A Framework for Acoustic Detection of COVID-19 based on Deep Learning

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Abstract
COVID-19 diagnosis is integral to the efforts of limiting the spread of the disease. However, diagnosing COVID-19 poses challenges and risks of further spread of the disease whilst also not always being easily accessible to all members of the public. This paper proposes a method to develop a novel non-invasive method to automatically classify the most common symptoms of COVID-19. The method is based on the classification of sounds associated with coughing and shortness of breath of potential COVID-19 patients. Our solution is based on Deep Learning technology through Convolutional Neural Network (CNN) with the aim of recognizing the shortness of breath and dry cough of carriers of COVID-19. This system will provide an effective and objective method for diagnosis to enable healthcare providers and the public to assess their conditions with high confidence prior to proceeding with further investigation and treatments. The core of this e-health based research focuses on developing an advanced AI based classification diagnostic engine with high accuracy that feeds into different modules of the platform according to the need-analysis which will be conducted. The classifier will also be trained incrementally through innovative feedback channels that rely on the consensus of the expertise labelling to ensure system integrity. The outcome of this research will be a platform accessible by patients, healthcare workers and decision makers through mobile computing technologies and remote terminals that will be used to capture the COVID-19 audible symptoms as well as presenting the outcome.

Key words:
COVID-19 diagnosis, Deep Learning, Convolutional Neural Network (CNN), E-health, artificial Intelligence (AI)

1. Introduction

COVID-19 [1] is a disease spread by novel coronavirus. According to World Health Organization (WHO), the new coronavirus disease COVID-19 [1, 2] is officially considered a pandemic which has caused widespread changes in societies throughout the world. COVID-19 is a highly contagious virus which can spread quickly and causes serious pneumonia. In fact, early diagnosis of COVID-19 is considered a crucial step to control the rapid spread of the virus. This step should be accurate and as quick as possible to be able to treat patients efficiently and to ovoid pneumonia which is the major cause of death provoked by this virus.

Until now, the Reverse Transcription-Polymerase Chain Reaction (RT-PCR) is recognized as the diagnosis method with the highest levels of accuracy. However, due to the excessive demands related to RT-PCR kits, a large-scale PCR diagnosis is still a challenging task. Similarly, COVID-19 diagnosis can be done by using chest CT (Computed Tomography) technology to detect early lung lesions. Due to the hundreds of slices in chest CT and the similar manifestations of this new lung disease to classical known pneumonia types, the diagnosis becomes very difficult. In other words, this type of diagnosis requires experienced radiologists to achieve high recognition accuracy [3].

Due to the shortcomings related to the inability to conduct mass COVID-19 screening of the public, authorities have resorted to limiting the tests to patients who show obvious symptoms of the disease. Therefore, a patient who shows obvious symptoms is advised to visit a COVID-19 testing site to conduct the test. This trip to the testing center constitutes an extra health hazard to the patient with suspected symptoms to either infect other people or get infected. The proposed system should provide an objective method to remotely classify the audible symptoms of the disease whether they are COVID-19 related or not, to provide some certainty to the patients on their emerging health condition. Our solution is based on deep learning technology through Convolutional Neural Network (CNN) with the aim to recognize the common COVID-19 symptoms, namely, shortness of breath and a cough.

1.1 Problem Statement

An open problem associated with COVID-19 pandemic has been to identify the affected persons at the early stages of the virus in order to provide adequate treatment. The aim of this paper is to propose a framework to diagnose the existence of the coronavirus with a novel non-invasive method by automatically classifying the most common symptoms of COVID-19. Moreover, the method would enable automatic classification of COVID-19 audible symptoms. The proposed system would contain a diagnosis

Manuscript received January 5, 2022
Manuscript revised January 20, 2022
https://doi.org/10.22937/IJCSNS.2022.22.1.58

engine which would enable to recognize the signatures of both normal and abnormal breathing and coughing using an available experimental dataset. In this paper, the conceptual design of the framework, including that of the underlying system, is proposed. The framework, as shown in Fig 2, also provides an innovative workflow and operational/business model, which would provide system evolutionary training, maintenance and take growth into consideration.

2. Related Work

Detecting COVID-19 early is crucial to treat the disease. Authors in [4] have provided a method for this based on the analysis of X-ray images. Due to the emerging public health situation provoked by the COVID-19 pandemic, many research endeavours were conducted in order to propose solutions for early diagnosis. In fact, we can cite the work of [5] which presents a preliminary COVID-19 screening based on data collection related to basic travel history using a smartphone-based online survey. In another study [6], the authors presented a Machine Learning algorithm used to analyze clinical datasets for early COVID-19 identification. Similarly, in the research presented by [7], the authors were focused on the general COVID-19 diagnosis based on Artificial Intelligence (AI). Also, the work of [8] presented a Deep Learning-based mechanism to identify COVID-19 and distinguish it from common pneumonia and similar respiratory diseases utilizing chest CT. In the work of [9], the authors gave an overview of how AI, Machine Learning and Deep Learning technologies can be used on international pandemic data, clinical data and genetic data. We can also cite the work of [10], which is based on the Convolutional Neural Network (CNN) chest ICT training for early detection of COVID-19.

In the work presented in [11], the authors proposed a solution to automatically detect and analyze coughs based on the CNN to classify the cough spectrograms for model training. Similarly, in the research proposed by [12], a solution is proposed for cough detection, cough classification and whooping sound detection. They are based on relevant feature extraction and the logistic regression model for classification tasks. In the work of [13], the authors focused on the automatic classification of wet and dry coughs based on a Logistic Regression Model (LRM). Also, the work in [14] presented an automatic mechanism to detect cough patterns from acoustic signals. The adopted algorithm uses three spectral features in conjunction with LRM to separate sound segments into cough and non-cough events.

The authors in [1] proposed a method to classify breathing sounds from Intensive Care Unit (ICU) patients. Firstly, breathing sounds were represented using the power spectrum and then aggregated the frequency axis that ranges between 0–800Hz to formulate a feature vector. Sounds were then segmented and finally classified using back-propagation neural networks into normal and abnormal categories.

The researchers in [15] proposed the use of Support Vector Machine (SVM) and CNN methods to classify respiratory sounds. They used Mel Frequency Cepstral Coefficient (MFCC) capabilities with the SVM and spectrogram images in conjunction with the CNN algorithm. The classification accuracy for their proposed model was between 62% and 86% for both CNN and SVM algorithms using different datasets.

Authors in [16] proposed a deep CNN-RNN model that categorizes respiratory acoustic signals based on Mel-spectrograms. The proposed hybrid model screens respiratory patients and establishes patient categorization models using limited datasets to detect anomalies. The proposed model reaches 71.81% accuracy using leave-one-out validation.

To the best of our knowledge, COVID-19 pre-diagnosis based on short breath and dry cough acoustic sound recognition is not yet studied. In this article, a CNN based solution is proposed, for early detection of COVID-19 symptoms based on acoustic data. Studies of some other aspects of COVID-19 can be found in [17-20].

3. Proposed Framework

In this section, design and specification of the proposed framework are discussed.

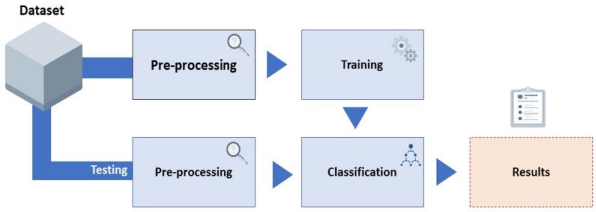

Fig. 1. Overall Design Concept

3.1. Design of the Proposed Framework

Figure 1 shows an overall design concept of our model. More information about the design of the proposed model is provided in two subsections, namely Pre-Processing and Pre-trained CNN Model. These two features provide the foundation for the design of the proposed framework:

- Pre-processing: Mel Frequency Cepstrum Coefficients (MFCC) is a technique utilized in speech recognition [9, 21]. MFCC is notably efficient in terms of its ability to depict speech amplitude spectrum in a compact format [21]. Moreover, MFCC starts by segmenting acoustic signals into separate frames with the main goal of eliminating edge effects. Following the previous step, by retaining only the logarithm of the amplitude spectrum relative to each frame, Discrete Fourier Transform (DFT) is computed. Then, spectrum

smoothing is performed to arrive at meaningful frequencies. In the proposed system, MFCC signal is represented by converting the output features into images (PNG format) that are then used as an input for CNN training models.

- Pre-trained CNN Model: Deep Learning methods are being widely used in computer vision due to their success in outperforming other Machine Learning techniques [21]. The proposed model is mainly based on CNN models which are capable of tolerating image noise such as distortion and illumination related changes [22]. The work conducted by [23] illustrates great success for CNN models in recognizing images and comparing complex datasets of images in different formats and qualities. In the context of the proposed solution, the fact that CNN models require small training datasets is exploited for fast and effective acoustic signal training.

3.2. Specification of Framework

Figure 2 shows the suggested framework of the system with its functionalities and flow of processes and activities. The main components of the proposed framework can be summarized as follows:

- Automatic acoustic pre-processing step to de-noise the signal. This step is necessary to allow for accurate detection and removal of noise in the acoustic cough signal segmentation. Consequently, infinite impulse response (IIR) filtering models will be used for noise and echo removal from the used acoustic datasets.

- Automatic breathing and cough acoustic signal segmentation. To be able to have accurate analysis of the cough acoustic signal, it will be vital to acquire appropriate breathing and cough acoustic segments. Breathing and cough acoustic signal segments will be based on two main datasets: COVID-19 breathing and cough wav signal and non-COVID-19 breathing and cough wav signal. These datasets will be used in the training phase preceding the automatic cough segment selection phase.

- Automatic breathing and cough segment selection. GMM Bi-clustering techniques will be used for automatic breathing and cough selection where appropriate. Hence, acoustic signals will be selected to be passed to a pre-trained CNN model.

- Convolutional Neural Network (CNN) training. CNN is a Machine Learning based technique for pattern recognition and will be used in the proposed system to detect COVID-19 dry cough and breathing acoustic patterns. A pre-trained CNN model will be utilized to generate COVID-19 diagnosis results. The diagnosis results will depend on the inputs represented in the smart phone from breathing and dry cough acoustic signals which are IRR-filtered, segmented, turned into PNG images and then passed to the CNN model for training or analysis.

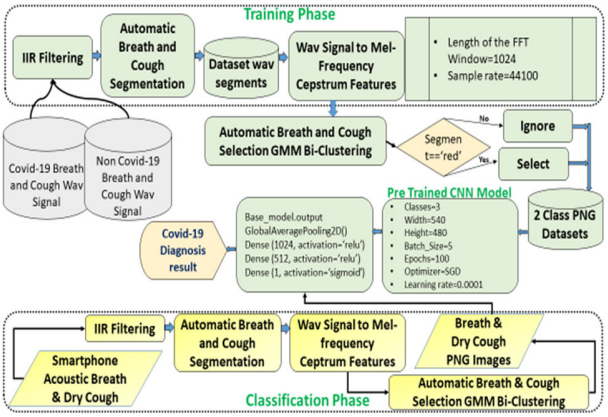

Fig. 2. Framework Architecture

4. Future Scope of Research

Acoustic Detection of COVID-19 is a novel scheme to detect the virus at early stage, based on dry cough and shortness of breath, in order to deal with the virus before it takes hold of the patient. As the model is novel, no data is available at the moment. It is expected that in future, when the model is put to practice, data would be available. At that stage it would be an interesting problem to analyse the data. Data analysis could also include simulation of the proposed model.

5. Conclusion

We proposed a novel system based on CNN training models for the detection of COVID-19 symptoms, namely shortness of breath and a dry cough. The proposed system is non-invasive and can be deployed in smart phones for prompt, easy and low risk initial diagnosis of COVID-19 before taking any further tests. The future work will aim to validate the accuracy of COVID-19 detection by sampling an appropriate dataset collection for system training and detection of COVID-19 symptoms. An appropriate sample of COVID-19 patients will have to be selected to collect the required set of acoustic signals which will be used for system training. Furthermore, samples will also have to be collected from non-infected participants so that the system can have ample training data to distinguish between the acoustic signals of COVID-19 infected samples and those of healthy samples.

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