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## IoMT-fog-cloud based architecture for Covid-19 detection

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### ABSTRACT

**Limitations of available literature:** Nowadays, coronavirus disease 2019 (COVID-19) is the world-wide pandemic due to its mutation over time. Several works done for covid-19 detection using different techniques however, the use of small datasets and the lack of validation tests still limit their works. Also, they depend only on the increasing the accuracy and the precision of the model without giving attention to their complexity which is one of the main conditions in the healthcare application. Moreover, the majority of healthcare applications with cloud computing use centralization transmission process of various and vast volumes of information what make the privacy and security of personal patient's data easy for hacking. Furthermore, the traditional architecture of the cloud showed many weaknesses such as the latency and the low persistent performance.

**Method proposed by the author with technical information:** In our system, we used Discrete Wavelet transform (DWT) and Principal Component Analysis (PCA) and different energy tracking methods such as Teager Kaiser Energy Operator (TKEO), Shannon Wavelet Entropy Energy (SWEE), Log Energy Entropy (LEE) for preprocessing the dataset. For the first step, DWT used to decompose the image into coefficients where each coefficient is vector of features. Then, we apply PCA for reduction the dimension by choosing the most essential features in features map. Moreover, we used TKEO, SHEE, LEE to track the energy in the features in order to select the best and the most optimal features to reduce the complexity of the model. Also, we used CNN model that contains convolution and pooling layers due to its efficacy in image processing. Furthermore, we depend on deep neurons using small kernel windows which provide better features learning and minimize the model's complexity.

The used DWT-PCA technique with TKEO filtering technique showed great results in terms of noise measure where the Peak Signal-to-Noise Ratio (PSNR) was 3.14 dB and the Signal-to-Noise Ratio (SNR) of original and preprocessed image was 1.48, 1.47 respectively which guaranteed the performance of the filtering techniques. The experimental results of the CNN model ensure the high performance of the proposed system in classifying the covid-19, pneumonia and normal cases with 97% of accuracy, 100% of precision, 97% of recall, 99% of F1-score, and 98% of AUC.

**Advantages and application of proposed method:** The use of DWT-PCA and TKEO optimize the selection of the optimal features and reduce the complexity of the model.

The proposed system achieves good results in identifying covid-19, pneumonia and normal cases.

The implementation of fog computing as an intermediate layer to solve the latency problem and computational cost which improve the Quality of Service (QoS) of the cloud.

Fog computing ensure the privacy and security of the patients' data.

With further refinement and validation, the IFC-Covid system will be real-time and effective application for covid-19 detection, which is user friendly and costless.

### 1. Introduction

The World Health Organization (WHO) considered Coronavirus

Disease of 2019 as a highly contagious viral illness caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and Middle Eastern Respiratory Syndrome (MERS). After the first appearance of

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COVID-19, on December 31, 2019, in Wuhan, Hubei Province, China, over than 4.8 million confirmed cases were reported because of their rapid prevalence in the whole world [1]. Meanwhile, the virus has the ability of genetic evolution with the development of mutations over time, which create new variants with different characteristics. According to WHO, four variants of concern (VOC) were discovered [2].

The first variant of the virus was in December 2020 in the United Kingdom (UK) called Alpha (B.1.1.7). During the same period, two other variants called Gamma (P.1 lineage) and Delta (B.1.617.2) were detected in Brazil and India respectively. While South Africa has discovered Beta (B.1.351) variant.

Experts from various organizations proposed various types of vaccines such as: Whole Virus, Protein Subunit, Viral Vector, and Nucleic Acid (RNA and DNA). The main objective of these categories is to get immunity to the virus, and stop transmission by smuggling the antigen into the body, or by using the body's cells to make the viral antigen [3].

WHO approved several vaccines for emergency or full use, such as Oxford–AstraZeneca [4], Pfizer–BioNTech [5], Sinopharm–BBIBP [6], Moderna [7], Sinovac [8], Janssen [9], and Sputnik V [10]. Although vaccines can help prevent most people from getting sick with the COVID-19 virus, they cannot protect everyone. In most cases, people who take all of the recommended doses still have the possibility to get

infected [11].

As result, Nowadays, the detection of COVID-19 in its first stages is still a necessity of time within the catastrophic impact of this pandemic.

The World Health Organization declared that Real-Time Reverse Transcriptase Chain Reaction or RT-PCR is the gold standard method for detecting COVID-19 because of their possibility in detecting the ribonucleic acid (RNA) of the virus [12]. In the literature, many researchers used Xray [13,14] and CT scan [15,16] images for Covid-19 detection and diagnosing with the help of AI technics. These techniques have resulted into very promising outcomes.

## 2. Background

Table 1 and Table 2 summarize several techniques that use ML and DL approaches to detect Covid-19.

On the other side, advancements in healthcare technology provide numerous benefits in terms of improving and safeguarding people's lives all over the world. Furthermore, modern communication technology has allowed medical services to be accessed from a distance. The goal of real-time monitoring and automated prediction and detection systems is to save lives and minimize medical costs. For example, combining cloud technology with the Internet of Things (IoT) or the Internet of Medical

**Table 1**  
State-of-art-work that used ML and DL for Covid-19.

Ref.	Dataset	Method used	Evaluation Metrics	Research challenges
[17]	Dataset of X-ray images and CT scan images provided by Dr. Joseph Cohen from the GitHub repository + COVID-19 Chest X-ray Dataset Initiative + Chest X-ray image dataset provided by Kaggle	VGG16, InceptionV3, ResNet50, Xception, DenseNet121 Decision Tree, Random Forest, AdaBoost, Bagging, SVM	Accuracy, Sensitivity, Specificity, F1-Score, AUC	Depend only on the classification of COVID-19 and normal X-ray images. They did not include other chest disease images such as bacterial pneumonia, viral pneumonia.
[18]	Chest X-ray images of COVID-19 obtained from the Kaggle database	PA (prophet algorithm), ARIMA, and LSTM + VGG16	Precision, Recall, and F-measure, Accuracy, Root Mean Square Error (RMSE)	Depend only on the classification of COVID-19 and normal X-ray images. They did not include other chest disease images such as bacterial pneumonia, viral pneumonia.
[19]	X-ray images of the chest from Cohen and Kaggle repositories	ResNet101 and ResNet-50	Precision, Recall, Accuracy,	The limited number of COVID-19 images
[20]	ChestX-ray14 dataset extracted from National Institutes of Health Clinical Centre, USA + COVID-19 X-ray data set curated by a group of researchers from the University of Montreal	ResNet-101	Sensitivity, Specificity, Accuracy and AUC	Lack of images used in the testing phase.
[21]	Chest x-ray scans Kaggle repository	Inception V3, Xception, and ResNeXt VGG16	Accuracy. Precision, Recall, F1-Score AUC, Accuracy	Small dataset.
[22]	Public Dataset of X-ray images from healthy, pneumonia and covid-19 patients	ResNet, VGG, Inception and Efficient Net	Accuracy	Small dataset
[23]	Publicly available COVID-19 chest X-ray image repository pneumonia, and normal\healthy individuals COVIDx CT-2A and COVIDx CT-2B datasets	COVID-Net-CT	Sensitivity, Specificity, Positive Predictive Value, and Negative Predictive Value, Accuracy	Small number of images in validation
[24]	A total of 1100 chest X-ray images were randomly selected from three different open sources: the GitHub repository shared by Joseph Cohen, Kaggle, Bachir, and Mooney. The chest X-ray images in the datasets	ResNet-v2 SVM	Sensitivity, Specificity, AUC, Positive Predictive Value, Negative Predictive Value, and Accuracy.	Lack of COVID-19 X-ray images
[25]	The datasets contain chest X-ray images of confirmed COVID-19 cases, other pneumonia, and no-findings (normal)			
[26]	Chest CT (CCT) images from local hospitals	CCSHNet	Micro-averaged (MA) F1 score, Sensitivity, Precision,	Small dataset
[27]	chest CT images	FGCNet	Fowlkes–Mallows index (FMI), Matthews correlation coefficient (MCC), F1, Sensitivity, Specificity, Precision and Accuracy.	Lack of clinical testing

**Table 2**  
Comparative analysis with state-of-art-work that used cloud computing and DL for Covid-19.

Work	Application	IoT	Fog	Cloud	DL
[47]	An automatic COVID-19 detection system	Yes	No	Yes	ResNet50
[48]	Corona virus detection	Yes	Yes	Yes	SVM, DNN, K-NN, LSTM, Naive Bayes, One Rule, NN, Decision Table
[49]	COVID-19 risky behavior monitoring system	Yes	No	Yes	CNN
[50]		Yes	Yes	Yes	No
[51]	Predict the potential threat of COVID-19	No	No	Yes	ML
Our approach (IFC-Covid)	COVID-19 and Pneumonia detection	Yes	Yes	Yes	CNN

Things (IoMT) allows for real-time detection and diagnosis of a sickness, which leads to early intervention that saves lives and lowers healthcare costs [28,29].

Cloud Computing is one of the major computing paradigms in the information technology domain [30]. The role of cloud computing is to serve the user’s requests for using the computing resources anytime and anywhere [31]. In general, the deployment in the cloud could be in Private Cloud, Public Cloud, Community Cloud, or Hybrid Cloud [32]. The Cloud provides three services: Software as a Service (SaaS), which provides software for users, Platform as a Service (PaaS), for software and application building, and Infrastructure as a Service (IaaS), for storage and computing process and network uses [30].

Fog Computing is an intermediate layer between the IoT devices and the cloud which aims to ameliorate the Quality of service (QoS) of the Cloud by providing several distributed nodes. Fog nodes are used to reduce traffic and latency issues, between users and the cloud, and energy consumption. Also, they provide computing and storage capacity and ensure secure communication between IoT devices and cloud [33].

2.1. Cloud computing in healthcare application

Cloud computing for medical purpose is based on a mobile device, cloud servers, and a network which provides real-time access to the resources in anytime and anywhere [34]. However, this traditional architecture of the cloud showed many weaknesses such as the time required for emergency cases [35]. Also, the increased amount of power consumption and the cost of data transmission to the cloud are some other short coming [36]. Moreover, the problems of latency and the low persistent performance are the limitations of the traditional structure of the cloud [37]. Furthermore, the high cost of the mobile environment needed for the medical scenarios of the patient [38].

2.2. Fog computing in healthcare application

Fog computing is a distributed structure of cloud computing that aims to make the data processing closer to the network edge which provides more suitable options to overcome the limitations of cloud computing [34]. First, it reduces the cost of memory usage, computational costs, and sensors power consumption. Fog computing offers a

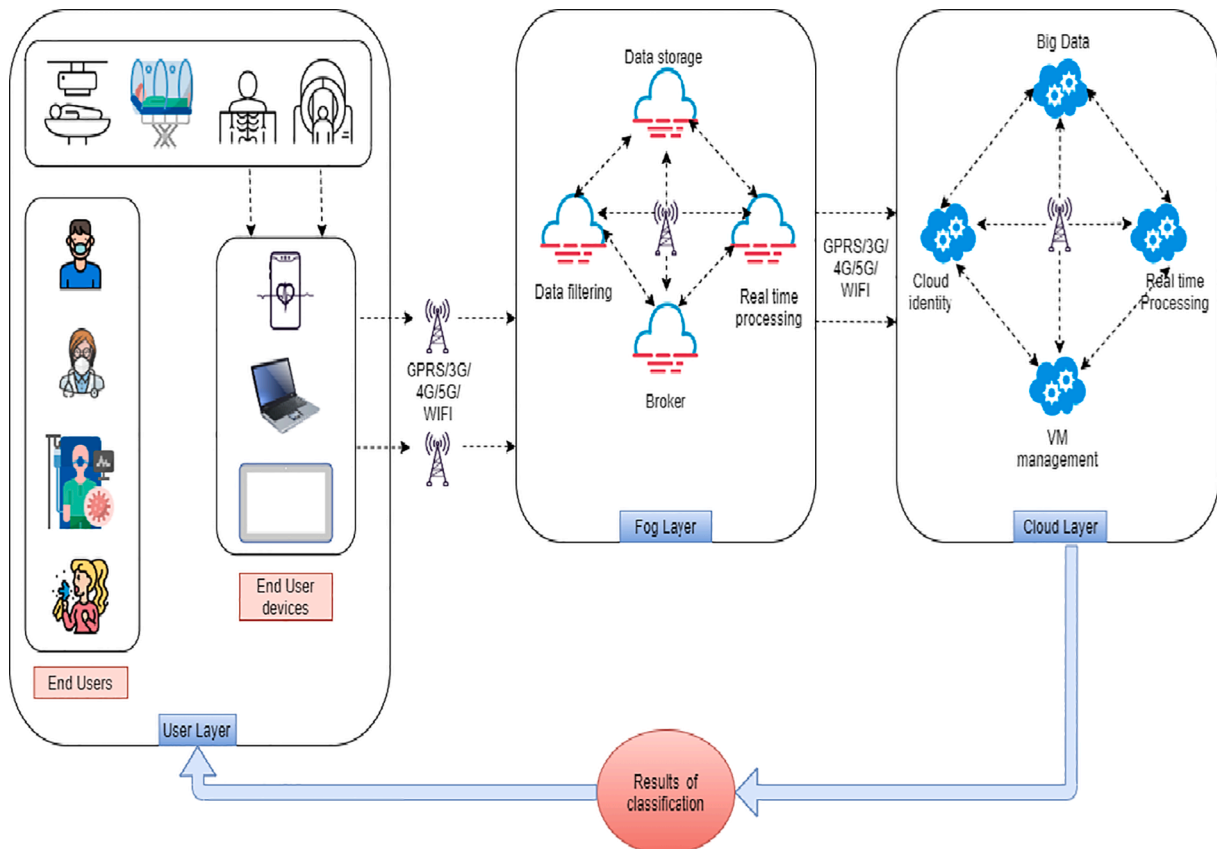


Fig. 1. The proposed IoMT based Fog-Cloud architecture for Covid-19.

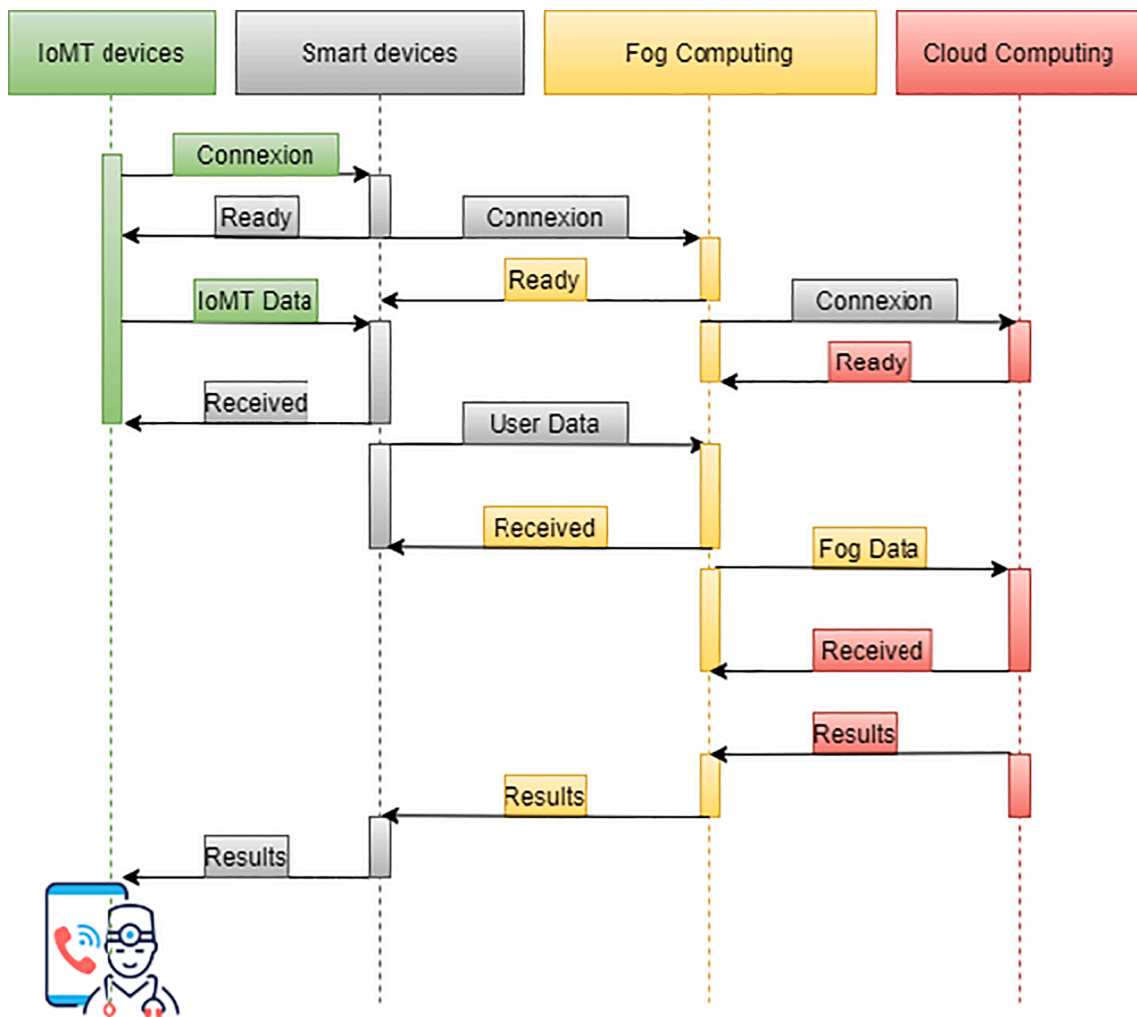


Fig. 7. Scenario of the proposed system.

lower latency by increasing the number of fog nodes or using various edge mining techniques to reduce the data transmission time [39]. In addition, the edge computing applications include a high degree of protection and authentication which ensure that patient information remains private [40,41]. Furthermore, instead of using detection sensors or GPS location systems, edge applications use specific localization techniques that detect the patient’s position in a more accurate and efficient way [42]. The energy consumption is reduced due to the shared structure of edge computing, encryption methods and categorization approaches for health care applications [43], edge mining [44], and proper resource management [45,46].

Healthcare applications, that are easy and simple to use, should be able to provide a variety of services to patients, without requiring any technical expertise or medical training. [43].

The main purpose of our contribution is to reduce the spread of this pandemic by early detection of the infected people and take the necessary actions as soon as possible. It has been proven that medical treatments are more effective if they are administrated as soon as the virus is detected. In order to implement such a system, we took advantage of the advanced technologies in the healthcare sector such as IoMT, Cloud computing, Fog computing. The composition of such components provides a real-time and secure system that could be easy to use for every user.

### 3. Material and methods

Nowadays, the early detection of the Covid-19 and taking the necessary remedies could decrease the spread of this pandemic. For this reason, designing solutions using the power of artificial intelligence such as deep learning, the advantages of IoMT, fog computing and cloud computing could be very promising approach.

#### 3.1. Deep learning approach

The implementation of real-time systems is still one of the biggest challenges that face developers. On the other hand, the urgent situation worldwide, which is to find a way to detect covid-19 in a fast and efficient manner. These are the most reasons that motivate us to introduce IoMT-based fog-cloud for the detection of Covid-19.

Our proposed IoMT–fog–cloud-based solution for Covid-19 detection (IFC-Covid) consists of three layers: user layer, fog layer and cloud layer. Fig. 1 presents the general architecture of our proposed model.

In general, Cloud and the Fog-based solution requires IoT devices, sensors, user devices, and different nodes that ensure the cloud and fog services. In addition, different communication protocols, such as Bluetooth, IEEE 802.15.4, 3G, 4G, 5G, and IEEE 802.11, are required.

#### I. User Layer

Several models of mobile or portable radiography are used in this

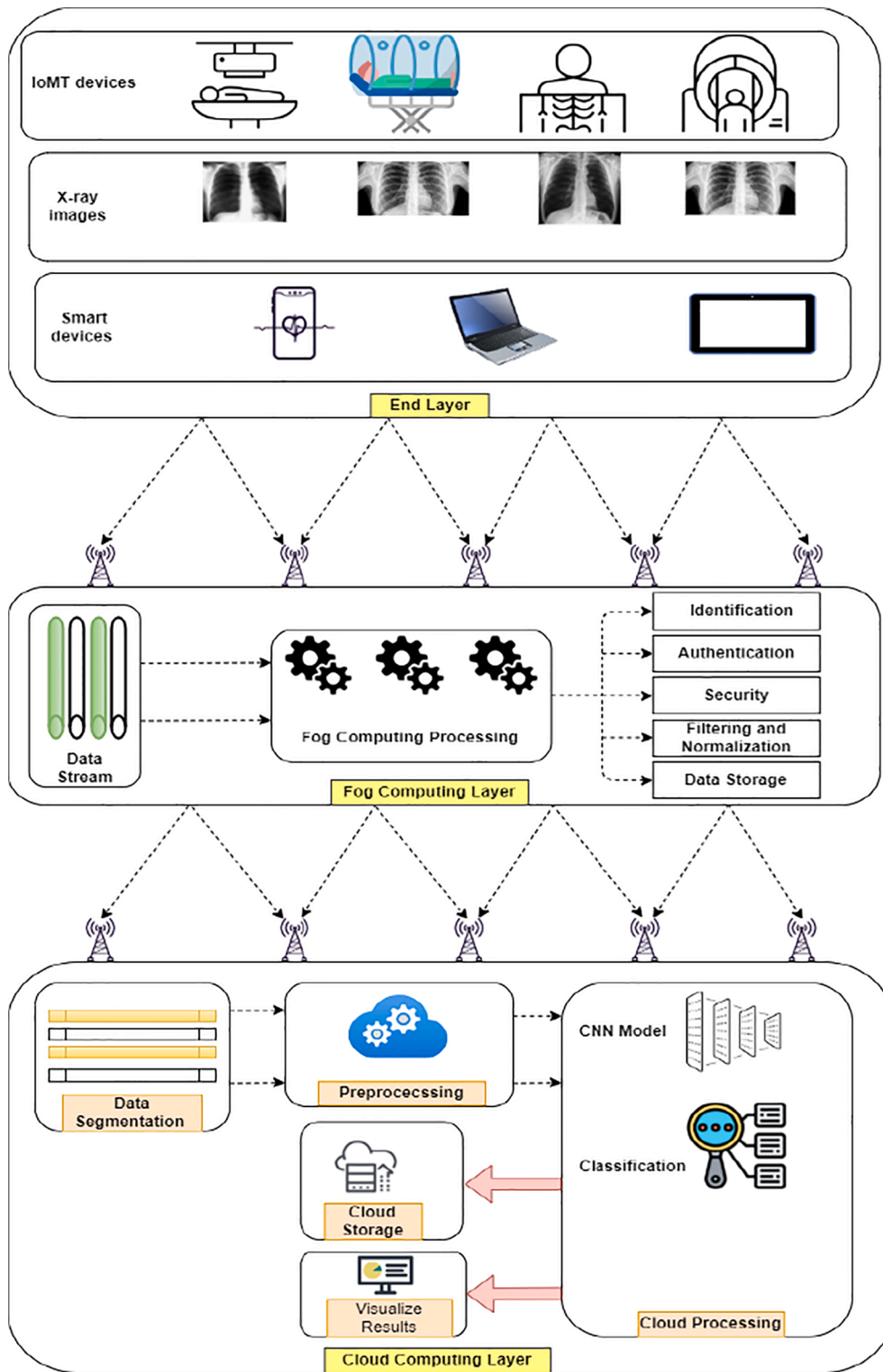


Fig. 2. The Composition of each layer of the IoMT based Fog-Cloud system for Covid-19.

layer as IoT devices. These devices are specially designed to adapt to the needs of intensive care units and emergency departments. They are perfectly maneuverable in any hospital environment because of their robustness and reliability as well as their levels of safety and comfort. In addition, they allow obtaining high quality images, even under difficult conditions.

### 3.1.1. End-user's device

The user has the opportunity to use a variety of devices such as smartphones, personal computers (PC), tablets. These devices are used to receive data from IoT devices and send it to the fog layer. Also, they visualize the results and notifications obtained from the fog or cloud, for the end-users. An important feature of designing a handy medical system is ensuring that users' gadgets have an adequate degree of visibility.



### 3.1.2. End-User

In general, the end-users in such medical application consist of the doctors, patients, nurses, and/or other users that are related to the patient. The role of the end-user is to send patient data to the fog (in our case X-ray images). After some processing steps in the fog and cloud, he/she receives the results of the data analytics that have been sent as input Fig. 7.

## II. Fog Layer

The secret of adding a fog computing layer to a cloud-based architecture is to bridge the gap of the cloud layer and ensure the real-time data analysis and the classification process. Moreover, it ensures several proprieties such as the privacy of the patient's data and its security. In addition, some preprocessing steps are done in the fog layer that helps and facilitate the analysis and classification process of the cloud layer, which reduces its latency and ensures its quality of service.

### III. Cloud Layer

The cloud layer is the main layer in a smart healthcare system. It provides several services with high computing capacity that are used in the analytic process. In addition, it provides huge space for data storage called data center.

### 3.2. Detailed architecture

In this part, we describe our system's design and show how the components of each tier communicate securely Fig. 2. We begin with a description of the system architecture, followed by a description of the security mechanism that is utilized to safeguard the privacy of patient data at various stages of processing. Next, we show how we train our CNN model on the passed dataset hosted in a data center. Due to the similarity of Pneumonia X-ray and Covid-19 X-ray, we train our model to discriminate between the two for better classification results.

#### I. End layer

Regarding Fog-Cloud-Covid19 system, this layer is composed from radiology devices and smart devices. The radiology devices can record the x-ray image of the patient. These radiology devices are equipped with sensors that allow them to communicate with other devices via Bluetooth or WiFi, 3G, 4G, 5G. After recording the x-ray images, the doctor sends it to smart devices such as phones, tablets, or laptop computers. Then, the patient or the doctor that receives the x-ray image on his/her smart device has to transmit it and other personal data to the fog layer. The main advantage of using an intermediate layer such as fog layer is to reduce time consumption, and cost which improves the quality of service of our system.

#### II. Fog layer

In the majority of healthcare applications that use cloud computing, the privacy and security of personal data of the patient can be easily hacked because of the centralization transmission process of various and vast volumes of information. We introduced a fog layer in our system to ensure the privacy and security of the data using several services such as:

**Identification:** The first process of the fog layer is identifying the user that are sending the data or allowing the creation of profiles for new users.

**Authentication:** In this step, the fog service has to check the authenticity of the user using authentication protocols such as Authenticated key Agreement (AKA) [52], Certificate Revocation List (CRL) and Online Certificate Status Protocol (OCSP), [41].

**Security:** The fog computing provides an encryption service to encrypt the user data and ensure its security. Several encryption

techniques are used in the literature such Elliptic-Curve Cryptography (ECC) [53], Privacy-Preserving Fog-Assisted Information Sharing Scheme (PFHD) [54], Bilinear pairing IBE [55], Modified Elliptic Curve Cryptography (MECC) [56], Fully Homomorphic Encryption Scheme (FHE) [57], and Enhanced Value Substitution (EVS) [58].

**Filtering and normalization:** After receiving the user data, some preprocessing steps are performed such as filtering and normalizing the data to make it ready for the processing process in the cloud layer. The purpose of this step is to reduce the processing steps of the cloud which minimizes its computing time.

**Data storage:** In the fog layer and after preprocessing steps, part of the user data has to be stored in fog repository for security and authentication procedures to ease the access and lockout process, authenticity of data, and lower the access control delivery cost.

## III. Cloud layer

The cloud layer is the main layer that consists of the analysis of the data and processing techniques then saving the data in the cloud storage and visualizing the resulting data.

**Preprocessing** In this step and after receiving data segmentation from the fog layer, some process has to be done such normalization and preparing this data to be passed to the processing step.

**Cloud Processing** In the processing layer several tasks have to be done such as preparing the Convolution Neural Network model to be trained on a dataset that contains three categories of samples: Covid-19 cases, Pneumonia cases, and Normal cases.

**CNN Model** Over the last few decades, the community of specialists in the field of medical research has developed several health care systems which make it possible to specify the doctor's decision on the case of his patient. Also, due to human nature and the possibility of making mistakes in diagnosing cases which are not related to the degree of knowledge of doctors, but also to how they deal with patient problems and other aspects [59]. However, the revolution of Artificial Intelligence (AI) in various domains help to answer several questions in a semi-automatic or automatic way. Deep Learning (DL) is AI technique that is used in the detection and prediction issues. Similar to the other domains, the healthcare area used many DL applications that achieved great results in many medical cases because of their capability to learn from the context using supervised learning, semi-supervised learning, and unsupervised learning. CNN is DL approach that specialized in image recognition, image classification, image prediction, detecting the abnormality of the signal records, etc. [60,61].

The auto extraction of the features from images and the deep analytics of CNN, are the main reasons that make us use the CNN for the training process in our system. Several researchers have used CNN for covid-19 detection [18,62].

In our system, we used CNN model that contains convolution and pooling layers due to its efficacy in image processing. Furthermore, we depend on deep neurons using small kernel windows which provide better features learning and minimize the model's complexity. The Covid-19 and pneumonia detection systems use x-ray pictures to create a deep model that extracts the most characteristics from the image. In our model, there are a total of six convolution layers and three completely linked layers (Table 3). After the features map is built, it must be sent to the flatten layer to prepare it for the completely linked layers. The last completely linked layer is dedicated to the final classification results.

### 3.3. Dataset

In our experimentation, we used a free big dataset that contains 6432 X-ray images extracted from Kaggle repository [63]. The dataset is divided in two folders for the training (5144 X-ray pictures) and test (1288 X-ray pictures). Each one of these folders contains three sub-folders named Covid-19, Normal, Pneumonia. After the extraction of the dataset, we apply some pre-processing methods then generating new

**Table 3**  
Summary of CNN model.

	Layer	Feature Map	Size	Kernel Size	Stride	Activation
Input	Image	1	180 × 180 × 3	–	–	–
1	Convolution 2D	32	180 × 180 × 3	2 × 2	2 × 2	Tanh
	Max Pooling 2D	32	90 × 90 × 32	2 × 2	2 × 2	
3	Convolution 2D	32	45 × 45 × 32	2 × 2	2 × 2	Tanh
	Max Pooling 2D	32	22 × 22 × 32	2 × 2	2 × 2	
5	Convolution 2D	64	11 × 11 × 64	2 × 2	2 × 2	Softsign
	Max Pooling 2D		5 × 5 × 64	2 × 2	2 × 2	
	Flatten	3200	–	–	–	–
8	FC	132	422532	–	–	Relu
9	FC	60	7980	–	–	Relu
Output	FC	3	183	–	–	Softmax

images for data augmentation.

### 3.4. Dataset preparation

Medical Image processing is an essential and critical step in medical field which aims to visualize the abnormalities and the special issues contained in the image. Image segmentation is one of the image processing steps which divides the original image into regions depending on specific characteristics of the image such as brightness, and grey level.

Wavelet transform is one of the powerful tools that used for different medical issues such as signal decomposition [64,65] and image decomposition [66–68].

In our case we use Discrete wavelet transform (DWT) with Bi-orthogonal 1.3 for the segmentation level in order to reduce the unnecessary data and optimize the analysis effort.

Moreover, the combination of wavelet transforms and reduction techniques such as Principal Component Analysis helped us in selecting the optimal features, reducing the complexity and ameliorating the accuracy of the neural network [69].

Principal Component Analysis (PCA) is linear algebra technique that generally used for feature extraction and dimensionality reduction. The purpose of PCA is to reduce the number of features whereas keeping most of the original ones in order to reduce the complexities of the model. The main steps of the PCA are: the standardization of the dataset into d-dimension, then building the covariance matrix, computing the eigenvectors and eigenvalues, selecting the k eigenvalues, in the end, generate the new k-dimensional features of the original dataset. [70].

In our case, we used PCA with only 80 of principle component

following these steps:

- Dividing the image into three components (Red, Green, Bleu) channels.
- Applying PCA to each channel.
- Applying inverse transform to transformed array.
- Inversing the transformation in order to rebuild the original image with only 80 of principal components.

Fig. 5 shows the resulting image using PCA with different values.

After using DWT on the images Fig. 4, we applied the entropy Fig. 6 for each coefficient in order to extract the optimal features using different kind of entropy such as Teager Kaiser Energy Operator, Log Energy Entropy, Shannon wavelet entropy energy.

Teager Kaiser Energy Operator (TKEO) is non-linear energy tracking operator which used for signal and image. The TKEO based on Amplitude Modulated- Frequency Modulated (AM-FM) for analyzing the data [71]. TKEO represented by Eq. (1).

$$\phi_2[I(x, y)] = \|\nabla I(x, y)\|^2 - I(x, y) \cdot \nabla^2[I(x, y)] \quad (1)$$

$$\nabla(I(x, y)) = \left( \frac{\partial I(x, y)}{\partial x}, \frac{\partial I(x, y)}{\partial y} \right) \quad (2)$$

$$I(x, y) = \sum_{k=1}^K a_k(x, y) \cos(\xi_k(x, y)) \quad (3)$$

Where  $a_k(x, y)$  represent the amplitude modulating of the image contrast in  $k$  narrowband component and  $\nabla \xi_k(x, y)$  represent frequency modulation of image structure properties in the instantaneous phase component  $\xi_k(x, y)$ .

Shannon Wavelet Entropy Energy (SWEE) is combination between wavelet, shannon entropy and energy. This combination used for effective analysis which extract optimal features using time frequency [72]. The Shannon wavelet entropy energy could be presented by Eq (4):

$$\eta(d) = \frac{E(d)}{Shannon_{Entropy}(d)} \quad (4)$$

$$E(d) = \sum_{k=1}^c |M_k(d)|^2 \quad (5)$$

Where  $E$  is energy of data ( $d$ ) in each wavelet coefficient. ( $c$ )

$$Shannon_{Entropy}(d) = - \sum_{k=1}^c P_k \log P_k \quad (6)$$

Where  $P_k$  is the energy probability of each wavelet coefficient and  $\sum_{k=1}^c P_k = 1$

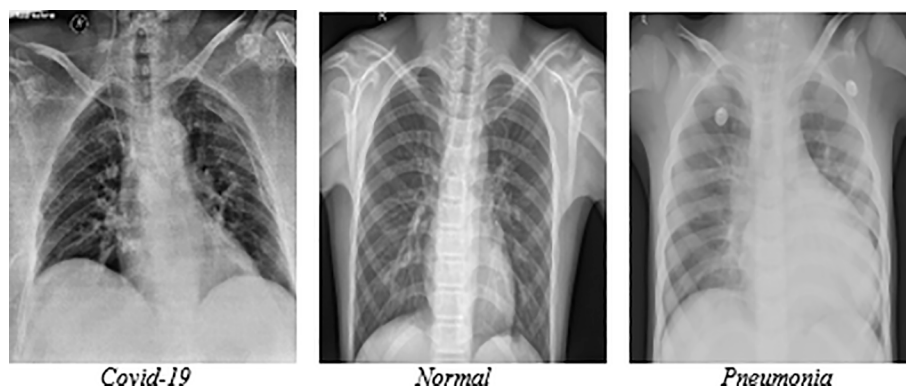


Fig. 3. Dataset samples.



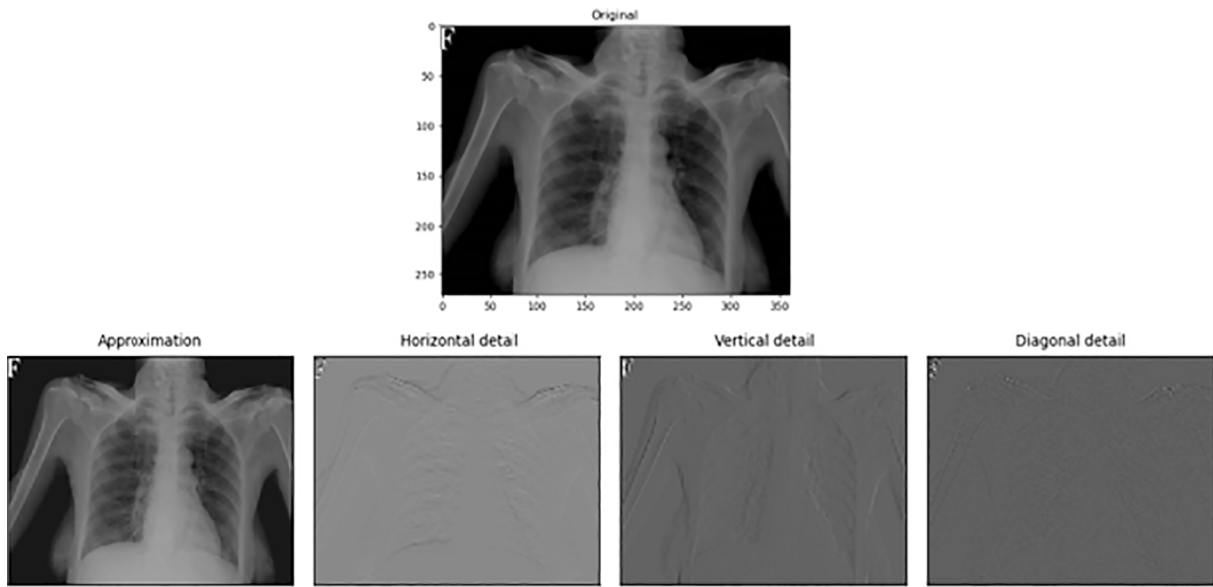


Fig. 4. The application of DWT on image with bior 1.3.

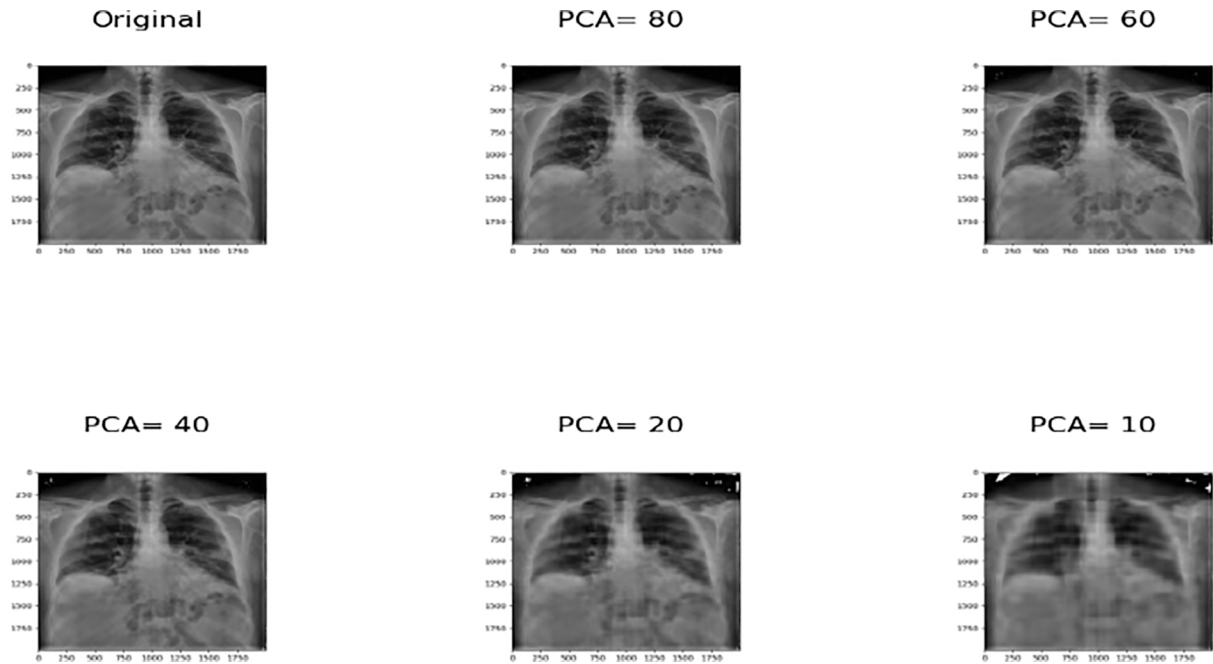


Fig. 5. The application of PCA with different values.

$$P_k = \frac{|M_k(d)|^2}{E(d)} \quad (7)$$

Log Energy Entropy (LEE) is feature extraction method based on the energy and it is similar to Shannon entropy. The main role of it is to calculate the uncertainty of features in data according to Eq (8) [73].

$$\text{LogEnergyEntropy}(d) = \sum_{k=1}^c \log(P_k^2) \quad (8)$$

Where  $P_k$  is the energy probability of each wavelet coefficient and  $\sum_{k=1}^c P_k = 1$

**Classification** Another processing step used in Computer-Aided Diagnosis (CAD) which considered as a key step in medical image processing. In the classification phase, the received images are passed to the CNN model to be classified. The output of this phase is the class of each

image. In our case, we have three classes: Covid-19, Normal, and Pneumonia (Fig. 3). Various classification metrics were used for the evaluation of our model: True Positive (TP), True Negative (TN), False Positive (FP), and False Negative (FN). These measures are used to calculate Recall, True Positive Rate (TPR), False Positive Rate (FPR), Precision, Specificity, Sensitivity, F1-score, and Accuracy.

$$\text{Recall} = \text{TPR} = \frac{TP}{TP + FN}$$

$$\text{Precision} = \frac{TP}{TP + FP}$$

$$\text{Specificity} = \frac{TN}{FP + TN}$$

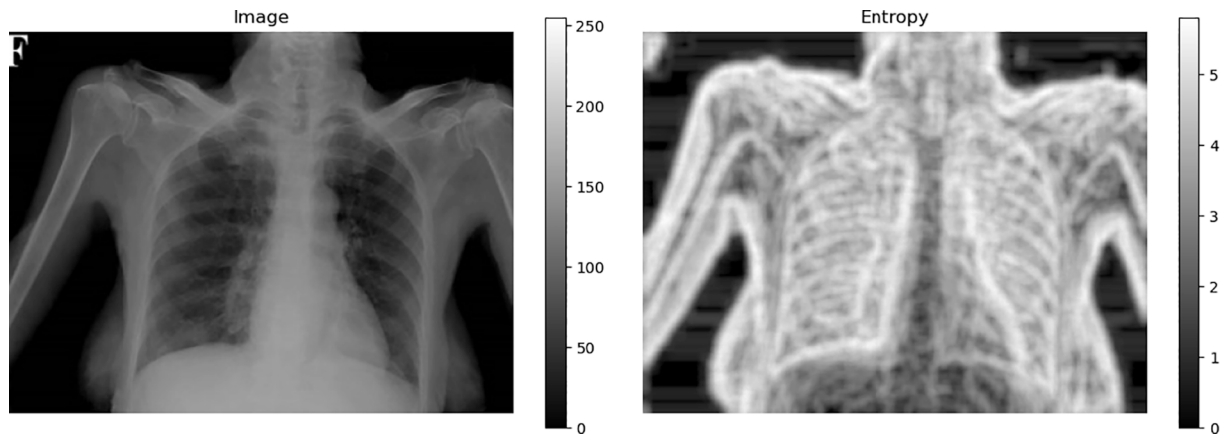


Fig. 6. The application of entropy on the image.

**Table 4**  
Classification results.

	Precision	Recall	F1-score	Accuracy
Covid-19	100%	97%	99%	97%
Normal	94%	90%	92%	97%
Pneumonia	96%	98%	97%	97%

$$\text{Sensitivity} = \frac{TP}{TP + FN}$$

$$\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN}$$

$$F1 - \text{score} = \frac{2TP}{2TP + FP + FN}$$

$$FPR = \frac{FP}{FP + TN}$$

**Cloud Storage** The cloud layer has a powerful capacity of storage which stores the big data received from the fog layer and also creates the user profile and stores the results of the classified data.

**Visualize results** This phase specialized in displaying analytical dashboards and the results of the classification.

#### 4. Results and discussion

In our implementation, we used Python with Keras and Tensorflow libraries which provide the needed tools for deep learning implementation. These libraries are built on top of the PyCharm environment. Lenovo PC with Windows 10 pro 64-bit, CPU of Intel Core i7, 3.60 GHz, 16 GB of RAM, Intel HD Graphics 4600 GPU and 1 T of storage are used. Our model achieves efficient results in term of classification metrics: 97% of accuracy, 100% of precision, 97% of recall and 99% for F1-score. [Table 4](#) summarizes the classification results of the model.

The application of DWT-PCA on the dataset during the preprocessing step has great impact in optimizing the model and reducing its complexity by reducing the trainable parameters (see [Table 5](#)). As shown in [Table 5](#), 28.24% of parameters are reduced, which improves the training time and reduces the complexity of the full model.

The measurement of the signal power and the noise power ratio (SNR) of the original image and the preprocessed image are shown in [Table 6](#). Moreover, we used peak signal-to-noise ratio (PSNR) to check the effect of the preprocessing step on the original dataset by using an original image and its preprocessed one. The result of PSNR is 3.14 dB which indicates that the maximum possible power and the corruption noise power do not have an effect on the resulting image and improves

**Table 5**  
The number of trainable parameters of the original dataset and the preprocessed dataset.

	Trainable parameters
Original dataset	658,119
Pre-processed dataset	472,263

**Table 6**  
The SNR and PSNR values of the original image and the preprocessed image.

	SNR (dB)	PSNR (dB)
Original image	1.48	3.14
Pre-processed image	1.47	

the effectiveness the use of DWT-PCA in the preprocessing step.

In addition, we instigated the energy mean for the identification process by estimating the pixel energy of the image using different kind of methods such TKEO, SHEE, LEE.

As shown in [Table 7](#), TKEO has the minimum energy with only 3.26 bits/pixel which improves its performance in tracking the energy of non-linear features. The use of TKEO, in these critical cases such x-ray images, has great impact on the correct identification of the x-ray images. This improves the performance of the system in distinguishing between covid-19, normal, and pneumonia cases.

We studied the performance of our system in the training process by comparing accuracy and loss metrics of the original dataset and the preprocessed dataset. However, the training process with preprocessed dataset showed better results in term of accuracy and loss where, the increasing green curve improves the high accuracy. Meanwhile, the loss function decreases until it reaches low values (see [Fig. 8](#)).

##### 4.1. Confusion matrix

A confusion matrix is machine learning metrics used in measuring the effectiveness and the performance of the system. Usually, it is used for binary or multiclass classification issues. The main role of the confusion matrix is to help understand how the classification model is confused when making predictions. Not only it captures how many errors were made, but also what kind of errors were made. The rows of the matrix represent occurrences of the actual class and the columns

**Table 7**  
The result of application TKEO, SWEE and LEE on the image.

	TKEO (bits/pixel)	SHEE (bits/pixel)	LEE (bits/pixel)
Image	3.26	6.75	4.68

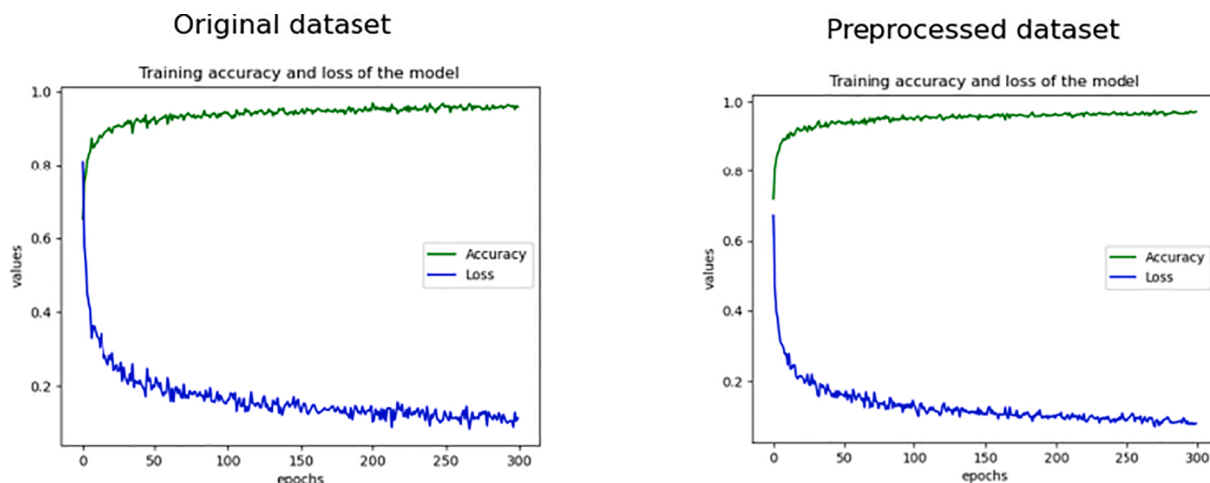


Fig. 8. The training accuracy and loss of the CNN model on the original dataset and preprocessed dataset.

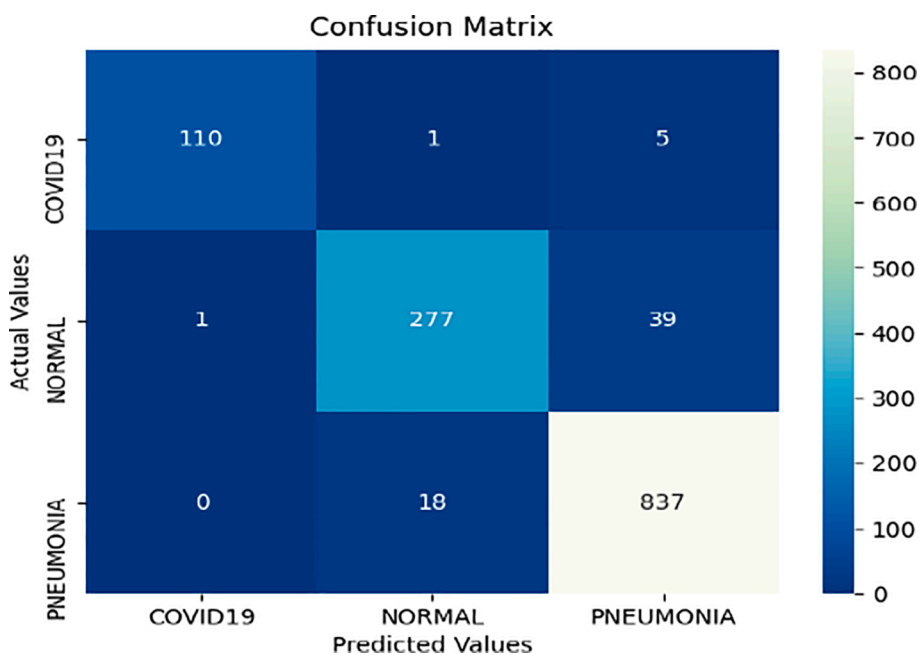


Fig. 9. Confusion matrix of the predicted classes.

represent instances of the projected category [74]. In other words, it keeps track of each class’s correct and wrong predictions.

To study the performance of our system we calculate True Positive (TP), True Negative (TN), False Positive (FP), and False Negative (FN). These metrics are used to visualize the results of predicting instances of each class. Fig. 9 shows that the model correctly predicted almost all the covid-19 samples used for the validation dataset, except one sample, predicted it as normal case and six samples as pneumonia. In addition, the system correctly predicted normal samples and missed a few samples (1 as covid-19 and 39 as pneumonia). Fig. 10 illustrates that 98% of pneumonia samples are correctly predicted by the model.

4.2. Area Under the ROC Curve

The Area Under Curve (AUC) is a description of the Receiver Operating Characteristic Curve (ROC curve), which assesses a classifier’s ability to differentiate across classes. Meanwhile, the ROC curve is a graph that uses the True Positive Rate (TPR) and False Positive Rate (FPR) to indicate how well a classification model performs across all

categorization levels (FPR) [75].

The ROC curve of our model is plotted to verify the classification performance of our model (Fig. 11). As we see in Fig. 10, the huge space between the green line and the blue line defines the AUC of the model and it reaches 0.98. In which the perfect diagnostic test of the classes where in the value 1.0. Also, the achieving AUC = 0.98 is reflection of the accuracy of the model in predicting classes what ensures the out-performance and the capacity of the model in classifying the classes.

5. Conclusion

Covid-19 is a serious topic that needs to be treated due to its impact on various domains such as industry, education, economic, etc. Because of the absence of a cure to this pandemic, the only way to deal with it is to reduce its spread by precaution methods and the early identification of the infected patients. With the revolution of artificial intelligence and its impact on the various domains. The health care sector, similar to other domains, adopted the AI approaches which resulted in great innovations in the medical field such as the Internet of medical things

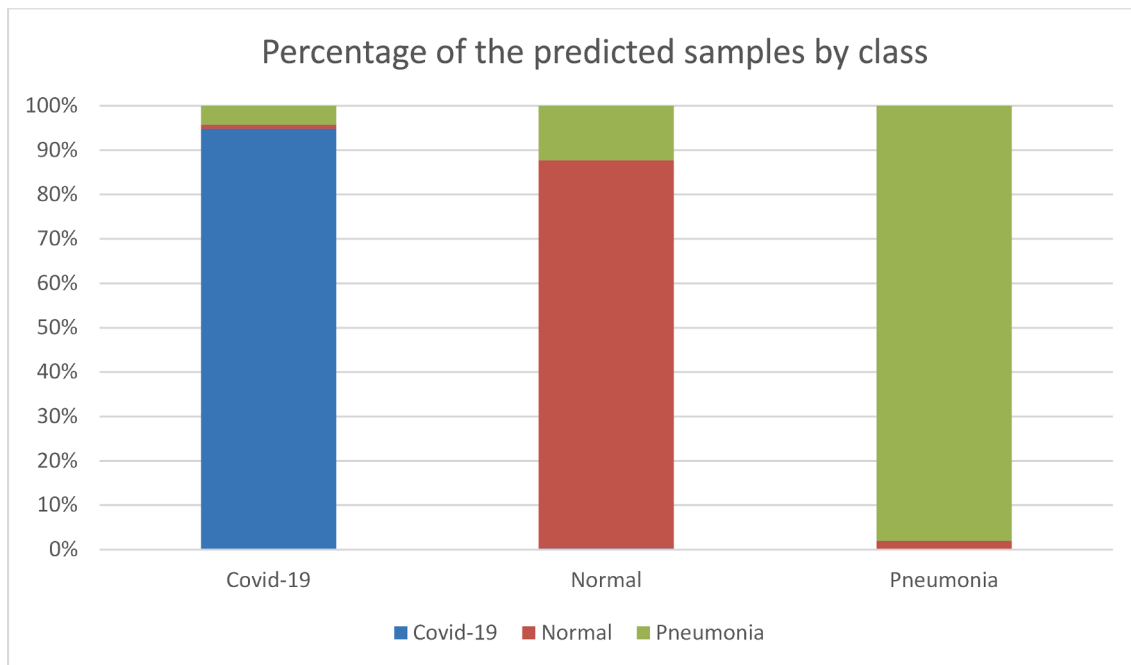


Fig. 10. The percentage of predicted samples by classes.

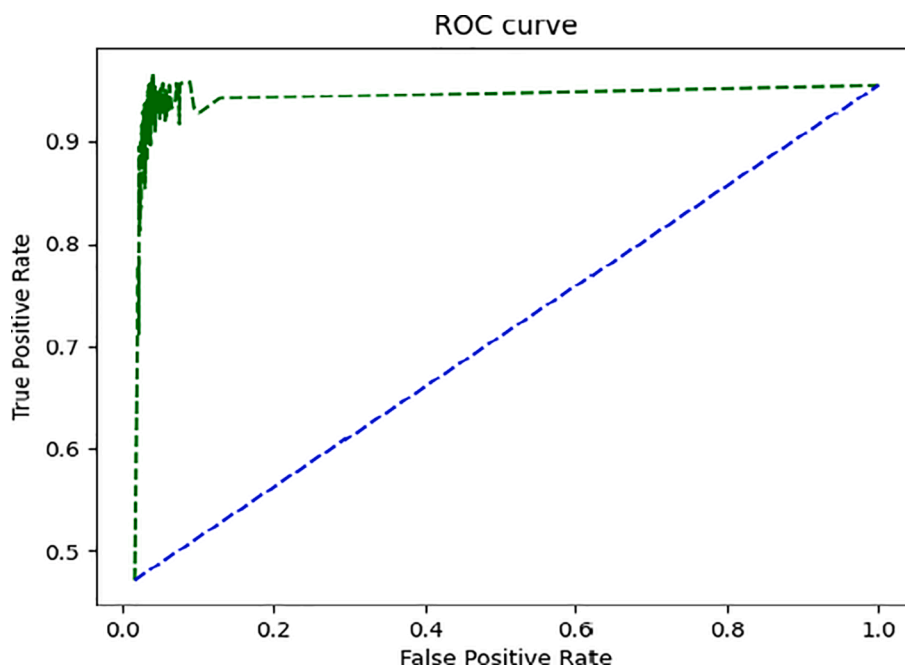


Fig. 11. The ROC curve of the model.

(IoMT). The IoMT helped to solve many medical issues that need a real-time response. In this paper, we propose IoMT-fog-cloud-based architecture for covid-19 detection. Our work aims to reduce the spread of the pandemic by early detection of the infected people. In addition, the proposed system facilitates the detection of covid-19 anywhere and anytime. The system is easy to use and user friendly. Furthermore, we focus on the Quality of Service (QoS) of the cloud by introducing an intermediate layer between the user and the cloud to reduce the latency and ensure real-time response. The privacy and security of the patient’s data were other objectives of our study. For better classification and identification results we combined Discrete Wavelet Transform and Principal Component Analysis (DWT-PCA) to extract the optimal

features and reduce the dimension. Also, we used different kind of energy tracking in the images to ameliorate the identification in the x-ray images. Our proposed filtering technique reduces the complexity of the model by reducing trainable parameters and minimizing the time. The evaluation of our CNN model in the classification showed an efficient performance which can classify the covid-19, pneumonia and normal cases with 97% and the precision rate reaches 100%. From the experimental results, our proposed system could be aid discission making in the identification of covid-19.

As future work, we aim to use the ElectroCardioGraph (ECG) for the covid-19 detection since the latest variants of covid-19 have effect on cardiovascular system. In addition, CT-images and X-ray images are not

suitable source for the identification of this new variants. Also, we aim to investigate the use of Empirical Wavelet Transform (EWT) and PCA for filtering process of the data.

### CRedit authorship contribution statement

**M.A. Khelili:** Conceptualization, Methodology, Software, Writing – original draft, Visualization, Investigation, Formal analysis. **S. Slatnia:** Writing – review & editing, Supervision, Validation. **O. Kazar:** Writing – review & editing, Supervision, Validation. **S. Harous:** Writing – review & editing, Validation.

### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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