HYBRID APPROACH BASED ON MACHINE LEARNING AND DYNAMIC CASE BASED REASONING FOR COVID-19 CLASSIFICATION

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ABSTRACT

COVID-19 has reached almost every country and affected millions of people because of its incredible speed of spread. Covid-19 had a bad territorial impact in its different dimensions: health, economic and social. Predicting infected cases in advance can help reduce the rate of its transmission and reduce the number of infected people. In this article, we propose a hybrid approach of covid-19 cases classification based on Multi-Agent System (MAS), Dynamic Case Based Reasoning approach, and the support vector machine supervised machine learning algorithm. The aim of this approach is to classify the cases' diagnostic as infected by COVID-19 or not to estimate suspected cases. It consists of an audio classifier for cough recognition by the SMV algorithm in the retrieve step of the Dynamic Case Based Reasoning to fetch a set of similar cases to our target case. To increase and enhance our working dataset, the data augmentation technique has been used. Then, our data has been preprocessed and cleaned to ensure the consistency and converted into a Mel-Spectrogram to extract useful features and transform them into significant feature images, so they will be used as input to our model. The test set of our model has reached an accuracy of 80% and a precision up to 95%.

Keywords: *Dynamic Case Based Reasoning (DCBR), Covid-19, Support Vector Machine (SVM), Mel-Spectrogram, Multi Agents System (MAS)*

1. INTRODUCTION

Coronavirus disease (COVID-19) is an infectious disease caused by the SARS-CoV-2 virus, it has appeared in Wuhan, China at the end of 2019. Few months later, the deadly virus spreads in the whole world and it turned out to be a pandemic in the entire world which is become a challenging and serious worldwide issue, it has impacted both mental and physical health as well economics, education, social relationship [1].

Infected people with the COVID-19 have experienced mild to moderate respiratory illness and can recover without hospitalization and some of them became seriously ill. What makes COVID-19 much more terrifying is his capacity of spreading between people and his ability to survive on surfaces for several hours, causing diseased millions of people and the availability of limited number of testing kits [2]. COVID-19 spreading is stochastic, the best way to follow it, prevent and slow down transmission is to be well informed about the virus and how it spreads, and also using similar past experiences of already infected cases to reuse their cough which will allow us to estimate new suspected cases in real time.

In this article, we propose a hybrid approach of covid-19 cases classification based on Multi Agent System, Case Based Reasoning approach, and the Support Vector Machine algorithm to classify people as infected by COVID-19 or not based on their cough recognition which can be used for COVID-19 testing to estimate suspected patients. As a first step, we improve the audio data by applying the data augmentation technique like noise injection, shifting time, pitch and speed modification. Afterwards, we preprocess our data to guarantee consistency and convert it into a Mel-Spectrogram. The Mel-spectrogram is an efficient way of processing audio files to extract useful characteristics for audio

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recognition [3]. Support vector machine is applied in the retrieve step of the Dynamic Case Based Reasoning cycle to classify the cough using the spectrogram with similar features.

The rest of this paper is organized as follows: Section two, provides the literature review. The proposed approach is designed in section three. Section four provides the result of the experiment using the DCBR, and the support vector machine algorithm. We conclude this paper with a conclusion and perspectives in section five.

2. LITERATURE REVIEW

2.1 Multi Agent System

Multi-agent system is a system which is composed of a set of agents that interact with each other in a common environment to reach their goals and solve a common problem [4]. The multi-agent system aims to organize the operation of the agents in the whole system, it distributes roles among the agents which are part of this architecture [5, 6]. Agents have the ability to acquire experience in their environment as depicted in [7,8] and capable of changing it with their actions. Agents can interact to share information, knowledge and tasks to achieve their goals [9]. An agent can act in the place of a consumer and perform work on their behalf [10]. Agents are autonomous, they can take decisions and execute actions on its environment to achieve certain objectives.

2.2 Dynamic Case Based Reasoning

DCBR is a problem solving paradigm that reusing past experiences to solve a new problem taking into consideration the previously solved ones [11]. The current problem to solve is called target case and the problem that has been already solved is called source case. The research on Case Based Reasoning can be dated back to 1975 and takes its origin from Schank's memory [12]. Dynamic Case based Reasoning can be applied to solve various problems, such as cooking, medicine, transportation, poetry and music generation. A given problem using the Dynamic Case Based Reasoning approach can be solved using the following steps, as shown in Figure 1: (1) Elaboration: Constructing the specifications of the problem to be solved, (2) Fetch similar cases, (3) Reuse these cases, (4) Evaluates the proposed solution and finally (5) Hold the proposed solution as a new case [13, 14]. These steps are more detailed in [15, 16].

In DCBR cycle, the execution of certain steps can be stopped, other steps can be re-executed each time a change in the specifications of the target case has been occurred, some steps can be repeated more than once.

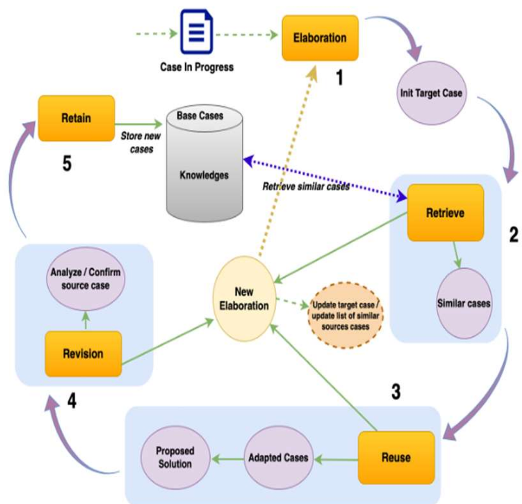

Figure 1: Dynamic CBR Cycle inspired from [14]

2.3 The SVM Classification Supervised Machine Learning Algorithm

The Support Vector Machine is a supervised machine learning algorithm that is used for classification, regression problems, and also for anomaly detection [17]. It was introduced since 1992 from a statistical learning theory developed by Vladimir Vapnick, Boser and Guyon. This model was quickly adopted due to its ability to work with high-dimensional data, its theoretical guarantees and the good results achieved in practice. Requiring a small number of parameters, SVMs are appreciated for their ease of use. The SVM can be defined as a prediction tool used to find a particular decision boundaries or hyperplane. It is widely used, and it is considered among robust techniques for classification analysis in machine learning. According to the used data, we use the SVM algorithm for binary classification [18]. The aim of the support vector machine is to find an optimal hyperplane in an N-dimensional space [19]. Hyperplanes are decision boundaries that can aid to distinctly classify data points [20, 21] and N is the number of features. The goal is to make the width of the margin between the two parallel clipping planes get the largest value. Those instances of data closest to the separating hyperplane are called support vectors. With the maximization of margin distance, future data points can be categorized with more confidence [22, 23]. To practice machine learning, there are many libraries that propose the SVM

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algorithm with Python language like Scikit-learn which offers a sklearn.svm module. Users can solve both classification and regression problems. The support vector machine can be used to solve diverse problems, we cite:

- Images classification: Several results show that the SVM achieve a higher accuracy in image classification and segmentation.
- Text and hypertext categorization, as we can reduce significantly the need of labeled data.
- The SVM is also very powerful in Hand-written characters recognition.
- Proteins classification in biology.

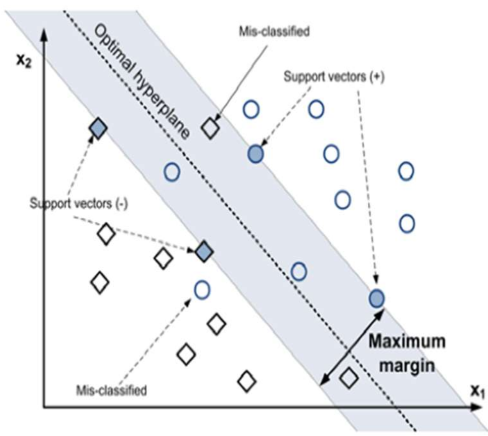

Figure 2: Optimal hyperplane and Support Vectors [17]

3. PROPOSED APPROACH AND ARCHITECTURE

The proposed approach consists of an audio classifier for cough recognition based on Multi-Agent System, Dynamic Case Based Reasoning and the Support Vector Machine supervised machine learning algorithm. As illustrated in Figure 3, our proposed approach incorporates several steps in the cough classification workflow. Before starting to analyze and classify a specific cough, it is necessary to localize the cough in the audio recording, then crop or segment the audio file accordingly [24]. This step is essential to clean the background noise and silence to enhance the audio data and facilitate the cough recognition. Thereafter, we preprocess our audio data source and convert it into a Mel-spectrogram, which is an effective tool to extract useful information and transform it into significant feature images. At last, these features will be used as input to our classifier model to classify the cough and fetch similar cases to the target case.

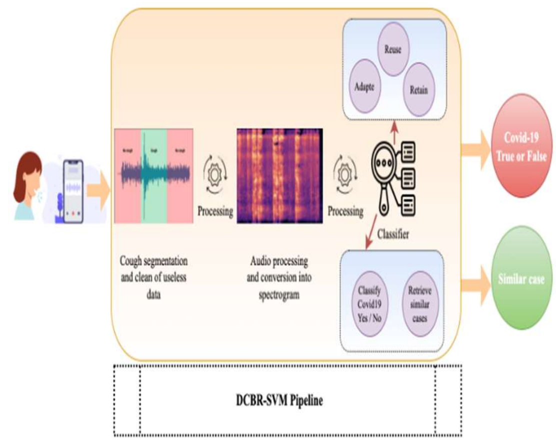

Figure 3: Workflow of our approach

Our proposed approach involves the use of a multi-Agents architecture in our Dynamic Case Based Reasoning cycle. The agents of our architecture perform specific tasks in each step of the DCBR cycle, they execute all the required tasks from constructing the characteristics of the Mel-spectrogram for cough recognition, classifying and retrieving similar cases for the target case. The Support Vector Machine Algorithm is used in the retrieve step of the Dynamic Case Based Reasoning cycle to build our Mel-spectrogram model.

Our proposed architecture is illustrated in Figure 4 below:

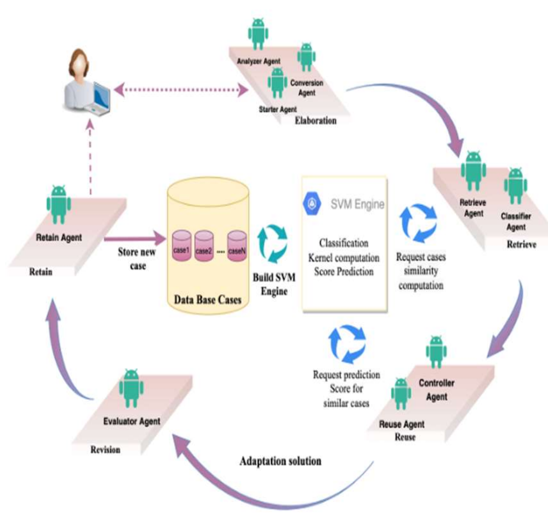

Figure 4: Our proposed architecture

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- Elaboration or Processing: Agents of this layer handle the collected information by the system and initialize the target case according to the provided input specifications. This layer contains three agents:
    - **Analyzer Agent**: An audio recording of the cough may in some cases contain background noise or silence which cause an overlay of a variety of uncorrelated sounds and make it difficult for recognition. The aim of this agent is to segment the cough, delete the segments which are not coughs or which present too much background noise and finally create the segment on our data base cases.
    - **Conversion Agent**: This agent processes the audio recording cough and convert it into spectrogram to extract useful features and transform them into significant feature images, so they will be used as input to our model.
    - **Starter Agent**: After cleaning, converting and extracting the features from the spectrogram, the starter agent builds and initializes our target case. That will serve to find similar cases in the data base cases.
- Retrieve Layer: This layer contains the following agents:
    - **The Classifier agent**: this agent aims to classify COVID-19 from other non-COVID-19 from the spectrogram images using our CBR-SVM system.
    - **The Retrieve agent**: This agent fetches a set of similar cases to the target case. For that, we applied the SVM computation method. This CBR system exploits the kernels mapping function as the similarity function.
- Reuse Layer: The agents of this layer reuse the cases that are judged similar to the target case. The reuse layer contains two agents:
    - **Reuse Agent**: This agent requests prediction score through the SVM engine for similar cases that have been proposed by the retrieve agent. Then, the reuse agent tries to fit the solutions by selecting the most appropriate and reuse them to acquire a new solution.
    - **Controller agent**: The controller agent checks asynchronously if there is a modification in the specifications of the target case and communicate with the starter agent if an update is needed.
- Revision Layer: The Evaluator agent of this layer evaluates the proposed solution and verify if it is close to our target case, otherwise a revision is advised.
- Retain Layer: If the prediction conditions are satisfied and exceeds a specific threshold level, the retain agent holds the proposed solution and a new case will be added as a new case for future utilization.

4. RESULTS AND DISCUSSION

4.1 Data Augmentation

To help training our model and to get a good accuracy, we need a huge amount of data. Data augmentation [25] is a method based on the principle of generating synthetic data. Creating new samples by applying transformations and tweaking little factors on the original data. With this method, we can get huge amount of enhanced data for a single sample and also increase the size of our data to avoid overfitting. For our cough recording, we apply some useful alterations, Noise addition, Time shifting, Pitch shifting and finally Time stretching. Numpy offers an easy way to handle noise injection and time shifting, while librosa which is a library for audio recognition allows pitch shifting and Time stretching to be manipulated easily with just one line of code.

- Noise addition: This involves the addition of a random value to the sample using numpy's normal method.

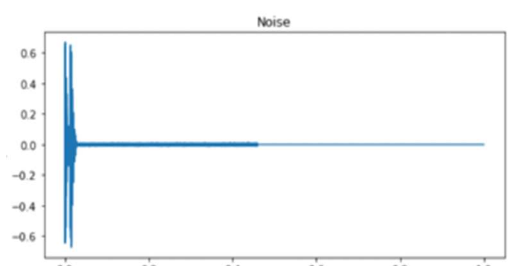

Figure 5: Noise addition

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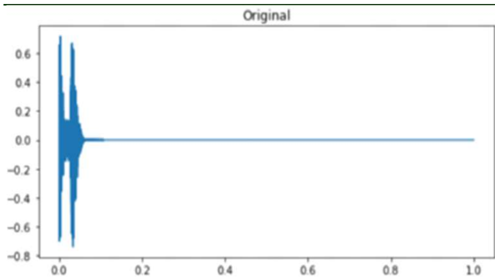


Figure 6: Original Audio

- Time shifting: To achieve that, we move the audio to the right or left by a random value along time axis.

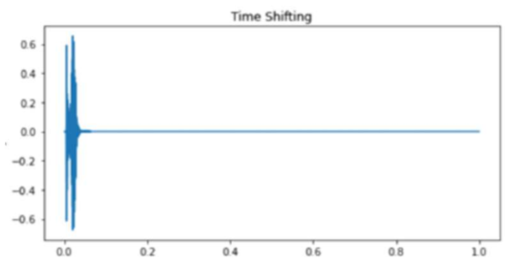


Figure 7: Time Shifting

- Pitch shifting: This process involves the change of the pitch of sound without affect its speed.

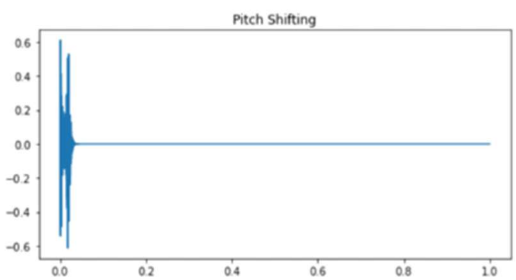


Figure 8: Pitch Shifting

- Time stretching: This is a process that consists on changing the speed of sound without affecting its pitch.

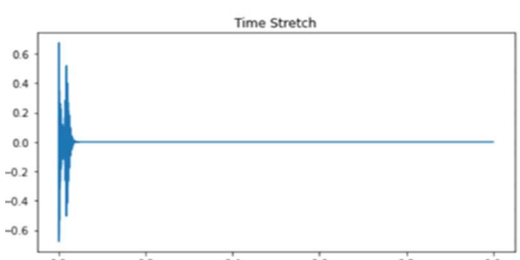
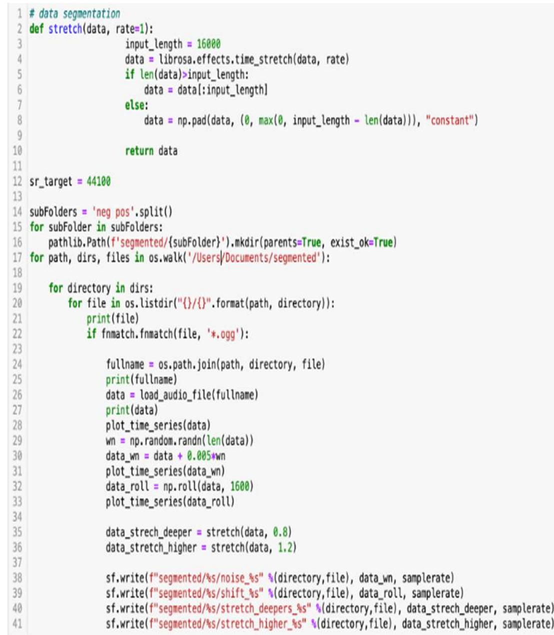


Figure 9: Time Stretching

The figure Fig.10 below represents the data augmentation code in python.



```python
# data segmentation
def stretch(data, rate=1):
                input_length = 16000
                data = librosa.effects.time_stretch(data, rate)
                if len(data)>input_length:
                    data = data[:input_length]
                else:
                    data = np.pad(data, (0, max(0, input_length - len(data))), "constant")

                return data

sr_target = 44100

subFolders = 'neg pos'.split()
for subFolder in subFolders:
    pathlib.Path(f'segmented/{subFolder}').mkdir(parents=True, exist_ok=True)
for path, dirs, files in os.walk('/Users/Documents/segmented'):

    for directory in dirs:
        for file in os.listdir("{}/{}".format(path, directory)):
            print(file)
            if fnmatch.fnmatch(file, '*.ogg'):

                fullname = os.path.join(path, directory, file)
                print(fullname)
                data = load_audio_file(fullname)
                print(data)
                plot_time_series(data)
                wn = np.random.randn(len(data))
                data_wn = data + 0.005*wn
                plot_time_series(data_wn)
                data_roll = np.roll(data, 1600)
                plot_time_series(data_roll)

                data_strech_deeper = stretch(data, 0.8)
                data_stretch_higher = stretch(data, 1.2)

                sf.write(f"segmented/%s/noise_%s" %(directory,file), data_wn, samplerate)
                sf.write(f"segmented/%s/shift_%s" %(directory,file), data_roll, samplerate)
                sf.write(f"segmented/%s/stretch_deepers_%s" %(directory,file), data_strech_deeper, samplerate)
                sf.write(f"segmented/%s/stretch_higher_%s" %(directory,file), data_stretch_higher, samplerate)
```

Figure 10: Data augmentation code in Python

4.2 Mel Spectrogram

A spectrogram is a way to represent visually the spectrum of frequencies of a signal as it changes over time at different frequencies. The MEL spectrogram is defined as a spectrogram where the frequencies are converted to the Mel scale [26].

After the audio data has been augmented and processed, we transform the new data into Mel-spectrograms so we can train our SVM model. Audio data contains complex features and characteristics. The Mel-Spectrogram is the efficient way to extract useful features and transform them into significant feature images for audio processing. In our implementation, we used the librosa python package [27] for audio analysis. Below, we show an example of figures for Mel-Spectrogram that covers some use cases after the data augmentation process.

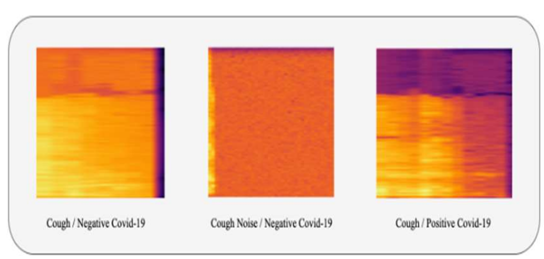


Figure 11: Cough Mel-Spectrogram

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The figure below represents the Spectrogram generation code in python.

```python
#Spectrogram Generation
cmap = plt.get_cmap('inferno')
fig = plt.figure(figsize=(8,4))
subFolders = 'neg pos'.split()
for subFolder in subFolders:
    pathlib.Path(f'Spectrogram Images/{subFolder}').mkdir(parents=True, exist_ok=True)
    for fileName in os.listdir(f'segmented/{subFolder}'):
        wave = f'segmented/{subFolder}/{fileName}'
        y, sr = librosa.load(wave, mono=True, duration=5)
        plt.specgram(y, NFFT=2048, Fs=2, Fc=0, noverlap=128, cmap=cmap, sides='default', mode='default', scale='
        plt.axis('off');
        plt.savefig(f'Spectrogram Images/{subFolder}/{fileName[:-3].replace(".", "")}.png')
        plt.clf()
```

Figure 12: Spectrogram generation code in Python

The figure below represents the CSV data base generation code in python. The data base contains useful features which have been extracted and transformed into significant feature images.

```python
# CSV data base Creation
file = open('covid_datast.csv', 'w', newline='')
with file:
    writer = csv.writer(file)
    writer.writerow(header)


subFolders = 'neg pos'.split()
for subFolder in subFolders:
    for fileName in os.listdir(f'segmented/{subFolder}'):
        wave = f'segmented/{subFolder}/{fileName}'
        y, sr = librosa.load(wave, mono=True, duration=5)
        rmse = librosa.feature.rms(y=y)[0]
        chroma_stft = librosa.feature.chroma_stft(y=y, sr=sr)
        spec_centt = librosa.feature.spectral_centroid(y=y, sr=sr)
        spec_bw = librosa.feature.spectral_bandwidth(y=y, sr=sr)
        rolloff = librosa.feature.spectral_rolloff(y=y, sr=sr)
        zcr = librosa.feature.zero_crossing_rate(y=y)
        mfcc = librosa.feature.mfcc(y=y, sr=sr)
        to_append = f'{fileName} {np.mean(chroma_stft)} {np.mean(rmse)} {np.mean(spec_centt)} {np.mean(spec_bw)}
        for e in mfcc:
            to_append += f' {np.mean(e)}'
        to_append += f' {subFolder}'

        file = open('covid_datast.csv', 'a', newline='')
        with file:
            writer = csv.writer(file)
            writer.writerow(to_append.split())
```

Figure 13: CSV data base generation code in Python

4.3 Data Presentation and Result

In this part, we aim to test the efficiency of our proposed approach for covid-19 classification modeling based on DCBR, MAS and the support vector machine supervised machine learning algorithm in the retrieve step of the DCBR cycle. Each audio signal is composed of many characteristics. The process of feature extraction in order to use them for analysis is called feature extraction. So, Firstly, we extract all features and characteristics from the Mel-spectrogram that we judge relevant for our problem [28]. In our case, we will extract Mel frequency cepstral coefficients (MFCC), spectral centroid, zero crossing rate, chromatic frequencies and spectral roll-off. Afterwards, all extracted features are then grouped together in a .csv file so that the SVM classification algorithms can be applied. All grouped Covid-19 cases in the .csv file represents a source Casei of our data base cases that are constructed with these features as follow:

$$\boldsymbol{Case_i} = \begin{pmatrix} chroma\ stft \\ rmse \\ spectral\ centroid \\ spectral\ bandwidth \\ spectral\ rolloff \\ zero\ crossing\ rate \\ mfcc1 \\ mfcc2 \\ \vdots \\ mfcc20 \end{pmatrix} \quad (1)$$

Our Data is an open cough Dataset made by a volunteer-run organization and which is labeled with COVID-19 PCR test status [29]. The total number of source cases obtained after the conversion of audios to spectrograms is 605, of which 365 cases represent negative cases for covid-19 and 240 are positive cases. Since we have a lot of features, and in order to simplify data visualization, the PCA (Principal Component Analysis) [30] technique has been used to reduce our dataset into 3- Dimensional format. Figure 14 below represents the repartition of our cases. Green dots represent the negative cases, and the red dots represent the positive cases.

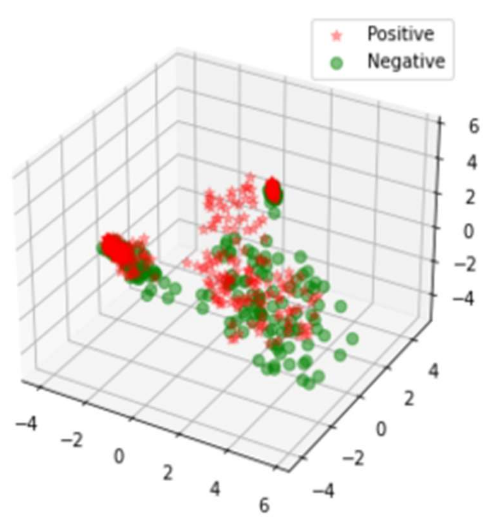

Figure 14: Dataset visualization

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In order to test the effectiveness of our SVM model, we split our dataset into two parts, training and test set. The evaluation of a model aims to estimate the accuracy of generalization of a model on future data (unseen data / out of samples). In order to evaluate a model, it is not recommended to use the same data that have been used in build phase, because, our model will always remember the entire training set and fits too closely to it, and therefore fails to predict the correct label. This is called overfitting. After training using the training set, the cases in the test set are used to compute three metrics, the accuracy, precision and recall. These metrics are used to evaluate on the one hand the classifier results and on the other hand the SVM computation method result which exploits the kernels mapping function to get similar cases of the source case.

During the training of our model, we recognized that the training set and test set quickly reached an accuracy of 80%, a precision up to 95% and finally a recall of 60% as seen in figure fig.15 below.

Our model can reach good recognition performance even if we have a diversified cough using data augmentation.

	Train Accuracy	Test Accuracy	Precision	Recall
SVM	0.8017	0.8099	0.942857	0.611111

Figure 15: SVM metrics

5. CONCLUSIONS AND PERSPECTIVES

In this work, we proposed a hybrid approach of covid-19 cases classification modeling based on Case Based Reasoning approach, Multi Agent System and the Support Vector Machine supervised machine learning algorithm to classify the diagnostic cases as infected by COVID-19 or not using cough recording features which are represented by MEL-Spectrogram. To improve the classification workflow, we have opted for the Support Vector Machine Algorithm that has been used as a pipeline of our DCBR cycle to classify cases and also retrieve source cases with high features similarity of our target case. From the experimental results based on the SVM classification and the SVM computation method which exploits the kernels mapping function to get similar cases, we can find that the proposed approach achieves good performance for cough classification and recognition. In order to test the effectiveness of our model, a set of MEL-Spectrograms have been used that were not included in the training phase.

The main contribution of this article is the combination of the multi agent system and Machine Learning algorithm in the retrieve phase of the dynamic case-based reasoning cycle. This will serve to find similar cases of our target case in the data base cases to classify them in real time as infected by COVID-19 or not based on their cough recognition which can be used for COVID-19 testing to estimate suspected patients. In this study, a real data set has been used and divided into training and testing dataset to examine the performance of our hybrid approach. The test set reached an accuracy of 80% and a precision up to 95%.

However, some limitations should be noted. First, our model requires a big number of cases to efficiently learn. The currently proposed study has only examined small-size data set from the same location. We also note the lack of various clinical characteristics of the affected patients. Another limitation concerns the validation of our model, which must be done by domain experts.

In future we will be focusing in testing the model on medium-size and large-size dataset and also to collect additional information about clinical characteristics of the affected patients to enhance the performance of our proposed approach. Finally, a web-based tool using MAS and DCBR for COVID-19 classification should be taken into account.

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