Asthma Attack Monitoring and Diagnosis: A Proposed System

Mahmood Al-khassaweneh[1*], Suzan Bani Mustafa[1], Faisal Abu-Ekteish[2]
[1]Computer Engineering Department, Hijjawi Faculty for Engineering and Technology, Yarmouk University
[2]Department of Pediatrics and Neonatology, Jordan University of Science and Technology
Irbid ,Jordan

***Abstract*- In recent decades, childhood asthma has become more widespread and thus become a worldwide concern. The diagnosis of childhood asthma depends highly on the physician experience and the collaboration from the child part, which sometimes hard to achieve. In many cases, the symptoms might mislead in the diagnosis of asthma. In this paper, we propose a method to diagnose and classify asthma in children. The proposed method is based on using cough sound to extract features that help in asthma diagnosis. Moreover, we propose a hardware system for asthma attack monitoring. The proposed system was implemented and performed by a self-developed computer program written in MATLAB using many cough sound samples of asthmatic and non-asthmatic children.**

Keywords: Asthma, Cough, Sound Analysis, Linear Correlation Coefficient, Normalized Root Mean Squared Error, Asthma Monitoring and Diagnosis.

I. INTRODUCTION

Asthma is the leading chronic childhood illness with substantial burden on affected children and their families [1]. Its prevalence has varied from one area of the world to another and between different age groups. Higher prevalence rate have been found among children in industrialized Western countries than in developing countries as in Asia and Africa [2]. Studies have suggested that asthma is more common in urban than rural areas [3, 4]. This variation has been explained partly by difference in methods used to study asthma and diagnostic criteria applied [5, 6]. Asthma prevalence in the Middle East is reported between 5-23%, but in general is lower than in developed countries [7-9]. Two studies have been conducted in Jordan to find the prevalence of asthma and wheeze among school children. The first study published in 1996 and showed asthma prevalence was 4.3% among primary school children in north of Jordan and the second study was part of the International Study of Asthma and Allergies in Childhood (ISAAC) –phase three published in 2009 . The study was conducted in Capital Amman and Mafraq province at the same period. The study showed asthma prevalence rate diagnosed by physician was 9.3% [10]. These figures include primary school children age 6-7year and older children 13-14 years of age. The physician diagnosed asthma rate was slightly higher among 6-to 7-year old children(9.4%) compared with (8.8%) the 13- to 14-year old group [10]. These studies showed the prevalence of asthma among Jordanian school children is increasing in last 10 years by more than 100% which is consistent with other international studies [11]. Several hypotheses have been proposed to explain the increased frequency of asthma in all age groups. These include improved hygiene resulting in less exposure to infectious pathogen, increase incidence of early respiratory viral infections and increased awareness and recognition of asthma by physician and patients [12, 13]. Pediatric asthma account for a large proportion of childhood hospitalization, healthcare visit, absenteeism from day care/school and missed work days of parents. Multiple factors are responsible for excessive asthma morbidity including under treatment, inadequate anti-inflammatory medication, lack of adherence to recommended medications and regimen and inadequate education of patient or caretaker. Better understanding of the natural course of asthma and improved asthma control can lead to a decreased burden on the patient, their family and society. The burden of asthma consists mainly of a decreased quality of life for the patient and their family, as well as high costs for society. The healthcare expenditures for asthma in developed countries are 1-2% of the total healthcare costs.

The burden of asthma among children is high in Jordan and it has an impact in their social, economic and quality of life. It is the most common cause of school absence in children. Jordan is a developing country with limited resources. At least 50% of our population is below the age of 18 years. Approximately 80% of children with asthma develop symptoms before five years of age, but the disease is frequently misdiagnosed or not suspected particularly in infants and toddlers [14]

Chronic symptoms are key aspects of asthma. The typical medical history provides key information in diagnosing asthma. Intermittent dry coughing mainly at the time of sleeping with or without expiratory wheezing are the most common symptoms of asthma. Cough can be the only clinical presentation of asthma in about 10% of asthmatic children. There are many symptoms could be present or absent and depends on the age of presentation. Not all asthmatic children

*Corresponding Author: khassaweneh@yu.edu.jo

have wheeze and not all wheezers are asthmatic. Differential diagnosis of childhood asthma is wide. Many childhood respiratory conditions can present as symptoms and signs similar to asthma like bronchiolitis, gastroesophygeal reflux, cystic fibrosis and many other conditions. There is no single test that we can depend on to confirm the diagnosis of asthma. So the diagnosis depends mainly on clinical profile of the patient. Finding another tool or test in addition to the clinical picture will be very helpful in confirm the diagnosis particularly in equivocal cases.

The symptoms of childhood asthma include coughing, wheezing, shortness of breath and chest narrowness. Asthma diagnosis can be difficult in children because there are other conditions that can cause similar symptoms and it is very complicated because of difficulty of understanding the children, so the operation of diagnosis is highly dependent on the physician experience and the collaboration from the child part. There is a relationship between the cough sound and the asthma in the children who do not wheeze. One of the medical publications [15] showed that asthma can be diagnosed by using coughing not by wheezing. The authors in [15] mention that asthma can occur without wheezing when obstruction involves predominantly the small airways. In addition, wheezing may be due to airway obstruction. However, in some types of asthma, coughing may be the only symptom, such as exercise-induced or nocturnal asthma. Therefore, it is preferred to use cough to diagnose asthma.

The research on how to diagnose asthma cough is few. For example in [16], the authors used the spectrogram and time-expanded waveform of the cough signal to diagnose asthma. Other researchers analyze the sound signal using the fast Fourier transform [17]. Recently in [18], the authors used wavelet transform to study the characteristics of the cough sound for asthmatic and non-asthmatic patients.

Our proposed method aims to collect and analyze cough sound signals of asthmatic and non-asthmatic children. The features extracted are used to diagnose asthma. The features that we propose in this paper are the Linear Correlation Coefficient and the Normalized Root Mean Squared Error (NRMSE). In this study, the proposed algorithm is developed using the MATLAB software. Moreover, in we introduce a suggested hardware design of the system with the main components for asthma attack monitoring based on the cough sound.

II. DATA COLLECTION

The cough sound signals were recorded in a quiet room using a digital recorder. The total number of recordings used in this study is twenty recordings, including ten recordings for asthmatic group and ten recordings for non-asthmatic group. The recording took place at Jordan University hospital in Amman and Princess Rahma Hospital in Irbid both in Jordan.

III. COUGH SOUND ANALYSIS

In order to study the feature of the recorded cough signal, we used the following two measures:

A. LINEAR CORRELATION COEFFICIENT

The correlation between two signals is a measure of how much the two signals are close to each other and is given by [9, 10]:

$$r=\frac{n\sum xy-\left(\sum x\right)\left(\sum y\right)}{\sqrt{n\left(\sum x^2\right)-\left(\sum x\right)^2}\sqrt{n\left(\sum y^2\right)-\left(\sum y\right)^2}} \qquad (1)$$

B. NORMALIZED ROOT MEAN SQUARED ERROR

The normalized root mean squared error (NRMSE) measures how much the two signals deviate from each other and is given by [11, 12]:

$$NRMSE=\frac{E\left(\left(\vartheta-\theta\right)^2\right)}{x_{mas}-x_{\min}} \qquad (2)$$

where E is the expected value.

IV. THE PROPOSED METHOD

The proposed method of using the cough signal to diagnose asthma can be summarized as follows:

1. The cough sound of the training samples for asthmatic and non-asthmatic patients are recorded
2. The average signal of the asthmatic and non-asthmatic patients is computed (Avg_A, Avg_NA), respectively.
3. The linear correlation coefficient (Corr) and the Normalized Root Mean Squared Error (NRMSE) are computed for every training sample.
4. We repeat step 3 with the testing samples. If the signal is correlated with the Avg_A then it is considered asthma, otherwise, it is considered non-asthma. Similarly, if the testing signal is having lower NRMSE with Avg_A then it is considered asthma otherwise, it is non-asthma.
5. The results of both the correlation and the NRMSE are used for final diagnosis. If both agree, then the decision is based on their agreement, whether it is asthma or non-asthma. If they differ in decision, the patient needs check.

V. RESULTS AND DISCUSSION

The proposed algorithm was tested on 20 samples. To clarify the naming of these samples. Letter M refers to male and F to female and the number indicates the age and the letter A for asthmatic and NA for non-asthmatic. The training samples are four samples (two males and two females) for each group, first group include: male 12 years asthmatic (M12A), female 12 years asthmatic (F12A), male 9 years asthmatic (M9A), female 9 years asthmatic (F9A), and second group include: male 12 years non-asthmatic (M12NA), female 12 years non-asthmatic (F12NA), male 9 years non-asthmatic (M9NA), female 9 years non-asthmatic (F9NA). The parameters Avg_A and Avg_NA are the average of asthmatic samples and non-asthmatic samples, respectively.

Table 1 shows the correlation coefficient between each cough sound samples and the average cough sound of asthmatic children and non-asthmatic children. Moreover, table 1 shows the normalized root mean square error (NRMSE) values. The results in this table are as expected in which the correlation is high for asthmatic signals with Avg_A and low for Avg_NA. Similarly, the NRMSE results show that for the asthmatic signals, the NRMSE is lower with the Avg_A and higher with Avg_NA.

	Correlation		NRMSE	
	Avg_NA	**Avg_A**	**Avg_NA**	**Avg_A**
M12NA	0.6357	0.2646	28.3504	32.9929
F12NA	0.4274	-0.0975	22.1329	27.8185
M9NA	0.1385	-0.5108	19.5549	25.4251
F9NA	0.5183	-0.1994	17.9859	25.6325
M12A	-0.1628	0.2120	23.5145	19.7620
F12A	-0.0730	0.6901	29.2596	20.2090
M9A	0.0025	0.1522	23.5914	22.0181
F9A	-0.0049	0.6516	31.4856	23.6711

Table 1: The Linear Correlation Coefficient for Cough Sound Samples.

The test samples (Test Sample1-12) that are tested represent: F8NA, F7A, M12A2, F11NA, F8A, M10A, M11NA, M11NA2, F10A, M7NA, M10NA and F9A2 respectively. Table 2 contains the linear correlation coefficient (Corr) and the normalized root mean square error (NRMSE) results for the test samples with Avg_A and Avg_NA.

From the results on table 1 and table 2, the signals were classified based on their correlation factors and NRMSE to be asthmatic or non-asthmatic. These decisions are then combined according to majority vote and classified into three categories: Non-Asthmatic (NA), Asthmatic (A) and Need to Check (NC) as shown in table 3.

Database Samples / Test Samples	**Corr**		**NRMSE**	
	Avg_NA	**Avg_A**	**Avg_NA**	**Avg_A**
Test Sample1	0.5551	-0.3621	18.4463	28.0828
Test Sample2	-0.0865	0.1801	35.8600	32.9434
Test Sample3	-0.4647	0.2246	36.9851	29.9118
Test Sample4	0.2013	0.0593	19.0928	20.4884
Test Sample5	-0.0612	0.0691	37.8376	36.3853
Test Sample6	-0.0654	-0.0068	22.9243	22.1147
Test Sample7	-0.2498	-0.1973	26.9675	26.1729
Test Sample8	0.3887	-0.0829	22.4268	27.4614
Test Sample9	-0.1286	0.1185	34.4459	31.7812
Test Sample10	0.1243	0.1936	22.6408	21.8421
Test Sample11	0.2693	-0.2626	31.3712	36.9374
Test Sample12	0.2411	-0.1694	34.1999	38.5711

Table 2: The Corr and NRMSE Results of the Test Samples.

Database Samples / Test Samples	**Corr**	**NRMSE**	**Actual**	Diagnosis
Test Sample1	NA	NA	**NA**	Non-Asthmatic
Test Sample2	A	A	**A**	Asthmatic
Test Sample3	A	A	**A**	Asthmatic
Test Sample4	NA	NA	**NA**	Non-Asthmatic
Test Sample5	A	A	**A**	Asthmatic
Test Sample6	NC	A	**A**	Need to Check
Test Sample7	NC	NC	**NA**	Need to Check
Test Sample8	NA	NA	**NA**	Non-Asthmatic
Test Sample9	A	A	**A**	Asthmatic
Test Sample10	NC	A	**NA**	Need to Check
Test Sample11	NA	NA	**NA**	Non-Asthmatic
Test Sample12	NA	NA	**A**	Non-Asthmatic

Table 3: The Classification of the Test Samples.

VI. PROPOSED HARDWARE SYSTEM

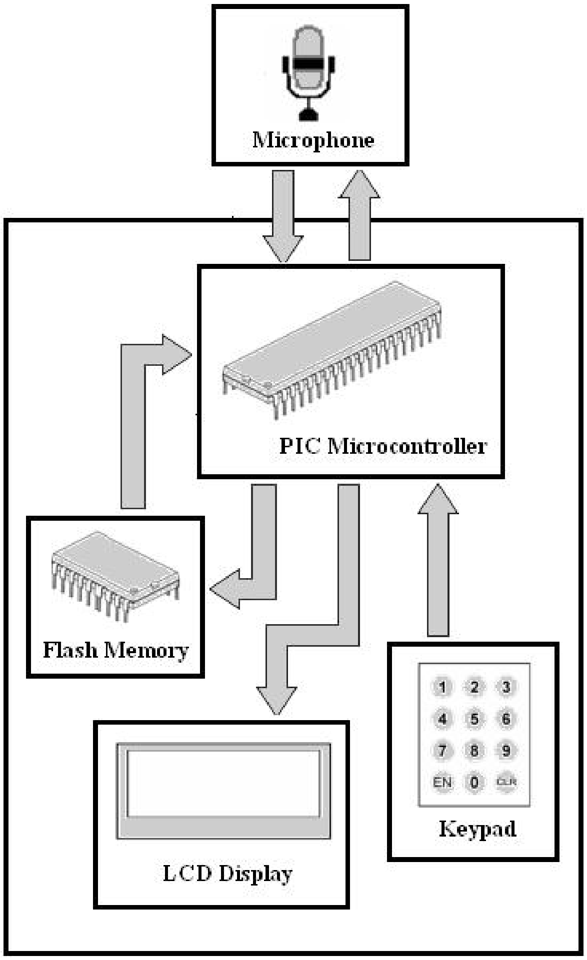

Fig.1. Hardware system for monitoring asthma attack

Since asthma attack can be serious and may cause death in severe cases, we propose a hardware system to monitor and diagnose asthma attack. The proposed system is shown in figure 1. The system takes and processes the cough sound and makes an automatic classification for the cough sound to diagnose the state of child according the method proposed previously. If an asthma attack present an alarm goes on (represented here by a message in the LCD display). The operation of the proposed embedded system can be summarized as follows:

After turning the power on, the Pic Microcontroller is initialized and when the user presses key EN in the keypad, the microphone is turned on, the cough sound (input audio) is transformed from acoustic signal to electric signal using the microphone. The input audio signal is then converted from analog data to digital data by the A/D converter inside the Pic Microcontroller. Next, the digital data of cough sound is stored in the flash memory. The microphone will still on and the cough sound (input audio) is continue to be read, converted and stored until the user presses key 0 in the keypad. When the user presses key 0, the microphone is turned off, the data stored in the flash memory will be loaded to start the cough sound analysis for diagnosis process. The results of the cough sound analysis and the final diagnosis will be stored in the flash memory. The final result (diagnosis of cough sound) will be displayed on the (LCD). For starting a new operation of diagnosis, the user will have to press key CLR in the keypad and the data will be cleared in the flash memory and the liquid crystal display (LCD) and so on.

VII. CONCLUSIONS

In this paper, we used cough signal to diagnose asthma. The cough sound analysis we performed enabled us to correctly classify about 85-90% of the sound cough records. Moreover, we proposed a hardware system to monitor asthma attack. The proposed hardware system can be used at homes to help parents monitor their asthmatic child.

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