there is an intense motion. If the ratio deviates more than a stablished threshold, movement detection is triggered.

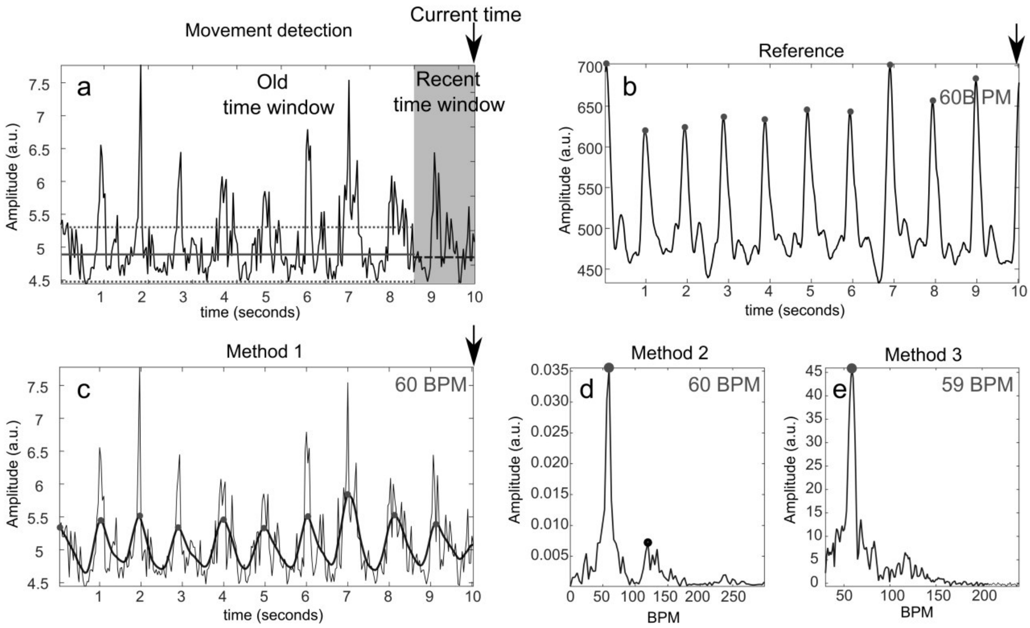

Figure 1 In-line processing of current time (black arrow) applying a 10 seconds window. (a) Original signal and movement detection mean values. Blue line represents the recent time mean value. Red line represents old time mean value. Dashed red is the 10% trigger threshold. (b) Pulse oximeter reference. (c) Method 1: original time signal (black) and smoothed (blue). (d) Method 2: Fourier Transform of the first derivative. (e) Method 3: convlution by sinusoid. For every method (b to e), the obtained instantaneous heart rate is displayed.

2.2 Heart rate measurement

2.2.1 Method 1: Filtered signal and peak detection

This is the most straightforward approach (Fig. 1c). Calculating the time lapse between 2 pulses, T, the frecuency in Hertzs can be calculated as the inverse: F=1/T, and in BPM as 60/T. The signal obtained with the specklegram sensor is very sensitive and noisy, so a moving average filter is applied to this signal to reduce noise. After this step, peaks are detected and the median time between pulses, Tm, is obtained.

2.2.2 Method 2: First derivative and Fourier Transform

The first derivative is used to remove the offset of the original signal, not affecting the peaks present in the signal. Then a soft moving average filter is applied and the Fast Fourier Transform (FFT) is obtained. The FFT frequency presenting the maximum component corresponds to the heartbeat, expressed in BPM (Fig. 1d). The previous moving average filter is needed to avoid high frequency noise.

2.2.3 Method 3: Convolution by known frequency signal

Firstly, a moving average filter is applied to this signal to reduce noise. Then, the signal is convoluted with sinusoids of different frequencies. The convolution result will be maximum when the specklegram sensor signal and the sinusoid present the same frequency (Fig. 4e). The frequency sweep, f_c, goes from 0.33Hz (to detect 20 BPM) to 4Hz (240 BPM). The different sinusoids are stored in advance, to reduce in-line computation time.

3. Experiments and results

Both the Band sensor and the Ring sensor were employed to take measurements simultaneously with a pulse oximeter meter which was acting as the reference. Two different 160-seconds-long measurements were taken with each sensor from each of the 20 volunteer (one laying on their back and one laying on their side). Those measurements were differentially processed before applying the movement detector and the three methods to detect the heart rate.

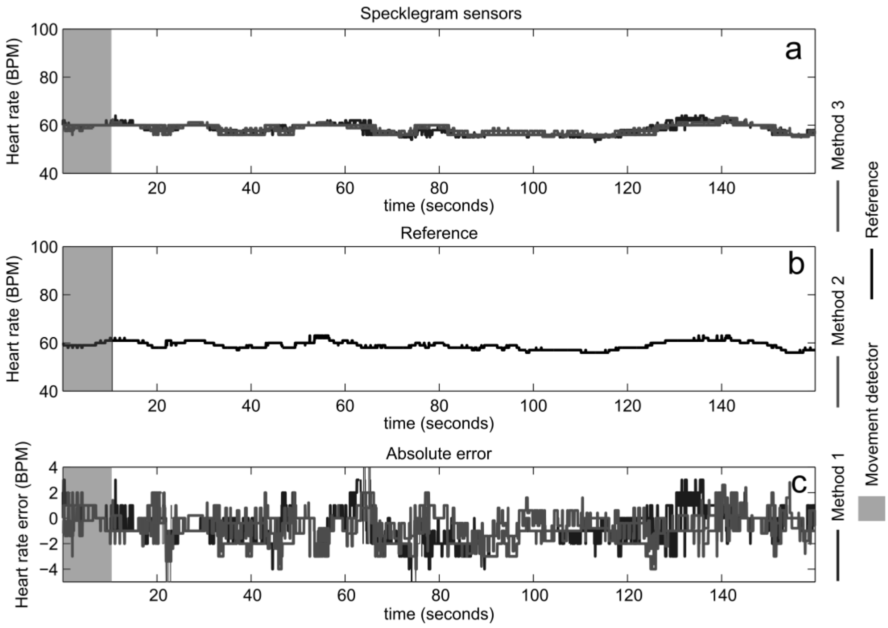

Figure 2 In-line processing result for one of the patients for a measurement of 160 seconds. (a) Heart rate estimated with the tree proposed methods. (b) Pulse oximeter reference. (c) Error for each of the three methods with respect to the reference. The reddish delimited region corresponds to movement detection active window, computed with the original signal. Note that it is active for the sequence beginning.

The performance (in terms of error) is tested for each method and sensor. The recorded 160 seconds measurements are processed frame by frame, mimicking real time acquisition. The mean heart rate obtained instantly can be compared in Fig. 2. The error percentage metric in Table 1 shows that measurements of laying on the side of the patient have better instant precision, both ring and band sensor and with the processing method 1. Also, method 3 performs good with the band sensor. In those cases, error is committed below 3% of the time.

	Side		Back	
Processing method	**Ring**	**Band**	**Ring**	**Band**
1	0.0248	0.0209	0.2778	0.2021
2	0.0741	0.0645	0.3102	0.2266
3	0.0415	0.0291	0.2714	0.1858

Table 1. Heart rate percentage error in time normalized for all the combinations.

4. Conclusion

A non-invasive monitoring system has been evaluated in this work and based on the obtained results it is possible to conclude that a fiber optic specklegram sensor exhibits the potential to be employed as a continuous monitoring heart rate and motion detection tool, achieving a high range of accuracy. The best-achieved results have been obtained using the band sensor and the smoothed signal method that also exhibits the best computation time. Eventually the combination of the optimal spatial distribution and the optimal processing method shows accuracies below 3% instantaneous error. As opposed to most of the current monitoring methods, this specklegram system is a low cost and widely applicable tool, hence it has the potential for being used as a basic monitoring system in all the hospital rooms and local environment.

5. Acknowledgements

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6. References

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