Remotely Diagnose Coronavirus by Recognizing and Counting of Coughs During Phone Calls

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Remotely Diagnose Coronavirus by Recognizing and Counting of Coughs During Phone Calls

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Abstract

In the presence of this paper, we aim to present the COVID-19-RCC protocol, a protocol that can reduce the spread of Corona-virus disease COVID-19 by remotely diagnosing of large people's groups, or even entire countries, in a parallel manner. The COVID-19-RCC protocol is an algorithm for recognizing and counting coughs during a phone's conversation (in real-time), where coughing is one of the main symptoms of Coronaviruses. The recognition is based on the analysis of the audio frequency spectrum during the call but without recording the content of the call. Based on the coughing, the stage of illness can be predicted and the probability of transferring the virus to and infecting peoples in the surrounding area can be reduced. Several studies have shown that human-to-human transmission of the Corona-viruses has occurred by droplets or direct contact, which shows us the importance of detecting patients who complain of coughing as a priority, in order to limit the spread, as coughing is the main factor behind the droplets. In general, peoples who complain of coughing can be considered to be at the origin of the spread of the virus. This protocol may not be the most effective, but COVID-19-RCC can be ready to use, executable and functional within 24 hours. Especially under these circumstances, we don't have enough time to develop a sophisticated solution!

Keywords

COVID-19; Coronavirus; Remotely diagnose; Detecting coughing; Audio Frequency Spectrum

Introduction

COVID-19-RCC protocol

The idea behind this concept is based on an old concept that said a package of half-solutions can perform as an effective solution. Remotely diagnose the virus by recognizing and counting of coughs during phone calls or even by installing a phone's application that activated on the background, isn't the perfect solution, also isn't the all-in-one solution, but we encourage the authorities to add this protocol on the existed package of solutions to strengthen the control's system since we have not yet reached the right treatment.

In China, they used drones to measure the temperature in the streets of a randomly selected group of people, and the Chinese never said how many we can scan from more than a billion people with drones? Definitely the amount of data is not enough, from the first moment the idea seemed useless and there was no need to apply it in the ground. In on other hand and so far, the Chinese have managed to reach the peak and have started to reduce the reproducibility of the virus while limiting its spread. At present, the virus continues to accelerate its spread in Europe and around the world.

Under these circumstances, many countries can't develop the same system that china used it in a short time, we have not the time! We suggesting to focus on the second symptom of the virus is the cough in the side of the fever, but the advantage of tracking the cough can be without the need to be on the ground nor on-air with drones to measure the temperature (that confirms the fever), in fact, you should be in telecom cables! Due to the Maxwell equations and linear algebra, the same cable can transmit the millions of data, audio and calls through it, in a parallel manner, without the interference, So let's use this advantage and install a small system (within 24h) to analyzing the audio frequency spectrum, that system has already existed. The system automatically starts working when a phone's call starts and recognizing and counting of coughs during the call.

You may think that cough detection is less effective than temperature measurement? But let's present some facts about the Corona-virus, the virus is transmitting only by droplets! and the main actor behind the droplets is the coughing more than the fever, however,

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the following paragraphs are detected to present and explain the importance of basing on the cough as a first diagnosis.

The spread of the virus is growing exponentially, so in order to control it, we must follow an exponential procedure too. The detection of coughing during phone calls gives us the same advantage of exponential growth because the call is between two people, so an action of anyone gives the state of two people in parallel. Moreover, to limit the virus, we must work on a large circle of probability and exclude unconfirmed cases, but rather rely on confirmed cases and investigate with patients to predict other inflected cases.

The quality of the system's predictions will increase over time thanks to the machine learning mechanisms, by classifying the caller that coughing on the grey list, after detecting the cough in a second call, a robot will call the caller and will ask him if he has claimed the symptoms of the virus, if yes, the caller will click 1 to react with the robot, then the caller will be classified on the blacklist if-else, the machine learning mechanisms will learn from this case to improve the classification.

Please note that this article is not a medical article or comes from a biology expert, we are simply trying to contribute what we can do, we do not intend to compete with professionals in their field. You will find below some probability models; they are not the right ones! We suggested it just to help explain the idea, they are not appropriate models! due to a lack of time. Also, due to a lack of time and sources, you will find a direct quote from other articles. I hope that there will be no problems with the original authors since we don't tend to have negatives intentions.

Coronavirus COVID-19

Since the onset of infection with the new coronavirus COVID-19 in Wuhan, China, in December 2019, it has spread rapidly in China and many other countries. To date, the new coronavirus has affected more than 145,798 confirmed patients (5,531 reported deaths and 67,003 recoveries) and has become a major global health concern.

As well as studies have reported a link between a local fish and wildlife market (Wuhan City) and most cases of infection, which indicate possible transmission from animals to humans, more and more studies have demonstrated human-to-human transmission of "COVID-19" by droplets or by direct contact.

The accelerated spread of the virus through human-to-human transmission has created an urgent need to develop and approve standard treatment protocols. Besides the lack of complete details on the structure and life cycle of the virus, therapeutic development is delayed, preventive measures remain the only procedure to limit the spread of COVID-19.

Few existing drugs have been evaluated for the treatment of COVID-19 and have shown promising good results in clinical applications. The chemicals used to "manage the symptoms of viral infection" have helped several patients in the early stages of their recovery.

To date, there is no known fully effective treatment for COVID-19. However, potential therapies are emerging as the clinical evaluation of existing antiviral drugs continues and as knowledge about this new coronavirus progresses.

Cough as a Symptom of Coronaviruses COVID-19

Clinical manifestations

The clinical study of patients infected with COVID-19 from different regions of China has shown a varied pattern of the disease. The study reports that the median age of the infected patients studied was 47 years, which indicates the presence of the infection in people of all ages. In addition, out of all the patients studied, ~41.9% werewomen, which indicates that the infections spread in different patients regardless of sex. The report indicates that the primary composite endpoint occurred in ~6% of patients. Patients outside

Symptoms and Signs	
Fever	~0.935
Cough	~0.697
Dyspnea	~0.345
Sputum production	~0.172
Myalgia	~0.276
Headache	~0.071
Diarrhea	~0.061
Rhinorrhea	~0.01
Sore throat or pharyngalia	~0.104

Table 1: Clinical manifestation from three study site, Wuhan[1]

Wuhan City have either been in touch with city residents at one time or have visited the city recently. Among the patients admitted for COVID-19, very few (only ~1.9%) had a history of direct contact with wildlife, which indicates that human-to-human transmission of the virus is favored [1].

Most patients had a common symptom of fever and cough. Many patients often presented without a fever, however, they developed it during the infection. The majority of patients developed fever (~43.8% on admission and ~93% during hospitalization) and nearly two-thirds of patients had cough (~70%) as common symptoms. The blood test showed lymphocytopenia (abnormally low levels of lymphocytes in the blood) in the majority of patients (~83% of patients) on admission to hospital. Diarrhea was not common in most cases. Patients developed full symptoms of VIDOC-19 within 2 to 7 days, i.e. the median incubation period for the development of infection was ~6.8 days with an interquartile range of 2 to 11 days in all patients[2] (Table 1).

Modulation of the inflection probability: 1 Suppose that the probability of transmission might come from to type of patient's groups, A (the patients that had cough as a symptom), B (the patients that had only fever a symptom).

$$P\sim 0.7\times \mathrm{P}(\mathrm{A})+0.3\times \mathrm{P}(\mathrm{B}) \quad (1)$$

Where:

$$\mathrm{P(B)}< \mathrm{P(A)} \quad (2)$$

Due to the ability to transmit the droplet to the near air as well as area. We can write the P as:

$$P\sim \mathrm{P}(\mathrm{A})(0.7+0.3\times \mathrm{n}),\mathrm{n}<1 \quad (3)$$

Infection transmission and epidemiology

Human-to-human transmission is the primary way of infection, transmission occurs from the symptomatic person through coughing or sneezing, transmission can also occur from an asymptomatic person, but the probability of this happening is much lower than for a person who reports coughing since transmission occurs from the symptomatic COVID-19 patient through the respiratory droplet when the patient coughs or sneezes.

Based on observation of data from the early epidemic in mainland China from January 10 to January 24, 2020, the trend of increasing incidence largely follows exponential growth, and the average number of basic reproductions R_0 has been estimated at a range of 2.24 to 3.58[1].

Another estimate based on data from December 31, 2019 to January 28, 2020 gave similar results, the R_0 for COVID-19 being 2.68 and the doubling time of the epidemic being 6.4 days. In addition, the current estimate of the average incubation period for COVID-19 was 6.8 days, which ranges from 2.1 to 11.1 days [1] (Figure 1).

Fitting of the spread: The fitted exponential function of the spread based on data that comes from Wuhan, from 21 January to 11 February.

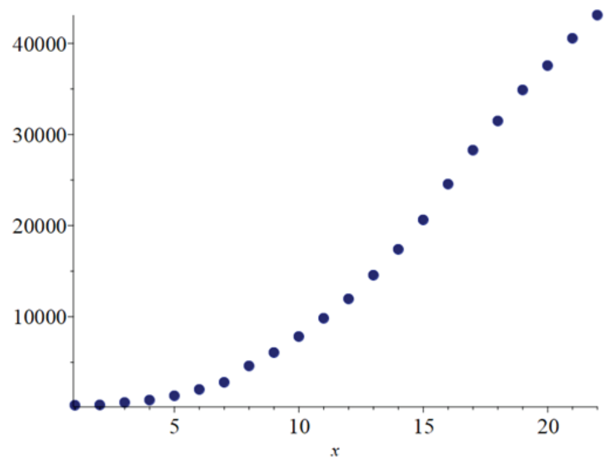

Figure 1: COVID-19 spread from 21 January to 11 February, Wuhan [1].

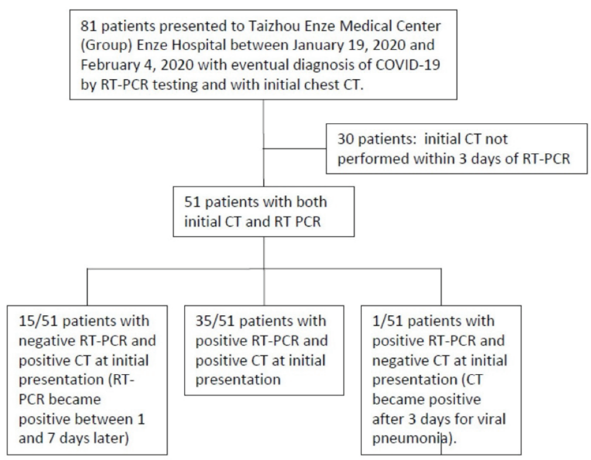

Figure 2: Flowchart of the tests[3].

$$411.416525063895 \times e^{0.2441080272906 \times x} \qquad (4)$$

Summary of the fitted function

Model:411.41653*exp(.24410803*x)

Coefficients: Estimate---Std.Error --- t-value --- P

Parameter 1: 6.019--- 0.1905--31.5973 --- 0.0000

Parameter 2: 0.2441---0.0145--- 16.8290 --- 0.0000

R-squared: 0.9979, Adjusted R-squared: 0.9977

Modulation of the inflection probability: Suppose that the probability of transmission depends on four main parameters, **a**(the number of coughs per minute), **b** (the average number of people encountered per day), **c**(the rate of effectiveness of protective actions) and**d**(the days on which the patient was influenced).

$$P \sim \left(\frac{1440 \times a \times b}{c}\right) \times d!$$

Based on the fact that the doubling time of the epidemic being 6.4 day and $R_0 \sim 2.86$, we can evaluate the **c** the rate of effectiveness of protective actions

Diagnosis

Patients at Taizhou Enze Medical Center were assessed from January 19, 2020, to February 4, 2020. During this period, chest CT and RT-PCR were performed for consecutive patients who presented with a history of travel or residence in Wuhan or local endemic areas or who had been in contact with people in these areas with fever and cough or respiratory symptoms within 14 days and 2 [3].

In the case of a first negative RT-PCR test, repeat tests were performed at intervals of 1 day or more, then included all patients who had undergone both a non-contrast chest CT scan and RT-PCR test within 3 days and who were finally diagnosed with a confirmed diagnosis of COVID-19 infection by RT-PCR (Figure 2) [3].

Typical and atypical chest CT results were recorded according to the scanner characteristics described above for the COVD-19. The detection rate of COVID-19 infection based on the initial chest CT scan and RT-PCR were compared, statistically, the analysis was performed with significance at the $p < 0.05$ level [3].

51 patients were included with a median age of 45 years. The patients had throat or sputum samples followed by one or more RT-PCR tests. The mean time from disease onset to CT scan and RT-PCR was 3 +/- 3 days. 36/51 patients had an initial RT-PCR positive for COVID-19, and 12/51 patients had COVID-19 confirmed by two nucleic acid RT-PCR tests and two patients by three tests and one patient by four tests after initial onset[3].

In this sample of patients, the difference in detection rates for patients who underwent initial CT (50/51 [98%, 95% CI 90-100%]) was greater than that for patients who underwent initial RT-PCR (36/51 [71%,95% CI 56-83%]) (p<0.001) [3].

Examples (A) Examples of typical chest CT findings compatible with COVID-19 pneumonia in patients with epidemiological and clinical presentation suspicious for COVID-19 infection (Figures 3-6) [3].

Examples (B) Examples of chest CT finding less commonly

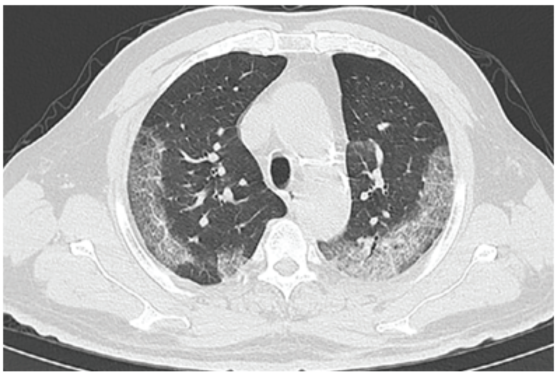

Figure 3: Example of a male, 74 years old with fever and cough for 5 days. Axial chest CT showed bilateral subpleural ground glass opacities (GGO)

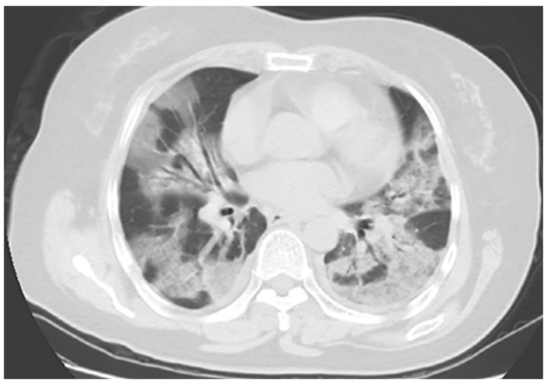

Figure 4: Example of a female, 55 years old, with fever and cough for 7 days. Axial chest CT showed extensive bilateral ground glass opacity and consolidation [3].

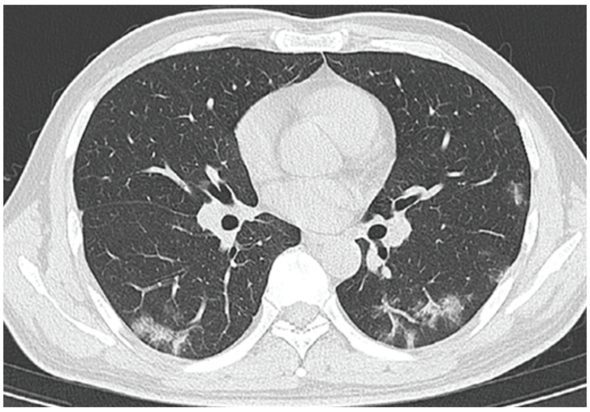

Figure 5: Example of a male, 43 years old, presenting with fever and cough for 1 week. Axial chest CT shows small bilateral are as of peripheral GGO with minimal consolidation [3].

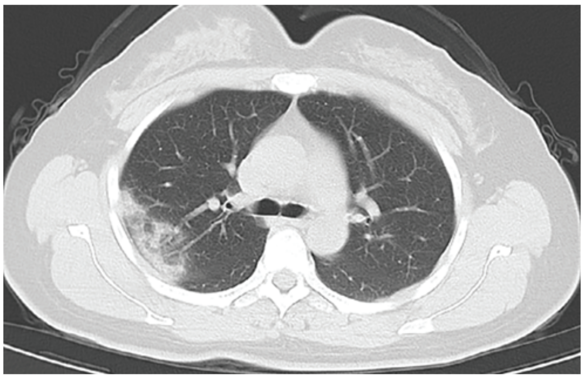

Figure 6: Example of a female, 43 years old presenting with fever with cough for 5 days. Axial chest CT shows the right lung region of peripheral consolidation[3].

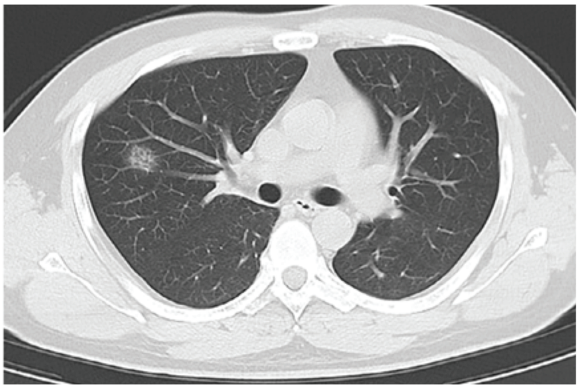

Figure 7: Example of a male, 36 years old with cough for 3 days. Axial chest CT shows a small focal and central ground glass opacity (GGO) in the right upper lobe [3].

reported in COVID-19 infection (atypical) in patients with epidemiological and clinical presentation suspicious for COVID-19 infection Figures (7-9).

Recognizing and Counting of Coughs on Audio Frequency Spectrum

Development of a cough recording system required as an essential first step is to clearly define the definition of cough. As the definition is determined by the modalities to be measured, a classical definition of cough consists of three phases:

1. Inspiration
2. Contraction of the exhalation muscles against a closed glottis
3. Sudden opening of the glottis with a sudden increase inflow

These phases can only be really appreciated if one monitors the flow, glottis movements and muscle activity which, although possible in the laboratory, are currently not practical in the remote measurement of spontaneous cough[4].

The pattern of the cough

It has been shown that the contraction of the expiratory muscles against the closed glottis, followed by the sudden opening of the glottis, generates particularly high flow rates. These "supramaximal flow rates" are higher than those observed on a standard maximum expiratory flow-volume curve and generate the characteristic sound we associate with coughing. This sound is often known as explosive or expulsive sound, with a chaotic and noisy waveform,(Figure 10) [4].

After this explosive sound, the amplitude of the sound decreases, which is called the intermediate phase, and finally, some coughs also contain a third vocal phase. This vocal phase is thought to be due to a second partial closure of the vocal cords which vibrate, producing a regular, periodic waveform similar to the vowels of speech (see Figure 10) [4].

Cough rarely occurs in isolation, especially in patients with chronic cough as is the case with COVID-19 Coronavirus. In the experience of these authors, one of the most common patterns is an

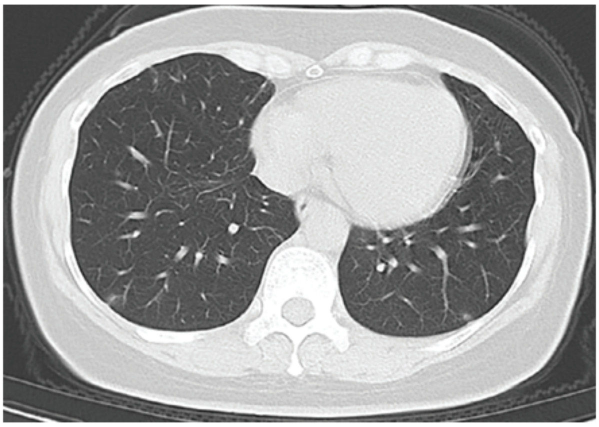

Figure 8: Example of a female, 40 years old. Axial chest CT shows small peripheral linear opacity bilaterally [3].

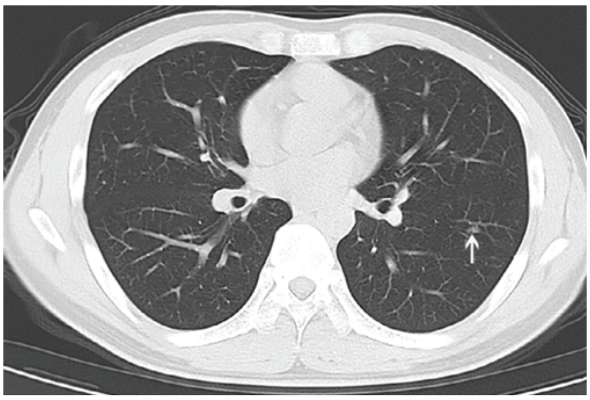

Figure 9: Example of a male, 31 years old with fever for 1 day. Axial chest CT shows a linear opacity in the left lower lateral mid lung[3].

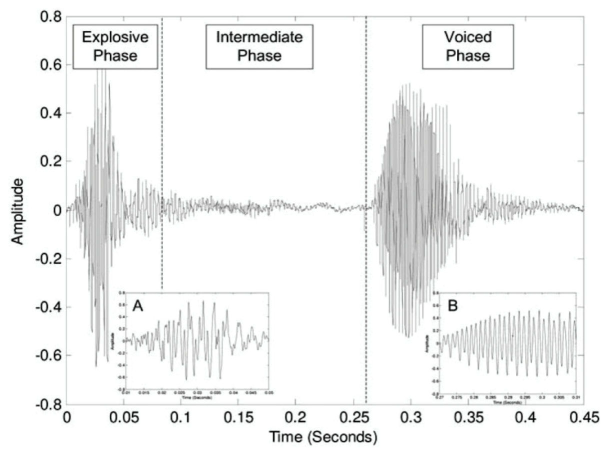

Figure 10: Typical cough waveform showing three phases of the sound. Insets show magnification of A explosive sound which is irregular and noise-like and B voiced phase which is regular and periodic[4].

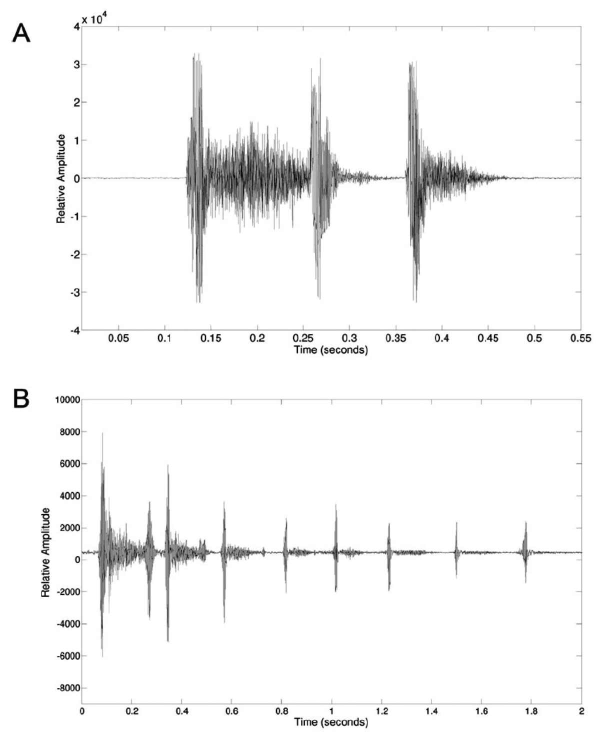

Figure 11: Patterns of coughing. (A) Pair of cough sounds and (B) Cough epoch containing multiple explosive phases [5].

explosive pair of sounds following a single breath. In many patients, prolonged trains of explosive sounds occur following a single breath. The terminology used to describe these episodes varies and includes coughs, spells, bursts or attacks.

From cough sound recordings containing the described waveforms, it is possible to extract a number of different cough characteristics. The most obvious parameter is the quantification of the number of coughs, but in addition, the intensity and quality of the cough sounds can provide other important information for remote diagnosis.

Cough frequency: Although cough is a very common symptom, until recently we knew remarkably little about the frequency of cough in patients with different conditions, nor is there a universally accepted method to quantify cough. The most intuitive way to count coughs is to count the number of explosive coughs. We have also experimented with counting the time spent coughing, the number of seconds per hour containing at least one explosive sound. The authors found that there is a strong linear relationship between the number of cough sounds and the time spent coughing. This seems to be a key element in defining the frequency of coughing, we believe that we can define this linear function using neural networks on large datasets of different people coughing, in particular we focus on defining a single disease, which is the Covid-19 Coronavirus (Figure 11).

Cough periods can be defined in at least two different ways:

1. As a series of explosive sounds in a single breath
2. In the form of continuous explosive sounds without a two-second pause.

For the first definition, it is necessary to be able to detect inspiratory phases in addition to coughing noises. We have compared the last definition, which consists of counting the explosive cough sounds and the time spent coughing. Coughing times are slightly less well correlated with other cough units, because the length of the time is not taken into account. In theory, if an intervention shortened the length of the epoch rather than reducing the number of epochs, this method would not be detected. [4].

Cough intensity: Cough intensity has been shown to be a key component of cough severity for patients, assessed as discrete in relation to cough frequency. Intense cough has been described as a "hard", "deep" or "severe" cough, sometimes associated with physical effects such as pain, discomfort and vomiting.Indeed, the most intense and therefore violent cough is likely to lead to more extreme physical complications such as broken ribs, hernias and syncope, but obtaining an objective measure of cough intensity is complex. It cannot be assumed that the strongest coughs are necessarilythemost intense coughs for patients. In addition, ifthe recording is made from a lapel microphone, the intensity is affected by several factors, including the distance between the mouth and the microphone. But fortunately, here we are trying to study a single disease, COVID-19, and it is easy to get a huge data set to help the neutral network learn quickly.

Physiological measurements during voluntary coughing can quantify the mechanical changes that occur during coughing, but there is little data to clarify the relationship between a patient's perception of intensity and these parameters and the sound of the cough if any. Recent studies have investigated muscle activation, flow rate and pressures generated during voluntary coughing in healthy volunteers. Subjects were asked to cough at three different levels of intensity but from fixed lung volumes. They found that all parameters increased significantly with cough intensity and that cough intensity was also correlated with some cough sound parameters (unpublished data), raising the possibility that a surrogate measure of cough intensity could be derived from cough sound recordings. Further research is needed to better understand the concept of cough intensity in patients and whether an objective measurement of cough intensity can be performed non-invasively and in an ambulatory setting. But we like to repeat what we said before about the possibilities to recognized in case if we are studying one disease in large data sets.

Cough quality: It is possible that useful information can be obtained from the quality of a patient's cough sounds. It is clear that clinicians who listen to cough sounds are able to distinguish coughs with sputum in the airway from dry coughs, but are less able to identify wheezing coughs or the underlying diagnosis of cough sounds. Publications from Korpas have already suggested that the study of voluntary cough noises or "tussophonography" may be useful in diagnosing respiratory disease, although the validity of these measures hasnot been fully established. However, more recent work combining voluntary cough sounds with flow measurements suggests that certain sound characteristics can predict abnormalities in lung function and the Gates Foundation has recently funded

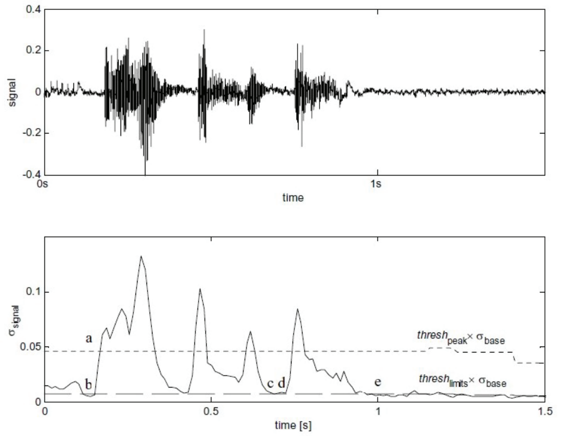

Figure 12: Sound detection. The top graph shows the original sound signal. In the bottom graph depicts σ_{signal} and the two baseline threshold lines in which $thresh_{peak}$ = 10 and $thresh_{limits}$ = 1.5. Point 2(a) indicates the first standard deviation larger than $thresh_{peak} \cdot \sigma_{background}$ Points 2(b) and 2(c) are the points nearest to point 2(a) where σ_{signal} is smaller than $thresh_{limits} \cdot \sigma_{background}$. The whole region between points 2(b) and 2(c) is a sound event. In the same way, the region between points 2(d) and 2(e) will be detected as a sound event [5].

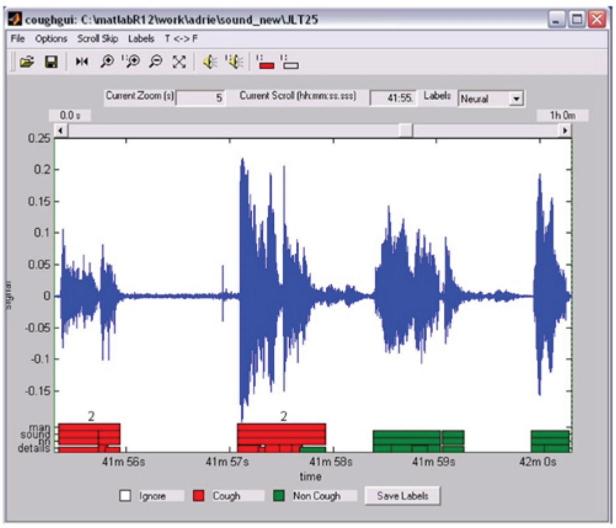

Figure 13: Graphical User Interface (GUI) for human listener [5].

a project to diagnose respiratory disease from voluntary coughs collected by mobile phone. They seem to be a good partner to carry out the protocol!

One of the potential difficulties in making diagnoses from spontaneous cough recordings is the variability of sound components both within and between diagnostic groups. However, it is possible to quantify characteristics such as the proportion of cough with sputum in the airway or wheezing, and this may be useful if representative sound characteristics can be identified and validated[4].

The methods of hull automated cough counter (HACC)

The method, hull automatic cough counter (HACC), works in three steps[5].

1. The signal is analysed to identify periods of sound in the recordings, these sound events are then extracted and any silent periods are omitted from further analysis.
2. Digital Signal Processing (DSP) is applied to calculate the feature vectors that represent each sound event. The techniques used are Linear Predictive Coding (LPC) and a filter bank type front-end processor. The resulting coefficients are reduced by Principal Component Analysis (PCA). This step highlights the components of the data that contain the most variance, so that only those components are used for further analysis.
3. The sound events are then classified into cough and non cough events using a probabilistic neural network (PNN). The PNN is trained to recognize the characteristic vectors of reference cough and noncough events and to classify future sound events appropriately.

Software: All software was developed under Matlab. The following Matlab toolboxes were used: PLS Toolbox version, Signal processing toolbox, Neural network toolbox, and Voicebox[5].

The first step: The audio recording is initially converted into a 44.1 kHz 16 bit mono Microsoft digital wave file. For this process, the sound recordings are analyzed at a sampling frequency of 11.025 kHz. The signal is then analyzed using the moving windowed signal standard deviation $\sigma_{\mathbf{signal}}$, i.e. the standard deviation as a function of time. The moving window works along the entire length of the audio signal, taking each frame as the center of a new window. This windowed standard deviation is similar to the more commonly used root mean square signal however, it corrects for deviations of the mean from zero. Portions of the signal containing no sound events will show a reasonably constant background signal (baseline) with small deviation relating to the inherent noise present in the signal. A sound event will cause the signal to rise above the baseline with a magnitude proportional to the validity of the signal. The moving window technique ensures the standard deviation of the background signal is not fixed forthe duration of the signal; instead $\sigma_{\mathbf{background}}$ at time t is calculated as the minimum $\sigma_{\mathbf{signal}}$ between the start of the window, ($\mathbf{t}$ - $\Delta t_{\mathbf{background}}$) and the end of the window, ($\mathbf{t}$+ $\Delta t_{\mathbf{background}}$). Sound events are thus detected when $\sigma_{\mathbf{signal}}$ for a particular window exceeds the threshold value, $\mathbf{thresh}_{\mathbf{peak}}$, multiplied by $\sigma_{\mathbf{background}}$ for that window. Although this procedure means that sound sensitivity varies to a certain extent, it allows for peak detection in noisy backgrounds. The start and end values of a sound event are defined as the nearest $\sigma_{\mathbf{signal}}$ before and after the peak maximum which is below the defined low level calculated by

$\mathbf{thresh}_{\mathbf{peak}} \times \sigma_{\mathbf{background}}$. Portions of the signal that are below this low level are removed and excluded from further analysis (Figure 12). The amount of noise within the section of the signal is then reduced by smoothing. The standard deviations for each frame in the section are plotted and treated as a series of peaks. Peaks with variations lower than the noise-level are removed. The remaining frames of the signal are compiled for signal processing[5].

The second step is the characterization of sound events using a signal processing step as shown in Figure 14 (i to k). The sound events identified by analysis of the signal are then characterized. Each window undergoes a parameter measurement step in which a set of parameters is determined and combined into a test pattern (termed a feature vector). Because windowing is used, multiple test patterns are created for a single sound event. These test patterns are compared with a set of Ntrain reference patterns for which the cough/non-cough classification is known. Depending on whether the test patterns are more similar to the cough or the non-cough reference patterns the corresponding sound event is classified as a cough or non-cough event respectively [5].

The third step is pattern comparison and decision-making as shown in Figure 14 (l to o). For this HACC uses a PNN. This network provides a general solution to pattern classification problems by following a Bayesian classifiers approach. The PNN stores the reference patterns. Instead of classifying single patterns, HACC classifies complete sound events. The $\rho_{\mathbf{k}}$ values for all test patterns belonging to the sound event are summed yielding a sum of

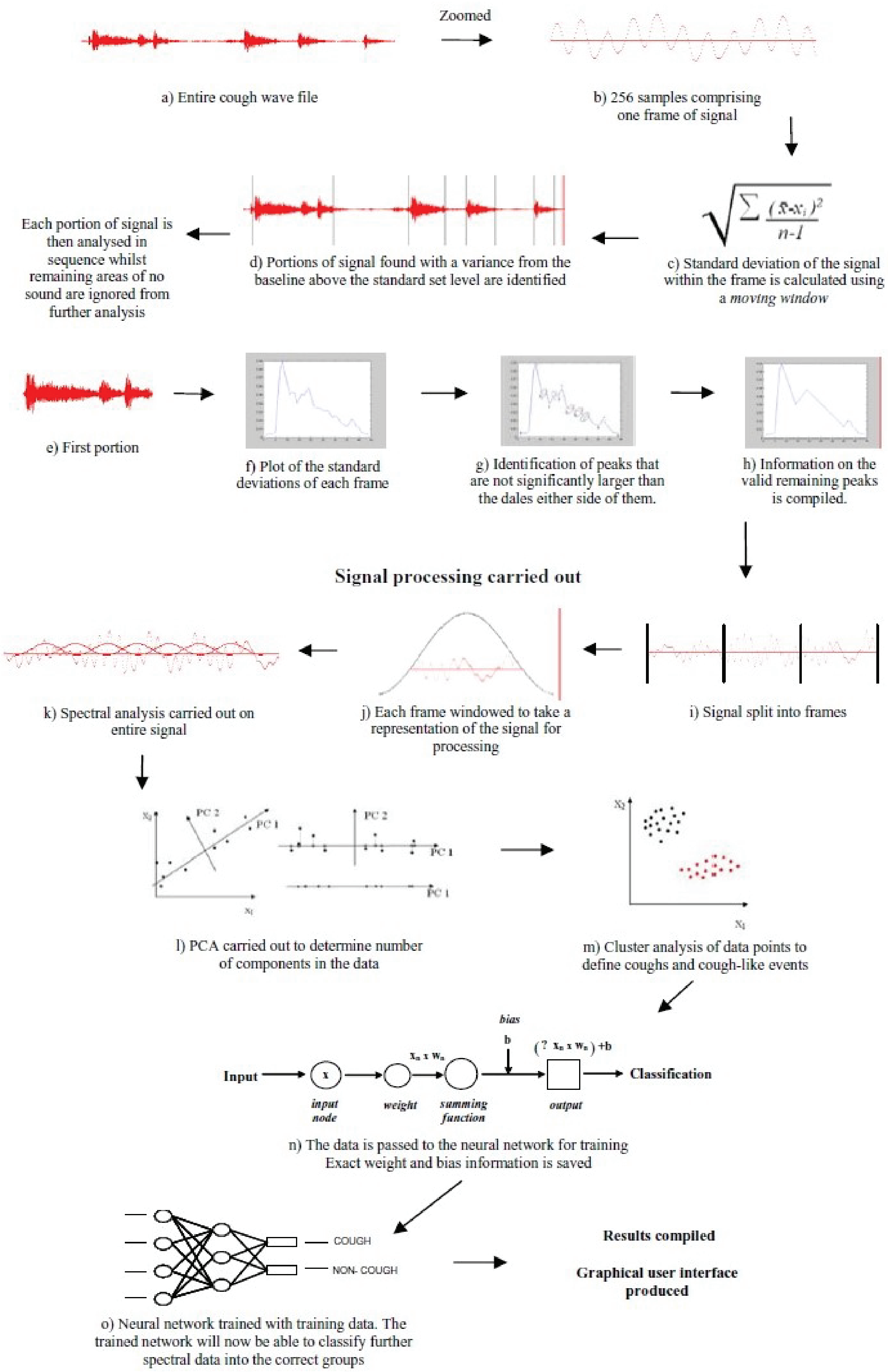

Figure 14: Pattern Recognition Approach to cough and non-cough classification[5].

Symbol	Meaning	Value
f_s	SamplingFrequency	$11025Hz$
t	Time in milliseconds	
$\sigma signal$	Windowed standard deviationofsignal	Calculated as a function oftime
$\Delta t Background$	Backgroundinterva	$11026 points (1000 ms)$
$thresh_{peak}$	High (eventdetection)threshold	$10.\sigma_{background}$
$threshlimits$	Low (event start andend)threshold	$2.\sigma_{background}$
$\sigma background$	Standard deviation of background	
$N train$	Number ofreferencepatterns	$150(75 cough/75 non-cough)$
$n b-o-f$	Number of mel bank-of-filter scepstral coefficients	$42(14+14.1^{st} derivatives+14.2^{nd} derivatives)$
$n LPC$	Number of LPCcepstralcoefficients	$14(noderivatives)$
$N cepstral$	Total number of cepstral coefficients	56
$N PCA$	Reduced number of features	45

Table 2: Symbols used and their settings [5]

probabilities $\sim\rho_{\mathbf{k}}$ for each class **k**. The sound event is classified as a member of the class with the largest $\sim\rho_{\mathbf{k}}$ [5].

Creation of the reference patterns

Sound recordings of **N** subjects are used to create a set of **M** cough patterns and **M** non-cough patterns.

The first step is to identify the appropriate cough and non-cough events in all **N** recordings. Adequacy is determined by the clarity of the sound and its ability to add relevant variations to the data set.Non-cough events are sounds present in the audio recording that are not coughs. These events are combined in an X_{cough} pattern matrix and an $X_{\text{non-cough}}$ pattern matrix [5]. The length of feature vectors in these matrices is reduced by performing principal component analysis (PCA). The combined X_{cough}, $X_{\text{non-cough}}$ matrix is first scaled automatically and then, as defined by the PCA, only scores that describe more than 0.5% of the variance are used. The experimental data are scaled using the means and variances of the baseline data and projected to the principal component space using a projection matrix. The reference models used for the creation of the NNLP are obtained by performing two **k-means**clustering of approximately 10,000 cough and non-cough models. The first 10,000 patterns are selected from the X_{cough} and $X_{\text{non-cough}}$ patterns. The reference patterns are then passed into the NDP for future classification of cough and non-cough patterns, see (Figure 12-14) (Table 2).

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