THE HEBREW UNIVERSITY OF JERUSALEM

ביה"ס להנדסה ולמדעי המחשב ע"ש רחל וסלים בנין

The Rachel and Selim Benin School of Computer Science and Engineering

RLC-S

Recognition and Localization of a Crackle Sound

Providing a clinical tool for assessing in crackle sound detection in a respiratory physiotherapy for Cystic Fibrosis Patients

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Problem Definition:

The respiratory physiotherapy is one of many treatments that Cystic Fibrosis[1] patients need as a daily routine.

Its implementation depends on the recognition and localization of a crackle sound. Crackle sound is a lung sound provides useful information for assessing and monitoring respiratory patients. The recognition and localization of a crackle sound considered as a serious obstacle for an experienced treatment.

Since the respiratory physiotherapy considered as the main treatment for easing breathing for CF patients, and the number of CF patients have increased markedly over the last few years, hence, there is a great need for devising a clinical tool to guarantee an efficient treatment.

Background:

Cystic fibrosis (CF) is an inherited disorder that causes severe damage to the lungs, digestive system and other organs in the body, and it limits the ability to breathe over time. This disorder is the second most common life-shortening, childhood-onset genetic disease.

The main Airway called the trachea branches into each of the lungs, the largest airway within each lung is called a bronchus and each bronchus branches into smaller airways called bronchioles. normally Airways are coated inside with a thin layer

of fluid in mucus, the mucus catches dust and germs from the air we breathe, in then hair-like projections on the airway surface call cilia push the mucus trap dust and germs out of the lungs. in cystic fibrosis, the mucus is so thick and sticky that the cilia can't push it out of your lungs this thick sticky mucus can build up trap germs like bacteria and block your Airways.[2]

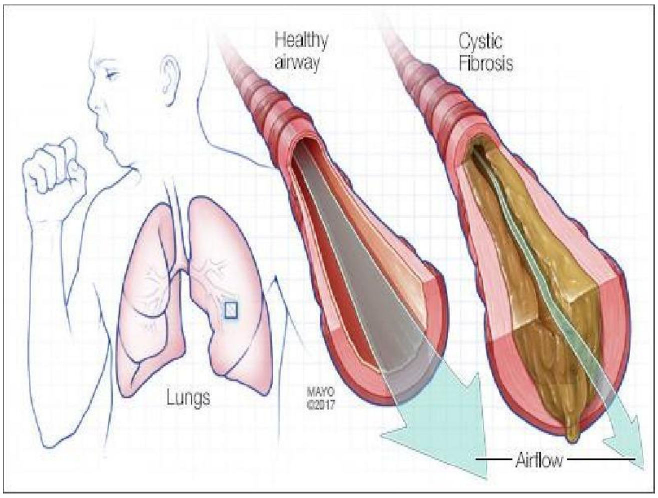


Figure 1: Airways Blockages

People with CF can have a variety of symptoms, including:

- Persistent coughing, at times with phlegm.
- Frequent lung infections including pneumonia or bronchitis.
- Wheezing or shortness of breath
- Poor growth or weight gain in spite of a good appetite.

[1] A hereditary disease that affects the lungs

[2] https://www.cff.org/What-is-CF/About-Cystic-Fibrosis/

One of the main CF symptoms is the chronic cough and great accumulation of phlegm. In addition, the accumulation of phlegm in the airways causes unusual noise called crackles.

Respiratory blockages caused by this disease can be treated by draining the secretions by respiratory physiotherapy. This kind of treatment is one of the daily treatments that CF patients must receive.

Respiratory physiotherapy is an airway clearance technique to drain the lungs. as a first step, the physiotherapist must locate the place of the crackle. during the treatment, the physiotherapist helps the patient to remove the secretions out by specific postures of breathing and pressing on the location of the crackle.

Therefore, the process of locating the exact place of the crackle is highly crucial. Thus physiotherapist use stethoscope, the stethoscope remains the most widely used instrument in clinical medicine and still guides diagnosis when other pulmonary function tests are not available, the auscultation by the stethoscope has several limitations, e.g., it is a subjective process that depends on the ability and expertise of the physician, it is limited by human audition, the stethoscope may be more adequate for cardiac auscultation, and the lung sounds are not permanently recorded for further analysis.[3]

As a try to simplify the diagnosis process, an electronic stethoscope was suggested. Unfortunately, this stethoscope can offer just the signal plot after the recording process was done for the sound that was received when it was located in a specific area in the patient upper body, which can provide easy visualization and editing for the recorded signal.

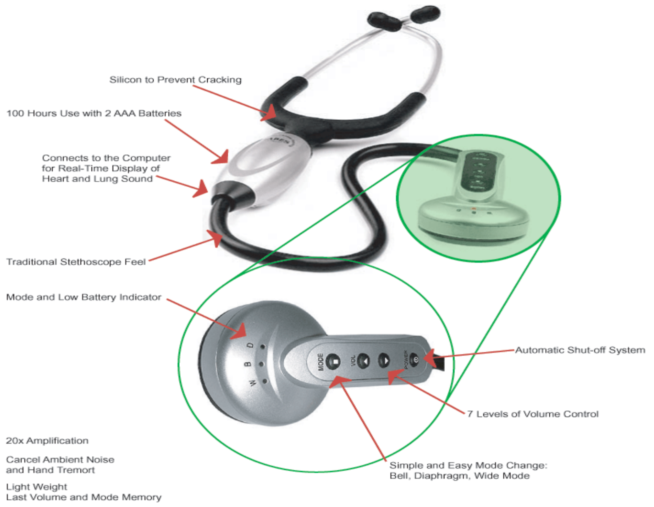


Figure 2: [Electronic Stethoscope]

Related Work:

Diagnosing disordered lung sounds brought up many years ago aiming to automatize the process.

As the crackle sound considered as one of these abnormal lung sounds, many diagnosing techniques were suggested beside factors that can distinguish a crackle sound from another.

Starting from the frequencies, normal breath sounds are noises with frequencies generally between 200 and 600 Hz while crackles are a sequence of explosive, nonmusical, interrupted pulmonary sounds with a wide spectrum of frequencies between 200 and 2500 Hz.[4]

[3] https://www.ncbi.nlm.nih.gov/pubmed/7501711

[4] https://patents.google.com/patent/US5218969A/en

Crackles also characterized by their specific waveform, their duration and their location in the respiratory cycle.[5]

Crackles detection has been also debated in many studies.

one method that was suggested is to split the detection process into three major stages:[6]

- a noise reduction filter is applied in order to delete the residual stationary noise in a nonstationary signal.
- a search of the waveform corresponding to a crackle.
- detected crackles are classified into two categories: fine and coarse crackles.

concerning the second step, a technique was offered for its implementation and is based on two steps: [7]

- A threshold (T) value is applied to the first derivative absolute value (FDAV) of lung sound to locate the "zone of interest".
- In this zone, a crackle is detected if certain conditions are verified.

Since technology companies usually aim to automatize our daily lives for facilitating them and for sure for their own profits, many companies had taken the responsibility to make progress in the whole crackles detection process.

So, the electronic stethoscope was suggested in the markets in many technology companies but as we mentioned before the final detection was not part of this service, final plots and recordings of the received signals were given by this stethoscope.[8]

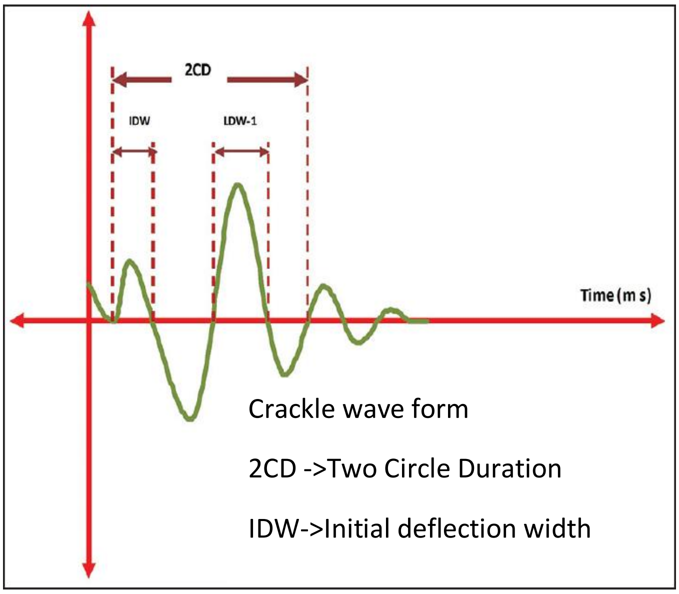


Figure 3: Crackle Waveform

Solution:

As previously mentioned, the detection and localizing the crackle sound are a pre-process that should be done.

Today this process is conducted by a regular stethoscope.

Clearly, using the stethoscope is not accurate enough, besides the time that it takes, especially in comparison with the short therapy time, which lasts 30 minutes.

Thus, conducting the pre-therapy diagnosis with a stethoscope is not recommended.

[5] https://patents.google.com/patent/US5218969A/en
[6] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2990233/
[7] https://www.ncbi.nlm.nih.gov/pubmed/9754686 (*)

[8] https://www.thinklabs.com/one-digital-stethoscope

Two possible approaches will help us to achieve our goal for optimizing pre-diagnosing therapy:

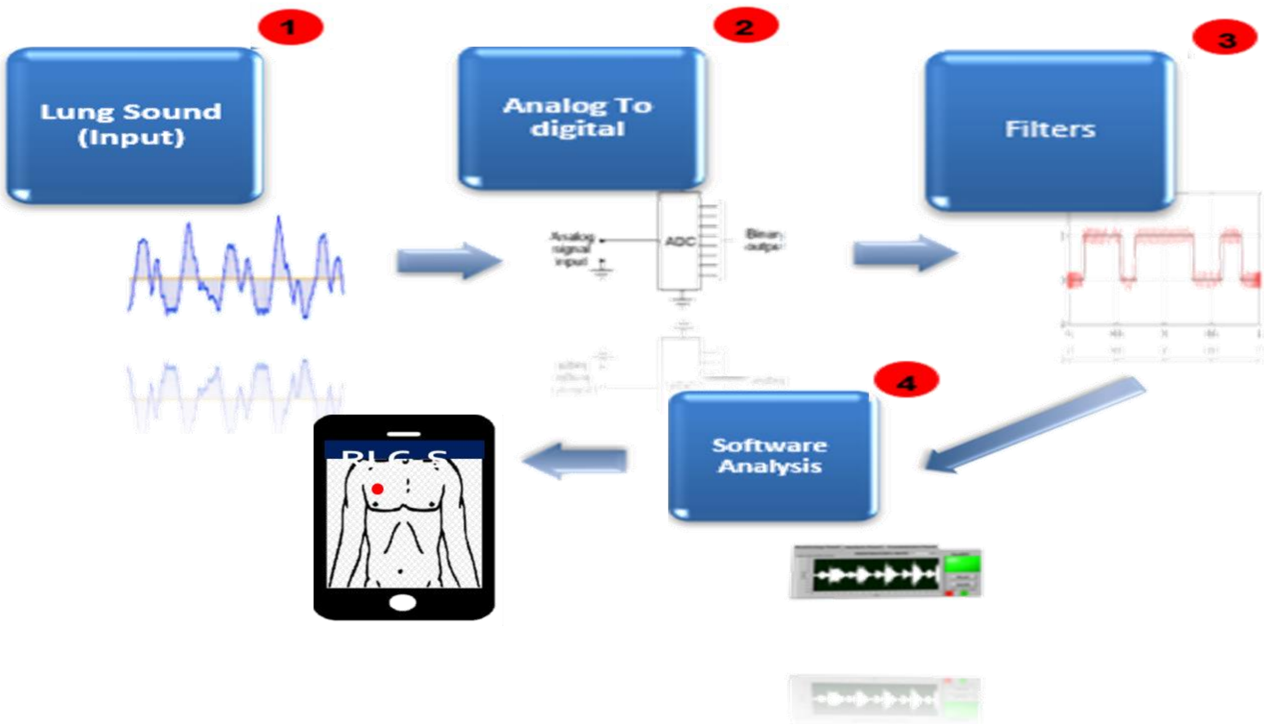
- machine learning- we can get audio recordings of CF patients breaths as a data set and start searching shared features to help us in the crackle detection process.
- Classical Signal Processing- we can do more research for conditions that should be verified to detect a crackle waveform in a received signal.

Proposed Solution:

since we are more experienced in signal processing and it might help us reach our goals earlier comparing to the second approach that demands more efforts to get

enough data and so more time, we will choose it as an initial approach, unless it will not work as planned we will move to the machine learning.

Key Components:



1. Lung sound(input): lung sound (input): it will be recorded using the microphone as a first step, then a USB card.
2. Analog to Digital using ADC (Analog to Digital Converter).
3. Filters: will be applied by an audio editor
4. software analysis: using Matlab / Python

Solution Feasibility:

As mentioned before, the suggested solution will be attached to many tools aiming to make it accomplished.
Starting from recording the breath signal by using an appropriate microphone that could fit with the frequencies of the input.
Then a USB card for storing the received data. An electronic stethoscope [9]can replace these two components.
Before start analyzing the signal, we should convert it from analog to digital using the ADC[10].
The audio editor that will be chosen is the WavePad[11].
The software analysis will be done by using Python as a priority, many libraries there will help us analyze the received input, such as Scipy.signal[12].
Our challenge will be recording the received signal and filter it to fit our requirements (without the surrounded noises).

Skateboard-Bike-Car

The basic goal we set to ourselves is to get a respiratory sound of CF Patient and automizing the pre-localization process of the crackle sound by devising a clinical tool to help the physiotherapist implement this process.
As a first step, the initial product that we started to work on is a tool(not close yet about how it will look like) will light a yellow led if no crackle was detected and red led if detected.
Later, if time permits, we will present a mobile health system(Mobile App) for the automated detection of crackle sounds comprised by an upper-body diagram wich doted by red dots that represent the crackle sounds locations that were detected, it will be implemented within Android.

Material that has been read:

- The DSP course's material.
- Using microphone and REAPER software to receive the sound of the breath, page 4 · https://www.diva-portal.org/smash/get/diva2:1128908/FULLTEXT01.pdf
- Explanation of the reception process with the help of Raspberry Pi and the microphone · https://scribles.net/voice-recording-on-raspberry-pi/
- Technique helping in the identification process · https://www.ncbi.nlm.nih.gov/pubmed/9754686
- Electronic stethoscope https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4496820/
- Explanation, with audio, about the different sounds emitted by CF patients · https://hawaiicopd.org/media/lung-sounds/
- Explanation about the reception of the sound of the breath · https://cdnlearn.adafruit.com/downloads/pdf/usb-audio-cards-with-a-raspberry-pi.pdf
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[9] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4496820/
[10] https://www.elprocus.com/analog-to-digital-adc-converter/
[11] https://www.nch.com.au/wavepad/index.html
[12] https://docs.scipy.org/doc/scipy/reference/signal.html

- Algorithm to recognize crackle https://www.mdpi.com/1424-8220/18/11/3813/htm

Technical aids :

- Hardware equipment:
  - Raspberry Pi
  - USB sound card
  - Microcontroller
  - Electronic stethoscope
- Software

  Learning how to use WavePad in order to filter our signal and any other audio modifications

  Libraries for signal processing (Python libraries).

: Status Update

We had a meeting with Ziv (Responsible for the Hardware components) and we discussed the opportunity for ordering a USB 6+1 Mic Array for providing more accuracy while detecting the exact location of the crackle sound. In the end, we decided to order the Electronic Stethoscope and let the Mic Array be as an enhancement tool as needed. we decided that our product will scan the upper body in six major locations on each side(left and right) and represent the location of the critical crackle in an upper-body diagram .

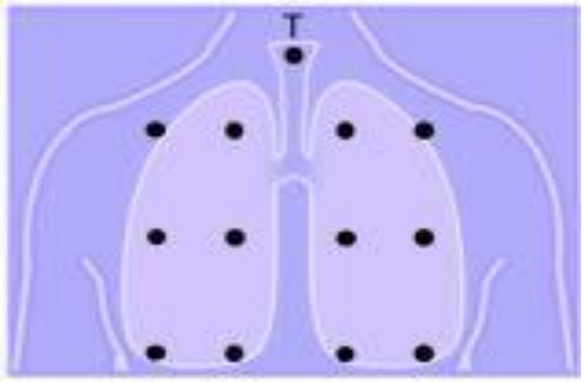

Figure 4: diagram of possible acquisition locations appears to associate a name to the acquired sound

As an update, we received the did stethoscope that Ziv ordered and a whole search of how the product works, also including many installations of programs that needed to start using it.

We succeeded to get our first recordings of the respiratory sounds for a normal breath and a CF patient breath and observed the huge noises that are attached in the second one.

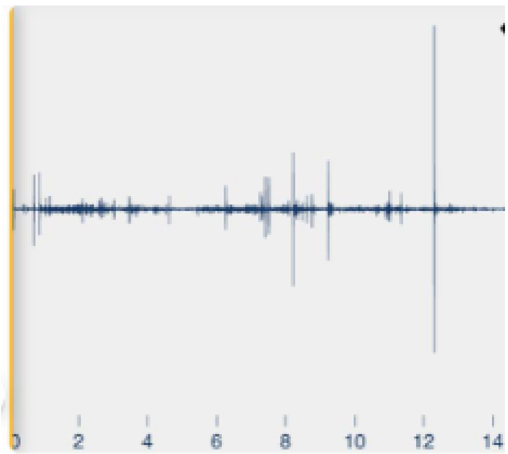

Figure 5: record of a normal breath(none CF)

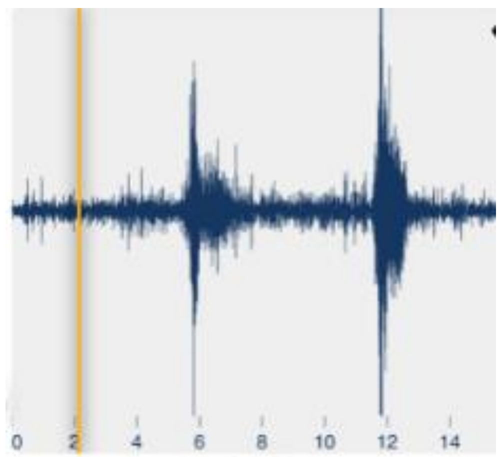

Figure 6: record of a CF patient

Also, we are in contact with the Tal-Hashomer hospital so the doctors in the CF department asked for a concluded report for our project and the upcoming work and also more details about how we want to start trying our product on their patients so they can give us the permission as soon as possible.

Evaluation and Verification:

As previously mentioned, the solution that we are suggesting is signal processing based.

So, the respiratory signal that will be received will be digitized using the Electronic Stethoscope so we can continue to the upcoming detection processes.

The Electronic Stethoscope stores an audio file in .wav format. The data sounds will digital filtered using a 500th order finite impulse response (FIR) bandpass filter between 75 and 1000 Hz to reduce the possible presence of heart sounds and other muscular noises. Filtered sound signals are normalized in amplitude in the range [−1, 1] to account for different amplitude variations between recordings. then the acquired signal s[n] and its filtered and normalized version sFN[n] will be visualization and analysis in terms of crackle detection directly in the diagram output. [13]

The solution will be evaluated in tested in two different sets of data. First, controlled scenarios with synthetic crackle waveform were generated and randomly inserted in the acquired respiratory sounds from healthy volunteers. Second, real acquired respiratory sounds were recorded at the bedside of Cystic Fibrosis patients.

Another way that we think that it will help us is to confirm the results that we get is to ask from a CF physician diagnosis for some CF patients so they will till us how close are the results from the real ones

13 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6263477/

Semester Schedule:

RLC-S					Powered by monday.com Click here to start your free trial
Reports of the project					
Name	**Owner**	**Status**	**Timeline - Start**	**Timeline - End**	**Priority**
First Report	va hassan, Janan Awav	Done	2019-05-05	2019-05-07	Medium
Git Respiratory	akiva hassan	Done	2019-06-06	2019-06-07	Medium
HelloWorld Python enviroment	Janan Awawdy	Done	2019-06-13	2019-06-13	Medium
Mini-report	va hassan, Janan Awav	Done	2019-06-14	2019-06-17	Medium
First Presentation	va hassan, Janan Awav	Done	2019-06-25	2019-06-27	High
Final Report	va hassan, Janan Awav	Done	2019-07-07	2019-07-10	High
Correspondence with Yuval(the advisor)					
Name	**Owner**	**Status**	**Timeline - Start**	**Timeline - End**	**Priority**
קבלת אישור מביתי החולים לקבל מידע על החולים	va hassan, Janan Awav	Working on it	2019-09-10	2019-09-10	High
Getting the received signal					
Name	**Owner**	**Status**	**Timeline - Start**	**Timeline - End**	**Priority**
קריאת שלושת המאמרים בנוגע לקליטת האות	akiva hassan	Done	2019-05-26	2019-05-31	High
בדיקת והזמנת רכיבים מתאמים לקליטת האות	Janan Awawdy	Done	2019-06-04	2019-06-07	Critical
פגישה עם זיו (אחראי חומרה)	ıan Awawdy, akiva has	Done	2019-05-31	2019-06-03	Critical
פגישת שלב עם אריאל ויובל	va hassan, Janan Awav	Done	2019-06-11	2019-06-15	High
ניסוי ראשוני של הרכיבים לקליטת האות	akiva hassan	Working on it	2019-08-27	2019-08-29	High
Exams period					
Name	**Owner**	**Status**	**Timeline - Start**	**Timeline - End**	**Priority**
תקופת מבחנים	ıan Awawdy, akiva has	Working on it	2019-06-21	2019-08-20	Critical
Signal Processing					
Name	**Owner**	**Status**	**Timeline - Start**	**Timeline - End**	**Priority**
למידת תוכנת ה wavepad לעומק	akiva hassan	Working on it	2019-09-01	2019-09-07	
למידת ספריות ה python לעיבוד אותות	Janan Awawdy	Working on it	2019-09-01	2019-09-07	High
לקשר בין שתי התוכנות	va hassan, Janan Awav	Working on it	2019-09-08	2019-09-11	High
עיבוד אות ראשוני למטרת זיהוי חרחור	va hassan, Janan Awav	Later	2019-09-12	2019-10-11	Critical
סיכום הממצאים עד כה והכנות למוצר הראשוני	va hassan, Janan Awav	Later	2019-10-13	2019-10-17	Critical
פגישת סיכום שלב עם אריאל ויובל	va hassan, Janan Awav	Later	2019-10-27	2019-11-01	High
Find An algorithm for an acuurate crackle detection(Ariel suggestion)					
Name	**Owner**	**Status**	**Timeline - Start**	**Timeline - End**	**Priority**
חיפוש מקורות מידע לגבי טכניקה לדיוק מיקום חרחור	akiva hassan	Done	2019-08-08	2019-08-16	Critical
למידת אלגוריתם הדיוק המיקום והתיעצות לגביו על יובל	akiva hassan	later	2019-08-24	2019-08-29	
פגישת סיכום שלב עם אריאל ויובל	va hassan, Janan Awav	Later	2019-10-17	2019-10-19	High
Primary Product					
Name	**Owner**	**Status**	**Timeline - Start**	**Timeline - End**	**Priority**
בנית מוצר ראשוני ישים	va hassan, Janan Awav	Later	2019-11-02	2019-11-24	Critical
Testing the Primary product					
Name	**Owner**	**Status**	**Timeline - Start**	**Timeline - End**	**Priority**
בדיקת מוצר ראשוני מול חולים	va hassan, Janan Awav	Later	2020-01-01	2020-01-30	High
הסקת מסקנות לגבי עדכונים במוצר	va hassan, Janan Awav	Later	2020-01-01	2020-01-30	High
פגישת סיכום שלב עם אריאל ויובל	va hassan, Janan Awav	Later	2020-01-31	2020-02-05	High
Enhancments for more Accuracy					
Name	**Owner**	**Status**	**Timeline - Start**	**Timeline - End**	**Priority**
בדיקת אפשרות לשיפור האלגוריתמים בעזרת ML		Later			
התייעצות עם מרצים מהתחום		Later			
פגישת סיכום שלב עם אריאל ויובל		Later			