Automatic Arrhythmia Detection Based on Heart Beat Interval Series Recorded Through Bed Sensors During Sleep

Matteo Migliorini[1], Ramona Cabiddu[1], Sergio Cerutti[1], Luca T Mainardi[1], Juha M Kortelainen[2], Anna M Bianchi[1]

[1]Department of Bioengineering, Politecnico di Milano, Milan, Italy
[2]VTT Technical Research Centre of Finland, Tampere, Finland

Abstract

A high frequency of cardiac arrhythmias has been reported in sleep disordered patients. In order to detect the presence of arrhythmia during sleep, cardiac activity needs to be monitored. Several devices exist able to provide reliable Heart Rate Variability (HRV) measures in a minimally-intrusive way. Hence, there is the need for the development of robust methods for arrhythmia detection based on HRV measures. In the present study a method for automatic arrhythmia detection based on the analysis of an inter-beat series was developed and validated on recordings coming from the MIT-BIH Arrhythmia Database. The method was also applied on a beat to beat interval series obtained from the ballistocardiographic (BCG) signal of one subject, which was recorded during sleep using an innovative bed sensor which allowed for a noncontact and unobtrusive recording. When compared to the results of arrhythmia detection performed on the electrocardiographic (ECG) signal (concurrently acquired using polysomnography) using Cardioline Cube HOLTER analysis software, our method achieved a sensitivity of 55.6%, a specificity of 94.7% and an accuracy of 91.8%. Our results suggest that the bed sensor could represent a reliable tool to assist the clinician in arrhythmia detection.

1. Introduction

Cardiovascular disease constitutes the major cause of mortality in developed countries [1]. Arrhythmia is a widely recognized cardiovascular risk factor associated with an increase of overall mortality [2, 3]. In patients with cardiac rhythm disorder growing interest has been focused, in recent years, on concomitant co-morbidities, including sleep disorders [4, 5]. A high frequency of cardiac rhythm disturbances among patients with sleep disorders was reported [6, 7]. Several sleep clinic-based studies reported cardiac arrhythmias in up to 60% of patients with obstructive sleep apnea (OSA) [8] and they are thought to be one of the factors contributing to their increased mortality [9]. Electrocardiographic (ECG) signals reflect the heart electrical activity and are commonly used by physicians to diagnose heart diseases.

During sleep studies visual analysis of electrocardiographic (ECG) signals is commonly performed to diagnose cardiac rhythm disorders [10], but it often results difficult because of the great amount of information that examinations provide [1]. Also, accurate visual evaluation is subject to a number of observer errors and does not provide complete and exhaustive information. Hence, there is the need for automatic, robust methods for arrhythmia detection, which could improve the recognition of patterns of clinical interest and assist physicians in the diagnose of cardiac diseases. Several arrhythmia classification algorithms based on ECG have been proposed over the last years [10]. However, the results from these studies have only been applied in clinical practice to perform Holter analyses, but not within sleep related studies. Moreover, the possibility of evaluating cardiac activity during sleep in a minimally-intrusive way is also needed.

In the present study an algorithm for automatic arrhythmia detection based on the analysis of an inter-beat series was developed and tested on a database annotated recordings. The algorithm was also applied on one HRV signal recorded on one subject during sleep. A bed sensor consisting in Emfit sensor foils placed into a bed mattress [11] was used to monitor the cardiac activity of the subject. The bed sensor allowed for a noncontact and unobtrusive recording of the ballistocardiographic (BCG) signal. A beat to beat interval series was subsequently obtained, on which the algorithm was then applied.

2. Methods

2.1. Signal recording: bed sensor

The non-obtrusive bed sensor measures multichannel

BCG signals using pressure sensitive foil electrodes which are placed under the bed mattress [11]. The electrodes are arranged in two columns and four rows, covering in total an area of 72 cm x 72 cm under the middle body of the sleeping subject. The on-board algorithms extract heart beat interval (HBI), respiration signal and movement activity for the subsequent sleep analysis. Heart beat extraction is based on multichannel averaged spectra, from which the HBI is detected using cepstrum analysis. The method also gives a *confidence index* for each HBI value, based on the sharpness of the cepstrum peak. The relative error of the HBI for normal subjects is 1.1 % in comparison with the reference ECG RR-interval, and the coverage is 88 %, leaving out mainly the movement periods during sleep [11]. Fig.1 shows an example of a normal ECG (top panel) and the symiltaneous BCG (second panel), while the bottom panel represents the RR series (circles) and the inter-beat intervals extracted from BCG (grey line). During arrhythmia events, the correspondence between the ECG RR-interval and the BCG signal decreases and the bed sensor heart beat extraction may become inaccurate as shown in Fig. 3. However, in those cases, the arrhythmia periods can still be detected on the basis of the irregularity of the estimated HBI values.

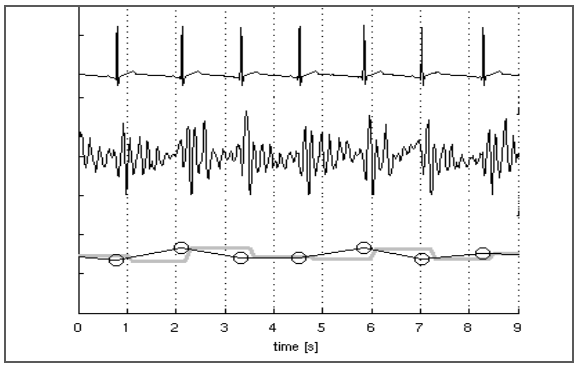

Figure 1: Example of the ECG (top), BCG (middle) and HBI obtained from the ECG (bottom, circles) and from the BCG (bottom, solid line) for a normal ECG.

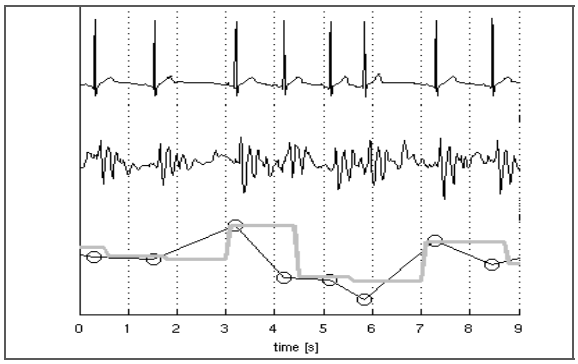

Figure 2: Example of the ECG (top), BCG (middle) and HBI obtained from the ECG (bottom, circles) and from the BCG (bottom, solid line) during arrhythmia.

2.2. Arrhythmia detection algorithm

Starting from the BCG the HBI signal is obtained and is analyzed for arrhythmia detection. The HBI signal contains a trend due to slow physiological modulation. As it might affect the subsequent statistical analysis, it must be removed. In order to calculate the trend a 150th order median filter is applied.

The HBI signal can be converted into a histogram representing the sample density distribution of inter-beat durations. A histogram is obtained for wakefulness, Rapid Eye Movement (REM) sleep and Not-REM (NREM) sleep periods. Inter-beat intervals can be classified as tachyarrhythmia or bradyarrhythmia episodes according to how much their duration differs from the average inter-beat interval time. Specifically, two thresholds are calculated as follows: for each sleep stage the higher threshold is calculated as the 95th percentile of the corresponding histogram, while the lower threshold is calculated as the product between coefficient -1.96 and the variance of the signal (Fig. 3). Peaks exceeding the thresholds are considered as potential arrhythmia episodes. In order to decide whether they are actual arrhythmia episodes or anomalies due to the quality of the signal or to the subject's movements, the *confidence index* described above is used: peaks exceeding the thresholds are considered as arrhythmia episodes only if the *confidence index* is equal or greater than 10%.

2.3. MIT-BIH arrhythmia database

The MIT Arrhythmia database was used for the validation of the presented method. 48 half-hour excerpts of two-channel ambulatory ECG recordings obtained from 47 subjects studied by the BIH Arrhythmia Laboratory were used (http://www.physionet.org/).

The recordings were digitized at 360 Hz with 11-bit resolution over a 10 mV range. Two or more cardiologists independently annotated each record. As the presented algorithm is only capable of detecting arrhythmia episodes based on changes in the heart rate (HR), only some annotations relative to types of arrhythmia which modify the HR were considered. Considered arrhythmias include atrial premature beat (A), aberrant atrial premature beat (a), junctional premature beat (j) and premature ventricular contraction (V).

Peaks were detected from the ECG by implementing the Pan-Tompkins algorithm [12], using the mean value of the filtered signal as a fixed threshold.

The algorithm for arrhythmia detection was then applied on the obtained RR series and the results were compared with arrhythmia events indicated in the MIT-BIH Arrhythmia database.

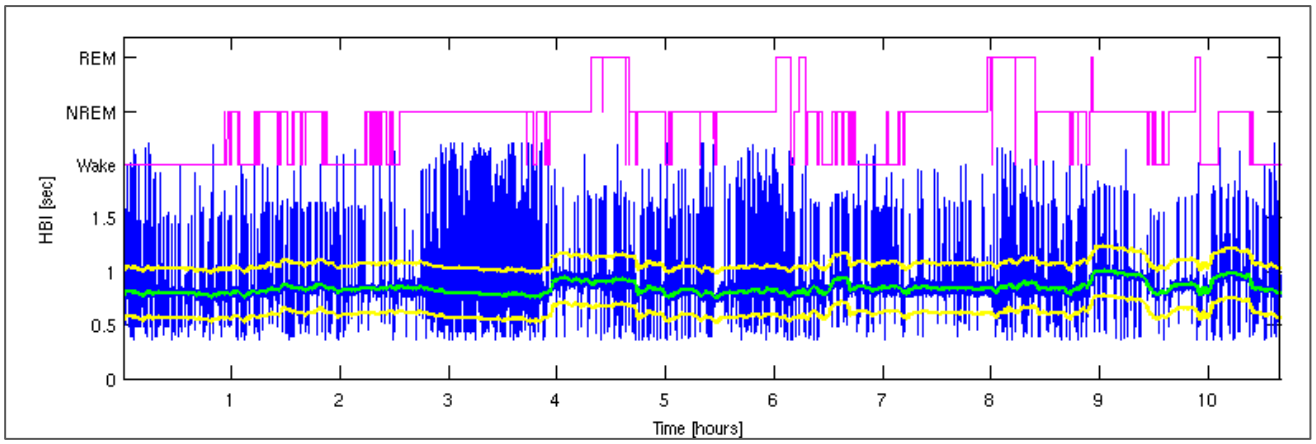

Figure 3: Heart Beat Interval (HBI) signal (blue) with indication of trend (green) and thresholds (yellow) as calculated implementing the presented arrhythmia detection algorithm. The Hypnogram is also showed (pink).

2.4. Clinical protocol

The arrhythmia detection algorithm was applied on signals obtained through the bed sensor during a night of sleep on one healthy subject. The HBI was sampled with a frequency of 5 Hz. For each subject several signals were recorded simultaneously through standard polysomnography. The ECG was recorded with a sample frequency of 500 Hz. The respiratory activity, the electroencephalogram (EEG), the electrooculogram (EOG) and the elecromyogram (EMG) were also recorded. For each subject the hypnogram was obtained by visual scoring performed on the EEG, EOG and EMG signals by an expert physician according to Rechtschaffen and Kales' standardized procedure [12]. Wakefulness state, REM and NREM sleep stages were indicated. From the ECG the HBI was obtained as described in section 2.1., while the RR series was extracted from the ECG. The algorithm was applied on both time series and results were compared.

3. Results

The MIT Arrhythmia database was used for the evaluation of the presented algorithm. Statistical measures were calculated to evaluate the algorithm performance. Sensitivity was calculated for each recording and for each type of arrhythmia. Specificity and accuracy were calculated for each recording, for all arrhythmia episodes. Global measures of sensitivity, specificity and accuracy were calculated for the whole population. Fig. 4 shows an example of a detrended ECG from the MIT-BIH Arrhythmia Database, with the upper and lower threshold for arrhythmia detection. Blue circles represent detected events, while red circles represent the database reference detections.

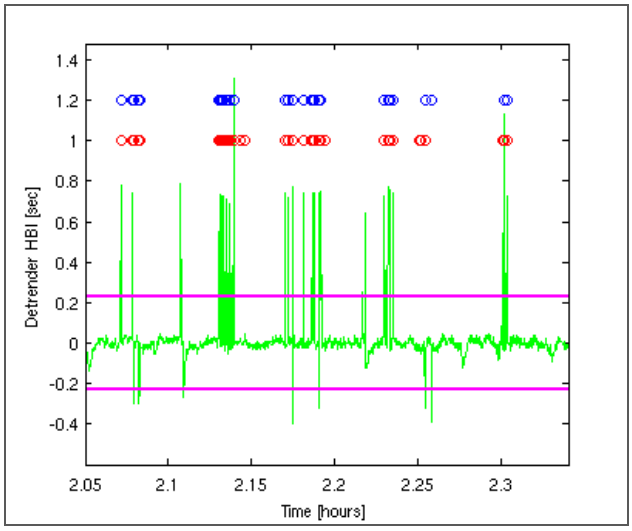

Figure 4: Detrended HBI (green) with indication of thresholds (pink). Blue and red circles represent arrhythmia episodes identified by the presented algorithm and arrhythmia episodes indicated on the MIT-BIH Arrhythmia Database, respectively.

The efficiency parameters used are accuracy, sensitivity and specificity.

Low sensitivity values were found for the detection of type A and type V arrhythmias, equal to 20% and 30%, respectively; higher sensitivity values were found for the detection of type a and J arrhythmias, equal to 71% and 74%, respectively.

The arrhythmia detection algorithm was then applied to the HBI signal derived from the BCG recorded on the subject and it performed with a sensitivity value of 55.6%, a specificity value of 94.7% and an accuracy value of 91.8%.

4. Discussion

A new method was presented to detect arrhythmic episodes by analyzing an inter-beat interval series derived from a BCG signal obtained using a bed sensor. The entire system (bed sensor and analysis procedures) can constitute an innovative tool for home monitoring of patients and subjects at risk of developing cardiac pathologies. In fact, the bed sensor is completely not invasive and not obstrusive and allows home recordings without interfering with the subject's daily life. Further, the automatic analysis procedure allows the identification of critical events and can produce alarms only in case of need.

Our algorithm was applied on a single subject but it will be necessary to test it on a higher number of subjects in order to obtain more reliable results. A quite low sensitivity value was obtained for the algorithm performance on the HBI signal, but it is important to keep in mind that the BCG signal characteristics change with ectopic beats (Fig. 2); an improvement of the detection algorithm may be achieved if the peak detection will be improved.

In sum, our results suggest the bed sensor might be a valuable tool to assist the physician in early arrhythmia detection and diagnosis formulation. Given its non-invasivity, it could be used to monitor a subject's cardiac activity during several nights, while the subject is comfortably sleeping in his bed. Future developments might include an algorithm improvement to make it capable of detecting arrhythmia episodes not only on the basis of HR modifications but also on the basis of morphological changes in signals representative of cardiac activity.

Acknowledgements

This work was partially supported by the HeartCycle Project ICT FP7 216695 of the European Community.

References

[1] Madeiro JP, Cortez PC, Oliveira FI, Siqueira RS. A new approach to QRS segmentation based on wavelet bases and adaptive threshold technique. Med Eng Phys 2007;:26-37.

[2] Schmidt C, Kisselbach J, Schweizer PA, Katus HA, Thomas D. The pathology and treatment of cardiac arrhythmias: focus on atrial fibrillation. Vasc Health Risk Manag 2011;7:193-202.

[3] Yap SC, Harris L, Chauhan VS, Oechslin EN, Silversides CK. Identifying high risk in adults with congenital heart disease and atrial arrhythmias. Am J Cardiol 2011;108:723-8.

[4] Coccagna G, Pollini A, Provini F. Cardiovascular disorders and obstructive sleep apnea syndrome. Clin Exp Hypertens 2006;28:217-24.

[5] Bitter T, Horstkotte D, Oldenburg O. Sleep disordered breathing and cardiac arrhythmias: mechanisms, interactions, and clinical relevance. Dtsch Med Wochenschr 2011;136:431-5.

[6] Olmetti F, La Rovere MT, Robbi E, Taurino AE, Fanfulla F. Nocturnal cardiac arrhythmia in patients with obstructive sleep apnea. Sleep Med 2008;9:475-80.

[7] Ludka O, Konecny T, Somers V. Sleep apnea, cardiac arrhythmias, and sudden death. Tex Heart Inst J 2011;38:340-3.

[8] Namtvedt SK, Randby A, Einvik G, Hrubos-Strøm H, Somers VK, Røsjø H, Omland T. Cardiac Arrhythmias in Obstructive Sleep Apnea (from the Akershus Sleep Apnea Project). Am J Cardiol 2011.

[9] Walia H, Strohl KP, Mehra R. Effect of continuous positive airway pressure on an atrial arrhythmia in a patient with mild obstructive sleep apnea. J Clin Sleep Med 2011;7:397-8.

[10] Kim J, Shin HS, Shin K, Lee M.Robust algorithm for arrhythmia classification in ECG using extreme learning machine. Biomed Eng Online 2009; 8:31.

[11] Kortelainen JM, Mendez MO, Matteucci M, Cerutti S, Bianchi AM. Sleep Staging based on Signals Acquired through Bed Sensor. IEEE¬TITB 2010;14:776-785.

[12] Pan J, Tompkins WJ. A Real-Time QRS Detection Algorithm. IEEE Trans Biomed 1985;32:230-236.

[13] Rechtschaffen A, Kales A. A manual of standardised technology; techniques and scoring systems for sleep stages of human objects, Public Health Service, US Government Printing Office 1986, Washington DC.

Address for correspondence.

Matteo Migliorini.
Department of Bioengineering
Politecnico di Milano
Via Golgi 39, 20133, Milano, Italy.
matteo.migliorini@mail.polimi.it