Respiratory Sound Analysis for Bronchial Asthma Diagnostics

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Received 17 January 2020; Accepted 05February 2020

Abstract: The proposed diagnostic method is based on calculating the energy of the sound wave, which can be characterized as an integral of the squared FFT harmonic amplitude through frequency from 100 to 1500 Hz.The method involves recording the patient's respiratory sounds using an electronic device followed by numerical investigation of the specific spectral characteristics of these sounds. In this work, we propose a computerized method allowing one to improve capabilities of the fast Fourier transform (FFT) processing of respiratory sounds results of which can be applied in the diagnosis of the airways' diseases including pediatric bronchial asthma. Sound signals of 51 school children (aged 11.2±3.2) suffering from bronchial asthma and 22 healthy volunteers (aged 11.6±2.5) were acquired, using a computer-assistance system for recording respiratory sound, from three points located in mouth, above the trachea and above the right lung. The determined criteria, cut-off value of the energy of the sound wave, can be used for diagnostic of bronchial asthma as well as for differential diagnostic of the health state of a bronchial patient: exacerbation or well controlled symptoms. The developed method of asthma diagnostic demonstrates appreciably higher sensitivity from 63% up to 100% at high specificity up to 100% than these characteristics achieved in the traditional clinic diagnostic methods. The proposed approach for analysis of the respiratory sound can be one of additional methods of asthma diagnostics for simultaneous implementation with other clinical methods and can find application in the development of real-time monitoring of the asthma patients and in control of treatment effectiveness. The method can be adapted for smart phone application or deployed in low cost embedded system for non-contact technology for respiratory sound analysis which is important for remotes.
Keywords: bronchial asthma, children, respiratory sounds, computing analyzing, Receiver Operating Characteristic (ROC) of analysis.

I. INTRODUCTION

Small airways' obstructions are the most important clinical features of the bronchial asthma and some chronic lung diseases [**Error! Reference source not found.**]. The asthma diagnostics is based on the lung function assessment which is difficult performed in some cases of pediatric asthma, and diagnosis results based on respiratory sound analysis are substantially subjective [[1],[3]].

Respiratory sounds, which are generated by the turbulent and laminar air flows in the airways of different diameters, provide invaluable information concerning the pathological processes in pulmonary tissue or airways [[1], [6], 7]. Changes of airway characteristics, caused by a disease, lead to the appearance of specific additional noises in the respiratory sounds. The characteristic wheezes are commonly observed at the examination of patients with obstructive diseases of airways, such as bronchial asthma (BA) [[1], [6], 7]. The duration of asthma wheezes is from 80 ms till 250 ms and their frequency lies within the range from 100 Hz and 2500 Hz with the fundamental frequency between 100 Hz and 1000 Hz according to [5, 10, 12] or between 400 Hz and 1600 Hz according to other data [9, 13,19, 22].

Auscultation with a stethoscope suffers from subjectivity and variability in the interpretation of its diagnostic information [2,3]. Computerized analysis of respiratory sounds can be employed to overcome the drawbacks of acoustic auscultation [4-8] and can be a powerful diagnostic tool in diagnostics of the airways' diseases including pediatric bronchial asthma [[4],5,23and references therein].

In this paper we describe the developed computer-based system for registration of the respiratory sound and method of the sound analysis for bronchial asthma diagnostics. Unlike previous computer diagnostic methods [5, 10, 12] the developed method gives a numerical characteristic of the sound the value of which allows one to diagnose the health state of patients: healthy, exacerbation, remission (well controlled asthmatic symptoms).

II. COMPUTER BASED SYSTEM FOR REGISTRATION OF THE RESPIRATORY SOUND

This cross-sectional comparative studywas carried out on patients of Department of Pediatrics, Perm State Medical University, Perm, Russiaand the sound analysis was performed together with the group of Physics Department, Ben-Gurion University, Beer-Sheva Israel from November 2018 to January 2020. A total 51 school children suffering from bronchial asthma and 22 healthy volunteers subjects (both male and females) of aged 11.2±3.2 years were for in this study.

Study Design: Simple cross-sectional comparative study.

Study Location: This was a tertiary care teaching hospital-based study done atDepartment of Pediatrics, Perm State Medical University, Perm

Study Duration: November 2018 to January 2020.

Sample size: 73 patients.

Sample size calculation: The sample size actually obtained for this study was 73 patients. We divided the asthmatic patients into two subgroups according to the state of health: «subgroup 1»- exacerbation of BA (n_1=19) and «subgroup 2» - BA withwell controlled symptoms (n_2=32). The clinical examination of the patients and the record of respiratory sounds were made in Perm children's city hospital No. 3 (Russia) The study complies with the declaration of Helsinki (adopted in June 1964, Helsinki, Finland) and revised in October 2000 (Edinburg, Scotland). Written informed consents were obtained from parents of all examined children.

Subjects & selection method: The study population was drawn from consecutive asthmatic patients who presented to Perm children's city hospital No. 3 (Russia). The clinical examination of the patients and the record of respiratory sounds were made in Perm children's city hospital No. 3 (Russia).

The main requirements to a registration system are:

- high linearity of the amplitude-frequency characteristic in the frequency range from 100 Hz to 2 kHz which is most informative for respiratory sounds;
- high sampling frequency allowing exactly discretization of a signal with frequency up to a few kHz;
- safeness (the system has to be safe for a patient and a doctor);
- using of the system does not require a special training;
- the system allows one to record at various points of the human body;
- light, suitable for easy transportation to using outside medical institutions.

We have designed and tested several registration systems built using parts available on the market. The systems contain an electronic sound sensor and an analog-to-digital convertor. One of the systems consists the microphone Sony (ECM 77B) and the external sound card (Sound BLASTER, Singapore) [23]. The modern stethoscopes, e.g. Panasonic, allows one to include electronic microphones in their design. Fig. 1 presents one of the developed systems. Using a sound generator of a white noise we tested the registration systems based on electret microphones included in stethoscopes and external sound cards. The developed systems demonstrate well linearity of the amplitude-frequency dependences in the frequency range from 100 Hz to 2000 Hz; the nonlinearity does not exceed the accuracy of measurement.

Fig. 1 Registration system based on the microphone Panasonic WM61a and sound card DEXP 3D CM108 USB 2.0.

The developed software allows us to record sound waves with sampling frequency up to 96 Hz. To reduce the influence of casual variations of respiratory sound intensity on the results the sounds are recorded during several respiratory cycles for about 25 s. The software allows one to introduce the main information about a patient (name, family, age, illness history, etc.) and to visually control the sound record. The software automatically detects also some defects (Fig. 2) of the records. The waveforms are presented in a normalized form, a signal is normalized by the highest amplitude. The presentation of the normalized spectra enables to avoid the necessity of taking into account the natural variations of the breathing intensity.

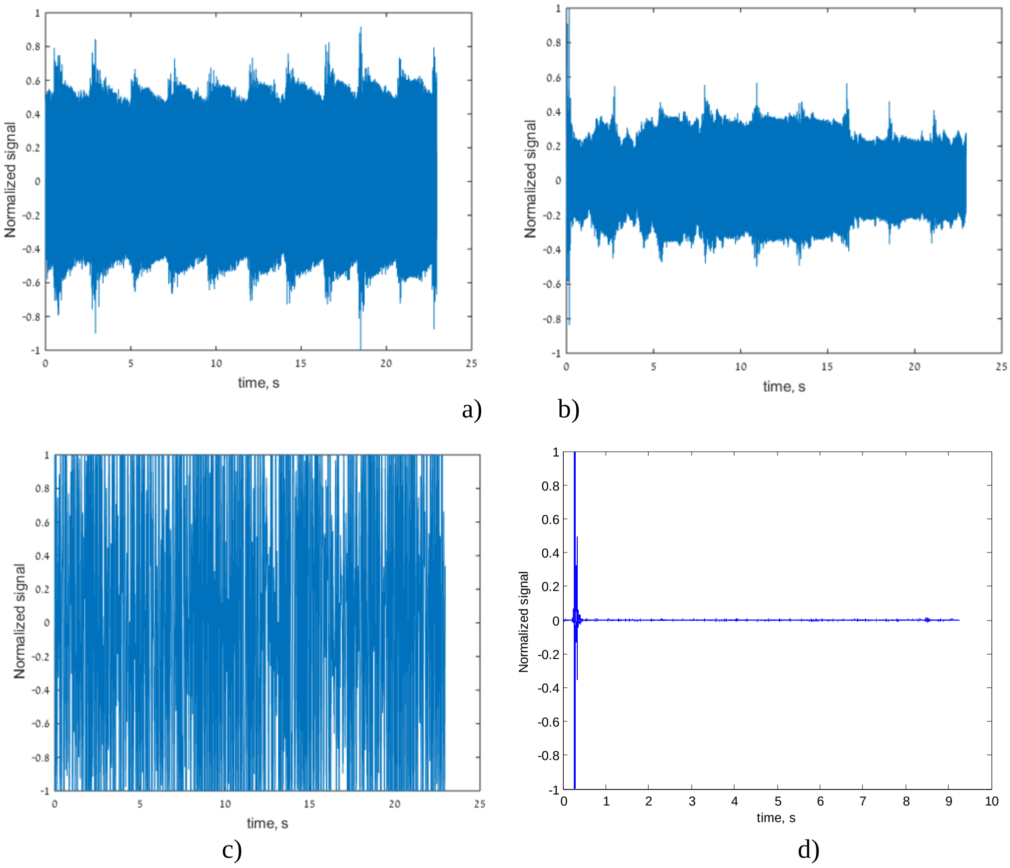


Fig. 2 Examples of the respiratory sound records: a) a normal record suitable for analysis; and records unsuitable for analysis: b) a patient or/and a microphone move; c) a signal is too strong; d) there is no contact of a microphone with the patient body.

III. COMPUTER ANALYSIS OF RESPIRATORY SOUND AND ASTHMA DIAGNOSTICS

Procedure methodology. The respiratory sounds were recorded by a microphone at three points: in immediate proximity to the mouth (point 1), at a point under the trachea (point 2) and at a point on the upper lobar of right lung (point 3). At choosing the characteristic points for the respiratory sounds we took into account, on the one hand, that asthma affects all bronchial tubes and, on the other hand, that the registered cardiac murmur should be reduced for more correct analysis of the respiratory sound. The respiratory sound from the third point can characterize a local lesion while the sound from the first and second points can contain a superposition of the specific asthma wheezes formed into all small airways. The superposition can amplify the wheezing. Difference in the form of the sound waves from the first and second points is determined by the influence of the air flow inside trachea, mouth, and nose. The analysis of the sound from several points allows us to define a more informative point.

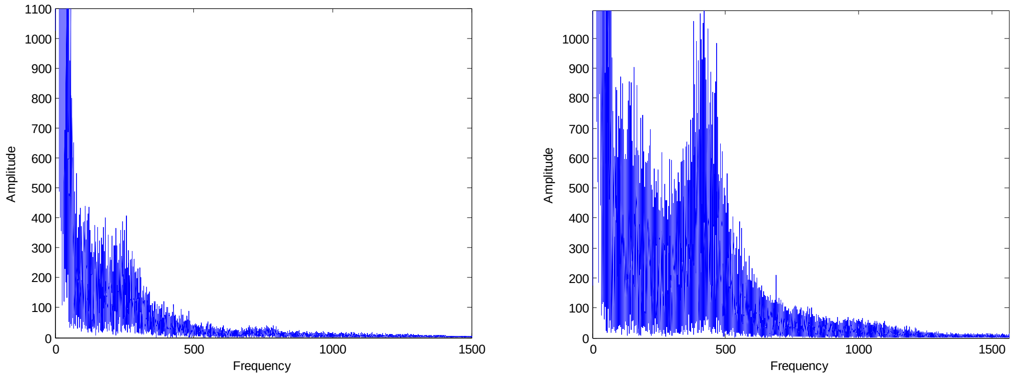
In the test 51 school children (aged 11.2±3.2) suffering from bronchial asthma and 22 healthy volunteers (school children, aged 11.6±2.5) have participated. We divided the asthmatic patients into two subgroups according to the state of health: «subgroup 1»- exacerbation of BA (n_1=19) and «subgroup 2» - BA well controlled symptoms (n_2=32). The clinical examination of the patients and the record of respiratory sounds were made in Perm children's city hospital No. 3 (Russia) The study complies with the declaration of Helsinki (adopted in June 1964, Helsinki, Finland) and revised in October 2000 (Edinburg, Scotland). Written informed consents were obtained from parents of all examined children.

The respiratory sound of asthmatic patients is characterized by existence of specific wheezing. The wheezinghas a typical duration between 80 ms and 250 ms, during the expiration phase, with the fundamental frequency from 100 Hz and 1600 Hz [5, 9,10, 12, 13,19, 22]. Thewheezingis manifested as an increase in the amplitudes of the harmonics of the Fast Fourier transform (FFT) in a certain frequency range (Fig.3). This increase in amplitude can be considered as increasing the energy of the sound wave, characterized by the quantity *E*, defined as

$$E = \int_{100}^{1500} F(f)^2 \, df \,, \qquad (1)$$

where *F* is the amplitude of the harmonic of frequency *f*.

As example Fig. 4presents the results of analysis of the respiratory sounds recorded at point 3. Note no all patients and volunteers could participate at all examinations.



a) b)

Fig. 3 FFT spectra of the respiratory sound signals from point 2 of a) a healthy volunteer and b) the bronchial asthma patient.

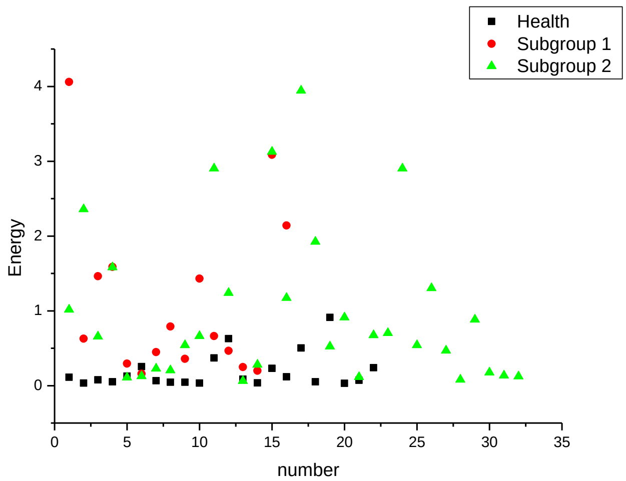


Fig. 4 Energy (in arbitrary units) of the respiratory sound at point 3. A number of an exam is listed on the horizontal axis (for each group the numbers areindependent).

Statistical analysis

The efficiency of the sound analysis assessment in each point is evaluated by calculating sensitivity (SEN), specificity (SPE) and Receiver Operating Characteristic (ROC) of analysis by using DeLong's method (1988) for the calculation of the Standard Error of the Area Under the Curve (AUC) and the Youden index (J)in two subgroups of BA. The Youden index:

$J = \max [SE_i + SP_i - 1]$

where SE_i and SP_i are the sensitivity and specificity over all possible threshold values [25].

SEN is the proportion of actual bronchial asthma cases correctly identified by the methods while SPE is the proportion of actual non-bronchial asthma (healthy) cases correctly identified. We used MedCalc Software version 14.12 (2014).

IV. RESULTS

We established the cut-off levels for each point of the respiratory sound registration and subgroup. The cut-off levels for both subgroups of asthmatic patients are highest for point 1 and decrease for second and third points (Table 1). Note that the cut-off levels of Subgroup 1 (Exacerbation of asthma) for points 2 and 3 are less than these levels for Subgroup 2 (asthma with well controlled symptoms, remission). This can be explained by the following: the asthmatic state is characterized by bronchial narrowing till the total spasm, when air flow is absent and, hence, respiratory sound is absent, too. In point 1 the relation between cut-off levels is reverse, it may be, due to intensification of respiratory sound in larynx. Various cut-off levels allow one to perform diagnostic of the state of patient health: separate Exacerbation of asthma and asthma with well controlled symptoms.

The maximal values of the Youden index are 0.6923 for point 1 and 0.6818 for point 2 for subgroup 1and 0.700 for point 3 for subgroup 2. Thus, the analysis of the respiratory sound at points 1 and 2 should be used for diagnosis of acute bronchial asthma and at points 3 should be used for its diagnosis with well controlled symptoms, respectively.

The proposed method has the biggest sensitivity for diagnosis of asthma exacerbation at point 2 (SEN = 100%), and for diagnosis of BA well controlled symptoms at point 1 (SEN = 73%) (Table 2). The results (Table 2) allow us to assume that respiratory sounds from points 1 and 2 are more suitable for screening-test and ones from point 3 – for differential diagnosis (SPE is 91% for asthma exacerbation and is 100% for asthma well controlled symptoms). Thus, the analysis of the sound at these points can be used for differential diagnosis.

The developed method of asthma diagnostic demonstrates appreciably higher sensitivity (SEN) from 63% up to 100% at high specificity (SPE) up to 100% than these characteristics achieved in the usual diagnostic methods: spirometry [26]: SEN = 29%, SPE =90%, and 39.8% of the correct test; peak flow variability in the SAPALDIA study [27]: SEN =40% and SPE=83%; for children [28]; SEN=31% and SPE=94%.

Table 1Cut-off levels and Youden indexesof the respiratory sound registration.

	Point 1		Point 2.		Point 3.	
	Cut-off level	J (Youden index)	Cut-off level	J (Youden index)	Cut-off level	J (Youden index)
Subgroup 1 Exacerbation of asthma	20.332	0.6923	0.1262	0.6818	0.1696	0.5933
Subgroup 2 asthma with well controlled symptoms	9.4577	0.4833	0.5021	0.5341	0.2877	0.7000

Table 2The results of ROC analysis for assessing the energy method analysis of respiratory sounds.

	Point 1.	Point 2.	Point 3.
Subgroup 1 Exacerbation of asthma	SEN =69% SPE= 100% AUC = 0.875 p<0.001	SEN = 100% SPE = 68% AUC = 0.895 p<0.001	SEN = 68% SPE = 91% AUC = 0.792 p<0.001
Subgroup 2 asthma well controlled symptoms	SEN = 73% SPE = 75% AUC =0.783 p=0.0051	SEN = 63% SPE = 91% AUC = 0.851 p<0.001	SEN = 70% SPE = 100% AUC = 0.893 p<0.001

V. DISCUSSION

The developed systems consisting electronic sound sensors, an analog-to-digital convertors, and software allow one to record the respiratory sound from various points at human body. The recorded audio fails are suitable for the computer diagnostics.

We developed the method of computer diagnostics of bronchial asthma based on the specific characteristics of respiratory sound. Respiratory sounds of patients with bronchial asthma are characterized by a specific wheezingwith duration from 80ms to 250 ms and presented in FFT spectra as harmonic amplitude increase within the frequency range near 400 Hz. These specific properties of wheezes make it possible to suggest a computerized processing method that can be a basic of an objective, automatic technique for bronchial asthma diagnosis. It was shown that the sound collected from the second point (under trachea) contains more information than those from the first and third points (in mouth and on right upper lobe of lung).

The empirical criteria of healthy and ill as well as for diagnosis of the health stage of patient were obtained. It should be noted that these criteria were obtained at the testing of a relatively small group of patients of a certain age (~12 years). Further studies should be performed to reveal the dependence of the criteria on age as well as to refine them after testing larger groups.

The proposed method of the respiratory sound analysis by calculating energy of respiratory sound has a high diagnostic value (AUC varies from 0.783 to 0.895). The proposed approach can be used for diagnosis of asthma (mainly at point 1 and 2) and for asthma differentiation with other lung diseases at point 3.

The proposed approach for analysis of the respiratory sound can find application in the development of real-time monitoring of the asthma patients which is especially important for small children for whom it is difficult to perform the lung function test.

VI. CONCLUSION

The results (Table 3) allow us to assume that respiratory sounds from points 1 and 2 are more suitable for screening-test and ones from point 3 – for differential diagnosis (SPE is 91% for BA exacerbation and is 100% for BA well controlled symptoms). Thus, the analysis of the sound at these points can be used for differential diagnosis.

ACKNOWLEDGMENTS

This research was supported by a grant from the Ministry of Science & Technology,Israel & Russian Foundation (RFBR),Russian Federation (the joint research project № 19-515-06001).

REFERENCES

[1]. Global Initiative for Asthma (GINA), 2018 GINA Report: Global Strategy for Asthma Management. Available from: https://ginasthma.org/2018-gina-report-global-strategy-for-asthma-management-and-prevention. Accessed October 20, 2018.

[2]. P. L. P. Brand, E. Baraldi, H. Bisgaard, A .L. Boner, J. A. Castro-Rodriguez, A. Custovic et al., Definition, assessment and treatment of wheezing disorders in preschool children: an evidence-based approach, ERS Task Force Report, *EurRespir J*, vol. 32, pp. 1096-1110, 2008;

[3]. Global Strategy for the Diagnosis and Management of Asthma in Children 5 Years and Younger: (GINA) 2009 available from: www.ginasthma.org

[4]. A. R. A. Sovijärvi, J. Vanderschoot, and J. E. Earis, Standardization of computerized respiratory sound analysis, *EurRespir Rev*, vol. 10, pp. 585-595, 2000;

[5]. S. Reichert, R. Gass, A. Hajjam, C. Brandt, E. Nguyen, K. Baldassari, and E. Andres, The ASAP project: A first step to an auscultation's school creation, *Respiratory Medicine CME* 2, pp. 7-14, 2009.

[6]. S. Reichert, R. Gass, C. Brandt, and E. Andres, Analysis of respiratory sounds: state of the art, *Clinical Medicine: Circulatory, Respiratory and Pulmonary Medicine*, vol. 2, pp. 45–58, 2008.

[7]. N. Gavriely, *Breath Sounds Methodology*, CRC Press, Boca Raton, 1995

[8]. S. Saeed and R. Body, Towards evidence based emergency medicine: best BETs from the Manchester Royal Infirmary. Auscultating to diagnose pneumonia, *Emerg Med J.*, vol. 24, pp. 294–96, 2007.

[9]. L. Hadjileontiadis, K. Panoulas, T. Penzel, V. Gross, and S. Panas, On applying continuous wavelet transform in wheeze analysis, *Engineering in Medicine and Biology Society IEEE*, vol. 2, pp. 3832–3835, 2004.

[10]. A. R. A. Sovijarvi, F. Dalmasso, J. Vanderschoot, L. P. Malmberg, G. Righini, and S. A. T. Stoneman, "Definition of terms for applications of respiratory sounds," *EurRespir Rev*. vol. 10, pp. 597–610, 2000.

[11]. A. R. A. Sovijarvi, L. P. Malmberg, G. Charbonneau, J. Vanderschoot, F. Dalmasso, C. Sacco, M. Rossi, and J. R. Earis, Characteristics of breath sounds and adventitious respiratory sounds, *EurRespir Rev.*, vol. 10, pp. 591–596, 2000.

[12]. K. Kosasih, U. R. Abeyratne, and V. Swarnkar, High frequency analysis of cough sounds in pediatric patients with respiratory diseases, *Conf. Proc IEEE Eng Med Biol Soc. 2012*; pp. 5654-5657, 2012.

[13]. A. Yi, A software toolkit for respiratory analysis, *MIT Computer Sound and Artificial Intelligence Laboratory*, vol. 1, pp. 215–216, 2004.
[14]. R. Mhetre, U. R. Bagal, Respiratory sound analysis for diagnostic information, *IOSR Journal of Electronical and Electronics Engineering*, vol. 9, 5, Ver. IV, pp. 42-46, 2014.
[15]. E.G. Furman, E.Y. Yakovleva, S.V. Malinin, G.Furman, V. Sokolovsky, Computer-assisted assay of respiratory sound of children suffering from bronchial asthma, *Clinical Medicine*, v. 6, no., 1, 83-87, 2014.
[16]. Thomas A. Lasko, Jui G. Bhagwat, Kelly H. Zou, Lucila Ohno-Machado. The use of receiver operating characteristic curves in biomedical informatics,*Journal of Biomedical Informatics* 38, 404–415, 2005
[17]. A. Schneider, L. Gindner, L. Tilemann, T. Schermer, G.-J. Dinant, F. Joachim Meyer and J. Szecsenyi, Diagnostic accuracy of spirometry in primary care,*BMC Pulmonary Medicine*9, 31, 2009,doi:10.1186/1471-2466-9-31
[18]. N. Künzli, E. Z. Stutz , A. P. Perruchoud, etal., Peak flow variability in the SAPALDIA study and its validity in screening for asthma-related conditions. *The SPALDIA Team. Am J Respir Crit Care Med.* 160(2):427-34, Aug. 1999.
[19]. M. A. Valadares et al., Sensitivity for the Diagnosis of Obstructive Disorder in Children of Asthmatic Mothers. *J Aller Ther*2013, S2 http://dx.doi.org/10.4172/2155-6121.S2-006

E. Furman, etal. "Respiratory sound analysis for bronchial asthma diagnostics."*IOSR Journal of Engineering (IOSRJEN),* 10(1), 2020, pp. 53-59.