Recently a non-invasive acoustical method has been developed to detect respiratory phases without airflow measurement, in which the average power of tracheal breath sounds is used to detect the onset of breaths [1]. We improved the accuracy of the breath onsets detection by applying variance fractal dimension $D_\sigma$. For the sake of a comparison, the same set of data as in [1] was used. Data included tracheal breath sound recorded simultaneously with airflow from nine healthy subjects. Variance fractal dimension was used to detect the onset of breaths directly from the time domain tracheal sound signals. Result shows that onsets can be detected by the peaks of the variance fractal dimension, with an accuracy of $40\pm 9$ ms. Comparing to the accuracy reported in the previous method ($41.5\pm 34.7$ ms), this study slightly improves the average error but also is more robust in term of standard deviation. It also provides an alternative approach to analyze breath sound signals in time domain. The result increases the reliability of acoustical phase detection algorithm and paves the way for further analysis such as actual amount of airflow estimation.

**Keywords** — respiratory sounds, variance fractal dimension, breath onsets, signal complexity

## I. INTRODUCTION

The determination of respiratory phases is essential in the study of respiratory and swallowing sounds [2]. To date, pneumotachograph, nasal cannulae connected to a pressure transducer, heated thermistor anemometry etc are commonly used to record respiratory airflow [3]. However, each method has its limitations when assessing the airflow of either a neurological impaired patient or a patient with physical deformities. In addition, some may even alter the pattern of respiration [1]. Acoustical analysis of respiratory sounds has recently provided an alternative way to detect respiratory phases without airflow measurement [1]. The acoustical phase detection algorithm has shown promising results in respiratory phase detection by using only tracheal and chest sounds. Breath onsets were detected by detecting minimum points of the average power of tracheal signals, where the tracheal sound intensity was low [1]. In this study however, we aimed to investigate the fractal dimension of the tracheal sound signal as another approach to detect the breath onsets.

Fractal dimension is a measure of complexity in a data set, either two or three-dimensional images or one-dimensional signals. It is used to analyze chaotic and non-chaotic signals in a wide range of scientific research, particularly in image compression, segmentation and in genetic maps [6,7,8]. Fractal dimension quantifies the complexity of an object which is obscure to human eyes. Variance fractal dimension $D_\sigma$ (Equation 1) is one of the ways to calculate fractal dimension [4,5]. Generally, fractal dimension can be obtained by taking the limit of the quotient of the log change of the object size and the log change of the measurement scale, as the measurement scale approaches zero (Equation 2). In deriving variance fractal dimension for one-dimensional data, sampled signal is the "object", variance ($\sigma$) of the sampled signal is the "object size", while the time interval between the samples used to calculate the variance, is the "measurement scale" ($\Delta t_k$). One property of fractal dimension is that they are independent of power content in the signal. This indicates that all signals, both with high or low amplitude, will produce the same magnitude of fractal dimension as long as they are composed of the same frequency components. In other words, fractal dimension calculates the complexity of signal and is immune to signal amplitude.

We postulate that breath sound signal has a chaotic feature during the short period of time between the phases (inspiration$\rightarrow$expiration or expiration$\rightarrow$inspiration). Therefore, we hypothesize that variance fractal dimension of respiratory sound has peaks at the breath onsets and this may lead to a better approach in the automated detection of the breath onsets by acoustical means. Hence, the main objective of this study was to detect and compare the accuracy of breath onset detection using variance fractal dimension with that of the previous method in [1].

## II. METHOD

**Subjects and data** —Data from 9 subjects were adopted from the previous research [1]. The tracheal sound was recorded by accelerometer and airflow was measured by a mouthpiece pneumotachograph. Figure 1 shows a typical sample of the respiratory sound and its corresponded airflow. The airflow and tracheal sound signals were
Respiratory Onset Detection Using Variance Fractal Dimension

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Abstract

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digitized simultaneously at a sampling rate of 10240 Hz. The detailed information about data can be found in [1].

FIGURE 1. A typical tracheal breath sound signal with its associated airflow.

Onset detection by variance dimension —— A time series representing a chaotic or non-chaotic process can be analyzed directly by examining the spread of the increments in the signal amplitude, e.g. variance, $\sigma^2$.

From [4,5], the variance fractal dimension is defined as:

$$D_\sigma = D_E - 1 + H$$  \hspace{1cm} (1)

where $D_E$ is the embedding dimension, which is the dimension of the embedding space, (i.e., for a curve $D_E=1$, a plane $D_E=2$ and for space $D_E=3$) and,

$$H = \lim_{\Delta t \to 0} \frac{\log(\text{Var}(\Delta S))}{2\log(\Delta t)}$$ \hspace{1cm} (2)

$S$ is the sound data samples and therefore $\Delta S$ is the variation of tracheal sound signal between two points.

$$\Delta t = |t_2 - t_1|$$

$$\Delta S_{\Delta t} = S(t_2) - S(t_1)$$

Figures 2 and 3 show $(\Delta S)_{\Delta t}$ and $\Delta t$ graphically.

FIGURE 2. Illustrating $(\Delta S)_{\Delta t}$.

To detect breath onsets, $D_\sigma$ was calculated using $N_T=128$ points (12.5ms) with 50% overlap between the adjacent segments. Then, a running window with approximately half breath size (0.7second) was used to detect all the peaks in $D_\sigma$.

III. RESULTS

FIGURE 3. Illustrating the measurement scale $\Delta t_K$ for $D_\sigma$ calculation. For dyadic measurement scale $\Delta t_K=2, 4, 8, 16, 32,\ldots$

Figure 4 shows the breath onsets detected from variance fractal dimension $D_\sigma$ with the actual corresponded airflow. Comparing with the actual airflow, the result shows an average error of $40 \pm 9$ ms, which is slightly less than the error presented in the previous study [1]. However, the standard deviation of the error in this method is much smaller than the previous one.

IV. DISCUSSION

In this study, we postulated that during the transition of breath phases, the sound signal has temporal chaotic features due to the momentum of airflow as it changes its direction. Hence, this leads to a chaotic process, which can
be detected by its signal complexity using variance fractal dimension $D_0$. As can be seen in Figure 4, variance fractal dimension approaches a value of two, indicating the signal during transition of phases has a complexity between a line and a plane. It cannot be a pure line because all data points do not lie in a straight line; it cannot be a plane as well since the area for one-dimensional signal is zero. This important characteristic of non-integer fractal dimension has been used extensively in describing and classifying speech phonemes [9].

The advantage of variance fractal dimension $D_0$ is that it does not compromise between frequency and time resolution, while the accuracy of breath onset detection by average power method depends on the window size to segment data and the window size option is limited by the trade off between the time and frequency resolution. $D_0$, however, concerns solely with time resolution $N_T$. By changing the size of $N_T$, the magnitude of $D_0$ also changes. Optimum $N_T$ interval size is obtained when $D_0$ shows prominent peaks.

The attraction of variance fractal dimension is also that $D_0$ can be calculated directly in time-domain. It can be programmed to have a real-time procedure to calculate $D_0$ while tracheal sound signal is being received.

In conclusion, the result of breath onset detection using variance fractal dimension is encouraging. Further experiments have to be carried out to examine whether variance fractal dimension is also useful in determination of respiratory phases from the chest sound signals.

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