# Estimation of respiratory rhythm during night sleep using a bio-radar

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## ABSTRACT

An assessment of bio-radiolocation monitoring of respiratory rhythm during sleep is given. Full-night respiratory inductance plethysmography (RIP) and bio-radiolocation (BRL) records were collected simultaneously in a sleep laboratory. Polysomnography data from 5 subjects without sleep breathing disorders were used. A multi-frequency bio-radar with step frequency modulation was applied. It has 8 operating frequencies ranging from 3.6 to 4.0 GHz. BRL data are recorded in two quadratures. Respiratory cycles were detected in time domain. Obtained data was used for the evaluation of correlation between BRL and RIP respiration rate estimates. Strong correlation between corresponding time series was revealed. BRL method is reliably implemented for estimation of respiratory rhythm and respiratory rate variability during full night sleep.

**Keywords:** bio-radiolocation, respiratory inductance plethysmography, sleep, respiratory rhythm, breathing, Doppler radar, vital signs, bio-radar

## 1. INTRODUCTION

There are four main vital signs: heart rate, respiratory rate, body temperature and blood pressure. Respiratory rate is supposed to be an indicator of health state and may be used for prediction of some disorders and mortality [1-3]. Usually, analysis of respiratory rate and associated changes in volume of chest wall abdominal and thoracic components is carried out applying respiratory plethysmography methods [4]. Respiratory inductance plethysmography (RIP) is the most common method in polysomnographic (PSG) laboratories for analyzing respiratory movements during sleep. There is interest to more comfortable non-contact systems of respiratory movement registration for ambulatory long-term monitoring.

Bioradiolocation (BRL) is a modern remote sensing technique allowing to perform noncontact vital signs monitoring of living objects (even behind optically opaque obstacles), on the base of analysis of specific biometric modulation in reflected radiolocation signal [5]. During tidal breathing process, the modulation is mostly determined by reciprocating displacements of skin surface in abdominal and thoracic areas of chest wall due to periodic contractions of respiratory muscles [6]. In medical practice, BRL technology application is known in somnology for noncontact screening of such types of sleep-disordered breathing as sleep apnea and sudden infant death syndromes [7].

Implementation of novel remote respiratory parameter registration techniques in clinical practice requires their mandatory verification with standard contact biomedical research methods [4]. Previously matching respiratory rate values registered applying in parallel BRL and RIP methods was [8-10] studied in details. Comparison of BRL and RIP signals on the basis of cross-correlation and spectral analysis of time series was also performed [11]. The studies used short records of signals. However, verification of BRL method for respiratory rhythm estimation in close to real-world conditions – long records with movement artifacts – has been of particular interest. Usually, respiratory rhythm is estimated by frequency domain analysis. Nevertheless, respiratory cycles detection by time domain analysis allows to get respiratory rate variability in analogy to heart rate variability, which provides information on the autonomic nervous

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system state. The study objective is to validate BRL method in respiratory cycles detection in time domain for long records obtained during sleep.

# 2. MATERIALS AND METHODS

## 2.1 Clinical protocol

We used the data from 5 subjects without sleep breathing disorders (SDB) who underwent PSG study in Sleep Medicine Laboratory at Federal Almazov Medical Research Centre (St. Petersburg, Russia). The subjects characteristics are presented in Table 1. Apnea-hypopnea index (AHI) is a parameter of sleep-disordered breathing severity. Subjects with AHI less than 5 episodes per hour of sleep are considered free of SDB. Sleep period is time interval from falling asleep to final awaking and including awakening during sleep. Sleep efficiency defined as:

$$S_{eff} = \frac{T_{sleep}}{T_{sleep} + T_{wake}}, \quad (1)$$

where $T_{sleep}$ is total time of sleep, and $T_{wake}$ is total time of awakening during recording both in sleep period and before and after sleep. Limb movement index (LMI) is registered by leg surface electromyography. It includes muscle tension and does not result in visible movement, but LMI strongly correlates with them. Four positions are differentiated during sleep: supine, prone, left and right sides. BRL signal is better registered when radio signal is reflected from chest. Therefore, supine position is ideal for BRL monitoring in this study design.

Table 1. Subjects characteristics (N=5).

| Subject | Age | Sex | Body mass index ($kg/m^2$) | Apnea-hypopnea index (episode/h) | Sleep period (min) | Sleep efficiency | Limb movement index (episode/h) | Supine position (%) |
|---|---|---|---|---|---|---|---|---|
| A | 24 | M | 24.2 | 0.1 | 658.0 | 86.1 | 7.4 | 47.8 |
| B | 53 | F | 30.1 | 4.0 | 596.2 | 91.7 | 3.8 | 24.4 |
| C | 27 | F | 17.0 | 2.6 | 496.8 | 85.9 | 9.1 | 27.9 |
| D | 54 | F | 26.5 | 3.1 | 529.3 | 78.3 | 34.8 | 55.5 |
| E | 22 | F | 17.7 | 0.2 | 531.8 | 93.5 | 3.16 | 9.6 |
| Mean | 36 | 1M/ 4F | 23.1 | 2.0 | 663.8 | 562.42 | 11.65 | 33.04 |

BRL and RIP signals were registered simultaneously during sleep (fig 1.). Full-night PSG (Embla N7000, Embla Systems LLC, Ontario, Canada) including registration of respiratory movements by RIP was performed. Abdominal and thoracic RIP signals were sampled at 10 Hz. BioRascan multifrequency BRL system with a continuous wave signal and step frequency modulation, developed at Remote Sensing Laboratory of Bauman Moscow State Technical University, was used in the experiments. The unit has 8 operating frequencies in the range from 3.6 to 4.0 GHz. The received signal is filtered by means of an active analog filter with a bandwidth 0.03–5.00 Hz. The sampling rate is 50 Hz. Data are recorded in two quadratures. The BRL signal power flux density is 1.36 μW/cm2, which grants safety for both patients and medical staff during cardiovascular and respiratory monitoring with BioRascan BRL system application [12].

Figure 1. Scheme of the experiment on simultaneous registration of BRL and PSG data during sleep.

## 2.2 Data processing

Detection of inspiratory peaks based on BRL and RIP signals must be made for verification of BRL. A very straightforward algorithm was used for RIP signal inspiratory peaks detection. It consisted of following step:

1. summation – half of sum of the abdominal and thoracic RIP signals was used in the subsequent analysis;
2. filtration – 3rd order Butterworth band pass filter 0.2 – 1.0 Hz was applied;
3. detection – inspiratory peaks were detected by algorithm of find local maximum.

BRL signal (fig 2.) as compared with RIP signal has a few peculiarities: subject's movements make more artifacts, strong amplitude changing in consequence of subject's displacement, phase shift results in the signal flip-over and inspiratory peaks are down.

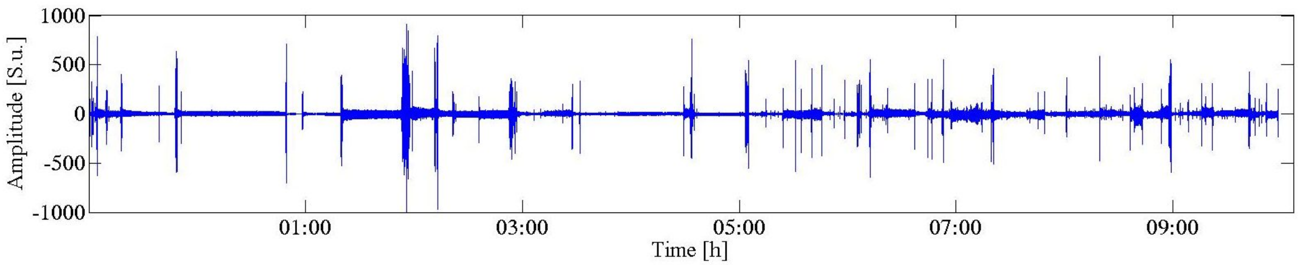


Figure 2. Original BRL signal during night. S.u. - standardized units.

Thus, an algorithm for inspiratory peaks detection by BRL is not so trivial. In total, 16 BRL signals were used (8 operating frequencies, each of them has *I* and *Q* quadrature). The algorithm is consisted of following step (fig. 2)

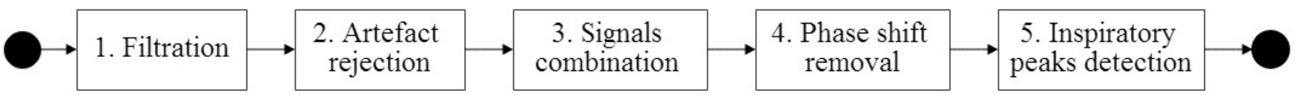


Figure 3. Scheme of the algorithm for estimation of respiratory rhythm by BRL.

1. Signals were filtered with band-pass 3rd order Butterworth filter of 0.2 Hz to 1.0 Hz.
2. BRL signal with maximum mean amplitude was selected and processed for the artifacts detection. A moving window function computes the mean windowed amplitudes (MVA). Each MVA was compared with a threshold value, window and *k* seconds after it was marked as artifact if MVA exceeds the threshold value. Threshold value was calculated by mean amplitude of the signal. If interval between artifacts was less than *r* then it was marked as artifact too. Parts of the signal which marked as artifacts were rejected.
3. Thus, the signal $S(t)$ was divided into inter-artifacts intervals (IAI) $S_i(t)$. The signal amplitude may be changed after each artifact due to subject's shift. Therefore for each IAI was found a signal with maximum amplitude from obtained 16 BRL signals $S^j_i(t)$, $j=1..16$. Finally, they were combined to one signal $S^c(t)$. The combined signal was used in the subsequent analysis.
4. For each IAI mean inspiratory peaks width was estimate for the signal $S^c_i(t)$ and for $-S^c_i(t)$. Inspiratory peaks were detected by local maximum search algorithm. The peak width was calculated on 0.7 height of the peak. If the mean width for $S^c_i(t)$ exceeds that for $-S^c_i(t)$ then this interval was turned over. Thus, cuspidal peaks corresponding to the breaths were turned up in $S^c(t)$.
5. Inspiratory peaks were detected by algorithm of find local maximum.

The BRL signal for different steps of the inspiratory peaks detection algorithm is presented in Figure 4.

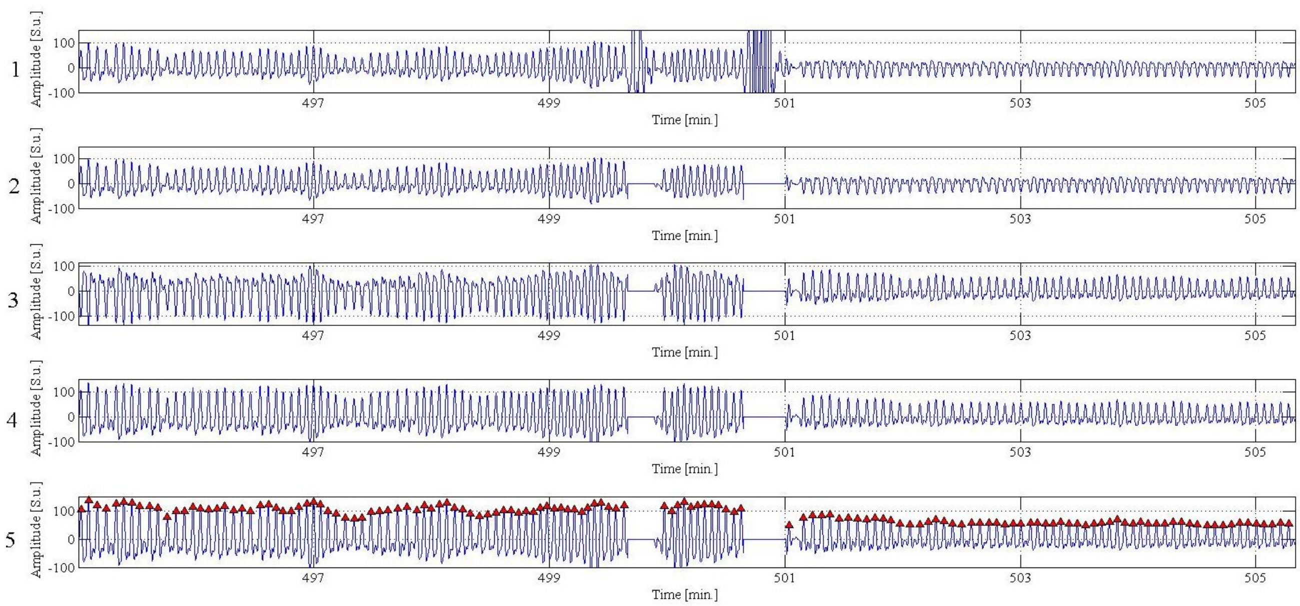


Figure 4. Results of the inspiratory peaks detection algorithm steps. 1 – filtered signal. 2 – signal after movement artifact rejection. 3– combined signal comprising the best inter-artifacts parts of signals. 4 – signal after phase shift rejection. 5 - inspiratory peaks detection. S.u. - standardized units.

Matlab software (The Mathworks Inc., Natick, MA, USA) was used to perform the data processing.

### 2.3 Validation

Start of the BRL and RIP signals were peak-to-peak synchronized. BRL and RIP signals were truncated to sleep period, i.e. parts of the signals in wakefulness time after and before sleep were deleted. Intervals of RIP signal corresponding to interval of BRL signal marked as artifact were rejected. Inspiratory peaks amount per minute (respiratory rhythm) were calculated for RIP and BRL signals (fig.5). Further, the Pearson's correlation coefficient was calculated between respiratory rhythms obtained by RIP and BRL methods for each subjects.

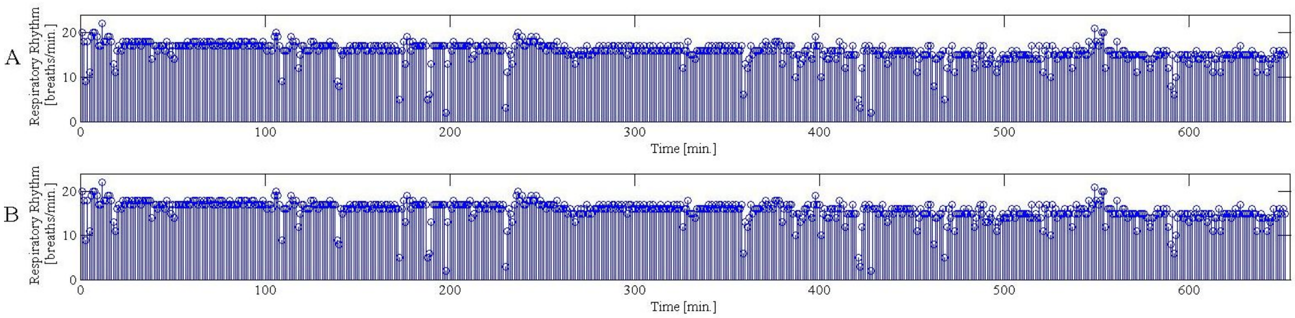


Figure 5. Comparison of respiratory rhythm estimation by BRL (A) and RIP (B) signals. Subject A.

## 3. RESULTS

Table 2 summarizes the accuracy of the algorithm of respiratory rhythm estimation by BRL. Pearson's correlation coefficient and percentage of rejected artifacts is presented.

Table 2. Summary of the algorithm accuracy.

| Subject | Correlation | Artifact time (%) |
|---|---|---|
| A | 0.97 | 4.75 |
| B | 0.96 | 4.29 |
| C | 0.98 | 6.15 |
| D | 0.97 | 13.50 |
| E | 0.96 | 5.32 |
| Mean | 0.97 | 6.80 |

## 4. DISCUSSION

The cross-correlation coefficient for BRL and RIP characteristic estimates of 0.97 indicates very strong correlation. The artifact time mean value of 6.8 % shows high sensitivity of BRL to movements. Subject D has significantly higher levels of artifacts. This is due to the fact that Subject D demonstrated more limb movements and lower sleep efficiently.

Usually, BRL verification experiments were made in idealized conditions – short records are used, radio signal is reflected from chest, subjects do not move [8-10]. This paper presents results which obtained in close to real-world conditions. Subjects were in different positions: supine, prone, left and right sides. Moreover, they changed position and moved the limbs. Furthermore, the inspiratory peak detection algorithm allows to obtain respiratory rate variability in analogy to heart rate variability. It can provide information on a state of the autonomic nervous system.

Although RIP and BRL signals were peak-to-peak synchronized, they were desynchronized subsequently (fig. 6). Desynchronization is not more than a half of respiratory cycle. This is apparently due to the absence of permanent time synchronization between BioRascan and Embla.

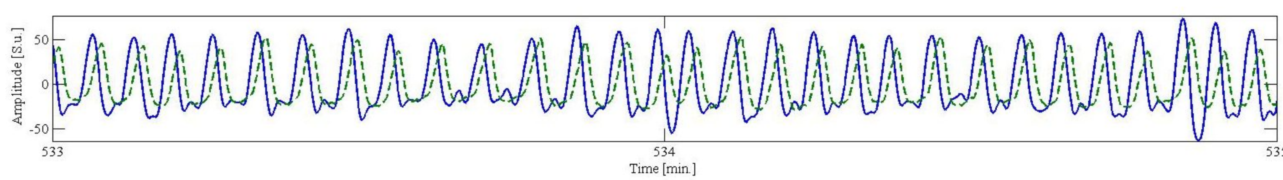


Figure 6. BRL and RIP signals desynchronization. The solid plot is the BRL signal. The dashed line is the RIP signal.

This study has two serious limitations. First of all, inspiratory peaks detection algorithm by BRL was compared with inspiratory peaks detection algorithm by RIP, but the RIP algorithm was not verified. Moreover, small sample was used. Although the results are preliminary, they may be quite useful for the development of non-contact sleep monitoring systems.

## 5. ACKNOWLEDGMENT

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