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Review Article

Evaluation of respiratory properties by means of fractional order models

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ABSTRACT

The goal of this paper is to model and analyze the properties of the respiratory system by means of fractional calculus. A linear fractional order system of commensurate order is obtained using the real and the imaginary parts of the measured respiratory impedance through an identification technique. In this context, the features used for the classification of some respiratory diseases are the identified parameters of the linear fractional order system of commensurate order. These features are then classified using the K-Nearest Neighbors (KNN) classifier. The proposed method has achieved an accuracy of 40% using only the first feature, however by using all the features the accuracy has increased up to 100%. The proposed classification technique is validated on 15 patients: healthy, asthma and chronic obstructive pulmonary disease (COPD).

Contents

1. Introduction

Fractional order systems modeling has become very common in physics and engineering [1–5,7], and emerged successfully in biomedical engineering field [8–10]. The works in [11–15] are made based on the fractal behavior of the anatomical structures and the dynamical physiologic networks. Several studies show a historical perspective of the dynamic link between fractal physiology and fractional calculus [16–18]. By applying fractional calculus to model the behavior of cells and tissues, we can begin to unravel the inherent complexity of individual molecules and membranes in a way that leads to an improved understanding of the overall biological function and behavior of living systems. In [8], the authors have given a simple way to characterize the physical and electrical properties of complex, heterogeneous and composite biomaterials by mean of fractional calculus models. This led to the conclusion that the fractional calculus suggests new experiments and measurements that can shed light on the meaning of biological system structure and dynamics.

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Recent studies in biomedical signal modeling have used fractional order system to model ECG signal [14,15], speech [19], EEG signal [20] and evaluation of respiratory impedance in several invasive animal studies [21–23]. In [24], the author has given a general idea of biomedical engineering applications of biology and mathematics by modeling the respiratory system. In [25], the authors have used fractional order model to characterize the impedance of its fractal structure. Besides, fractional order model have been involved for characterizing the impedance of the human respiratory system in many cases, with the healthy subjects [26], kyphoscoliosis [27], asthma [28] and COPD [29].

The aim of this paper is to evaluate the properties of the human respiratory system by means of fractional order model. In this context, a linear fractional system of commensurate order estimated by the fractional modeling of the respiratory impedance of the human respiratory system is presented. Given the real and the imaginary parts of the respiratory impedance, the parameters of the proposed model will be derived and used in order to distinguish between healthy, asthma and COPD diseases, based on the K-Nearest Neighbors classifier.

The rest of the paper is organized as follows: Section 2 introduces the database, the respiratory impedance, the modeling of the impedance of the respiratory system using a linear fractional order system and the proposed classification method. Section 3 discusses the classification technique followed by Section 4 where the conclusions are given.

2. Materials and methods

2.1. Patients

The study includes three sets of data collected from 15 subjects. These are 5 healthy subjects without a history of respiratory diseases considered as baseline and 10 patients diagnosed with two types of respiratory diseases (asthma and COPD), who performed the periodic evaluation of their lung function at Ghent University Hospital, Belgium. During the data recording the subjects were sitting in an upright position. The subjects' average breathing rate was around 0.4 Hz for healthy, 0.7 Hz for asthma and 0.25 for COPD. Biometric and spirometric variables are listed in Table 1. Written informed consent was obtained from all participants. This study and the consent procedure were approved by the local ethical committee of Ghent University Hospital, Ethical advice number B670201111936.

Table 1
Biometric parameters of the healthy, asthma and COPD subjects Values are presented as mean ± standard deviation.

	Healthy (5)	Asthma (5)	COPD (5)
Female/Male	1/4	2/3	0/5
Age (Years)	55 ± 5	52 ± 6	66 ± 5
Height (m)	1.70 ± 0.05	1.68 ± 0.05	1.67 ± 0.04
Weight (kg)	70 ± 15	70 ± 10	80 ± 13
BMI (kg/m^2)	24 ± 5	25 ± 5	28 ± 4

2.2. Input impedance measurement

Standard forced oscillation technique device applies small air pressure oscillations into the respiratory system during tidal breathing. Commercially available devices use a loudspeaker connected to a chamber to generate the pressure oscillations between 4 and 48 Hz. However these are broadly used, they can only create reliable oscillations until 4 Hz [24]. The FOT device developed presented in Fig. 1 creates reliable pressure oscillations by means of ventilators until the breathing frequency (0.1 Hz). A pushing fan draws fresh air into the devices and creates pressure oscillations which are guided through straws towards the respiratory system of the patient. The straws are necessary to guarantee a laminar flow. Air expired by the patient is drawn out of the device by the pulling fan. These fans are driven by a PWM signal which is generated by a PIC (Peripheral Interface Controller) microcontroller, and create pressure oscillations with a peak-to-peak size of 0.1 and 0.3 kPa. These values assure the patients safety and ensure the linearity of the system. Linearity is necessary to measure the respiratory input impedance. Therefore are the pressure $p(t)$ and flow $q(t)$ measured at the mouthpiece by the use of two pressure sensors and a pneumotachograph. The inner and outer pressure sensors are applied to measure the differential pressure across the pneumotachograph. The absolute pressure on the inner side of the pneumotachograph is calculated via this differential pressure and is assumed to be the same as in the device. Details on the device have been published in [6,31].

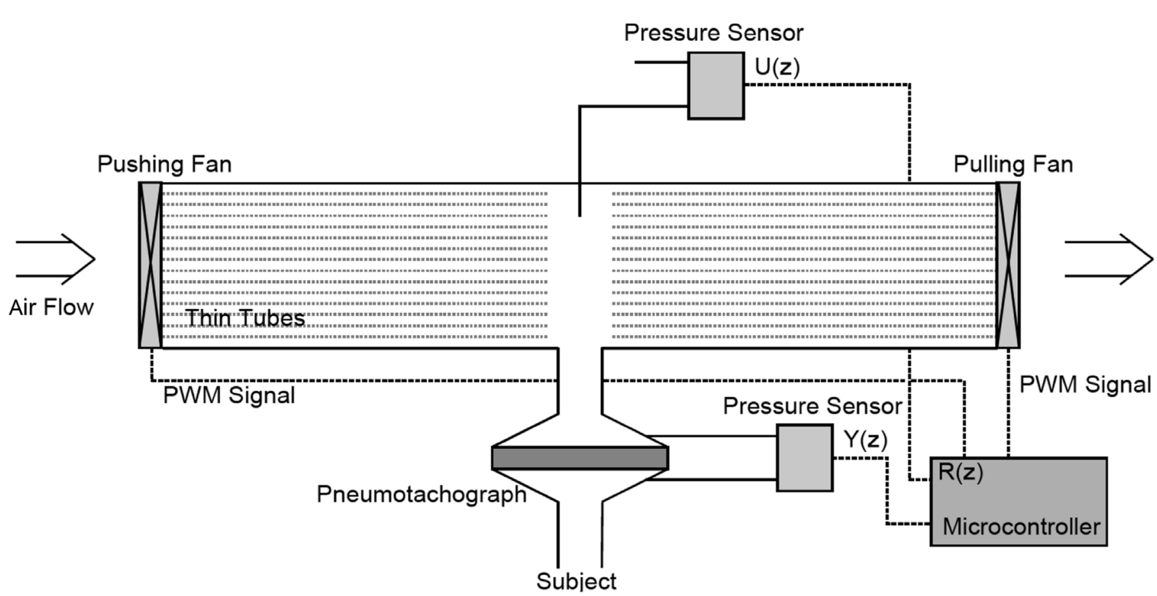

Fig. 1. Forced oscillation technique FOT device for low frequencies impedance evaluation.