ISSN 2278-3091
Volume 9, No.4, July – August 2020
International Journal of Advanced Trends in Computer Science and Engineering
Available Online at http://www.warse.org/IJATCSE/static/pdf/file/ijatcse236942020.pdf
https://doi.org/10.30534/ijatcse/2020/236942020

ECG Classification using Deep Convolutional Neural Networks and Data Analysis

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ABSTRACT

ECG (Electrocardiogram) is a reliable and efficient test for monitoring the activities inside the cardiovascular system. The ECG reports are used to measure the electrical activities of the heartbeat which can be useful for many important conclusions regarding the heart diseases. In the recent past, there has been a lot of attention for the classification of these heartbeats using the ECG reports. In the last few years, Artificial Intelligence and Machine Learning are serving a lot in the area of automation in the medical and health-care domain. Deep Learning techniques are really growing day-by-day and Neural Networks are one of the major advancements in it. Neural Networks are really efficient in the problems like classification and segmentation. This study proposes a Deep CNN based model for classification of heartbeat using the ECG reports in five different classes which correspond to the different types of arrhythmia that are according to the standards of AAMI-EC57. We have evaluated our model on the Physionet's MIT-BIH and PTB Diagnostics datasets.

Key words: Deep learning, Deep Convolutional Neural Network, ECG Classification, Machine Learning.

1. INTRODUCTION

ECG was first invented in 1895 and it has gained a lot of popularity in analysis of cardiovascular system and the measurement of electrical activity of the heartbeat. An ECG report depends upon the signals generated by electrical activities of the heart during the heartbeat generation. This signal is used to predict the state of patient who is suffering from a heart disease. ECG reports are really useful in the medical domain for revealing the facts about the heart of a human being. The data generated from this ECG report is a time series data and like other time series data it is very difficult to detect and categorize various wave-forms and morphology in the signal. The manual analysis of these ECG reports can lead to mistakes due to lack of technical knowledge and the complexity of the waveforms.

Heart is considered as an important organ for human body. It pumps blood which transforms nutrients throughout the body. Heart diseases are very common since last few decades and due to hypertension and a lot of pressure on human beings, there are a lot of cases of heart related diseases everyday throughout the world and the analysis and diagnosis of types of disease is a slow procedure and will remain slow if the automation is not introduced here. Due to complexity of data and it's visualization it is tough, complicated and time taking process for proper classification. [33]

The industries like medical and health-care are highly dependent upon the IT industry since last few years and the IT industry has also served a lot to these domains. There is a major role of Industry 4.0 in these real-world domains. There have been a lot of advancements in the IT industry for dealing with the real world problems related to different domains. [21]

After the intervention of Artificial Intelligence in medical science, it has been believed that these kinds of complex problems can be solved by the complex and automated algorithms of AI even without the involvement of humans [24]. Artificial Intelligence and Machine learning have contributed a lot in medical science, health-care and other biomedical areas in the last few years. The problem of classification of ECG reports can be solved by taking the aid of deep learning and neural networks. This paper is about a framework for the classification of ECG reports using deep learning and deep CNN. [20]

The sub-domains of AI especially Deep Learning has been evolved a lot in last few years in the medical and health-care use-cases and it is also giving very good results [29]. It provides doctors the ease to analyze the disease and treat it with great precision.This helps in providing better medical care [27]. It also helps in discovering a new drug. It analyses a patient's medical history and guides the doctor to provide the patient with better medical attention. It also comes handy in medical imaging like MRI scans, CT scans, ECG and all [16, 37]. It helps the doctor to diagnosis the dreadful disease and provides the patients with better medical attention [31]. One of the biggest achievements of deep learning is detecting the Alzheimer's disease as early as possible.

Neural Networks are the most widely used algorithms in deep learning which has helped it a lot to grow [30]. Computer Vision, Image Classification and Image Segmentation are some of the important applications of neural networks in various domains [15]. These were the complex problems which was not possible to solve before deep learning [25]. There are a lot of machines that detect heart disease by the help of machine learning and deep learning. There are a lot of methods by which a model can detect heart disease. It can detect by training on the X-Ray images of the diseased person [38], by taking important features like blood pressure, resting blood pressure and all. It can also predict the type of heart disease by the help of ECG signals [32, 23].

This paper mainly focuses on the classification of a heart disease named Arrhythmia, which is a disease related to the rate of heart beat. In this disease, the heart beats too quickly or slowly or in an irregular manner. When the heart beats too faster than normal range then it is called tachycardia and when it's slower than faster than it is known as bradycardia. A very common type of arrhythmia is arterial fibrillation in which the heart beat becomes irregular and faster than normal. [6]. The main purpose of the study is to propose a methodology using a famous Deep Learning algorithm called CNN which will classify the type of heartbeat with the given ECG report data.

Table 1: Mappings between different categories and their annotations [7]

Category	Annotations
N	Normal Heart beat
S	Arterial Premature Heart beat
V	Ventricular premature heart beat
F	Ventricular fusion heart beat
Q	Fusion of paced and normal (unclassified)

Table 1 signifies the mappings between different categories of heart beats in the ECG report with their corresponding description.

2. LITERATURE SURVEY

M. Kachuee et.al. [1] have proposed a technique for the classification and detection heartbeats using CNN. They have implemented a technique for transferring the knowledge acquired myocardial infarction (MI) classification task. They have also analyzed their work with different papers and compared the results with them.

S. H. Jambukia et.al. [2] have done a survey in their paper and explained different aspects of ECG classification along with the issues in the process of classification. They have compared and given a tabular survey of different approaches by different authors in their paper. In this survey they have compared different papers on the basis of parameters like features, pre-processing techniques, dataset, modelling techniques, performance metrics and accuracy.

Y. Ji et.al. [3] have implemented a model and proposed that which is based on Faster regions in Convolutional Neural Network. In this paper, they have performed the signal pre-processing, transformed the ECG signals to images, performed R-Wave detection, extracted the ECG beat and given a faster R-CNN architecture for the classification of ECG. They have also compared the support vector machine (SVM) classifier with their proposed R-CNN approach.

A transfer learning approach has been experimented and proposed by G.V. Steenkiste et.al. [4] in their work. In their work they have proposed a convolutional network which is optimized by genetic algorithm. They have transferred the knowledge from MIT-BIH dataset to e-ECG database.

In a recent work by Z. Dokur et.al. [5] have implemented a convolutional neural network technique and they are taking the 2-D images of 1-D ECG records as an important consideration. They have used a small size of a neural network to provide high performance using Walsh Functions (WF), and have investigated the drawbacks of converting 1-D images to 2-D images.

A. Isin et.al. [26] in their recent work have implemented a model using transferred Deep CNN model called AlexNet as an image feature extractor and their own implementation of back propagation neural network for main classification. They were getting a testing accuracy of 92%.

O. Yildirim et.al. [34] has proposed a model which takes the help of LSTM network model for the categorizing ECG signals. In their study a new model for deep learning has been proposed which is a DBLSTM-WS. The authors have implemented a new wavelet based layer which generates the sequences of ECG signal. Under this layer, the decomposition of ECG signals takes place based on

frequency sub-bands. For the load of LSTM networks the sub bands are used as order. The performance of unidirectional and bidirectional network models are compared in this study. The accuracy that the authors have got is 99.39%. As per their observation, the wavelet based layer used in the study enhances the performance of the respective models.

S.L. Oh et.al. [35] proposes a model which implements the CNN and LSTM collectively for automated diagnosis of arrhythmia. In the paper the authors have proposed a system that helps in diagnosis of normal sinus rhythm, LBB, RBB, APB, and PVC. The proposed model is giving an accuracy of 98.10% and sensitivity of 97.50%. Their proposed model can detect and cure arrhythmia.

M.K. Das et.al. [36] proposes a model that is capable of classifying ECG beats based on the set of features. Their proposed model can detect normal heart beat, ventricular ectopic beat, supra-ventricular ectopic beat, fusion heart beat, and unknown beat. In this paper the proposed model has used two feature extraction techniques that are S-transform based featureswith temporal features and combination of ST and WT based features with temporal features. The performance of the model which uses the proposed feature extraction techniques are 95.70%, 78.05%, 49.60%, 89.68% and 33.89% respectively.

3. BACKGROUND STUDY

Deep CNN are the set of neural network based algorithms mainly used for solving complex problems related to images [22]. These are artificial neural networks that work on the principle of convolution operation in mathematics that is why the name is Convolutional Neural Network. The Deep CNN can be constructed using different layers which are given below. [8]

3.1. Convolution layer

The Convolution layer is the heart of the CNN as it has the core process of convolution in its operation. Convolution is a mathematical operation over on functions f and g which as a result produces a third function representing change in shape of one modified by the other [17]. The images are read by computers in the form of matrices and these matrices are used to further processing. A convolution operation is performed to the input matrices in the convolution layer [10]. The convolution layer consists of a set of filters (or kernels) and biases. These filters are trained to learn the features of the images [11].

In the context of CNN, in a feature matrix is extracted when the input image matrix is convoluted with the kernel matrix. The feature matrix is a type of matrix which contains all the important features related to the image. Our model contains 3 convolution layers of different sizes and the kernel matrix is taken of size 3x3. The architecture of the CNN model can be depicted in Figure. 1. We have used the Rectified Linear Unit (ReLU) activation function in the interior layers of Convolution.

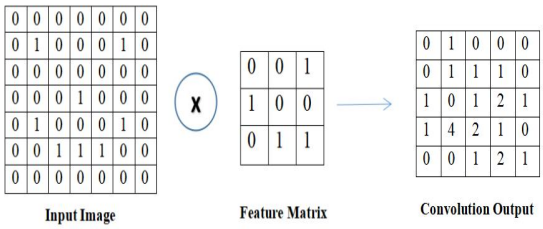

Figure 1: Convolution Step

3.2. Pooling layer

Pooling layer often comes after the convolutional layer and this layer is considered as one of the most crucial layer. Pooling layers are of various types which are Max Pooling, Average pooling and Global average pooling. The pooling layer can be considered as a down sampling strategy as the main aim behind the concept of pooling is to extract important features which in turn will decrease the size of the image. In our model we have used max pooling.

In the pooling layer, we reduce the size of matrix which was obtained as a result in the convolution layer by taking important features of the image into consideration [10]. This pooling step helps us reduce the computational complexity as we will be getting a reduced convoluted image with only the features of our interest [12]. Different types of pooling techniques were introduced in recent times. Two categories of pooling techniques are there, one is value based pooling and the other is rank based pooling [9]. These techniques are further divided into sub-categories. Figure 2 depicts the pooling operation using max pooling technique and average pooling technique.

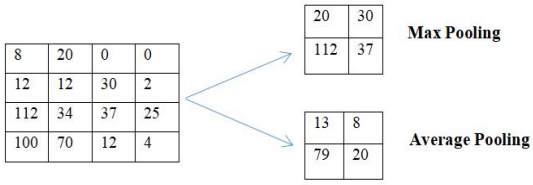

Figure 2: Pooling step

3.3. Flattening

Flattening as the name suggest, is a process which is used to convert a matrix to a list. The convolution and pooling steps are performed over the matrices and those matrices are required to be converted to a vector in order to pass them to the ANN. The Flattening process will convert a matrix generated by the CNN to the vector which are compatible for ANN. [18]

After a number of convolution layers and pooling layers in place for feature extraction, the flattening is used to convert matrix to a vector. This flattening process is then followed by an ANN i.e. Artificial Neural Network which actually performs classification and the output of this ANN is the final output. Figure 3 depicts the flattening operation in the CNN algorithm.

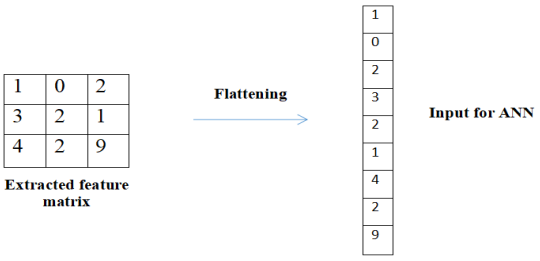

Figure 3: Flattening

3.4. Artificial Neural Network

After the feature extraction done by the Deep CNN architecture, various algorithmscan be applied to the features for further processing as we are having the raw data/features related to the domain with us. One of the most popular techniques is ANN, i.e. the Artificial Neural Network.

This ANN can be used to process the extracted data/features from the images and we have used the same for classification purpose. We have used a 2- hidden layer ANN setup which is performing the classification operation.

The deep CNN model consists of several layers of convolution, pooling and full connection. The CNN architecture used in our model is shown in Figure 4.

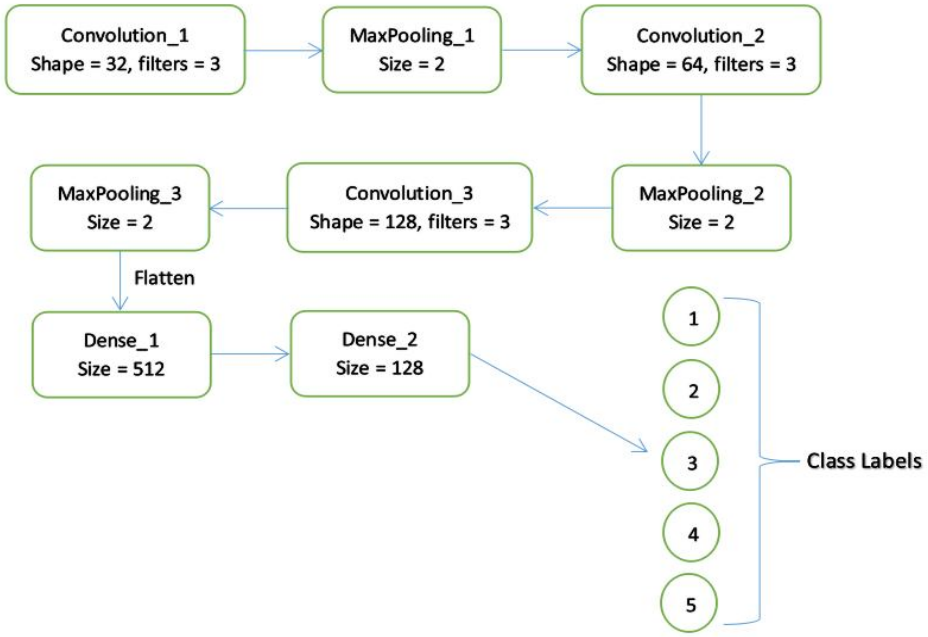

Figure 4: CNN architecture for our proposed model

4. PROPOSED METHODOLOGY

This paper focuses on the implementation of Deep CNN which is a complex architecture in terms of technicality. Also any AI and data science problem is solved in a step-wise process. Following are the steps followed in our proposed methodology.

4.1. Dataset description

ECG classification is a very sensitive real world problem to solve as it relates the technology with the life or death of a human being. So, the data source must be a reliable so as to train the model. In our case, we have used a dataset from the official MIT-BIH dataset website [28]. In this dataset, the values of amplitudes are given which corresponds to electrocardiogram (ECG) shape of the heart beat. These signals are pre-processed and segmented. The dataset contains 109446 samples 48 half- hour excerpts of two channel ambulatory ECG recordings. The data is categorized in 5 classes which denote the state of the heart according to the signals.

The dataset collected contains 187 columns which correspond to the snapshot of time at which the heartbeat is recorded.

4.2. Data preparation and analysis

Before starting to work with the neural network and actual logic the data preparation and analysis is a very vital process in which we will prepare the data for our work and visualize that for proper analysis. In the data preparation, we are using the pandas library in order to import and create a data frame. This data frame will have our whole dataset which is having a total of 187 columns. Figure 5 shows the sample graph after analysis which is a graph of amplitude against time and this is the actual data present in the dataset.

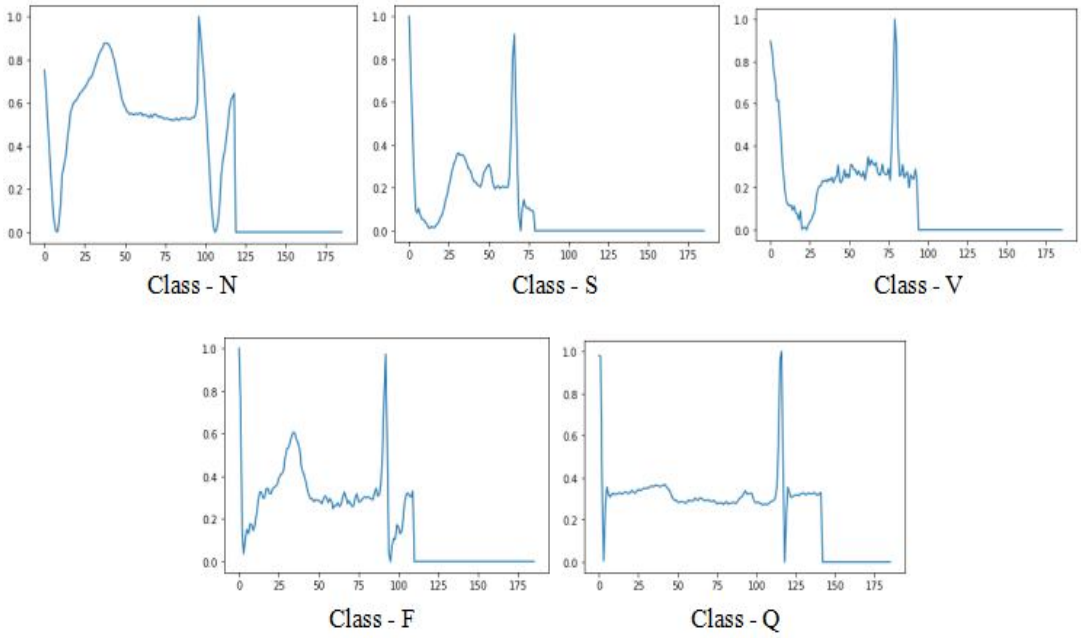

Figure 5: 1-beat waveform visualization for each class present in the dataset

4.3. Re-sampling the Data

For better training of the model, we need the data in an appropriate proportion i.e. all the classes must have an appropriate proportion of data points. But many a times we don't get the data in proportion so we need to apply some sampling techniques in order to make the data proportional whenever we find that the data in the dataset are not distributed in similar ratio we either up sample the data or down sample it. Up-sampling means increasing the frequency of the sample and down sampling means decreasing the frequency of the sample. In our case we have done up sampling of the data samples since we had less amount of data samples. We have up sampled the data up to 10000 samples.

4.4. Noise

For better training of the model, the ECG beats must contain some peaks which can be done by adding some additional noise to the data which in our case is a Gaussian noise. We are adding some external Gaussian noise to the data points which will give us a more disturbed form of beats which will ultimately add some more peaks to the data.

4.5. Defining our neural network

After adding some noise in our data we need to train it in order to do some prediction on it. Training is very important phase in any deep learning model. We need to train our model to do any kind of prediction on it. So, the dataset is divided into training and test datasets. We have further divided training set into training feature set and testing feature set and we have further divided testing set into training label set and testing label set. After dividing our model we have taken the feature training set and label testing set and have trained them on the Convolutional Neural Network. Neural networks are combination of algorithms which desperately finds an underlying pattern or relationship between two entities. It acts just as a human brain operates. In short we can refer neural network as a set or systems of neurons which can be either organic or artificial in nature. Neural Networks are applied in various real-world problem solving with the help of architectures like ANN, CNN, RNN, LSTM, GANS, etc. Out of all these neural networks we have build our CNN based model because it is the best when it comes to work images.

Convolutional Neural Networks is class of deep learning algorithm which is proficient in working with images. It is commonly used to analyse visual imagery. The architecture of Convolutional Neural Network similar to that of connectivity pattern of human brain and was inspired by the organization of visual cortex. A Convolutional Neural network is divided into various layers which are convolutional layer, pooling and flattening layer.

4.6. Image augmentation

Image augmentation as the name suggests means augmenting the image artificially. This technique is implemented for making training of the model more efficient. Image augmentation technique is used to expand the size of the dataset by generating new images artificially [14]. It is performed so that the classifier performs well. The image size is increased by rotating the images, shearing the images and flipping it. [13]

4.7. Classification using ANN

ANNs (Artificial Neural Networks) are the algorithm which works on the principle of neurons and human brain in its core. The ANN can be used for various purposes and we have used that for classification process. After extraction of features from the images in the dataset, the Artificial Neural Network is implemented for the classification process. This ANN architecture is followed after the flattening step and continues till the final output. We have implemented a 3-layer ANN for classification which follows the dimensions defined in Fig. 6.

4.8. Output and result interpretation

The classification process gives a result in terms of nodes which represent each class. In this model, the output layer contains 5 nodes as it is a 5-class classification problem. We have used the Softmax activation function in the output layer as this is a multi-class classification problem.

5. RESULT AND DISCUSSION

Machine learning and deep learning are two fields in computer science which have immensely helped the field of medical and healthcare [19]. All these fields have given incredible results in different domains of real-world as well. We have used a deep learning technique called Deep CNN and applied that to a healthcare domain which is giving good results after execution. After implementing the Deep CNN model as proposed in this paper, we are getting an accuracy of 98.18% in training phase and 95.56% in testing phase.

The results in terms of accuracy curve and loss curve can be seen in Figure 6 and Figure 7 respectively.

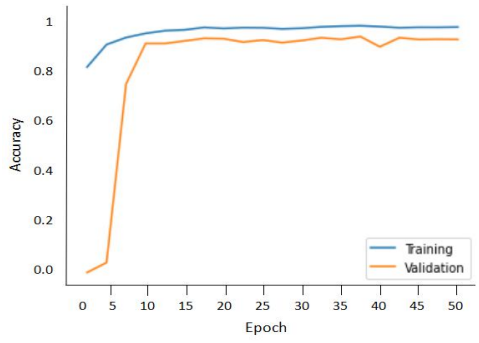

Figure 6: Model Accuracy curve

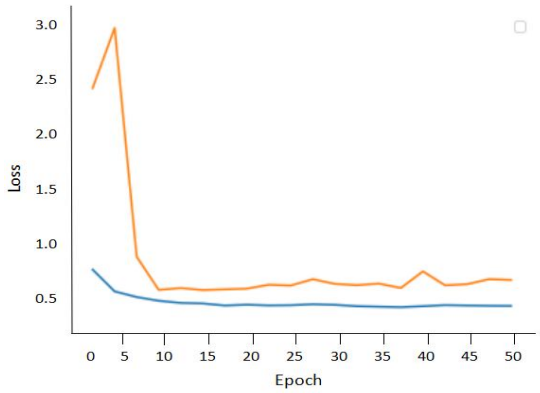

Figure 7: Model Loss Curve

From the above graphs, it is evident that the model is performing well as the accuracy in case of testing is incrementally increasing and converging with the training one. Same is the case with loss, the loss in this model is decreasing at a good rate and converging with the training loss at a point.

6. CONCLUSION AND FUTURE WORK

Artificial Intelligence has played a big role in the lives of human beings. Real world sectors like medical, health-care, finance, and many more are dependent on AI. The sub-domains of AI like Machine Learning and Deep Learning are considered as flagship technologies in today's generation. Deep learning techniques like image classification and image segmentation are highly used in health-care industry. This study has implemented a model which covers a big aspect of health-care i.e. ECG report classification.

The proposed model can be implemented in embedded systems and other biotechnological devices in order to get automated and accurate results. These steps for automation will give a rapid growth in the health-care industry and will lead to a better tomorrow.

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