Overview of Methods for Respiratory Signal Modeling

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Abstract: - In imaging of the chest or abdomen, motion artifact is an unavoidable problem. In the radiation treatment, motion of organs is caused by the respiratory activity. This creates the unavoidable problem for implementation of the safe and effective cancer treatment with preserving the healthy tissue. Computation of the estimated respiratory signal is necessary to irradiate corresponding dose during the inspiration or expiration. This study is focused on the review of various mathematical models for the respiratory modelling, which provides the basis for the most clinically applied methods of computing the estimated respiratory signals. In this article, we compared the most popular methods for modeling the estimated respiratory wave, the results of our modeling are presented in the resulting table (including the correlation coefficient *R*).

Key-Words: baseline drift, Lujan model, motion artifact, fitting sine function, respiratory waveform, respiratory signal.

1 Introduction

Breathing consists of two phases: inspiration and expiration. During inspiration, the diaphragm and the intercostal muscles contract. During expiration the diaphragm and the muscles relax. When a breath is taken, air passes in through the nostrils, through the nasal passages, into the pharynx, through the larynx, down the trachea, into one of the main bronchi, then into the smaller bronchial tubules, through even smaller bronchioles, and into a microscopic air sac called the alveolus [1, 17]. Namely here, the external respiration occurs [14, 3, 9].

It is important to emphasize that in imaging of the chest or abdomen, motion artifact is the unavoidable problem. In the radiation treatment, motion of organs is caused by the respiration activity. This creates the unavoidable problem for implementation of the safe and effective cancer treatment with preserving the healthy tissue [2, 5, 16].

The chest radiography remains the mainstay of imaging evaluation in the respiratory failure, not only in the primary diagnosis, but, also, in monitoring of the therapy and the day-to-day management of tubes and lines [8, 18]. However, the chest radiography limitations that must be kept in the borne in mind. It is a well-known fact that many of the patterns of abnormality are relatively non-specific in the diagnostic terms. Many things have been written and said about the ICU patients, where the positioning and exposure are often sub-optimal and may strongly vary from examination to examination. Hence, it is important to strive for the radiographic continuity and recording of exposure factors for each patient to promote consistency and provide comparable follow-up examinations [12, 13, 10].

2 Method and Material

Purpose of modelling the respiratory signals is to minimize the motion artifact, which occurs when the image of decreases and increases since the patient's breath [7, 15]. Thus, during the treatment the burden on the patient can be minimized and the high quality of the cancer management be provided.

2.1 Respiratory Gating System

In this study, the AZ-733V Respiratory Gating System is used to record the respiratory signal. The respiratory information detected by the Load Cell (pressure sensor) (Fig. 1) is displayed as the respiratory wave on the PC display (within 100 msec) [6].

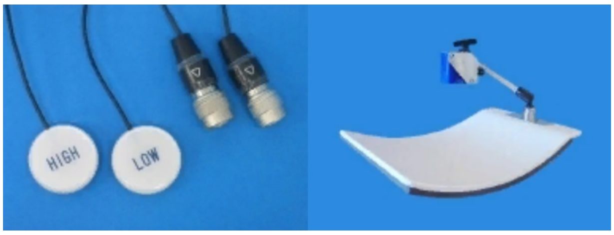

Figure 1. ANZAI Belt's Load Cell.

To record the acquired respiratory signal for 10 minutes, the ANZAI belt [4] is set around in the abdomen. The noise, baseline-drift and saturation lead to artifacts in the recorded signal. Fig. 2 shows the respiratory signal for 7 seconds.

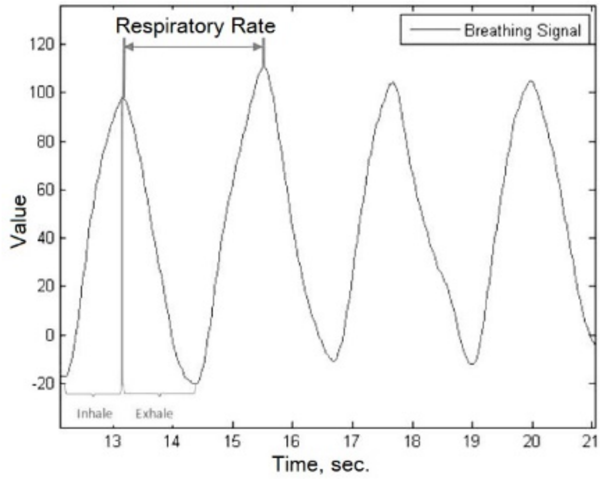

Figure 2. Respiratory signal recorded from ANZAI belt.

This signal has no artifacts the comparing to the signal with the baseline-drift artifact (Fig. 3). After an analyzing of recorded signal given by defining parameters of the signal, such as respiratory rate, inhalation phase and exhalation phase.
Fig.3 shows the signal with baseline-drift artifact. It is necessary to remove the artifacts by using several mathematics estimation functions. In additional to this, this study evidently demonstrates that the artifacts of Fig. 3 can be overcome by fitting of a polynomial function.

2.1 Polynomial Function

Fitting of a polynomial to the data is performed by removing the baseline-drift. Defining the polynomial parameters consists in the coefficient calculating for a polynomial $p(x)$ of degree n that is a best fit (in a least-squares sense) for the data. The coefficients for a polynomial $p(x)$ of degree 5 that is a better fit for the data. Equation (1) represents polynomial of five degree fitted to the respiratory signal to remove the baseline-drift.

$$p(x) = p_1x^5 + p_2x^4 + p_3x^3 + \\ + p_4x^2 + p_5x + p_6 \quad (1)$$

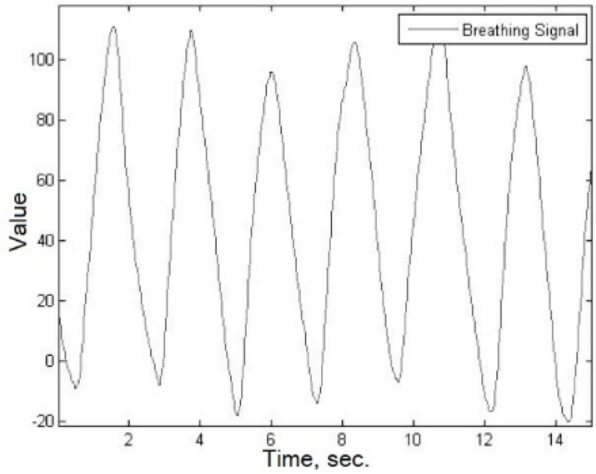

Figure 3. Respiratory signal of 15 sec of normal breathing with baseline-drift.

2.2 Fitting by the Sine Function

The fitting algorithm works on the basis of the fitting the sine wave to the breathing signal by taking the maximum value and minimum values of the signal. The difference between the minimum and maximum values used as the signal value. Finally, computing zero-crossing, estimating the period, and the offset are implemented for equation (2). The fitting function is calculated as the sine function, which is described by equation (2).

$$p(x) = b_1 \sin\left(\frac{2\pi x}{b_2} + 2\pi b_3\right) + b_4 \quad (2)$$

2.3 Respiratory Cycle Modelling (Lujan's Model)

It is generally assumed that the stable value of respiratory signal reaches their final position at 90% exhale and 0% inhale. Several models of the breathing cycles have been proposed in the literature. Lujan et al. presents models the dynamic breathing volume curve [11]. It is important to emphasize that the Lujan model is based on a periodic but asymmetric function (more time spent at exhalation versus inhalation). Below, in equation (3), V_0 is the volume at exhalation that corresponds to the tidal volume (TV), which is the amount of air breathed in or out during normal respiration, $V_0 + b$ is the volume at inhalation, τ is the period of the breathing cycle, n is a parameter that determines the general shape of the model, and φ is the starting phase of the breathing cycle (Fig. 4). This model represents apriory knowledge of a conventional breathing cycle.

$$V(t) = V_0 + b\,cos^{2n}(\frac{\pi t}{\tau} + \varphi) \qquad (3)$$

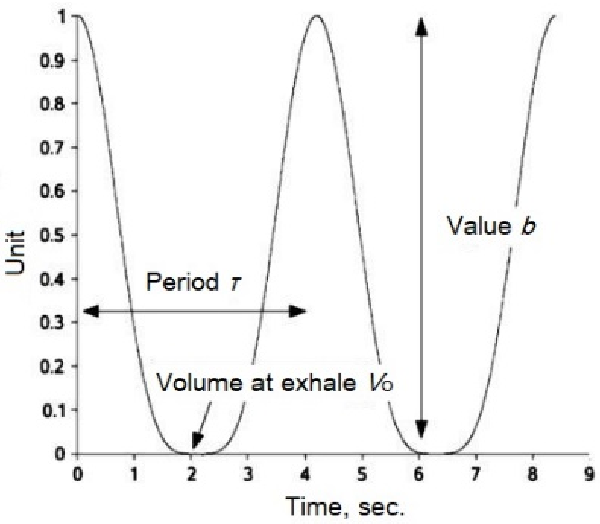

Figure 4. Breathing cycle modelling proposed by Lujan et. al.

4 Conclusion

Below is Table 1 with the results of modelling the estimated respiratory waveform.

Table 1: The results of modelling the estimated respiratory waveform.

Method	Estimated Parameters	Figure	R, %
Polynomial Function	$p_1 = 10.2396$; $p_2 = -9.3853$; $p_3 = -37.8728$; $p_4 = 15.8164$; $p_5 = 23.1214$; $p_6 = 44.5939$.	Fig. 5	0.5138
Fitting Sine Function	$b_1 = 50.8764$; $b_2 = 2.3274$; $b_3 = -0.7346$; $b_4 = 0.0000$.	Fig. 6	0.6325
Respiratory Cycle Modeling (Lujans Model)	$b = 49.5569$; $\tau = 2.3273$; $\varphi = -1.2077$ $n = 0.7215$; $V_0 = 0.0000$.	Fig. 7	0.6200

All the methods describe respiratory signal with relatively the same accuracy. To acquire the input respiratory signal, the program used quire the data given by ANZAI belt. The date of the respiratory signal were uploaded to program in the txt format. The program outputs the estimated respiratory signal in the txt file and plots the results calculated by three methods.

Many things have been written and said about a respiratory simulation. However, the mathematical models have using for studies of sensitive populations and the home-land security community, in cases where respiratory studies on humans cannot be conducted because of radiation.

4 Acknowledgements

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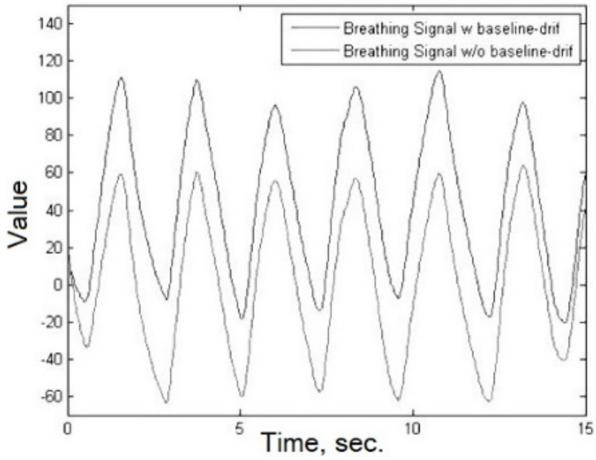

Figure 5. The difference between the signal with and the signal without baseline-drift artifact.

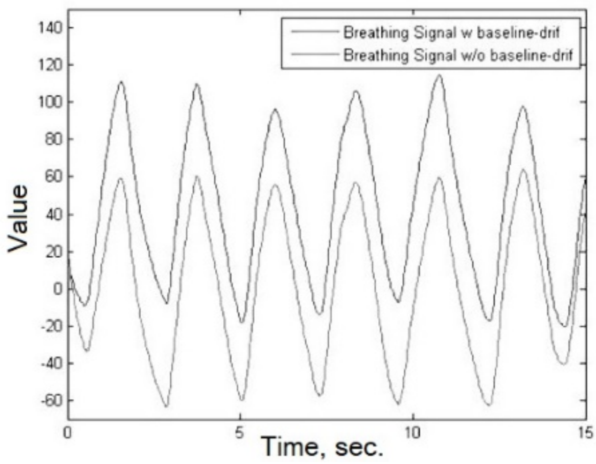

Figure 6. Respiratory signal (black) and sine wave fitted to the respiratory signal (grey).

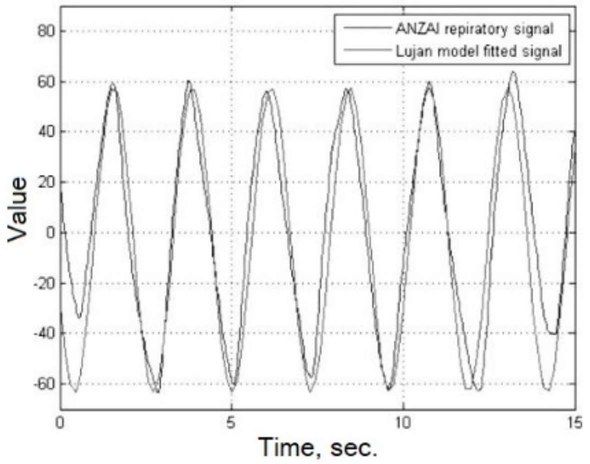

Figure 7. ANZAI respiratory signal (black), Lujan et. al. model (fitted function to the respiratory signal) (grey) (n = 0.7215).

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