2016 Conference on Advances in Signal Processing (CASP)
Cummins College of Engineering for Women, Pune. Jun 9-11, 2016

Level of Asthma: Mathematical Formulation based on Acoustic parameters

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***Abstract*—One of the most important research topics in biomedical electronics now-a-days is voice analysis. Voice medium is the most natural form of communication known to human civilization. Voice analysis can help in extracting information about a person's health and can help in determining if a person is suffering from some kind of illness such as cough, cold, fever etc. Voice analysis can also help in determining a person's emotion since a normal human voice is different from the voice when the person is happy, sad, anxious, stressed etc. There are several voice pathological disorders related with nasal, neural, respiratory and larynx diseases. As a result, analysis and diagnosis of vocal disorders has become an important medical procedure. This paper presents a method to differentiate five categories of people – i) healthy people, ii) people suffering from intermittent asthma, iii) people suffering from mild asthma, iv) people suffering from moderate asthma, and v) people suffering from severe asthma, based on their voice analysis. The method involves the development of a numerical formula using the voice parameters, like Fundamental Frequency, Jitter, Shimmer and Maximum Phonation Time. The purpose of this study is to determine the Level of Asthma in a person by their voice analysis.**

Keywords— Asthma, Level of Asthma, Acoustic analysis, Multi-Dimensional Voice Program, Computerized Speech Lab

I. INTRODUCTION

Voice involves two separate processes: first one produces an initial sound and the other one modifies it. For example, at the larynx, a sound is produced whose spectrum contains several different frequencies. Then, using tongue, teeth, lips, velum etc., the spectrum of that sound is modified over time. The energy required for producing sound while speaking comes from air expelled from the lungs. This flow passes between the vocal folds at the larynx. The vocal folds vibrate in voiced speech, which allows passage of air puffs, which, in turn, produces sound waves. The vocal folds do not vibrate while whispering, but are held close together, which produces an irregular flow of air. This, in turn, makes a sound comprising a mixture of several frequencies, which is called broadband sound. This allows us to divide speech sounds into voiced and unvoiced [1].

The most natural form of communication known to human civilization is voice medium. Voice communication is required in a person's professional as well as in personal life. It is required for earning livelihood, expressing feelings, and in other day-to-day social interactions [2]. In police and Forensic Scientists, sometimes voice is the only clue available in identifying the criminal. The voice of each person is different because the anatomy of vocal cavity, oral cavity, nasal cavity, and vocal cords is specific to the individual. People in different countries, in fact, people in different parts of the same country, speak with different accents. There are some people who run their words together, and there are others who talk with pauses between their words [3].

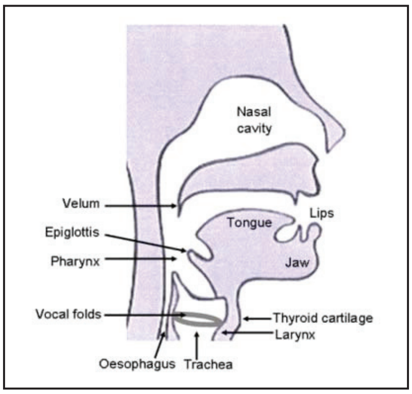

Figure 1. Elements involved in speech production [1].

There are several voice pathologic disorders related with nasal, neural, respiratory and larynx diseases. As a result, analysis and diagnosis of vocal disorders has become an important medical procedure. Table 1 shows the parameters that can be extracted using voice analysis, and the information that can be extracted from those voice parameters [2].

TABLE I. PARAMETERIC FEATURES OF VOICE [2]

Parameters	Features	Information extracted
Amplitude	Shim (local, db)	Variation in loudness of voice.
Frequency	Jitter (local, absolute)	Variation in pitch of voice.
Pitch	Maximum/Minimum pitch	Peaks of the sound spectrum of voice
Harmonic	Noise-to-harmonic ratio	Relative highness or lowness of voice.
Pulse	Standard deviation of period, period of pulses	Speech rate of speaker.

Asthma is a chronic lung disease, characterized by airway inflammation, airway obstruction and airway hyper-responsiveness. Asthma can cause repeated episodes of wheezing, breathing difficulty and cough. An acute asthma results in inflammation and swelling of the airway lining in the lungs. Alongwith this, mucus production occurs in the airway and muscles around the airway spasm, which result in reduction of airflow. The common signs and symptoms of an acute asthma episode include coughing, wheezing, breathlessness, increased respiratory rate, chest tightness, chest or abdominal pain, fatigue, agitation, inability to participate in sports and increased pulse rate [3]. People suffering from asthma often have a history of cold before the onset of exacerbation. The cause of most exacerbations, however, remains controversial despite numerous studies [4]. In Australia, asthma is the leading cause of hospitalization of children with an increasing prevalence. The risk of asthma in children is significantly reduced if exclusive breast feeding is done for at least 4 months. Various factors present in early life, such as being male, low birth weight, young maternal age, maternal smoking etc., may result in an increased susceptance to asthma [5].

Previous works on the detection of asthma using voice analysis indicate that when compared with healthy people, for asthmatic people, the Jitter and NHR values are high [6], the value of Intensity is low [7]. As compared with Shimmer values for healthy people, the people suffering from Chronic Obstructive Pulmonary Disease (COPD) have higher Shimmer values [8]. The people having chronic cough (CC) and paradoxical vocal fold movement (PVFM) have low Maximum Phonation Time (MPT) and Intensity than healthy people as indicated in [9].

This paper will present with a method to design an FPGA based chip that can identify people having asthma using their voice analysis, and further, determine if the level of asthma is intermittent, mild, moderate or severe. Firstly, the voice samples of all the participants, healthy and all types of asthmatic, will be recorded, and from those samples, various voice parameters, like Shimmer, Jitter, Fundamental Frequency etc., will be extracted using the MDVP feature of CSL program. Apart from this, the Maximum Phonation Time for all the participants will also be recorded. The values of these parameters will, then, be compared between healthy and asthmatic. Those parameters, that will show a significant difference, will be considered while developing the numerical formula to determine the level of asthma. This formula, once developed and validated, would, then, be implemented on FPGA using Verilog.

II. Methodology

A total of 62 voice samples were collected, whose details are as given below.

1. Healthy – 22 samples
2. Intermittent asthma – 10 samples
3. Mild asthma – 15 samples
4. Moderate asthma – 5 samples
5. Severe asthma – 10 samples

The age group of healthy people was 18 to 31 years, and that of asthmatic patients was 17 to 55 years.

The flowchart shown in Figure 2 represents the various steps involved in the project. The way how each step has been or has to be implemented is discussed briefly below.

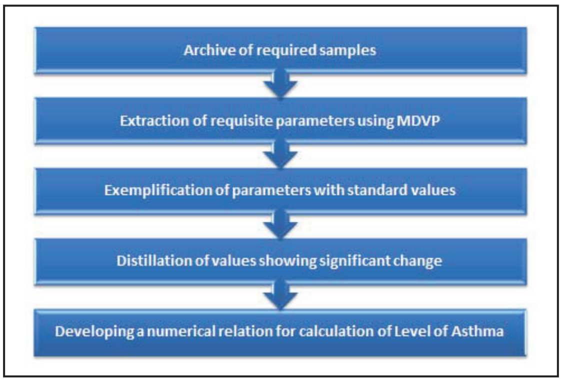

Figure 2. Steps involved in the project.

A. Voice Sample Recording

A vocal microphone (SM48-LC, SHURE) was used to record the samples. The samples were recorded at a sampling rate of 44.1 kHz. The distance between the microphone and mouth of the participants was 12 cm, and the microphone was kept at an angle of 45 degrees with the horizontal. The samples were recorded in the following way:

1. The participants were asked to produce sustained phonation of /a/ sound at their normal pitch and loudness for 4 seconds.
2. The above step was repeated 5 times for every participant.
3. The participants were asked to phonate /a/ for as long as possible.
4. The above step was repeated 3 times, and the maximum value among the 3 trials was considered as Maximum Phonation Time.

B. Parameter extraction and comparison

The Multi-Dimensional Voice Program (MDVP, Model 5105, KayPENTAX) feature of Computerized Speech Lab (CSL, Model 4500, KayPENTAX) was used to extract the voice parameters.

The MDVP voice parameters, that showed a significant difference when the different groups were compared, were considered for numerical relation formulation. These parameters are explained below.

Fo: Fundamental Frequency
Jitt: Jitter (%)
Shim: Shimmer (%)
vFo: Coefficient of fundamental frequency variation
DUV: Degree of Voiceless
DSH: Degree of Sub-Harmonics
SPI: Soft Phonation Index
MPT: Maximum Phonation Time

C. *Numerical Analysis*

Using those parameters that show a significant difference between healthy and asthmatic people, we can establish a linear relationship of the form:

$$LoA = (n1*p1) + (n2*p2) + (n3*p3) + \dots$$

where LoA represents Level of Asthma,
n1, n2, n3, … represent integral values,
p1, p2, p3, … represent MDVP parameters.
For example:

$$LoA = (0.025*Fo) + (0.08*DSH) - (0.012*Jitt) + \dots$$

LoA = 0-0.99, would indicate that person is healthy.
LoA = 1-1.99, would indicate that person is suffering from asthma and Level of Asthma is Intermittent.
LoA = 2-2.99, would indicate that person is suffering from asthma and Level of Asthma is Mild.
LoA = 3-3.99, would indicate that person is suffering from asthma and Level of Asthma is Moderate.
LoA = 4-4.99, would indicate that person is suffering from asthma and Level of Asthma is Severe.

The numerical formula, once formulated, would be tested for validation [10].

III. RESULTS AND ANALYSIS

After the acoustic analysis was performed on all the participants, it was found that there were several parameters that showed variations when the different groups were compared. The values of the acoustic parameters for males, females and people (include combined data for both males and females) were considered separately. Tables 2, 3, 4, 5 and 6 show the minimum, maximum and mean values of the MDVP parameters for healthy and asthmatic males, females and people respectively. The abbreviations used in these tables are as following :

Min – Minimum, Max – Maximum
M – Males, F – Females
P – People (males and females combined)

TABLE II. ACOUSTIC PARAMETER VALUES FOR HEALTHY SAMPLES

MDVP Parameter	Min Value			Max Value			Mean Value		
	M	F	P	M	F	P	M	F	P
Jitt	0.25	2.17	0.25	2.72	5.53	5.53	0.90	3.83	2.10
vFo	0.66	1.82	0.66	2.18	40.12	40.12	1.12	25.83	11.23
Shim	3.09	5.89	3.09	10.92	15.35	15.35	6.32	11.66	8.51
SPI	7.11	6.86	6.86	20.66	25.85	25.85	16.25	12.79	14.84
DSH	0	7.63	0	10.16	34.17	34.17	1.28	19.23	8.62
DUV	0	0.75	0	35.34	55.64	55.64	10.12	20.72	14.46
Fo	103.42	199.01	103.42	144.73	249.96	249.96	122.03	212.96	159.23
MPT	12.49	8.84	8.84	25.1	15.42	25.1	18.28	11.90	15.67

TABLE III. ACOUSTIC PARAMETER VALUES FOR INTERMITTENT ASTHMATIC SAMPLES

MDVP Parameter	Min Value			Max Value			Mean Value		
	M	F	P	M	F	P	M	F	P
Jitt	0.87	0.44	0.44	1.54	0.64	1.54	1.07	0.50	0.79
vFo	1.1	0.96	0.96	1.80	1.86	1.86	1.38	1.26	1.32
Shim	5.82	2.87	2.87	7.23	3.46	7.23	6.43	3.05	4.74
SPI	37.54	12.91	12.91	41.43	18.59	41.43	39.47	15.08	27.28
DSH	0	0	0	0	0	0	0	0	0
DUV	4.51	0	0	16.54	0	16.54	10.98	0	5.49
Fo	106.07	175.75	106.07	106.87	179.49	179.49	106.43	177.92	142.18
MPT	8.39	8.25	8.25	8.39	8.25	8.39	8.39	8.25	8.32

TABLE IV. ACOUSTIC PARAMETER VALUES FOR MILD ASTHMATIC SAMPLES

MDVP Parameter	Min Value			Max Value			Mean Value		
	M	F	P	M	F	P	M	F	P
Jitt	0.41	1.35	0.41	0.9	4.22	4.22	0.69	2.62	1.98
vFo	0.69	1.27	0.69	2.45	11.07	11.07	1.47	3.62	2.91
Shim	3.59	5.21	3.59	4.23	9.05	9.05	3.86	6.97	5.93
SPI	12.23	12.95	12.23	20.96	27.48	27.48	15.98	21.88	19.91
DSH	0	0	0	0	8.33	8.33	0	4.40	2.93
DUV	3.76	0	0	12.03	7.52	12.03	7.38	2.18	3.91
Fo	123.43	227.98	123.43	130.84	239.32	239.32	126.73	234.01	198.25
MPT	7.53	7.5	7.5	7.53	7.86	7.86	7.53	7.68	7.63

TABLE V. ACOUSTIC PARAMETER VALUES FOR MODERATE ASTHMATIC SAMPLES

MDVP Parameter	Min Value			Max Value			Mean Value		
	M	F	P	M	F	P	M	F	P
Jitt	0.90	-	0.90	5.28	-	5.28	2.47	-	2.47
vFo	1.10	-	1.10	6.40	-	6.40	2.89	-	2.89
Shim	3.45	-	3.45	9.84	-	9.84	5.37	-	5.37
SPI	21.87	-	21.87	29.10	-	29.10	24.94	-	24.94
DSH	0	-	0	24.24	-	24.24	5.30	-	5.30
DUV	0	-	0	0.75	-	0.75	0.30	-	0.30
Fo	145.65	-	145.65	150.89	-	150.89	146.97	-	146.97
MPT	10.95	-	10.95	10.95	-	10.95	10.95	-	10.95

TABLE VI. ACOUSTIC PARAMETER VALUES FOR SEVERE ASTHMATIC SAMPLES

MDVP Parameter	Min Value			Max Value			Mean Value		
	M	F	P	M	F	P	M	F	P
Jitt	1.83	2.07	1.83	2.56	5.73	5.73	2.21	3.06	2.63
vFo	1.5	2.44	1.5	1.96	5.07	5.07	1.76	3.11	2.43
Shim	8.44	3.50	3.50	9.82	14.43	14.43	9.31	6.87	8.09
SPI	25.84	19.57	19.57	29.55	24.87	29.55	27.94	21.91	24.93
DSH	0	1.50	0	0	29.23	29.23	0	10.09	5.04
DUV	13.53	0	0	26.32	2.26	26.43	19.39	0.90	10.15
Fo	133.86	167.29	133.86	136.09	175.72	175.72	134.75	169.87	152.31
MPT	8.58	7.12	7.12	8.58	7.12	8.58	8.58	7.12	7.85

The above tables clearly indicate the variation in parameter values between different groups. For example, for males, the minimum value of Jitter for healthy group is 0.25, mild asthmatic group is 0.41, intermittent asthmatic group is 0.87, moderate asthmatic group is 0.90, and severe asthmatic group is 1.83. It indicates that the value of Jitter is lowest for healthy group and highest for people suffering from severe asthma. It can also be seen that the value of Maximum Phonation Time (mean) is highest for healthy people and lowest for people suffering from severe asthma.

The mean values of Jitt, SPI, Fo and MPT for all the five groups can be seen separately for males, females and people in Figures 3, 4 and 5 respectively. The graphs in these figures have been plotted on a logarithmic scale using base 10.

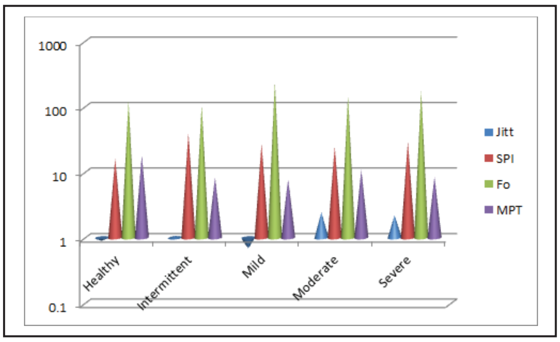

Figure 3. Mean values of acoustic parameters for males.

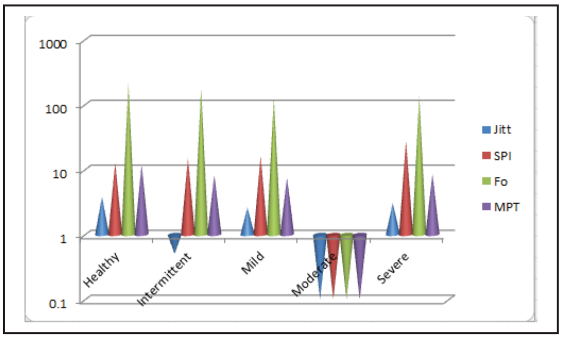

Figure 4. Mean values of acoustic parameters for females.

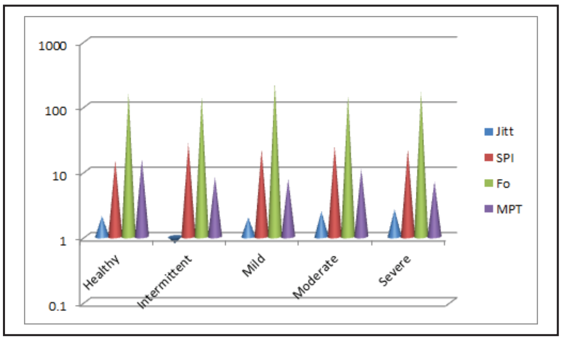

Figure 5. Mean values of acoustic parameters for people.

IV. Conclusion

From the acoustic analysis, it was found that there were several parameters, whose values showed variations when the different groups were compared. It has been decided that amongst all those parameters, four parameters (Jitt, SPI, Fo and MPT) would be used in developing the numerical formula as they showed significant and logical variations. Once formulated, the validation can be done.

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