# Characterization of Cough Sounds Based on Measured Sound Pressure Levels from Arduino-Based MAX9814 Sound Sensor

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Research has been conducted on the characterization of coughing sounds based on the measured sound pressure level of the Arduino-based MAX9814 sound sensor to determine the characteristics of coughing sounds based on the Sound Pressure Level (SPL). This research method is carried out by designing sound sensor hardware and software using the MAX9814 sound sensor. After that, recording the coughing sound data from the cough voice coswara respondent data set using a sound sensor and converting it to SPL data. After that, the cough SPL data was analyzed from the SPL cycle graph during recording and the cough phase pattern. And the resulting characterization of coughing sound based on coughing pressure using an Arduino-based MAX9814 sound sensor produced a coughing sound character in terms of sound pressure level (SPL) based on the expulsive phase and the intermediate phase of coughing. The expulsive phase indicator is emphasized the intensity of occurrence and density in one cycle of recording coughing sounds. And for the intermediate phase based on the drop rate of the SPL back to the SPL position without coughing. The SPL of cough detected by the MAX9814 sound sensor is ±80dB.

Keywords: Characterization, Cough, Sensor, Sound Presure Level

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## I. INTRODUCTION

Covid-19 is a respiratory infection caused by the severe acute respiratory syndrome corona virus 2 (SARS-CoV-2). According to coswara data, the disease, which is officially declared a pandemic, has infected millions of humans worldwide, and has a mortality rate of between 1-10% in most countries. A common symptom of the corona virus is a cough. Fig. 1 is the spectogram of recordings from a healthy adult voice sound, cough sound and breathing sound [1].

Studies show that lung disease has different bio-markers in the speech-breathing cycle. The study reported in demonstrated that threshold voice pressure, defined as the minimum lung pressure required to initiate and maintain vocal cord oscillations, is correlated with vocal fatigue. The impact of laryngeal dysfunction on breathing patterns on reading speech is analyzed in [2]. Fig. 1(a) depicts the spectrogram of a voice sound. It contrast to coughing and breath sound samples, there are sounds that are clearly visible as harmonics.

Coughing is a powerful reflex mechanism for clearing the central airways (trachea and main bronchi) of inhaled and secreted materials. Typically, this follows a well-defined pattern, with initial inspiration, glottal closure and development of high thoracic pressure, followed by explosive expiratory flow as the glottis opens with continued expiratory efforts [3]. Sound produced during coughing by air turbulence, tissue vibration, and movement of fluid through the airways [4]. This turbulence produces sound with a broadband "noisy" character, the frequency content of which depends on the speed, density of the gas, and the dimensions of the airways from source to mouth.

Scientific cough recorder and analysis by measuring the movement of the diaphragm using various types of sensors. Cough detection is done by observing the movement of the chest wall, measuring air flow, measuring electromyography, electroglottography and electrocardiography. An intuitive, non-invasive and clear cough marker is the sound of coughing. Physiologically, cough is a defense mechanism that prevents the entry of foreign objects into the lower respiratory tract and helps cleanse the respiratory system of dirt [5, 6]. There are three phases in cough which can be seen in Fig. 2:

1. Inspiratory phase, the glottis is fully open due to air being drawn into the lungs.

2. Compressive phase, the glottis is fully closed due to the respiratory muscles contracting and pressing air into the glottis thereby increasing the pressure.

3. Expulsive phase, there are three phases in this section, namely:

    (a) Explosive phase, the glottis reopens suddenly due to air being expelled quickly. This is the source of the coughing sound produced.

    (b) In the intermediate phase, the vocal cords close briefly.

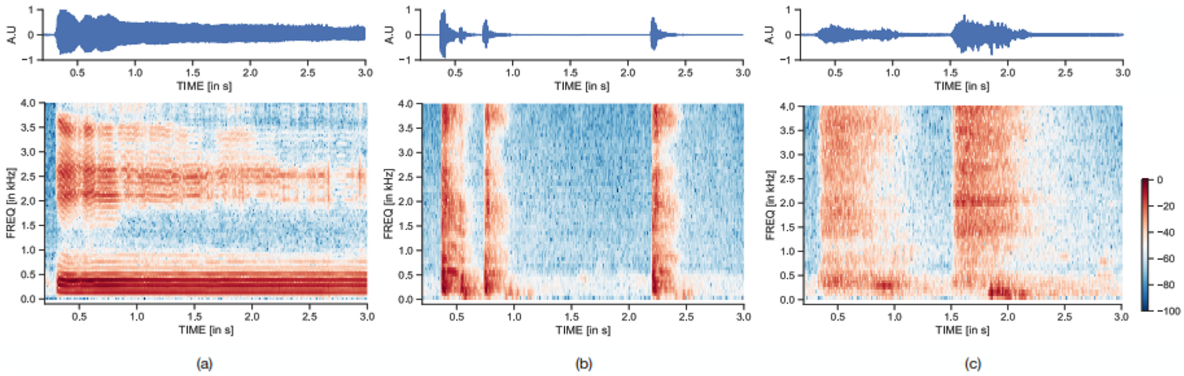


FIG. 1: Spectogram of recordings from, a) a healthy adult voice sound, b) cough sounds, c) breathing sound [1].

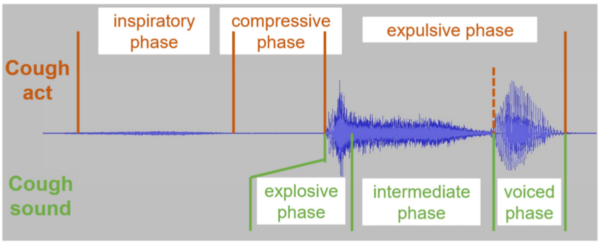


FIG. 2: Waveform of a cough [7].

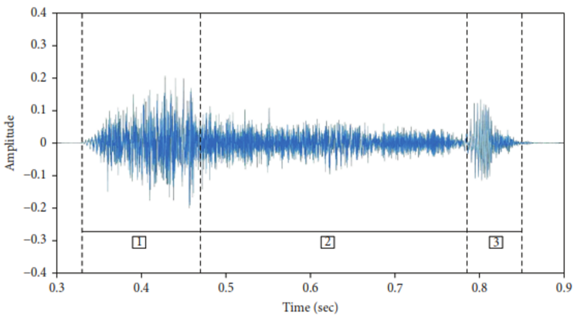


FIG. 3: Cough sound waveform in three phases (1) exhalation with coughing (2) attenuation of coughing sound (3) coughing sound with closing of the vocal cords [10].

(c) Voiced phase, for the second time which results in a further increase in voice at the end of the cough [7].

Fig. 1(b) shows a wide band spectrogram of a sequence of three sound signals for a heavy cough. Each cough lasted nearly 300 ms, and the spectrum showed broad spectral spread over 500 Hz, 1:5 kHz, and 3:8 kHz. The acoustic features of the coughing sound depend on the velocity of the airflow as well as the dimensions of the vocal tract and airways [3]. This makes it possible to detect coughing sounds in audio recordings [8].

Another common symptom for Covid-19 can be seen from breathing. This can be shown as shortness of breath. Breath sounds show a different pattern for asthmatic conditions compared to healthy individuals. The use of breath sounds can be seen in Fig. 1(c), it shows a wide-band spectrogram of the cycle of inhalation and exhalation during breathing.

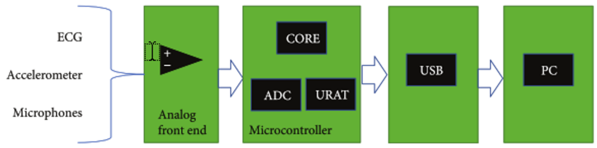


FIG. 4: Schematic of a cough detection circuit [10].

Cough generally occurs due to deep breathing along with closure of the glottis and colliding with the respiratory muscles [9]. Due to the resistance of the glottis when it opens for a moment it will cause air to enter with a choking sensation resulting in a coughing sound. In general, a cough consists of three phases: the first phase is an exhalation of exhalation due to the sudden opening of the glottis. The second phase, the middle phase with attenuated cough sounds and the third phase, the coughing sounds begin to disappear due to closure of the vocal cords [10, 11]. Fig. 3 shows the waveform of a cough sound in three phases.

Researchers used a cough detection method with a two-aspect model, namely recording cough sounds and monitoring cough sounds, while also using cough processing algorithms. Cough monitors can also be based on the frequency of coughing sounds and compared with identification from human hearing. The current study, has not found an accurate system model for the detection of coughing sounds that can represent human hearing [12, 13]. Usually the detection model uses a sound sensor and is assisted by other sensors as shown in Fig. 4.

To analyze Covid-19 based on breathing, coughing, and speech sounds can be seen from the audio. The audio data collected included fast and slow breathing, deep and shallow coughs, continuous vocal phonation and spoken numbers. Age, gender, geographic location, current health status and pre-existing medical conditions were also recorded. Health status included 'healthy', 'affected', 'cured' or 'infected'. Audio recordings were sampled at 44.1 KHz and subjects were

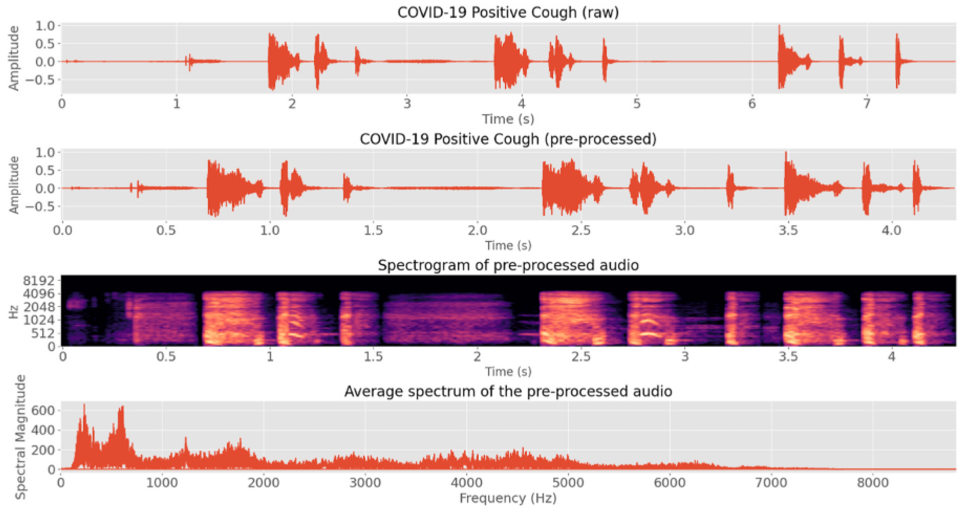


FIG. 5: A processed Covid-19 cough audio which is shorter than the original cough audio but keeps all spectrum resolution [14].

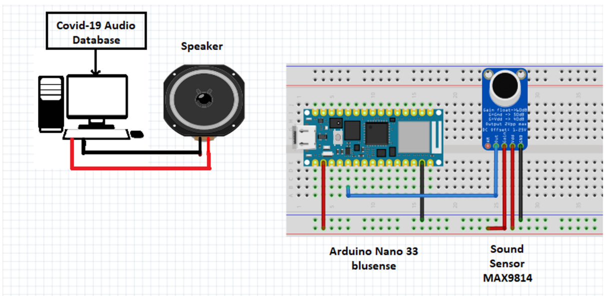


FIG. 6: Sound Sensor schematic and cough sound measurement system.

from all continents except Africa. Can be seen in Fig. 5 shows an example of the original raw audio, as well as the pre-processed [14].

Thus, based on the sound sensor-based cough analysis research that has been carried out, the signal data is a sound signal based on sound amplitude at each frequency. So that it is necessary to review the characteristics of the cough sound based on sound pressure. This is because it is related to the loudness of the sound to the changing air pressure and the distribution of droplet velocity when the air pressure from coughing increases.

## II. METHOD

### A. Hardware Prototype Design

The design of sound sensor hardware as a sound pressure measurement tool uses the MAX9814 sound sensor as a sound signal data input device and Arduino Nano 33 Ble Sense as a microcontroller that converts sensor data (analog) into digital signals (dB data). This circuit is assembled into an integrated circuit system. This research circuit is as shown in the following Fig. 6.

### B. Software Prototype Design

Software design that is compiling commands or instruction codes given to the microcontroller to convert the sensor analog signal data into digital data which will produce sound pressure level (SPL) data. The software is completely designed using Arduino IDE using C++ Language.

### C. Cough voice data recording

Cough sound data using a dataset from the ” project (https://coswara.iisc.ac.in/). The data set is in the form of recordings of coughing sounds from various types of patients and respondents during a pandemic from around the world. The coughing sounds data is then played using a speaker with an audible frequency response of 20Hz 20 KHz. Then, the sound produced by the speaker is measured using the sound sensor used in this study. The sensor analog signal data is digitized using a microcontroller so that the resulting measurement data in real time SPL is recorded on the MS. Excel makes use of the microcontroller serial connection.

### D. Cough sound SST analysis and characterization

Cough sound analysis is seen from the cough graph in one recording cycle with the x-axis being the period and the y-axis being the SPL (dB) to determine the peak of coughing in one time cycle. The second analysis is the density of the peak decibel value at each time which will give different characteristics to the nature of the cough sound both from the type and condition of the patient.

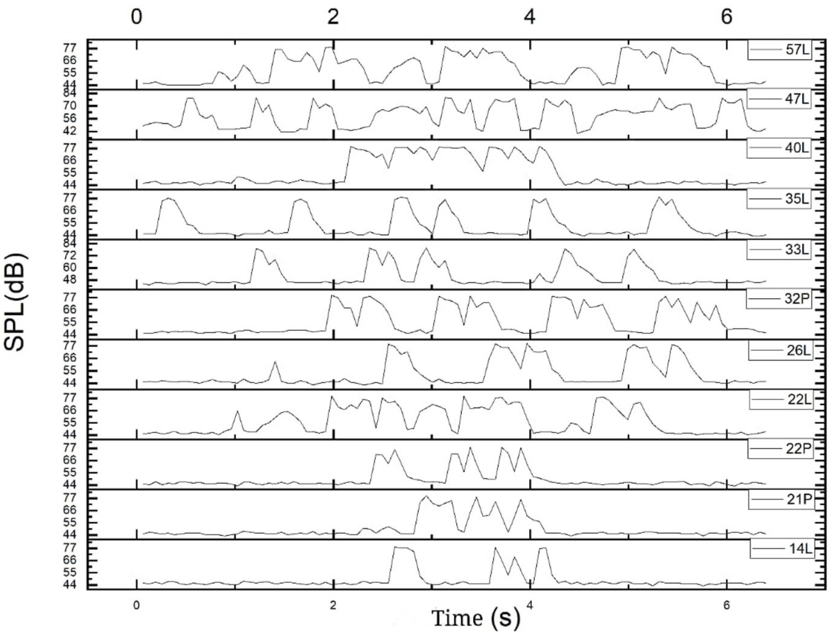


FIG. 7: Sound Presure Level (SPL) measured cough audio sample, L indicates male and P indicates Female patient and number indicates age.

TABLE I: Respondent's Health History data

| Sample | Age | Covid_Status | Gender | Smoker | Asthma | Cold | Cough | Diabetes | Fever | Loss Of_Smell | Pneumonia |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 14 | Healthy | Male | | | | | | | | |
| 2 | 21 | Healthy | Female | | | | | | | | |
| 3 | 22 | Resp_illness_not_identified | Male | | | | True | | | | |
| 4 | 22 | Healthy | Female | | | | | | | | |
| 5 | 26 | Healthy | Male | True | | | | | | | |
| 6 | 32 | Resp_illness_not_identified | Female | | True | | | | | | |
| 7 | 33 | Healthy | Male | | | | | | | | |
| 8 | 35 | No_resp_illness_exposed | Male | | | | | | | | |
| 9 | 40 | Positive_mild | Male | True | True | True | True | True | True | True | True |
| 10 | 47 | No_resp_illness_exposed | Male | | | True | | | | | |
| 11 | 57 | Healthy | Male | | | | | True | | | |

## III. RESULTS AND DISCUSSION

The voice sample data downloaded from the ” repository set of 11 samples contained recorded coughing data accompanied by the respondent's health history data as shown in Table I. This table data will be used as a reference for the correlation of the patient's condition with the records cough sounds SPL pattern.

For audio recording data, coughing sounds from the database are played through speakers and detected by sound sensors. Then the data is processed by the microcontroller so as to produce SPL data every time during the recording cycle. The data is plotted with the x-axis being the period and the y-axis being the SPL (dB) as shown in Fig. 7.

In general cough diagnosis studies, coughing consists of three phases of inhalation of air into the lungs (inspiratory phase) then the air is compressed because the glottis valve is closed, but the inhalation of air is still ongoing (compressive phase) after which the air is expelled, namely the expulsive phase because the glottis valve is open. During this last phase, it will determine the type of cough, sometimes the cycle period is very short and light, or once and for a long time. It will indicate a heavy, medium or light cough.

These coughing phases can be seen and seen from the audio graph, but in the frequency domain the cough frequency ranges from 50 to 900 Hz in the sound wave and the Y-axis is the wave amplitude. In the graph of this study, the cough signal is seen from the sound SPL as shown in Fig. 7. It turns out that on review and SPL the cough cycle inheritance still appears where the expulsive phase is the most visible. However, the other phases are not clearly visible so that the respi-

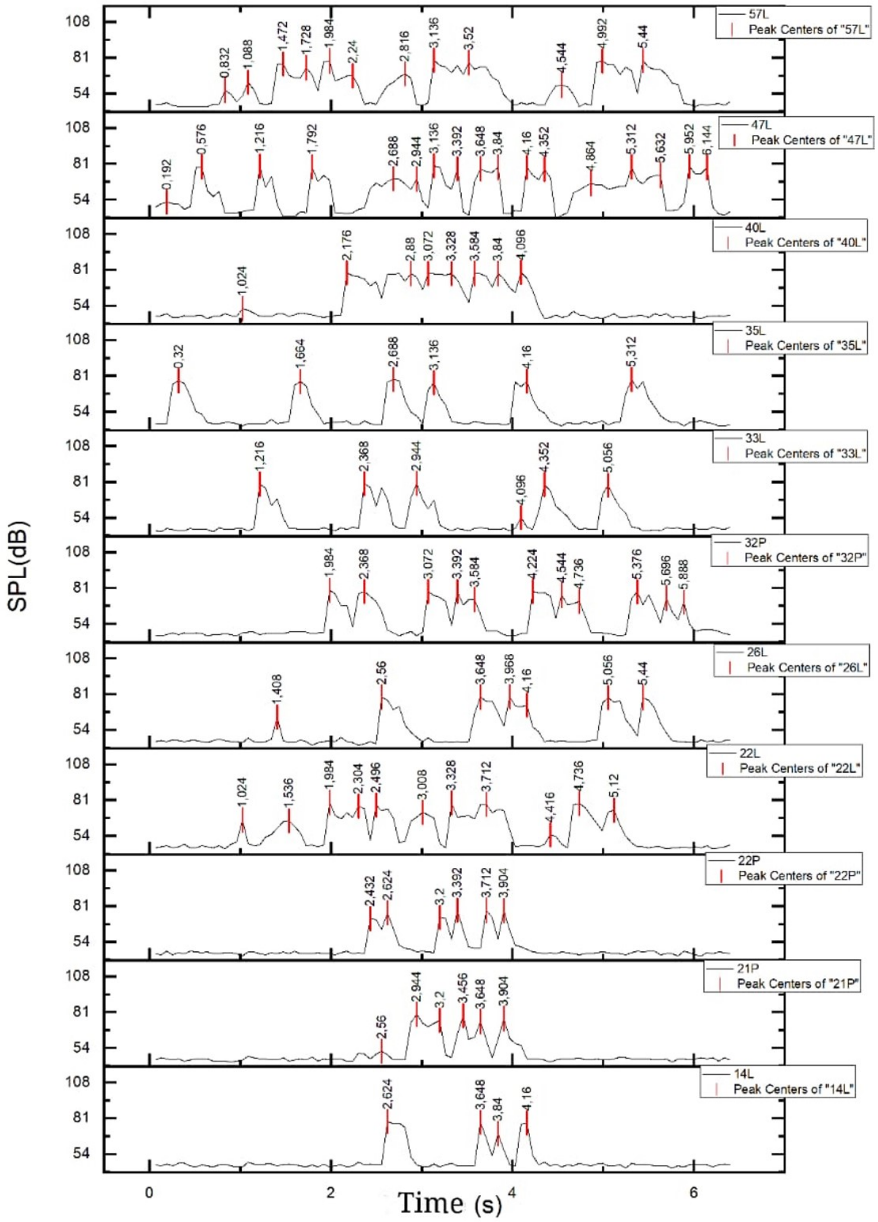


FIG. 8: Peak to Peak SPL cough audio sample.

ration process that occurs will be difficult to detect so that is one of the shortcomings of the analysis of cough sound from sound pressure. However, the SPL signal is very reliable as an electric pulse that is very fast and easy to analyze and is used as a limit range to trigger voice-based medical devices to provide quick decisions compared to signals in audio signals in the form of sound wave packets (frequency) which are continuous signals so that health devices using this reference must perform further computations and package these audio signals as pulse packets which ultimately refer to the SPL signal.

The SPL signal for coughing also indicates the amount of air pressure exerted by the environment when coughing, which brings droplets into the air. So that the greater the SPL sound, he stronger the droplet particles scatter. SPL value can be used as an indicator of cough characterization for Covid-19 disease because this virus spreads through droplets. In Fig. 7, the cough SPL value is around 80 dB when converted in to sound pressure, the sound pressure value is around 0.2 Pa, which is equivalent to 0.2 N/m$^2$ and this is very strong for throwing droplets and in each sounds sample the data set gives an expulsive phase more than once. So that the probability of droplets leaving the environment is more.

Each individual has different cough characteristics seen from the SPL value during one cycle of cough recording sam-

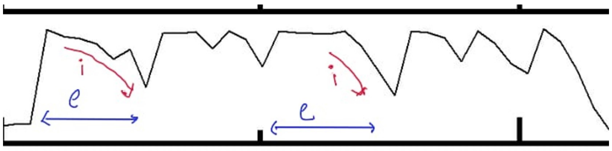


FIG. 9: $e$ for expulsive phase, $i$ for intermediate phase or drop phase.

pling time. When viewed from the SPL and the expulsive phase of the cough data, there is a cough with a direct expulsive phase at high SPL and a short cycle as in the sample of patients 35L (age 35 years, male). There is also a long expulsive phase or adjacent expulsive phase as in the 40L patient sample (age 40 years, male). And it turns out that from the patient history, the 35L sample patient was a normal patient and the 40L sample patient was positive for Covid-19. So sometimes the expulsive cough phase is short and not consecutive is a normal cough trait, while the expulsive cough phase is long and or consecutively indicated by Covid-19. This is also reinforced by the analysis of the detection of SPL peaks as shown in Fig. 8.

The detection of SPL peaks in the cough signal strengthens the concept of the expulsive phase of cough analysis related to the patient's condition. In the 40L sample the distance between the SPL peaks is 0.256 seconds and in the 35 L patient 1.152 seconds so that the P-P SPL 40L is shorter than 35L but there is a healthy patient status such as in patient 21P it turns out to have a P-P phase as well as the 40L sample, but in healthy condition so additional reference for the indication of distinguishing characteristics is needed, namely the drop phase or the intermediate phase in the expulsive phase. This phase shows a rapid decrease in SPL before being connected to the next peak phase which distinguishes the 40L and 21P patient data. Seen in the patient sample 40L tight and there is no intermediate phase of cough or drop-down phase.

## IV. CONCLUSION

Characterization of coughing sounds based on coughing pressure using an Arduino-based MAX9814 sound sensor produced a coughing sound character in terms of sound pressure level (SPL) based on the expulsive phase and the intermediate phase of coughing. The expulsive phase indicator is emphasized the intensity of occurrence and density in one cycle of recording coughing sounds. And for the intermediate phase, it is based on the speed of the SPL drop back to the SPL position without coughing. The SPL of cough detected by the MAX9814 sound sensor is $\pm$80dB.

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